# ELECTRICITY AND THE ENVIRONMENT

PROCEEDINGS OF THE SENIOR EXPERT SYMPOSIUM
HELSINKI, FINLAND, 13–17 MAY 1991
JOINTLY ORGANIZED BY

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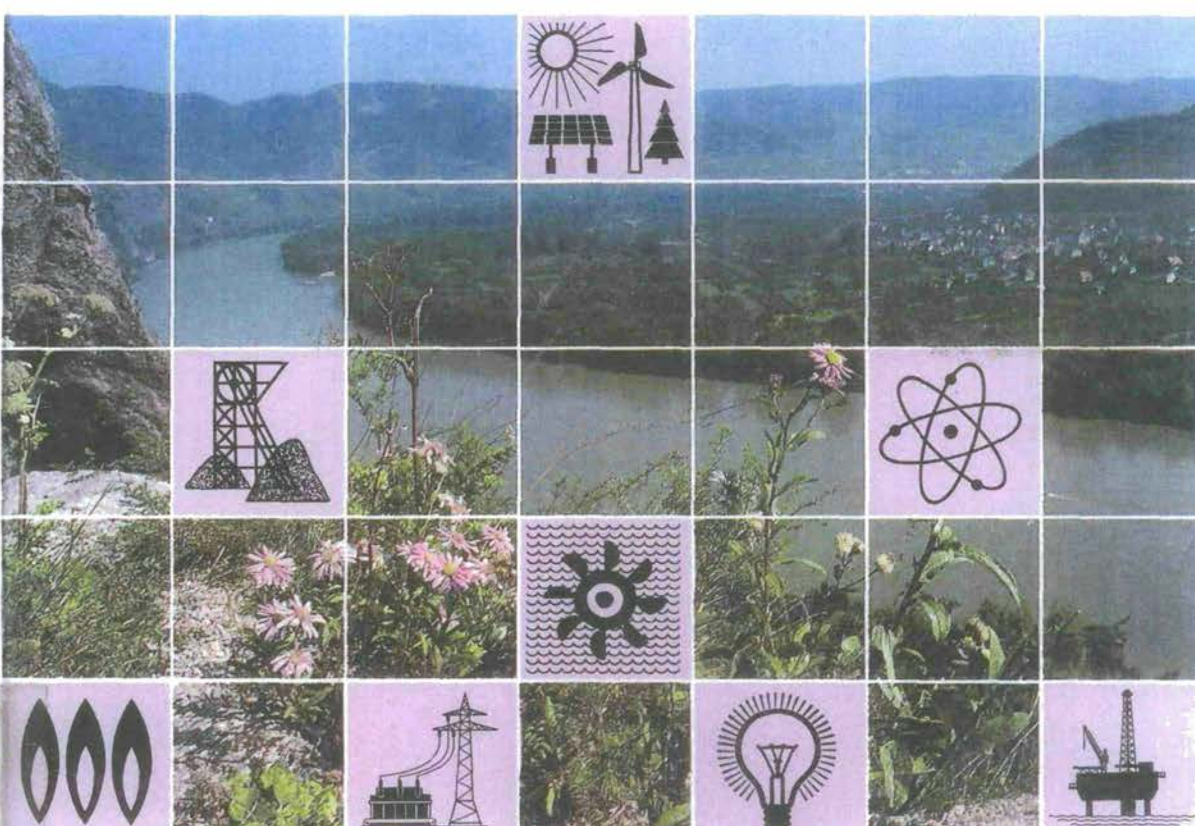

INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA, 1991

# ELECTRICITY AND THE ENVIRONMENT

PROCEEDINGS SERIES

# ELECTRICITY AND THE ENVIRONMENT

PROCEEDINGS OF A SENIOR EXPERT SYMPOSIUM
ON ELECTRICITY AND THE ENVIRONMENT
JOINTLY ORGANIZED BY THE
COMMISSION OF THE EUROPEAN COMMUNITIES (CEC),
COUNCIL FOR MUTUAL ECONOMIC ASSISTANCE (CMEA),
ECONOMIC COMMISSION FOR EUROPE (ECE),
INTERNATIONAL ATOMIC ENERGY AGENCY (IAEA),
INTERNATIONAL ENERGY AGENCY (IEA),
INTERNATIONAL INSTITUTE
FOR APPLIED SYSTEMS ANALYSIS (IIASA),
NUCLEAR ENERGY AGENCY OF THE OECD (OECD/NEA),
UNITED NATIONS ENVIRONMENT PROGRAMME (UNEP),
WORLD BANK (IBRD),
WORLD HEALTH ORGANIZATION (WHO),
WORLD METEOROLOGICAL ORGANIZATION (WMO)
IN CO-OPERATION WITH THE
GOVERNMENT OF FINLAND
AND HELD IN HELSINKI, FINLAND, 13–17 MAY 1991



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# FOREWORD

The Senior Expert Symposium on Electricity and the Environment was held from 13 to 17 May 1991, in Helsinki, Finland. It was organized jointly by the Commission of the European Communities (CEC), the Council for Mutual Economic Assistance (CMEA), the International Atomic Energy Agency (IAEA), the International Energy Agency (IEA), the International Institute for Applied Systems Analysis (IIASA), the Nuclear Energy Agency of the OECD (OECD/NEA), the Economic Commission for Europe (ECE), the United Nations Environment Programme (UNEP), the World Bank (IBRD), the World Health Organization (WHO) and the World Meteorological Organization (WMO) and was hosted by the Ministry of Trade and Industry of the Government of Finland. More than 300 participants from 40 countries and 20 organizations took part.

The objective of the Symposium was to provide a comprehensive assessment of the environmental and health factors as well as the economic factors involved in supplying electricity services, and to suggest a framework within which these issues should be taken into account in making future plans and decisions on electricity production and use. The potential role of different ways of meeting electricity service requirements was also to be analysed, taking into consideration both demand side and supply side options in the light of their comparative economic, environmental and health related impacts.

In the light of these objectives, International Expert Groups prepared Key Issues Papers on four topics that were selected as the central themes for consideration at the Symposium. A Joint Steering Committee, composed of representatives from the sponsoring organizations and Finland as the host country, provided overall guidance to the Symposium and to the work of the four Expert Groups.

**Key Issues Paper 1, Energy and Electricity Supply and Demand: Implications for the Global Environment,** assessed scenarios of future energy requirements, the share of electricity in the end use energy mix in the context of social, environmental and technological development, and the role of electricity in minimizing impacts on the environment.

**Key Issues Paper 2, Energy Sources and Technologies for Electricity Generation,** reviewed the characteristics of different energy sources and technologies for electricity generation, namely, fossil fuels, nuclear energy and renewable energy sources, from the perspectives of resource base, technological capability (including ways of protecting the environment) and economic viability.

**Key Issues Paper 3, Comparative Environmental and Health Effects of Different Energy Systems for Electricity Generation,** made a comparative assessment of the overall environmental and health effects of different energy systems for electricity generation, under normal operating and accident conditions, and covering the entire cycle of energy production, conversion and end use.

**Key Issues Paper 4, Incorporation of Environmental and Health Impacts into Policy, Planning and Decision Making for the Electricity Sector,** examined issues and options for managing the impact of the electricity sector on environment and health, and the framework for incorporating environmental and health impacts into the decision making process for electricity policies and strategies.

During the Symposium, keynote addresses and invited papers presented by leading experts and policy makers provided additional related information. The key issues were explored further in discussions by the participants and the panels of experts, which helped to highlight the main problems to be addressed in the design and implementation of electricity sector policies that reconcile health and environmental protection objectives with the requirements for adequate and economic supplies of electricity to meet development needs.

The Proceedings contain all the addresses and papers presented, together with summaries of the discussions that took place. The Key Issues Papers are presented in a separate publication.

The organizations sponsoring the Symposium wish to record their sincere thanks to the Government of Finland and to the authorities of the City of Helsinki for the facilities made available and the substantial support provided. These contributed greatly to the smooth running and success of the Symposium.

*EDITORIAL NOTE*

# OPENING SESSION

**Chairman**
**H. BLIX**
International Atomic Energy Agency (IAEA)

# CONTENTS

## ENERGY SOURCES AND TECHNOLOGIES FOR ELECTRICITY GENERATION (Topical Session 2)



## COMPARATIVE ENVIRONMENTAL AND HEALTH EFFECTS OF DIFFERENT ENERGY SYSTEMS FOR ELECTRICITY GENERATION (Topical Session 3)



## INCORPORATION OF ENVIRONMENTAL AND HEALTH IMPACTS INTO POLICY, PLANNING AND DECISION MAKING FOR THE ELECTRICITY SECTOR (Topical Session 4)

## LUNCHEON SESSIONS



## POLICY ASPECTS OF ELECTRICITY AND THE ENVIRONMENT (General Plenary Session)

**KEY ISSUES AND FINDINGS AND ROUND TABLE ON CHALLENGES FOR INTERNATIONAL CO-OPERATION (Closing Session)**

# OPENING STATEMENTS

**Kauko Juhantalo**
Minister of Trade and Industry,
Government of Finland,
Helsinki, Finland

On behalf of the host organization, the Finnish Ministry of Trade and Industry, I am privileged to welcome the participants of the Senior Expert Symposium on Electricity and the Environment to Finland. Personally, I am particularly pleased that my Government had the opportunity of contributing to this joint effort as the host country, and of placing the facilities of the Finlandia Hall at the disposal of the Symposium.

A well functioning energy supply and a reasonable level of energy prices support propitious economic development and promote social welfare and stable political development. Technical skills in the use of energy technologies have, over time, created opportunities for developing society. In this respect, the situation is likely to remain unchanged in the future.

However, in approaching the crucial task of securing energy supplies, we still have to find an answer to the problem of how to achieve this without limiting the opportunities for development of future generations. We all know that many of the most serious dangers affecting the ecological balance and social justice in the world — climate changes, acidification, inequitable use of the world's energy resources — are the direct consequence of an excessive consumption of energy.

The aim of this Symposium is to gather together senior experts from governmental organizations, power industries and research institutes in order to assess the potential role of different power technologies in meeting electricity requirements within a time horizon of 30 years and in the light of their environmental impacts. It is expected that suggestions will be made as to the institutional procedures which could facilitate decision making in the electricity supply sector.

In recent years, many industrialized countries have encountered the same difficulty in meeting the new power requirements, namely, a general trend towards a weakening ability to choose between the various electricity generating options. In my view, this is partly due to a lack of or contradictory information on the trends in electricity consumption and the real potentials for reducing electricity use. All too often expectations are overoptimistic as to the time-frame within which new and alternative technologies will reach the commercial stage of development.

Against this background, it is becoming increasingly clear that the world has only one way of solving these problems: to increase and intensify co-ordinated international action. Therefore, it is encouraging to perceive the new will and form of co-operation represented by the organization of this Symposium. Supported by

11 international organizations of the United Nations family and major regional organizations from Europe, the Symposium is an exceptionally large joint international effort. The comprehensive preparatory work has also been a unique example of co-operation, and should be utilized as a model in the future.

Furthermore, taking into account the participants' professional experience and extensive knowledge of the various environmental impacts connected with electricity generation, I am convinced that the Symposium will make a valuable contribution towards a highly topical debate on this important issue. In particular, I believe that the conclusions reached will be recognized as useful input to the UN Conference on Environment and Development to be held in Brazil in 1992.

In conclusion, I would like to express the wish that the Symposium has a successful outcome and that all the participants enjoy their stay in Helsinki.

**Hans Blix**
Director General,
International Atomic Energy Agency,
Vienna

I am very happy to welcome you all to this Senior Expert Symposium on Electricity and the Environment jointly organized by a number of intergovernmental organizations. On behalf of the organizers and the participants, I would also like to express great appreciation to the Government of Finland for hosting the Symposium and for generously supporting it. Finland's Government, like many others, will have to come to grips with the demand for more electricity and, in doing so, will have to take into consideration environmental and other objections that may be raised against any proposed solution — apart, of course, from questions of economy, energy independence and other factors that are relevant in the choice of energy sources for electricity.

There is no intergovernmental organization in the United Nations family or outside it that covers comprehensively the issue of energy and the various health and environmental concerns linked to the production and use of energy, — particularly electricity. In preparing the Key Issues Papers for this Symposium, however, the sponsoring organizations have brought their collective knowledge and experience to bear. It is noteworthy that such excellent and close co-operation has been possible and I want to thank all those who have worked so hard to prepare these papers.

There is no doubt that the discussion on which we are embarking is timely. There is tremendous tension, locally, regionally and globally, between the demands for more energy, notably electricity, and the demands for the protection of life, health and the environment.

In general, developing countries use a fraction of the per capita energy consumed by industrialized countries. To take electricity specifically, Bangladesh, for instance, uses less than 100 kW·h per capita per year, while Norway uses more than 25 000 kW·h. It cannot be doubted that developing countries will seek to expand their energy production and use, in particular their use of electricity. Indeed, we can also expect industrialized countries to do so. France, which is known for its rapid expansion of electricity generation through nuclear power, is now using some 6500 kW·h per capita per year, and is currently exporting some electricity. Can we doubt, however, that in due course the French will increase their reliance on electricity, as the Norwegians have done?

Despite this reality, there is an awareness that increased electricity generation in some areas may call for the construction of dams and the flooding of large areas of land, or may require the construction of nuclear power stations or the burning of increasing quantities of fossil fuels at a time when 25% of the $CO_2$ emissions to the atmosphere are already caused by electricity generation in fossil powered plants. This is the uncomfortable background of the Symposium.

At the national level, many governments are familiar with the dilemma. They see a need for greater electricity generation, yet both hydro schemes and nuclear projects may be blocked by popular referenda, and greater use of fossil fuels may be vigorously opposed. In developing countries, concern is usually concentrated on negative local consequences, such as loss of farm land, and less on future global effects. At the regional level, we see discussions about the environmental impact of $SO_2$ and $NO_x$ emissions on forests and lakes. In Europe, 60% of the $SO_2$ emissions and 30% of the $NO_x$ emissions are from electricity generation, as revealed in Key Issues Paper No. 3. It is not surprising that the recent proposal for an energy charter to be adopted by all European countries, including the USSR, emphasizes environmental protection as one of its objectives. At the global level, concerns are focused on the risk of global warming, which is linked to $CO_2$ emissions from the burning of fossil fuels.

In such uncomfortable situations, countries tend to call conferences for discussions and possible action. The problem of transboundary pollution from the burning of fossil fuels ($SO_2$ and $NO_x$) can be tackled technically, but it needs capital and time. The problem of $CO_2$ and other greenhouse gases is more intractable. The Intergovernmental Panel on Climate Change (IPCC) has been examining this problem for some time and the United Nations Conference on Environment and Development will have to address it in Rio de Janeiro in 1992.

Conferences are one consideration, answers are another. The World Commission on Environment and Development, while advocating what it termed to be a low energy path and urging the development of renewable sources of energy, admitted that it had no satisfactory solution to the dilemma.

Others have been less modest and have suggested that we can eliminate nuclear power and reduce our reliance on fossil fuels if we are simply less wasteful in our use of energy and rely more on renewable sources such as solar and wind power. They point to the use of the best available technology, such as new types of light bulbs and refrigerators which use much less electricity than the more common types currently in use. Much of this discussion relies on anecdotal evidence; however, this does not mean that it is without influence. As individuals, our attitudes are often formed by the evidence we see with our own eyes or encounter in the media: the accident at Chernobyl, the burning of oil wells in Kuwait, an explosion in a coal mine, brown-outs in Florida, demonstration of an electric car, aircraft partially fuelled by hydrogen, discussions among scientists about cold fusion, a wind power plan somewhere in the world, etc.

Although as individuals we allow ourselves to be influenced when forming our opinions, because we cannot systematically study all the problems that affect us, we still want society as a whole to have the fullest and best possible basis for rational action. However, we reserve the right to continue forming our views on the basis of anecdotal evidence and impressions, even when the most systematic data have been compiled. Moreover, different political groupings can usually be relied upon to draw different conclusions from the same data. Nevertheless, I think the common man and woman are much wiser than the story which had him/her say, "I don't need nuclear power, I need electricity". I think the common man and woman know that all electricity generation has some impact on life, health and the environment and that it is meaningful for governmental and intergovermental authorities to try to introduce objective assessments and data into discussions. This, indeed, is the hypothesis on which the Symposium rests.

The cursory reader of the Key Issues Papers may perhaps feel that they present no startling revelations. More attentive readers — as I am confident the participants are — will, I am sure, find a wealth of data and much sober judgement. We look to you to examine the papers critically and intensely, and to endorse, correct or add to the information therein. I hope the Key Issues Papers, as they emerge from this Symposium, will form a very respectable input to the Rio Conference and to the discussions on global warming, which will certainly continue for a long time thereafter.

Let me highlight a few points that I found particularly interesting as I read the papers.

*First*, more electricity will need to be generated, particularly in developing countries. Efficiency gains, although very substantial and necessary, will not neutralize increased demand.

Let us note from the outset, as is done in Key Issues Paper No. 1, that availability of electricity offers a highly significant improvement in the standard of living and quality of life. A friend of mine told me that his father, who is 105 years old, had recently been asked what he thought was the most important change he had experienced in the world during his long life. Without hesitation, the father, a professor, answered, "The introduction of electricity". I am telling you this story and beginning with this point because voices are sometimes heard urging a return to lifestyles with minimal reliance on electricity. The reality is that electricity transports energy to our doorsteps and houses; ample lighting prolongs our days and makes our streets light at night; electric pumps bring water to fields and houses; refrigerators and deep freezers keep our food fresh and reduce spoilage; television allows us to meet the whole world at home; and electric stoves, irons, vacuum cleaners and innumerable other items make our lives more comfortable.

A basic factor that leads to an increasing demand for electricity — apart from the wish for higher standards of living — is, globally, the population increase. Although it is fundamental not only for the use of electricity but also for the whole question of the environment, I cannot pass the population issue in silence. It is estimated that at the time of the birth of Christ there were some 350 million people on Earth. In the year 1900, there were 1.5 billion ($10^9$), in 1990 about 5 billion, and in the year 2000 we expect there to be some 6 billion. Thus, in the last 10 years of this century the human population will increase roughly as much as it did during the preceeding 1900 years! No meaningful discussion can be pursued on the future of the global environment without an examination of the population issue. This must be borne in mind, although it falls outside the problems we are examining here.

It is not surprising that, in general, use of electricity increases faster than use of energy. In many industrial processes, switching to electricity permits the saving of primary energy, because electricity is more efficient and flexible in end use. Moreover, there are often significant environmental gains, as the end use of electricity is very clean. Use of electric trolley buses instead of diesel buses is but one example. If I were allowed two wishes for the environment, the first would be for an economically viable, electric car, and the second for a system of fast electric trains linking countries and continents and reducing the need to lift people to an altitude of 10 000 metres at high energy cost for travelling even moderate distances.

It is rightly emphasized in the Key Issues Papers that it is not electricity that we appreciate, but rather the services electricity provides. If the cost of increasing efficiency in the production, transmission and end use of electricity is reasonable, we should prefer this greater efficiency for economic reasons as well as for environmental reasons, since lower consumption reduces the impact of electricity generation on the environment.

Efficiency improvement is not really an issue. What is an issue is how much savings can be achieved and how fast. It is interesting to note that the authors of the Key Issues Papers agree that increased efficiency in electricity use will by no means neutralize the greater demand that flows from an increased reliance on electricity services. New refrigerators will consume less electricity, yes, but there will be so many more refrigerators that the increased number will use a greater amount of electricity. For example, China has the ambition to ensure that each household has a refrigerator. Even if these appliances were the most current and efficient models and were modest in size, they would call for a base load electric capacity of some 20 000 MW(e) — or 20 large nuclear power reactors of 1000 MW(e) each!

The *second* point I would like to highlight from the Key Issues Papers is their emphasis that all energy sources have some impact upon life, health and the environment, that all sources will be needed and that the real question before us will not be the inclusion or exclusion of some options but rather their optimal mix, nationally and internationally.

Against the background of the often heated and polemic public discussion of the environmental consequences of energy choices, the dispassionate analysis given in Key Issues Paper No. 3 inspires confidence. The starting point is that the authors deal either with the experienced consequences of energy sources actually used or with assessed real risk, but not with 'perceived' risk. The public's — or for that matter the policy makers'— perception of risk is, indeed, often a significant factor in society's choice of an energy mix. Attempts to assess risks objectively should, however, be based on experience and facts. It should certainly be our hope and working hypothesis that such objective assessment will, in the long run, influence both policy makers and the public.

It seems most sensible to examine the risks and consequences that relate to the whole fuel cycle of an energy source, ranging from the extraction of gas or the mining of coal or uranium, transportation, burning, to waste disposal and emissions. What we want to measure, after all, are the total consequences to health and the enviroment of the use of a given quantity of electricity.

Other important distinctions made in the Key Issues Papers are those between risk in routine operations and risk in accidents. For example, emissions from a coal powered plant in routine operation are very substantial, while there are no emissions from the routine operation of a hydropower station and a very small amount from nuclear power stations in routine operation. By contrast, an accident in a nuclear power plant could result in important emissions, and accidents in hydro dams might have catastrophic effects.

The differentiation urged between local, regional and global impacts and between direct and indirect health effects also seems necessary. Comparison between the global impact of one energy source with the local impact of another is not meaningful. For indirect health effects we learn that, while these are estimated for radiation, they are not assessed for, say, emissions from fossil fuel burning, causing the release of metals such as mercury or aluminium, because estimates are not available in the latter cases. Such facts must be borne in mind.

The distinctions and reservations made in the Key Issues Papers, as well as the lacunae in data, lead to limitations in the conclusions that can be drawn. Even so, the conclusions and calculations which we find should be of much general interest.

It certainly sounds realistic when, in Key Issues Paper No. 1, it is noted that the lead times for changing supply mixes are long and that fossil fuels will continue to be a main energy source for electricity generation for a long time to come. The paper is also consistent with other competent analyses when it foresees that the contribution of renewable sources of energy other than hydropower to electricity generation is likely to remain small, and that natural gas, as a relatively inexpensive and clean option, will play an important role in impact reduction, especially in Europe and North America, in the short and medium terms.

The *last* point I should like to cite is both reassuring and disconcerting. The reassuring statement is in Key Issues Paper No. 3 which states that, "all the major fuel cycles in the electricity generation systems, when fitted to state of the art technology, are able to deliver electricity at relatively low risks to health and the environment". The ominous statement, also in Key Issues Paper No. 3, is, "An exception is $CO_2$ emissions from fossil fuels". Indeed, in Key Issues Paper No. 1 it is noted that "the most ambitious feasible global target for carbon emissions from the total energy sources in the year 2010 would involve emissions above those released in 1990". This seems far from the famous Toronto Conference target of a 20% reduction in the 1988 $CO_2$ emissions by the year 2005.

In the dispassionate language of the papers it is concluded in Key Issues Paper No. 3, on the issue of climate change, that "energy mixes with a high component of low grade fossil fuel of a low energy delivery to the $CO_2$ emission ratio are at the high end of the risk spectrum''.

I think you will forgive me if I end my quotations by another line from Key Issues Paper No. 1, ''Nuclear energy has the potential to make a significant contribution towards a reduction in carbon emissions''; I am obliged also to quote the end of that same sentence, ... ''but its social acceptability remains in question''.

I dare not hope that the social acceptability of nuclear power will be directly affected by the papers at this Symposium. I am convinced, however, that scientific and impartial examination of the relation between electricity and the environment, as provided in the papers, is a wise approach that may have positive long term effects and contribute to rational discussion.

**Esko Aho**
Prime Minister,
Government of Finland,
Helsinki, Finland

Today, our world is facing greater challenges than ever before in respect to our quality of living. We have managed to release increasing numbers of people from the yoke of manual labour and, instead, to have given them an opportunity for intellectual work and promotion of mental development. This is attributable both to the techno-scientific development, or the human insight and ability to use its products, and the natural resources of the globe. For this evolution, it has certainly been of great importance that nature has offered easily exploitable, solid state energy resources — first biofuels and wind power, and later water power, fossil fuels and nuclear power — and that mankind has learned to use them efficiently.

However, this happy Shangri-La is increasingly being overshadowed by the environmental effects of the standard of living we have achieved. Almost every day, the news media bring to light the negative environmental impacts of our modern way of life: the forest disasters caused by acid deposition in the cold zones of the globe, the threat of climatic change and the thinning of the ozone layer around the globe. These factors threaten all the inhabitants of the Earth in one way or another. We know that, to a great extent, these threats are connected to our present forms of energy production and energy consumption. We also know that these problems are linked to the activities of modern society, not the least of which are the economic factors. It is also evident that these problems can be solved only by means of extensive national and international co-operation.

In industrialized countries, it is still considered justified to use energy consuming machines for liberating people from routine physical activities so that they can concentrate on pursuits that enrich human life. This should not only be the privilege of citizens in industrialized countries but should also be available to people in developing countries.

What, then, is the role of electricity in realizing these targets, and what is its role from the environmental point of view? In industrialized countries, the role of electricity is an ambivalent one, considering both the environmental effects of the various forms of electricity generation and the social benefits that electricity provides. We all appreciate the comfort and freedom that use of electricity allows. Evidence of this is the ever increasing popularity of electric lighting, radios, televisions, washing machines, electric stoves and many other electric household appliances. The significance of these devices for freedom from routine work is usually not called into question. In our public discussion on environmental matters, trams, electric cars and the underground are seen as non-polluting and environmentally safe alternatives to city traffic. For the intercity transport of goods and passengers, rapid electric trains are planned to replace combustion engine cars and airborne transport.

It is evident that the pressures of increased use of electricity will become stronger in industrialized countries in the future for the sole reason that electricity will be used to replace the more polluting forms of energy. Another reason for a future worldwide increase in the use of electricity is that citizens of developing countries want to raise their standard of living, and they must be provided with equal opportunities of realizing these wishes. We are all faced with the problem of how to meet these aspirations while at the same time keeping our environment clean, healthy and safe.

I am delighted that we, in Finland, have had the opportunity of arranging this Symposium; and I am even more pleased that participation is on such a broad base. To the best of my knowledge, this is the first time that environmental issues will be discussed and remedies for the conflicts between energy and the environment sought by scientists, government officials, industrial leaders and other experts. This diversity of participants testifies to the sense of responsibility and willingness to co-operate among international communities for the future of mankind and our entire planet.

The relations between energy and the environment are linked to intergovernmental activities in so many ways that solving the problems exclusively at the national level, or from only a national perspective, is well nigh impossible. The old and somewhat hackneyed phrase that pollution does not respect national boundaries still holds today. Despite all our joint efforts, we continue to pollute each others' territory. The best available technical facilities adapted to the natural resources of individual states should be made available to all nations, including developing countries. For this purpose, co-operation in the transfer of technology is necessary. Environmental reforms resulting from economic remedies and market dynamics, regarded as essential in today's world, can be successful only if they are adopted in all countries at the same time, but international co-operation is essential if these goals are to be realized.

Finland is determined to be one of the leading nations in the field of environmental protection. We are among the signatories of the Helsinki Protocol relating to the ECE Convention on Long Range Transboundary Air Pollution. The signatories of the Helsinki Protocol have made the commitment that, before 1994, they will reduce their sulphur emissions by 30% from the 1980 level. To date, Finland has managed to reduce its emissions to an even greater extent than agreed upon, i.e. by nearly 60%. However, even such a drastic reduction in sulphur emissions is not enough to save our natural environment from acidification. This is why the Finnish Government decided, in January 1991, to begin a 10 year programme for reducing Finland's sulphur emissions by approximately 80% of the 1980 level. As far as we can see, only this scale of emissions reduction, provided that it is simultaneously supplemented with an equal reduction in the long range transboundary air pollution received by Finland, will enable the country to maintain acid depositions under the critical level.

Regarding the ECE Convention, Finland has signed the Sofia Protocol and Declaration for a reduction in the emission of nitrogen oxides by some 30% before the year 1998. Governmental regulations concerning such emissions, issued in March 1991, will result in approximately one-half of the planned reduction. At present, the government is considering how the second half of this reduction target could be achieved.

At the Second Global Climate Conference held in October and November 1990, the majority of industrialized countries, including Finland, declared that they are aiming to freeze their emissions of greenhouse gases, especially those containing carbon dioxide, at the current levels by the turn of the century. At present, an ad hoc committee is planning appropriate measures for the implementation of this plan in Finland.

From the Finnish point of view, it is also of paramount importance that international co-operation be intensified in the field of electricity generation risk management, which is one of the topics of this Symposium. It can be stated with satisfaction that in recent years co-operation in nuclear safety has both increased and diversified.The projects that Western European countries have launched to assist countries in Eastern Europe in upgrading their nuclear power plants are good examples of such co-operation. The safety missions and other services offered by the International Atomic Energy Agency, which are designed to enhance the operational safety of nuclear power plants, as well as the establishment of the World Association of Nuclear Operators, are additional examples. Finland considers it important that the IAEA takes a central role in international co-operation for nuclear safety. It also feels that the Agency should constantly seek new methods for improving safety in the use of nuclear energy worldwide.

A national long range strategy is being prepared in Finland to provide our nation with central objectives for potential energy economy. National targets and international agreements and declarations on environmental matters, as well as the 'Principles for Sustainable Development' of the World Commission on Environment and Development, form the fundamental support of this strategy. During the preparation of this programme, the question of how the energy policy could be integrated into the objectives of the national economy and environmental policy was asked repeatedly. Central to this are the issues of solving environmental problems by means of energy economy, especially through the saving of electricity, and alternative methods of producing electricity. I have noted, to my pleasure, that all these questions are indeed among the key issues of this Symposium.

You are starting a busy week with discussions on problems that are considered difficult throughout the world. I do believe, however, that the questions I have posed on this occasion will find good answers in the final report of this Symposium. I am also convinced that the ideas voiced and the results given will make a valuable contribution to the longer term international debate on these issues.

## Keynote Address

# ELECTRICITY AND ENVIRONMENTAL POLICIES OF THE EUROPEAN COMMUNITY IN RELATION TO GLOBAL CLIMATE CHANGE ISSUES

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**Abstract**

ELECTRICITY AND ENVIRONMENTAL POLICIES OF THE EUROPEAN COMMUNITY IN RELATION TO GLOBAL CLIMATE CHANGE ISSUES.

Over the past 40 years, successive European Environment Programmes have emphasized protection of the environment as an increasingly important factor in policy planning and implementation. In response to the likely effect of $CO_2$ emissions on global climate change, the European Community Member States adopted the objective of stabilizing the total $CO_2$ emissions at the 1990 level by the year 2000, with a further decrease thereafter. Specific measures are being pursued, including: encouraging energy efficiency and energy conservation; promoting fuel substitution, particularly use of natural gas; examining use of fiscal instruments to reflect the real environmental costs in energy pricing; and furthering research into new and renewable energy sources for electricity generation. The nuclear industry can also make a significant contribution towards reducing the greenhouse effect, but it will have to gain public acceptance. This is one of the aims of the European Council Directive. The CEC is prepared to make specific proposals in order to find balanced solutions to the environmental problems caused by electricity. It will, however, be necessary to establish a common understanding of such problems on a global scale.

It would be negligent of me if I did not first express my thanks to the organizers of this Symposium, to the host city of Helsinki and to the Finnish Government for their invitation to this beautiful country and its capital.

In view of the unmistakable environmental problems facing us on all sides, the European Community welcomes the initiative taken by the International Atomic Energy Agency in organizing this Senior Expert Symposium on Electricity and the Environment. The responsible European Commission departments were pleased to accept the invitation to play an active part in the Symposium and are committed to making it a success. On behalf of the Commission of the European Communities (CEC) I would like to thank you for this opportunity to present some aspects of the Community's policy in the field of electricity and the environment in relation to global climate change issues.

Over the past 40 years, protection of the environment has become an increasingly important factor in policy planning and implementation. This Symposium, jointly organized by 11 international organizations, demonstrates the excellent level of international co-operation in the field of environmental protection, and the important role played by international organizations in meeting both their own objectives and those of the international community.

The 1972 Conference on the Environment in Stockholm prompted the European Community to take action in dealing with air, water and soil pollution. In 1973, after the number of Member States rose from six to nine, the Ministers for the Environment adopted the first European Environment Programme. This was based on the principle that 'environmental pollution should always be avoided' and that the progress provided for in the European Economic Community Treaty should be accompanied by concern for the environment, and at the lowest possible cost to the general public. This 4 year programme focused mainly on improving water quality and also dealt with waste, motor fuels and noise.

The Second European Community Environment Programme, covering the period 1972 to 1981, was initiated partly because of the ongoing deterioration of air. For the first time, it dealt with the protection of nature and drinking water, as well as protection from chemicals.

The Third Environment Programme, from 1982 to 1986, emphasized the need to implement existing regulations and announced a new Community programme of legislation.

In 1985, the twelve Member States of the Community agreed on the Fourth 1986 to 1991 Environment Programme. This programme covered mainly environmental research and genetic engineering as well as the environment policy for agriculture, and also discussed whether emission limits or quality targets should be set.

The main purpose of the Fifth Environment Programme, now in preparation, is to establish a 'policy for the environment' which takes account of the technical, economic and political realities. It must be the driving force for the ecological rehabilitation of Europe.

As long ago as the early 1960s, competent scientists postulated the existence of the hole in the ozone layer of the Earth and the greenhouse effect. In 1979, satellites in the United States of America confirmed the depletion of the ozone layer in the stratosphere around the South Pole. The Villach Conference of 1985 then described the greenhouse effect and scenarios for its influence on global climate change. It was easy to identify the chemical substances causing the ozone hole; immediate political action was planned. The causes of the greenhouse effect and its consequences were summarized at the Villach Conference, but political action will be more difficult to carry out because of the current lack of knowledge on the complexity of the phenomenon. However, inadequate information on the scientific interconnections involved should not be used as a reason for postponing measures to deal with climate change.

The EC Member States fully support the conclusions of the Villach Conference and believe that only the broadest international collaboration can effectively counteract this man induced climate change. At the October 1990 meeting, the Member States adopted a common position on climate change policy and created the framework for achieving the Community objective of stabilizing the total $CO_2$ emissions at the 1990 level by the year 2000, and an even further decrease thereafter.

I would like to present a set of Community initiatives which we believe will contribute to achieving this objective. The Community recognizes that $CO_2$ is currently thought to be largely responsible for the greenhouse effect and that most man made $CO_2$ emissions are due to commercial fossil fuel burning for electric power production and industrial heating. The Community therefore asked the energy industry to examine the implications of their energy production activities for the environment. A code of conduct accepted by the Community's energy industries was designed to demonstrate such a commitment. This code of conduct, developed jointly by national authorities and the Community, demonstrates to the public that the energy industry is founded on strong ethical principles and that national authorities are responsible for enforcing the law.

It is obvious that direct measures by the Community are needed to discipline the energy industry. This has been highlighted in several Community Energy Policy statements. One of the specific areas for Community action is the commitment to energy efficiency and energy conservation. To achieve the greatest environmental benefit, there is no doubt that energy efficiency is the best strategy. The Community considers that increased efficiency at the end user side is a central element and several programmes are financially supporting this action. It is important to stress that the Community strategy is to improve efficiency without causing any reduction in the quality of life or comfort. R&D programmes are being carried out in order to support the Community's action in the field of energy conservation at the end user level and in the generating sector to improve the efficiency of fossil fuel power stations.

It seems that in the near future fuel substitution will be the most efficient and economic means of reducing greenhouse gas emissions. Natural gas is the cleanest fossil fuel; it does not generate any ash, dust or smoke and only releases about half as much $CO_2$ to produce the same amount of energy as coal. Increased use of natural gas in the Community, instead of other solid fuels, would have the most positive effects for the environment; the Community is analysing all these aspects. At the same time, the CEC is reviewing its directive on the use of gas in power stations and will then be in a position to make detailed proposals to the energy industry, not only in the Member States but also in other countries.

This brings us to the next Community action on energy saving activities. The well known concept of using fiscal instruments is to be improved in order to ensure that the price of energy reflects not only market oriented constraints but also the full social costs of energy production. To include the real environmental costs in the price of energy would encourage more rational use of energy, especially electricity, and would accelerate adoption by the market of alternative and renewable sources of energy. It should be pointed out that the Community has agreed to study the issue of fiscal instruments and the environment and to draw up proposals.

The supply side of electric energy contributes directly to the production of $CO_2$ and other greenhouse gases. In any neutral and objective discussion on the interaction between electricity and the environment, it should be pointed out that nuclear energy can make a great contribution towards reducing the greenhouse effect. At present, nuclear energy is already the major source of electricity production in the European Community, but its savings on $CO_2$ production represent only about 8% of the $CO_2$ produced globally by the burning of fossil fuels. Use of nuclear energy varies considerably between Member States. Only six have nuclear power and only two are currently building new nuclear power stations. Nuclear power will only have a future if it can be made acceptable to the general public. This is one of the aims of the Council Directive on informing the general public about the health protection measures taken or planned by national authorities.

The Community regularly examines the whole range of its legal activities in the field of nuclear energy, as set out in the Euratom Treaty. The latter covers nuclear safety, health protection measures and environmental impact assessments. On the basis of its overall view of the situation, the Community is extending and initiating measures to ensure that optimum conditions are created in order to protect the health of the general public and workers against the dangers arising from the use of nuclear technology, and that maximum safety conditions are applied. These activities are integrated with those of the IAEA, and frequent consultations take place that allow for a mutual and fruitful exchange of experience and information.

Apart from nuclear technology, the Community supports research and technical development to improve the efficiency of power plants. In the near future, a large number of old power stations will have to be replaced, therefore future capacity planning will form the basis for the installation of more efficient fossil fuel power plants and new generations of inherently safe nuclear power plants. Furthermore, substantial reductions in the electricity production capacity would be achieved if more information were provided and joint consultation took place on future investment.

The favourite solution of environmentalists to the problems of electricity production is the use of renewable energies. Commercial use of this energy source only contributes 3% to the gross internal energy consumption in the Community. The many different types of such energy, e.g. solar, wind, biomass, mini-hydro and geothermal, make it difficult to estimate their potential in the near future, but they are unlikely to contribute more than 8% to the total electricity production. At the moment, solar energy is the only widely used renewable source of energy, and current trends indicate a breakthrough, especially in developing countries and in special applications.

Forecast and Assessment in the Science and Technology Programme of the Community has been set up to support projects on the use of renewables and to reflect on the experience of non-Community countries. Three parallel programmes have been launched by the CEC in order to support the development of renewable sources of energy, non-nuclear energy systems and energy saving techniques. However, without any fiscal initiatives, improvement in statistical databases or appropriate financial means, exploitation of renewables will be limited.

The objectives of the Community's 1995 Energy and Environment Policy Programme are based on the principle that well balanced solutions are to be found by making use of the best available and economically justified technologies. The new Framework Programme for Research and Technical Development will, in general, provide the technological basis for progress in these matters. The Energy Saving Programme emphasizes that, overall, beneficial effects to the environment can be achieved by wider use of the combined heat and power technology, both by industry and by households of the general public. The Council of Ministers of the CEC adopted the Recommendation to promote co-operation between public utilities and the producers of electricity in order to prevent residual heat releases to the environment.

I would like to mention a further Community activity which is designed to reduce environmental impacts from the use of electricity. The most important factor in this regard is the type of energy chosen for heating purposes in cities. Incorporation of energy and environmental considerations into urban planning is of prime importance in bringing about the desired reductions. The United Nations predicts that by the year 2000 there will be about 60 cities with more than 5 million inhabitants. No city with such numbers existed in 1900. Urbanization will have the largest impact on the environment over the next few years, especially in developing countries. The Community is also affected by this problem. The energy and environment systems for cities will gain substantial experience and the Community's programme will serve as a basis for regional electricity planning systems and should help to reduce global environmental degradation.

I would like to conclude by making certain general observations. From the Community's point of view, all these initiatives and proposals are in recognition of the increasing importance of the environmental dimension in energy policy. One important way of improving environmental protection is to reduce releases of greenhouse gases, sulphur oxides, dust and ash. The contribution of the electricity sector to the production of $CO_2$ and other greenhouse gases must also be reduced. The

CEC is prepared to make specific proposals in order to find well balanced solutions to the environmental problems caused by electricity. The Community has to act as the European legislative authority, where national laws or administrative procedures are insufficient because of the global dimension of the problems involved. In the near future it will be necessary to establish a common global understanding of environmental problems.

As mentioned at the beginning of this statement, the Community is still examining possible courses of action. This will be followed by the operational stage, involving the preparation of specific Council Directives or Recommendations on specific problems. The CEC is hoping to receive from this Symposium suggestions and criticisms that will lead to more effective measures for bringing about a substantial improvement in the environment. In this context, may I thank all the international experts for their contributions to this Symposium and I hope that your discussions will be most fruitful.

## Keynote Address

# INDUSTRIALIZED COUNTRIES AND THEIR POLICIES IN RELATION TO ELECTRICITY AND THE ENVIRONMENT

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### Abstract

INDUSTRIALIZED COUNTRIES AND THEIR POLICIES IN RELATION TO ELECTRICITY AND THE ENVIRONMENT.

Since its very beginning in 1974, the prime objective of the IEA has been to assist Member Governments in improving their energy security, both individually and collectively. Experience concerning questions of energy policy and the various shapes energy policies may take in a market economy environment has accumulated over the past 15 years. The range of energy policies includes short term emergency response measures and long term measures that combine market driven and government actions. Particular attention has been assigned to energy efficiency and conservation investments, fuel supply diversification and expansion of indigenous energy production. Throughout the OECD and in the rest of the world, the demand for electricity is increasing, due to its versatility, transportability and controllability, as well as to steady advances in the standard of living. A number of vital questions arise with regard to meeting the increased demand for electric energy over the next several decades. A brief look is taken at all the energy source options: oil, coal, natural gas, nuclear and renewables. Matters of current concern to utilities in OECD countries are the growing need for environmental protection and for pollution abatement, growing awareness of the need for more competition in the electricity sector, concerns about energy efficiency and conservation, and uncertainty about future markets. These are in addition to the more traditional obligations historically imposed on utilities by government regulators, i.e. to provide a reliable service to customers. How to reconcile and pursue these sometimes conflicting goals is a significant challenge for utilities today. Progress has been made by most OECD countries in controlling air pollutants from the combustion of fossil fuels and in reducing the other environmental impacts associated with energy supply and use. In previous years, most countries had already introduced emission standards for $SO_2$, $NO_x$ and particulates for new large combustion facilities and many had adopted standards for existing facilities. However, the most prominent environmental issue in 1991 is the threat of global climate change. Although many OECD countries clearly see the need to formulate policies to deal with climate change, there are wide variations in approach. Most countries are in the process of developing plans of action. Before the UN Conference on Environment and Development to be held in Brazil in 1992, it will be necessary to formulate environmental policies and to approach the difficult question of comparability between countries. To balance the complex and sometimes conflicting goals of eco-

nomic, energy, trade and environmental policies, governments could place increasing emphasis on the development of economic instruments, enabling markets to seek the most efficient, combined approach. All countries in the world at large face choices related to the build-up of their electricity mix. They must answer these questions: In which geographical area, and among which energy sources, should diversification be pursued? How far should efficient electricity end use be promoted? How can the potential of nuclear power be reconciled with the general public's apparent lack of confidence in this energy source? It is apparent that there are almost as many solutions to the questions of electricity production and supply as there are countries. The large variety of situations and solutions found in the IEA's Member Countries, combined with their political willingness to share their good and bad experiences, can provide a basis whereby experts from other countries obtain first hand information on how to proceed with their own electricity sectors. In this context, international co-operation would definitely improve the policy base of developing countries and transitional economies by providing them with inputs indispensable to the task of coping with the challenges of the next century.

## 1. THE INTERNATIONAL ENERGY AGENCY (IEA) AND ITS ACTIVITIES

I very much welcome the opportunity to address this Symposium on the trends and policies in the Member Countries of the IEA as they affect and are affected by the electricity sector and its environmental implications. I shall take this chance to range my remarks widely, partly because the session is devoted to general policy issues, and partly because I see that you are going to discuss the technical and environmental aspects of electricity supply and demand in great detail later in the programme.

I plan to say a few words about IEA policies in these areas and then to discuss some recent trends in electricity production and supply. Finally, I shall raise some issues concerning regulatory and structural changes and environmental problems that increasingly affect the electricity industry.

Since its very beginning in 1974, the prime objective of the IEA has been to assist Member Governments in improving their energy security, both individually and collectively. Experience on questions of energy policy, and the various shapes energy policies may take in a market economy environment, has accumulated over the past 15 years. The range of energy policies includes short term emergency response measures and longer term measures that combine market driven and government actions. Particular attention has been assigned to energy efficiency and conservation investments, fuel supply diversification and expansion of indigenous energy production. The important goal of efficient energy markets has stimulated support for greater competition in energy supply, market deregulation and privatization efforts, and a progressive reduction in energy and technology trade barriers. The IEA's role in these measures has been to establish and maintain an emergency preparedness system, a framework for collaboration on energy research, development and demonstration between Member Countries, in addition to advising them on the effectiveness of their energy policies.

Over the past 2 years, the IEA has undertaken major work on fuel supply issues in the electricity sector to provide our Member Governments with a view of the prospects for each fuel. Recommendations for policy changes have also been put forward by the IEA and reports have been prepared on each of the fuels used in electricity generation. These cover oil, nuclear power, hydroelectricity, other renewables, natural gas, coal and investments in existing generating capacity.

These reports are now being updated and combined into a single text on the provision of electricity in OECD countries. This document will describe the development of electricity consumption and trade, alternative sources of electricity supply, the opportunities for fuel switching in the longer term, some of the environmental consequences of electricity generation and consumption, energy security issues, and actions that governments may take to enhance the diversity and security of fuel inputs into the electricity supply. Other work undertaken by the IEA covers electricity end use efficiency, energy efficiency and its contribution to environmental goals, as well as electricity and the environment.

## 2. TRENDS IN ELECTRICITY SUPPLY

The demand for electricity is increasing throughout the OECD countries and in the rest of the world, due to its versatility, transportability and controllability, as well as to the steady advances being made in the standard of living. However, a number of vital questions arises with regard to meeting the increased demand for electric energy over the next several decades. High capital intensity, long construction times and the changing circumstances of demand side management increase the difficulty involved in forecasting future electricity needs and in keeping supply in balance with demand. Changing environmental requirements can introduce technological risk, complicate facility siting and increase costs.

In 1990, the installed electricity generation capacity in OECD countries was 1584 GW, of which 511 GW was solid fuel fired, 357 GW hydropower, 242 GW oil fired, 205 GW natural gas fired, 269 GW nuclear power, and less than 1 GW from solar, wind or geothermal energies. The share of fuels used for electricity generation differed greatly among OECD countries. Coal is the leading fuel, contributing more than 50% of the fuel input in the following countries, beginning with those receiving the highest input from coal: Denmark, Australia, the United Kingdom, Greece, the United States of America and Germany. In several countries, hydropower provides more than 50% of the electricity, namely New Zealand, Austria, Luxembourg, Canada, Switzerland and Sweden. Hydropower provides almost all the electricity generated in Norway and Iceland. Nuclear power is by far the main electricity source in France and Belgium, and has a share of over 40% in

Switzerland, Sweden and Spain. Only in the Netherlands is natural gas the leading fuel (54%), while Italy and Portugal depend mainly on oil.

Let us take a brief look at each of these energy source options. The share of oil in electricity generation in OECD countries has fallen from about 26% in 1973 to around 8% today, although it remains high in one or two countries. In most countries, substantial oil fired capacity is maintained in reserve to meet unexpected demand peaks or to make up for losses if other generating sources such as hydropower or nuclear plants are not fully available. Where oil is used in multi-fuelled plants, energy security is not put under threat if the alternative fuel is readily available and the use of oil is kept sensitive to market conditions. However, there is a wide range of fuels available for electricity generation and IEA Member Countries do not plan to build new oil fired power plants.

Electricity generated by coal fired plants has increased greatly over the past decade, and now provides over 40% of the electricity in the OECD region. The smaller differential between prices for coal and for competing fuels (oil and natural gas) has influenced current generating patterns as well as investments in new capacity. Changes in the regulatory climate that favour small scale and independent power generation and growing requirements to meet stricter environmental regulations are increasing the pressure on coal fired generation. The rate of commissioning of new coal fired power plants has dropped since the mid-1980s, partially because of overbuilding in previous years. In some cases, to avoid or delay decisions on building new capacity, repowering or retrofitting of existing coal fired stations can prolong their useful life and improve their environmental performance. However, further development and the installation of 'clean coal' technologies will be crucial if coal is to continue to make a major contribution to electicity generation.

Natural gas is widely regarded as the fuel with the best growth prospects in electricity generation in the OECD region. This is because recent technological advances have raised the thermodynamic efficiency of gas fired units. These advances make natural gas a more competitive base load fuel and also broaden the economic applications in industry. High efficiency gas turbines have become key components in industrial and utility combined cycle generation systems which include dual or multifired capabilities, as well as in industrial co-generation systems. The trend towards more use of natural gas is further aided by the changing institutional and regulatory framework in the electricity industry, the increasing importance of the environmental advantages of natural gas and the greater general uncertainty in the electricity industry. As a result, projections for natural gas use have constantly been revised upwards in recent years. The total OECD gas fired capacity is expected to increase from 205 GW in 1989 to approximately 240 GW by 2000, since legislative barriers against the construction of new natural gas fired capacities were removed in the USA and in countries of the European Communities.

From the aspect of security of gas supply, sufficient gas reserves exist for significant increases in demand, but only at higher gas prices. Moreover, these gas reserves will only be developed if the political and economic climate is favourable for the necessary investment to take place.

There is no doubt that the growing share of electricity generated by nuclear power plants, which from 1965 to 1990 increased to nearly one-quarter of the total OECD electricity generation, contributed greatly to meeting the increased electricity demand and to reducing the dependence on oil fired generation. This progress increased the energy security of all OECD countries.

Clearly, nuclear power stations emit no greenhouse gases, but there are problems of public acceptance in many countries. The IEA Energy Ministers will discuss this issue when they meet on 3 June 1991 and I foresee a debate between those countries who consider nuclear power as an essential part of their energy mix and those who do not.

The total OECD nuclear capacity connected to the grid in 1990 was 268 GW. From 1974 to 1984, the operating nuclear capacity in OECD countries increased by nearly 13% per year. Growth slowed to 7% annually between 1984 and 1990, and is estimated to slow further to 1.3% per year in the 1990s. Nuclear plants provided a peak 23% of the total electricity generated in the OECD area in 1990, but the share is expected to drop by 2000. Among the 13 OECD countries which utilize nuclear energy, the share of nuclear power in electricity generation varies widely. A total of 34 GW of additional capacity was under construction in 1990 in Canada, France, Germany, Japan, Spain, the UK and the USA, and further plants are in various stages of planning. Issues such as regulatory policies, the costs of nuclear power and the location of sites for long term disposal of nuclear wastes continue to affect decisions on investments in new nuclear power generation units.

It is necessary to continue making improvements in the safety standards of nuclear facilities and to keep the public regularly informed on nuclear matters and involved in decisions relating to the nuclear industry.

In total, renewable energy sources contributed about 7% to OECD energy supplies in 1989. Hydropower is by far the most important. It made up 23% of the total installed OECD electricity generation capacity in 1990 and contributed 19% to the total generation (19% in North America, 22% in Europe and 15% in the Pacific region), but in some countries its share was considerably higher. Governments' projections show an increase in installed hydroelectric capacity from 357 GW at the end of 1990 to nearly 400 GW by 2000, but with the projected growth in electricity demand, the hydropower component of both capacity and generation is expected to drop slightly in relation to other sources. Public concern about environmental issues also includes hydropower. Although there is still substantial unharnessed potential in several countries, suitable and environmentally acceptable sites are increasingly difficult to find.

The resolve of governments to pay more attention to the development of non-hydroelectric renewable energy sources has increased markedly in the last years. At present, non-hydro renewables supply only a small fraction (around 1%) of the total

OECD energy needs, mostly from biomass, and in particular wood. It has been recognized that for environmental as well as energy security reasons, future contributions of these energy sources will have to be increased substantially. The potential of renewable energy sources will depend on several related factors, including technological developments, environmental factors, reliability, cost structures, institutional barriers and government incentives.

However, most renewable energy sources, especially electricity produced from solar and wind power, are currently only competitive in special locations and under special conditions. As a consequence, although the contribution of renewable sources of energy is set to increase in most countries, sometimes at impressive rates, they will not replace fossil fuels to any significant extent over the next few decades, even with increased government incentives. Under these assumptions it seems possible that the share of non-hydroelectric electricity generating capacity could rise from the current level of about 1% to around 4-5% within the next 10–15 years.

## 3. ENVIRONMENTAL DIMENSION

The growing need for environmental protection and pollution abatement, the growing awareness of the need for more competition in the electricity sector, concerns about energy efficiency and conservation, and uncertainty about future markets are matters of current concern to utilities in OECD countries. These are in addition to the more traditional obligations historically imposed on utilities by government regulators to provide a reliable service to customers. How to reconcile and pursue these sometimes conflicting goals is a significant challenge for utilities today.

The long standing environmental consequences of electricity production, such as air and water pollution, acid deposition, waste disposal, noise, land use and siting impacts, currently receive sustained attention. Progress has been made by most OECD countries in controlling air pollutants from the combustion of fossil fuels and in reducing the other environmental impacts associated with energy supply and use. In previous years, most countries had already introduced emission standards for $SO_2$, $NO_x$ and particulates for new large combustion facilities and many had adopted standards for existing facilities. The EC Directive on emission limits for $SO_2$, $NO_x$ and particulate matter from large stationary sources will bring standards for new facilities in Member States to a minimum level of uniformity. In addition, phased emission targets will limit the overall emissions from existing plants. In the USA, the 1990 Clean Air Amendments contain provisions for acid rain and air toxins which will affect many electric utilities.

Flue gas desulphurization (FGD) units have been installed since the 1970s in Japan and the USA and since the mid-1980s in some European countries, in particular in Austria, Germany and the Netherlands. These five countries together account for about 95% of the existing units worldwide. Yet in OECD countries, two-thirds of the operating coal fired electricity generation capacity is still not equipped with FGD equipment. The UK has reduced its previous plan for retrofitting FGD by 1998 from 12 to 8 GW, while otherwise leaving the privatized generating companies the choice between FGD, low sulphur coal imports and switching to natural gas. Measures already taken have significantly reduced $SO_2$ and particulate emissions in most IEA countries since 1970. With respect to $NO_x$, significant reductions in emissions have been achieved in some stationary sources, most notably again in the USA, Japan, Austria, Germany and the Netherlands, beginning with those countries achieving the highest input from coal.

However, the most prominent environmental issue in 1991 is the threat of global climate change. Although many OECD countries clearly see the need to formulate policies to deal with climate change, there are wide variations in approach. Most countries are in the process of developing plans of action. In taking what we call the 'Road to Rio', i.e. the run up to the UN Conference on Environment and Development to be held in Brazil in 1992, it will be necessary to formulate environmental policies and to approach the difficult question of comparability between countries.

The IEA is participating in the Intergovernmental Negotiating Committee on a Framework Convention on Climate Change and in the Intergovernmental Panel on Climate Change (IPCC) dealing with policy issues. As is known, the Panel is working towards a better understanding of the science and effects of global warming and the possible measures to combat it.

As part of the IEA contribution to the IPCC work and the subsequent United Nations negotiations, we have carried out a number of illustrative simulations such as the imposition of a carbon tax, improved energy efficiency and more nuclear power for electricity to indicate the scale of the policies that would be required to stabilize $CO_2$ emissions by the year 2005. These simulations are not IEA recommendations, but they have indicated the political and economic problems involved and the scale of measures that would be needed to stabilize $CO_2$ emissions in the OECD alone. The problems of stabilizing $CO_2$ emissions for the world as a whole and of sharing the costs, especially for developing countries, are an order of magnitude greater.

In this area of its work, the IEA has emphasized the need to evaluate properly the response measures proposed, especially in relation to determining the costs and benefits involved, before committing the world economy to an unnecessarily costly or irrevocable response strategy. We are currently liaising with our colleagues in the Economics and Statistics Directorate of the OECD on a project to estimate the economic costs of a number of proposed policies for reducing emissions of greenhouse gases.

However, the implications for the electricity industry are clear: greater energy efficiency on the part of consumers, greater use of less carbon intensive fuels and greater conversion efficiency in coal burning plants all point to lower future coal use in power generation than is currently envisaged.

As a means of balancing the complex and sometimes conflicting goals of economic, energy, trade and environmental policies, governments could place increasing emphasis on the development of economic instruments, enabling markets to seek the most efficient, combined approach. Structural changes continued in the electricity industry in 1989 and 1990 away from traditional, centralized electricity generation towards more competition and smaller, decentralized forms of supply. In the UK, privatization of the electricity industry neared completion. Privatization was also being pursued or considered in Austria, Australia and New Zealand. In Belgium, the Netherlands, Norway, Portugal and Spain reorganization of the electricity industry was expected to improve efficiency. Deregulation of the electricity industry continued in the USA.

In Germany, the building of an efficient, cost effective and non-monopolistic energy system is of major importance. Together with substantial environmental improvements and the provision of adequate electricity generating capacity, these provide some of the prerequisites for economic progress in the eastern States.

Many of the energy conservation policies started in 1989 and 1990 emphasized improved efficiency in the use and generation of electricity. Electric utilities have increasingly concentrated on load management, that is, encouraging consumers to shift power demand to less expensive non-peak periods such as the early morning. Flattening the daily load curve cuts unit generating costs by increasing the average rate of use of capital equipment, but it also reduces the need for peaking facilities, which often run on the most expensive fuels. Higher tariffs during peak hours and lower ones during off peak hours, our 'time of use' tariffs, have encouraged load shifts.

In recent years, governments and utilities have expanded efforts to manage electricity supply difficulties by finding ways of improving efficiency in its use. Load management has thereby evolved into the more general concept of demand side management (DSM) which has become fairly common in North America. A number of utilities in Sweden started DSM programmes in 1990, as did utilities in Denmark, as well as the Electricity Supply Board in Ireland and the Association of Distribution Utilities in the Netherlands.

## 4. NON-MEMBER COUNTRIES

By having to confront all these issues in a world context I think that this Symposium is both timely and full of promise. It will offer a unique opportunity of comparing views on the future of the electric system and the choices that are being faced by developing countries and economies in transition. All countries have to face the choices related to the buildup of their electricity mix. For example, they must answer the following questions: In which geographical area, and among which energy sources, should diversification be pursued? How far should efficient electricity end use be promoted? How can the potential of nuclear power be reconciled with the general public's apparent lack of confidence in this energy source?

It is apparent that there are almost as many solutions to the questions of electricity production and supply as there are countries. In the first place, this is because the relations between the functioning of the market and the actions of governments are complex. They are influenced by economic factors. Frequently, they are also affected by other considerations, for example, by differences in climate, geography, resource base and level of industrialization. Some countries have oil, some coal, some natural gas and some hydroelectricity. Some countries can export energy, while others are barely self-sufficient. Many countries have little or no economically viable energy resources and have to import the bulk of their needs.

It is not surprising, therefore, that there is no standard electricity policy in market economies. However, in parallel with these differences in the electricity and energy policies of IEA Member Countries, there are also similarities. All countries have to find a balance between adequate, secure energy supplies, economic growth and protection of the environment, at the national and global levels. While making efforts to consolidate their electricity policies all countries depend, to a greater or lesser extent, on the importation and acquisition of technologies from abroad, and on R&D co-operation, in order to supplement their own capabilities.

Countries should avoid providing financial support to their electricity industries and they should not offer protection, through barriers to trade, to their primary energy industries that supply electricity production. Budget deficits have often led, in the past, to political turmoil and should be avoided.

The large variety of situations and solutions found in the IEA's Member Countries, combined with their political willingness to share their good and bad experiences, can provide a basis whereby experts from other countries obtain first hand information on how to proceed with their own electricity sectors. In this context, international co-operation would definitely improve the policy base of developing countries and transitional economies by providing them with inputs indispensable to the task of coping with the challenges of the next century.

## 5. CLOSING REMARKS

Before closing, let me add that I find this Symposium particularly impressive because it has been prepared jointly by such a large number of international organizations. I do not want to anticipate any judgement on the results of the discussion that you will have during the next 3 days, but the fact that 11 international organizations are all represented here and are working together smoothly around the same table is a great success in itself.

The IEA looks forward to continuing co-operation in resolving some of the problems that countries of the world are facing. We also look forward to working closely with the experts who attend this Symposium in order to address electricity and environmental issues and to ensure proper consideration of the goals of energy security, environmental protection and economic growth. Thank you again for being given the opportunity of sharing these thoughts with you.

## Keynote Address

# ENERGY AND ELECTRICITY NEEDS FOR THE ECONOMIC DEVELOPMENT OF DEVELOPING COUNTRIES
## *Implications of global environmental issues*

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### Abstract

ENERGY AND ELECTRICITY NEEDS FOR THE ECONOMIC DEVELOPMENT OF DEVELOPING COUNTRIES: IMPLICATIONS OF GLOBAL ENVIRONMENTAL ISSUES.

Atmospheric pollution, acid rain, ozonosphere damage, environmental deterioration and a continuous reduction in biological species have become common concerns of the present day world community. It is becoming increasingly clear that worsening deterioration in the global environment has endangered the lives and development of all mankind. The energy industry is, at the same time, the physical foundation for the development of modern society and an important source of environmental pollution. Therefore, it is a realistic and severe challenge to seek economically feasible and environmentally sound approaches to developing the energy industry. To achieve appropriate growth in the national economy, China will employ some strategic measures to control pollution growth, to save energy and to increase the efficiency of energy utilization. To raise the share of primary energy used for electricity generation, China plans to set up integrated bases near the coal mines for coal, electricity and power plants, as well as to spread the innovation of boilers and popularize the use of fluidized bed combustion and desulphurizing facilities. Also on the agenda are programmes to replace decentralized heating boilers with co-generation units, and to develop and utilize energy resources that cause less or no pollution. China also intends to develop nuclear energy, encourage the use of wind energy, solar energy and biogas resources in remote pastoral and mountainous areas, promote research on new and renewable energy resources, follow the line of advanced technologies, etc. Because industrialized countries produce three-quarters of the $CO_2$ emitted into the atmosphere, they should be made accountable for having caused irreparable global environmental pollution. They should also undertake more of the responsibility for global environmental protection, since their financial resources are greater and their technologies more advanced.

I have the honour to extend, on behalf of the Chinese Government, warm congratulations on the opening of the Senior Expert Symposium on Electricity and the Environment.

Since World War II, the world has been faced with many environmental challenges. Atmospheric pollution, acid rain, ozonosphere damage, environmental deterioration and a continuous reduction in biological species have become common concerns of the present day world community. It is becoming increasingly clear that worsening deterioration in the global environment has endangered the lives and progress of all mankind.

Environmental protection and economic development considerations form an organic whole whose components promote and condition each other. Social and economic development must be based on sustainable natural resources and favourable ecological environment, while protection of the global environment can only be achieved in conjunction with social and economic development. Industrialized countries, whose financial and technological resources are greater, should contribute more towards improving and protecting the global environment. Developing countries should seek measures that suit their national conditions in order to control and protect the environment, along with the prerequisite of realizing economic growth and controlling population increases. Every attempt should be made to avoid the same development–pollution–control course followed by developed countries in their progress towards industrialization. Economic development and environmental protection should be afforded equal importance.

The energy industry is, at the same time, the physical foundation for the development of modern society and a significant source of environmental pollution. Therefore, it is a realistic and severe challenge to seek economically feasible and environmentally sound approaches to developing the energy industry.

Since World War II, developing countries, which make up three-quarters of the world's population, have made remarkable progress in improving their national economies and striving for economic independence. However, for various subjective and objective reasons, their economic growth has not been satisfactory. Especially since the 1980s, the rate of economic growth has been hindered in many developing countries. According to statistics published by the World Bank (7 December, 1988), in 1967, the average Gross National Product (GNP) per capita in developing countries was US $170, while in developed countries it was US $2530, with a ratio of 1:14.9. In 1987, these figures increased to US $720 and US $14 580, respectively, with a ratio of 1:20.2. As can be seen, the difference has widened greatly.

The lag in economic growth facing developing countries is mainly because of historic reasons. Of these, the inequitable international economic order has been one of the most important constraining factors. Looking ahead to the last decade of this century, it is estimated that economic development in developing countries will increase only slowly. This long standing economic delay is bound to affect severely any improvements in the global environment and worsen global environmental deterioration. Therefore, it is unlikely that developing countries will be able to participate in the protection of the global environmental or establish a sound mechanism for its improvement until a new and more equitable international economic order is established. Only such an order would accelerate economic growth in developing countries, narrow the gap between rich and poor countries worldwide and favour stable, sustainable and common development in the world economy.

Social and economic development, which symbolizes the progress of human society, relies on the consumption of energy. The objective of the industrialization process in any country is to show a continuous increase in the level of replacement of human and animal power by energy consuming machines for production activities. As statistically indicated, the average energy consumption per capita in developing countries is only one-sixth that of industrialized countries. Furthermore, a large part of energy generation in developing countries is derived from plants, deforested woods and other low grade energy resources. According to the forecast made at the 14th World Energy Congress held in Montreal, Quebec, in 1989 [1], by the end of this century the energy demand in developing countries will increase greatly from the current level, while the total energy consumption worldwide will increase to 16 000–19 000 million tonnes of coal equivalent (tce) over the same period. Developing countries, which possess 75% of the world's population, account for only about 20% of the world's total energy consumption. As a result, it is unfair to criticize developing countries for showing a constant rise in their energy consumption level or for using more high grade fossil energy resources; in fact, this is an unavoidable trend if they are to develop their economies.

Facing the problem of ever increasing energy consumption, every country has to deal with the question of how to reduce atmospheric pollution and protect the environment when drawing up its national economic development strategy.

China is a developing country with a population of 1.13 billion ($10^9$), a large country in both energy production and consumption. In 1990, the gross primary energy production had risen to 1040 million tce, of which coal accounted for 74.1%, oil 19.3%, natural gas 2% and hydropower 4.6%. The annual electricity generation had risen to 618 TW·h, including 126 TW·h from hydropower. As a nation, China ranks third in the world regarding primary energy production; its installed capacity and electricity generation rank fifth and fourth, respectively. The average energy consumption per capita is 860 kg of coal equivalent, only one-third of the world's average, and electricity generation per capita is 550 kW·h, only one-quarter of the world's average.

Another characteristic is that the energy consumption per unit GNP is among the highest in the world. These statistics imply that the country is a large producer of energy, but also that it has quite a low per capita energy consumption level.

For these reasons, China has adopted the following development strategy. In an effort to modernize the energy industries, every effort is being made to increase energy utilization efficiency and to make use of every possibility of reducing atmospheric pollution in order to protect the environment and avoid following the example set by developed countries: pollution first and control later. It has been forecast that in China the total demand for primary energy by the year 2000 will exceed 1400 million tce.

To ensure appropriate growth in the national economy, the following corresponding strategic measures are to be taken:

**(1) Control of population growth:** According to the national census carried out in 1990, China's population had reached 1.13 billion. The annual population growth was 14.4‰. If the population growth rate remains at its present level, the population of China will be 1.2 billion by the year 2000. Thus, actively implementing birth control and thereby population control has proved to be a very successful way of effecting a reduction in total energy consumption.

**(2) Energy savings and an increase in the efficiency of energy utilization:** This is one of the key policies of the Chinese Government. On the basis of the 1990 statistics, the energy consumption per 10 000 yuan (US $1887 equivalent) GNP was 9.4 tce. Although 30% lower than the coefficient of 10 years ago, this amount indicates that China is still in a situation of low efficiency and high cost energy consumption compared with some developed countries of the world. There exists in China a great potential to save energy, raise efficiency and reduce consumption according to the following detailed measures:

(a) Raise the share of primary energy used for electricity generation as an important means of improving energy efficiency and also of reducing environmental pollution in concentrated population areas. The 1990 figures indicate that only 23% of primary energy is used for electricity generation, while developed countries have approached a ratio of 35–45%.

(b) Carry out technical renovation in order to raise the energy efficiency. Replace gradually, small sized generating units (under 25 MW) by constructing a large number of 300–800 MW units with high and supercritical parameters. The transmission loss will then be reduced and the coal consumption per kilowatt-hour will be lowered by about 3 g per year. The 1990 statistics show that the average coal consumption per kilowatt-hour in Chinese fossil power plants is 430 g, while that in advanced units is only 320 g. If the gross annual electricity output is 500 TW·h, then 50 million tonnes of coal will be saved each year.

(c) Build integrated bases for coal mining and electricity generation and also 'mine mouth' power plants. Improve combustion techniques, spread the innovation of boilers and promote use of fluidized bed combustion and desulphurizing facilities as a means of centralized control of environmental pollution.

(d) Replace decentralized heating boilers with co-generation units in order to improve the heat value efficiency. According to incomplete statistics, over

700 000 small boilers provide heating all over China. After their replacement, the heat efficiency could rise by 10–20%.

**(3) Development and utilization of energy resources that cause less or no pollution:** China has plentiful hydropower resources. The exploitable resources so far explored amounted to 370 GW at the end of 1990, and the installed capacity of hydropower was 35 GW, accounting for only 9% of the total hydro resources and 4.6% of the primary energy production. Therefore, it is an important energy policy for China to develop hydropower vigorously in order to optimize the energy structure, reduce atmospheric pollution and decrease emissions of $CO_2$ and other poisonous gases. A number of large hydropower plants will be built within the next 10 years and the proportion of hydropower in the primary energy structure will be raised from 4.6–6.8%. This increase will contribute not only to the environmental protection of China but also to the alleviation of global climate changes caused by $CO_2$ emissions. From the perspective of global environmental protection, the more China develops hydropower, the more it will contribute to an improvement in the world's environment. If international monetary organizations were to provide China with financial support to develop hydropower, this would also help the country and the environment worldwide.

If nuclear energy can be developed as planned, another significant step will be taken towards protecting the environment and developing the energy structure. Within the next 10 years, the Chinese Government has plans to build a number of nuclear power plants based on the prerequisite of ensuring safety and mastering the technology. These plans will help to realize gradually the localization of equipment manufacturing in order to lower the engineering costs and lay a solid foundation for the rapid development of nuclear power in the next century.

To popularize the use of wind, solar and geothermal energies as well as biogas resources in remote pastoral and mountainous areas is another of China's energy objectives. There are plans to replace the use of plants and wood as living energy resources in rural areas in order to improve the ecological balance and protect the physical environment.

China also intends to promote actively research on new and renewable energy resources and follow the line of advanced technologies in fields such as the use of hydrogen power, highly efficient photovaltic conversion techniques and marine energy, as well as research on and design of new and advanced nuclear power reactors, e.g. fast breeder reactors, etc.

Extension of economic structural reforms, rational readjustment of energy pricing, promotion of energy conservation and raising of efficiency by means of marketing mechanisms are also scheduled.

Each developing country should design its individual development strategy and energy policy according to its own national situation in order to enable the mutual promotion of environmental protection and economic development, so as to realize economic progress quickly and narrow the gap with developed countries.

The average annual energy consumption per capita worldwide is two to three times greater than that of developing countries. Because industrialized nations produced three-quarters of the $CO_2$ emitted into the atmosphere, they should be made accountable for having caused irreparable global environmental pollution. They should also undertake more of the responsibility for global environment protection, since their financial resources are greater and their technologies more advanced. Industrialized countries should moderate their national energy consumption growth and make more effort to restrain $CO_2$ emissions. They should also provide additional financial and technological support as well as assistance to developing countries so that they can develop their energy strategies and protect the environment, as laid out in the Montreal Protocol in June 1990, with ''the best available environmentally sound technologies [being] transferred expeditiously on a fair and most favourable basis'' [1]. Industrialized nations need to build up a just and equitable international economic order so that trade protectionism is eliminated and transfer of polluting industries is prohibited.

When the present day world community attaches equal importance to the global development and environmental issue, and takes on, as a common endeavour of all nations, effective and feasible measures, the Earth will surely become a cleaner and more beautiful place on which to live.

## REFERENCE

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## Keynote Address

# POLICY ASPECTS OF ELECTRICITY AND THE ENVIRONMENT IN EGYPT

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**Abstract**

POLICY ASPECTS OF ELECTRICITY AND THE ENVIRONMENT IN EGYPT.

Egypt is facing many challenges, most of which stem from the high population growth rate. Efforts to improve the standard of living require substantive development of Egypt's economic, technical, community, electricity and energy infrastructures. Over the past three decades, the electric energy demand has increased more than 15 fold, requiring development of sound national electric energy policies based on rational use of indigenous resources which are, unfortunately, limited. Realization of such policies faces a number of economic and social constraints, all of which need great efforts to overcome. Environmental considerations within Egypt's electric energy policies are focusing more attention on the degradation in environmental conditions, which is in line with growing public concern about this issue, both locally and internationally. An alarming increase in pollution levels in the urban areas of Egypt has necessitated the creation of new laws to curb pollution of the air and the environment, in addition to adhering to strict standards for effluents from thermal power stations.

## 1. INTRODUCTION

It is a great honour for me to have been given this opportunity of addressing this prominent gathering of experts from all over the world. The question I plan to address is whether in a developing country like Egypt, with all its ills and insurmountable problems, there is room for environmental considerations in its electricity policies.

Each and every developing country strives to improve the standard of living of its inhabitants. This can only be achieved by developing its infrastructures, whether they be of an economic, technical or community nature.

Ideally, such development has to be balanced in every respect. *First:* There has to be a balance between satisfying the needs of the present generation and providing equal opportunities for future generations to satisfy their own needs. If we exhaust our resources or ruin our environment, we shall make life much more difficult for subsequent generations. *Second:* A balance has to be found between local considerations and regional or international considerations. We are now living in a small and transparent world. Social, cultural and environmental conditions may have transboundary impacts on neighbouring countries; sometimes, the impact may even reach distant countries. *Third:* Dreams and realities have to be matched. Every wish cannot be fulfilled and in such a situation a realistic approach has to be taken. There is an Arabic saying: "What cannot be achieved completely, should not be left altogether". *Fourth:* The economic and social branches of development have to go hand in hand, as well as the infrastructural needs of each. Emphasis that is too one sided generally has an unstabilizing effect on society; therefore, we cannot afford to sacrifice one issue for the sake of another. *Last:* We have to realize that we are living in an ever changing and often unpredictable world. Many developing countries are located in regions of persistent political turmoil. At any time, somewhere around the world, events may occur which can affect countries near or far, large or small. Developing countries are even more susceptible to such events. With their limited resources and means, they cannot escape the severe impact that such events may leave, some of which prevail for years or even decades. The Gulf war is a vivid example of such a situation: almost every country worldwide was affected economically, but developing countries were certainly the most seriously hit.

As a result, to reach sustainable, balanced development in any country is not an easy task. It is even more difficult and complex when developing countries are considered. One has to admit, with admiration, that some developing countries have been able to cross the threshold and are now in a position to achieve sustainable and relatively high rates of development. However, many such countries are still unable to acquire this balance, or else they have to accept compromises or sacrifices in order to realize only partial solutions.

In discussing the specific case of Egypt, I will try to explain how — in the midst of all the complexities and challenges that abound for many developing countries — it was possible to set up policies that led to the realization of a relatively successful electricity generating programme, while observing many other considerations, including that of the environment.

## 2. THE PARTICULAR CHALLENGES FACING EGYPT

Many of Egypt's requirements and problems stem from the high population growth rate. Over the past decade, the population has increased from nearly 43 million in 1980 to about 55 million in 1990, i.e. 12 million more people in only 10 years. It is not only the size of the population that is a problem, but also the fact that about 50% of the population is under 20 years of age. All efforts to slow this growth in population have met with little success, and it is expected that the numbers will rise to 65–70 million by the year 2000. This spiralling population growth results in excessive stresses on urban growth, land use, social improvement and welfare, and the need for more land for cultivation and also for industrial expansion to meet basic economic needs.

With an area of a little over 1 million square kilometres, Egypt is considered a relatively large country. However, less than 10% of this area is inhabited, the rest is desert. The majority of the population lives on or near the rich lands of the Nile Delta, the Nile Valley and along the Suez Canal. About one-fourth of the population lives in the metropolitan Cairo area, and continuous migration contributes greatly to the problems of urban pressure. Accordingly, a long range policy was set to suppress the growth of existing urban centres and to create new population centres with a view to attracting and accommodating most of the growing population. Such centres are either new industrial oriented cities or concentrations on new lands reclaimed from the desert. To realize these aims involves many and complex challenges, including the development of social, economic and technical infrastructures; of prime importance is an infrastructure for electricity supply, which is needed for all types of development.

Egypt also has a limited capability for expanding its agricultural production. It has had to change its economy from being agriculturally based to one which is principally based on industry and service activities, e.g. tourism. Achieving these goals also required, and continues to require, substantive development of Egypt's economic, transport, communications, community, electricity and energy infrastructures; this means facing further challenges and generating even more electricity.

Such development of the electric energy system should always be compatible with the broader national objectives that have dictated some of the major fundamental changes in the social and institutional structures relating to Egypt's economic system, management authorization, pricing system, etc.

How were we able to meet the electric energy requirements under such complex conditions? And what policies did we adopt? Before these points are discussed it is necessary to review the electric energy demands and the resources that contribute towards satisfying such demands.

## 3. ELECTRIC ENERGY REQUIREMENTS

Electricity was introduced into Egypt in 1894. Until the 1940s, use was mainly limited to lighting in streets and houses and operation of tramways. The real increase in demand, however, began in the early 1960s. The peak load in 1960 was only 372 MW. It increased at an average annual rate of 11.7% to reach 1100 MW in 1970, then at an average rate of 11.3% to reach 3239 MW by 1980. In the 1980s, it continued to increase, rising to 11% during the first 5 year plan 1982/1983 to 1986/1987, with a peak load of 5800 MW; by 1990 it had reached 7000 MW.

Because of the prevailing economic conditions, the increase in demand is likely to subside appreciably in the 1990s. It is expected to be about 6.2% during the period 1992–1997, then to level off at 6% until 2005. Accordingly, the peak load is expected to be 10 500 MW by 1996–1997, the end of the third 5 year plan, and to reach about 13 000 MW by the year 2000. If current efforts to boost the economy meet with success, this figure may rise even further.

Generation of electric energy followed the same pattern. In 1960, it was only 1.9 GW·h, increasing to 6.9 GW·h in 1970, with an average annual rate of increase of 8.6%. In 1980, it had increased to 18.43 GW·h, an increase of about 10%. Throughout the 1980s it continued to increase, with a relatively high rate of about 10% annually. In the first 5 year plan, 1982–1987, generation increased from 24.6 GW·h to nearly 38 GW·h; in 1990 it had reached 42.5 GW·h. However, in a similar manner to demand, generation is expected to fall to 6.2% in the period 1992–1997 and to level off at 5.6% until 2005. This means that electricity generation may reach 65 GW·h in 1997, and about 100 GW·h in the year 2005, unless there is another economic surge, in which case there should be a further rise in generation.

Therefore, within three decades the peak load and the energy generated increased at an average annual rate of about 11.5% and about 10%, respectively. Both these figures are high, but they reflect the situation in a number of developing countries.

Despite the growth in population, the per capita rate also increased greatly; it was less than 50 kW·h in 1960 but rose to about 800 kW·h in 1990, i.e. an increase of more than 15 fold.

To satisfy this ever growing need for electric energy, tremendous effort was required, including systematic planning, top priority governmental support and large investments. Because of the relatively good credibility of the electricity sector, the government was able to secure appreciable financing in the form of aid or soft loans for electricity projects, without which the task would have been impossible.

## 4. ENERGY RESOURCES

To develop a sound national electric energy policy, a country has to rely on its indigenous resources. However, for purely economic reasons, situations may arise in which the preferred approach is to import energy, even if domestic resources are available. Egypt can in no way be considered rich in energy resources. On the contrary, those that exist are only likely to last until the turn of the century; thereafter, the country may have to rely on additional imported sources.

The main commercial energy resources in Egypt are hydro, oil, natural gas and uranium. There are only limited coal resources, largely unexploited as yet.

At present, the Nile River is the only source of hydropower in Egypt. Most of the water has already been harnessed through the Aswan Dam and the High Dam complex. The Old and New Aswan hydro stations generate 545 MW, and the High Dam hydro station 2100 MW. The stations are only 6 km apart and form a kind of cascade. In total, this hydro complex generates 2645 MW, supplying about 10 GW·h yearly, depending on the flood level of the Nile and, consequently, the amount of water stored behind the High Dam, and on the irrigation requirements.

The proven recoverable oil resources are about 600 million tonnes, mostly located in the Gulf of Suez Basin. In 1988, oil production was about 46 million tonnes; 45% is consumed locally, nearly half for electricity generation.

The estimated proven reserves of natural gas are about 290 billion ($10^9$) cubic metres. The majority of these reserves are found in the Delta Basin, the Western Desert and the Gulf of Suez. In 1990, gas production was about 5 billion cubic metres used mainly for electric power generation (about 50%) and in industry, especially the chemical and fertilizer industries, in addition to household use.

The coal deposits in Egypt are very limited, and are located at three places in the Sinai: Tor, Oyon Moussa and El-Maghara. The latter location has the best quality coal, and studies have shown the economic feasibility of using it. The Maghara deposit is estimated to be about 40–50 million tonnes of recoverable resources, with an annual production in the range of 0.6 million tonnes. Owing to the high quality of this coal, it is used mainly in the iron and steel industry rather than for producing electric energy. Other coal deposits either have poor geological characteristics for recovery or are not economic to exploit. Egypt imports about 1.25 million tonnes of coal per year for its industrial requirements.

Uranium deposits show more promise than coal. They appear as secondary minerals in granitic formations in the Eastern Plateau of Egypt and the Sinai and in sedimentary rocks in the Sinai. Speculative resources are estimated to be 13 000 tonnes. Feasibility studies are being carried out with a view to producing uranium as a by-product from the processing of phosphate ores to phosphoric acid. Egypt has high deposits of such ores. There is also some uranium in the black sands found in abundance to the north of the Nile Delta.

New and renewable energy resources (sun, wind, etc.) are used on a limited scale. Egypt falls within the solar belt and receives around 300 days of sunshine per year. The coastal areas and the southwestern parts of the country have reasonably high wind velocities (7 m/s); in fact, the Gulf of Suez and the Red Sea areas have a relatively high wind velocity all year round. However, with current technology, new and renewable resources may only contribute a few per cent to the electric energy supply of Egypt by the end of this century.

## 5. BASIC ELECTRIC ENERGY STRATEGY

Because of the limited indigenous energy resources in Egypt, it is necessary to optimize their use. On this basis, an electric energy basic policy was set in 1980 and approved by the Egyptian Government and Parliament. The strategy has been translated into the following main policies:

(1) Use of hydro resources to the maximum possible extent as a clean and reliable source
(2) Application conservation techniques and incentives to curb the high increases in demand
(3) Use of as much natural gas as possible, depending on its availability
(4) Introduction of alternative energy sources such as coal fired and nuclear power plants to reduce the dependence on oil
(5) Use of new and renewable resources whenever technically and economically viable.

About 80% of the hydropower is already harnessed. Hydroelectric power stations are now being installed on the main barrages over the Nile River; this could add another 1 GW·h annually. Additional mini-hydro stations are also planned on the branches and canals of the river.

Great emphasis has been placed on conservation, including generation, transmission and use. Many of the older stations have been refurbished to improve their efficiency and to reduce their fuel consumption. Ways of reducing transmission losses are being observed. Conservation and load management techniques in industry are receiving great support in government policies. Finally, the electricity pricing system is structured to encourage consumer conservation.

The policy is to use more and more natural gas to operate electric power stations because of the economic and environmental advantages it has over oil. Egyptian gas is 'sweet', i.e. free of sulpher, which is a blessing. However, gas for electricity generation has a lower priority than for industrial and residential use; as a result, the amount provided for firing a power station is not enough to substitute for all the oil, therefore all power stations are dual firing.

To reduce dependence on oil, and because there is not enough local natural gas, alternative sources of power generation are being planned, namely coal and nuclear. It was anticipated that coal fired and nuclear power plants would join the grid in the late 1980s. However, for economic and financial reasons, and because of the Chernobyl accident, this has been delayed until after 1995.

New and renewable energy resources such as solar and wind are attracting great attention. Efforts are being made to develop reliable and commercially attractive systems for such resources, particularly wind energy. The nucleus for a power generated wind farm is being established in the Hurgada area on the Red Sea.

As can be seen, in all the set policies environmental considerations are not spelled out clearly or separately. However, each of the five policies has an inherent element of environmental impact. In fact, all of them, except that for coal fired plants, can be considered environmentally compatible policies.

Having set the above mentioned strategy and policies, the task of the electricity sector was then to draw up plans to realize these policies. In some areas it was a success; in others some constraints or difficulties were apparent.

## 6. CONSTRAINTS IN REALIZING THE POLICIES AND PLANS

Although the plans tried to incorporate all the foreseen parameters and to use well established methods for future projections, some constraints appeared, e.g. uncertainties in demand projections, public response to the set conservation policies, subsidies in energy prices, public opinion on the alternatives to oil, and the scarcity of financing.

### 6.1. Uncertainties in demand projections

In general, planning in the electricity sector has, primarily, to be long range, while in other sectors it is short range. In addition, the flow of information between sectors is often neither consistent nor timely, nor is it based on reasonably assured studies; this sometimes creates surprises in demand that are not always foreseen.

Social development also adds to the problem of uncertainty. Estimates of consumption in rural areas fell short of the real figures when electricity was introduced. Egyptian ex-patriots who have worked in other Arab countries and who now live in the countryside bring back with them all kinds of electricity consuming equipment as well as the bad habits that they have picked up in these oil rich and electricity cheap countries. This rapid change in rural society was not anticipated.

### 6.2. Public response to set conservation policies

To curb the rapid growth in electric energy demand, negative incentives are being used: an escalating tariff structure leaves only small consumers with an appreciable subsidy. Even this subsidy is being reduced gradually so that real prices can be realized by 1994–1995. However, most of the Egyptian population is hungry for electricity. Understandably, everyone claims his/her right to enjoy electric appliances, sometimes even luxury items such as video cassette recorders and air conditioners, as long as they can afford to pay the electricity bill. As is customary in Egypt, at celebrations, weddings and ceremonials electric decorations are used; such use of electricity is often irrational.

### 6.3. Subsidies in energy prices

The Egyptian Electricity Authority (EEA), the only utility in Egypt, obtains its oil and gas for power stations at subsidized prices; it pays only 50 Egyptian pounds (about US $15) per tonne of fuel oil. Thus, it can also sell electricity at the subsidized level, with no financial loss. If the EEA has to import coal at international prices, then it is forced to sell electricity on an economic basis. This is difficult at the moment. A different government agency has to import the coal and sell it at the subsidized price to the EEA in order to keep the economic balance. This problem has not yet been solved, and is causing delays in the coal fired plant programme.

In addition, subsidies in electricity prices create difficulties with some financial institutions such as the World Bank. This is the reason why, within the framework of economic reform programmes, subsidies in electricity are to be lifted stepwise within about 3 years.

### 6.4. Public opinion on the alternatives to oil

Both the coal and nuclear power options have a problem with public acceptance. Regarding nuclear power, Chernobyl had a drastic (negative) effect on the Egyptian public as well as decision makers, as everywhere else worldwide. Before the government agrees to resume the nuclear power programme, strong assurances will have to be secured that the safety and reliability of nuclear plants are guaranteed totally.

Coal fired power plants will not be completely accepted unless environmental considerations are observed. Concern over the environmental impact of importing and burning coal is mounting with the worldwide concern about global warming. The public will now have to be satisfied that the measures taken in coal plants to reduce environmental impacts are adequate.

### 6.5. Scarcity of financing

The high rate of growth in electric energy demand has resulted in large investment requirements to build and operate more power stations, transmission lines and other electric facilities. The country has to rely on external financial sources to cope with the heavy funding required. Many factors affect such financing internationally, the most important of which is the economic credibility of the country. Egypt is doing its utmost to improve its economy with a view to achieving such credibility. Agreements with the World Bank and the International Monetary Fund have already been reached; these should pave the way to opening more sources of financing for the electricity sector.

## 7. ENVIRONMENTAL CONSIDERATIONS IN EGYPTIAN ELECTRIC POLICIES

Some of the laws and decrees in Egypt include implicit environmental considerations; others were enacted to create instruments and bodies that have to deal with environmental matters such as establishing the High Committee for Protection of Air from Pollution in 1969, and the Egyptian Environmental Affairs Agency (EEAA) in 1982. However, such laws and decrees can no longer cope with the current requirements for a clean environment. For example, the current standards governing effluents from power stations were set by the Ministry of Health in the 1960s, long before the general public became so concerned about environmental issues. At the time, they were adequate for a society that was based mainly on agriculture. However, since then many industries have been introduced and expanded, and society has changed appreciably, with motor cars now jamming the streets. All this happened when environmental protection was being given less attention. As a result, these standards are no longer practical. In fact, measurements taken around thermal power stations show that the background level of pollutants is much higher than the incremental additions resulting from power station effluents.

Because of this growing concern over the degradation in environmental conditions and the increase in pollution levels, the government is now in the process of enacting two new laws: one on Protection of the Environment and the other on Protecting the Air from Pollution, which are expected to be passed by Parliament soon; detailed codes and regulations will follow their enactment and the EEAA will be their enforcing arm. These laws aim at addressing current concerns about all aspects of pollution, and at introducing ways and means of enforcing protection of the environment as a whole and the air in particular.

In the electricity sector, operating rules require strict adherance to the set levels for environmental protection, sometimes dictated by international financing institutions such as the World Bank. Measures to reduce air pollutants, particularly $SO_2$, $NO_x$ and total suspended particles, are multifold:

(1) Use of as much natural gas as is available; luckily, our natural gas is free of sulphur and does not produce suspended particles
(2) Suppression of $NO_x$ by applying conventional methods such as water injection through the combustion system or by introducing staging into the combustion process (adjusting the flame temperature and combustion time)
(3) Construction of power stations with high chimneys to reduce the pollutant concentrations at ground level
(4) Conversion of all free areas around the power stations to green areas to help reduce the effect of $CO_2$ releases; competition among power station managers is always prevalent, but this is encouraged strongly.

Thermal pollution from condenser cooling water is avoided by properly designing the discharge systems. For power stations on the Nile River, the differences in temperature between the cooling water and the river water have to be eliminated within 50 metres.

Concerning plans for future power generation from coal fired stations, the set policies take environmental concerns into full consideration:

(a) Sites for coal fired plants are chosen far away from the Nile Valley or populated areas, e.g. Oyon Moussa and Zaafarana on the Gulf of Suez, and Sidi Kreir on the Mediterranean coast
(b) Use of electrostatic precipitators of high efficiency, and burning of coal with a low ash content
(c) In addition to having a low ash content, imported coal has to be of high quality, i.e. with a low sulphur content
(d) Chimneys have to be at least 250 metres high
(e) Highly efficient burning techniques should be used to reduce $NO_x$ emissions.

All other major power generation projects are carefully studied from the environmental point of view. If they carry any appreciable environmental risk, it becomes difficult, if not impossible, to justify them, for example, the Quattara Depression Solar Hydro Project. The Quattara Depression covers an area as large as Switzerland. It is located in the Western Desert 55–75 km from the Mediterranean Sea; at its lowest point it is 134 metres below sea level. It appears to be quite attractive as a hydro project. However, studies have shown that the following possible side effects and environmental impacts may materialize if the project were to be undertaken: an increase in the seismic activity of the region through the activation of natural faults as a result of the large volume of water, an increase in humidity from evaporation of the large surface of water, a possible increase in the level of subsurface water in the Delta area, changes in the ecology of the area, etc. Some of these effects would be tolerable, others not. Therefore, the project was set aside for further studies on the future of the electricity demand.

## 8. CONCLUSIONS

In conclusion, Egypt not only has to carry its own burdens, but also those that arise from the unstable nature of the area in which it is located. In the midst of all these problems and considering all the challenges that it has to face, one feels quite proud that the country has been able to realize a successful electric energy programme. In addition to covering all the electricity demands, a reserve capacity of about 15% exists. All the electric energy projects have been implemented in a manner such that local and international standards for the environment have, to a great extent, been satisfied.

We are concerned with our own and the global environment. Within our long term policies, we are looking ahead to interconnecting, through our grid, the huge hydro resources of Central Africa to Europe with a view to tapping clean energy sources so that global environmental degradation is reduced. Protection of the environment has a very high priority in our policies and plans, and it always will.

# ENERGY AND ELECTRICITY SUPPLY AND DEMAND:
## *Implications for the Global Environment*

**(Topical Session 1)**

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# CHAIRMAN'S REPORT

# ENERGY AND ELECTRICITY SUPPLY AND DEMAND
*Implications for the Global Environment*

## Key Issues Paper No. 1

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## 1. INTRODUCTION

It is both an honour and a pleasure to be invited to present to this distinguished audience the contribution of International Expert Group 1 on the long term outlook for the global supply and demand of energy and electricity. It is also an awesome task; to present you a vision of the future, to identify the key implications for policy concern and to sketch a way forward in meeting these challenges.

Clearly one cannot, in the time available, go into detail, add a nuance, expand the argument and otherwise reflect the richness of the report. For example, I will not discuss the scenario approach used to define some reference numbers for the two time horizons we examined: to 2010, and later to 2050. I would like to identify the main issues of relevance to you as policy makers and only comment on details where they are necessary to put into context a particular point which otherwise might seem out of context.

As an economist, I intend to remain restrained in my reference to both numbers and caveats; these are, however, in the paper. Perhaps some figures do give an indication of the challenge confronting us all. Today we consume globally some 9 billion ($10^9$) tonnes of oil equivalent (toe) energy. In 2010, this could rise to 12 billion toe, and if we speculate further into the future we might face requirements of some 21 billion toe in 2050.

If we are right, and there are more efficient ways of producing and using energy, then we could make a substantial cut in our energy requirements without constraining people's aspirations for a better life. How to do so is the issue we address in our paper.

The policy challenges facing not only those in energy but also those concerned with economic growth and social development will be determined by the answers we give to the questions:

(a) Can we continue to develop the world's energy supplies on a secure and economic basis, sufficient to maintain economic growth, while at the same time ensuring that the global environment is protected and indeed improved?
(b) Will improvements in technologies ease the tensions in achieving these objectives by offering us more efficient means of both producing and using energy and electricity?

In responding to these challenges we are, in fact, creating the energy agenda for the 1990s. However, this is an agenda which does not stand in isolation — it reflects the world's concern, expressed in different ways, about social and economic development. In meeting this overall challenge we are confronted with a number of individual policy questions. How much effort should we use to realize the emission reduction potentials in the electricity sector through efficiency improvements: increased use of non-fossil supply sources and increased use of lower impact fossil fuel based supply sources? Is there the political will and how much of this should be focused on impact reductions? Within the global community, who should do what in meeting targets? To put this simply but perhaps more bluntly, what share of global effort should be assumed by particular countries and regions and how do they relate in answering the challenging questions posed?

These issues are complex and controversial enough when considered in isolation. Within the context of other social concerns, ranging from jobs to social well being, they are even more complicated because of the resources available in the world to meet the whole host of social end economic needs, funding, leadership attention — all of these are finite.

Resources focused on electricity are not available to resolve other issues; indeed, the reverse is true. There is competition between scarce resources. This is not to say, for example, that environmental management in the electricity sector is not related to sustainable development more generally. Various policy areas are related in deeply significant ways, but energy and environmental specialists must remind themselves that others may consider different issues to be of higher priority. This complicates the realization of electricity supply targets, however well founded they may be.

How then to deal with the questions. Perhaps it is naive to say so clearly at the beginning of my report, but the fact is, we do not have answers! The kernel of our paper is to facilitate a dialogue between often opposing interests, leading eventually to a better understanding between world partners and to the beginning of a 'process' by which these answers can be found and implemented.

Addressing the issues, our views may be summarized under three headings: reconciling development needs with environmental impacts; the potentials and limits of alternative paths; and different regional roles and realities.

## (1) Reconciling development needs with environmental impacts

This presents one of the major challenges to policy makers:

(a) Electricity is essential to social and economic development
(b) The global demand for electricity services will continue to increase, subject only to constraints on economic growth
(c) The electricity sector can make significant contributions to a reduction in future environmental impacts
(d) The most stringent global impact reduction targets cannot be met by the electric power sector without curtailing electricity services significantly
(e) Less stringent targets can be met, but only with forceful policy intervention
(f) In the event, substantial progress with impact reduction will require sustained attention to capital investment and institutional development needs in the electric power sector.

This is the framework for considering electricity futures which emerged from our reflections on the challenge of meeting the social, economic and environmental aspirations of people throughout the world, and the consequences of these on the demand and supply of electricity services.

## (2) The potentials and limits of alternative paths

Clearly, any evaluation of paths for electricity system development is pervaded by uncertainty and diversity. When long term economic, political and energy conditions cannot be forecast with confidence, when countries and regions differ from each other dramatically in their resources and needs and, furthermore, when the range of electricity options is apparently so extensive, it is difficult to get decision makers to take firm decisions. The challenge is to incorporate these complexities into strategy development without allowing inaction to result. In the meantime, institutional inertia, uncertainty and diversity complicate any global effort to reduce environmental impacts associated with the provision of electricity services.

We consider that in highlighting the potentials and indeed the limits of alternative paths, the following could be helpful guidelines:

(a) Efficiency improvement throughout electric power systems, from generation to end use, has a substantial potential to reduce impacts on health and the environment

(b) Efficiency improvement alone, however, will not realize the full potential for impact reduction
(c) To realize the entire potential for impact reduction, each part of the electrical system must play its role; other alternatives include supply options that do not emit greenhouse gases and those that emit fewer gases
(d) Coal will represent powerful competition with alternative energy sources in many countries
(e) Oil will continue to be used for electricity generation where it is competitive and where other energy sources are not readily available
(f) Natural gas will play an important role in impact reduction, especially in Europe and North America, but the magnitude of its availability is uncertain
(g) Nuclear energy has the potential to make a significant contribution towards a reduction in carbon emissions, but its social acceptability remains in question
(h) Hydroelectric energy could play an important role globally because of its large resource potential, particularly in developing countries, and its freedom from carbon emissions; but this source also raises other environmental concerns
(i) Other renewable energy sources are increasing their contribution towards electricity generation, but they are unlikely to meet a large share of the global electricity demand.

Other renewable energy sources also have the potential to meet more electricity service needs than at present although, based on currently available technologies, the outlook for meeting a large share of global needs (i.e. more than 5%) is not bright. Alternatives such as photovoltaic power, wind power and geothermal energy are establishing a record of success at sites where favourable resource endowment corresponds with appropriate local demand. However, the contributions of renewable sources on a regional or local level could be significant.

The technologies are continuing to improve, and production costs are decreasing. It is possible that some modest subsidies for these options, because they are relatively benevolent environmentally, will improve their prospects even further over the next several decades.

### (3) Different regional roles and realities

Appropriate and effective strategies for impact reduction will be region, country and location specific. Because countries and regions differ so markedly in their energy and economic conditions, their institutional settings and their priorities and preferences, detailed strategies for impact reduction cannot be introduced very usefully at a global level. They will emerge from local decision making processes, responding in part to global concerns and in part to resource allocations in local and national contexts.

## 2. ISSUES AND OPTIONS FOR OECD COUNTRIES

The major issues for OECD countries in reducing carbon emissions and other environmental emissions associated with electricity services seem to lie in three areas:

(a) Leadership in developing and demonstrating the potentials for electricity efficiency improvement and alternative supply technologies
(b) Willingness to make tough policy decisions in these regards
(c) Co-operation with other countries in R&D, technology transfer and financial partnerships.

Where available options are being underutilized, or where innovative options need to be demonstrated in order to reduce uncertainties, or where R&D can make better options available, global progress depends largely on actions by the higher income countries to set the pace. Except for some relatively small scale exceptions, whatever options these countries are unwilling to advance are not likely to progress very quickly.

Significant reductions in global environmental impacts from electricity are unlikely unless the higher income countries are willing to accept significant social, economic and political costs — or at least risks. To meet the global average targets, these countries will have to reduce their emissions and other impacts by a far greater percentage. Furthermore, a willingness on the part of decision makers in low and middle income countries to make difficult decisions is likely to await evidence that higher income countries are willing to do so. The prospects appear to be brighter in some OECD countries than in others.

In many cases, substantial progress in low and middle income countries depends on access to innovative tchnologies, capital investment and other resources that depend largely on the policies and actions of higher income countries. The challenge is to approach such relationships in a spirit of true partnership, recognizing the validity of the concerns of all the partners.

## 3. ISSUES AND OPTIONS FOR THE SOVIET UNION AND EASTERN EUROPE

The issues and options for the Soviet Union and Eastern Europe are distinct and reflect realities which must be confronted in the context of prevailing uncertainties. Two particular challenges are outstanding: the potential for energy efficiency improvement and the evolution of institutions for implementing energy options.

In addition, the electricity demand and supply future of the Soviet Union and Eastern Europe depends in the longer term on two further sets of issues: the availability of capital for electric power sector investment and the availability of natural gas as a fuel source for electric power generation.

Experts from within this region report significant potential for efficiency improvement in electricity production and end use, the latter particularly in the Soviet Union. The issue is, where and when can the potential be realized, given the importance of other policy concerns and the effect of uncertainties on decision making.

The key to implementing impact reducing options such as efficiency improvement is effective institutions, but the current process of structural change means widespread uncertainties about the institutional roles and the 'rules of the game'. The issue is, when and how will institutions in this region be able to pursue electricity system options that appear to make sense for the longer term.

An absolutely fundamental requirement for impact reduction in this region is financial resources to implement electricity system strategies. This can be considered a global as well as a regional issue. Why — very simply because of the importance of international public and private sector institutions in responding to the need.

The most attractive and accessible supply side alternative to coal in this region is natural gas, but its availability within, and even more acutely outside, the Soviet Union is still uncertain, especially for the longer term. Regional prospects depend on the size of the Soviet Union's reserves and the potential to export to other regions.

## 4. ISSUES AND OPTIONS FOR DEVELOPING COUNTRIES

While the simplicity achieved in separating the world into three main groups may facilitate the presentation of our analysis, the reality is that within each of the groupings used there is a wide range of diversity. In the case of developing countries, this grouping covers an exceedingly wide range of conditions, from rapidly industrializing countries such as Brazil and the Republic of Korea to relatively small and low income countries such as Haiti and the Sudan.

As in the other two regions, this classification deals inadequately with the diversity. As mentioned earlier, effective energy and electricity strategies will necessarily be finely tuned to local conditions, because there is no such thing as a 'typical' country or region in the world today. While mindful of the distinctions just mentioned, developing countries, in contributing to local strategies for impact reduction, are distinctive in the importance of: development imperatives requiring further environmental impacts; capital requirements for expanding electricity services; efficiency improvements in end use and supply systems; and international co-operation as a mechanism for accelerating desirable change.

One reality is that economic and social development is not the only top priority; it is a target with which every other target simply must be reconciled. The other reality is that a number of the most prominent developing countries, with large populations and growing economies, have abundant coal resources for electric power generation which they plan to use. Strategies are available to reduce the environmental impacts, but carbon emissions from developing countries will increase.

The capital requirements are clear; the issues pertain to how to meet the needs. The current debt burden in many countries constitutes one hurdle. Questions about institutional performance under current policy conditions represent another. Competing demands for investment in other sectors of developing economies are still another. Together, they add up to a momumental challenge for both development and environmental management. One possibility is to relate international capital access to impact reduction, but both political and ethical issues are raised if this is at the expense of economic progress.

Efficiency improvements in the power cycle are easier to achieve than improvements in end use efficiencies, but they are constrained by the availability of capital. The task of improving end use efficiencies is further limited by the dispersion of decision making by individual consumers and the absence of effective institutional mechanisms.

Although developing countries are extremely diverse in their electricity system conditions and choices, it appears that the prospects for reducing environmental impacts from electricity service provision will be focused on five kinds of option:

(a) Efficiency improvement, especially in the electricity systems of countries planning to use coal as the major fuel source for electric power generation
(b) Natural gas, wherever it is available and appropriate
(c) Biomass, especially in areas recently deforested but with environmental conditions favourable to biomass production
(d) Other renewable energy sources, including small hydroelectric and landfill gas facilities, in appropriate areas
(e) Institutional change.

In combination, these areas can make a significant difference to the global environmental picture without sacrificing development. However, it is unrealistic and unfair to expect developing countries to take actions to reduce emissions at the expense of their economic and social development. In a number of countries, such as China and India, with an abundance of local cheap resources, coal use will certainly increase in the next generation; this reality must be recognized in determining global emission reduction targets and response strategies.

## 5. ENERGY AND ELECTRICITY ARE NOT ENDS IN THEMSELVES

The demand for energy and electricity is a derived demand and they are not ends in themselves. The above options for reducing the environmental impacts of energy use for electricity generation must be accompanied by equally vigorous actions in improving energy efficiencies in other areas in which fuels are used directly for heat or power, notably for transport.

There is a need for complementary policies, for instance, in transportation, in industry, and in how we design and live in our towns. Thus, energy policy options can only be effective if they are incorporated into a comprehensive and complementary policy framework.

Improvements in technologies will certainly complement improvements in end use efficiencies. There is a reservoir of efficiency improvements to be achieved, but practical experience tells us that not all theoretical and potential efficiencies in the imagination of some analysts can be effectively achieved in the reality of normal living.

However much we might regret this, and while we hope we are wrong, we should plan on more realistic efficiency assessments when meeting human needs.

## 6. CONCLUDING REMARKS

Although all projections are surrounded by uncertainty and complicated by diversity, we would suggest, as a basis for discussion, that:

(a) World energy demand and the resulting carbon emissions could, over the next two decades or so, be reduced by 15–20% below what we would otherwise have achieved and that this result would be without major political and economic costs.

(b) World energy demand over this period could be reduced by 25–30% through vigorous intervention, carrying political and economic costs that may become acceptable, given the high level of concern about environmental protection.

(c) At the highest level of a 30% reduction in world energy consumption, the resulting world energy demand and corresponding carbon emissions would still be higher than those in 1988. However, for OECD countries they could be 20% lower than at the end of the 1980s; for the Soviet Union and Eastern Europe they may be about the same.

(d) For the group of developing countries they would probably be some 50% higher. This increase would arise from the combined effects of continuing economic growth per capita and rising population.

(e) If we achieve such a target, we broadly estimate that carbon emissions from the electric power sector would nonetheless increase by some 20–40% by 2010, compared with the emission levels of 1988. This reflects the increased demand for electricity services, particularly in developing countries; this demand would exceed the gains in efficiency.

A 30% reduction in global carbon emissions below the reference projection for 2010 would be a formidable challenge but, while considered unlikely, could be possible. Even though this overall level of achievement is less than the target proposed by the Toronto Conference, it contributes towards the same objective in that it aims at pushing the limits of environmental protection without causing unacceptable losses in economic growth and development. It accepts that the demand for electricity services and facilities will continue to increase more rapidly than the overall use of energy. Given more political will and social awareness of the environmental impacts, or indeed unexpected breakthroughs in technology, an even higher level of achievement may be attained.

In the meantime, even the lower targets will require substantial commitment by national and global policy makers, and by society as a whole. This commitment must begin now. Every year that firm decisions are delayed, the long term curve for global energy requirements and environmental emissions will rise and the pressures on sustained development will increase.

The electric power sector of the world's nations has been part of the problem in the past because of its commitment to meeting rising electricity demands, but at the same time it is also an essential part of the solution. The challenge is to mobilize effectively the tools and expertise of the electric power sector in order to respond to the global search for economic progress and environmental protection.

The occasion is appropriate to extend a word of thanks to my colleagues in preparing the paper which I have had the pleasure of presenting to you. Each contributed to all the issues in debate and did so in a most helpful and constructive way so that the paper on this very complex and difficult subject is presented with the unanimous support of all the members of the Group.

We have sought, through our individual and collective contributions, an approach which takes into account the needs of people as expressed in the demand for electricity services, and the different options and approaches in meeting these needs. Clearly, these demand patterns express the social and economic stages of development in different parts of the world, with each of these areas reflecting their individual responses to the balance between development concerns, environmental imperatives and how these interact with energy and, in particular, the electricity sector.

# EFFICIENT USE OF ELECTRICITY
## *Possibilities and limits*

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**Abstract**

EFFICIENT USE OF ELECTRICITY: POSSIBILITIES AND LIMITS.

The possibilities for improving energy efficiency, especially electricity, are outlined. The potential for energy conservation is analysed, both from the technical and the economic point of view. On the basis of the Finnish situation, details are given of the experience gained in analysing the potential for conservation in Finland. Energy use is fairly efficient in Finland, but more efficient use is possible in most major energy sectors. The greatest potential is in those sectors in which the know how is limited and where energy costs play a minor role, e.g. in households, the commercial sector and small and medium sized industries. There is less potential for energy conservation in the process industry, but even here it is likely that more efficient technologies will be available in the future. It may be possible to freeze the growth in total energy consumption, but this will be very difficult to achieve over the next 10–20 years if the national economy continues to grow as forecast. A reduction in the end use consumption of fuels is also feasible. Freezing of electricity consumption does not appear to be possible over the same period, even if all the energy conservation potential is taken into account. A reduction in $CO_2$ emissions by improving end use and generation technologies appears to be almost impossible if the new generation capacity is based on fossil fuels. The technical potential for conservation in the end use is similar for electricity and fuels; however, conservation of electricity appears to be more economical. For the consumer, conservation is not always tempting; in practice, it slows down the conservation rate. Efficient use of energy is closely related to the resources (manpower and finances) that are available; the cost of conservation increases quite rapidly if the targets are high. It is also known from history that various measures do not always progress as planned, which means that public conservation will have to be increased considerably.

## 1. INTRODUCTION

The possibilities for improving efficiency in the energy and electricity sectors in different countries are highly dependent on the local circumstances in each country. Indigenous energy sources, current energy production systems, consumption levels and structures, price levels and tariff policies, economic situations, etc.

will all affect future energy use. Therefore, the measures taken to improve energy efficiency may differ from country to country; those used in one country are not necessarily the most efficient in another.

On the other hand, there are many similarities between countries: the technology applied to rationalize the use of energy can usually be applied in various countries; the motivation to use energy efficiently for environmental reasons is internationally accepted; and economic integration and harmonization of technical standards and directives, especially in Europe, have a common base to the energy market. This means that, especially in industrialized countries, there are similar possibilities for improving the efficiency of the energy sector because of mutual economic backgrounds. Developing countries have a large potential for energy conservation, but the main obstacles they face are invariably of an economic or institutional nature. Naturally, some measures taken in industrialized countries can also be used in developing countries when the local conditions are carefully taken into consideration.

In the paper, the possibilities for improving energy efficiency, especially electricity, are outlined, mainly for Finland. Some comparisons are made between Finland and other OECD countries, and an attempt has been made to draw more general conclusions. Most of the information provided here is based on the energy conservation study [1] carried out by the Technical Research Centre of Finland and financed by the Ministry of Trade and Industry, Finland.

## 2. STRUCTURE OF ENERGY PRODUCTION AND CONSUMPTION IN FINLAND

### 2.1. Energy

Table I shows primary energy consumption in Finland, indicating that the share of imported energy is over 70%. The share of imported fossil fuels (oil, natural gas and coal) is almost 50%.

Table II describes primary energy consumption by sector. Industry covers about 45% of the total consumption and, of this, fuels account for slightly more than 50%, the rest being covered by electricity. Within the industrial sector, the forest industry dominates with a share of over 50% of the total primary energy consumption. The basic metal production and chemical industries are two other larger consumers of energy.

The share of space heating is about 20% from primary energy consumption because of the climate; the transport sector accounts for about 14%; and the remaining 19% includes domestic consumption, the service sector, etc.

TABLE I. PRIMARY ENERGY CONSUMPTION BY ENERGY SOURCE

| Source | Consumption (million toe) | | Share (%) | |
|---|---|---|---|---|
| | (1988) | (1990) | (1988) | (1990) |
| Oil | 9.5 | 9.15 | 32 | 30 |
| Natural gas | 1.4 | 2.25 | 5 | 7 |
| Coal | 3.5 | 3.25 | 12 | 11 |
| Nuclear | 4.6 | 4.54 | 16 | 15 |
| Imported energy | 1.9 | 2.69 | 6 | 9 |
| *Total imported energy* | 20.9 | 21.88 | 71 | 72 |
| Hydro | 3.3 | 2.69 | 11 | 9 |
| Peat | 1.0 | 1.24 | 3 | 4 |
| Other domestic | 4.4 | 4.50 | 15 | 15 |
| *Total domestic energy* | 8.7 | 8.43 | 29 | 28 |
| *Total* | 29.6 | 30.31 | 100 | 100 |

TABLE II. PRIMARY ENERGY CONSUMPTION BY SECTOR (1988)

| Sector | Consumption (million toe) | Share (%) |
|---|---|---|
| Industry | 7.2 | 24 |
| Transport | 3.7 | 13 |
| Space heating | 2.8 | 9 |
| Other sectors | 0.9 | 3 |
| Co-generation in district heating | 3.2 | 11 |
| Separate electricity | 11.2 | 38 |
| Others | 0.6 | 2 |
| *Total* | 29.6 | 100 |

## 2.2. Electricity

Table III shows the electricity supply by source in Finland. The total supply was 62.5 TW·h in 1990, of which nuclear power and co-generation have the largest share. Co-generation includes combined steam and electricity generation in industry (about 55%) and combined heat and electricity generation in district heating power

TABLE III. ELECTRICITY SUPPLY BY SOURCE

| Source | Supply (TW·h) | | Share (%) | |
|---|---|---|---|---|
| | (1988) | (1990) | (1988) | (1990) |
| Hydro | 13.2 | 10.8 | 23 | 17 |
| Industrial back pressure | 6.9 | 7.7 | 12 | 12 |
| Co-generation in district heating | 7.1 | 8.6 | 12 | 14 |
| Nuclear | 18.4 | 18.1 | 31 | 29 |
| Condensing power | 5.0 | 6.0 | 9 | 10 |
| Gas turbines, etc. | 0.6 | 0.5 | 1 | 1 |
| Net import | 7.4 | 10.8 | 13 | 17 |
| *Total* | 58.6 | 62.5 | 100 | 100 |

TABLE IV. ELECTRICITY CONSUMPTION BY SECTOR (1988)

| Sector | Consumption (TW·h) | Share (%) |
|---|---|---|
| Transport | 0.4 | 1 |
| Industry | 31.0 | 53 |
| Space heating | 6.1 | 10 |
| Household | 8.3 | 14 |
| Services | 8.7 | 15 |
| Others | 1.1 | 2 |
| Losses | 3.0 | 5 |
| *Total* | 58.6 | 100 |

TABLE V. AVERAGE ELECTRICITY PRICE BY TYPE OF CONSUMER (1 January 1991) (4 Finnish penniä = 1 US cent)

| Consumer type | Average price (p/kW·h) | Annual consumption (MW·h) |
|---|---|---|
| Household, flat | 46.1 | 2 |
| Household, detached house | 40.2 | 5 |
| Direct electric heating | 30.6 | 18 |
| Small scale industry | 39.2 | 150 |
| Medium scale industry | 30.1 | 2 000 |
| Large scale industry | 17.3 | 500 000 |

plants (about 45%). The share of conventional condensing power is only 11%, which means that the efficiency of electricity generation in Finland is quite high when considering the atmospheric releases from power plants.

Table IV shows the electricity consumption by sector in 1988. The share of the industrial sector is over 50% and, of this, the process industry plays a dominant role (about two-thirds). Some other larger sectors, in order of consumption, are service, household and electric space heating.

In Table V, the average prices of electricity for some specific types of consumer are given as of 1 January 1991.

## 2.3. Development of characteristic consumption and energy intensities in Finland and in other OECD countries

Figure 1 describes the end use consumption of primary energy per capita in some OECD countries (1970–1987) (the data enumerated throughout were compiled before the unification of Germany in October 1990) [2]. It shows that Finnish consumption per capita is higher than that in most other countries; the trend has been increasing slightly, in contrast to most other countries. The main reason for this is the high energy consumption in the process industry as well as the rapid economic development that has taken place over the past 20 years. If consumption is calculated per Gross National Product (GNP), as shown in Fig. 2, the trend in Finland has been decreasing and is similar to other countries, in spite of the increases shown over the past few years [2, 3].

For electricity consumption, the level per capita and the increase in consumption in Finland are even greater than for the total energy consumption (see Figs 3–5).

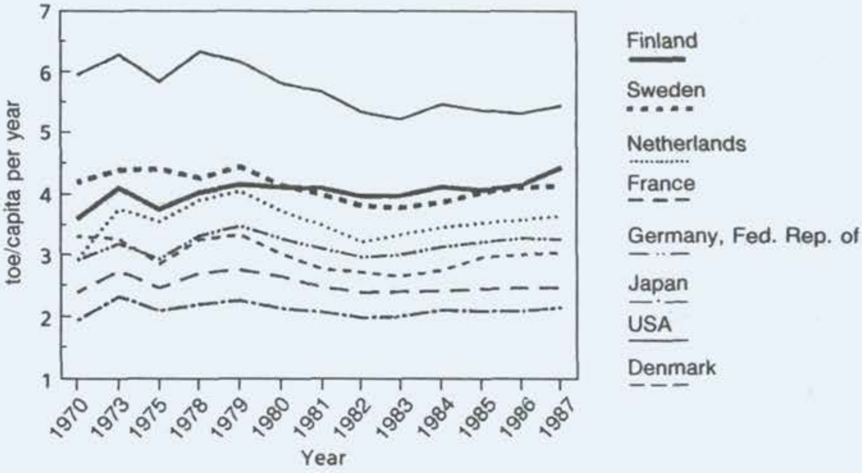


*FIG. 1. End use consumption of primary energy per capita.*

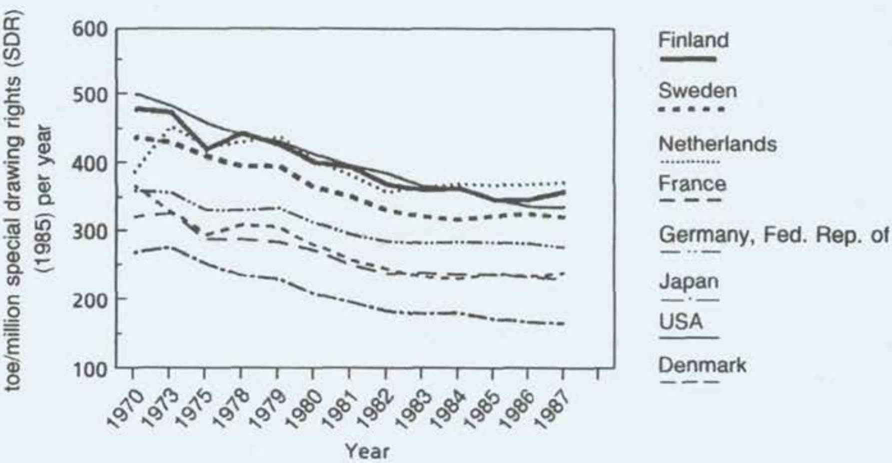


*FIG. 2. Energy intensity of primary energy (end use consumption per GNP).*

The high consumption level can mainly be explained by energy intensive industry. The rapid growth in electricity consumption in industry is because of the steep rise in production, a general transition from fuels to electricity, and the introduction of new electricity intensive processes, especially in the forest industry.

In Fig. 4, the effect of industry has been subtracted from consumption. It can be seen that the growth in consumption per capita is still higher than that in most other countries; the trend is similar to those in Sweden and France. In Finland, the main reason for this is the rapid increase in electric space heating over the past 20 years. The average consumption of electricity in space heating per capita was about 1200 kW·h in 1987. For these reasons, electricity intensity has increased in Finland, as can be seen in Fig. 5.

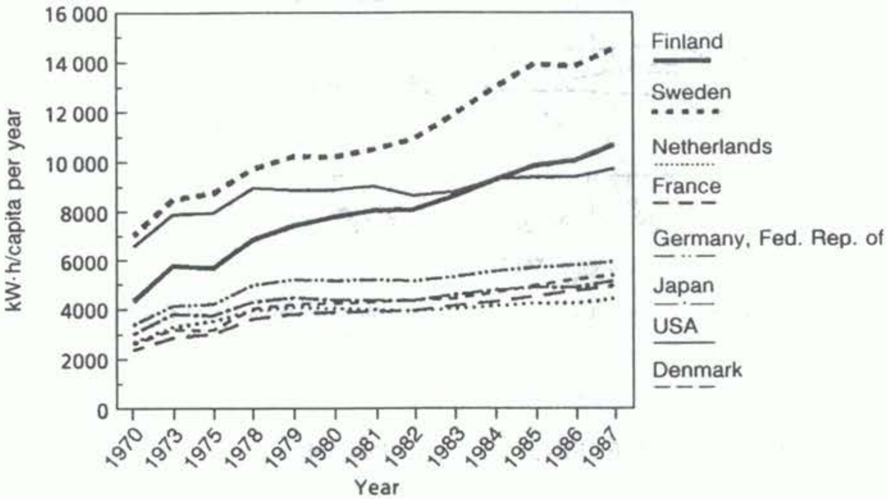


*FIG. 3. Electricity consumption per capita.*

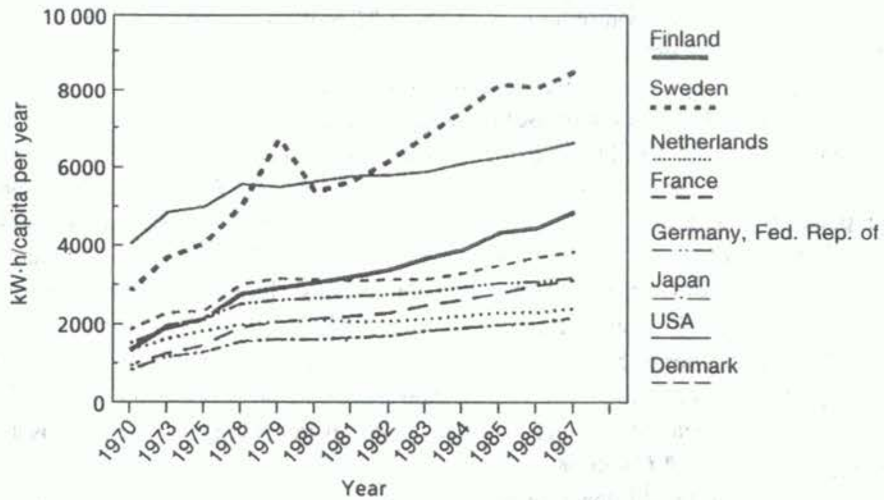


*FIG. 4. Electricity consumption per capita without industry.*

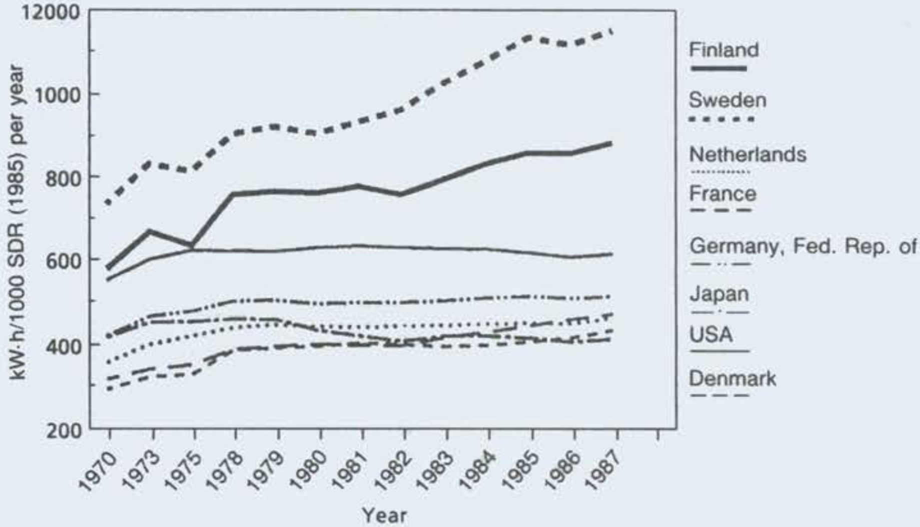


*FIG. 5. Electricity intensity (electricity consumption per GNP).*

## 3. EFFICIENCY OF ENERGY USE IN FINLAND

In 1988, the primary energy consumption of Finland was about 30 million tonnes of coal equivalent (toe) calculated according to the method used by the OECD (nuclear, hydro and imported electricity are transformed to primary energy as if the corresponding electricity were generated in normal condensing power plants). The corresponding end use consumption was about 21 million toe, which is about 70% that of the primary energy.

End use energy is converted to a useful form of energy in consumer's conversion equipment. The amount of useful energy (called here, useful energy II) is estimated to be about 13.8 million toe in the Finnish case, which is about two-thirds that of end use energy and about 46% that of the primary energy. This total energy consumption efficiency corresponds to the figures estimated from Eurostat statistics [4] for Western European countries, which vary between 33 and 43% (Denmark, Federal Republic of Germany and the Netherlands, 43%; Italy, 41%; France and the United Kingdom, 37%; and Spain and Portugal, 31–33%).

Even after energy conversion, there may be some losses before the energy is actually utilized, for example, in energy transfer from conversion equipment to the actual place of utilization. A rough estimate of final useful energy (called here, useful energy I) is about 12.6 million toe, with about 42% from primary energy.

Thus, theoretically, the potential for energy conservation is almost 60% if the amount of useful energy is considered to be the same as today. However, the amount

TABLE VI. ENERGY LOSSES IN THE ENERGY SYSTEM BY TECHNOLOGY (1988)

| Technology | End use consumption | | | Losses in generation and transmission (million toe) | Losses in fuel production (million toe) | Demand for primary energy (million toe) | Eff(II) (%) |
|---|---|---|---|---|---|---|---|
| | Useful energy I (million toe) | Useful energy II (million toe) | Losses (million toe) | | | | |
| Boilers | 8.66 | 9.72 | 2.17 | 0.50 | 0.13 | 12.53 | 78 |
| Motors and drives | 1.00 | 1.05 | 2.92 | | 0.19 | 4.16 | 25 |
| *Fuel based (total)* | 9.66 | 10.77 | 5.10 | 0.50 | 0.32 | 16.69 | 65 |
| Resistance heating | 0.77 | 0.90 | 0.13 | 1.62 | 0.04 | 2.69 | 33 |
| Electric drives | 1.64 | 1.64 | 1.06 | 4.26 | 0.09 | 7.06 | 23 |
| Lighting | 0.23 | 0.23 | 0.48 | 1.11 | 0.04 | 1.86 | 12 |
| Other uses | 0.26 | 0.26 | 0.27 | 0.84 | — | 1.37 | 19 |
| *Electricity (total)* | 2.90 | 3.03 | 1.93 | 7.83 | 0.17 | 12.97 | 23 |
| *Energy (total)* | 12.56 | 13.80 | 7.03 | 8.34 | 0.48 | 29.66 | 46 |

TABLE VII. EFFICIENCIES OF END USE ENERGY BY SECTOR

| Sector | Useful energy II (million toe) | Losses (million toe) | Total end use energy (million toe) | Efficiency (%) |
|---|---|---|---|---|
| Space heating | 4.05 | 1.04 | 5.10 | 80 |
| Transport | 1.01 | 2.76 | 3.77 | 27 |
| Household | 0.36 | 0.41 | 0.76 | 47 |
| Services | 0.23 | 0.55 | 0.78 | 30 |
| Agriculture | 0.51 | 0.34 | 0.85 | 60 |
| Building construction | 0.14 | 0.03 | 0.17 | 81 |
| Industry | 7.51 | 1.90 | 9.40 | 80 |
| *Total* | 13.80 | 7.03 | 20.84 | 66 |

of such energy can be reduced by improving technology and construction; for example, the amount of space heating can be reduced considerably with better heat insulation and use of internal heat sources in buildings.

In Table VI, the efficiencies of different end use technologies are analysed under Finnish conditions. The total efficiency (Eff(II)), measured as the difference between useful energy II and primary energy, is about 65% for fuels and 23% for electricity (calculated according to the OECD method). The lowest efficiency is for lighting (12%). The consumption efficiency of electric drives is also less than 25%.

The efficiencies of end use energy by sector are compared in Table VII. The lowest efficiencies (less than 50%) are in the transport, service and household sectors.

## 4. POSSIBILITIES FOR IMPROVING ENERGY EFFICIENCY IN THE FUTURE

### 4.1. Methodology used

The possibilities for and costs of improving energy efficiency were estimated and the effects on a reduction in greenhouse gases were considered. In spite of the improvements made in energy efficiency, there are also other ways of reducing energy use such as a decrease in the general consumption level, or of reducing harmful effects such as a decrease in flue gas releases. Therefore, the feasibility of efficiency improvements is compared with other methods by taking into consideration the marginal costs of different approaches.

In assessing the efficiency improvements in energy use, the following alternatives were considered:

(1) To stop wasting energy, which can be done without any changes in consumption habits
(2) To introduce new technologies in customer equipment
(3) To change consumption habits.

Analysis has been carried out by consumption sector, considering in each sector the different technologies for improving efficiency, and also by estimating, in each case, the amount of useless energy that can be reduced without any harm to consumers. In each sector, the technologies and their costs were estimated by using the following categories:

(a) Basic technology, which is that currently used by the average customer
(b) The most effective commercial technology in use today
(c) Prototype technologies, which are those proved to function, mainly at the laboratory level, without any decisions having been taken on their commercialization or prototype; this type of technology could be available in 10–20 years, but penetration into the market will take much longer
(d) In some cases, efforts have been made to estimate some type of target technology, which means some kind of realizable techno-economic limit to their efficiency.

The main emphasis in this study has been placed on the above mentioned end use efficiencies, but some estimates have also been made on the possibilities for energy generation technologies. Structural changes in the industry sector, especially in the forest industry, have been estimated; these results are not discussed in detail here.

### 4.2. Principles used in the economic considerations

The economy of various new technologies has been estimated using long range marginal costs. These include the costs of all additional investments and the changes in operational costs. For each technology, the difference between the marginal costs of all the above mentioned alternative technologies was estimated:

(1) Between the most effective commercial technology and the average current technology
(2) Between prototype technology and the most effective commercial technology
(3) In some cases, also between target technology and prototype technology.

TABLE VIII. POTENTIALS FOR IMPROVING THE EFFICIENCY OF END USE ENERGY

| Alternative improvements | Fuels (%) | Electricity (%) | Total (%) |
|---|---|---|---|
| (a) Stop wasting energy | -5 | -5 | -5 |
| (b) (a) + the most effective current technology, from the consumer's viewpoint (1990 price level) | -7 | -12 | -8 |
| (c) Like (b), but from the energy-economic viewpoint | -11 | -17 | -12 |
| (d) (c) + changes in consumption habits | -13 | -20 | -14 |
| (e) (d) without requirements for economy | -22 | -21 | -22 |
| (f) (e) including prototype technology | -35 | -33 | -35 |

TABLE IX. TOTAL POTENTIAL FOR IMPROVING THE EFFICIENCY OF END USE ENERGY BY SECTOR

| Sector | Potential for improvement (%) | | | |
|---|---|---|---|---|
| | Current technology | | Prototype technology | |
| | Fuels | Electricity | Fuels | Electricity |
| Buildings | -30 | -20 | -56 | -46 |
| Household | | -47 | | -65 |
| Services | | -40 | | -51 |
| Transport | -27 | | -39 | |
| Small/medium industries | -21 | -14 | -24 | -18 |
| Forest industry | -16 | -9 | -21 | -21 |
| Chemical industry | -13 | -5 | -23 | -13 |
| Metal production | -1 | -5 | -13 | -29 |
| Other consumption | -21 | | -24 | |
| *Total* | -22 | -21 | -35 | -33 |

Considerations have been made from the point of view of different decision makers, the most important of which are either for energy economy or for private decision makers. The main difference between these two considerations is the differing rate of return for the capital investments. In energy–economic considerations this has been estimated at 5% (real interest), but in the private sector it is much higher. In enquiries carried out, the requirement for the rate of return proved to be about 30% for households and for industry (this percentage was then applied to this study).

Tariff prices, including both energy and fixed charges, are used as the long range marginal costs of energy for different consumer types. The prices applied for different consumer types were:

(1) *Electricity*

| | |
|---|---|
| Households | 44.3 Finnish penniä/kW·h (11.1 US cent/kW·h) |
| Service sector | 44.3 Finnish penniä/kW·h (11.1 US cent/kW·h) |
| Process industry | 16.2 Finnish penniä/kW·h (4.1 US cent/kW·h) |
| Other industries | 28.5 Finnish penniä/kW·h (7.1 US cent/kW·h) |

(2) *Heat energy*

| | |
|---|---|
| Process industry | 6 Finnish penniä/kW·h (1.5 US cent/kW·h) |
| Other industries | 10 Finnish penniä/kW·h (2.5 US cent/kW·h) |

The above prices, corresponding to the price levels for the year 1990, were applied to all basic calculations. The other price levels used in the comparisons were about 1.15 fold for electricity and about 1.5 fold for heat; they have been estimated to correspond to the price levels for the year 2010.

### 4.3. Techno-economic potential for improving efficiency in end use energy

Tables VIII and IX summarize the main results of end use energy. Table VIII shows the estimated potentials, and includes all the sectors and technologies studied. It indicates that a 5% improvement can be achieved by not wasting energy. Useless consumption is highest in households (10%), the service sector (10%) and small and medium sized industries (7%), and is lowest in the process industry. However, to achieve a reduction in useless consumption, changes in the attitude of consumers will be necessary. Table IX shows the total potential with current technology and prototype technology by sector. The possibilities for reducing specific consumption are greatest in households, the service sector, the transport sector, small and medium sized industries and heat energy in the process industry. A considerable reduction in the electric energy of the latter industry will require large input to the R&D of various processes.

The optimum techno-economic potential depends on the energy price level. Figures 6 and 7 describe the marginal values of efficiency improvements, which are

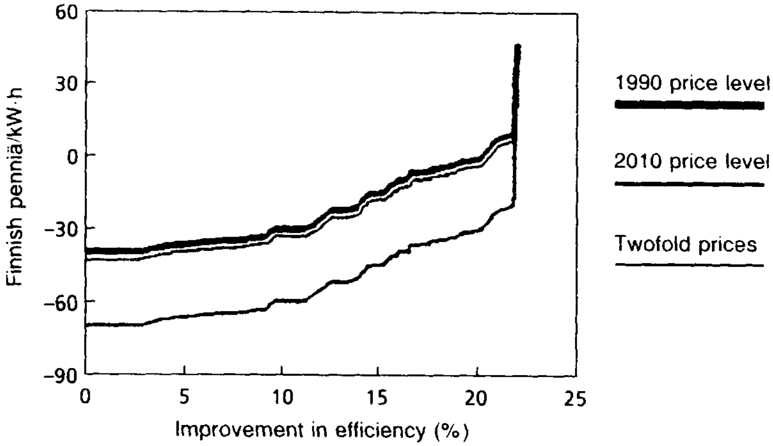


*FIG. 6. Marginal values of efficiency improvements in electricity uses.*

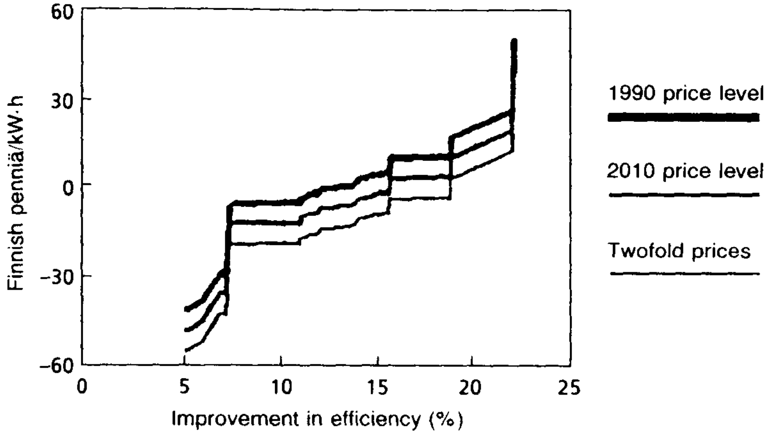


*FIG. 7. Marginal values of efficiency improvements in fuel uses (4 Finnish penniä = 1 US cent).*

calculated by subtracting the benefits accrued from a reduction in energy consumption from the long range marginal costs of additional investments. A negative marginal value means that the benefits are higher than the costs and that the investments are profitable. The curves of Figs 6 and 7 are calculated for energy economy.

It is not possible to discuss separately all the details of each technology by sector. Figures 8 and 9 give examples from small and medium sized industries. Figure 8

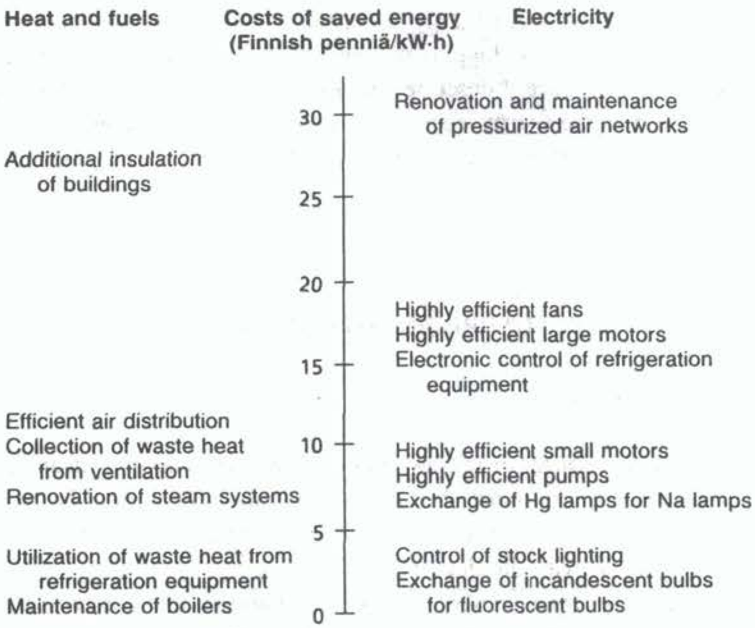


*FIG. 8. Costs of saved energy using current technologies in small and medium sized industries (4 Finnish penniä = 1 US cent).*

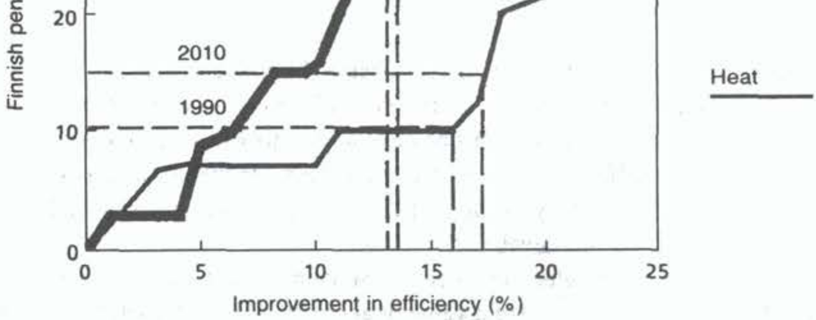


*FIG. 9. Marginal costs of efficiency improvements in small and medium sized industries: energy-economy calculations (4 Finnish penniä = 1 US cent).*

demonstrates the costs of saved energy in current technologies. Application of such technologies is economical as long as the cost of the saved energy is less than the price of that energy. Figure 9 describes the marginal costs of efficiency improvements as a function of the energy–economic potential. From the figure it can be concluded that, at the current price level, the potential for electricity is about 13% and for heat about 16%.

## 5. SCENARIOS FOR FUTURE ENERGY NEEDS

### 5.1. Basic assumptions

Improvement in energy efficiency does not mean that energy consumption will necessarily decrease in the future, because at the same time certain factors play a role in the increased demand for energy, the most important of which are a growth in the GNP and an increase in electricity intensity.

In the scanerios presented here, the basic assumptions and scenarios have been selected from Ref. [5], which is the latest survey on alternative paths in the energy economy of Finland prepared by the Ministry of Trade and Industry. The basic scenario assumes that the GNP will be 1.67 fold in 2010 compared with 1988, which is the base year. Furthermore, it includes some assumptions on structural changes in energy production as well as an increase in electricity intensity. This basic scenario leads to a certain increase in primary energy and electricity consumption, as well as in a release of greenhouse gases.

In this study, different conservation scenarios are compared with the basic scenario. The former include structural changes in the economy, the above mentioned efficiency improvements in end use and improvements in energy generation.

### 5.2. Basic results

Figure 10 shows that in the basic scenario the primary energy consumption increases by about 22 million toe, from about 30 million toe in 1988. Structural changes in the economy result in a decrease in the growth of primary energy, to about 14 million toe. If the most effective technology for the use and generation of energy could be utilized totally by the year 2010, primary energy consumption could remain at about the current level.

Figure 11 shows the electricity demand situation. The basic growth in demand is about 52 TW·h, from the current value of about 60 TW·h. Structural changes in the economy and complete utilization of current technology cannot compensate for this increase; after such measures are taken, the value will still be 20 TW·h.

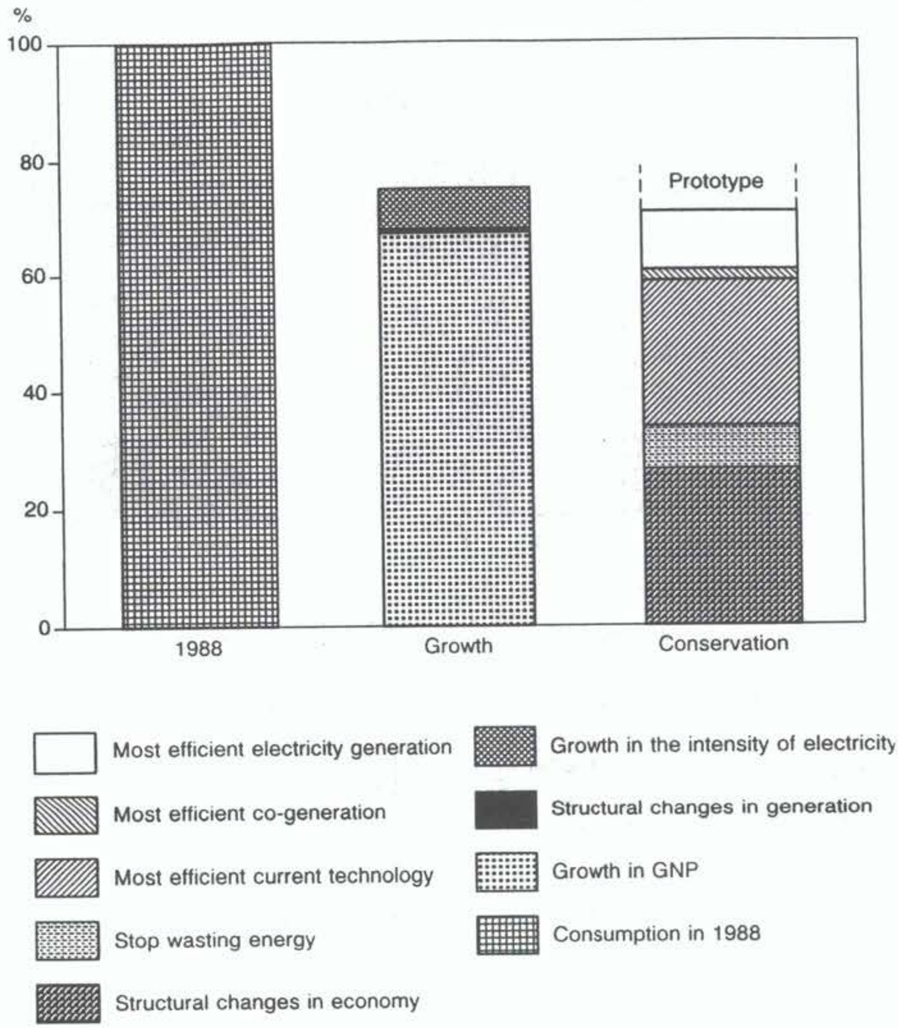


*FIG. 10. Factors affecting the consumption of primary energy (1988–2010).*

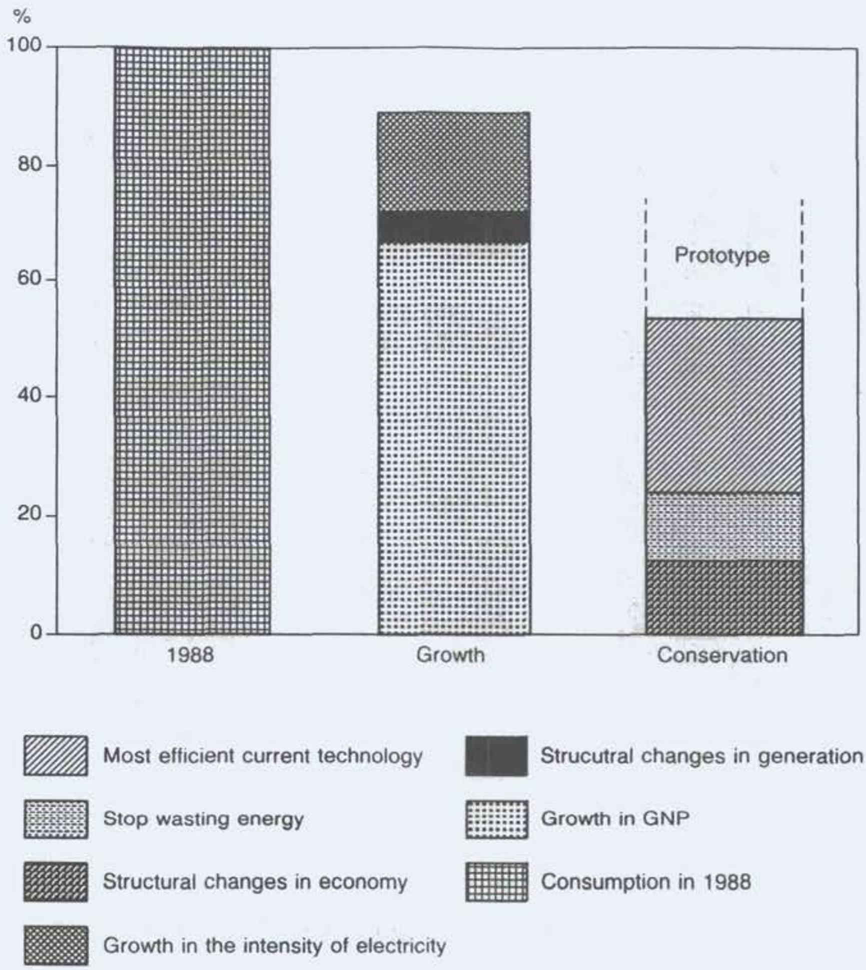


*FIG. 11. Factors affecting the consumption of electricity (1988–2010).*

Energy use in Finland results in the release of about 67 million tonnes of greenhouse gases (calculated as equivalent $CO_2$ tonnes). The growth in gases for 2010 will be about 90 million tonnes, assuming that the new electricity generation capacity is based on coal (see Fig. 12). The structure of the economy is, however, changing; this reduces the growth to about 60 million tonnes. By taking into account all possible measures based on current technology, the growth would be about 8 million tonnes.

### 5.3. Some economic and financial aspects

Use of the most effective technology requires large additional investments in energy economy; rough estimates are FIM 120 billion ($10^9$) (about US $30 billion) (Table X). The highest investments are required for space heating, but also in the industrial sector the annual investment costs are over FIM 1 billion.

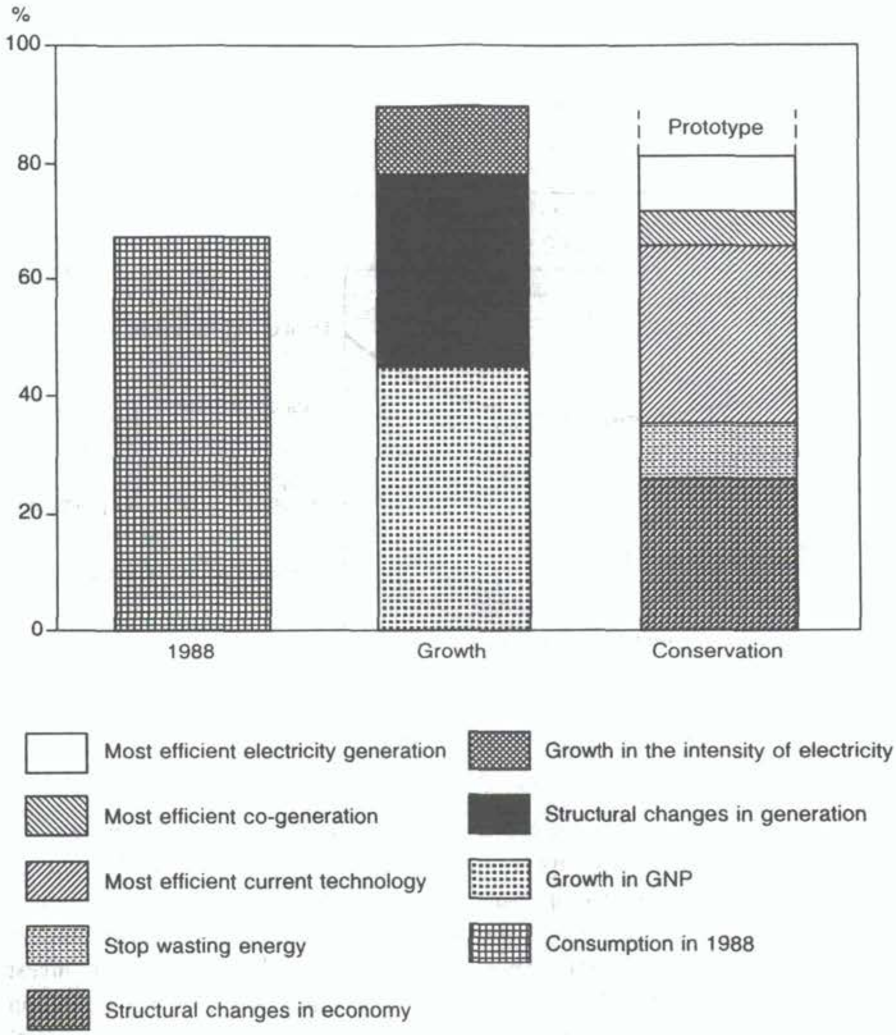


*FIG. 12. Factors affecting the release of greenhouse gases (1988–2010).*

TABLE X. ADDITIONAL INVESTMENTS NEEDED FOR UTILIZATION OF THE MOST EFFICIENT CURRENT TECHNOLOGY OVER THE NEXT 10–15 YEARS
(in $10^9$ FIM; 4 FIM = 1 US dollar)

| Sector | Electricity | Fuels | Total | Annual costs |
|---|---|---|---|---|
| Industry | 7 | 9 | 16 | 1.1 |
| Space heating | 8 | 76 | 84 | 5.6 |
| Transport | 0 | 1 | 1 | 0.1 |
| Household | 6 | 0 | 6 | 0.4 |
| Services | 8 | 2 | 8 | 0.6 |
| Others | 0 | 2 | 3 | 0.2 |
| *Total* | 30 | 89 | 118 | 7.9 |

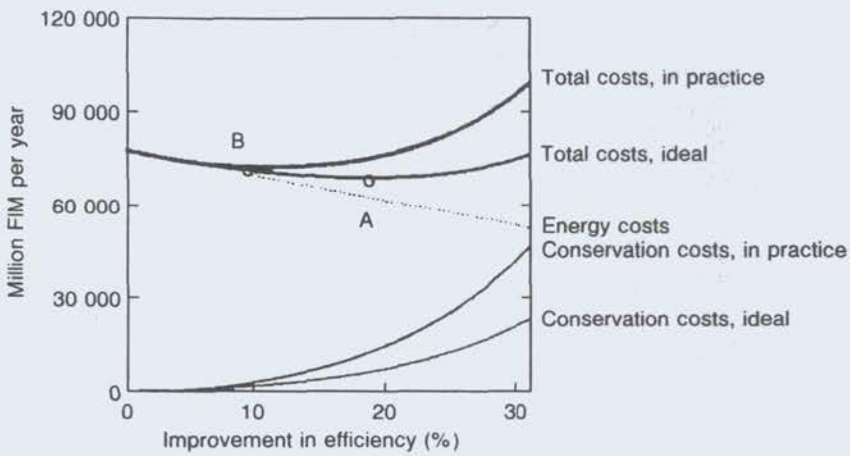


*FIG. 13. Least cast solution from the energy-economy viewpoint (4 FIM = 1 US dollar).*

Figure 13 shows the 'least cost solution' from the energy-economy point of view in the year 2010. If improvement in efficiency is ideal, i.e. if all investments are 100% successful, then the optimum target for efficiency improvements will be about 20% (point A). In practice, the number of successful investments is less, perhaps 50% (according to experience). This means that almost double the investment is needed to achieve a 20% improvement; this is no longer a least cost solution, although the total costs are about the same as those without improvements. A practical least cost solution would lead to an improvement in efficiency of about 10%.

## 6. CONCLUSIONS

To achieve considerable improvement in energy efficiency, a large number of economic measures are required. Although many technologies are profitable from the energy–economic point of view, they are not necessarily profitable for the private sector because of the demand for a high rate of return of investment. In principle, this gap can be reduced, either by increasing energy prices or by subsidizing investments. Raising the price alone is not usually effective, because under Finnish conditions the prices have to be threefold higher in order to achieve all the targets.

Only in the industrial and transport sectors could subsidies for investment be reasonable; 20–40% support would result in considerable improvements in efficiency. Some subsidies for investment have already been made in the building sector, but the results are insignificant.

In the transport, service and household sectors it is difficult to introduce economic measures because of the lack of consumer expertise. On the other hand, the potential is high in these sectors; international co-operation will be needed to develop standards, norms, energy labelling, etc.

Abandonment of useless energy does not require high investment, but the attitude of consumers will have to change. It is estimated that in Finland about FIM 100–200 million per year will be needed for this purpose.

One problem in energy conservation is the long period needed to achieve results. The main reason for this is the lifespan of equipment and processes. It is impractical to change equipment simply because of energy economy, but when the life of the equipment comes to an end it should, naturally, be replaced with equipment that is as efficient as possible.

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# ELECTRIFICATION AND SOCIAL AND ECONOMIC DEVELOPMENT

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**Abstract**

ELECTRIFICATION AND SOCIAL AND ECONOMIC DEVELOPMENT.

Electricity supply is an essential component of any economic development strategy. Population growth and industrialization are driving forces that will increase electricity consumption rapidly in developing countries (LDCs) for many years to come. Indeed, modernization and increases in productivity are difficult to conceive in LDCs without a substantial increase in their per capita electricity consumption. The electricity supply industry (ESI) is, however, a capital intensive industry. A substantial share of the scarce financial and technological resources available in LDCs is captured by the electricity sector, producing considerable macroeconomic and environmental impacts that are not always assessed correctly. The current trends in electricity consumption in LDCs are reviewed, as well as future plans. There was a substantial slowdown in the annual rates of increase in electricity consumption in the 1980s, mainly as a result of the debt crisis. Utility forecasts for future consumption remain high, although the financial situation is very poor. Population growth, the low level of electricity consumption per capita and the deep rooted perception that electricity supply is a key factor in economic development induce optimism for the future. The four key issues facing the ESI in LDCs are analysed: the financial crisis; the technology policy; regulation reform; and long term sustainability. Obviously, the difficult financial situation of the ESI in LDCs is the most pressing issue. Neverheless, it is difficult to envisage any solution to the financial crisis if no changes are introduced, both in the regulatory regime and in the technology policy. Moreover, it is important to assess the long term effects carefully, particularly as far the environment and fuel markets are concerned.

## 1. INTRODUCTION

Energy is a pervasive commodity. Few human activities in modern society can circumvent the use of some form of energy. Not surprisingly, energy supply is perceived by policy makers as being an essential infrastructure that induces both increases in economic productivity and improvements in social life. Although there is growing criticism of the naive view that a rise in energy consumption automatically indicates economic development [1], there is empirical evidence that energy supply can revolutionize economic and social life, notably among the poor, and especially in rural areas [2, 3].

Perhaps the most immediately perceived impact of energy is on social life: it makes it possible to teach and study at night, enhancing education; television sets can be used, unlocking the narrow perimeter of local life and offering a global perception of human existence; use of refrigerators changes daily cooking and shopping behaviour, etc. A point that should not be neglected, however, is the profound modification that energy induces on economic life. Indeed, energy plays a catalytic role in most economic settings: it stimulates changes in working hours; it develops new activities, and hence employment; it increases labour productivity, etc. It is difficult to argue that the poor of developing countries (LDCs) should be denied access to modern sources of energy, especially electricity, if this is one of the ways in which they can be offered hope for a better standard of living.

Until quite recently, there was no substantial disagreement among energy policy makers about the need for widespread energy supply, in both the urban and rural areas of LDCs. The experience gained in developed countries (DCs) supported the view that economic development and living standards were improved pari passu with increased energy consumption. In the 1980s, however, statistical evidence showed that the growth in Gross Domestic Product (GDP) in DCs was not coupled with growth in energy consumption. Besides, it became clear that, although energy supply is necessary to foster economic development, it is not reason enough; indeed, actual experience in LDCs has shown that energy supply can only produce effective development when coupled with other factors such as banking, roads and communications. Such evidence generated some scepticism about the role of energy in economic development.

Energy supply is expensive and capital intensive; it is particularly so in circumstances where the energy consumption per capita is low and dispersed, a situation that is typical in LDCs. In spite of capital scarcity, LDCs have invested heavily in the electricity supply industry (ESI) since World War II in order to make electricity available to their populations as fast as possible. In some way, this policy was a response to pressures from such populations, which perceive electricity as a source of improvement in their living standards. Indeed, electricity supply is a critical political issue in LDCs: a universal supply of electricity is even an objective inscribed in some constitutions.

Facing strong political pressures and assuming that electricity supply would increase productivity and generate economic growth (thereby generating revenues to pay for electricity supply in the long run), policy makers in LDCs had no hesitation in allocating large financial and technological resources to develop their ESIs. Unfortunately, the expected financial return on electricity investments did not materialize. Nowadays, the ESI is facing huge financial problems in most LDCs, which is jeopardizing their future industrialization process [4].

The financial crisis faced by most utilities in LDCs is urging a substantial review of the electrification policies. Some authors recommended postponing expansion of the electricity supply to those that cannot afford to pay actual electricity prices [5]. Obviously, there is strong resistance to such a policy from people who have no electricity. They suspect, in my view correctly, that they will be denied the opportunity of modernizing and improving their lives.

Field studies in LDCs have revealed clearly that the poor are prepared to use a high proportion of their income in order to have access to electricity supply [2, 3]. It seems, therefore, that the electrification issue needs to be assessed more carefully before any policy decision is made to postpone it. Under no circumstances should policies be prescribed for all LDCs. Although there are many similarities among them, it is rather misleading to imagine that all their ESIs are in the same situation; quite the contrary, there are large discrepancies in their situations, which require country specific policies [4].

## 2. TRENDS IN ELECTRICITY CONSUMPTION

After World War II, the growth in electricity consumption was vigorous and consistent, both in developing and developed countries. Population growth, urbanization and industrialization were the reasons for the high annual increase in electric-

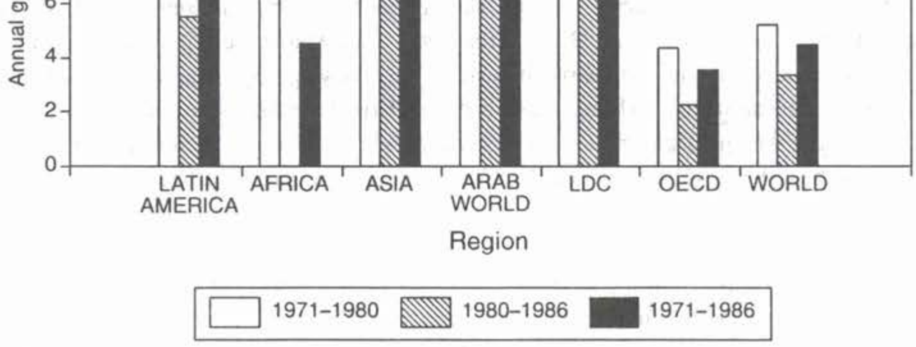


*FIG. 1. Electricity generation [6].*

ity consumption. Some ESI analysts used to say that there was a law controlling electricity demand: *it should double every 10 years.*

However, the trend in electricity consumption changed sharply after the oil crisis. The first signs of these changes appeared in DCs, where the electricity generation growth rate was halved between 1971 and 1986 (Fig. 1) [6]. The levelling out of the population in such countries played a significant role in this downturn, but changes in the composition of the GDP and energy saving technologies were also considerable [7]. Forecasts of electricity demand in DCs are nowadays far less optimistic, although the GDP growth is expected to remain at relatively healthy levels. A post-industrial society that is likely to rely on non-energy intensive materials and is eager to use energy efficiently will probably add to its GDP without a substantial growth in electricity consumption [8].

### 2.1. Past trends

In LDCs, electricity consumption continued to increase at a relatively high rate during the 1970s and most of the 1980s (Fig. 1). Indeed, in the 1970s the rate of growth in electricity generation in LDCs was 9.8% (more than twice the rate of DCs). Although this rate was reduced in the 1980s (7.1%), it remained substantially higher than that of DCs (2.2%). It is worth noting that as far as the rate of electricity generation is concerned large differences among developing regions emerged in the 1980s. In Africa, electricity consumption was actually reduced between 1980 and 1986, revealing the dramatic downturn in its economic development process. In Latin America, there was a considerable slowdown, but this did not jeopardize the industrialization process of the region. In Asia, the rate of growth was reduced, but it still remained at a fairly high level (7.5%).

The driving forces that induced fast growth in the electricity consumption of LDCs in the past still exist. Indeed, the population in LDCs continues to grow rapidly and many of the electric appliances that are currently used in DCs are now becoming widespread in LDC dwellings. Therefore, it is not surprising that electricity consumption is still increasing rapidly in the household sector of LDCs, despite their low growth in GDP. Moreover, industrialization in LDCs is still largely based on energy intensive industries, in many cases to supply markets in industrialized nations which are closing down their own domestic plants.

There was no clear indication that the growth in electricity consumption was likely to be reduced substantially in LDCs until the debt crisis devastated their economies. For instance, Thailand was able to overcome the financial problems induced by the debt crisis, but it still experiences a rate of growth in electricity consumption that is over 10% per year [9]. Indeed, electricity consumption per capita is still very low in LDCs, although among countries it varies substantially, subject to their per capita income level (Fig. 2) [4]. The middle income countries of Latin America are consuming over 1000 kW·h per inhabitant per year; the low income countries of

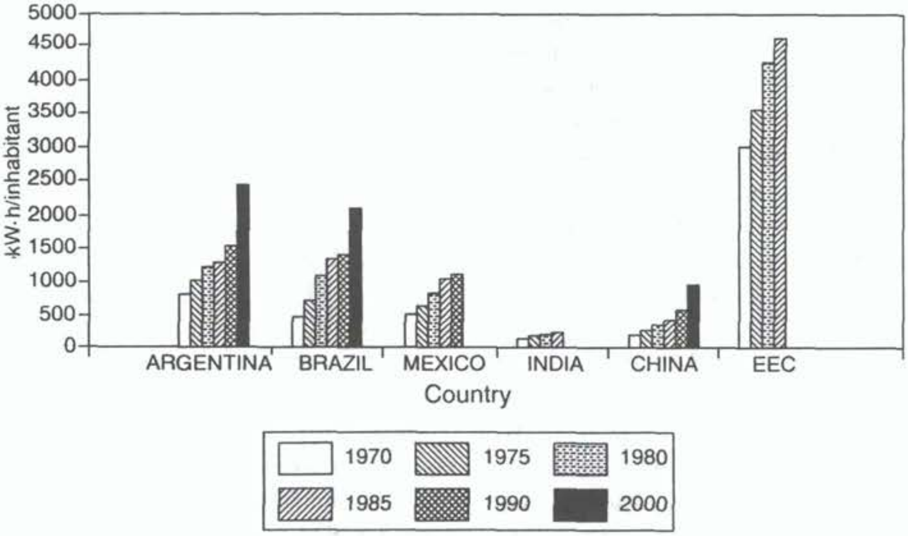


*FIG. 2. Electricity consumption per capita [4].*

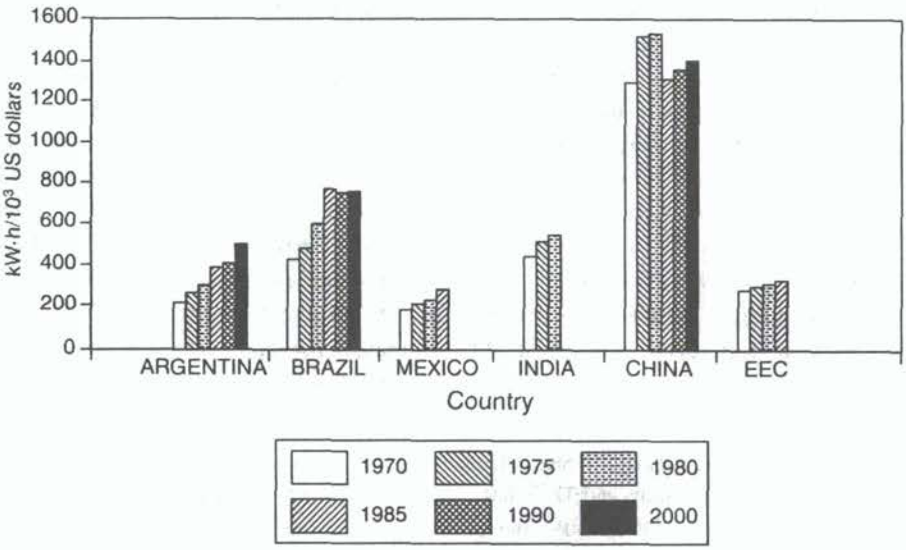


*FIG. 3. Electricity consumption per GDP [4].*

Asia are consuming less than 500 kW·h; and the very poor African countries consume less than 50 kW·h. These figures differ widely to those in DCs, where electricity consumption per capita is over 5000 kW·h. This enormous gap suggests that electricity consumption will increase substantially in most LDCs.

Therefore, both historical trends and comparative analyses support the view that electricity consumption should increase rapidly in LDCs, if it is assumed that they are to achieve sustained economic growth. This background, compounded with political pressure from their populations, induces LDC utilities to plan for large increases in the supply capacity.

### 2.2. Future trends

A recent study made by the World Bank [10] reviewed plans for an increase in electricity consumption in 70 LDCs, representing around 98% of the total LDC electricity demand. It concluded that LDC utilities are forecasting a 6.6% per year average increase in electricity consumption for the 1990s. It is important to note that this forecast contemplates quite substantial differences among developing regions: Asia forecasts a growth rate of 7.7% per year, Latin America 5.6% and Africa 4.9%. These figures are consistent with early 1980 historical trends in Asia and Latin America; in Africa, the forecast, although optimistic if compared with the early 1980s, is consistent with the historical trend shown over the past 20 years.

As far as installed capacity is concerned, utility plans are less optimistic, both in Latin America (4.6%) and in Africa (2.2%), but they remain close to the demand forecast in Asia (7.6%). Many countries in the first two regions installed large power plant capacity in the 1980s; however, electricity consumption did not increase as expected because of the economic slowdown generated by the debt crisis. Consequently, a significant share of the existing installed capacity remains idle. Plans for the 1990s intend to make use of this idle capacity in order to cover increases in electricity consumption, thereby reducing the need for growth in generation capacity.

Recent studies of the electricity system in a few key LDCs, prepared by COPED[1], identified signs that the forecasts of electricity demand made by utilities are still overoptimistic [4]. Although the per capita electricity consumption in LDCs is low compared with DCs (Fig. 2) [4], a few factors lead us to believe that in the foreseeable future electricity consumption in LDCs is likely to reduce its growth rate below historical levels. The most obvious reason for this, particularly in Latin America and Africa, is the macroeconomic instability generated by the debt crisis.

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[1] COPED is a network of research centres from Latin America (Argentina, Brazil and Mexico), Asia (China, India and Thailand), Africa (Senegal and Algeria) and Europe (United Kingdom and France) that jointly studies energy policy issues in developing countries. COPED periodically publishes a bulletin that makes its work available to a wide audience, both in developing and developed countries.

As a result, the scope for industrialization in most LDCs was reduced substantially, thereby limiting the use of electricity among producers and householders.

However, there are at least two other factors that should reduce the growth rate of electricity consumption in LDCs even further: price and technology. Electricity tariffs are often relatively low in LDCs as result of past policies that intended to reduce the inflationary impact of growing electricity costs. In recent years, there was a move to increase electricity tariffs, but they still remain lower than the long run development costs in many countries. Inevitably, electricity prices will have to be increased to cover costs, curbing electricity demand. Moreover, there are no signs that LDCs have taken advantage of the more efficient electricity related technologies already available in DCs; in fact, the role of efficient technologies in electricity demand patterns has generally been neglected by LDC utilities. Economic efficiency, and thereby energy efficiency, will necessarily play a more significant role in the future, especially if new sources of dynamism are found to re-activate economic growth. Consequently, the rate of growth in electricity consumption is, eventually, likely to be lower than the historical figures.

Indeed, electricity consumption per unit of GDP is relatively high in most LDCs compared with DCs (Fig. 3) [4]. This suggests that either electricity is inefficiently used or else it is largely used in households (thereby contributing too little to GDP growth). Actually, both factors explain the relatively poor economic output induced by electricity use in LDCs. Policies in LDCs need to be reviewed in order to improve electricity efficiency at the end user level, which would also increase economic efficiency.

## 3. KEY ISSUES

Over the past 40 years, large investments have been made by LDCs to develop their ESIs. Their objective was to provide cheap electricity in order to induce industrialization, to increase productivity and, ultimately, to improve living standards. There are obvious conflicts between these objectives and the actual economic situation of LDCs. From the macroeconomic point of view, LDCs suffer from a scarcity of financial resources, particularly hard currency, but electricity supply is capital intensive and requires large quantities of import. From the microeconomic point of view, a large share of the population of LDCs has no ability to pay for electricity supply. On the assumption that, first, increases in productivity would eventually solve these underlying conflicts and, second, that the equity issue, particularly absolute poverty, had to be addressed in any event, both governments and international development agencies offered financial support to the ESI of LDCs.

These investments resulted in an impressive increase in installed capacity and a growing share of electricity supply to LDC populations. Nevertheless, in most LDCs there are geographical areas and social groups that still have no electricity.

TABLE I. LDC POWER CAPITAL EXPENDITURES IN THE 1990s ($10^9$ US dollars) [10]

| | Asia | Europe, Middle East and North Africa | Latin America countries | Africa | Total | Percentage |
|---|---|---|---|---|---|---|
| Generation | 277 | 79 | 83 | 6 | 445 | 60.0 |
| Transmission | 39 | 8 | 32 | 2 | 81 | 10.9 |
| Distribution | 100 | 23 | 27 | 2 | 152 | 20.5 |
| General | 39 | 11 | 13 | 1 | 64 | 8.6 |
| *Total* | 455 | 121 | 155 | 11 | 742 | 100.0 |
| *Percentage* | 61.3 | 16.3 | 20.9 | 1.5 | 100.0 | 100.0 |

The most dramatic situations are found in Sub-Saharan Africa and Indochina, where only a small share of the urban population has electricity and where there is no meaningful electrification in rural areas. Moreover, the reliability of their electricity system and the quality of the services provided are very poor.

The situation is much better in North Africa, in most parts of Latin America and in South-East and North-East Asia. In these regions, urban populations are almost universally supplied with electricity and a large share of the rural population has access to electricity. In addition, their electricity systems are reliable and the quality of the services provided is generally good. China and India are in an intermediate position; their figures for the population supplied with electricity are similar to Latin America, but the quality of the services provided is similar to that of Africa.

### 3.1. Financial crisis

LDCs have not abandoned their objective of making electricity universally available. Their utilities are planning large increases in electricity supply and, in order to convert these plans into reality, quite substantial investments are envisaged. The World Bank estimates that around US $742 billion ($10^9$) (1989) are required by LDC utilities in order to realize their plans (Table I) [10]; around 38% (US $282 billion) of the total financial needs is in foreign currency. However, there are many doubts as to the ability of most LDCs to finance these investments, particularly as far as foreign currency is concerned.

Indeed, except in South-East and North-East Asia, the financial situation of LDC utilities is difficult, if not critical [4]. To achieve the social, regional and macroeconomic objectives, electricity prices were kept unrealistically low for many years, and no subsides were offered to compensate the utility for higher costs. In Africa, there are situations where the tariffs do not even cover the fuel costs. In China and India, the tariffs in rural areas remain substantially low in order to promote agricultural production. In Latin America, the tariffs were reduced steadily during the 1980s, despite the fact that the electricity costs were growing. In addition, many consumers, especially government agencies, that are facing financial problems simply do not pay their electricity bills. These policies have led to a rapid deterioration in the financial situation of LDC utilities.

It is necessary to mention that LDC authorities are aware of these problems. Electricity tariffs are increasing and some measures have been enforced to reduce the debt of utilities. However, the problems of financing new projects remain, since the cash flow of utilities can, optimistically, only self-finance 40% of their planned investments. Moreover, financial support from governments and international development agencies is diminishing. Indeed, the debt crisis is dramatically undermining public accounts in most LDCs; in practice, this denies any significant financial assistance from treasuries to the ESI. Simultaneously, international development agencies changed their view about the role of the ESI in the economic development process of LDCs and thus reduced their willingness to finance electricity projects [11].

The World Bank estimates that no more than 25% of the financial needs of the ESI in LDCs can be covered by bilateral and multilateral financial sources; the remaining 75% share has to be self-financed, partly by utilities and partly by private sources, either domestic or international [12]. This critical situation is inducing LDC governments to stimulate the participation of private investors in the ESI. Many LDCs are considering opening the ESI to private investors, but they are facing great difficulty in finding a suitable role for such investment that would preserve the role of the ESI in the economic development process. In Latin America, several governments have declared their willingness to privatize the ESI, but they have not clearly indicated how; a similar situation exists in other developing regions.

### 3.2. Technology policy

Nationalized LDC utilities had to face a lack of domestic technological capabilities when they started to operate. Training of nationals was undertaken to improve the domestic capability of operating and maintaining power plants (user technological capabilities); and import substitution policies were implemented to improve the capability of adapting, modifying and, eventually, designing power plants. In larger countries, the building up of a domestic capital goods industry was fostered with a view to exploiting the procurement policy of domestic utilities.

Nevertheless, the technological performance of LDC utilities deteriorated quite substantially after the oil crisis: transmission and distribution losses increased, thermal efficiency was reduced, reserve margins were increased, the reliability of power plants was diminished, etc. The critical factor that induced utilities to follow this trend was the severe macroeconomic context within which they had to operate, especially in the 1980s. Indeed, in having to face the financial constraints imposed by government pricing policies, LDC utilities had to postpone crucial investments in generation, transmission and distribution, thus inducing a decline in performance. However, management and technology responsibilities in this process should not be discounted.

The economic and technological problems faced by utilities have become much more complex since the oil crisis started. The cycle of cost cutting innovations, increasing demand levels and economies of scale, and the generally low interest rates that allowed the ESI to grow rapidly with a fall in real costs during the 1950s and 1960s came to an end in the 1970s. Great uncertainties about the future and escalating costs are now realities which utilities have to face. Moreover, centralization and a monopoly system, which were sources of performance improvements in the past, are currently viewed with scepticism.

Accustomed to making decisions on the assumption that a relatively certain future was secure and that the macroeconomic impacts of the ESI were positive, management has had some difficulty in adapting to the new situation. For instance, most forecasts of electricity demand in LDCs still do not assess the effects that escalating tariffs and efficient end use technologies will necessarily have on electricity demand. Not surprisingly, actual consumption is consistently below the demand forecasts, thereby increasing the electricity costs.

In the 1960s and 1970s, the ESI of LDCs improved its technological performance by introducing successive vintages of new, more efficient technologies imported from DCs [13]. Incremental change received little attention from policy makers, despite the substantial role it can play in technological improvements [6]. As soon as large increments in power were no longer introduced into the electricity system of LDCs, their technological performance started to deteriorate; and the capabilities that were needed to operate, modify and adapt their technologies, in order to improve their efficiency, were in short supply.

### 3.3. Regulation

It has been argued that the source of these inefficiencies is the 'monolithic control' LDC governments hold over the ESI: it avoids competition and allows government interference in management decisions [5]. These authors suggest that the ESI should be privatized in LDCs in order to bring in market forces, to avoid government interference and to promote decentralization. However, the experience of privatization in DCs so far indicates that, although government interference can be diminished, it cannot be abolished; it also shows that competition in the ESI is necessarily limited by the nature of the power supply [14].

Electricity supply has far reaching social and economic implications that are quite complex to assess, particularly in LDCs; besides, it has technological characteristics which predominantly induce collusion rather than competition in pursuit of economic efficiency [15]. Indeed, emphasis on privatization has eclipsed the fundamental issue that needs to be addressed urgently: *regulation*.

The regulatory regime used for the ESI in LDCs is outdated; the situation within which utilities have to operate has changed radically over the past two decades, but the regulatory regime has not. For instance, there are still generation by non-utility producers; these constrain the development of efficient co-generation technologies. Another example is the existence of regulations governing the import of capital goods; this restricts competition and increases investment costs.

There is an urgent need to review the regulatory regimes governing the ESI in LDCs. The dichotomy between privatization and state control is misleading. LDCs should rather look for a rational balance between public and private ownership under a new regulatory regime that induces economic, social, technological and environmental efficiencies. The regulator should have an intermediary role between government and utilities, ensuring that utilities follow strategic and macroeconomic government directives, but protecting utilities from day to day government political interference.

### 3.4. Sustainability

There are obvious conflicts among the different objectives settled for the ESI and its long term sustainability. Financial viability, for instance, conflicts with social equity, security of supply and regional development. Obviously, this is not a problem specific to LDCs, as British privatization is highlighting. In the United Kingdom, large provisions have had to be made in order to guarantee a market share in the ESI for nuclear power and for domestic coal.

Three issues deserve particular attention in LDCs: rural electrification, technological choice and environmental protection. First, rural electrification is likely to suffer most from the drift towards improving the financial situation of utilities. Strategies for rural development must be reviewed and alternatives to the grid have to be considered in order to provide electricity to rural areas. It is worth mentioning that this issue is particularly pressing in poorer LDCs, since rural electrification is negligible.

Second, high interest rates and financial constraints induce a technological choice of less capital intensive technologies. Fossil fuelled thermal power plants, consuming tradeable energy sources (oil and coal mainly), are likely to be chosen instead of hydropower and other renewable energy sources, which are non-tradeable and largely available in many LDCs [16]. This technological trajectory will accentuate, in the long term, the already difficult situation of external accounts in most LDCs.

Third, and of greatest importance, is the environment. Although there are technical and managerial options that can improve both financial and environmental efficiencies, the speed of change required to meet such financial targets will mean that the environment is likely to be neglected by utilities pressed to solve their financial crises as soon as possible. There are clear signs that utilities in LDCs are introducing environmental concerns into their decision making process. Nevertheless, there is a large amount of evidence that the environmental record of LDC utilities is poor. Moreover, the choice of thermal power plants instead of renewable energy sources will add substantially to global emissions of warming gases.

## 4. CONCLUSIONS AND POLICY GUIDELINES

Electricity consumption per capita in LDCs is still very low, but it is perceived by their populations as an essential factor that can open opportunities for social and economic improvement. Although it can be argued that electricity does not guarantee economic development, there is strong evidence that electricity supply is a fundamental component of any strategy intended to improve productivity and living standards. Therefore, it is not surprising that LDCs utilities are planning to increase their electricity supply rapidly.

Nevertheless, there are grave doubts about the ability of LDC utilities to finance the investments they are planning. Their financial situation is poor and their recent performance weak, both economically and technologically. Even though the macroeconomic context can be blamed for most of these problems, there is a need to review the pricing policy, the technology policy and the regulatory regime that governs the ESI in LDCs if a sustainable future is envisaged, particularly as far environmental protection is concerned. It seems politically inconceivable to propose policies that would postpone electrification indefinitely for non-electrified areas.

A few points deserve closer attention:

**(a) Financial viability:** The ESI has to recover its ability to invest, otherwise its role in the economic development process will be jeopardized. However, there is no easy solution to this complex issue. Certainly, the self-financing ratio of utilities must be increased in order to reduce external financial needs. A profound review of tariffs is, therefore, unavoidable; the average price of electricity has to be increased to cover average costs, although tariffs can accommodate social or regional policies. Moreover, a proper role in the ESI must be offered to private investors to increase the ESI's capacity to invest; it should be noted that technological innovations such as co-generation could make it possible to reconcile private and public ownership in the ESI without concessions to the main objectives.

**(b) Innovation:** The technological performance of LDC utilities can and must be improved substantially. The existing installed capacity can supply a larger electricity demand if the technology policy is oriented to incremental innovation rather than to radical change. Interconnection of electric grids, both domestically and internationally, offers opportunities of reducing the reserve margin and increasing the reliability of the electricity system. Rural electrification can be speeded up if technological standards are reviewed in order to accept local adapted technologies. Electricity conservation and co-generation can be sources of improvements in performance if the technological capabilities (often confined in the ESI) are widespread among industrial electricity users.

(c) **Sustainability:** The social, economic and environmental impacts of electricity supply and use have to be assessed more carefully. High rates of interest induce the ESI in LDCs towards thermal power; this depletes tradeable energy sources. By the same token, the role of renewable, non-tradeable energy sources such as hydropower is likely to be reduced. This technological trend will have great long term effects, both on fuel markets and the environment. Moreover, it will worsen the already difficult situation of the LDC trade balance: the long term is being sacrificed to solve the short term financial problems. There is a trade-off between the long and the short term that has to be considered carefully.

(d) **Regulation:** The regulatory regime of the ESI in LDCs is outdated; it has to be substantially reviewed. The regulator has to be independent and strong enough to force utilities to operate under government energy policy guidelines, but it must offer simultaneous scope for the utilities to manage their own business on a healthy financial basis. The concept of a contract plan, already in use in some LDCs, seems to be a step forward in this direction. Moreover, independent private generators must be offered a fair opportunity of having access to the grid and, eventually, to consumers, and consumers have to be protected from the monopoly power of the utilities. New regulations are usually controversial; the experience of DCs suggests that progressive reforms are more likely to receive political acceptance.

(e) **Aid:** The financial problems faced by LDC utilities have to be assessed in the context of the debt crisis. It is fundamental to understand clearly that utilities cannot solve their financial difficulties if a proper solution is not found to the macroeconomic problems of their countries. In this context, it is worth remembering that, at its conception, the purpose of the World Bank was to compensate for the inadequacies of private capital markets, and to provide funding for projects that show a good rate of return in the long term, even though they may appear unattractive to private investors.

(f) **Technological co-operation:** Technological transfer will play a considerable role in the improvement in performance of LDC utilities in the years to come. To increase its effectiveness, however, it must go far beyond the selling of equipment and technical assistance. It is necessary to support acquisition of technological capabilities to buy, operate, maintain and improve the performance of electricity related technologies. Development agencies should abandon their narrow project by project approach; instead, they should adopt a long term strategy that maximizes the learning effects of different electricity projects and support the domestic acquisition of technological capabilities.

(g) **Institutional reforms:** DCs have experienced different reforms in their ESIs over the past 10 years. The UK has, perhaps, been the most radical; its ESI was almost entirely privatized and competition in generation and distribution was introduced. In other countries, reforms have been more limited, focusing less attention on ownership and generally involving access to the grid for independent generators. It is important that in its attempts to influence reforms in the South, the North does not misinterpret its own experience. Privatization is limited in scope and it is proving difficult to implement. The underlying organizing principle of the ESI is still co-operation rather than competition.

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# ROLE OF ELECTRICITY IN MINIMIZING ENVIRONMENTAL IMPACTS

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## Abstract

ROLE OF ELECTRICITY IN MINIMIZING ENVIRONMENTAL IMPACTS.

The electricity sector is expected to play a central role in efforts to minimize the environmental impacts of energy. The electric utility industry consumes far more fossil fuels than any other single industry and electricity generation is the only large scale means of converting innovative energy sources such as nuclear power and renewable energies to a useful form for mankind. Since electricity is not only a clean form of energy but is also of the highest quality in terms of energy service efficiency, the environmental impacts of energy use can be reduced significantly by substituting electricity for other energy forms. The general benefits associated with electricity have partly been realized; however, there are further potentials to improve environmental performances in the electricity sector itself. The technical potentials of supply and demand side electricity are identified and the prospects for achieving the potentials are discussed. As a result, many technical potentials are identified. Steady improvements on the supply side are anticipated, particularly by combining technologies and/or integration of the energy systems. However, this generally takes a long time to realize, since most cost effective improvements have already been achieved. On the other hand, many technical potentials for efficiency improvements on the demand side appear to be realized in a rather short time. However, it would be a difficult challenge to mobilize and/or invent effective incentive schemes to influence consumers in selecting efficient end use technologies.

## 1. ELECTRICITY AND THE ENVIRONMENT

The electricity sector, like other energy sectors, causes various impacts on the environment. Electricity generation by burning fossil fuels pollutes the air with combustion by-products, such as sulphur dioxide and nitrogen oxides, and brings about the threat of climate change by massive emissions of $CO_2$. Use of fossil fuel for electricity generation is also indirectly responsible for many environmental impacts caused by the exploitation and transport of these fuels, for example, marine pollution from oil spills and land destruction from open cast coal mining. Even hydropower generation involves substantial change in land use. Nuclear power produces radioactive wastes, and raises public concern about the safety and health risks.

Electricity use, on the other hand, is generally clean and safe. No hazardous pollutant is emitted at the end use. Since electricity is a clean form of energy and is also of the highest quality in terms of energy service efficiency, the environmental impacts of energy use could be reduced significantly by substituting electricity for other energy forms. The effect of electrification could be particularly great in developing countries. Thus, the electricity sector is expected to play a central role in minimizing the environmental impacts of energy.

If we can neglect the minimal environmental impacts associated with the end use of electricity, then the environmental impacts of the electricity sector, from primary energy input to electricity end use, can be described conceptually as follows:

$$\text{(Environmental impact)} = X \times Y \times Z \times \text{(energy service)}$$

where $X = \text{(environmental impact)/(primary energy input)}$
$Y = \text{(primary energy input)/(electricity use)}$
$Z = \text{(electricity use)/(energy service)}$.

To minimize environmental impacts while maintaining the level of energy services, the X, Y and Z factors should be reduced. A reduction in X means that environmentally benign resources are used for primary energy input, and/or anti-pollution technologies are introduced for supplying a clean form of energy. To reduce Y and Z, the efficiency of electricity supply and electricity end use, respectively, should be improved.

Taking $CO_2$ emission control as being of primary environmental concern, the technical potentials for reducing these factors are identified and then the prospects of achieving such potentials are discussed.

## 2. ELECTRICITY AS A MEANS OF SUPPLYING CLEAN ENERGY

### 2.1. Share of the electricity sector in the energy system

The electric power industry consumes far more primary fuels than any other single industry. The growth in electricity use in most industrialized countries has been faster than the total energy requirements since the birth of the electric utility industry. As a result, the share of electricity in the total final energy consumption in the late 1980s reached a level of 15–20% (around 30–40% in terms of primary energy input) in most OECD countries. The electricity share increased continuously in all sectors other than the transportation sector. While electricity generation involves unavoidable energy losses, according to the second law of thermodynamics, electrification, particularly in industrial processes, usually contributes to the overall energy efficiency improvements.

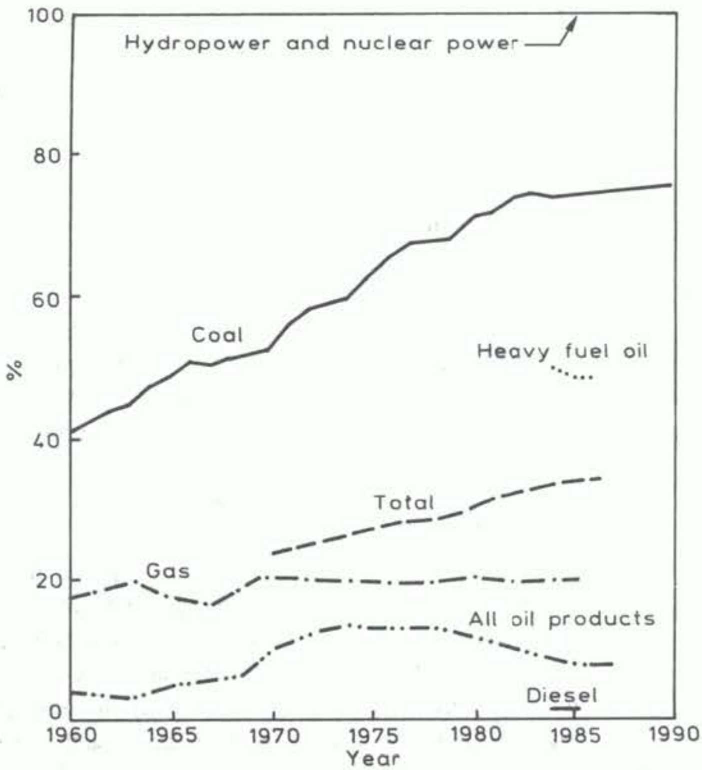


*FIG. 1. Percentage of indirect use of fuels via electricity to total use (OECD countries) [1].*

For OECD countries, the percentage of each energy form being converted to electricity is plotted in Fig. 1 [1]. Hydropower and nuclear energy are exclusively converted to electricity. For coal, 75% is converted to electricity, the remaining 25% being used in its direct form, primarily in the steel and cement industries. Reflecting the policies set in OECD countries to reduce dependence on oil since the first oil crisis in 1973, the share of oil products converted to electricity has decreased to a level of around 10%. Regarding natural gas, around 20% has been used constantly for electricity generation over the past few decades.

## 2.2. Centralized use of fossil fuels in the electricity sector

The huge amount of fossil fuels needed for electricity generation is mainly burned at large central power stations; thus, advantage can be taken of economies of scale in applying anti-pollution technologies such as scrubbing sulphur dioxide from flue gases. The emission sources of pollutants can be isolated by the appropriate site selection of such central power stations. Concerning $CO_2$ removal from flue gases, which is now under R&D as one of the technical measures to prevent global warming, it is becoming most promising to apply this method to a large fossil fired power station located close to an appropriate site for disposal of the recovered $CO_2$, e.g. in coastal regions.

### 2.3. Non-fossil energy use in the electricity sector

Electricity generation is the only large scale way of making non-fossil energy sources such as nuclear power and renewable energies useful to consumers. $CO_2$ free, non-fossil energy sources have an absolute value in coping with global warming, although they may have their own environmental problems, as already stated. If the electricity currently generated by nuclear and hydropower were to be supplied by coal fired power plants, the annual $CO_2$ emissions worldwide would increase by around 400 and 500 million tonnes, respectively; thus, $CO_2$ emissions from fossil fuel burning would increase by about 15%.

In addition to nuclear and hydropower, among the most promising non-fossil energies for electricity generation are geothermal energy, biomass energy, solar thermal energy, the photovoltaic system, wind power, tidal power, wave power and ocean thermal electric conversion. It would also be important to develop innovative energy carriers which can be converted to and from electricity, for example, hydrogen to tap natural energy resources in remote areas and to increase the share of electricity in the energy system. There are, however, many technological, economic and societal barriers in realizing the potential benefits of these new energy technologies. Long range planning, with explicit targets, could play a key role in overcoming these barriers.

## 3. EFFICIENCY IMPROVEMENTS IN THE ELECTRICITY SUPPLY

### 3.1. Efficiency of electricity generation

Technologies for fossil fired power plants are well developed. The efficiency of electricity generation in conventional thermal power plants, which employ boilers and steam turbine generation systems, has been improved to about 40% at the supply end; this is close to the steam cycle technology limit. As shown in Fig. 2 [2], the average thermal efficiency of operating steam power plants in Japan has improved rapidly, from less than 20% to more than 35% during the 1950s and 1960s. The rate of improvement in average efficiency, however, has stagnated over the past 20 years, reflecting the technological difficulties involved in further efficiency improvements, energy losses because of pollution control equipment and the lowered rate of replacing old plants with more advanced, efficient ones.

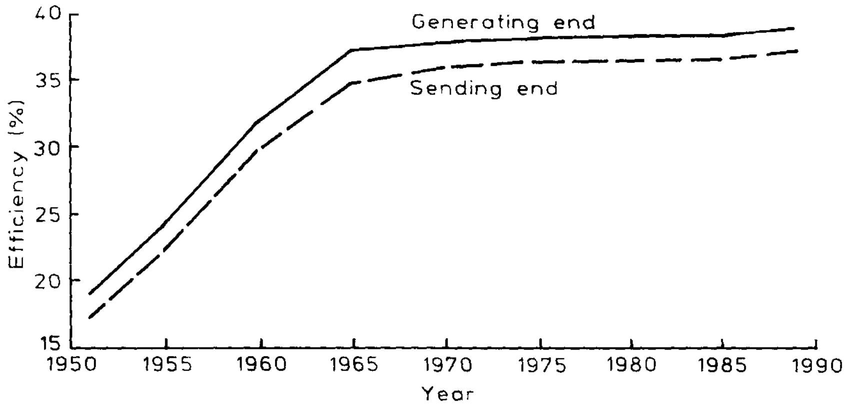


*FIG. 2. Average thermal efficiency of operating steam power plants in Japan [2].*

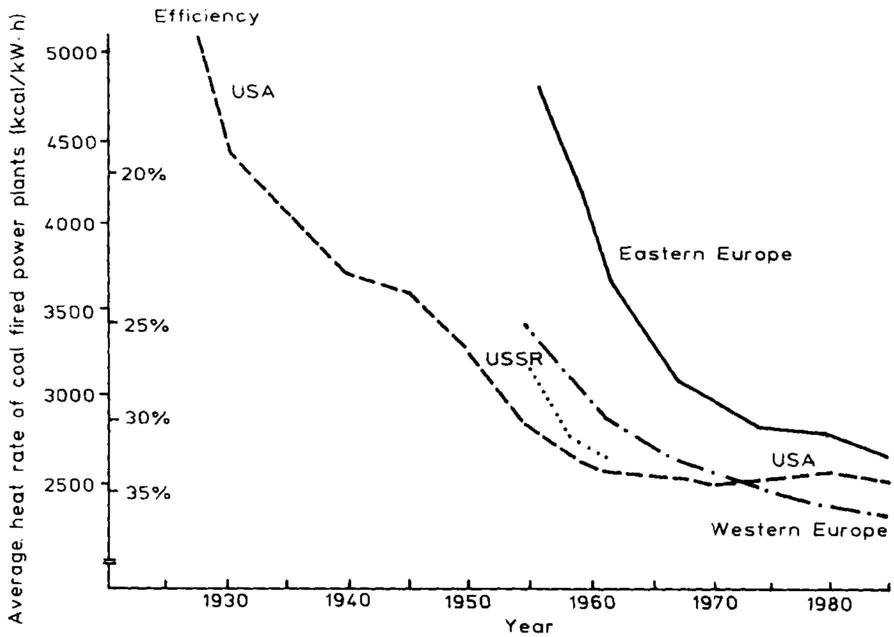


*FIG. 3. Improvements in power plant efficiencies [1].*

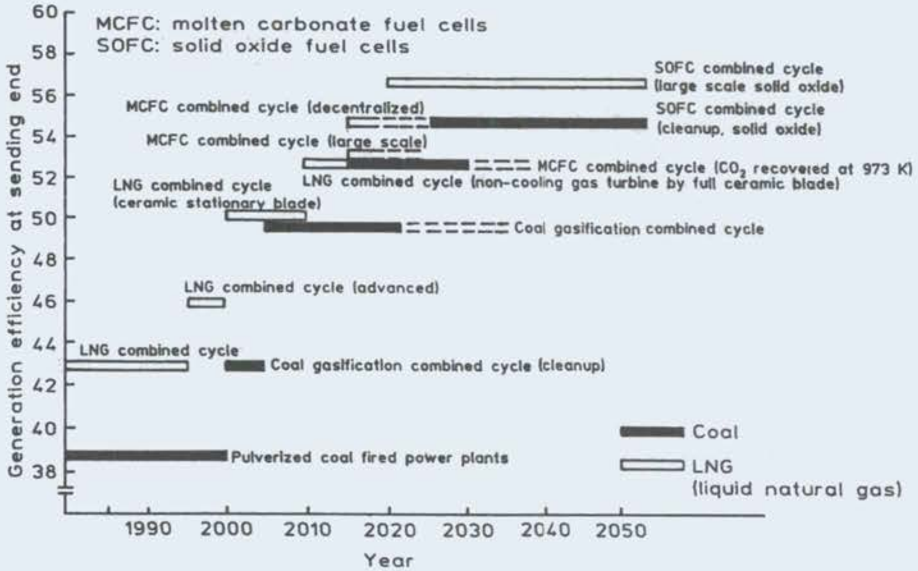


*FIG. 4. Expected efficiency growth in advanced fossil fuel generation systems [3].*

Similar trends in efficiency improvements can also be found in other parts of the world, as seen in Fig. 3 [1]. Regarding actually achieved efficiencies in electricity generation, however, there are still significant performance gaps among countries. Technology transfer and development to fill the gaps could contribute towards enhancing the global average efficiency of electricity generation.

In technically advanced countries such as Japan there appears to be little room for efficiency improvements in conventional steam power generation. Technical potentials for a breakthrough in electricity generation efficiency, however, can be found by combining steam cycle technologies with other generation technologies. A typical example, which has already been commercialized, is combined cycle generation, which utilizes waste heat from the gas turbine for boiling water to drive the steam turbine. In Japan, 43% of the efficiency at the sending end is achieved in combined cycle power plants using liquid natural gas (LNG). As shown in Fig. 4 [3], efficiency is expected to rise to more than 50% by developing a ceramic blade gas turbine, and close to 60% by combining advanced fuel cells such as molten carbonate fuel cells (MCFC) and solid oxide fuel cells (SOFC). Gasified coal as well as natural gas will be used for such advanced combined cycle generation technologies. In the long run, other direct power generation technologies such as magneto-hydrodynamic (MHD) generation and thermo-electric conversion may also be used.

Furthermore, where LNG is stored, the associated cold heat and expansion energy can also be used for electricity generation. More than ten such LNG cold heat generation plants, with a total capacity of about 60 MW(e), are now operating in Japan.

Under the prospects for technology development described above, the average efficiency of thermal power plants operating in Japan in 2050 is expected to increase to 50–55%. Together with increases in the share of non-fossil electricity generation, about two-thirds of the total electricity generation in 2050, $CO_2$ emissions from the electricity sector in Japan could remain constant or even be lowered while supplying more than twice as much electricity as today [3].

### 3.2. Losses in the transmission and distribution systems

The technologies for transmitting and distributing electricity have matured. As shown in Fig. 5 [2], the transmission and distribution loss factors in Japan decreased from about 25% in 1950 to less than 6% in 1980. The significant reductions in losses were achieved mainly through raising the voltages of transmission and distribution lines. Over the past 10 years, the loss factor has remained constant. While many 500 kV transmission lines are now in operation and a 1000 kV line is about to go into service, the effects of reducing losses have partly been cancelled out because they are being used to connect load centres with nuclear power stations and/or pumped hydropower stations located in remote areas.

As in the case of generation efficiency, similar trends of efficiency improvements in transmission and distribution systems can be found in other parts of the world. However, since innovations in a network are rather slow, particularly for a system with a low growth rate, and since transmission efficiency is significantly

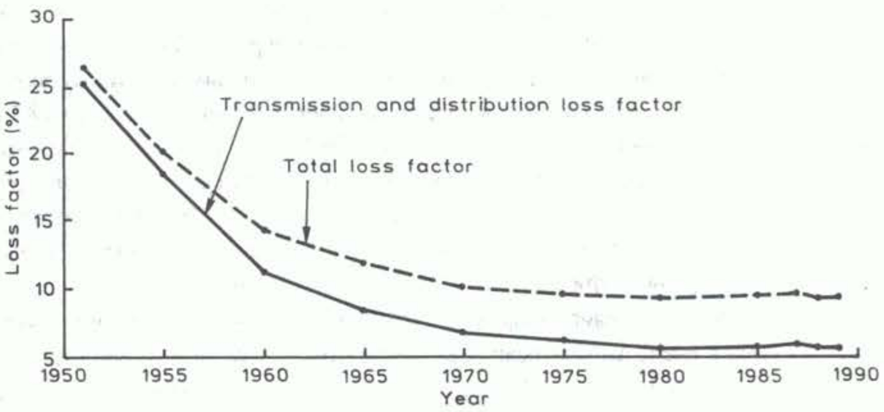


*FIG. 5. Transmission and distribution losses in Japan; the total loss factor includes electricity consumed in power plants [2].*

affected by geographical conditions, relatively wide differences exist in efficiencies among countries. Even in developed countries, the loss factors of transmission and distribution systems range from about 4 to 9%. In the long run, these differences will lessen, then the global average efficiency is likely to increase by a few per cent.

Several technological potentials for a breakthrough in efficiency improvements in transmission and distribution systems can be identified, for example, a superconductive network, amorphous core transformers, higher distribution voltages and further penetration of power electronics. The contributions made by the latter three options, however, are marginal, probably less than 1%, while penetration of power electronics could enhance the flexibility of electricity networks significantly. On the other hand, the effect of a superconductive network that includes superconductive cables, transformers and generators could be revolutionary. If superconductivity makes it possible to transport electricity anywhere in the world without losses and at a reasonable cost, then the impact will certainly be beyond that of efficiency improvements in electricity transport. Many energy resources currently unused, such as hydropower resources in remote areas and gas and oil reserves in Arctic regions, could be tapped. Unstable natural energies such as solar and wind power could be made into reliable power sources if they are linked and controlled globally. Through globally linked electric grids, the aggregate demand profile would be levelled, so making the electricity supply more efficient.

### 3.3. Electricity storage systems

It seems strange to maintain that electricity storage systems could contribute to an efficient electricity supply. Indeed, storage systems involve energy losses during charge and discharge, and storage itself. The efficiency of pumped storage hydropower plants, currently the most popular large scale electricity storage technology available, is about 70%. The introduction of storage systems is usually justified by the economic argument that they can maintain high capacity factors for capital intensive base load power facilities such as nuclear power plants. Storage systems, however, could also contribute to the overall efficiency of electricity supply by making it possible for thermal power plants to operate constantly at rated capacities. Thermal power plants are designed to be most efficient when operating at their rated capacities. Besides, since most storage systems have excellent dynamic operating performances, they are used to follow load fluctuations; thus, the spinning reserves of thermal power plants, which consume extra fuels, can be reduced.

The efficiency of storage systems can be improved in two ways: by improving storage efficiency itself, and by locating storage systems close to load centres, thus reducing the transmission losses. Among the technological potentials for improving the efficiency of storage systems are compressed air energy storage, advanced storage batteries, hydrogen production and superconductive magnetic field energy storage.

### 3.4. Co-generation systems

A co-generation system is an energy efficient system that supplies both electricity and heat. In industrial processes such as those used in the paper and pulp, iron and steel, as well as the chemical industries, co-generation systems have been used commonly. A significant portion of the capacity of non-utility electricity generation, which was around 17 GW(e) in 1989, representing about one-tenth of the total power plant capacity in Japan, is supplied through co-generation systems. The prospects of these industrial co-generation systems depend on the future of individual industries. The co-generation systems that have recently attracted much attention are those relatively small capacities which provide customers in the commercial sector with electricity, hot water, heating and cooling.

Small scale co-generation systems began penetrating the Japanese energy market in the early 1980s; the number of installations has increased rapidly, to about 350, with a total capacity of around 150 MW(e) in 1989. These co-generation systems employ gas engines, diesel engines or gas turbines for generating electricity. Fuel cells will be also used in the future. The efficiency of the current co-generation systems is 20–30% for electricity generation and 40–50% for heat recovery; thus, the integrated efficiency is expected to be as high as 70–80%. The actual efficiency, however, depends on the profiles of the electricity and heat loads. A relatively large and constant heat load is an important condition for achieving high efficiency and good economy.

The effect of the co-generation systems on the efficiency of electricity generation should be examined carefully. Co-generation systems pursue the efficiency of combined supplies of heat and power within a relatively small network, the size of which is limited by heat supply technologies. On the other hand, the economies of scale of electricity networks still exist, at least in combining many electricity demands, while the economies of scale of generation technologies are not so certain. Thus, the penetration of co-generation systems into electricity supply may erode the inherent efficiency associated with a large scale electricity network. Institutional arrangements such as a prudent rate schedule for trading between co-generation systems and electricity networks could play an important role. It is important in the long run to construct an efficient and flexible integrated energy system to realize ideal cascaded utilization of various energy carriers.

## 4. EFFICIENCY IMPROVEMENTS IN ELECTRICITY END USE

In general, electricity is the most efficient way of providing energy services because, theoretically, it can be converted to 'work', the highest form of energy, at 100% efficiency. However, the inherent efficiency of this refined energy form does not necessarily guarantee the highest efficiency in actual energy use. The efficiency of electricity varies significantly, depending on the end use technologies.

To evaluate the maximum technical potential for energy savings, many recent attempts have been made to identify the most efficient electric end use technologies. According to the results of Faruqui et al. [4], maximum savings in electricity in the United States of America in the year 2000 could range between 24 and 44%, even when only currently available technologies are taken into consideration. According to the study, in the housing sector efficient technologies for lighting, space heating and water heating offer the greatest opportunities; in the commercial sector technologies for lighting and space cooling have a large potential for efficiency improvements; efficient technologies for motive power are most promising in the industrial sector. However, the results obtained under USA conditions cannot be applied to the rest of the world because the structure of end use electricity demand differs among countries and evaluation of the technical potentials for electricity savings depends strongly on the performance of the end use technologies currently available.

Reflecting the difficulty in defining energy services, categorization of electric end use technologies is not well established. Although the electric utility industry began by providing lighting services, its energy services were soon diversified to motive power, electrochemical reactions and heating; it now also covers air conditioning, telecommunications, computing, etc. It is not an easy task to analyse the efficiencies of so many diverse end use technologies. Besides, efficiency improvements in electricity end use have been achieved not only in individual components such as motors and compressors but also in the advances made in control systems such as microcomputers and power electronics.

In the following sections, several important technology developments in electric end use efficiencies are reviewed.

### 4.1. Lighting

As is well known, in 1879, Thomas Alva Edison invented an incandescent bulb with a carbon filament made of Japanese bamboo; as a result, in 1882, the basic structure of the electric utility industry was founded with the supply of electricity to the bulbs of some 100 buildings. Since then, end use technologies for lighting have made significant progress.

Efficiency improvements in light sources have been achieved through the evolution of performance within each technology as well as through the progress from one technology to another. Although the efficiency of incandescent bulbs reached a saturation point more than 50 years ago with the introduction of a tungsten filament, incandescent bulbs remain a viable technology for lighting, competing with fluorescent bulbs. The fact that incandescent bulbs still retain a large share of the market in spite of the fact that their energy efficiency is less than one-third that of the fluorescent bulb and their life one-fifth shorter suggests that there is a complicated pattern of consumer preference.

The efficiency of fluorescent bulbs has been improved over the past decades, and several recent innovations are now being introduced. A ball shaped fluorescent bulb that is compatible with an incandescent bulb has been developed and efficiency has been increased by introducing a compact tube made of rare earth fluorescent materials and of a low temperature design. Both the efficiency and quality of light have been improved by developing a three wave enhancing lamp and high frequency electronic ballasts with inverters. Thus, the current fluorescent bulb is 50% more efficient than the conventional fluorescent bulb, and is now almost half of the theoretical maximum for white light, i.e. 220 lumen per watt.[1]

Many other technical factors play an important role in enhancing the efficiency of lighting, e.g. reflecting covers for lamps, cleaning of dust off lamp surfaces, light reflections from ceilings, walls and floors, and automatic lighting control using a sunlight sensor.

### 4.2. Electric appliances in the household

Electricity consumption in the housing sector in Japan has increased rapidly and now represents about one-fourth of the total electricity demand. The rapid growth was brought about by electric appliances such as refrigerators, televisions and air conditioners.

As shown in Fig, 6 [5], the energy efficiency of these electric appliances was improved substantially after the first oil crisis in 1973.

The electricity consumption of freezers and refrigerators was reduced to about one-third that in 1973. This efficiency improvement is the combined result of many design changes, e.g. more efficient compressors and motors, thicker insulation, elimination of various heaters, placing of fan motors outside the equipment, etc. Furthermore, the electricity consumption of refrigerators of larger capacity, which have become more popular as living standards have improved, has been reduced more rapidly than refrigerators of small capacity.

The electric power consumption of colour television sets improved from 140 watt in 1973 to 83 watt in 1985 for the 19–20 inch class.[2] Substantial efficiency improvements were made even before the first oil crisis by using transistors instead of vacuum tubes; as a result, electric power consumption was reduced by about half. Further efficiency improvements were realized by developing circuit elements, from transistors to an integrated circuit, to a large scale integrated circuit to a cathode ray tube (CRT), all of which consume less energy. However, the elec-

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[1] 1 lm = 1 candela × 1 steradian.

[2] 1 inch = $2.54 \times 10^{1}$ mm.

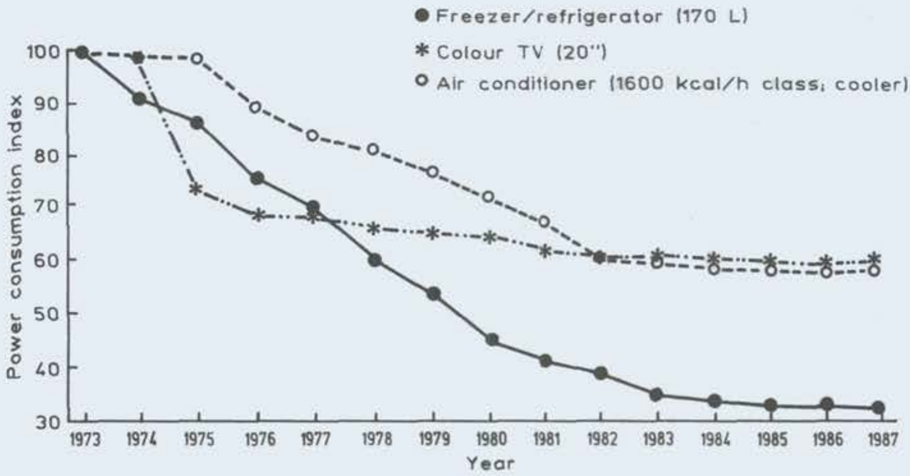


*FIG. 6. Power consumption index of household electric appliances (in watt, except for the refrigerator, which is in MW·h/month) (1973 = 100) [5].*

tricity consumption of televisions is again increasing in Japan because larger sets, of around 30 inch, are becoming popular. Regarding the technical potentials for further efficiency improvements, using a liquid crystal display instead of CRTs, which has been realized in small portable televisions, shows promise but the effects are marginal.

Air conditioners have penetrated Japanese households gradually and are now to be found in 90% of households, except in Hokkaido, where the demand for cooling is extremely low. Almost half of the air conditioners now in use have heat pumps, which are used as coolers in summer and as heaters in winter. Throughout the two oil crises, the electric power consumption of air conditioners was reduced to a level of about 60% that used in 1973 by adopting rotary compressors, improving heat exchangers, etc. Still further energy savings are being promoted through use of microcomputers for fine control and non-stop capacity control using inverters; thus, current state of the art heat pumps are about 20–30% more energy efficient than conventional ones. To insulate housing is considered to be one of the most effective ways of improving efficiency in Japan; only around 20% of the existing houses are insulated, although more than 70% of the newly built houses are insulated.

For other household electric appliances, energy efficiencies were improved after the first oil crisis, for example, the electric power consumption of vacuum cleaners was reduced by 17% during the period 1973–1988. Most of the technical efficiency improvements were achieved in the 1980s, but because consumers still prefer higher performance and larger capacity appliances, the electricity consumption in Japanese households is still increasing substantially. Penetration of modern, efficient electric appliances into new end use fields such as heat pumps for space heating and microwave ovens and magnetic cookers using eddy current for cooking has also contributed to the increase in electricity consumption. Such developments in electric household appliances could improve the overall energy efficiencies and enhance the quality of living.

### 4.3. Advanced heat pumps

In addition to home space heating, heat pump systems have been applied widely through technological developments and their use is spreading rapidly. Heat pumps with energy storage systems, using inexpensive night electricity, are becoming popular for commercial buildings and apartment housing. Large scale heat pumps can supply hot water as well as space cooling and heating. Heat pump systems using urban waste heat, such as warm river water and the exhaust heat of underground substations, are attracting more attention as a viable means of enhancing the overall energy efficiency. Heat pump systems are also being introduced to industrial fields.

Development of the superheat pump accumulation system, which is being promoted as part of the Moonlight Project, the Japanese Government's R&D programme for energy conservation, could make more advanced heat pump technologies available to various fields. Two types of target performance have been set for the superheat pump: one is a highly efficient heat pump with a coefficient of performance (COP) of around 8 and an output temperature of around 85°C; the other is a high temperature heat pump with an output temperature of 150–300°C and a COP of more than 3. The former can be used for air conditioning and for supplying hot water, and the latter for industrial heating.

### 4.4. Motors

Motive power is by far the largest end use service supplied by electricity. The efficiency of the motors themselves is believed to be more than 80% and there seems little room for improvement. According to Tsuchiya [6], however, there are various ways in which losses of energy in motor use can be reduced, e.g. by maintaining the rated voltage, by decreasing idling, by keeping an optimum load, by improving the motor drive, and by controlling the power factor and the speed.

Although mentioned last, control of speed is of greatest importance for efficiency improvements in motor use. Speed or rotation control plays the most essential role in improving efficiency in the driving blowers, fans, and/or pumps used for variable loads. The conventional method of controlling fluid flow is to install a damper in order to adjust the area of flow to load while running a motor at a rated output. Such control of the flow involves much energy loss. These losses can be avoided by adjusting the motor speed or capacity. More efficient methods of adjusting to variable loads are achieved by fluid coupling and frequency control of the motors.

During the period immediately after the second oil crisis, when energy conservation was an urgent target in Japan, inverters were introduced extensively as part of the variable speed devices for both large and medium capacity motors in order to conserve energy in machines handling liquids and gases in the industrial sector. The performance and function of transistor inverters and gate turn-off thyrister inverters have been raised remarkably, and the rotation control systems of induction motors using inverters are spreading the range of application rapidly from manufacturing industries to the transport sector, and then to the commercial and housing sectors. For example, motive power for elevators has been reduced by almost half in a very short time as a result of improved control.

### 4.5. Industrial electric furnaces

Industrial electric furnaces are widely used and have a large potential to save electricity, and the related costs. Improved thermal insulation, fine temperature control and continuous production would certainly contribute to further energy savings. These measures for improving heating efficiencies are realized relatively easily in electric furnaces because electricity is a convenient form for fine control.

For metal smelting, the specific electricity consumption of arc furnaces was reduced from about 500 kW·h/t to about 400 kW·h/t of steel ingot between 1970 and 1985. This energy saving was achieved by oxygen injection, and the other measures described above. In the future, DC arc furnaces with thyrister control could reduce electricity consumption by 5–10% compared with AC arc furnaces. The laser beam is still expensive, but it has a great potential to save energy for spot heating. Mircowave and far infrared rays could improve efficiency by heating and drying directly inside the materials. The effect of these emerging technologies will only be realized in the future.

## 5. PROSPECTS FOR REALIZING THE TECHNICAL POTENTIALS

Development of clean energy sources and efficiency improvements have an absolute value, since the same service is supplied with less impact on the environment and/or less consumption of resources. As stated above, the electricity sector has a large technical potential to develop in these directions. There are, however, various barriers to realizing the technical potentials.

Regarding a clean energy supply, while scrubbing combustion by-products such as sulphur dioxide from flue gases of fossil fired power plants are a matter of economics, the technical option of $CO_2$ removal and disposal is still in the early stages of development. To ensure that nuclear power remains a viable energy option, countermeasures will have to be addressed in order to cope with global environmental issues and worldwide public concern about safety, health risks and nuclear weapon proliferation. To make various solar energies a reliable and substantive energy source, the economic performance of related technologies will have to be improved significantly. The hydropower potential worldwide is still large, but the remaining resources are mostly confined to remote areas. In general, it would take a long time to develop new clean energy sources which can meet global requirements.

Efficiency improvements, on the other hand, appear to show more promise, even within a rather short time horizon. However, many difficulties are present in efficiency improvements. Energy efficiency is among the many factors which are taken into account when entrepreneurs and/or householders adopt a new technology. There seem to be considerable differences between supply side and demand side criteria for adopting technical options in electricity efficiency improvements. For supply side options, cost effectiveness is the most satisfactory condition for adoption, whereas for demand side options, cost effectiveness is only the minimum requirement.

Steady improvements can be anticipated in supply side efficiencies through market forces, but the gains in efficiency improvement are likely to be marginal, since most cost effective improvements have already been realized. On the other hand, to realize in a timely manner the large potential for efficiency improvements in demand side technologies, some intentional incentive schemes such as demand side management should be introduced. Opinions differ on the 'natural' rate of efficiency improvements in energy use.

There are, indeed, several encouraging estimates on the cost effectiveness of demand side options for electricity efficiency improvements. As reported by Fickett et al. [7], there is a huge potential for cost effective electricity savings in the USA. In the estimate made by the Rocky Mountain Institute, nearly one-fifth of the total electricity demand in 2000 can be saved (with benefits) and some three-fourths at a cost of less than 4 cents per kilowatt-hour. The Electric Power Research Institute is not as optimistic: it maintains that about 30% of the total electricity demand can be saved at a cost of less than 4 cents per kilowatt-hour.

However, care should be taken in accepting these cost estimates for electricity savings because many assumptions, explicit or implicit, are involved in making such estimates. For example, the discount rate assumed for cost evaluation may be too low for residential customers, and subtle, but quite sensitive, conditions for selecting end use technologies such as the space for installation may be ignored in the estimate. Besides, there are many barriers other than cost, such as safety, reliability, lack of information, insufficient supply capacity, etc.

The role of electricity in minimizing environmental impacts is quite significant, and the technical potential is large; however, as many policy instruments and as much ingenuity as possible should be mobilized to realize the technical potential. Technological R&D, guided by a commitment to achieve sustainable development, will lead the way to a more efficient and environmentally benign energy system.

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# SUMMARY OF THE DISCUSSION OF KEY ISSUES

## Topical Session 1

*Chairman:* **G. Sánchez-Sierra** (Organización Latinoamericana de Energía) (OLADE)

*Rapporteur:* **K. Leydon** (Commission of the European Communities) (CEC)

*Panellists:* **R. Eden** (United Kingdom)
**J. Eibenschutz** (Mexico)
**H. Khatib** (World Energy Council) (WEC)
**Byung-Jae Lim** (Republic of Korea)
**T. Wilbanks** (United States of America)

A. McKECHNIE (World Bank) (IBRD) noted that S. Kärkkäinen's paper (SM-323/16) had demonstrated the high potential for improving the efficiency of energy and electricity use and had shown both the technical potential for savings and the potential savings which could be achieved at prevailing energy prices. However, it was not clear whether realization of this potential assumed completely rational consumers with perfect information and a greater interest in purchases of energy rather than other commodities. In assessing the level of potential savings it was important to study the behavioural response of consumers to realizing the energy savings potential and to determine what proportion of the feasible savings at a particular level of energy prices was likely to be realized.

S. BOYLE (Greenpeace) noted that in discussing efficiency improvements S. Kärkkäinen (Finland) had used a 5% rate of return on invested capital for electricity suppliers, but a 30% rate for end use efficiency by consumers. Such an approach was bound to lead to a very unbalanced conclusion and also substantially underestimated the economic potential of efficiency. It would be interesting to know what the conclusions of his study would have been if supply and end use had been analysed at a 10% rate of return, as is normally done in true least cost studies and has been done by many electric utilities in the United States of America. With regard to Key Issues Paper No. 1, he believed that the technical potential for efficiency improvement was much greater than indicated in the paper and wondered what assumptions had been made in establishing these figures. In his view, the potential for efficiency improvements was 40–85% for lighting, 25–40% for industrial motors, 40–80% for appliances and 15–40% for most industrial processes.

R. EDEN (UK) welcomed the participation of Greenpeace in the meeting and noted that the discussion would have benefited from a greater presence of environmental groups to ensure that the social and political issues involved in seeking a response to concern about the global environment were not underestimated. He said that Expert Group 1 believed that the best way of slowing down the increase in greenhouse gases was to improve the efficiency of energy and electricity production and use. The Group had considered changes that were likely to be feasible and which had a reasonable chance of success. The Group's analysis suggested that efficiency gains resulting in reduced energy use in industrialized countries would eventually be overwhelmed by the impact of increasing per capita energy demand and population growth in developing countries. The question was therefore whether more radical action should be taken and whether such action would be politically feasible or socially acceptable.

H. FUCHS (Switzerland) pointed out that, in practice, efficiency improvements were governed by a law of diminishing returns. For example, if someone ran 100 metres in 20 seconds, it would be relatively easy to improve the time to 15 seconds, but for most people it would not be possible to reduce the time to 10 seconds.

A. PALMGREN (Finland) said that, according to research performed by the Finnish utility Imatran Voima Oy (IVO) in co-operation with the University of Oslo, the potential for fuel and electrical energy conservation at existing energy price levels was approximately 7–8%, given a payback time of 10 years or less. It was possible that 50% of that potential could be achieved during the present decade without subsidies and without artificial price increases. This conservation level was taken into account in the analysis which had resulted in a forecast of an annual increase of 2–2.5% in electricity consumption in Finland. Analysis of indirect and direct energy use showed that heating and transport were the most promising areas for conservation. Lighting in homes accounted for only 2% of the total energy consumed by individuals and most energy use was indirect, associated with housing construction, foodstuffs, etc.

G.P. HALBRITTER (CEC) *(Consultant)* pointed out that the conclusion reached in Key Issues Paper No. 1 that $CO_2$ emissions would continue to rise until the year 2010 was unacceptable. Mental breakthroughs would be necessary to find unconventional solutions and the assumption of a correlation between the standard of living and electricity demand and the demand for ever increasing electricity generation was too simple for developed countries. He was surprised at the CEC scenarios for the European Community, which suggested that the ratio of final to primary energy demand would decrease in the future. The paper had adopted an approach which was too general and more differentiated electricity scenarios should be developed. Emphasis also seemed to be placed on the residential sector, whereas, in fact, the industrial sector was the main consumer of electricity, accounting for more than three-quarters of the electricity demand. Industrial sectors should be examined individually and the electricity conservation potential analysed in areas such as the production of aluminium and tin foil.

T. WILBANKS (USA) pointed out that most of those attending the Symposium were energy rather than environmental experts and that their job was to ensure that the social and economic development of their fellow citizens was not limited by a shortage of affordable energy. The rising concern about the environment was exerting pressure on energy experts who, on the one hand, were expected to deliver the energy services society needed for its development and, on the other, were being told that many of the options that they would otherwise recommend were unacceptable.

Global environmental change was not just a question of $CO_2$ emissions and power plants were not the only source of $CO_2$ emissions. It was important to retain a proper perspective. Greenhouse gas emissions consisted primarily of contributions from three sectors of the economy — the electrical sector, the industrial sector and the transportation sector. In many cases, industrial emissions were greater than those from power plants and emissions from the transportation sector were nearly as great as those from power plants.

While there was agreement between energy experts and environmentalists on measures such as efficiency improvements, such measures were only of temporary benefit. As H. Fuchs (Switzerland) had pointed out, efficiency improvements were governed by a law of diminishing returns. Ultimately, decisions would have to be made regarding electricity options for the long term in order to provide electricity in large quantities for industrial societies. In his view, choices would have to be made between coal and nuclear power as the two major large scale electricity options, or social changes would have to come about which would make the quality of life less dependent on electricity.

L. HAMILTON (USA) wondered why there was so little long term R&D in the area of energy conservation.

Byung-Jae LIM (Republic of Korea) said that he believed that the characteristics of the mechanisms of a market driven economy made such R&D difficult. In such an economy, a firm's actions were affected by their expected profitability. The profitability of R&D investment in energy conservation involved a high level of uncertainty and risk from the firm's point of view. Consumers were very slow to respond to energy conservation technologies, owing to a lack of information, limited access to capital, etc. Many studies had shown that consumers required very short payback periods for energy efficiency investments and therefore their rates of return were very high. Under such circumstances, it was very difficult for firms to make significant long term R&D investments in the area of energy conservation. Governments should therefore take the initiative and promote energy conservation R&D investment by providing incentives and subsidies and by making regulatory changes.

E. MARSHALL (UK) wondered whether it was possible to develop further the work on electricity supply and demand to include costs and the availability of finance. Without work in this area, it seemed unlikely that the necessary impact could be achieved to affect policy making and to establish a clear list of priorities and choices.

J. EIBENSCHUTZ (Mexico) said that given the difficulties faced by developing countries in obtaining resources to meet their requirements for energy, which was fundamental to achieving development, a change in the world's financial structure was necessary. Industrial sectors in developed countries were suffering from lack of work, while developing countries were suffering from lack of resources and had to import many of the goods they required. The developments in Eastern Europe had caused financial institutions and donor countries to overstep their normal limits in order to support the new political and social structure in Eastern Europe. Perhaps a similar approach would have to be adopted for developing countries, which had no reason to change their economic system but would require economic assistance for their development.

Another handicap which developing countries had to face was pressure from the international community, and particularly intergovernmental agencies, to minimize the environmental impact of energy production. The potential efficiency of investments to reduce environmental impacts in developing countries was much higher than that in developed countries, which had already lowered their emissions to a relatively reasonable level. Environmental problems affected mankind in general and should be treated on a global rather than on a local scale and resources allocated accordingly so as to ensure maximum overall efficiency.

H. KHATIB (WEC) noted that a survey carried out to assess the response of all countries of the world to environmental problems showed that global environmental problems did not figure high on the list of priorities of developing countries, which were more interested in meeting their day to day needs. Developing countries lacked two basic ingredients for dealing with environmental problems, namely availability of capital and availability of know how. A global fund should therefore be established to channel investment and technology to those countries most in need of it in order to enable them to deal with environmental problems. Assistance should be provided on a cost–benefit basis so that it would be given to countries which could use the money to achieve the highest environmental benefit.

K. KING (World Bank) (IBRD) noted that there was a distinction between domestic and global environmental impacts. Key Issues Paper No. 1 had placed emphasis on the global impact, whereas the other Key Issues Papers dealt more with domestic impacts. Most countries, particularly developing countries, were likely, as H. Khatib (WEC) had pointed out, to focus their attention on urgent domestic and, perhaps, regional impacts resulting in benefits to the country concerned, and only then would they consider the contribution they could make to improving the global environment by reducing $CO_2$ emissions. It would therefore be useful for Key Issues Paper No. 1 to include a scenario which showed what the $CO_2$ reductions would be if countries focused on their domestic requirements and what domestic cost implications and trade-offs would be involved if they made an additional contribution to the global environment by reducing $CO_2$ further.

J.C. GEIDL (USA) noted that Table II of Key Issues Paper No. 1 indicated that proven world coal reserves amounted to 723 billion ($10^9$) tonnes of oil equivalent, with a reserve/production ratio of 230 years. While the text defined reserves as economically recoverable resources, it did not clarify that coal reserves were further limited by the accessibility, the depth of the coal deposit, the seam thickness and the environmental constraints on the recoverability, as in the case of coal reserves situated under river beds or cities. In addition, the production and marketability of certain qualities of coal were limited by environmental constraints on the $SO_2$ and $NO_x$ emissions. In view of those constraints, a more careful calculation needed to be made of recoverable coal, taking into account location and quality. Although there were abundant coal reserves in the world, up to date information was lacking on recoverable reserves. The reserve/production ratio might in fact be significantly less than 230 years.

C. BURNHAM (Canada) wondered whether there were sufficient natural gas reserves to accommodate the scale of fuel substitution suggested in Key Issues Paper No. 1 and whether estimates had been made which compared the potential reserves with the projected consumption of natural gas. Since use of natural gas at the point of use, for example in the case of space heating, was more efficient than use for electricity generation, natural gas should perhaps be conserved for uses other than electricity generation.

R. EDEN (UK) said that Expert Group 1 had recognized the current growth in the use of natural gas for electricity generation and the consequent benefits resulting from lower emissions and improved efficiencies. While the Group did express some uncertainty about the extent of natural gas reserves and resources, the major oil and gas companies took the view that actual resources of natural gas were probably much larger than the current proven reserves. It was therefore possible that natural gas could remain a substantial contributor to electricity generation for at least the first half of the 21st Century, and possibly for longer. With regard to the way in which it could best be used, there were difficulties in assessing efficiency at the point of use. For example, in the domestic sector, if a house was highly insulated the cheapest way to heat it was by electricity, because the capital costs were so much lower than the capital costs required to bring natural gas into the house.

H. KHATIB (WEC) agreed with R. Eden (UK) that while, in contrast to oil, there were prospects for discovering large reserves of natural gas in the future, gas was cumbersome and expensive to transport. One of the best ways of transporting gas was normally to convert it into electricity at the well site and then to transport it as electricity to the consumers. It was in the majority of cases the most economical and the cleanest way of using natural gas.

J. ESCUDERO (Spain) noted that Key Issues Paper No. 1 predicted that new and renewable sources of energy would play only a very small role in the future. This prediction was based on past and present experience and could be misleading, since energy prices were currently low for political reasons and they also did not internalize environmental costs. Once the real price of energy was recognized and environmental costs internalized, it was likely that there would be strong incentives to develop, improve and introduce new and renewable energies, resulting in possible, as yet unforeseen, breakthroughs.

T. WILBANKS (USA) said that exciting developments were taking place in the area of renewable energy options: photovoltaic cell manufacturers worldwide were producing at full capacity; commercial use of wind power was expanding rapidly; and biomass energy technology was perhaps the most promising area in which major breakthroughs could occur during the course of the following decade. However, the percentage share of renewable energies in total electricity production remained very small. Given the continuous increase in total electricity production, use of renewable energies would have to grow very rapidly in order for their share of total electricity production to increase substantially.

Increases in energy prices would help to make renewable energy technologies more competitive, but they would also make efficiency improvements more attractive. In many countries, substantial increases in energy prices, in order to make energy options more competitive, would face social and political opposition, since higher energy prices would be linked with a reduction in the quality of life. Whether or not prices rose substantially, the use, competitiveness and technological attractiveness of renewable energy options would increase. However, a large scale increase in their share of total electricity production from some 2–3% to 20–30% was difficult to envisage at present.

L. D'ANDREA (Economic Commission for Europe) (ECE) wondered what the prospects of promoting electric vehicles were and whether more could be done by the international community, through governmental and non-governmental organizations, to promote this form of transportation.

T. KANOH (Japan) added that, within the OECD, fuel switching (in final energy consumption) from oil to electricity had been implemented in the industrial and residential sectors since 1973. However, in the transportation sector the share of oil products was still 99%.

R. EDEN (UK) said that he believed that electric cars, possibly with hybrid systems, could reduce local environmental pollution and possibly greenhouse gas emissions and that in southern California legislation on the local environment could lead to a substantial growth in the use of electric cars there. Although use of such cars was likely to involve higher costs to the community, which could not be met in less wealthy parts of the world, if they were used successfully in southern California their economic efficiency should improve and they could become more widespread. The second transport area which could benefit from increased use of electric vehicles was public transport in cities. Their use could reduce the pollution resulting from the current inefficient use of private cars in crowded cities.

G. SANCHEZ-SIERRA (OLADE) (*Chairman*) noted that while electric vehicles were an excellent alternative from the technical point of view, their development was not a financially feasible option for developing countries. Since such development would be a good way of reducing $CO_2$ emissions, it would be an ideal area for international co-operation and for industrialized countries to demonstrate their commitment to reducing $CO_2$ emissions.

As a final remark on a more general note, he said that while discussions had focused on technical and economic aspects, public acceptance was an aspect which should not be forgotten. It was a problem faced in different ways by both industrialized and developing countries. Industrialized countries had the financial resources and willingness to pay for the buildup of new power plants, but they encountered major problems of public and political acceptance. In developing countries, there were generally no political difficulties associated with the construction of power plants, but there was a lack of financial resources and therefore an unwillingness to pay. In both cases, there were problems associated with the user, in other words of public acceptance.

J.C. GEIDL (USA) noted that, in discussing supply options that did not emit greenhouse gases, Key Issues Paper No. 1 failed to make any reference to solar thermal energy as a source of electricity. In the USA, 900 million kW·h/a was currently being produced from solar thermal energy without any subsidies and a growth rate of 10% per year was projected up to the year 2010.

R.W. MORRISON (Canada) pointed out that rather than focusing, as Key Issues Paper No. 1 did, on the chain of logic suggesting that wealth created increases in electricity demand, which led to additional adverse impacts on health and the environment, it would be useful to consider that electricity created wealth, in the sense of information, technology and communications, and that such wealth had a beneficial impact on health and the environment.

J. MURRAY (Uranium Institute) felt that it would be useful to know what percentage of the world's population was served by grid electricity and what percentage had no access to electricity. With regard to efficiency improvements in the domestic sector, it would be interesting to know whether refrigerators which did not involve carbofluorocarbons would use substantially more electricity.

P. MATHIEU (Belgium) considered that it would be useful to know the percentage contribution of power plants to global $CO_2$ emissions. In developed countries, cars and domestic appliances produced major amounts, not only of $CO_2$ but also of other pollutants. It would be interesting to know the ratio between $CO_2$ emissions resulting from electricity production and total $CO_2$ emissions in European Community countries. Before establishing regulations, it was important to identify the target. Attention should also be given to the problems of $N_2O$ emissions, which made additional contributions to the greenhouse effect.

# ENERGY SOURCES AND TECHNOLOGIES FOR ELECTRICITY GENERATION

**(Topical Session 2)**

**Chairmen**

**Y.I. PETRYAEV**
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# CHAIRMAN'S REPORT

# ENERGY SOURCES AND TECHNOLOGIES FOR ELECTRICITY GENERATION

## Key Issues Paper No. 2

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## 1. INTRODUCTION

International Expert Group 2, which I had the pleasure to chair and guide through more than 1 year of discussion, was assigned by the Joint Steering Committee the objectives to 'provide information on present electricity generation technologies and available options in the light of their economic, environmental and technological characteristics to assist those involved in planning and decision making in the electricity sector'. This objective was articulated along more specific tasks, such as:

(a) To define the status and prospects of electricity generating technologies along a 30 year time perspective
(b) To gain insights on how power generating technologies can achieve changing and emerging environmental objectives
(c) To determine which technologies for electricity production and supply will become economically viable
(d) To define the non-technological and non-economic factors that may influence market penetration
(e) To suggest what can be done to accelerate technology innovation and to improve technology availability, in particular with regard to the needs of developing countries.

Clearly, given the complexity of these tasks, it was not possible to find exhaustive answers. The Group rather sought to debate the major problems and to agree on some basic issues, part of which can also be proposed for further analysis and investigation.

One of the advantages of electricity as an energy form is that it can be generated from a wide variety of possible sources. Solid fuels, natural gas, oil, nuclear and hydro represent practically all the electricity produced in the world today, since other renewable energy sources only have a minor share, although their contributions may be significant at the local level. There will be a need to continue augmenting power generation and supplying options over the next decades because of the expected growth in electricity and the need to replace retiring plants. With new demand requirements, efficiency gains will not be sufficient to cope with base, medium and peak conditions as load shapes vary. Changing and emerging environmental concerns also require new investments but they introduce technological risk, complicate facility siting and generally increase costs.

The growing demand for electricity services and the environmental challenges create pressures for technology innovation on several fronts. As the construction costs of power plants over the next decades are likely to run into hundreds of billions of dollars, and as electricity markets are becoming more competitive in many areas, there is pressure to produce power more economically. As environmental regulations cope with concern about urban smog, ozone depletion, acid rain and global climate change, there is pressure to produce power with lower emissions of particulates, nitrogen oxides, sulphur dioxide and carbon dioxide. Economic and environmental pressures will not only require that utilities build new plants as cheaply as possible, but also that they upgrade and extend the performance of existing plants, and that they engage in aggressive programmes of demand side management.

## 2. STATUS AND PROSPECTS OF POWER GENERATING TECHNOLOGIES

Several taxonomies can be proposed to classify power supply options, but it is easy to argue that options for the future will still build upon the three broad categories of fossil fuels, nuclear energy and renewable energy sources, including geothermal energy. In particular, coal reserves are very large, and will be adequate to meet almost any conceivable level of consumption for periods measured in centuries, while world coal prices may remain relatively stable. Thus, given the availability of well established conversion technologies, coal will not be displaced easily from electricity generation. In developing countries, for instance, coal use is likely to increase significantly in the coming decades. As the narrowing of the gap between coal and oil prices and coal and natural gas prices shows signs of persisting longer than was generally forecast a few years ago, the future role of coal has begun to look less secure. Adding to this stress in some countries are those pressures associated with requirements to meet ever stricter environmental regulations. A major challenge, therefore, is to develop and promote deployment of techniques for using coal more efficiently and with reduced environmental impacts, the 'clean coal' or 'advanced coal' technologies.

I will not talk about oil, although fuel oil may continue to play a significant role in power generation for a number of utilities and countries. Natural gas use for power generation is expected to increase rapidly throughout the world, partly due to environmental concerns. Natural gas reserves will be able to sustain current consumption rates for several decades, and their rate of growth gives reason to be optimistic about the future availability of gas to satisfy expanded uses. However, large scale switching from coal to natural gas for electricity generation may be difficult to achieve in the long term. In fact, such fuel switching in the electricity sector could have the potential effect of diverting natural gas from other uses. Eventually, many of the power plants initially fuelled with natural gas may have to switch to gas produced from coal.

In the case of nuclear energy, the experts observed that there are no concerns regarding the uranium resource base. The resource base is also large for renewable energies. In particular, the solar and wind resource base is immense, being larger than the total world energy demand. It is dispersed, however, and often requires tremendous technological effort to concentrate it.

The changes in fossil fuel technology for power production, in particular for coal, are increasingly driven by the need to reduce the costs of complying with heightened environmental requirements. As a result, the environmental performance criterion in power plant design can be given an importance equivalent to the engineering criteria of thermal efficiency and reliability. Increasing concern about the environment has led to requirements for plants to emit fewer pollutants, either by retrofitting and refurbishing already existing power plants, or by developing new combustion technologies.

Future steam power plants may also consist of systems that integrate pollution control into the combustion process, rather than by adding scrubber systems for post-combustion removal of the pollutants from the flue gases. For example, fluidized combustion permits the burning of a wider variety of coals and lower grade fuels than is possible in conventional pulverized fuel power plants.

New developments concern the use of natural gas in combined cycle power plants that have a gas turbine with a steam turbine. Other advanced cycles could be deployed over the next decades, including magnetohydrodynamic conversion and fuel cells. Natural gas adoption for power generation may also prepare further coal use through the coal gasification route.

Nuclear power is a proven electricity generating technology that emits no sulphur dioxide, nitrogen oxides or greenhouse gases. Virtually every nuclear power plant in free market countries has operated safely. Most active nuclear power plants worldwide use ordinary water (light water) to remove heat from the nuclear reactor. Improved light water reactors are under construction, while advanced evolutionary designs for water cooled reactors which will benefit from the lessons learned in operating today's nuclear power plants are currently under development.

There is broad public consensus on the need to solve the nuclear waste problem and strong scientific and technical agreement on the approaches to be used in order to cope with it. Several evolutionary reactor designs that are already on the drawing board feature passive safety systems. These systems will minimize the need for the operator to intervene in the event of an accident or breakdown. They will use certain physical properties of materials, along with gravity to remove heat automatically in an emergency, thus reducing the likelihood of human errors and better ensuring an emergency response. Simplified engineering designs, lower construction costs and a generally reduced size of the power plant will ensue. In addition, it is expected that more advanced next generation nuclear reactors will come on line towards the end of the time period considered; these nuclear reactors may bring other advantages such as cost, operation, fuel use and versatility of application. Nuclear fusion power applications, however, are likely to take a much longer time.

Use of new renewable energy sources for power production has made significant progress over the past 10–20 years. Renewable energy technologies generally contribute little or no environmental pollution. Burning municipal waste reduces the need for, and the problems associated with, landfill space. As emerging renewable energy sources such as wind and solar power become cost effective, renewable energy use would penetrate more broadly into the electric grid. Mature renewable energy technologies such as hydroelectricity and geothermal power will continue their progress, although in several cases their application could be constrained by excessive regulatory requirements as well as environmental concerns.

## 3. HOW TO ACHIEVE THE CHANGING ENVIRONMENTAL OBJECTIVES

Growing environmental challenges will create greater incentives to develop and deploy new innovative technologies. Public concern is growing and there is an increasing base of scientific knowledge on the seriousness of the threat to the environment. In addition, several environmental dimensions, embracing air and water pollutants, solid waste disposal, radioactive wastes and other vectors, have clearly been recognized. An important issue appears to be the search for an integrated approach to total waste minimization and the optimization of total resource use, including the material and land requirements.

As a consequence, technology improvements and 'add on' equipment would not provide the solution, and development of new technology trajectories may be required. The entire fuel cycle and life cycle of the power plants, with their environmental impacts, are becoming important. At the same time, development and deployment of technologies are increasingly coming under the scrutiny of the public and this, in itself, creates greater pressures.

In environmental terms, most fossil fuel technologies have the serious drawback of producing substantial amounts of air pollutants, and there is a large amount of solid waste in the case of coal. The most notable air pollutants are nitrogen oxides, sulphur dioxide and carbon dioxide, which are believed to contribute to acid rain and global warming. Significant reductions can be achieved by switching fuel from high to low carbon emitting sources, and through progress in conversion efficiencies.

Through using more advanced technologies, particularly fuel cells, air pollutants can be reduced significantly, or even eliminated. A reduction in carbon dioxide within the time-span of the study is most likely to be achieved through increased thermal efficiency.

Nuclear power and its fuel cycle produce radioactive wastes in which there are varying degrees of contamination from a range of radioactive isotopes. The problems of managing and disposing of this waste are most demanding for high level waste, which results from the reprocessing of spent fuel, or by the decision in some countries to dispose of the spent fuel itself.

Several renewable technologies offer an alternative path for reducing air pollution at the plant level, e.g. solar, wind, wave, ocean thermal and tidal power, but in general the amount of solid waste is very limited if compared with fossil fuelled power plants. Nevertheless, land requirements could be substantial, especially with solar and wind power generation.

With enhanced awareness of the environmental impact, we increasingly face the phenomenon that 'nobody wants power stations but everyone wants electricity'. Policy makers, regulators, utilities, engineering companies and equipment manufacturers will have to be more sensitive to public concerns. To meet future electricity requirements, there will be a need for integrated technology policies which promote environmental protection and energy security. The traditional approach of seeking to produce plentiful and cheap electricity needs to be reconciled with the heightened awareness of and desire for environmental quality associated with electricity generation. There are no technological 'saviours' in sight over the next 30 years or so. No ultimate solutions that can cope with all the environmental concerns will be available, because no technology is impact free.

Increasing evidence of the risk of global warming and climate change makes urgent the definition of a technology response. In the short to medium term, electric utilities will find it very difficult to implement, on a large scale, actions for an accelerated reduction in carbon dioxide emissions without incurring high costs and market distortions. In the absence of revolutionary breakthroughs that totally replace fossil fuel use, the key elements of an interim 'technology' response strategy will include upgrading the efficiency of existing fossil plants, expanding the use of natural gas in new plants, deploying improved and advanced nuclear power plants, expanding the use of hydropower resources, promoting other renewable energy sources where economically viable, and accelerating investment in cost effective measures for demand management and end use efficiency improvement. It would be especially beneficial to close the large efficiency gaps among countries and, in particular, between industrialized and developing countries. Such an interim strategy, utilizing cost effective technologies that are generally worth applying irrespective of global environmental benefits, will 'buy time' for further R&D on carbon free and low carbon technologies. In the longer term, the generating capacity may be dominated by nuclear power plants, renewable technologies and innovative fossil fuel technologies with low emissions of greenhouse gases. Direct recovery and disposal of carbon dioxide from stack gases could be a long term option, but its economic prospects and timing are very uncertain.

## 4. ECONOMICS OF ELECTRICITY GENERATION

The cost–benefit ratio of electricity generation technologies will remain the key element in the choice among generation options. Clearly, the relative values of these ratios for the different technologies will vary according to the regulatory regime. In the economic analyses of the Group, technologies were compared on a single cost reference basis, without regard for international differences in systems of taxation and finance. The representative technologies were idealized, although it is apparent that site conditions and utility preferences will impact power plant design and generation costs.

As a result of the economic analysis it appears that:

(a) Fossil fuelled power plants will continue to have a future, but emphasis will be placed on clean coal technologies and natural gas systems. Advanced options will become cost competitive, with the progress being made in the reduction of waste and conventional pollutants and the increase in conversion efficiency. Near term technology options refer to the use of natural gas for power production, which is expected to expand rapidly. This natural gas growth trajectory is coupled with the fact that most current techniques and technologies for producing, transporting and converting natural gas into electricity appear to offer ample capacity for technological innovation.

(b) Nuclear power is the most likely non-fossil source which can be adopted on a much larger scale and with costs that are competitive with fossil fuels for base load generation. Technological innovation would improve the economic prospects.

(c) Large scale cost effective adoption of new renewable energy sources for base load power generation still appears to require considerable development. The economics of photovoltaic, solar thermal and wind power systems for electricity generation will augment enormously over the next decades, but they will still be expensive. With successful R&D, these technologies may be able to produce competitive electric power at optimum geographical locations. In this case, they may supply peak power in conjunction with fossil or nuclear base load plants, or displace scarce fuels by providing a secure energy option. As a stand alone alternative to fossil or nuclear plants, these technologies would require energy storage which significantly increases the costs. There remains a potential for economic breakthroughs, particularly in photovoltaic. However, use of hydropower and geothermal energy is already cost effective in many situations and would remain so, depending on the availability of the resources. A promising case is offered by biomass and urban waste; such sources could provide a small fraction of electricity in industrialized countries but a significant fraction in developing countries. Advances in biomass conversion and use would combine with reversing land clearing trends.

## 5. OTHER FACTORS THAT INFLUENCE MARKET DEVELOPMENT

Power generators and industry face dynamic market conditions, which will require a variety of technology and response options. The varying market conditions that have been addressed include: the size of the customer base, the expected rate of growth in electricity demand, the level of competition, the rate of retirement of existing capacities, the need to meet changing load curves and the ability to access adequate capital for capacity expansion.

Markets must ultimately determine the most economic mix of electricity supply options. In principle, competitive markets ensure economic efficiency and provide the best context to promote technological innovation. Regulations should be reformed that unnecessarily impede the development of electricity sources and that reduce the ability to respond to changing conditions. Public participation and environmental safeguards should be sought, while duplicative or cumbersome regulatory procedures should be eliminated.

Along these lines it can be assumed that in some industrialized countries electric utilities will increasingly be evolving over the next decades, from being supply only oriented entities which build and maintain large electricity production facilities, to supply co-ordination and service oriented electricity organizations in which the cost of expanding or replacing generating capacity is balanced against the cost of increasing the efficiency of both supply and end use. Consequently, the number of technology and response options will rise.

Security of supply is, and will remain, an important factor in the adoption of technology solutions, not so much for electric utilities as for governments and regulators. Energy source diversity would decrease supply vulnerability, while technological diversity would allow a closer match of capacity with the load curve, thus minimizing the resource use. This strategy includes the introduction of energy efficient power systems such as co-generation and fuel flexible plants. Yet, local and regional situations are encountered which may require the use or adaptation of special technologies because of the physical constraints, limits on available investment capital, unique resource endowments, and political and regulatory frameworks.

To cope with the wide range of environmental concerns, electric utilities will often find that new technologies are more expensive than traditional technologies. The cost issue is particularly urgent for renewable power options which, in many cases, are several times more expensive than conventional options per kilowatt-hour of electricity produced. The cost of a number of renewable energy technologies will be significantly lowered through continued development efforts, but the answers to how far and how soon are fairly uncertain. Cost may also be a significant issue for nuclear power in a number of countries, as regulatory uncertainties, lack of standardized designs and uncertain costs for waste disposal and plant decommissioning have, in some cases, led to widely varying estimates. Furthermore, cost is a major uncertainty for gas fired power, which may be relatively less expensive to build but could prove quite costly to run if gas prices were to rise more rapidly than expected.

## 6. HOW TO ACCELERATE TECHNOLOGY INNOVATION AND IMPROVE TECHNOLOGY AVAILABILITY

Over the next three decades, a diversified technology development and deployment strategy will have to be pursued in order to forecast the market. Electric utilities throughout the industrialized world as well as in the developing world will face a number of common problems: heavy capital cost burdens, rising fuel prices and increasingly stringent environmental regulations. Solutions to these problems will require improved power system efficiency, increased unit modularity and standardization, diversification of fuels, management of energy demand and better pollution control. Meeting these ends in a world of uncertainty will require the development of a wide variety of technologies because only with a broad technology base will utilities have the flexibility to respond in a cost effective manner to changing market conditions and regulations. In this context, it is important to note that no single technology will be the best choice for every situation, since the cost and availability of energy sources will vary on a regional and national basis.

It also appears appropriate for the electricity generation sector to pursue several strategies, including:

(a) Vigorous development of advanced technology that offers the potential of significant new capabilities for the electric industry at an affordable cost and an acceptable level of environmental impact
(b) Increased emphasis on total power system concepts and technological synergisms at the power system level
(c) Joint efforts to reduce barriers to technological innovation and to modify the institutional and regulatory constraints which impede it
(d) Additional enhancement of market size and deployment opportunities through increased technical and regulatory standardization, system interconnection, technology transfer of experience and best practice information (both nationally and internationally), and public education and awareness programmes.

As a result, there is a significant and challenging opportunity for governments and electric utilities to collaborate in the implementation of a transition to a new era of power generator technologies, and to assist each other, and newly industrializing nations and transitional economies, in minimizing the pitfalls and maximizing the benefits of such a transition. Governments and regulators need to implement creative measures that will overcome some of the deployment barriers in order to ease the introduction of new, environmentally appropriate generating technologies. A regulatory framework should be designed to give utilities better signals on where to invest and to appraise the total life cycle costs as well as the social costs of the facilities.

To meet both medium and long term objectives, there should be a balance among research, demonstration and deployment strategies. This is essential, both to ensure application of new and improved electricity generating systems and to facilitate their prospects for commercialization. Co-operation among utilities, engineering and equipment industries, regulatory agencies and research centres is a key element. This includes more interaction among utilities themselves and between utilities and governments, suppliers and consumers.

On the other hand, enhanced international co-operation in R&D and technology transfer is needed to facilitate implementation of the most efficient electricity generation systems. The need for international co-operation is increasing because of the global character of many of the problems as well as the opportunities facing the electric sector and the internationalization of technology markets. Because adoption of new technologies may provide global and regional benefits, it is in the interests of the industrialized world to assist this process in whatever form it deems most appropriate. Ad hoc international mechanisms for information exchange and technology transfer should be established to fill gaps, especially in the fossil fuel and renewable energy areas. It should be stressed that there are no 'low grade' or second class technologies prepared especially for developing countries. Rather, effective technology transfer, equity investments and adherence to free market principles should provide developing countries with more opportunities of deploying environmentally appropriate technologies from the beginning, or of modifying and retrofitting existing plants.

However, the rapid growth in demand for electricity services in developing countries requires special action. Rapid growth combined with lack of access to adequate capital may lead to less than optimal options being deployed. There is a need to close the gap between the state of the art in industrialized countries and the technologies currently being deployed in developing countries.

## 7. CLOSING REMARKS

Electricity is clean, convenient and flexible at its point of use. These benefits are gained at the expense of concentrated environmental impact, complex technology and high cost investment in fixed facilities at the point of production. Conversely, the pace of deployment of new technology in the electricity industry is subject to a fragile agreement among buyers, suppliers and the public that such actions are in the shared interest and should be encouraged. Changing economic and environmental requirements are placing greater stress on investment decisions. Changing patterns of demand growth, combined with growing application of demand side and grid management, make both the forecasting of load and the financing of large new capacity units more difficult.

Despite these issues and problems, or perhaps because of them, the electric supply sector is seeing the emerging availability of an unprecedented diversity of alternative fuel supplies and systems. Market forces must ultimately determine the most viable technologies that are likely to co-exist and share markets, since no single approach is likely to be the most appropriate for the needs and resources of different nations, or even across different regions of the same country. Opportunities for improvement exist in every area, both now, in the medium term and for the longer term future. We should be able to take advantage of them.

Finally, I want to express my gratitude to all the experts who contributed to the work that we accomplished and the findings.

# TRENDS IN RESEARCH AND DEVELOPMENT OF ADVANCED FOSSIL FUEL TECHNOLOGIES FOR ELECTRIC POWER GENERATION

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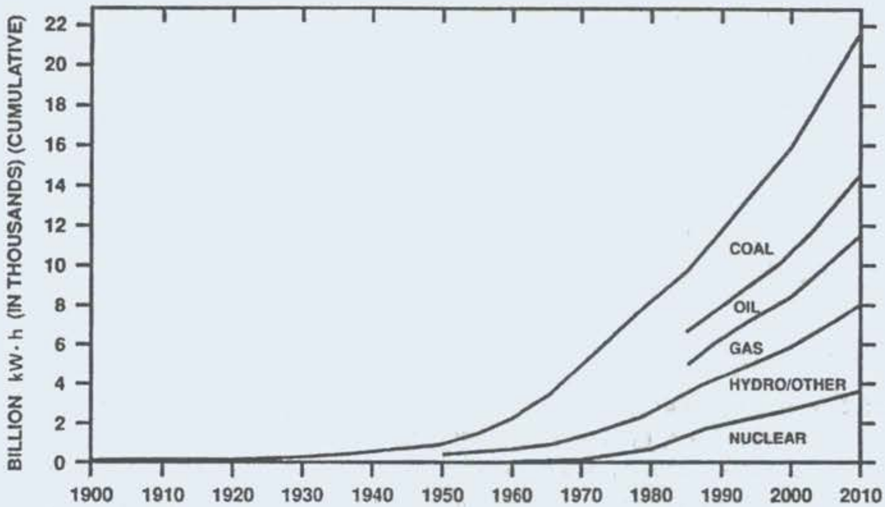
**Abstract**

TRENDS IN RESEARCH AND DEVELOPMENT OF ADVANCED FOSSIL FUEL TECHNOLOGIES FOR ELECTRIC POWER GENERATION.

Since the end of World War II, lectrical generation has increased dramatically worldwide. Today total world electricity generation is about 12 trillion kW·h, approximately two-thirds of it generated by fossil fuels. By the year 2010, world electricity generation is expected to be greater than 20 trillion kW·h per year, with almost 14 trillion kW·h of that generated by fossil fuels. The situation in the United States of America is even more dramatic. Fossil fuels account presently for over 70% of the energy input for US electricity generation, which in 1991 amounts to almost 3 trillion kW·h. Coal provides about three-fourths of the fossil fuel contribution. If no energy policy changes occur, by the year 2010 in the USA over three-fourths of all electricity generation will be fuelled by fossil fuels. As a corrective measure in the USA, a National Energy Strategy (NES) has been proposed that, if enacted, will change US energy policies by reducing somewhat the expected US annual electricity requirements. The NES also forecasts a larger role for nuclear energy and for renewables for US power generation needs, with less emphasis on the use of fossil fuels because expected growth in the use of fossil fuels raises concerns about possible health and environmental effects. However, the switch to new efficient and environmentally superior electricity generating technologies will permit growth while ensuring that the environment is protected. The purpose of the paper is to provide an overview of the new advanced technologies for power generation and to describe natural gas based as well as coal combustion and coal gasification technologies.

## 1. INTRODUCTION

For many decades, fossil fuels have provided the major energy supply for world electricity generation. As shown in Fig. 1, since the end of World War II, world electrical generation has increased dramatically. In 1950, world electricity generation amounted to only about one trillion kW·h, about one-half of that generated hydroelectrically and about one-half generated using fossil fuels (coal, oil and

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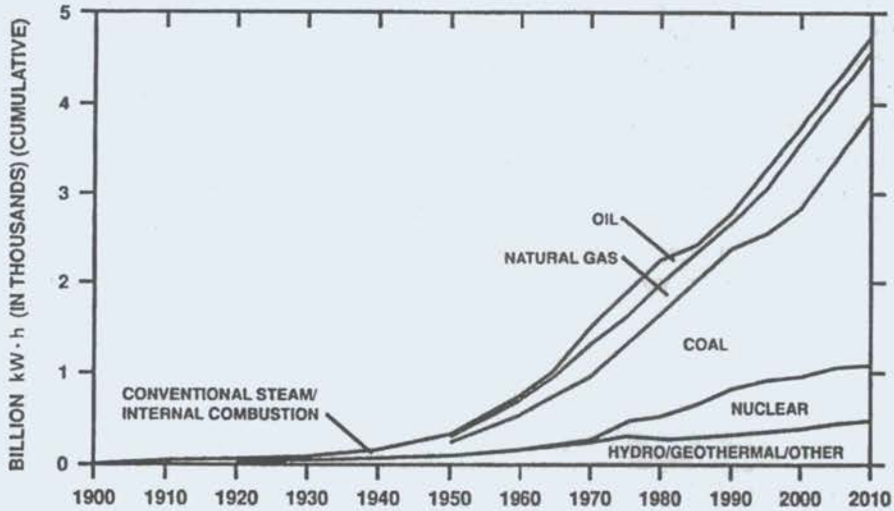
2000-2010: US DEPARTMENT OF ENERGY PROJECTIONS, 3.1% ANNUAL GROWTH.

*FIG. 1. World electricity generation (1900–2010).*

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1990-2010: NATIONAL ENERGY STRATEGY, FINAL CURRENT POLICY CASE, US DEPARTMENT OF ENERGY, 1991.

*FIG. 2. Electricity generation by electric utilities (USA) (1902–2010).*

natural gas).[1] Today, about 40 years later, total world electricity generation is about 12 trillion kW·h, approximately two-thirds of it generated by fossil fuels. In the next 20 years, we can see that not only does projected world electricity generation rise, but the rate of increase will escalate as well. By the year 2010, world electricity generation is expected to be greater than 20 trillion kW·h annually. Of that, almost 14 trillion kW·h will be generated using fossil fuels, with coal accounting for almost one-half of the fossil fuel contribution.

In the United States of America, the situation is even more pronounced. As shown in Fig. 2, US electricity generation has increased from less than 500 billion kW·h in 1950 to almost three trillion kW·h in 1991.[2] By the year 2010, if there are no changes in current energy policies, US electricity generation is expected to be greater than 4.5 trillion kW·h. Fossil fuels presently account for over 70% of the energy input for US electricity generation, with coal being about three-fourths of the fossil fuel contribution. If no energy policy changes occur, by the year 2010 the disparity between fossil fuel and non-fossil fuel electricity generation in the USA will be enormous — over three-fourths of all electricity generation will be fuelled by fossil fuels, with coal accounting for almost 80% of the fossil fuel contribution.

As a corrective measure, a National Energy Strategy (NES) has been proposed that, if enacted, will change US energy policies. As shown in Fig. 3, the NES would somewhat reduce expected US annual electricity generation requirements to about four trillion kW·h by the year 2010, with greater effects in subsequent decades. In addition to lower generation requirements, the NES also forecasts a larger role for nuclear energy and for renewables for US power generation needs, with corresponding lower emphasis on fossil fuels. As shown in Fig. 4, by the year 2030 under the NES, energy input to electricity generation from coal would be about 27 quadrillion Btu versus about 50 quadrillion Btu under the current policy.[3]

The large expected growth in the use of fossil fuels for electricity generation in the foreseeable future raises concerns about possible health and environmental effects, and also about the impact on global warming. However, the switch to new, highly efficient and environmentally superior electricity generating technologies as they become available will allow the growth to take place while ensuring that the environment is protected.

The side benefits from the use of these new technologies are not insignificant. New market opportunities will be created that will benefit both the technology developer and local industry that will supply manpower for construction and subsequent operation. New industries will be created to market useful materials and chemicals recovered as by-products that formerly were waste streams or sources of

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[1] 1 trillion = $10^{12}$.

[2] 1 billion = $10^{9}$.

[3] 1 Btu = $1.055 \times 10^{3}$ J; 1 quadrillion = $10^{15}$.

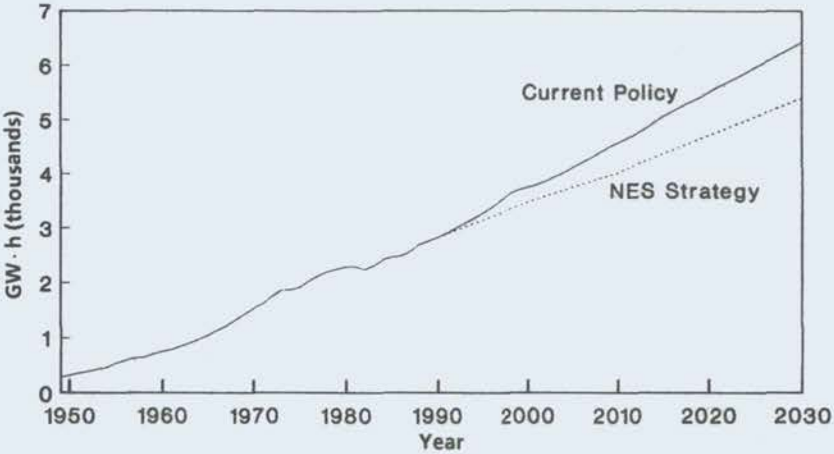


*FIG. 3. Electricity generation (USA) and the National Energy Strategy (NES) scenario.*

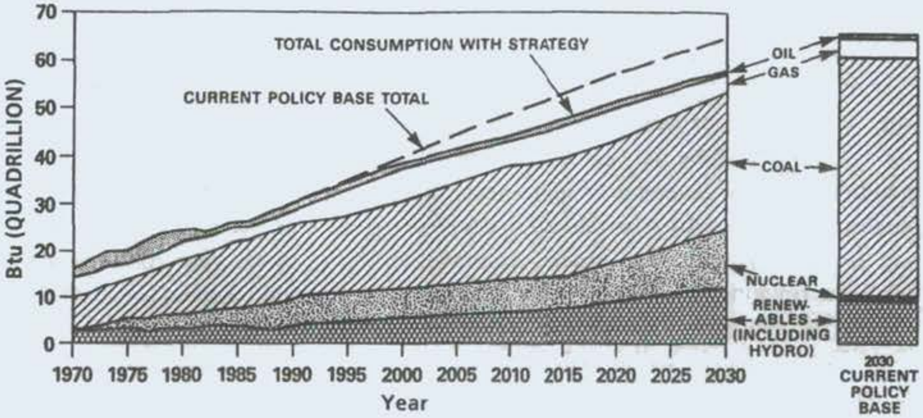


*FIG. 4. National Energy Strategy projected changes in the mix of fuels used to generate electricity.*

pollution. Ongoing research and development to further improve these technologies as time goes on will strengthen the technological base of all countries involved.

The purpose of this paper is to provide an overview of the new, advanced technologies for power generation. The remainder of this paper will describe natural gas based technologies such as steam injection cycles and fuel cells, coal combustion technologies such as atmospheric and pressurized fluidized bed combustors, and coal gasification technologies such as combined cycle systems and gasification/fuel cell systems.

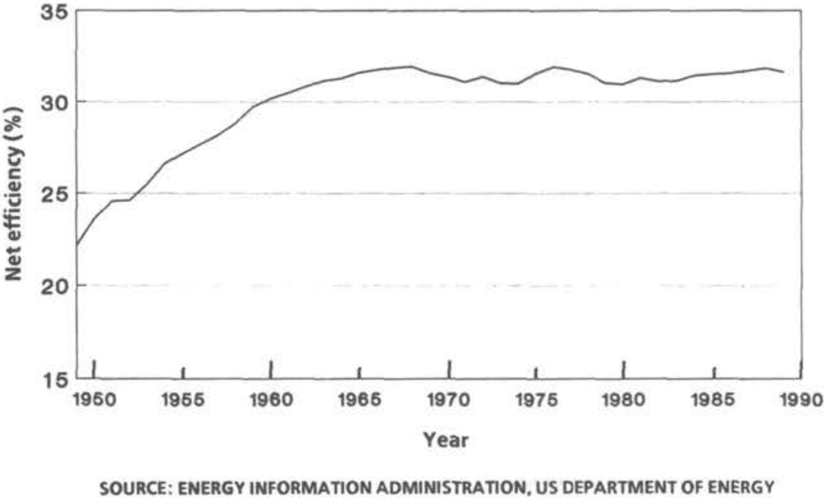


*FIG. 5. Average net efficiency of natural gas fired power plants.*

## 2. HISTORICAL TRENDS IN POWER PLANT EFFICIENCIES

Over the last century, the introduction of new power generating technologies has had a dramatic effect on power plant net efficiencies. As shown in Fig. 5, in the USA, natural gas fired power plant average net efficiency has improved from about 22% in 1950 to about 32% today[4], a result due to progressive improvements in the Brayton cycle gas turbine design. Further significant efficiency improvements for the basic gas turbine do not appear likely, however, without material science advancements that would allow much higher gas inlet temperatures than are now possible and/or completely new cycle configurations.

The average net efficiency of Rankine cycle coal fired power plants in the USA has made an even greater improvement. In the early part of the century, crude stoker type coal fired power plants were dreadfully inefficient, sending a large quantity of the incoming coal up the stack with the flue gases or through the grate into the bottom ash. As shown in Fig. 6, net efficiencies of these power plants were usually less than 10%. New technology of the 1920s and 1930s introduced the use of pulverized coal. These new water cooled furnaces were generally much larger than their predecessors, were designed for elevated temperatures and steam pressures, and they also pioneered the use of reheaters and superheaters. All of these contributed to the upward trend in power plant efficiencies that flattened out at about 20% by the 1940s. In the 1950s, the continuing trend to larger generating unit sizes and the

[4] All net efficiencies are calculated on the basis of higher heating values (HHV).

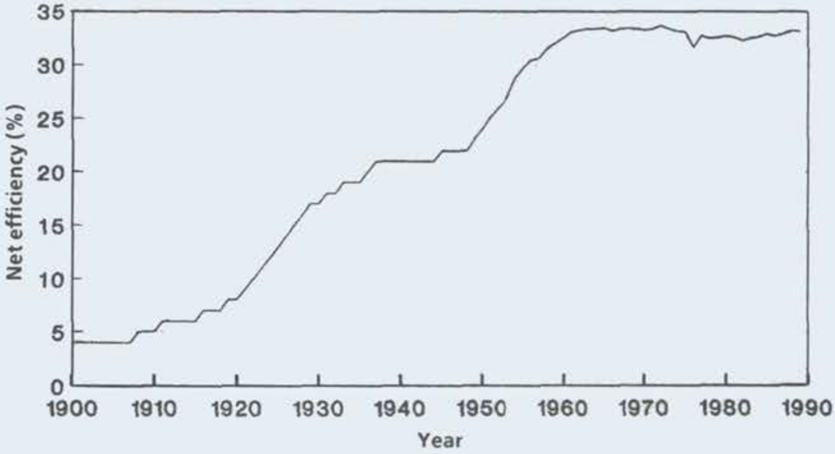


*FIG. 6. Average net efficiency of coal fired power plants.*

introduction of 'supercritical' steam generation systems, with operating conditions above the thermodynamic critical temperature and pressure for water, further increased net average efficiency to about 33%, where it has remained since about the early 1960s. There has been no further improvement in net efficiencies since then for two primary reasons: utility companies are finding it cost effective to invest money for life extension of existing power plants rather than to build new ones; also an effective thermodynamic limit of Rankine cycle pulverized coal power plants has been reached whereby further efficiency improvements can be achieved only at the so-far prohibitive cost of severe materials science problems associated with containment of superheated steam.

While it may not be feasible to overcome material science limitations that prevent further net efficiency improvements for Brayton cycle and Rankine cycle power systems, the new technologies mentioned above manage to overcome these efficiency barriers in two ways: by combining Brayton and Rankine cycles into a 'combined cycle' power system, or by employing a technology that does not depend on either the Brayton or Rankine thermodynamic cycle.

## 3. NATURAL GAS BASED POWER SYSTEMS

Advanced natural gas based power generating technology in general falls into three major classifications: combined cycle systems, steam injection systems, and fuel cells.

Combined cycle systems utilize a Rankine cycle heat recovery steam generator to generate additional power from gas turbine exhaust gases, with overall net system efficiencies of about 45% (HHV). Natural gas combined cycle systems are now coming into commercial use in the USA and elsewhere.

A somewhat different technology is the steam injected gas turbine. In this technology, instead of a combined cycle the Brayton cycle is modified by injecting the steam from the heat recovery system directly into the gas turbine rather than utilizing a separate Rankine cycle. Steam injection has been shown to result in slightly lower efficiencies and slightly higher capital costs than those of the combined cycle systems, but steam injection systems are more compact than combined cycle systems, and are more applicable to smaller sized electrical generating units. The intercooled steam injected gas turbine is being studied as a means of boosting system efficiency without sacrificing the compactness of steam injection systems. Other variations on steam injection include the so-called humid air turbine (HAT) cycle currently under review by the Electric Power Research Institute in Palo Alto, California. The HAT cycle utilizes a heat recovery system to run a saturator that humidifies combustion air entering the gas turbine. The additional mass of the water vapour passing through the turbine significantly increases the overall net system efficiency, and since production of steam is not required, weaker sources of waste heat can be recovered.

The ultimate future of natural gas based power generating technology may lie in fuel cells, which do not rely on thermodynamic cycles for power production. Fuel cells are electrochemical energy producing devices, reacting hydrogen with oxygen to produce water vapour and electrical energy. Besides hydrogen, fuel cells can also utilize methane and other hydrogen containing fuel gases such as those found in natural gas, which are reformed either outside or inside the fuel cell in the presence of water vapour. Presently, there are three types of fuel cells under development. Phosphoric acid fuel cells (PAFC) utilize liquid phosphoric acid as an electrolyte, are capable of producing electrical power at about 40 to 48% net efficiency, and are expected to see commercial use by the mid-1990s.

Two other types of fuel cells are also under development: molten carbonate fuel cells (MCFC) and solid oxide fuel cells (SOFC). MCFC technology is capable of yielding a much greater net efficiency than PAFCs, as high as about 65% for advanced MCFC system concepts which are not expected to be commercialized until the beginning of the next century. Instead of a phosphoric acid electrolyte, the MCFC utilizes molten alkali metal carbonate, and operates at a much higher temperature than PAFCs (650°C vs. 200°C). This elevated operating temperature permits the use of a secondary Rankine cycle heat recovery system for production of additional power, which contributes to the overall high efficiency of MCFC systems. SOFC technology is somewhat similar to that of the MCFC, in that the relatively high operating temperature of the cell (1000°C) permits the use of a secondary Rankine cycle for additional power production; advanced SOFC system concepts

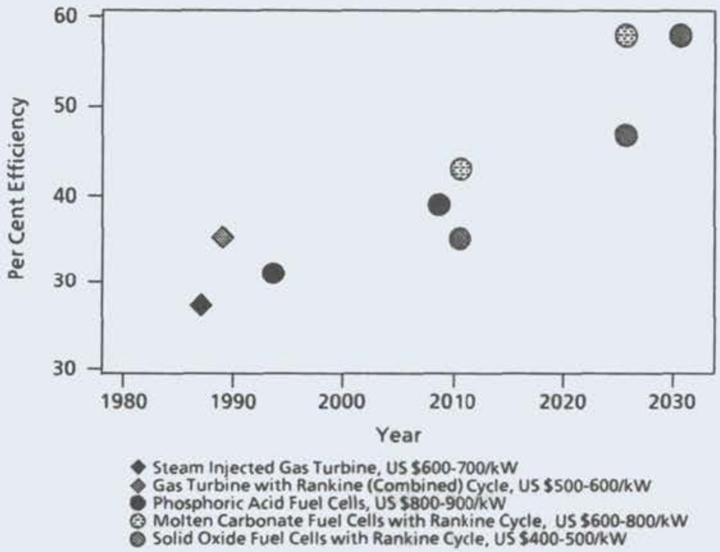


*FIG. 7. Future of natural gas power plants.*

will also be capable of up to about 65% net efficiency for electric power production. However, instead of molten alkali carbonates, SOFCs utilize a solid yttria stabilized zirconium oxide electrolyte. SOFCs can also have higher power densities than MCFCs which, combined with their relatively less expensive ceramic construction, result in a slight capital cost advantage for SOFCs over MCFCs. A comparison of advanced natural gas power generating technologies is shown in Fig. 7.

## 4. COAL COMBUSTION BASED POWER SYSTEMS

Advanced coal combustion based power generating technology in general falls into three major classifications: atmospheric fluidized bed combustion (AFBC) systems, pressurized fluidized bed combustion (PFBC) systems, and coal fired magnetohydrodynamic (MHD) combined cycle systems. A fourth classification, comprised of direct and indirect fired turbines, is also being supported by the United States Department of Energy (DOE). However, these systems will not be discussed in this paper because of current insufficient information concerning their expected net efficiencies, capital costs and commercialization.

The principle behind fluidized bed combustion (FBC) is passing combustion air upwards through a granular bed of hot coal and limestone. At the correct throughput and velocity, the air expands the volume, or 'fluidizes' the bed as combustion occurs. The $SO_x$ containing combustion gases then react with the lime in the bed (which has been calcined from the limestone at the elevated temperature in the bed), removing up to about 95% of the $SO_x$ from the combustion gases. And, since FBC systems are designed to operate at lower temperatures than pulverized coal combustion systems, relatively lower $NO_x$ amounts are produced in a fluidized bed combustor. Electrical power is generated by a modified Rankine cycle, with additional power being generated by a gas turbine Brayton cycle in PFBC systems.

AFBC technology falls into two sub-classifications: bubbling bed combustion systems and circulating bed combustion systems. Circulating bed systems differ from bubbling bed systems in that they utilize a higher velocity combustion air flow, resulting in a more turbulent bed. Whereas a bubbling bed system has a measurable bed height, circulating bed combustors are generally taller than their AFBC counterparts and have no discernible bed boundaries. Net system efficiencies of the two types of AFBC are comparable; however, relatively longer contact time between the bed and combustion gases in a circulating bed combustor makes it possible for a lower limestone to coal ratio to be used. The DOE's Clean Coal Technology programme currently has two AFBC projects active, at Nucla, Colorado, and at Tallahassee, Florida (the Tallahassee project is still in the design stage). Both are the circulating bed variety of AFBC. Additionally, other AFBC demonstrations not associated with the Clean Coal Technology programme are also planned or under way; one example is the Tennessee Valley Authority's bubbling bed AFBC at a utility site near Paducah, Kentucky. AFBCs are generally very reliable power producing systems that do not require post-combustion flue gas cleanup devices; they can use any rank of coal, and solid waste from an AFBC is really a by-product that is usable in a variety of applications, such as fertilizers and building materials. However, the AFBC is not a combined cycle system; the best net system efficiency expected for an advanced, fully optimized AFBC is only about 36%.

The inherent advantage of PFBC systems over AFBCs is that the PFBC is a combined cycle system. PFBC systems operate at about 10–15 atm pressure[5] (depending on specific plant design), which makes possible the use of a gas turbine topping cycle with the combustion gases, resulting in a much greater net system efficiency than for AFBC systems. PFBC technology falls into three sub-classifications; besides bubbling bed and circulating bed systems, there is also under study an advanced PFBC that will utilize a partial gasification operation to generate char for feed to the PFBC and a fuel gas to mix with PFBC exhaust gases for combustion in a Brayton cycle gas turbine. Typical net system efficiencies for PFBC power plants are in the high 30 to low 40% range. The net system efficiency predicted for the advanced PFBC is about 45%. The DOE's Clean Coal Technology programme

[5] 1 atm = $1.013\ 25 \times 10^5$ Pa.

currently has three PFBC projects active. One of them is a circulating bed PFBC that is still in the design stage and whose site has not yet been finalized. The other two are bubbling bed PFBCs: the Tidd facility at Brilliant, Ohio, and the larger Sporn facility being constructed at New Haven, West Virginia. Outside the USA, PFBC power plants have recently begun operation at Escatron, Spain, and Värtan, Sweden; the Värtan PFBC provides district heating as well as electrical power for the city of Värtan. PFBCs have similar advantages as AFBCs, in that they do not require post-combustion flue gas cleanup devices and do produce ash that is a usable by-product. The modularity of PFBC systems also minimizes field fabrication requirements.

Coal fired MHD is an advanced technology that is not expected to be commercialized until at least the first part of the next century. The principle behind MHD is the combustion of coal at a very high temperature so that a potassium containing 'seed' material that enters the combustor with the coal produces positive charged potassium ions. As the ion containing combustion gas exits the combustor, it passes through a very strong magnetic field from which electrical energy results. Additional power is generated by a heat recovery Rankine steam cycle. Overall net system efficiencies for coal fired MHD power systems are expected to be over 50% and as high as 61% for a fully optimized system. A comparison of advanced coal combustion power generating technologies is shown in Fig. 8.

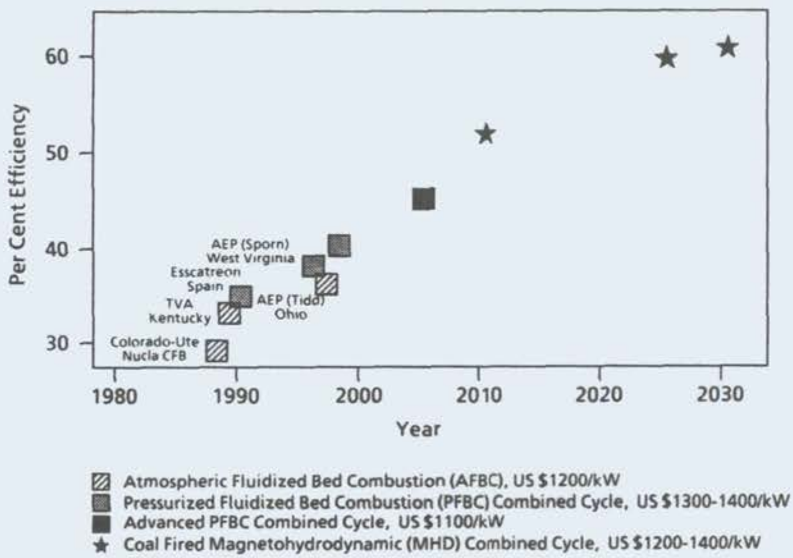


*FIG. 8. Future of coal combustion power plants.*

## 5. COAL GASIFICATION BASED POWER SYSTEMS

The DOE categorizes advanced coal gasification based power generating technology as belonging to one of four different 'generations'. The first generation, exemplified by integrated gasification combined cycle (IGCC) power plants such as the Cool Water Demonstration Plant in California, utilizes oxygen blown gasification, 'cold' desulphurization of the resulting fuel gas by one of several commercial processes, and a combined cycle featuring a Brayton cycle combustion turbine and a heat recovery Rankine steam cycle. First generation IGCC plants are capable of net system efficiencies of up to about 40%. There currently are no first generation IGCC power plants in the DOE's Clean Coal Technology programme, although commercial plants are planned in the USA at Freetown, Massachusetts, and Terre Haute, Indiana. A commercial IGCC plant is also under construction at Buggenum in the Netherlands.

Second generation IGCC systems being considered in the USA feature air blown instead of oxygen blown gasification, and 'hot' desulphurization of fuel gas using a regenerable metal oxide species at elevated temperatures. Second generation systems feature lower capital costs and higher net system efficiencies than those of comparable first generation IGCCs. Second generation IGCC plants will be capable of net system efficiencies of up to about 42%. The DOE's Clean Coal Technology programme currently has two second generation IGCC projects active; these will be located at Tallahassee, Florida, and Springfield, Illinois.

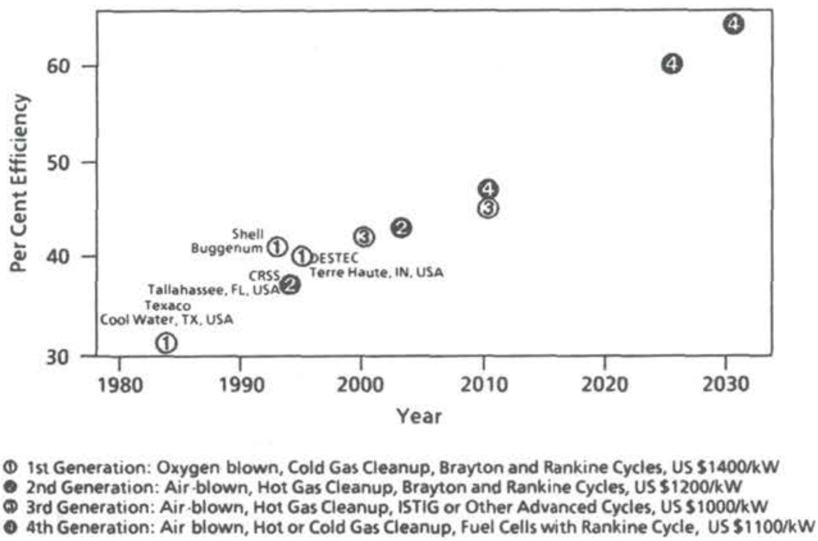


*FIG. 9. Future of coal gasification power plants.*

Third generation coal gasification based power systems will also utilize air blown gasification, but instead of a combined cycle they will have an advanced intercooled steam injected turbine or similar variant. System studies indicate that third generation systems will be capable of net system efficiencies of approximately 45%. Fourth generation systems will replace the gas turbine entirely with either the MCFC or SOFC systems as described earlier; these systems will have overall net system efficiencies ranging from about 45% when the technology is first commercialized to more than 60% after technology improvements to gasifiers and fuel cells are progressively introduced over the next several decades.

Coal gasification based power systems, in general, can utilize a broad range of coal types and produce useful by-products such as elemental sulphur. The modularity of gasification based power systems also lends itself easily to shop fabrication and staged construction, where a combined cycle power plant can be built to operate initially using natural gas with the possibility of subsequent changeover to gasified coal once a gasifier is installed. A comparison of advanced coal gasification power generating technologies is shown in Fig. 9.

## 6. ACID RAIN EMISSIONS REDUCTION BENEFITS

Considerable environmental benefits accrue from the introduction and use of advanced, high efficiency power generation technology. One of the most obvious is the relatively low amount of $SO_2$ and $NO_x$ emissions that result from the use of these new high efficiency power generation technologies. As shown in Fig. 10, a typical 'uncontrolled' pulverized coal power plant (i.e. without flue gas scrubbers or $NO_x$ controls) that uses bituminous coal containing 2 1/2% sulphur by weight will emit about 200 t $SO_x$ per MW·a of electricity generated. That same plant will also emit about 30 t $NO_x$ per MW·a.

The use of advanced coal fired power generation technology can provide a substantial improvement over this 'uncontrolled' base case. Examples of potential improvements are illustrated in Fig. 10. AFBC technology is approximately equivalent in emissions reduction capability as pulverized coal combustion with advanced flue gas scrubbing and $NO_x$ controls. With AFBC technology, typically about 95% of the $SO_2$ emissions and about 60% of the $NO_x$ emissions that would have occurred in the 'uncontrolled' plant are eliminated. This would result in $SO_2$ and $NO_x$ emissions (for that same coal) of 10 and 12 t/MW·a, respectively. A slight improvement can be anticipated if a PFBC is used instead of an AFBC, owing to PFBC's better $NO_x$ reduction attributes and overall higher net system efficiency. Expected $SO_2$ and $NO_x$ emissions would then be 9 and 8 t/MW·a, respectively.

Even more advantageous emissions reductions occur from use of gasification based power generation technologies. First and second generation IGCC systems are about equivalent in $SO_2$ and $NO_x$ removal capabilities. For these technologies,

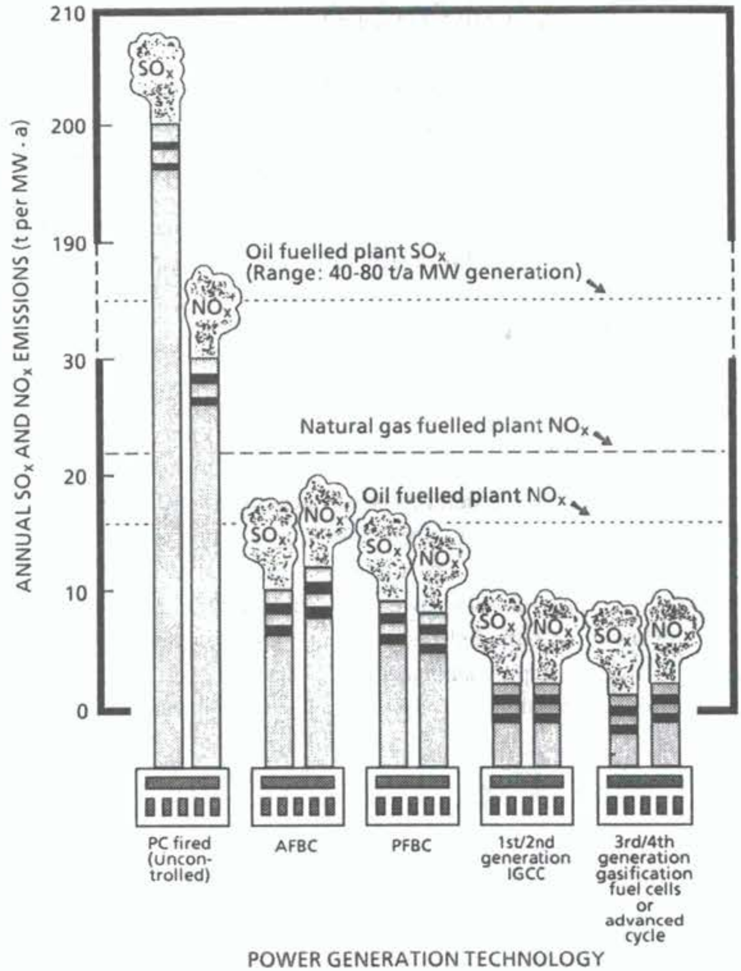


*FIG. 10. $SO_x$ and $NO_x$ emissions versus type of electric generating plant (PC: pulverized coal; IGCC: integrated gasification combined cycle).*

about 99% of the $SO_2$ emissions and over 90% of the $NO_x$ emissions that would have occurred in the 'uncontrolled' plant are eliminated, resulting in $SO_2$ and $NO_x$ emissions (for that same 2 1/2% sulphur coal) each about 2 t/MW·a. A slight further improvement can be anticipated from the use of third or fourth generation coal gasification based systems, owing to their overall higher net system efficiencies. Expected $SO_2$ and $NO_x$ emissions would then be 1 and 2 t/MW·a, respectively.

## 7. GREENHOUSE GAS EMISSIONS REDUCTION BENEFITS

Besides reducing acid rain emissions, the use of advanced coal fired power generation technology can provide a significant improvement in $CO_2$ emissions as well. Production of $CO_2$ is inversely related to power plant efficiency; as an example, a 100 MW power plant of 40% net efficiency will emit 17.5% less $CO_2$ than a 100 MW power plant of 33% efficiency that uses the same fuel supply. Therefore, the replacement of ageing, lower efficiency power plants with advanced, high efficiency power generating systems of equal capacity will result in the generation of significantly lower amounts of $CO_2$.

## 8. CONCLUSIONS

New and advanced high efficiency power generating technologies will provide a cost effective means of meeting electricity demands of the next century. These technologies also result in significantly lower generation of acid rain and greenhouse gas emissions, as compared with lower efficiency power generating systems in current use worldwide. Continued research on these new technologies should be encouraged so that a rapid advancement towards early demonstration and commercialization is possible.

# TRENDS AND OUTLOOK FOR NUCLEAR POWER DEVELOPMENT INCLUDING ADVANCED NUCLEAR REACTORS

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**Abstract**

TRENDS AND OUTLOOK FOR NUCLEAR POWER DEVELOPMENT INCLUDING ADVANCED NUCLEAR REACTORS.

A brief overview is provided of the current deployment of nuclear plants and the outlook for the next few decades is outlined. New demands are being made of nuclear technology and the development goals to meet these demands are discussed in the paper. The technology which can be expected to be available over the next decade or so is then considered. The paper closes with brief remarks on the market potential for non-electric uses and on the scope for enhanced collaboration on advanced reactor technology.

## 1. STATUS AND TRENDS

The use of nuclear power for electricity production dates back to the late 1950s. Up to the end of 1990, some 5620 reactor-years of experience had been accumulated providing a good basis for further development.

Nuclear electricity generation in Organization for Economic Co-Operation and Development (OECD) countries totalled 1531.6 TW·h in 1990, providing 23% of total electricity generation in the area. Roughly the same proportion is expected to continue during the next decade. Worldwide there were 424 nuclear reactors connected to electricity grids at the end of 1990 and altogether these accounted for about 17% of the world's total electricity production. Thus nuclear energy plays a very important role in energy supply, but the expansion rate of nuclear electricity generation has become markedly less than the rate expected a decade ago.

The way in which predictions for the OECD area have changed is illustrated in Fig. 1. This experience is probably fairly representative of the world as a whole. It teaches us to be careful in making judgements about future possibilities, but it does not necessarily teach us that forecasts of nuclear power should be continually reduced.

Our best estimates for the next decade or so are set out in Table I and are based on the material provided by the governments of OECD countries to the Nuclear Energy Agency (NEA) for three regions [1] and on International Atomic Energy

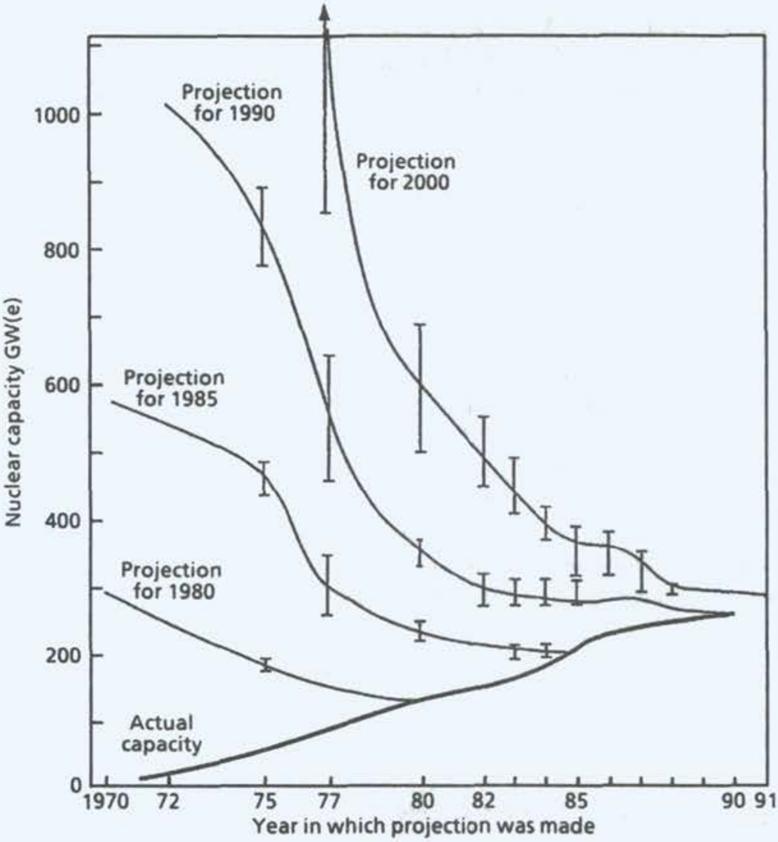


*FIG. 1. Projected nuclear capacity for OECD countries in relation to the year in which the projection was made.*

Agency (IAEA) data and estimates for the remainder of the world [2]. Over this period there seems to be no great likelihood of significant growth in nuclear capacity. Even if political conditions were to change radically in favour of nuclear power, there would be some lag in bringing new capacity on-stream. The response time of the electricity generating industry is quite large and will preclude rapid changes over the period of a decade.

Looking further ahead it is clear that statements about expectations need to be 'hedged about' with many more qualifications added. All forecasts will be inaccurate. In our work on long term prospects we have preferred to try to bracket the most likely ranges of outcomes with scenarios which we hope will cover (in concept) the middle two-thirds of the spectrum of probabilities. In our last in-depth exercise, which was conducted as a basis for analysing potential requirements for uranium to

TABLE I. PROJECTIONS OF INSTALLED NUCLEAR CAPACITY (MW)

| Region | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|
| **Non-OECD[a] countries** | | | | | |
| Latin America | 2 200 | 5 600 | 6 400 | 6 400–8 350 | 6 400–8 300 |
| Eastern Europe | 42 800 | 52 200 | 64 300–70 700 | 77 700–93 150 | 99 700–140 900 |
| Africa | 1 850 | 1 800 | 1 800 | 1 800–3 300 | 1 800–4 800 |
| Middle East & South Asia | 1 500 | 2 100–2 600 | 3 500–5 900 | 7 700–10 500 | 12 700–19 700 |
| South East Asia & Pacific | 0 | 0 | 0 | 0–900 | 0–5 600 |
| Far East | 12 100 | 15 200 | 19 300–19 900 | 22 500–24 400 | 25 600–34 400 |
| **OECD countries** | | | | | |
| North America | 113 700 | 116 300 | 121 500–121 700 | 123 600–125 500 | 120 900–133 200 |
| Europe | 117 700 | 124 300 | 126 300–127 300 | 128 300–137 100 | 128 800–159 200 |
| Pacific | 30 400 | 39 100 | 43 000–52 000 | 52 000–60 000 | 60 000–70 000 |
| **TOTAL** | 322 250 | 356 900 | 386 500–405 900 | 420 200–466 700 | 456 100–576 600 |

[a] These regions are as defined by the IAEA but with OECD countries separated out.

**Sources:** For non-OECD countries: IAEA Secretariat Estimates [2]; for OECD countries: OECD Nuclear Energy Data (1991) [1].

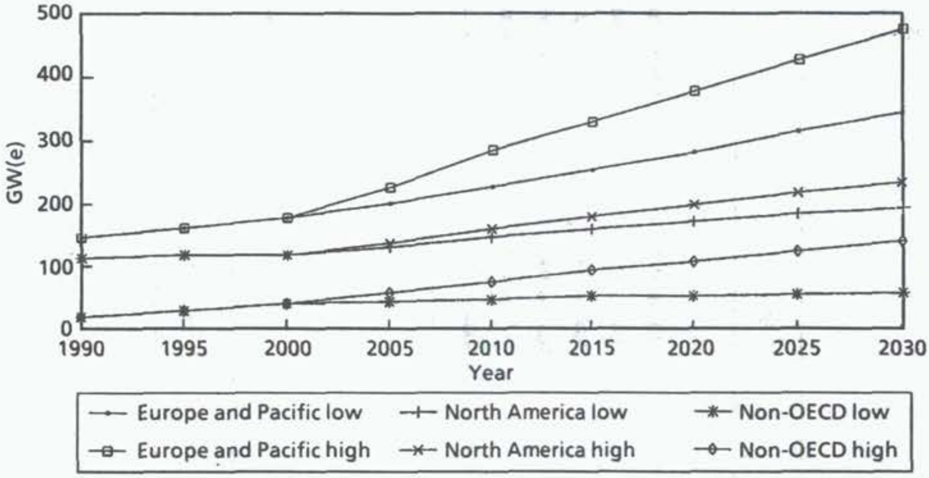


*FIG. 2. Projected installed nuclear capacity by region (1990–2030).*

the year 2030 [3], we declined to investigate the effect of not building any more reactors to replace the current capacity. We also eschewed any scenario which would approach the limits of what would be constructed and brought into service. In addition we attempted to avoid a high growth scenario which took account of possible political reactions to increased evidence for, and action against, climate change arising from the use of fossil fuels. We tried to outline a low growth scenario in which there would be continued, but perhaps grudging, acceptance of nuclear power in countries already using it. For the high growth case an attempt was made to imagine what would happen if there were a gradually increasing public acceptance of nuclear power on the assumption that major accidents were avoided and radioactive waste disposal arrangements were implemented and found to operate as predicted.

In the view of the people advising on the scenarios there was no possibility of constructing a sophisticated mathematical model. Simplicity had to suffice. The results are shown in Fig. 2. There was no attempt to take explicit account of the economics of nuclear and competing electricity production technology. Implicitly it was assumed that nuclear power plants would be broadly competitive with coal fired plants in most countries during the early years, with the tendency for fossil fuels to become more expensive, favouring an increased penetration of nuclear technology in later years.

It was also implicit that nuclear technology would not stand still. The demands made on the technology by investors, operators, regulators and the public have changed considerably over the last 30 years and can be presumed to continue to change in the future. The next sections review some of the current aims and development efforts, primarily from the standpoint of OECD members. It is clear, however, that the operations of any country's nuclear facilities can have global significance, hence the general trends are of relevance everywhere.

## 2. DEVELOPMENT GOALS

One reason for reduced expectations of growth in nuclear capacity was the growing public concern for nuclear safety following the Chernobyl nuclear accident. That accident and the Three Mile Island incident made it difficult to obtain public acceptance for construction of new nuclear power plants in almost all OECD countries. Some countries even changed their policies on nuclear power and have decided to apply moratoria on additions to nuclear power plant capacity or to withdraw from nuclear generation. Although reactors in the OECD countries have a very good safety record, and the Three Mile Island incident could be taken as a demonstration of the good performance of defence-in-depth arrangements (as little radioactivity escaped and no injury to the public occurred, there is a perceived need to allay public fears and give greater confidence that investments as well as public health will be protected, leading, in some countries, to a wish, if possible, to avoid the need for evacuation zones around nuclear power plants.

A current inhibitor to the relaunching of nuclear power programmes, at least in some countries, is the public's concern over the environmental impact of the nuclear fuel cycle. The worry is not concerned so much with normal plant operation but rather with abnormal situations; there are also concerns about reprocessing (in the United Kingdom, for example) or waste management.

The operation of nuclear power plants and nuclear fuel cycle facilities makes a very small contribution to the greenhouse gases, the polar ozone holes or acid rain compared with fossil fuelled plants, since nuclear operations emit no $SO_2$, $CO_2$, $No_x$, methane or chlorofluorocarbons. It has been estimated that use of nuclear power in OECD countries avoided emissions of from 0.3 to 0.34 Gt of $CO_2$, measured as carbon, in 1987 and that the avoidance will rise to between 0.44 and 0.5 Gt/a by the year 2005 according to current plans [4]. In France, where nuclear power has expanded to provide three-quarters of the electricity produced, the emissions in Electricité de France (EdF) plants of $SO_2$ dropped by a factor of 10, $CO_2$ by a factor of 6, and dust by a factor of almost 40 [5]. There is, however, a proper and widespread concern about the potential for polluting the environment with radioactive materials. There is a wide technical consensus that the necessary long term exclusion of radioactive waste from the biosphere can be achieved, but the general public is far from convinced. The fact that there has been no pressing technical or economic need to put long term storage facilities into immediate service has created the wrong impression that certain problems are not solved.

Another major reason for the slowdown of nuclear power expansion has been the greatly reduced expectation of electricity demand, which has affected orders for all types of generating plants. The prospects for nuclear power have also been affected by the decline in fossil fuel prices and the lowered expectations of future prices for these fuels. Additionally the potential availability of new, more fuel efficient and environmentally clean fossil fuel combustion technologies may remove some barriers to their wider use. Certainly the relatively short lead time and low investment costs for small scale plant construction provides utilities with flexibility in timing their investment decisions and reduces financing costs. This attraction could also accrue to smaller nuclear plants should they be offered on the market.

The costs of some stages of the back end of the fuel cycle, including decommissioning of reactors and facilities as well as radioactive waste management, remain uncertain in the absence of demonstrated and clearly defined national policies. Improvement of the economics of nuclear power by measures such as reduction of capital cost and reduction of construction period, including time for regulatory action, is needed as is the clarification of nuclear fuel cycle costs. Factors other than capital cost reduction have only a minority influence on nuclear electricity generation costs, so that the existing uncertainties in other cost factors are very much less important economically. This is not widely appreciated outside the nuclear industry.

To date nuclear power in the civil sector has been used predominantly for electricity generation, although some use is made of waste heat for process and district heating. With some modifications to technology and public attitudes, nuclear power could have widespread use for these purposes and for uses such as marine propulsion and desalination, which received some attention in the early days of nuclear development. A major impact on land transport will be available if and when electrically driven road vehicles become economically acceptable.

In terms of the currently foreseeable use of nuclear power up to about the year 2030, there appear to exist abundant resources of high and medium grade uranium, although considerable exploration and development would be necessary to ensure that the resources would be available in a timely manner. If, however, the OECD countries as a whole were to use nuclear energy to the same extent as France and Belgium, it seems likely that all the currently estimated high and medium grade resources would be committed to fuel reactors in place by 2030. Before that point decisions will be needed on the extent to which to pursue breeder technologies, which can multiply the energy derived from the resource base by about 60; it will also be necessary to take decisions on exploration for and exploitation of lower grades of ore, possibly in modified fuel cycles.

The R&D programmes which are being pursued to meet these challenges have the following goals:

(a) Reduce the residual risks of operation of nuclear power plants
(b) Demonstrate the nuclear industry's ability to cope economically and safely with its radioactive wastes

(c) Improve the economics of nuclear power
(d) Widen the applicability of nuclear power
(e) Expand the resource base.

## 3. DEVELOPMENT OF TECHNOLOGIES

Developments are taking place to meet all these goals listed above. In practice any programme or project will contribute to the achievement of several goals. For the purposes of this paper it is convenient to treat separately the following technologies:

— Radioactive waste management
— Reactor technologies (water cooled, gas cooled, liquid metal cooled)
— Fuel cycle technologies.

### 3.1. Radioactive waste management

The operations of the nuclear industry produce radioactive waste in which there are varying degrees of contamination caused by a range of radioactive isotopes. The emission of ionizing radiation from these radionuclides is potentially harmful. Exposure to ionizing radiation may occur as a result of the release of radioactive materials into the human living environment. In these respects, they have the same intake and exposure routes as many other hazardous substances. Only the additional route, that of direct exposure of the body to external radiation, is unique to radionuclides. The potential consequences of exposure to radioactive materials can also be compared with those from other hazardous materials.

Radioactive waste disposal systems are designed for operation long into the future. As a result, the regulatory, social and political dimensions of this challenge have been widely debated. In many cases, the conclusions reached and the technical and methodological advances achieved can influence the handling of a much broader challenge currently facing society. That challenge is the safe and final disposal of highly toxic hazardous wastes. A survey in the United Kingdom indicated that in one year more than 4 million $m^3$ of toxic wastes are produced, of which 1.1% is radioactive, and of the radioactive waste 0.1% by volume is high level radioactive waste (HLW).

It is the HLW which results from the reprocessing of spent fuel, or from the decision in some countries to dispose of the spent fuel itself, that poses most starkly the problem of radioactive waste disposal. These materials contain actinides (i.e. atoms with atomic numbers from 89 upwards), including some which have very long half-lives (so that it is many thousands of years before the radioactivity falls to background levels). These materials also contain short to medium lived fission products in such concentrations that for several decades a large amount of heat is produced by the radioactive decay so that special measures are needed to avoid damage to structures containing the wastes.

Current concepts for disposing of HLW (and other radioactive waste) call for a multiple barrier approach with a number of interrelated, often redundant barriers between the waste and the human environment. The performance of the engineered barriers as well as the necessary geological conditions have been extensively studied as has the method of conditioning spent fuel before disposal.

In the case of HLW, the waste form acts as the first barrier to radionuclide migration. This is important during the period immediately after disposal when the radiation and heat generation are still high. Two materials for the first barrier have been developed: a borosilicate glass and a synthetic rock. Their purpose is to resist leaching by groundwater. Reprocessing companies in France and the United Kingdom are already producing on a commercial scale discs of glass containing HLW.

The waste matrix is held in a container which can be designed to be a barrier resistant to the chemical and physical environment expected in the waste repository. The next engineered barrier consists of the backfill material (e.g. clay) placed around the waste containers. It can also consist of materials used for backfilling of drillholes, access shafts, and tunnels in the repository. The backfill inhibits the movement of water within the repository and may provide a chemical environment that reduces the solubilities of many radionuclides, thus serving to retard their transport.

The last barrier is a geological formation of such stability that, should all else fail, it will prevent the migration of radioactive species into the biosphere for the length of time necessary to ensure that any subsequent release to the human environment will be compatible with accepted radiation protection criteria. Granite shields and salt deposits have shown their stability over geologically long periods so they are suitable candidate host rocks. Certain deposits of tuff and of clay are also being considered. The NEA sponsors an international research project at the Stripa mine in Sweden where the properties of granite are investigated in relation to the use of such rock for a waste repository. Other underground R&D laboratories in Belgium, Canada, Germany, Switzerland and the United States of America are included in a co-ordinated assessment programme. A further line of attack, commensurate with the very long time-scales which have to be considered, is to study natural analogues — natural deposits of radioactive material where the effects of dispersion processes, such as leaching by groundwater, can be investigated after geologically long periods. The NEA set up the Alligator Rivers Natural Analogue Project in Australia for this purpose.

On the basis of the many research programmes completed or in progress, the NEA's Radioactive Waste Management Committee has reaffirmed its confidence in the safety and feasibility of the geological disposal of radioactive wastes. Even when waste repositories have been operated for a few years, however, it will not be possible to assert solely from the experience gained that the repository will perform as required for as long as required. Considerable effort is therefore invested in setting up and refining methods of assessing the performance on the basis of models of the repositories' behaviour. This is backed up by a major effort to develop databases on relevant physical and chemical parameters, e.g. thermochemical and sorption data. The performance assessments extend to consideration of human intrusion into a waste repository. Recently the NEA and the IAEA, with the endorsement of experts of the Commission of the European Communities, issued a Collective Opinion based on a review of experience with safety assessment of waste disposal systems. They considered "that appropriate use of safety assessment methods, coupled with sufficient information from proposed disposal sites, can provide the technical basis to decide whether specific disposal systems would offer to society a satisfactory level of safety for both current and future generations" [6].

A major motivator of the wide range of research work is the need to convince a sceptical public that radioactive waste can indeed be safely managed. It is also true that refined understanding might enable repositories to be designed, constructed and operated for a reduced cost. There is no globally valid estimate of the cost of disposing of nuclear waste but the technical community does not doubt that it will be only a small part of the total fuel cycle costs. For example the NEA's report, Economics of the Nuclear Fuel Cycle published in 1985 [7], included a calculation that the back end cost of a reprocessing cycle (after allowing credits for recycled plutonium and uranium) would be 1.75 mill/kW·h out of a total fuel cycle cost of 8.56 mill/kW·h.[1] For a once-through cycle the figures were, respectively, 0.97 and 7.78 mill/kW·h. As noted previously several countries have research programmes including underground facilities. Only Sweden and the USA have made firm plans for constructing final repositories, in both cases for spent fuel. Sweden plans to construct a final repository beginning in the year 2010. The US plans to have a federal repository operating before then have recently been stalled by opposition at the State level.

The technical problems of disposing of low level waste (LLW) and intermediate level waste (ILW) arise more from their bulk than from the intrinsic difficulty of containing them. Therefore attention is being given to compaction methods (e.g. electrolytic refining to separate radioactive isotopes from steel structures recovered from reactor cores, incineration of LLWs — paper, clothing, etc.). As yet no permanent repository is operating for ILWs (e.g. the discarded cans of reprocessed fuel) but several countries have LLW repositories which present no problems in terms of radioactive releases. From 1967 to 1981 LLW was dumped at a monitored site in the North Atlantic. Although the detailed monitoring had not detected any release of radiation and the practice was judged technically sound by the NEA's Co-ordinated Research and Environmental Surveillance Programme, it was decided at the meeting of the London Convention on the Prevention of Marine

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[1] mill (= US $\$10^{-3}$ = 0.1 cent).

Pollution by Dumping of Wastes and Other Matters in 1982 to suspend these operations.

There are significant political problems relating to radioactive waste disposal but there is considerable confidence within the technical community that a satisfactory solution can be implemented as soon as the necessary characterization of candidate sites can be completed.

## 3.2. Reactor technologies

### *3.2.1. Water cooled reactors*

The bulk, some 80%, of the world's present reactors are water cooled and moderated. Globally some 4405 reactor-years and 9 months of experience had been accumulated with such reactors by the end of 1990. A high degree of availability and high load factors have been achieved — over the last 5 years annual average load factors have been above 80% in several European countries as they were in Canada earlier. Six of the 25 countries using nuclear power report lifetime average energy availabilities above 80% and a further 10 countries report more than 70% availability. In several countries, particularly those which have benefited from series ordering, nuclear power is highly competitive. Thus it is not surprising that many utilities and vendors favour an evolutionary approach to reactor development.

In this evolutionary approach, which is already leading to considerable improvement of reactor designs, the goals are to increase the safety margins, to simplify and reduce the cost of construction and operation, to shorten lead times (partly by improved planning and in some countries partly by having standardized designs certified in advance by safety authorities), and to reduce radiation doses to operators. An example of this approach is the Tokyo Electric Power Company order for two 1350 MW(e) boiling water reactors (BWRs) to be operational in 1996 and 1998. This type of BWR has a volume of about 70% that of previous BWRs of similar size; it uses internal coolant pumps to reduce piping, welding and the frequency of in-service inspection. These features will reduce construction costs and, together with design features oriented to easier service and maintenance, will cut worker radiation exposures.

Several concepts are being developed which take the evolutionary path a stage further. All water cooled reactors rely to some extent on so-called 'passive safety features' — some have negative feedback between reactivity and temperature and between reactivity and void volume, and some have convective circulation of cooling water in accident situations. The latter aspects can be exploited more readily in designs which are smaller physically and have lower power densities. The proponents of three such concepts believe that these water cooled reactors can be built for US \$1300–1500/kW (cf. US \$1300–2500/kW for large plants of current design quoted by respondents to the joint International Energy Agency (IEA)/NEA study on comparative electricity generation costs) [8]. The aim is that such reactors could be built in 3 to 4 years, based on a high degree of factory assembly of systems and subsystems and of stabilized licensing requirements. Typically these designs feature large water pools located above the core to be fed into it by gravity in the event of an accident. The simplicity of design is indicated by Westinghouse Electric Corporation's suggestion that their AP600 reactor design will need about half the concrete, half the large pumps and heat exchangers, 60% fewer valves, 60% fewer pipes and 80% less control cable than a 600 MW reactor of currently used design.

Progress with these designs is such that the manufacturers hope to have them licensed or certified as meeting or exceeding today's safety requirements by the mid-1990s so that they could be operating by about the year 2000 if orders were forthcoming.

Some of the design changes are a reaction to the complexity of the design which came from the overlaying of layers and layers of new regulatory requirements. In some countries, however, there are suggestions that such evolutionary improvements will not suffice to provide the demonstrable safety which investors and the public want. Several designs of a more radical nature intend to respond to these pressures including ABB Atom AB's Process Inherent Ultimate Safety Reactor, the University of Tokyo's Intrinsically Safe Economical Reactor, the Japan Atomic Energy Research Institute's System Integrated Pressurized Water Reactor and the Safe Integral Reactor concept offered by a UK–US ad hoc industrial group. These designs all have a much greater reliance on thermohydraulic phenomena to ensure safety, with the intention of virtually eliminating any possibility of a core melt accident and dispensing with the need for operator action to prevent that type of occurrence.

These 'revolutionary' concepts will require prototype or demonstration reactors before they can be accepted as available for commercialization so they cannot be expected to be available before about the year 2005. The economics of these concepts are necessarily less certain than those for other designs but, for example, ABB Atom AB believes that the overall cost of electricity generated from a 630–650 MW(e) PIUS plant will be close to that for a 700 MW(e) BWR plant.

The concepts outlined above aim at improved safety and economics (including improved protection of the investment) but developments are also taking place in respect to other objectives. There is already some use of process heat from the CANDU reactors at Bruce, Ontario, and in Switzerland waste heat from BWRs is used for district heating. The steam temperature produced by water cooled reactors places some limits on their application in the field of process heat, and their generally large size and the public perceptions of their safety limit their use in district heating. Canada has developed and marketed a very small (20 MW), passively safe reactor, called Slowpoke, specifically for space heating markets as the reactor should be licensable for siting very close to heat loads, e.g. in a large hospital. In addition, interest developed early in the history of nuclear power in the use of nuclear desalination plants and this may be revived.

Water cooled reactors are of crucial importance in naval submarines and other warships but, apart from some use in Soviet ice breakers, they have not achieved widespread use in civilian fleets, although during the early 1970s, the ships Savannah and Otto Hahn demonstrated the technical feasibility of commercial use. There appears to be no technical barrier to the use of reactors in marine propulsion, but their economics must be shown to be favourable and their safety demonstrated to the satisfaction of regulatory authorities.

Developments to extend the resource base are pursued in the sense that uranium requirements can be reduced by fuel management, fuel design, reactor design and fuel substitution. Improved fuel management and design can lead to greater burnup of the fuel with extension from the currently common 33 MW·d/kg to 50 MW·d/kg or higher without reducing safety. Estimates vary as to the magnitude of the uranium savings, but might be in the range 10–15% by the year 2000. The use of higher burnup with longer operating cycles can also improve the overall economics by US $2–4 million per fuel cycle, or roughly 10% of the fuel cycle cost. The use of less absorbing materials in the fuel (and core) can lead to economy in the use of neutrons, hence lower enrichment requirement and natural uranium feedstock use. Continuous progress is being made in this way (see, for example, Ref. [9]).

Current LWRs can take up to 30% of their fuel as MOX (mixed uranium/plutonium oxide pellets with typically about 5% plutonium), without departing from normal safety and control requirements. Already there are plans to use MOX in 40–45 reactors in the OECD.

Another line being followed is that of high conversion reactors in which a more energetic neutron flux drives the nuclear reaction further, producing internally and consuming more plutonium than in current uranium fuelled light water reactors (LWRs). On the basis of current design studies it is envisaged that these reactors can be developed by only partial replacement of core internals and that only a small cost penalty (perhaps 1 to 2% in one case) over current capital costs would be incurred for about a 10% reduction of fuel cycle costs in a first stage. Other, less tested concepts envisage flexibility of use of plutonium and uranium, with uranium requirements cut by up to 33%. If uranium prices gave adequate incentives, the first stage of these changes could be introduced with a lead time of less than 10 years.

### *3.2.2. Gas cooled reactors (GCRs)*

The first civil nuclear reactors in western Europe were gas cooled. Only the UK has used them to any significant extent and experience there has been mixed, although the most recent ones are reported to be operating well and economically. Interest in increasing the efficiency of GCRs by using higher operating temperatures led to the NEA's Dragon Project which terminated in 1972 after considerable experience with the new fuel types had been gained. Based in part on this work, development of high temperature GCRs has been carried forward in Germany (advanced thermal reactor (ATR), thorium high temperature reactor (THTR)) and in the USA (Fort St. Vrain). Japan has begun the construction of a high temperature test reactor. There reactors use helium as the coolant and outlet temperatures of 950°C have been obtained in an ATR which operated successfully from 1966 to 1988.

Much effort has been devoted to fuel development. Uranium dioxide in the form of spheres about 0.4 mm in diameter is encapsulated in layers of pyrolitic carbon and silicon carbide before being dispersed in a graphite matrix. In the German case the fuel elements are spherical and the core consists of a graphite and steel barrel (hence the term 'pebble bed reactor'). On-line refuelling is provided for. In the US case the fuel particles are compacted into channels in hexagonal graphite prisms which are also pierced by cooling channels and are placed into a graphite block. It has been demonstrated that there is a very low failure rate of these fuel elements and for reactor powers of 200–350 MW(th), and core power density from 3 to 6 $W/cm^3$, it can be expected confidently that no emergency conditions can produce temperatures high enough (i.e. above 1600°C) to increase the fuel failure rate markedly. Fission products are retained within the fuel elements in all conditions so far conceived so that off-site radioactive pollution after an incident is negligible. Fission product retention also contributes to the operator dose in normal operation, being about one-tenth of that routinely achieved in US LWRs. Technically it appears feasible to construct a reactor in which radioactive release can be limited to such a degree that these reactors can be placed in close proximity to industrial plants.

One drawback of these concepts is the loss of economies of scale, but that disadvantage might be offset by a desire to increase capacity in relatively small increments or to have multiple plants provide high assurance of the continuity of electricity or heat supply. In that context it is claimed that for a US design at a plant size of 266 MW(e) (2 modules of 133 MW(e)), the levellized electricity cost would be competitive with the cost of similarly sized conventional coal plants using US $1.86/GJ coal for plants starting up in the year 2010. (Other assumptions were 80% capacity factor and cost escalation at 1% from 1987.)

In terms of extending the resource base it may be noted that the high temperature gas reactor (HTGR) with a thorium/high enriched uranium (T/HEU) fuel can achieve, without reprocessing, the same uranium economy as with the recycling of plutonium as MOX fuel in LWRs. There is considerable experience with the T/HEU fuel cycle, but owing to important unresolved questions of availability of highly enriched uranium fuel and of waste disposal, as well as low uranium prices, it is not being pursued in Germany. In the USA application of a thorium/20% enriched uranium fuel cycle is still being pursued for the modular HTGR (MHTGR). Low cost thorium reserves are believed to be abundant, with some 2.4 million t of resources (compared to 3.4 million t U) identified in the two most reliable categories.

Current interest in this technology has been affected by problems at the US Fort St. Vrain and THTR reactors although attempts are being made to market modular high temperature GCRs in the USA. The thrust of current HTGR development is to expand into new markets, such as co-generation, with process heat or district heat. The outlet coolant quality could allow wide usage in chemical plants, enhanced oil recovery and clean processing of coal or oil shales.

### *3.2.3. Liquid metal cooled reactors (LMRs)*

Breeder reactors using liquid metal coolant were conceived in the very early years of civil nuclear power when it was considered that uranium was scarce yet there would be a need for large scale recourse to nuclear power. The introduction of breeder reactors has not been seen as urgent for some years, but on the basis of reasonable assumptions about the continued use of nuclear power it seems very likely that all the world's uranium from low cost (less than US $130/kg) conventional sources will have been committed to reactor use by about the year 2040. Enhanced use of nuclear power to avoid $CO_2$ emissions could lead to major price rises for uranium before 2030. Many currently used reactors will need replacing in the period from 2010 to 2030 and their owners will be faced with judgements as to the economics of replacing them with a second generation of reactors using a once-through fuel cycle or the alternative of switching to breeder reactors. Current development efforts on these reactors are aimed at presenting them as a credibly safe and economic alternative by about 2010 so that a timely decision can be made. Their potential for ameliorating the disposal of radioactive waste is also being explored.

Already a 1200 MW(e) sodium cooled fast breeder reactor (FBR) is operating at full power in France. France has operated the 233 MW(e) Phénix since 1973 and the UK the 250 MW(e) Prototype Fast Reactor since 1975. Germany has built, but will not operate, the 295 MW(e) SNR-300. All three countries have prepared design concepts for a power station in the range of from 1300 to 1500 MW(e), using a pool of sodium as coolant. Since 1988 they have joined their research, development and design efforts into one co-operative programme.

Japan and the USA have worked on cooling by liquid sodium in loops. Japan is operating a 100 MW(th) prototype and building a 250 MW(e) reactor which is expected to go critical in 1992. The USA has operated fuel and coolant test rigs over the last 30 years and US organizations have developed a concept for a modular LMR providing 1395 MW(e) from three groups in each of three modules.

Both the pool and loop types of plant have been designed to have good safety margins so that limited or no operator action is required to prevent coolant boiling or fuel melting in accident situations. However, many research projects are continuing in order to achieve very high fuel burnup (with a long term goal of from 150 000 to 200 000 MW·d/t), control of impurities in the coolant, and greater understanding of core physics, thermohydraulics (including passive decay heat removal) and material properties relevant to the safe and efficient operation of FBRs.

One motivation of this research is to achieve lower capital costs, as currently FBRs are a factor of 1.5 more expensive to construct. French and German studies suggest that considerable savings can be made by a 20 to 30% reduction of the weight of materials for the nuclear steam supply system (NSSS). Further savings can be made in the balance of plant by enhancing reliance on passive safety features in the NSSS. Fuel cycle costs can already be predicted to be comparable with once-through fuel cycle costs with burnup levels already achieved (using current prices for uranium and fuel cycle service costs which are expected for routine large scale operations). Nevertheless efforts continue to improve the efficiency and cost of reprocessing. In the United Kingdom and French programmes, closure of the fuel cycle has already been demonstrated with satisfactorily high (>99%) recovery of plutonium, using the Purex chemical separation process on the oxide fuel.

An alternative fuel cycle proposal, being developed in the USA, envisages a metal fuel (plutonium, uranium, zirconium alloy) which would be reprocessed by melting and electrolytic separation. Experience with test rigs and research reactors suggests that this fuel can be expected to be highly reliable in operation, with test burnups of 170 MW·d/kg already achieved. The thermal conductive and neutronic properties of the metal fuel have been shown in test reactors to provide wide safety margins to coolant boiling and fuel failure in loss of coolant or loss of heat sink accidents. The proponents of this approach claimed that by integrating a reactor, a pyrometallurgical reprocessing plant and a fuel fabrication unit on one site (the integrated fast reactor or IFR concept) the fuel cycle costs would be considerably less than those for the oxide/Purex cycle.

One of the arguments adduced in favour of any fuel cycle involving reprocessing is that the volume of highly radioactive heat producing wastes is considerably reduced, thus presenting an easier disposal problem than that for spent fuel itself. One advantage claimed for the fast reactor is that the actinides produced in the reactor can be retained in the recycled fuel and consumed so that the remaining waste decays to background levels of radiation in about 300 years, rather than the thousands of years otherwise required.

### 3.3. Fuel cycle technologies

Under the heading of fuel cycle technologies can be mentioned all the activities from exploration for uranium through mining, ore concentration, conversion, enrichment, fuel fabrication and transport to spent fuel transport and storage. Technically these activities can be carried out safely so the major concerns are with economics and the resource base.

Fuel cycle costs account for about one-fifth of total levellized nuclear electricity generation costs. The total cost is not susceptible, therefore, to major impact by a change in the cost of a single part of the fuel cycle; this situation can be expected to remain true even for new generation reactors with lower capital costs. Nevertheless there are commercial forces leading to a wide variety of developments, particularly for enrichment and fuel fabrication.

Enrichment of uranium in the isotope $^{235}U$ (from its natural level of 0.7% to between 2.5 and 4% for currently operated power reactors) was first performed commercially in diffusion plants. More recently ultra-high-speed centrifuges have been used, aiming to exploit lower electricity demand for a given amount of separative work. The plant size for economic operation tends to be lower with this technology than the size for diffusion plants. Both technologies appear competitive at current prices of about US $100/kg per SWU. Small efforts have been put into developing a chemical and a fluidics technology, but the most important alternative currently under development depends on the excitation of $^{235}U$ atoms by laser light (atomic vapour laser isotope separation or AVLIS). This development has been pushed furthest in the USA with the aim of commercial introduction before the year 2000 and a production cost of about US $70/kg per SWU. Earlier thoughts that it would be economical to use this approach to extract all the $^{235}U$ (rather than leaving 'tails' containing about 0.2% $^{235}U$), thus extending the effective resource base, appear to have been dropped. Centrifuge proponents contend that their costs can be lowered to a similar extent.

All fuel manufacturers strive to improve the reliability and utilization of fuel by changes in materials and configuration. Reactor manufacturers and utilities contribute by modifying the operating cycle and core management to obtain higher burnup of fuels. The effect of this kind of activity can be illustrated by a 10% fuel cost saving achieved by EdF in its 900 MW(e) reactors by increasing fuel enrichment and burnup. Worthwhile economies can be achieved by operating a reactor consistently close to its operating design limits so the introduction of improved in-core instrumentation is also considered important, as is the improvement of reactivity control by the introduction of burnable poisons into the fuel.

Uranium exploration and extraction technology advanced significantly up to the mid-1970s but more recently there has been little pressure for advancement. Uranium is already derived from very low level resources (e.g. at 0.12% in the Olympic Dam mine in Australia). The technology for exploitation of more costly resources is fundamentally available although it may need adjustments in order to cope more economically with lower grade resources particularly when they are not associated with other economically useful metals.

## 4. MARKET POTENTIAL

It has already been demonstrated in Belgium and France that it is feasible to supply 70% of the electricity demand from nuclear power. This involves a degree of load following which could conceivably be increased with further attention to the selection of reactor, fuel design and materials. However the limit appears more likely to arise from non-technical factors, such as the diseconomy of providing a highly capital intensive plant for peak loads. Furthermore, should hydrogen become a widely used energy vector, it might be envisaged that nuclear electricity could be used to produce hydrogen to be used as fuel in peaking plants as well as for fuel cells and other transportable energy converters, thus pushing the use of nuclear power higher.

Nuclear reactors could be used as direct heat sources for a wide variety of industrial, commercial and residential uses. Many of these heat loads are less than 200 MW so they will require full development of small power reactors and, for some applications, the development of further heat transfer technology. A number of industries, including food processing, paper and textiles, could be serviced by PWRs. Other industries, including non-ferrous metals, heavy oil production, petrochemicals and coal gasification, would need the higher temperatures available from HTGRs.

Given sufficient economic or political incentives, the necessary development work could well be achieved by, perhaps, the year 2005. At that time there could be several hundred sites worldwide where reactors in the range of 150–250 MW could be utilized, the number of opportunities increasing thereafter in line with growth in energy demand, although only a very small proportion could be expected to use nuclear reactors in the first decades of the next century. A recent study by the IAEA suggests a demand for additional seawater desalination capacity of 12 million $m^3$/d in the Mediterranean area and in the Middle East by the year 2000. This area is an obvious market in which nuclear produced heat could be exploited if it were economical.

## 5. INTERNATIONAL CO-OPERATION

In the fields of waste management, safety and decommissioning there is already a great deal of multinational co-operation through organizations such as the NEA and the IAEA, as well as through bilateral agreements. These exchanges are extremely fruitful, possibly because they are far removed from commercial pressures. In the field of reactor development there is also a wide variety of international exchanges.

Most of the LWR developments are the subject of international collaboration between commercial organizations. Informal information exchange on HTGCRs and FBRs is quite extensive, but suggestions have been made that there would be an advantage from wider and more formally based exchange mechanisms.

The European fast breeder programme is now conducted under the umbrella of an intergovernmental agreement with further agreements between national utilities and development organizations. The work in Japan and the USA related to fast reactors has some connections but neither programme is strongly linked with the European effort, largely because the states of development are rather different as are the programme aims.

The objective of wider collaboration would be to facilitate the preservation of expertise, the search for economies in the design of FBRs, the demonstration of actinide burning fuel cycles and the construction of further commercial demonstration reactors, given that there is likely to be at least a 15 year and possibly a 20 year delay before any commercial order will be placed.

In the case of HTGCRs and other reactors used primarily for supplying heat, the aim might be somewhat different. A large part of the market envisaged for these reactors would depend on their being considered safe enough to locate near population or industrial centres. Furthermore, it has been argued, the effort involved to obtain siting and licensing consents will be disproportionately more burdensome for smaller reactors than for larger. It is therefore desirable to arrange that demonstration and licensing activities should have international rather than national significance. International collaboration to establish widely valid safety criteria and to see that HTGCR and other heating reactor concepts satisfy them would be extremely useful, although this would be an ambitious goal.

## 6. CONCLUSIONS

The following comments were made by an experts group assessing advanced technologies for water cooled reactors but they seem appropriate to all advanced nuclear technologies:

(1) The fact that reactor improvements can be made in future applications does not reflect adversely on present operating systems. It is typical of any advancing technology that experience identifies opportunities for improvement, but this does not mean that the current technology is unsatisfactory or obsolete. The desire to further reduce the residual risk of future reactor operations, for example, does not indicate that the current generation of nuclear power plants is not safe enough. Rather, some hard won knowledge has been gained which should be a foundation for further reduction of residual risk and further protection of the utility investment in nuclear plants.

(2) Such technologies should provide the public with the dual benefits of lower cost electricity and, at the same time, greater environmental and public health protection as compared to alternative energy sources.

There is evidently enormous scope for the introduction of new electricity generating capacity which, taken over the whole fuel cycle, is economical, safe and of minimal environmental impact. There seems good reason to believe that the nuclear option can measure up to these requirements. The nuclear industry has already, in some countries, demonstrated its ability to do so, and elsewhere it is taking steps to match the good performances that have been achieved. The industry is also showing the commitment of providing new technology to meet the increasing demands of competition and public acceptance. It seems realistic, therefore, to suppose that nuclear power will play an important and increasing role in furnishing secure supplies of electricity while meeting the need to protect the environment.

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# TECHNOLOGICAL AND ECONOMIC DEVELOPMENT OUTLOOK FOR RENEWABLE ENERGY SOURCES FOR ELECTRICITY GENERATION

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**Abstract**

TECHNOLOGICAL AND ECONOMIC DEVELOPMENT OUTLOOK FOR RENEWABLE ENERGY SOURCES FOR ELECTRICITY GENERATION.

Renewable energy sources are potentially capable of providing a significant fraction of world energy needs in the 21st Century. Among other reasons (security of supply, regional development, etc.), the development of renewable energies is desirable for its positive environmental impact, in particular in the area of global warming. Since renewable energy resources are well distributed over the whole Earth, they, unlike many other energy sources, offer the possibility of a global response to global change. Renewable energies were the subject of very important positive developments during the 1980s. In parallel with hydropower, which already has made a significant contribution in the electricity production of many countries, wind energy, photovoltaics, biomass, tidal and wave power can also be used for large scale electricity production in the future. The development and the market penetration of renewables in the future will strongly depend on RD&D investment. Modest budgets compared to other energy sources have been allocated for R&D on renewable energies. Further R&D, though, can improve the technical quality of products and decrease their costs. The progressive introduction of renewable energies into the future energy market requires that they be economically competitive. A large range of renewable energies which are cost competitive already exists today. It is even more the case when these energies are considered on a macroeconomic scale. The non-internalization into market prices of the external costs of energy goes to the expense of renewable energies which are then penalized in terms of macroeconomic competitiveness with fossil and nuclear energy. Market introduction and development of renewable energies cannot be achieved solely with the conventional schemes currently employed for classical products and conventional energy systems. New promotion schemes are necessary, among which an aggressive R&D strategy will play a major role.

## 1. INTRODUCTION

Generation of electricity is a major source of pollution. The classic pollution processes are far from being overcome whilst global warming has been rediscovered as a basic and additional problem. It is estimated that at least one-third of Europe's $CO_2$ emissions and 28% of the emissions in the United States of America result from the production of power. An ever increasing world population and further economic growth in industrial as well as in developing countries will stimulate energy consumption. This energy must be clean. Unlike most conventional energies, renewable energies are clean per se. All of them produce no $CO_2$. The further development of renewables for the energy scenarios of the 21st Century is of high priority because it is better to prevent pollution than to cure it.

It is estimated that renewable energy presently contributes 6–7% of the European and 8% of the US energy supply and 16% worldwide [1]. This estimate includes mostly hydroelectricity and heat for households. Several projections for various European Community (EC) Member Countries anticipate an increase of these contributions of up to 20% for the year 2010 and beyond. For the United States of America a recent report [2] predicts the share of renewables for the year 2010 to be between 11% for a business as usual scenario and 18% for a scenario with RD&D intensification. The World Watch Institute in the USA has estimated for the year 2030 a share of 50% for all renewables worldwide. In view of the usual lead time for the introduction of new energies, such assumptions may be overoptimistic. However, increasing environmental concern, as well as the threatening restrictions on the conventional energy supply side, may make some kind of crash programme necessary to accelerate the development process.

In the future, wind, photovoltaics and biomass technologies, which are all insignificant at the present time, will have a large role to play in the energy scenarios of industrialized countries. The measures which will be taken eventually to accelerate the integration of these new technologies into existing energy networks and distribution schemes will determine their future market success. But renewables can play an even more significant role in the future energy scenarios of developing countries, since they need not rely on huge electricity distribution networks. The renewables are available, decentralized and come in all suitable sizes. An intensive North–South co-operation on renewable energies is needed in order to help developing countries harness these resources to meet their future energy needs.

Compared with their state of development more than 10 or 15 years ago, renewable energies were the subject of very important positive developments during the 1980s, despite a mostly unfavourable political climate for renewable energies during that period. Today, there is a wide choice of renewable energy technologies and systems which have achieved cost competitiveness. The technical and industrial readiness of these energies and the environmental and social demand for clean and renewable energies will, without any doubt, lead to an acceleration of their development. The years up to 2000 will be particularly important and decisive for taking the right decisions on strategies, policies and implementation.

## 2. TECHNICAL AND ECONOMIC OVERVIEW OF RENEWABLE ENERGIES

### 2.1. Wind energy

Of all the renewables (excluding hydropower) wind energy is the closest to the market. There are approximately 350 MW from wind energy installed in Europe and 1500 MW in the USA. However, governments and utilities in several European countries are considering the rapid introduction of wind farms into their generation networks. By the year 2000, according to current estimates, more than 4000 MW could be installed in the EC countries.

Since the end of the 1970s when wind energy began its rapid development, the size of machines has increased continuously. In the 200–400 kW range, the production costs per kilowatt-hour are currently the lowest. Table I shows, as an example, estimated costs of electricity derived from wind with a commercial 200 kW turbine for various wind speeds [3]. The turnkey cost of such a unit, based on construction in Germany, is at present about US $1200 per installed kW. The table shows that electricity costs for wind energy look fairly competitive. This analysis is confirmed by large projects in Denmark; a total of 42 MW, employing machines in the range of 90 to 300 kW, was recently installed there at an average total generation cost of US $0.072 per kW·h.

TABLE I. ELECTRICITY PRODUCTION COSTS FOR COMMERCIAL WIND MACHINES [3]

| Wind speed (at 30 m height/m per second) | Total generation cost (US $ per kW·h) |
|---|---|
| 5.5 | 0.155 |
| 6.5 | 0.108 |
| 7.5 | 0.078 |
| 8.5 | 0.060 |

Notes: Lifetime: 15 years.
Cash discount rate: 10%.
Annual O&M costs: 2% of capital cost.
Availability: 95%.
Array efficiency: 90%.

For large scale implementation in the future, it may be desirable to develop larger machines, in the megawatt range. From the standpoint of operation and maintenance, large rather than small machines currently appear to be more suitable for utility networks. Hence much development activity in Europe is devoted currently to this goal.

There are, though, two main problems which can affect future implementation of wind energy. Firstly, there may be a limitation on the installed capacity owing to the difficulty of finding environmentally acceptable erection sites in sufficient numbers at favourable locations, i.e. those of highest wind speed. The second problem is the accommodation of large percentages of wind generation capacity in current and future electricity grids.

It has been established that sufficient sites are available in Europe to meet, if necessary, all the electricity consumption of the EC. However, many sites are ruled out for environmental reasons; hence offshore sites are being envisaged. The first experimental wind farm, consisting of 11 × 450 kW turbines is being installed in the Danish Baltic sea. The investment costs could be at least twice as high as the costs for onshore systems, and thus the difference could only be offset by the higher wind speeds over the open sea.

## 2.2. Photovoltaics

The commitment of the energy industry to photovoltaics (PVs) has recently been strongly increased. Nevertheless, worldwide markets currently in the 40 MW per year range are still very modest for PVs. At present costs of more than US $5 per watt, there are only some market niches such as telecommunication systems, power for remote houses, for islands and for special applications in developing countries, e.g. water pumping.

This market, though, is particularly important from a social standpoint. Thousands of remote houses in Italy and Spain have recently been electrified by installing PV power systems. The 3000 solar pumps installed in the rural tropical zone ameliorate considerably the quality of life of the poor population in this region. Many of the 6000 people living in the 1500 solar houses installed in Polynesia would have left if they did not have this minimum comfort.

The development of central PV plants for electricity networks is being actively pursued. Power plants in the 700–5200 kW range are currently in operation in the USA and plants in the 300–3000 kW range are being built in Europe. The generation cost varies from 40 ¢/kW·h to US $1.6/kW·h.

Photovoltaic technology has made considerable advances during the last few decades. From the 6% efficiency of the first silicon solar modules in 1954, today's efficiencies vary from 12.5% (industrial series production) to 37% (best laboratory performance).

TABLE II. ELECTRICITY COSTS FROM SMALL GRID CONNECTED PHOTOVOLTAIC SYSTEMS [4]

| | |
|---|---|
| ***Germany*** | |
| Annual irradiation (kW·h per m$^2$) | 1100–1400 |
| Cost/kW·h 1990 (¢) | 56–45 |
| Cost/kW·h 1995 (¢) | 21—15 |
| ***France*** | |
| Annual irradiation (kW·h per m$^2$) | 1100–1900 |
| Cost/kW·h 1990 (¢) | 56–34 |
| Cost/kW·h 1995 (¢) | 21—12 |
| ***Italy*** | |
| Annual irradiation (kW·h per m$^2$) | 1300–1900 |
| Cost/kW·h 1990 (¢) | 48–34 |
| Cost/kW·h 1995 (¢) | 17—12 |

It is important to note that, contrary to the long term trend towards decreasing cost, in the very short term the cost of PV modules is likely to rise, because there is a shortage of supply in the market. A few years from now, however, probably by 1995, crystalline silicon solar modules could become available at US $1.70 per peak watt as compared to US $5 today, according to estimates by the French industry. At that price, the market would no doubt increase manifold.

Table II gives an overview of kilowatt-hour costs at present and in 1995 for three countries in the EC [4]. Further in the future, the French industry estimates that with crystalline silicon solar modules, a price of 9 ¢/kW·h could be achieved by the year 2000.

Besides crystalline silicon, thin film solar cells and especially amorphous silicon still attract interest. Although virtually non-existent in today's power market, thin film solar cells in the long term remain interesting because they offer prospects to achieve ultimately a lower cost than with crystalline silicon. In particular they cost considerably less than US $1 per peak watt, at which price crystalline silicon seems to level off.

## 2.3. Biomass

Energy is derived from two large biomass resources, namely residues such as fuelwood, urban waste etc. and energy crops in agroforestry. Of even greater importance for the future is the potential of biomass energy plantations. This energy is environmentally benign since it involves no $SO_2$ emissions, has very low $NO_x$ content (less than 25 ppm) and all the released $CO_2$ can be recycled. The potential all over the world is enormous. In Europe, for example, if only the 20 million ha of land on which food production should be phased out to eliminate surpluses were used for energy plantations, a sizeable fraction of the EC fuel consumption could eventually be met by biomass. Carefully designed afforestation programmes totalling 100 million ha, envisaged under a sustainable development scenario, would be physically capable of supplying more than 30% of current global electricity demand [5].

There are several competing technical routes for the conversion and utilization of biomass feedstock with a view to the electricity market. Many biofuels, such as ethanol, bio-oil and methanol are less polluting and of a better quality than most of the conventional fuels such as coal or lignite, or even conventional oil used for electricity production. In those countries using thermoelectric stations, the biofuels could substitute for the conventional fuels, with a minimum of investment. The bio-oil, produced through the 'flash pyrolysis' process from cane sugar, could be used in thermoelectric stations for the production of 'clean' electric energy at a cost of about 7 ¢/kW·h [6].

On the large (MW) scale, purpose grown biomass, agricultural residues or municipal solid waste can be used as fuels to raise steam in a conventional boiler, using a turbine as the prime mover to drive the generator. Many such plants in the 10–50 MW range are already used to generate power from agricultural and forest industry residues. Almost 10 GW of capacity are in operation in the USA. Recent assessments of emerging technologies suggest that power plants of 5–20 MW could be designed with steam injected gas turbines using bio-oil produced from pyrolysis. This system, which could be commercially available in 3 to 4 years, offers the prospect of a significant reduction of pollution to a cost of around 5 ¢/kW·h.

At the kilowatt-hour scale, suitable for decentralized applications, electricity generation from wet residues and manure has been successfully implemented using biogas as a fuel, whilst a number of different types of small gasifiers have been integrated with internal combustion engines of various types. One approach which is currently being investigated is the modification of diesel or Otto cycle engines so that they can run on biofuels. The use of novel high temperature ceramic gas turbines could reduce the generation cost to 5.5 ¢/kW·h [7].

It is interesting to note that biomass appears to be cost competitive for all conventional energy markets today. In practice, however, the biomass market is almost non-existent. The economic costs are less relevant than the opportunity costs which represent the incentive for the farmer to grow energy crops, or for a utility to substitute a conventional fuel. Opportunity costs are difficult to determine in general terms. Furthermore, agricultural practices for biomass production, the necessary conversion devices, new turbines etc. are not yet ready. Hence the different schemes are promising in a medium and long term perspective. Further extensive effort is required to strengthen R&D and organize implementation schemes.

### 2.4. Tidal and wave power

In Europe, a 240 MW tidal scheme is currently in operation at La Rance in France, although particular interest in the expansion of this form of generation is focused in the United Kingdom where feasibility studies are being pursued on a single project across the River Severn, with a rating of some 7.2 GW and the capacity alone to produce about 5% of the UK's electricity. Apart from this one major project, studies have identified many smaller potential sites around the UK. If every reasonably practicable estuary in the UK were to be employed for tidal power, the yield would be about 53 TW·h/a representing about 20% of present electricity demand in England and Wales.

The issue of project funding is important because the cost of generated electricity is dependent on the cost of money, particularly for renewable generating technologies where most of the expenditure is 'up front' capital cost. At a 6% discount rate (currently used in the UK for public sector funds) the Severn, Mersey and two or three smaller UK sites would generate at US $0.058–0.073/kW·h and could contribute 20 TW·h/a (about 7% of UK electricity demand). With construction in the private sector, and capital discounted at e.g. 10% per year, the cost of electricity nearly doubles and ceases to be attractive when compared with coal.

With regard to wave power, attention was initially focused on large scale devices moored several kilometres offshore. However, on further investigation, such devices appeared to have little chance of being able to compete economically with conventional sources and attention was then switched to smaller scale units constructed at the sea shore.

## 3. CURRENT AND FUTURE RD&D ACTIVITIES AND GOALS

The development and the market penetration of renewables in the future will strongly depend on the RD&D investment. A US Government study recently published [2] showed that a 2.5% increase to RD&D funding would allow an increase in the penetration of renewables in the USA from the present level of 8% to 28% by the year 2030. The two alternative scenarios, business as usual and national premiums, would instead produce only 15% and 22% penetration.

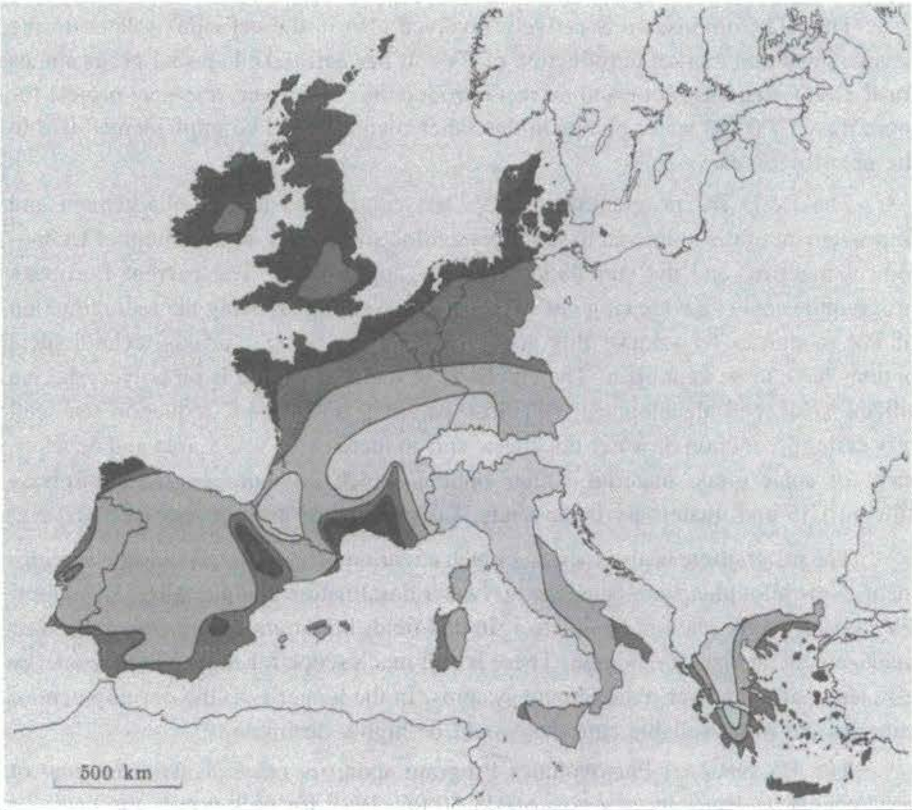
Compared to other energy technologies, the technical risk of R&D in renewable energies is low because the wide variety of options makes it possible to spread the risk and improves the probability of further success. Furthermore, renewable systems are comparatively small and can be developed on a small scale. A 'small step approach' is inherent for R&D in this field. It provides the opportunity for continuous control of success and permanent readjustment of strategies if necessary.

As mentioned before, most renewable energies are cost competitive today and their implementation first of all requires investments for industrial and commercial development. However, there is tremendous hope for further R&D to improve the technical quality of products and to decrease their costs. The situation results from the fact that R&D efforts on renewable energies were only very recent and included very modest budgets compared to other energy sources for large scale utilization. Hence many technological routes have so far remained unexplored. The performance of most products and systems can be improved.

The current R&D activities are related to the topics mentioned in the previous paragraph. Most of the industrial countries are financing R&D activities on wind energy and demonstration projects of large scale machines have accounted for large proportions of the expenditure. They have not resulted, though, in the commercial production of machines of this size. A considerable effort is still needed, using new ideas and the experience gained from these projects. One of the main objectives of the EC's DG XII wind energy R&D programme is the development of large wind turbines. In a previous energy programme, which ended in 1989, 3 MW sized wind turbines were constructed. Their evaluation is currently presented in the framework of the current JOULE programme. Moreover, after the completion of a strategy study on the characteristics of the next generation of large wind turbines, a call for proposals for the design and construction of price competitive new megawatt size machines is about to be launched.

Although the level of funding of the EC's R&D programme has been modest, it has succeeded in promoting and co-ordinating most of the R&D carried out in the EC. The European Wind Atlas (see Fig. 1) was produced and all major technological aspects related to the further development of wind technology have been addressed: development of new components (new blade profiles, new generators etc.) as well as problems arising from the large scale implementation (finding erection sites, reducing noise generation, improving wind farm efficiency, level of wind penetration, acceptability of existing electrical networks etc.).

In the USA, the wind energy research programme funded by the Department of Energy has made it a short term goal to understand the existing technical problems of the operating machines and to develop new tools and methods to help industry design advanced machines. The long term goal is to develop advanced concepts in high efficiency systems and components through close interaction with the wind industry.




| Wind resources[a] at 50 m above ground level for different topographic conditions | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Sheltered terrain[b] | | Open plain[c] | | At a sea coast[d] | | Open sea[e] | | Hills and ridges[f] | |
| | m/s | W/m² | m/s | W/m² | m/s | W/m² | m/s | W/m² | m/s | W/m² |
| | > 6.0 | > 250 | > 7.5 | > 500 | > 8.5 | > 700 | > 9.0 | > 800 | > 11.5 | > 1800 |
| | 5.0-6.0 | 150-250 | 6.5-7.5 | 300-500 | 7.0-8.5 | 400-700 | 8.0-9.0 | 600-800 | 10.0-11.5 | 1200-1800 |
| | 4.5-5.0 | 100-150 | 5.5-6.5 | 200-300 | 6.0-7.0 | 250-400 | 7.0-8.0 | 400-600 | 8.5-10.0 | 700-1200 |
| | 3.5-4.5 | 50-100 | 4.5-5.5 | 100-200 | 5.0-6.0 | 150-250 | 5.5-7.0 | 200-400 | 7.0-8.5 | 400-700 |
| | < 3.5 | < 50 | < 4.5 | < 100 | < 5.0 | < 150 | < 5.5 | < 200 | < 7.0 | < 400 |

[a] The resources refer to the power present in the wind. A wind turbine can utilize between 20 and 30% of the available resources. The resources are calculated for an air density of 1.23 kg/m$^3$, corresponding to standard sea level pressure and a temperature of 15°C. Air density decreases with height but up to 1000 m above sea level the resulting reduction of the power densities is less than 10%.

[b] Urban districts, forest and farm land with many windbreaks (roughness class 3).

[c] Open landscapes with few windbreaks (roughness class 1). In general, the most favourable inland sites on level land are found here.

[d] The classes pertain to a straight coastline, a uniform wind rise and a land surface with few windbreaks (roughness class 1). Resources will be higher, and closer to open sea values, if winds from the sea occur more frequently, i.e. the wind rise is not uniform and/or the land protrudes into the sea. Conversely, resources will generally be smaller, and closer to land values, if winds from land occur more frequently.

[e] More than 10 km offshore (roughness class 0).

[f] The classes correspond to 50% overspeeding and were calculated for a site on the summit of a single axisymmetric hill with a height of 400 m and a base diameter of 4 km. The overspeeding depends on the height, length and specific setting of the hill.

*FIG. 1. Wind resource map for the European Community Member Countries [3].*

The EC Commission is actively involved also in the activities related to the development and market introduction of PVs. It has earmarked special programmes for R,D&D, demonstration and market introduction. Moreover, a special project for more than 1200 PV water pumps in the Sahel countries will be implemented within the next three years.

The R&D EC programme on PVs has contributed to the enlargement and improvement of the industrial base for crystalline silicon, the achievement of technological maturity and the stimulation of early applications. The current European programme covers a wide range of subjects, the overall goal being the cost reduction of PV modules. To achieve this goal, for the time being, various technological options have to be kept open. The emphasis of the programme is on polycrystalline silicon solar cell development. Critical parameters for cost reduction are cell processing, reduction of wafer thickness, and an increase of wafer area and development of solar grade material. Other options which are pursued are amorphous silicon, CIS and quaternary compounds, CdSe and, last but not least, CdTe.

The programme is also focusing much attention on system technology development. New pilot plants are being set up (water desalination and pumping, PV-diesel, PV-house, 1 MW plant in Spain etc.). In this field, important parameters are power management and battery storage. There is still much scope for improving the energy efficiency of the power management systems. In the longer run, the development of cheaper and more reliable batteries would be highly desirable.

The US National Photovoltaics Program sponsors research with the goal of producing PV electricity at a cost of US $0.06/kW·h for bulk power markets. To achieve this goal, the programme conducts R&D in a variety of PV technology areas, thereby increasing the overall probability of success: advanced thin film materials (crystalline silicon, GaAs), fundamental research in developing an improved solar radiation model, software and instrumentation, collector research (flat plate and concentrator module) and systems research (with the focus on improving PV system performance and cost).

The bioenergy sector is not explored very much. There are many innovative techniques and technologies involved which still need experimentation. For this reason, there is R&D activity in all aspects of bioenergy: biomass production, biomass conversion and the electricity production process.

The research activities have permitted the identification of the most appropriate crops for energy conversion: woody species (short rotation forestry), annual and perennial grasses and other C4 plants, in particular, sweet sorghum and miscanthus. Grasses and sorghum may be ground into a powder suitable for the direct feeding of high temperature turbines in the few hundred kilowatt range. For large power plants, charcoal and/or oils obtained by pyrolysis of lignocellulosic material are possible fuels [8]. The current RD&D activities should prove the promising economic prospects of the use of these crops.

Flash pyrolysis is one of the most attractive thermochemical routes by which biomass can be upgraded to fuels and chemicals. It is the one which promises the best results for the production of bio-oils. A number of different approaches have been taken in order to optimize an efficient pollution free system. These include the construction of a 1 t/h fluid bed pilot plant in Raiano, Italy, whose main products are charcoal and oil. The efforts in this area are continuing.

As far as the technologies involved in multimegawatt power production units are concerned, the focus is on the development of systems integrating the flash pyrolysis process with steam injected gas turbines. They could be available in a few years.

For the smaller systems (kilowatt scale), studies on the possibility of using novel high temperature small turbines, fitted with ceramic parts, are being carried out as part of a programme on small scale electrification funded by the EC. It is believed that these turbines will be able to run on a number of different types of biofuel, including solid particulate material and bio-oils. These turbines are expected to run at high efficiencies of 40–50% compared with conventional internal combustion engines at 20–30% efficiency. The first pilot project, consisting of a 500 kW mobile unit, is currently under construction.

The R&D activities should be intensified. In the following list, some R&D goals are outlined which should be achievable by the year 2000:

- For PVs, the target is to achieve competitiveness with conventional grid power. To this end, a production cost of PV modules of 1000 European Currency Units (ECU)/kW has to be demonstrated by the year 2000.
- For wind energy, the challenge is to develop commercial machines in the megawatt power size. The target is to achieve a cost of 1000 ECU/kW per installed operational 1 MW machine for sites with more than 6.6 m/s average wind speed.
- Biofuels derived from agricultural biomass plantations have to become cost competitive with conventional fuels, in particular with coal and oil. C4 plants (sweet sorghum is a good example) are promising to achieve sufficiently high yields for producing bio-oil at a cost competitive with heavy fuel oil, while providing the farmer with an attractive yearly income. Crude bio-oil could then be produced at 125 ECU/t or less.

## 4. RENEWABLE ENERGIES AND THE ENVIRONMENT

Concerted coverage by scientists, politicians, legislators and the media alike has brought matters of the environment to everyone's attention. As a result there is widespread concern about the environmental effects of conventional energy consumption. Burning fuel produces polluting emissions which contribute to global warming and acid rain. The great advantage of renewable energies is that they are clean per se and produce no $CO_2$. Moreover, since renewable energy resources are well distributed over the whole Earth, they offer the possibility of a global response to global change.

In order to fight the danger of global warming, leading industrial countries have agreed to reduce $CO_2$ emissions by 20% by the year 2005. Much progress is expected through energy saving. However, gains that could be achieved by improved energy efficiency in industrial countries may be more than offset by relatively small increases in energy consumption per capita in the developing world. It may therefore prove difficult even to stabilize fossil carbon emissions anywhere near current levels by conservation measures alone. There is a clear role for renewable energies to augment the impact of energy efficient technologies.

For every 1 kW·h of electricity generated by renewable energy rather than coal, the emission of 1 kg of $CO_2$ is avoided. In Europe, approximately one-third of the $CO_2$ emissions come from electricity generation sources. For every 1% of conventional generation capacity displaced by renewable energy, a 0.3% reduction in $CO_2$ emissions is obtained.

The reduction of $SO_2$ and $NO_2$ emissions which contribute to acid rain are an important part of the environmental impact of renewable energy. Again the clean nature of renewable energy means that it is free from such pollutants.

## 5. MARKET PENETRATION PERSPECTIVES

### 5.1. The potential world renewable power market

The world market for power production from renewable energies can be divided into three quite distinct markets: grid connected in the industrialized world, grid connected in the developing world and stand alone systems.

The grid connected market in the industrialized world is the largest market at present. The already existing installations are mainly hydroelectric, but there are 9 GW of bioelectricity and 1.5 GW of wind power installed in the USA and 350 MW of wind power in Europe. In Denmark, 1.4% of the country's electricity production is presently covered by wind energy. Studies, though, predict significant contributions of the renewables in the USA and the EC power generation systems for the years 2010 and 2030. In a study by the European Wind Energy Association, performed for the EEC, the possible impact of wind power for 2010 is estimated at 2.5% of European electricity production and at 10% for 2030.

The size of the market in the industrialized world outside the USA and the EC is very difficult to quantify, but there is presently considerable activity in Australia, Canada, Israel and Sweden. It is within the EEC that the major market developments will take place in the near future.

Pollution problems combined with a chronic shortage of power make eastern Europe a very attractive market for renewables. However, there is little internal money available to finance such activities and foreign aid would be required to initiate any major programme.

There is a potentially vast stand alone market in the industrialized as well as in the developing world. Technical developments are required though before this market can readily be exploited.

Although the forecasts for the per capita energy consumption in the industrialized world show a small decrease in the coming decades, the opposite is true for developing countries. This fact combined with the rapid growth of the population in those areas (United Nations forecasts give an estimate of 6.9 billion ($10^9$) people in the developing world for the year 2025 compared with the actual 4 billion) will certainly pose a threat to the world's environment, which the renewables could reduce significantly. However, developing countries alone cannot, and should not, pay the price of a problem which concerns the whole world. They have neither the expertise nor the financial strength to develop modern renewable energy systems.

In many areas of the world, the only economically feasible way to meet the energy needs of the population is through the use of decentralized power systems. Renewable energy systems are the most appropriate for such applications. The short term needs can be covered with the introduction of small systems for pumping water and battery charging. The use of renewables can encourage public acceptance of the technologies and can help in the development of local expertise which can then be used in a later stage for the adoption of larger systems.

### 5.2. Steps towards implementation

For renewable energy to make a significant contribution to the electricity requirements of the world in the relatively near future, its development must be stimulated. Otherwise, society will not be able to benefit from its environmental and social advantages. Lead time under normal conditions for new energy sources is in the order of several decades.

The Brundtland Report says that "every effort should be made to develop the potential for renewable energy which could form the foundation of the global energy structure during the 21st Century" [9]. At the heart of the notion of sustainable development is the ethical imperative that the stock of environmental capital must be preserved for future generations. To a degree, of course, this ethical premise limits the role of markets. Translated into practical terms, it means that the economic assessment of all forms of energy must include external costs.

### *5.2.1. External costs of energy*

There are at least four different types of external costs which should be considered when comparing renewable energies with conventional sources and utilization schemes. The first concerns pollution effects due to $SO_2$, $NO_x$, radioactive fallout or other emissions. The second concerns the greenhouse effect. The third is related to the benefits accruing to a national economy as a result of the domestic production of energy and the consequent displacement of imported fossil fuels. The fourth has to do with the cost involved in the military or other protection needed to secure the sources of supply.

As regards chemical and radioactive pollution, most of the economic consequences have still to be evaluated. A start has been made for electricity production in Germany [10] with the conclusion that the external costs of fossil energy utilization are in the range of up to 4¢/kW·h and in the case of nuclear up to 8¢/kW·h of electricity produced. For renewable energies, the external costs would be negligible. For the USA a study concluded that for fossil sources, external costs could be up to 7¢/kW·h. These external costs depend in any case on local conditions and the detail of electricity networks.

The second environmental effect to be considered as an external cost of energy production is global warming. It is estimated that the cost of fossil fuels would have to be increased in the range of 50–150% of present energy prices in order to attain a $CO_2$ emission reduction of the order of 20%, if price regulation alone were relied upon. Hence, the external costs involved in $CO_2$ emissions are extremely high and may dramatically change economic competitiveness in favour of renewable energies.

The Commission of the European Communities discussed at the beginning of 1991 a global price increase of conventional energy in the order of US $10/barrel mark-up. Three-quarters of such a new fiscal instrument would represent an energy tax reflecting the thermal equivalent content of fuels. The other quarter would represent a carbon charge modulated according to carbon content. Renewable energy sources would, in principle, be exempted from these energy taxes and charges. The development and increased use of renewable energy sources could make a significant contribution to the limitation of $CO_2$ emissions in the medium and long term perspective.

The third factor having a macroeconomic impact involves the national economy. When renewable energies are produced in a country, new industrial activity and new jobs are created, thus contributing to the gross domestic product and producing tax revenues. The renewables displace imported fuels which do not have these effects. Furthermore, the balance of payments is improved accordingly. In quantitative terms it is estimated that these two effects add virtually another US $5 per barrel equivalent to the advantage of renewable energies.

A fourth aspect involving external costs for conventional energies is the need for protection of conventional resources and their exploitation. This includes, for example, protection of nuclear installations. It would also include military expenses for the protection of oil resources in the Persian Gulf region and elsewhere. This additional cost of oil could add an extra US $10 per barrel equivalent.

Obviously, all the above costs to society have not been internalized so far, but they should be. The overall cost of each energy system would then be reflected in market prices, much to the benefit of the renewables.

### 5.2.2. *Need for action*

In the free market economy, new products are accepted by the market only if they are cheaper and/or more convenient than conventional products. Conventional energy systems involve long development and construction times. Renewable energies therefore must become part of a long range planning process so as to profit from the opportunity windows in the overall installation process of energy capacity in the various sectors of utilization.

It will not suffice to ensure that renewable energy products are as good and as cheap as conventional products in the market place. They must be better and cheaper. This can only be achieved by a number of specific promotional measures. The following measures would all be necessary:

— At the national and international levels, policy decisions have to be taken and market goals defined in order to set a general framework and express the willingness of the decision makers to foster the development and market introduction of renewable energies.
— A first prerequisite of market introduction is the development of well designed products already industrially and commercially available for easy utilization and integration. For complete production systems, in particular if they involve a high degree of complexity, demonstration projects are needed to give an example.
— Regulations are necessary to make the existing energy networks accessible to this new source of decentralized and renewable energy. This applies in particular to the feeding of renewable electricity into utility networks. It should be noted that significant progress has been made in the last few years in Europe to achieve co-operation with the utilities for the rising renewable electricity input to the grid and to reimburse suppliers at an appropriate rate. For renewable fuels, and in particular biofuels, the same requirements have to be fulfilled concerning integration into the conventional oil and gas networks, including refineries etc.
— Financial support is of critical importance in order to improve the market competitiveness of renewable energies. Direct subsidies for development, manufacturing and utilization of renewable energy products have to be considered. A second instrument for the same objectives is the combination of tax

deduction and cost shifting in favour of renewable energies through charges for conventional energies. It is important to note that these measures are not meant to develop unfair competition at the expense of public budgets. On the contrary, these subsidies should reflect and be quantitatively in accordance with the macroeconomic cost-benefits of renewable energies for society, i.e. these subsidies are the result of the internalization of external costs. They are in the financial interest of society and not at its expense.

— Upstream of market R&D there remains an essential instrument of promotion, namely initial R&D and scientific and technological promotion. These activities are the starting point of improved performance and reliability of products and systems as well as of further cost reductions.

## 6. CONCLUSIONS

Renewable energies will experience an important development in the next century. They will contribute considerably to the resolution of the environmental problems worldwide.

Technical and economic analysis shows that many of the renewable energies are going to become cost competitive with conventional energies in purely economic terms, and even more so if external costs are taken into account.

The rate of the introduction of renewable energies into the electricity generation systems will depend on the way they will be involved in the energy planning process. Public support for R&D and market introduction will be essential in that respect. It is important to recognize that, although some parts of the world have free market economies, the energy market is not free. It is regulated and it cannot exist without planning. For the future, renewable energies must be included in such a planning process, however in a way which is different from the conventional methods employed. Renewable energies need decisions made and methods implemented which are specific to them.

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# SUMMARY OF THE DISCUSSION OF KEY ISSUES

## Topical Session 2

*Chairman:* **P.U. Fischer** (Switzerland)

*Rapporteur:* **S. Garribba** (International Energy Agency) (IEA)

*Panellists:* **J. Beurskens** (Netherlands)
**G. Booras** (United States of America)
**T. Kanoh** (Japan)
**H.-D. Schilling** (Germany)
**B. Semenov** (International Atomic Energy Agency) (IAEA)
**V. Sidorenko** (Union of Soviet Socialist Republics)

P. MATHIEU (Belgium) wondered, given the alternatives of an integrated gasification combined cycle plant (IGCC), a pressurized fluidized bed combustion plant (PFBC) or an advanced pulverized coal steam power plant, what would be considered the best choice for decision makers in industrialized countries which had no nuclear programmes or where the nuclear programme had been stopped or suspended. He personally would recommend an IGCC plant, since it was modular and flexible in terms of construction, fuel type and operation mode. Construction, and hence the capital cost involved, could therefore be phased. As a result, the financial risk was lower and the growth in electricity demand could be followed more closely. Moreover, IGCC plants permitted a sulphur retention level of more than 99.9%. There was evident interest in such a plant in the Netherlands, where a demonstration unit had been built in Buggenum with a rating of 250 MW(e); it was expected to be upgraded to 600 MW(e).

H.-D. SCHILLING (Germany) agreed that it was worth developing IGCC plants and noted that development was under way in Japan and the USA. The plant mentioned at Buggenum, with incidentally a capacity of 285 MW(e) not 250 MW(e), was under construction, but not yet completed and would not become operational until 1993. A second plant, with a capacity of 300 MW(e) and due to become operational in 1995, was under construction in Germany. It was based on brown coal and used the high temperature Winkler brown coal gasification technology. Any decision regarding the construction of a commercial plant would depend on the operational results of these plants, in terms of efficiency, availability and operational safety. If a decision was taken to construct a commercial plant, such a plant could not expect to become operational before the year 2000.

T. KANOH (Japan) said that the prospects for improvements in the thermal efficiency of combined cycle power plants were very good. In Japan, construction of generators of this type at the Yokohama power station would begin shortly. They were expected to have a thermal efficiency of 47%; relative to the current 38% efficiency this meant a 24% reduction in both fuel consumption and $CO_2$ emissions. Coal gasification and combined cycle plants presented very promising possibilities for the clean use of coal in the medium and long term. Coal was an attractive resource with extensive availability and low costs. Research was being carried out in Japan and one of the recent developments was the establishment of the IGCC Engineering Research Association to undertake research and to develop a 200 t/d pilot entrained flow coal gasification combined cycle plant. It was expected that these efforts would culminate in the successful development of an IGCC with a unit capacity of over 250 MW and a thermal efficiency of more than 43% by about the year 2000.

G. BOORAS (USA) said that in view of the low capital cost of combined cycle plants (US \$500–US \$600/kW) and the availability of relatively low cost natural gas, several utilities in the USA were considering the phased construction of natural gas fired combined cycle plants allowing for the addition of coal gasification. Such plants would also provide great flexibility and enable utilities to respond to changes in fuel prices and in the availability of natural gas. Natural gas prices were expected to escalate much faster than coal prices, and with the increase in price of natural gas, gasification facilities could be added to allow the combined cycle to fire clean, coal derived gas. This phased concept has been demonstrated by the Dow Chemical Company at its Plaguemine facility in Louisiana, where two natural gas fired Westinghouse 501D gas turbines have been modified to burn syngas from a Dow coal gasifier. This concept provided utilities with increased fuel flexibility and the gasifier was added only when the projected fuel prices showed that it was economically advisable. There were many issues to be considered before initiating a phased construction programme, including selection of site, selection of the gasification process, degree of prior investment, degree of integration between the combined cycle and gasification plant, etc. These issues have been discussed in a recent report by the Electric Power Research Institute (EPRI), Palo Alto, on the phased construction of gasification combined cycle power plants.

P. DASTIDAR (IAEA) pointed out that in Key Issues Paper No. 2 no explicit distinction was made between mature commercial technologies and potential technologies of the future. It was important to make such a distinction, since promising new technologies might not realize their apparent potential, as seemed to be the case for example of magnetohydrodynamics.

G. BOORAS (USA) disagreed with this statement. In his view a distinction had been made in the paper between mature commercial technologies and future emerging technologies. It was recognized that many of the advanced technologies were currently in the early stages of development and that many existing commercial technologies were expected to demonstrate cost and performance improvements over the following few decades. Assessment of technologies in the paper was therefore divided into three decades: 1990–2000, 2000–2010 and 2010–2020. The efficiency, environmental emissions and costs for the various power generation technologies were shown only for the time period in which the technology was expected to become commercially deployable. For example, in Table IV, integrated gasification fuel cell power plants were not expected to be commercialized until 2010 and therefore no values were shown in the table for the first two periods.

H.-D. SCHILLING (Germany) noted that within the next 40 years mankind would use more energy than the total cumulative use so far, the greatest share being made up of coal, mineral oil and natural gas. Consequently, the emissions would be nearly as high as all the emissions accumulated so far, particularly for $CO_2$. Development of new technologies was necessary, but they normally required a period of at least one human generation to reach full maturity. Available technologies therefore had to be applied as soon as possible, particularly in those countries where there was a great potential for improvement and further development. There were a number of options for reducing $CO_2$ emissions, including retrofitting of plants, especially in countries with low efficient technologies, increased use of district heating plants, of co-generation plants, of coal based combined cycle plants, including coal gasification, of nuclear power plants, and finally of hydroelectric power plants, for which there was great worldwide potential. Solar and wind energy should be further developed, but they could not be relied upon to solve the energy and environmental problems of the coming decades.

H. KHATIB (World Energy Council), noting that much optimism had been expressed regarding the future efficiency of electricity production but that little had been said about the costs and investment requirements, wondered whether a cost–benefit analysis had been carried out. Developing countries, in particular, lacked the financial resources to invest in modern technology that was environmentally more acceptable.

J. BEURSKENS (Netherlands) agreed that Key Issues Paper No. 2 included little information on the costs involved, but the background papers, which would be published in the IAEA-TECDOC Series, would contain quite detailed information on the costs; in most of the papers, an explicit economic model was presented which could be used to calculate the costs per kilowatt-hour.

G. BOORAS (USA) pointed out that although it was true that many of the more advanced fossil fuel technologies involved higher capital cost, they were generally more efficient than the older technologies and the savings in fuel costs resulting from greater efficiency would more than offset the higher capital cost of advanced technologies.

F.H. HAMMAD (Egypt) noted that although the use of nuclear energy had led to accidents such as those at Three Mile Island and Chernobyl, which had cast doubts about the future of nuclear energy, it did provide a solution to the problem of global warming and, as such, was an option which should be pursued in developing countries. Use of nuclear energy in developing countries would have several advantages: it would minimize emissions of greenhouse gases; it would extend the lifetime of fossil fuel reserves; and, provided the record of operating safety was good, it would help to improve public acceptance of nuclear power in industrialized countries.

B. SEMENOV (IAEA) agreed that developing countries should not be excluded from the list of potential beneficiaries of nuclear power. However, the timing for the introduction of nuclear power and the scale of its development was different for different countries, depending on the energy and electricity requirements, the availability of resources and the situation in terms of infrastructure and manpower. Some developing countries had already very successfully demonstrated wide use of nuclear power. In the Republic of Korea, for example, nuclear power plants accounted for about 50% of the electricity production.

G. SANCHEZ-SIERRA (Organización Latinoamericana de Energía) (OLADE) said that, in theory, renewable energies were a good area for increasing North–South co-operation. However, in practice, the situation was very different. There had been virtually no North–South transfer of technology over the past decade in the area of renewable energies, particularly in the cases of wind energy and photovoltaic cells.

J. BEURSKENS (Netherlands) agreed that international co-operation in renewable energies between industrialized and developing countries was virtually non-existent, although it did exist between industrialized countries. Promising initiatives for bilateral co-operation with developing countries in the area of renewable energies had proved unsuccessful owing to undue optimism on the part of those involved. It was unrealistic to assume a development period of 3–4 years for the application of such technologies in areas where no infrastructure existed. Incorrect perception of the development times needed before successful commercialization had suggested that renewable energy technologies were unsuitable. However, if reasonable periods of time for the introduction of such technologies were accepted and if the work was carried out on a proper bilateral basis and on a small scale, such schemes could be introduced successfully. Too much emphasis had been placed on commercialization rather than on R&D. Increased R&D budgets for renewable energies in industrialized countries would offer possibilities for greater international co-operation and it was up to multinational organizations to take more initiatives.

T. KANOH (Japan) noted that in the case of hydroelectric power, resources were available in developing countries, but they were generally situated a long way from the point at which the power was needed. Furthermore, lack of resources and infrastructure hampered development. To overcome these problems, surveys should be promoted and international co-operation developed. In the case of photovoltaic cells, it was still uncertain whether the existing type of cell would be widely used in industrialized countries located at higher latitudes in the northern hemisphere. However, this type of energy ought to prove more useful in arid countries and in developing countries in the equatorial zone where solar energy was abundantly available. It would be worth considering supplying power generated in this way to other areas via superconductive transmission.

S. GARRIBBA (IEA) said that in the case of photovoltaic cells, international co-operation was also difficult among industrialized countries. There were a number of bilateral agreements in this area, but co-operation was difficult because a number of the technology advances might also have non-energy implications and were therefore well protected. There was also keen competition among many of the developers of this technology. The situation was less complex for wind energy. Since wind energy was much more local in nature than solar energy, co-operation in this area was determined by the availability of the resource base.

E. MARSHALL (United Kingdom) noted that it was essential to include environmental costs in comparative economic assessments of different power generation technologies. Failure to include such costs gave a false impression of the true economics. She wondered whether environmental cost data and scenarios could be included in the material on comparative power generation economics prepared for the 1992 United Nations Conference on Environment and Development.

G. BOORAS (USA) agreed that environmental costs should be included. In Key Issues Paper No. 2, the cost of electricity for various power generating technologies had been compared using the conventional generation cost methodology, which included capital related costs, operating and maintenance costs and fuel costs. No attempt had been made to include the full environmental cost of emissions generated by each technology, since there was not yet any generally recognized method for establishing the magnitude of these external costs.

In his organization, the EPRI, work had begun on the development of methodologies to internalize the cost of atmospheric and solid waste emissions. It was believed that such work would ultimately provide a more valid comparison of different power generation technologies. The cost of various atmospheric emissions would, in theory, be based on the incremental cost of controlling or eliminating the given emissions. For example, in the USA, new legislation to control atmospheric pollution was expected to permit trading of sulphur dioxide emission allowances. Utilities would be faced with the decision to control emissions by adding flue gas desulphurization equipment or to buy emission allowances. The market value of these emission allowances would then establish a reference cost for sulphur dioxide emissions from the various power generation technologies.

H.-D. SCHILLING (Germany) believed that, at least in industrialized countries, the costs of technologies to avoid environmental impacts, although high, were bearable. In Germany, for example, the cost of a programme to reduce sulphur and nitrogen dioxide emissions was DM 22 billion ($10^9$), with running costs of DM 5 billion per year, amounting to DM 300–400 per capita.

B. SEMENOV (IAEA) said that as a representative of nuclear technology he welcomed the question and fully agreed that all health and environmental costs, or at least the costs of pollution prevention and waste management for the whole fuel cycle, should be included in the electricity generation costs. Of course, it was very difficult to quantify the health and environmental impacts of different energy sources. As far as air pollution was concerned, normal operation of nuclear power plants produced virtually no air pollution. However, in the case of organic fuels, the electricity production cost should include either the cost of prevention measures or the cost of the harm or damage caused to the population and the environment. With regard to solid or liquid wastes related to electricity production, although all wastes from the nuclear fuel cycle were properly managed and the total fuel cycle cost (including waste management and disposal) was normally included in the electricity generation cost, he was not aware that a similar approach was adopted in other electricity generating industries which produced large amounts of harmful wastes such as heavy metals, fly ashes, etc.

H.-D. SCHILLING (Germany) pointed out that solid waste from fossil fuelled plants could be used in the area of civil engineering. In Germany, for example, 92% of the ash from hard coal power stations was used in the civil engineering industry and, in fact, the subsidiaries of large utilities made a profit from this waste.

J. VAN DE VATE (IAEA) said that it was claimed in Key Issues Paper No. 2 that natural gas fired technologies had lower $CO_2$ emissions than coal fired technologies. He disagreed with this view. On the basis of the $CO_2$ production rates, natural gas was preferable to coal as an energy source. However, the additional greenhouse effect of methane emissions from natural gas increased the greenhouse effect of natural gas substantially. He believed that the globally averaged leakage rates of natural gas were much higher than was usually shown and were, in fact, in the order of 10% of natural gas consumption. Furthermore, the global warming potential (the factor needed to determine the $CO_2$ equivalence of greenhouse gas levels) of atmospheric methane was very high when the indirect effects of methane were included. Taking into account global considerations related to methane sources and sinks and the fossil content of atmospheric methane, an estimated fossil methane rate of about 100 Tg/a was obtained. By subtracting the emissions from coal mining and methane hydrates, which accounted for about 30 Tg, one obtained a figure of about 70 Tg/a for natural gas related releases. Given a global natural gas consumption of 1000 Tg, the leakage rate was of the order of 10% of natural gas consumption. On the basis of this percentage and assuming a global warming potential for methane of 50 (which took into account the indirect greenhouse effects of methane), the greenhouse effect of natural gas appeared to be 20–30% higher than that of coal.

S. GARRIBBA (IEA) pointed out that methane had a different time-span in terms of $CO_2$ equivalence and that the data on natural gas leakage presented by J. van de Vate (IAEA) were very much on the high side. There were also leakages of natural gas associated with coal mining which depended on the type of coal and the type of mining. It was therefore difficult to maintain that the $CO_2$ equivalent emissions of natural gas were higher than coal.

K. KING (World Bank) (IBRD) said it was evident from Key Issues Papers Nos 1 and 2 that, even with very stringent efficiency improvements, the current mix of supply technology, coupled with rapid economic development in the developing world, would not permit stabilization of atmospheric greenhouse gases for a very long time. Alternative supply strategies therefore had to be selected for the longer term (25–40 years) and alternative R&D funding scenarios had to be established. Key Issues Paper No. 2 appeared to imply that nuclear energy would retain the lion's share of the budget for R&D. However, despite sustained and massive funding, nuclear power was still a modest contributor to the world's energy needs and posed still unresolved problems of public acceptance. If an alternative funding scenario was considered whereby new and renewable energy forms were funded as generously as nuclear power, he wondered whether the tremendous cost reduction achieved in the last decade in solar and other technologies would continue to the point where it would be possible for future electricity production to exclude both nuclear and fossil fuel.

G.R. GROB (Switzerland) also wondered why, worldwide, only a small fraction of the money allocated for research in the area of nuclear energy was set aside for the development of clean renewable energies.

J. BEURSKENS (Netherlands) agreed that in many, but not all, cases R&D budgets for renewable energies were marginal compared with the budgets available for other very long term sustainable energy options such as nuclear fusion. He believed that the allocation of larger R&D budgets for solar energy, wind energy and biomass could accelerate the commercialization of these systems. International organizations could play a much more active role, particularly in the promotion of demonstration projects, which were a very useful vehicle for international co-operation.

B. SEMENOV (IAEA) pointed out that it was his understanding that in the USA the figures for expenditure on R&D in the areas of renewable energies and nuclear energy were comparable. However, he believed that the reason why less money was generally made available for the development of renewable energy compared with nuclear energy was related to decision makers' expectations of quick, reliable returns on the money spent.

T. KANOH (Japan) said that he believed that a multifaceted approach should be adopted in the allocation of R&D resources so as to cover all types of energy and technology and that flexibility in considering the strengths and weaknesses of each type was needed.

L. D'ANDREA (Economic Council for Europe) (ECE) wondered what oil prices would be needed to encourage the private sector to invest on a large scale in the development of renewable energies. As the introduction of new and renewable energies was promoted in the 1970s when there were high oil prices, it appeared that prices were the key to the commercial introduction of these types of energy.

J. BEURSKENS (Netherlands) noted that, even with existing oil prices, private companies were already investing in renewable energy systems in a number of countries, e.g. Denmark and the USA, where there were virtually no subsidies, and in the Netherlands, where private companies and banks were legally able to invest in renewable energy plants. For the time being, these investments were primarily in the area of wind energy, since solar energy was still too expensive.

H.-D. SCHILLING (Germany) wondered whether, in the case of wind energy, a backup solution or conventional power plant was necessary when the wind was not blowing.

J. BEURSKENS (Netherlands) said that the load factor and the capacity credit had to be considered. With the current mix of systems, as long as the additional plants were a small fraction of the total installed capacity, storage was not necessary and the capacity credit was equivalent to the average power of the additional plants, which was about 20–30% of installed power in the case of wind energy. The capacity factor could be included in the cost factor, as was done for fossil fuel and nuclear plants also not having a capacity factor of 100%. If penetration increased to more than 20–30%, storage systems would have to be used, thereby increasing the cost of renewable energy sources.

A. PALMGREN (Finland) wondered what basis was used for estimating the 'social cost' of 8 US cents/kW·h for the radioactive wastes from nuclear plants mentioned A. Zervos in his paper (SM-323/21). In Finland, the costs, included in the price of electricity, of all radioactive waste management and decommissioning of plants was calculated to be approximately 0.5 US cents/kW·h, which was less than 10% of the figure quoted by A. Zervos (CEC).

S. GARRIBBA (IEA) noted that the reason why the external cost and internalization of the external cost had not been included in Key Issues Paper No. 2 was because there was no recognized methodology for doing so. Without an explicit agreed methodology, figures such as 8 US cents/kW·h for radioactive wastes from nuclear plants were rather arbitrary.

O. HOHMEYER (CEC) *(Consultant)* said that the figures on the external costs of nuclear power quoted by A. Zervos (CEC) were based on two studies, one by himself, referenced in the paper, and one by Ottinger et al. entitled The Environmental Costs of Electric Power Production. Both studies referred to the cost of nuclear accidents involving major releases of radioactivity rather than the cost of radioactive waste disposal.

F. HORIYA (Japan) wondered how public concern about nuclear energy could be resolved so that nuclear power generation could contribute to the future electricity system.

V. SIDORENKO (USSR) noted that after the Chernobyl accident there had been strong opposition to the construction of new nuclear power plants in the Soviet Union. However, in the last few months the first signs of new attitudes had emerged. The local authorities in five or six regions were considering the siting of new nuclear power plants or had decided upon the construction of new units. Three main factors were responsible for this change in attitude: as a result of political and social changes, there was now more participation by the local authorities and the general public in decisions affecting the population; the development of new regional economic structures had given greater economic independence and greater responsibility for energy supplies to local authorities; and there was better understanding and improved public awareness of the technological and safety aspects of new plants.

# COMPARATIVE ENVIRONMENTAL AND HEALTH EFFECTS OF DIFFERENT ENERGY SYSTEMS FOR ELECTRICITY GENERATION

**(Topical Session 3)**

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# CHAIRMAN'S REPORT

# COMPARATIVE ENVIRONMENTAL AND HEALTH EFFECTS OF DIFFERENT ENERGY SYSTEMS FOR ELECTRICITY GENERATION

## Key Issues Paper No. 3

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## 1. INTRODUCTION

For those of us who have been concerned with issues of fuel supply and fuel use for 15 years or more, we find ourselves now witnessing an essentially similar situation to that of the mid-1970s. This action replay relates to the similar conditions that exist now and those from about 1975, when new technological responses were sought to alleviate the effect of oil price rises; but now, post-Chernobyl, post-Intergovernmental Panel on Climate Change (IPCC), and post-$SO_2$ and $NO_x$ Protocols, responses are required to meet new environmental concerns and expectations. Today, fuel use shifts versus fuel use reduction is again on the agenda, at least in developed countries.

It is this focus on environmental impacts, including health effects resulting from the use of different fuels and technologies to generate electricity, that has been the concern of International Expert Group 3. The paper presents the Group's considered conclusions.

Simply put, the Group asked itself, is it possible to assess the health and environmental risks of different methods of electricity generation (employing different fuels and different technologies) in such a way that useful, even quantitative, indications can be given to policy makers concerned with planning developments in the electricity generating sector? As you might expect, the answer is, well, yes and no! Let me first give you the good news.

## 2. COMPARATIVE RISK ASSESSMENT AND HEALTH IMPACTS

Since the 1970s, detailed, carefully delineated assessments have been undertaken on the health impacts of fuel use, including fuel used to generate electricity.

The system to be assessed has been carefully delineated, and the precise fuel used and the technology employed have been characterized. Distinctions have been made between the effects on the workforce and the general public. The resulting mortality estimates have been distinguished from morbidity. Short and long term effects have been assessed separately and routine operation effects distinguished from accidents. Records have allowed epidemiological studies to be undertaken. Experimental evidence from in vivo and in vitro test systems have been employed in assessments and theoretical results from models have been used to help assess present and future risks.

By normalizing health risks on the basis of a unit of electricity generated each year (for example, fatalities per GW(e)·a), comparative assessments have been established. Thus, for the coal fuel cycle (coal → electricity) it has been possible to assess the immediate and delayed risks from underground and surface mining, from the transport of coal and from the power generation system. It has been feasible to do the same where oil, gas, peat or nuclear fuel, and other fuels, have been used. Comparable fatality rates, in the occupational and public sectors, for immediate and delayed effects are then obtainable.

Much of this patient, detailed work forms the basis of our knowledge of effects, and protection through the standards evolved and the control technologies adopted to meet them.

However, the bad news is:

(a) There have been deficiencies in delineating entire fuel cycles, either through lack of care or failure to obtain a full data set
(b) Difficulties do arise when making comparisons where different technologies, safety measures and pollution controls are applied, and in transferring estimates from developed countries to developing countries
(c) It is not easy to take account of changes in practice that occur over time
(d) Mortality is better documented, and can be better estimated, than the risk of disease (morbidity)
(e) Low level risk may be difficult to detect and difficult to estimate correctly
(f) Comparative risk assessment in relation to environmental receptors is poorly developed and lacks a generally accepted conceptual and methodological framework.

These problems mean that it is not usually possible to come forward with a single assessment value that can be used directly in making policy decisions. It is this fact that, to some extent, has led to the lower profile of comparative risk studies in recent years.

## 3. ENVIRONMENTAL IMPACTS OF DIFFERENT ELECTRICITY GENERATING SYSTEMS

Assessment and comparison of the environmental impacts from different energy sources used in the generation of electricity are not easy matters. The waste substances generated may enter the atmosphere or aquatic systems, or affect terrestrial systems. Waste products change their chemical form, interact and move from one sink to another, each displaying different residence times and effects. The relationships between the time and point of release, and the time and point of effect are poorly understood. There is no 'common' receptor (such as man, for health effects). Thus, it is not possible to identify a common criterion by which to assess and compare impacts. Not only are the effects not susceptible to quantification, but there is also no general agreement on what should be quantified.

Three main methods have been emerging that allow some kind of comparison of environmental impacts:

(a) **Ranking assessment procedures** are well developed in certain areas of environmental assessment and it is possible to display the relative importance of impacts for a range of fuels, at various stages of the fuel cycle, so that the major effects that need attention are clearly exposed. The approach is non-parametric and not ideal for comparative purposes, but in the absence of other methods may constitute a useful start to the comparative assessment process. An example of this is given in the paper.

(b) **Emission values and ambient quality indices**, normalized per unit of electricity generated, represent another method of initiating assessments of environmental impacts.

(c) **The critical load and critical level concept** is a useful tool for quantifying environmental impacts. A limit is set below which it is estimated that damage will not occur. If information is available on how far these loads are exceeded, or likely to be in the future — either in terms of absolute excess or, more satisfactorily, in terms of the excess in relation to the critical value — then this may be taken as a quantitative measure of the likely impact on the ecosystem. Such values of excess may be compared to obtain comparative risk estimates. Further, with modelling facilities it is possible to investigate what effect various levels of abatement will have and to compare this with other control options.

In considering environmental impacts, it is necessary to take account of the scale of such impacts. Local effects are likely to be susceptible to effective control. However, where large quantities of fuel are burnt, even with highly efficient control devices, discernible local impacts may occur.

Regional environmental effects, such as those due to sulphur dioxide and nitrogen oxide emissions, raise significant economic and political issues. Such gases, or their transformation products, are transported over long distances before being deposited. Thus, impacts may only remotely be linked to emission sources and a degree of co-ordinated abatement action, involving many countries, will be necessary. Within Europe, $SO_2$ and $NO_x$ International Protocols have begun to address this problem, as feasible control technologies are available and variously installed. This kind of action has led to improvements in acidified lakes and the prospect of a reduction in the frequency of forest soil acidification and forest damage.

The major global environmental effect giving cause for concern is the increase in atmospheric concentrations of carbon dioxide and other radiatively active trace gases over the past four decades. Rises in the concentration of these gases give the potential for climatic warming to occur. The IPCC recently assessed the scientific basis of this phenomenon, the likely impacts and the policy responses necessary to manage such changes. The relative overall contribution of the electricity generating sector is in the region of 25%.

Global Circulation Models suggest that surface mean temperature increases of 1.5–4.5°C might occur with a doubling of the atmospheric $CO_2$ concentration. Changes in patterns of rainfall distribution might result. Such climate change could have severe repercussions on land use patterns, coastal regions threatened by rises in the mean sea level and on storm frequencies, civil engineering practices, human migration and even human health. Control, or adaptive responses, would require enormous international co-operation and expenditure, or curtailment of development plans.

IPCC assessments are not presented as being fully proven, nor do they deny that uncertainties remain. Global Circulation Models are constantly being improved and are likely to yield fresh insights. However, the high degree of scientific consensus has resulted in this environmental impact being taken very seriously and there is an appreciation of the wisdom of adopting the precautionary principle.

## 4. HEALTH RISK EVALUATION

In spite of the qualifications that have been attached to health risk comparisons, it is possible to elucidate some general evaluations. Fossil fuels used in electricity generation exhibit relatively high accident rates that dominate the occupational risk sector; the relatively large amounts of gaseous and solid wastes generated dominate the risks to the public. Renewable energy exhibits by far its highest risk in the occupational sector, linked to construction. Use of nuclear fuel for electricity generation is characterized in the occupational risk sector by mining and power production. Long term waste management is of concern to the public.

All major fuel cycles in electricity generation systems, when in routine operation and fitted with state of the art technology, are able to deliver electricity with relatively low risks to health. Current assessments place renewable and nuclear energy systems at the lower end of the risk spectrum and coal and oil at the higher end.

## 5. ENVIRONMENTAL RISK EVALUATION

It is not possible to be quite so specific about the risks to the environment as it is for health. However, state of the art control technology minimizes environmental impacts to a level where the major risks are greatly reduced. The exception to this is $CO_2$ emissions from fossil fuels. This brings the climate change issue to the top of the present environmental impacts agenda. Energy conservation and energy mixes with low contributions from fossil fuel are ways of addressing this issue and economic, social and political constraints are central to reaching decisions on methods of generating electricity that take this issue into account.

## 6. ACCIDENTS

What I have just said applies to routine operating conditions. There is a potential for severe accidents with most energy systems. Major accidents can be documented in coal, oil and gas fuel cycles, and hydropower. The Chernobyl accident, the worst to have taken place in the nuclear fuel cycle, resulted in 31 immediate deaths. Morbidity and longer term mortality statistics still await assessment and there is no question that, as with other accidents, long term effects exist. In addition, a large area of land was contaminated and many people had to be evacuated. However, a complete and accessible database is required before a true comparison of accidental risks from different methods of electricity generation can be made on a reliable basis.

## 7. THE FUTURE

Uncertainties are always likely to be a feature of comparative risk assessment. These arise from the normal statistical features of sample data (so that ranges or confidence limits need to be stipulated), but also because historical data or extrapolations have to be employed. They also result from data obtained from model runs that are based on the structure of the model system, itself subject to uncertainty.

Not all uncertainties can be eradicated, but they can be exposed and understood. Their existence does not invalidate comparative risk assessment procedures.

Other uncertainties will arise because it is unlikely that it will ever be possible to establish universal agreement and acceptance on the definition of the boundaries of fuel cycles, how technological developments can continually be incorporated into assessments or which are the most appropriate environmental indicators to employ and how such indicators could yield quantitative results.

However, the time is ripe for a new initiative, to build upon the pioneering work in comparative risk assessment of the 1970s and early 1980s. Establishment of a comprehensive, internationally co-ordinated database on the health impacts of different energy sources is now a feasible goal. Hand in hand with this should be encouragement of work on developing methodologies that will allow environmental impacts to be presented in comparative ways. A soundly based, explorative case study in this area should be a first step towards introducing comparative environmental risk assessment into decision making in energy planning for electricity generation, and other activities where a comparative approach to development impacts is essential.

Comparative health risk assessment is an important tool that can provide significant input to decision making on electricity generation planning; comparative environmental risk assessment has the potential to develop also into an invaluable and necessary approach in such planning activities. The usefulness and potential of these techniques justify support and development so that an international consensus is established to ensure that electricity generating options are considered in a proper perspective and the true costs reflected in the decision making process.

Finally, I would like to thank my colleagues on the Group. It was their written contributions and the points raised in discussions that formed the substance of the paper.

# ENERGY AND GLOBAL CLIMATE CHANGE ISSUES

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**Abstract**

ENERGY AND GLOBAL CLIMATE CHANGE ISSUES.

The paper considers the policy questions associated with global warming and with the fact that such policies will lead to future differences in the use of energy sources. Also discussed are the causes and the evidence of the greenhouse effect, as well as the human activities that have contributed to the growth in the concentrations of carbon dioxide, chlorofluorocarbons, methane and nitrous oxide, as well as to ozone changes. The responses of the Earth–atmosphere system to these increases in greenhouse gases are surface warming, increased water vapour, changes in the reflecting properties of ice–snow and alterations to the ecosystem. For calculating such climate changes, the Intergovernmental Panel on Climate Change has developed four scenarios for the future emissions of greenhouse gases and suggests that options for managing predicted climate change are likely to be combinations of slowing down as well as adapting to that change.

## 1. INTRODUCTION

Climate change can come about by changes in solar output, the Earth's orbital characteristics and atmospheric composition. Policy questions associated with the predicted global warming resulting from increasing atmospheric concentrations of greenhouse gases are likely to lead in the future to a use of energy sources different from what we know today.

Almost all the material presented in this paper is taken from the report, Scientific Assessment of Climate Change prepared by the Science Working Group (Working Group 1) of the Intergovernmental Panel on Climate Change (IPCC).

## 2. GREENHOUSE EFFECT

The Earth would be some 32°C cooler at present were it not for the natural greenhouse effect. The part of the atmosphere where weather and climate phenomena occur — the troposphere — is not directly warmed by the solar radiation which passes through it on its way to the Earth's surface. This radiation, most of

TABLE I. COMPARISON OF THE COMPOSITIONS OF VENUS, EARTH AND MARS

| | Surface pressure (relative to Earth) | Main greenhouse gases | Surface temperature in absence of greenhouse effect | Observed surface temperature | Warming due to greenhouse effect |
|---|---|---|---|---|---|
| Venus | 90 | >90% $CO_2$ | -46°C | 477°C | 523°C |
| Earth | 1 | ~0.04% $CO_2$<br>~1% $H_2O$ | -18°C | 15°C | 33°C |
| Mars | 0.007 | >80% $CO_2$ | -57°C | -47°C | 10°C |

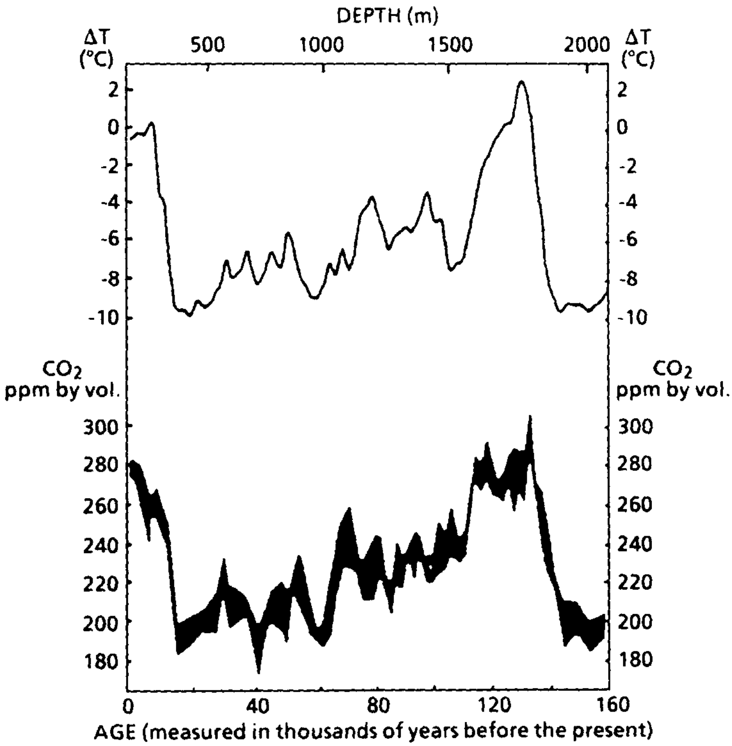


*FIG. 1. Carbon dioxide concentrations (below) and estimated temperature changes (above) during the past 160 000 years as determined on the ice core from Vostok, Antarctica. Temperatures were estimated on the basis of measured deuterium concentrations..*

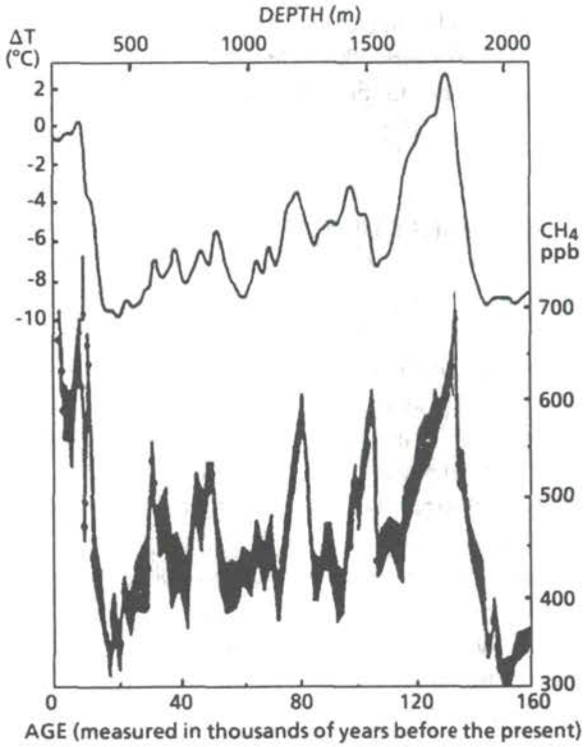


*FIG. 2. Methane concentrations (below) and estimated temperature changes (above) during the past 160 000 years (determined in same manner as in Fig. 1).*

it in the visible part of the spectrum, warms the surface; the surface is then, in turn, radiated. Because its temperature is lower than that of the sun, this terrestrial radiation occurs predominantly in the form of infrared rays.

Water vapour, carbon dioxide and ozone, the greenhouse gases occurring in the natural atmosphere (in this order of importance) absorb part of the terrestrial radiation and in the process warm the troposphere. The tropospheric air, in turn, reradiates upwards and downwards. The downward reradiation reaches the surface and adds to its warming by solar radiation. This atmospheric reradiation directed towards the surface is the greenhouse effect.

Thus, if the greenhouse gases should increase in the atmosphere and/or new ones are added, the greenhouse effect would be enhanced.

## 3. OBSERVATIONAL EVIDENCE FOR THE GREENHOUSE EFFECT

The compositions of Venus, Earth and Mars are quite different from one another. Neverthless, their observed surface temperatures (see Table I) are in good agreement with calculations based on the greenhouse theory. Also, ice core measurements, dating back 16 000 years, show that the Earth's surface temperature was closely correlated to the concentrations of carbon dioxide and methane (see Figs 1 and 2).

## 4. GREENHOUSE GASES DUE TO HUMAN ACTIVITIES

Important additional trace gases (trace because their concentrations are in parts per million, billion or trillion by volume) with greenhouse properties have come to be known as the chlorofluorocarbons (CFCs), methane and nitrous oxide.[1]

Human activities, such as energy production, industrial endeavours, agriculture and animal husbandry contribute to growth in the concentrations of carbon dioxide, CFCs, methane and nitrous oxide as well as to changes in ozone. The contribution to water vapour changes from human activities (such as emissions from jet aircraft) is insignificant.

Carbon dioxide emission results primarily (about four-fifths) from energy generation while methane (about two-thirds) comes from rice paddies, cattle, landfills, mining, venting during oil extraction and biomass burning. Nitrous oxide results from fertilizer use, combustion and biomass burning.

The CFCs are purely man-made and are the prime agents in inducing ozone loss above the troposphere. The climate effect of such ozone loss, and that of ozone generated in urban areas, is complicated and cannot be generalized; but it is of much smaller magnitude than that of the other greenhouse gases.

Table II is a summary of key greenhouse gases influenced by human activities. A noteworthy item here which has policy implications is the atmospheric lifetimes of the molecules (see below).

## 5. FEEDBACK

The initial response of the Earth–atmosphere system to increases in the greenhouse gas concentrations is that of warming which then leads to other phenomena that affect the warming itself.

### 5.1. Surface warming

Surface warming would lead to greater evaporation of water, adding to the greenhouse effect. Water vapour also absorbs solar radiation. The net effect of

[1] 1 billion = $10^9$; 1 trillion = $10^{12}$.

TABLE II. SUMMARY OF KEY GREENHOUSE GASES INFLUENCED BY HUMAN ACTIVITIES[a]

| Parameter | $CO_2$ | $CH_4$ | CFC-11 | CFC-12 | $N_2O$ |
|---|---|---|---|---|---|
| Pre-industrial atmospheric concentration (1750–1800) | 280 ppmv[b] | 0.8 ppmv | 0 | 0 | 288 ppbv |
| Current atmospheric concentration (1990)[c] | 353 ppmv | 1.72 ppmv | 280 pptv[b] | 484 pptv | 310 ppbv |
| Current rate of annual atmospheric accumulation | 1.8 ppmv (0.5%) | 0.015 ppmv (0.9%) | 9.5 pptv (4%) | 17 pptv (4%) | 0.8 ppbv (0.25%) |
| Atmospheric lifetime[d] (years) | (50–200) | 10 | 65 | 130 | 150 |

[a] Ozone has not been included because of lack of precise data.

[b] ppmv: parts per million by volume; ppbv: parts per billion by volume; pptv: parts per trillion by volume.

[c] The current (1990) concentrations have been estimated on the basis of an extrapolation of measurements reported for earlier years, assuming that the recent trends remained approximately constant.

[d] For each gas in the table, except $CO_2$, the lifetime is defined here as the ratio of the atmospheric content to the total rate of removal. This time-scale also characterizes the rate of adjustment of the atmospheric concentrations if the emission rates are changed abruptly. $CO_2$ is a special case since it has no real sinks, but is merely circulated between various reservoirs (atmosphere, ocean, biota). The lifetime of $CO_2$ given in the table is a rough indication of the time it would take for the $CO_2$ concentration to adjust to changes in the emissions.

increased water vapour is an amplification of the greenhouse effect by a factor of 1.6 (for a scenario where the carbon dioxide concentration is twice its pre-industrial value).

### 5.2. Increased water vapour

More water vapour is likely to lead to additional clouds. Depending upon whether they are water or ice clouds, high or low, thick or thin, such clouds may add to or counteract the greenhouse effect, since they affect the incoming solar as

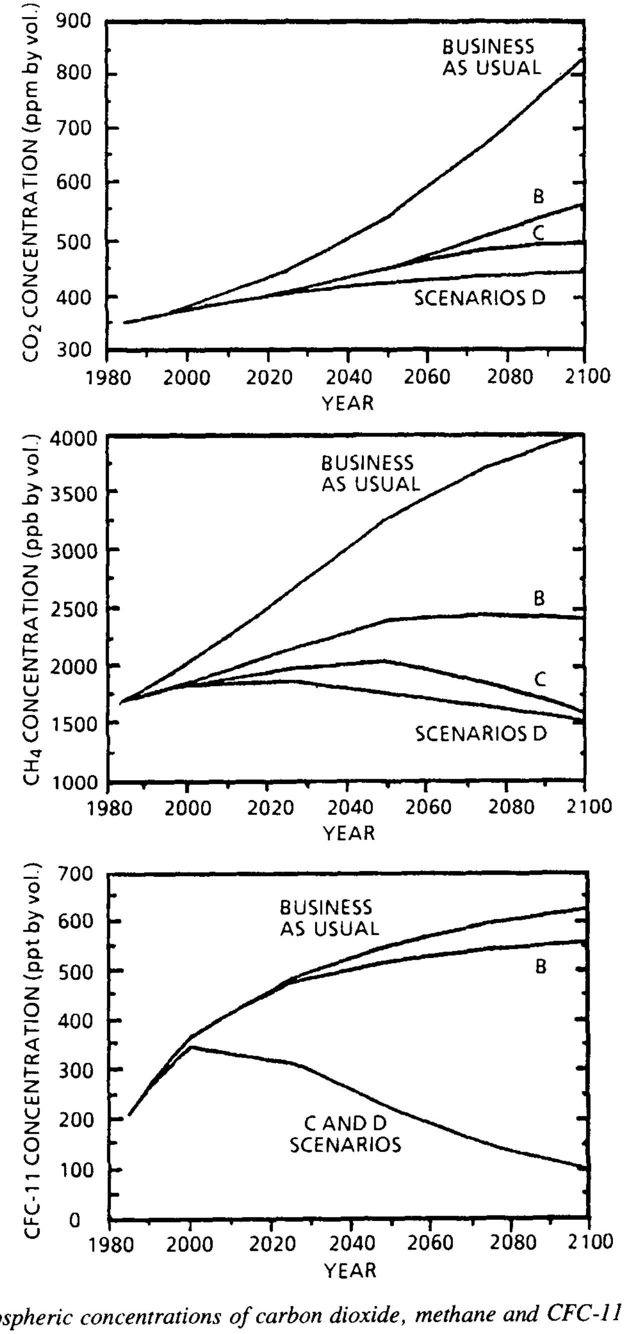


*FIG. 3. Atmospheric concentrations of carbon dioxide, methane and CFC-11 resulting from the four IPCC emission scenarios.*

well as the outgoing terrestrial radiation. It is not yet possible to determine with confidence either the sign or the magnitude of the cloud feedback.

### 5.3. Ice-snow

A third factor is the possible change in the reflecting properties of ice-snow. In a warmer Earth, with less ice-snow, less solar radiation would be reflected, thereby leading to a warmer surface.

### 5.4. Atmospheric composition

Ecosystems can change with warming in such a way that the atmospheric composition is altered further. The change could be increases in greenhouse gases (e.g. carbon dioxide, methane) and in atmospheric aerosols (e.g. dimethylsulphide emissions from a warmed ocean). The latter are not long lasting but can act as condensation nuclei for the formation of cloud particles through processes that were previously only qualitatively understood.

## 6. PREDICTIONS OF CLIMATE CHANGE

In addition to the feedback processes, two uncertainties are introduced in the calculations: uncertainty about (1) the future concentrations of the greenhouse gases and (2) the vast heat storage capacity of the oceans with attendant atmosphere–ocean interaction.

### 6.1. Emission scenarios

For calculating climate change, the IPCC developed four scenarios for the future emissions of greenhouse gases. These assume that an equivalent doubling of carbon dioxide from its pre-industrial value would occur according to the following schedule (see Fig. 3):

| Year | Scenario |
|---|---|
| 2025 | Business as Usual or Scenario A |
| 2040 | Scenario B |
| 2050 | Scenario C |
| 2090 | Scenario D |

The term equivalent doubling of carbon dioxide is used to denote the radiative forcing effect of all the greenhouse gases, which equals that effect due to a doubling of pre-industrial carbon dioxide concentration alone.

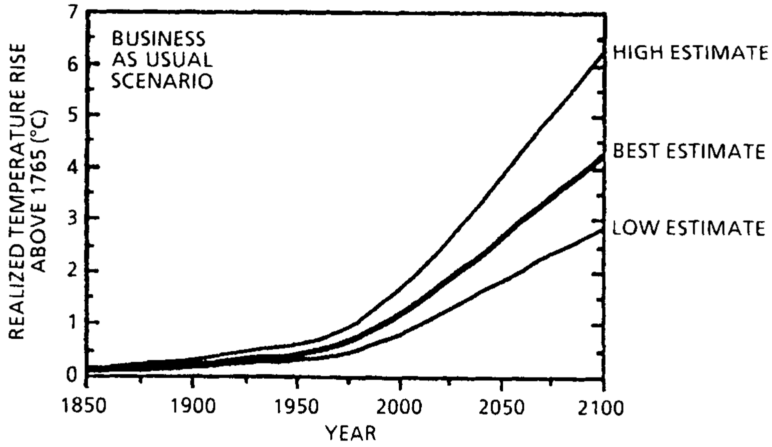


*FIG. 4. Simulation of the increase in global mean temperature from the years 1850–1990 owing to observed increases in greenhouse gases, and predictions of the rise between 1990 and 2100 resulting from the Business as Usual Scenario.*

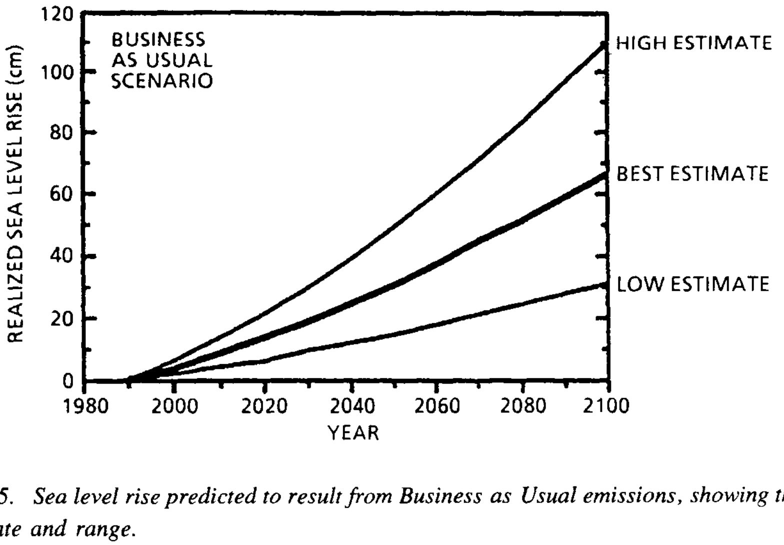


*FIG. 5. Sea level rise predicted to result from Business as Usual emissions, showing the best estimate and range.*

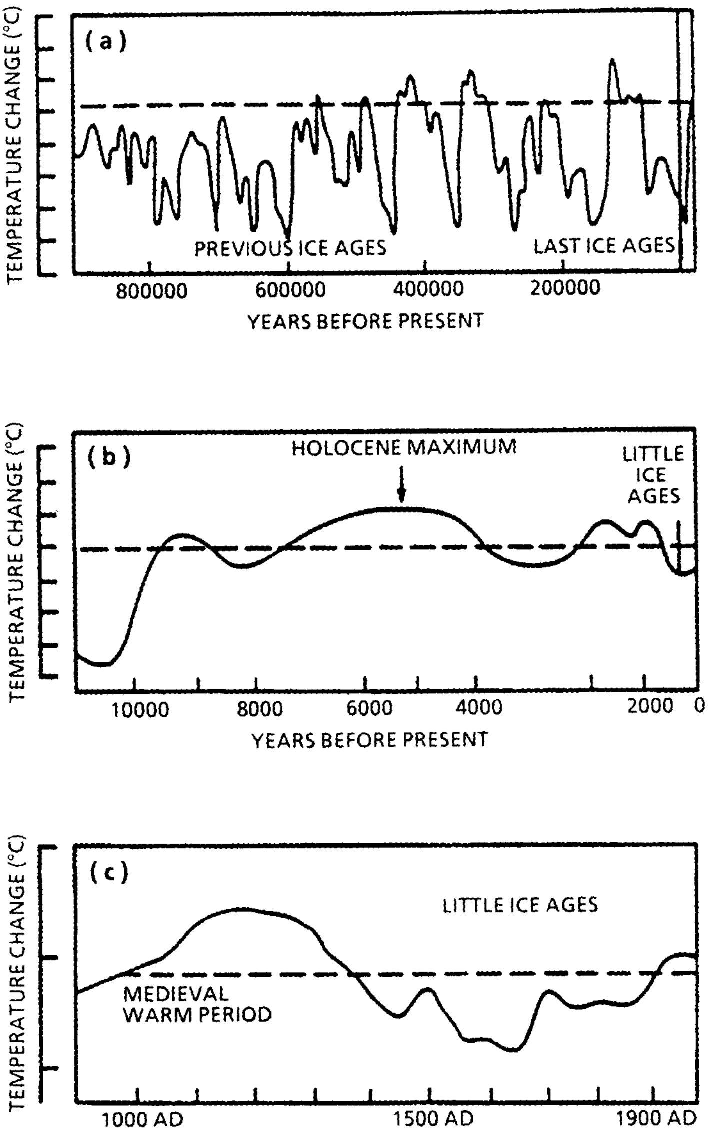


*FIG. 6. Relative variations of global temperature since the Pleistocene Era on three time-scales: (a) the last million years; (b) the last 10 000 years; (c) the last 1000 years. The dotted line nominally represents conditions near the beginning of the 20th Century; the distance between two lines indicates 1 °C difference.*

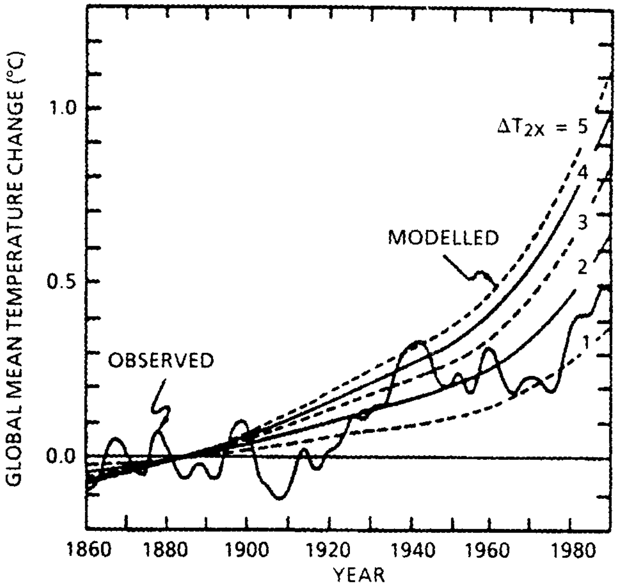


*FIG. 7. Global mean temperature change observed and modelled.*

TABLE III. REALIZED CLIMATE CHANGE

| Scenario | Rate of increase of temperature (°C/decade) | Realized temperature rise by the year 2090 (°C) | Realized sea level rise by the year 2090 (cm) |
|---|---|---|---|
| A or Business as Usual | 0.3 | 4.0 | 60 |
| B | 0.2 | 3.0 | 40 |
| C | 0.1 | 2.3 | 35 |

### 6.2. Calculations of climate change

The calculated increase in the average global surface temperature for the Business as Usual Scenario or Scenario A is shown in Fig. 4. One quantifiable immediate consequence of any temperature increase is that of the rise in sea level; the calculated increase for the same scenario is shown in Fig. 5.

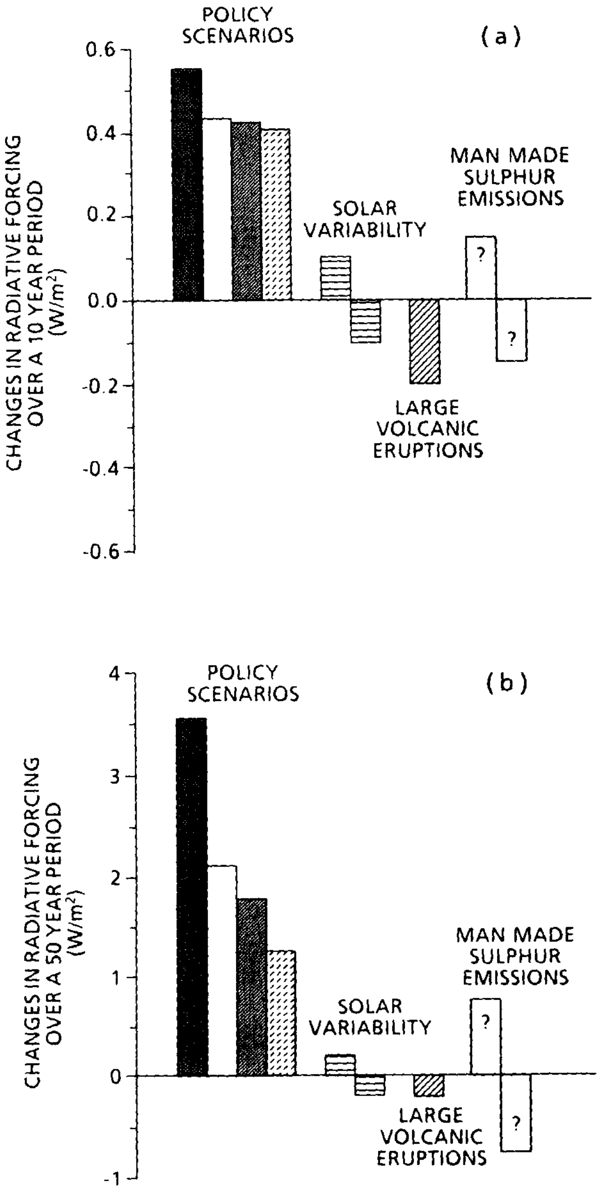


*FIG. 8. Comparison of different radiative forcing mechanisms for: (a) a 10 year period, and (b) a 50 year period in the future. The greenhouse gas forcings are for the periods 1990–2000 and 2000–2050 respectively, using the four policy scenarios. Forcings due to changes in solar radiation and sulphur emissions could be either positive or negative over the two periods.*

TABLE IV. GLOBAL WARMING POTENTIALS
(Warming effect of an emission of 1 kg of each gas relative to that of $CO_2$)

| Gas | Time-horizon (years) | | |
|---|---|---|---|
| | 20 | 100 | 500 |
| Carbon dioxide | 1 | 1 | 1 |
| Methane (including indirect) | 63 | 21 | 9 |
| Nitrous oxide | 270 | 290 | 190 |
| CFC-11 | 4500 | 3500 | 1500 |
| CFC-12 | 7100 | 7300 | 4500 |
| HCFC-22 | 4100 | 1500 | 510 |

[a] These numbers are best estimates calculated on the basis of present day atmospheric composition.

TABLE V. RELATIVE CUMULATIVE CLIMATE EFFECT OF 1990 MAN MADE EMISSIONS

| Gas | GWP (100 years horizon) | 1990 emissions (Tg)[a] | Relative contribution (over 100 years) |
|---|---|---|---|
| Carbon dioxide | 1 | 26 000[a] | 61% |
| Methane[b] | 21 | 300 | 15% |
| Nitrous oxide | 290 | 6 | 4% |
| CFCs | Various | 0.9 | 11% |
| HCFC-22 | 1500 | 0.1 | 0.5% |
| Others | Various | | 8.5% |

[a] 26 000 Tg (teragrams) of carbon dioxide — 7000 Tg (= 7 Gt) of carbon.

[b] These values include the indirect effect of these emissions on other greenhouse gases via chemical reactions in the atmosphere. Such estimates are highly model dependent and should be considered preliminary and subject to change. The estimated effect of ozone is included under 'others'.

The ranges shown in these figures result from partial considerations of the uncertainties and feedback mentioned above.

Table III summarizes the calculations for the other IPCC emissions scenarios. It may be seen from this table, and from Fig. 6, that the predicted rate of change is more than the observed value in the last 10 000 years.

The calculations are compared with available instrumental observations in Fig. 7.

## 7. IMPLICATIONS FOR POLICY MAKING

### 7.1. Relative importance of climate change agents

Figure 8 illustrates the relative importance of changes in solar output, aerosol, concentrations (from volcanic and anthropogenic sulphur emissions), and greenhouse gases for decadal and longer time-scales. It may be seen that the greenhouse gas forcing becomes increasingly important for longer time-scales.

### 7.2. Global warming potential (GWP)

Greenhouse forcing of a given greenhouse gas will depend upon its concentration, radiative effectiveness, and lifetime. As seen in Table II, for example, methane has a lifetime of 10 years compared to that of carbon dioxide with 50–200 years.

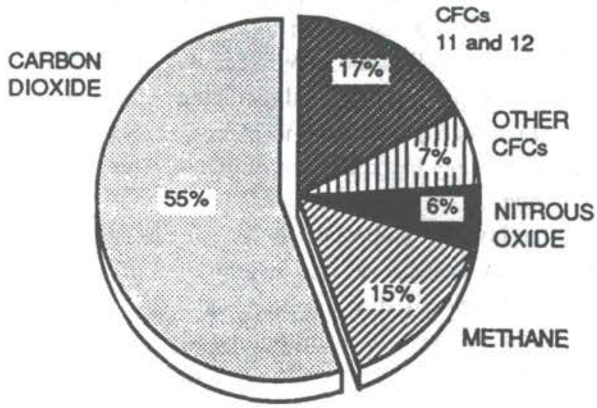


*FIG. 9. Contribution from each of the man made greenhouse gases to the change in radiative forcing from the years 1980 to 1990. The contribution from ozone may also be significant, but cannot be quantified at present.*

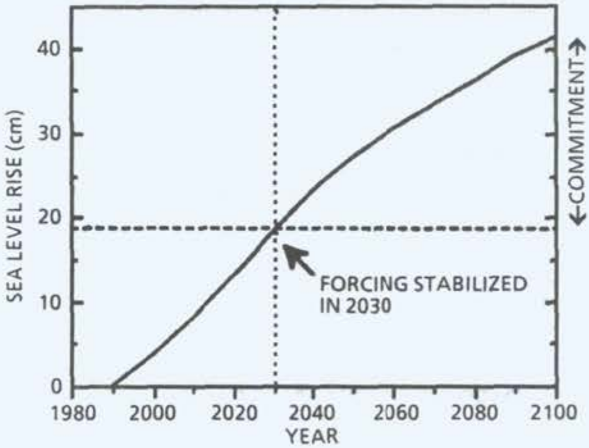


*FIG. 10. Commitment to sea level rise in the year 2030. The curve shows the sea level rise due to Business as Usual emissions to the year 2030, with the additional rise that would occur in the remainder of the century even if climate forcing were stabilized in 2030.*

On the other hand, it is radiatively 21 times more effective molecule for molecule than carbon dioxide. (On a kilogram for kilogram basis, the radiative effectiveness is 58.) Again, CFC-12 is 16 000 more effective than carbon dioxide on a per molecule basis, but its concentration is 484 parts per trillion, compared to 353 parts per million of carbon dioxide.

The concept of the global warming potential has been suggested for evaluating the potential climate effect of a given greenhouse gas. As the IPCC report, Climate Change, states, the index defines the time integrated warming effect due to an instantaneous release of 1 kg of a given gas in today's atmosphere, relative to that of carbon dioxide [1]. Table IV lists the GWPs for the important greenhouse gases. The numbers shown are preliminary. Indirect climate effects (due to molecules affected by chemical interactions in the atmosphere), overlapping absorption among molecules, and the uncertainty in the lifetime of carbon dioxide (some of these model dependent) have a bearing on GWP estimates.

The longer time-horizon is appropriate for calculating cumulative effects and for impact analyses such as sea level rise and survival of natural ecosystems. For example, HCFC-22 (15 year lifetime), a proposed CFC replacement, has a GWP similar to CFC-11 with a 20 year horizon, but not for a 100 year horizon. Methane would be more effective in the first few decades after its release.

The relative cumulative climate effect of 1990 anthropogenic emissions is shown in Table V. The figure for carbon dioxide may be compared with that in Fig. 9, where the contribution to today's radiative forcing is given; the number then rises from 55 to 61%.

### 7.3. Equilibrium versus realized effects

Not all of the response of the Earth–atmosphere system to an increased greenhouse forcing is immediately realized, because of the thermal inertia of the oceans and the nature of the air–sea interaction. The climate evolves towards an equilibrium state for the new forcing. Thus, at any given time, the realized temperature is less than what it would be at equilibrium. Nonetheless, the climate is committed to the equilibrium temperature once the greenhouse forcing is increased. This is more readily seen in the case of the sea level rise (Fig. 10).

## 8. CONCLUSIONS

The options for managing the predicted climate change are likely to be combinations of slowing down the change as well as adaptation to the change. The former implies reducing or even stopping the increases in the greenhouse gas concentrations. Carbon dioxide, with its relative contribution to the warming, will receive much attention.

## REFERENCE

[1] INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, Climate Change: The IPCC Scientific Assessment, Cambridge University Press, Cambridge (1990).

# CANCER RISKS RELATED TO DIFFERENT ENERGY SOURCES

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## Abstract

CANCER RISKS RELATED TO DIFFERENT ENERGY SOURCES.

The International Agency for Research on Cancer has previously evaluated the cancer risks associated with fossil fuel based industrial processes such as coal gasification and coke production, substances and mixtures such as coal tars, coal tar pitch and mineral oils, and a number of substances emitted from fossil fuelled plants such as benzo[a]pyrene and other polycyclic aromatic hydrocarbons, arsenic, beryllium, cadmium, chromium, nickel, lead and formaldehyde. On the basis of these evaluations and other evidence from the literature, the carcinogenic risks to the general population and occupational groups from the fossil fuel cycle, the nuclear fuel cycle and renewable cycles are reviewed. Cancer risks from waste disposal, accidents and misuses, and electricity distribution are also considered. No cycle appears to be totally free from cancer risk, but quantification of the effects of such exposures (in particular of those involving potential exposure to large amounts of carcinogens such as coal, oil and nuclear) requires the application of methods which are subject to considerable margins of error. Uncertainties due to inadequate data and unconfirmed assumptions are discussed. Cancer risks related to the operation of renewable energy sources are negligible, although there may be some risks from the construction of such installations. The elements of knowledge at our disposal do not encourage any attempt towards a quantitative comparative risk assessment. However, even in the absence of an accurate quantification of risk, a qualitative indication of carcinogenic hazards should lead to preventive measures.

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# 1. INTRODUCTION

## 1.1. Health risks from electricity production and other energy uses

Electricity production entails a wide range of health risks for both workers and the general public [1]. Some are well known (e.g. accidental deaths among coal miners), but many others are still matters of debate (e.g. increased cancer risk in populations living close to nuclear power plants). Acute health effects, such as accidents, account for the majority of deaths related to electricity production, according to some authors [2–4]. However, the burden of chronic diseases is more difficult to estimate, and low estimates may reflect lack of knowledge as well as lack of risk. In particular, cancer is more difficult to quantify than other chronic health effects, because of its long latency, the lack of specificity of most etiological associations so far elucidated, in particular for the more common cancers (i.e. one exposure may cause several types of cancer and the same cancer can be due to several exposures), and the relative rareness of most cancer types.

A further health consequence of electricity production is psychological, mainly stress, which may lead to increased morbidity. The perception of risk from various forms of electricity production may not reflect the actual risk. In particular, nuclear power, because it is relatively new compared to coal burning and because radiation cannot be sensed, is a priori more stressful for the neighbouring populations than heavily polluting, but more familiar, oil or coal burning plants. In addition, the long half-life of radionuclides and the awareness, perhaps exaggerated but nevertheless justified, that the adverse health effects of radiations may manifest themselves not only on the individuals exposed but also on their descendants, certainly contribute to increasing the fear of nuclear power. Recently, a study from the United Kingdom suggested an increase in child leukaemia following paternal exposure to radiation in the nuclear industry [5].

The paper reviews the evidence on cancer risks to humans of the electricity production cycles, and discusses the problems to be faced in attempting quantitative comparative risk assessment. Acute and non-neoplastic chronic health effects are not discussed in detail, although many of the exposures that are reviewed are known or suspected to be related to non-neoplastic conditions.

Energy from water power and photovoltaic cycles is specific to electricity production, and nuclear derived energy other than electric has been used for military purposes; fossil fuels such as coal, petroleum and natural gas, on the other hand, have been used for centuries as sources of energy for various purposes. Therefore, there is a substantial overlap in exposures to fuel components and emissions between the different uses of fossil fuel. This problem is particularly relevant for populations living in industrialized urban areas who are exposed to combustion products from vehicular traffic, industrial plants, including power plants, as well as the residential and commercial uses of fossil fuel. To better assess the impact of electricity production on cancer and other health outcomes in human populations, one should ideally study populations living in rural areas where one or several large power plants or other electricity related industries are by far the major sources of exposure. Even in this case, however, the results of epidemiological studies are difficult to interpret because of concurrent exposure to the same or similar chemicals from non-industrial sources, such as smoking, diet and indoor burning of wood and fossil fuels for domestic heating and cooking. Furthermore, the interaction between agents from different exposure circumstances, such as smoking and air pollution, may result in inhancement of carcinogenic risk beyond additivity.

Furthermore, any modification in electricity production and use should be considered in the wider context of total energy use, e.g. an increase in electric power used for domestic heating may result in a similar decrease in the use of other types of energy. This can make it difficult to estimate the overall changes in the health effects among the exposed populations.

### 1.2. Methodological problems in evaluating cancer risk from environmental exposures

Data for identifying and quantifying the cancer risk due to exposures related to energy production and distribution and the fuel process come mainly from two types of study: (1) epidemiological (most often cohort) studies of individuals exposed to specific substances or mixtures of substances of interest in particular industries; these are usually occupational studies (because of the greater ease in identifying the populations at risk and measuring the exposures that, as a rule, are much higher than for the general population); (2) ecological and geographical correlation studies based on comparing the mortality or morbidity rate between groups of population with presumed different levels of environmental exposure.

Occupational epidemiological studies carried out within a given industry are best suited to determining occupational cancer risks in that industry. For industries involved in energy production or distribution and in waste storage, however, this approach has not been consistently applied; published epidemiological studies consider only cancer risk among coal and uranium miners and workers in coal burning factories, the nuclear fuel cycle and petroleum refining. Except for ionizing radiation, exposure data are rarely of sufficient quality to permit this.

To estimate risk for the general population from environmental exposures resulting from energy production, the two approaches can be used, and sometimes combined. Geographical correlation studies are interesting because they are studies of the population of interest; however, in order for them to reveal an increased risk based on population statistics, this risk must be quite large [6]. Moreover, the precision with which it will be estimated, and its validity for extrapolation to other populations, will be poor because of the absence of quantitative individual exposure data and of other information of interest. Finally, the choice of an adequate 'non-exposed' reference area is nearly always problematic.

The other approach relies on extrapolation from the more precise risk estimates obtained in occupational studies to populations that are environmentally exposed. This generally involves obtaining detailed dose measurements at the level of small population subgroups or of individuals [7, 8], for which the risk must be estimated; extrapolating risk coefficients to low exposure levels; and taking into account the effects of age, sex, individual susceptibility and other potential exposures, all of which may modify the risk.

Additional sources of data for estimating risks (be they environmental or occupational) are long term animal tests and short term tests [9]. For some agents of concern, such as polycyclic aromatic hydrocarbons (PAHs), the only available quantitative data are experimental [10]. The problems involved in assessing risks become even greater because of the need to extrapolate from data on a limited number of species and strains with single, well characterized exposures to genetically polymorphic human populations who are exposed simultaneously to many different agents, and from cellular and subcellular models to entire organisms.

TABLE I. CHEMICALS OCCURRING IN ELECTRICITY PRODUCTION THAT ARE CONSIDERED TO BE CARCINOGENIC (GROUP 1), PROBABLY CARCINOGENIC (GROUP 2A) OR POSSIBLY CARCINOGENIC (GROUP 2B) TO HUMANS IN IARC MONOGRAPHS VOLS 1–53 [11][a]

| Pollutant | Evaluation |
|---|---|
| *Inorganic substances* | |
| Arsenic and arsenic compounds[b] | 1 |
| Asbestos | 1 |
| Chromium [VI] compounds | 1 |
| Nickel compounds | 1 |
| Radon and its decay products | 1 |
| Beryllium and beryllium compounds | 2A |
| Cadmium and cadmium compounds | 2A |
| Silica, crystalline | 2A |
| Antimony trioxide | 2B |
| Inorganic lead compounds | 2B |
| Nickel, metallic | 2B |

TABLE I (cont.)

| Pollutant | Evaluation |
|---|---|
| *Polycyclic aromatic hydrocarbons* | |
| Benz[a]anthracene | 2A |
| Benzo[a]pyrene | 2A |
| Dibenz[a,h]anthracene | 2A |
| Benzo[b]fluoranthene | 2B |
| Benzo[j]fluoranthene | 2B |
| Benzo[k]fluoranthene | 2B |
| Dibenzo[a,e]pyrene | 2B |
| Dibenzo[a,h]pyrene | 2B |
| Dibenzo[a,i]pyrene | 2B |
| Dibenzo[a,l]pyrene | 2B |
| Indeno[1,2,3-cd]pyrene | 2B |
| *Polycyclic nitroaromatic hydrocarbons* | |
| 1,6-Dinitropyrene | 2B |
| 1,8-Dinitropyrene | 2B |
| 6-Nitrochrysene | 2B |
| 2-Nitrofluorene | 2B |
| 1-Nitropyrene | 2B |
| 4-Nitropyrene | 2B |
| *Others* | |
| Benzene | 1 |
| Soots | 1 |
| Ethylene dibromide | 2A |
| Formaldehyde | 2A |

[a] For definitions of the groups, see Ref. [10].

[b] This evaluation applies to the group of chemicals as a whole and not necessarily to all individual chemicals within the group.

### 1.3. IARC monographs programme

A number of chemicals which occur in electricity production have been considered in the International Agency for Research on Cancer (IARC) Monographs programme [11], which publishes critical reviews of data on carcinogenicity for chemicals and complex mixtures to which humans are known to be exposed, and on specific cultural or occupational exposures. These data are evaluated in terms of human risk with the help of international working groups of experts in chemical carcinogenesis and related fields; in some cases, indications are given as to where additional research efforts are needed (Table I).

## 2. CARCINOGENIC RISK FROM ELECTRICITY PRODUCTION CYCLES

In this section, the different energy cycles are reviewed briefly with respect to carcinogenic risk to the public and workers under normal conditions. A few specific aspects are discussed in more detail in the following sections.

### 2.1. Coal

Coal is the most widely used fossil fuel in electricity production. Most of the environmental and health problems associated with coal use come from its impurities, which are higher in lignite or brown coal than in black coal (anthracite) [12].

Cancer risk among coal miners has been studied extensively. The overall results from cohort studies indicate a 50% increase in mortality from stomach cancer among coal miners. Three case control studies on stomach cancer carried out among mining populations all identified increased risks, but they were not statistically significant. On no occasion was the relative risk above 2. Lung cancer mortality was elevated in the largest cohort study of miners carried out in the United States of America and also among silicotic miners in Canada who were awarded compensation before 1956. In all other studies no increase was observed. The overall standardized mortality ratio (SMR) for lung cancer, as estimated from the cohort studies, was very close to that expected from the national reference mortality rates [13, 14].

Air emissions from diesel equipment and air pollutants from burning mines and waste piles, as well as air emissions from coal transportation vehicle engines, may lead to environmental exposure to carcinogens.

Among the products released to the atmosphere during coal combustion are $SO_2$, $NO_x$, CO, hydrocarbons, PAHs, metals and radionuclides. Their concentrations depend on the composition of the coal, the operating conditions of the plant and the local atmospheric conditions [15]. Therefore, it is difficult to estimate a range of emissions for coal fired power plants that would be valid in different geographical and temporal settings: examples of estimates based on measurements in the early

TABLE II. ESTIMATES OF AIR EMISSIONS BY FUEL TYPE FOR FOSSIL FUELLED CENTRAL STATION ELECTRICITY GENERATION (t/GW(e)·a) [3]

| Fuel type | Particulates | $SO_2$ | $NO_x$ | Hydrocarbons |
|---|---|---|---|---|
| Coal | 1160 | 23200 | 23200 | 44.9 |
| Wood | 4460 | 3920 | 9090 | 18200 |
| Oil | 1160 | 31000 | 11600 | 273 |
| Natural gas | 1160 | 21.5 | 2500 | 35.6 |

1980s in the USA are presented in Table II. However, in comparison with other fossil fuels used for electricity generation, it is clear that coal will cause higher emissions of particulates.

PAHs are distributed widely in the human environment, albeit at low concentrations. In industrial environments, the level of these compounds may be much higher. Epidemiological studies provided evidence to their carcinogenicity, but as PAHs almost always occur as mixutres, the carcinogenicity to humans cannot be referred to individual compounds. Information from experiments in animals has therefore been essential in establishing their carcinogenicity. Benzo[a]pyrene (B[a]P) [10, 16] is used as the indicator compound for the presence of PAHs in environmental material, since it has been found consistently in mixtures of such compounds. B[a]P and two others, benz[a]anthracene [10, 17] and dibenz[a,h]anthracene [10, 18], are considered to be probably carcinogenic to humans on the basis of experimental data obtained from both whole animals and in vitro test systems. Experimental data indicate that other such compounds are possibly carcinogenic to humans (Table I).

More data are available on the carcinogenicity of mixtures containing PAHs, mainly from studies in occupational settings. Thus, carcinogenicity to humans has now been established for coal tar pitches, encountered in a number of industrial situations and in roofers [10]; for coal tars [10, 19] used medicinally and also present in fossil fuelled power plants and other industries; for untreated and mildly treated mineral oils [10, 20] used in the past in textile production and metal machining and by printing pressmen; for shale oils [10, 21]; and for soots [10, 22]. All of these mixtures produce cancers of the skin, but many also increase the incidences of cancer at other sites, including the urinary and respiratory systems.

Evidence with regard to the carcinogenicity of other mixtures containing PAHs, such as creosotes, bitumens and carbon blacks, is less clear cut, mainly because of a paucity of epidemiological data [10]. However, experiments in animals with extracts of both bitumens and carbon blacks have clearly shown a carcinogenic effect, indicating their possible carcinogenicity to humans.

Among other chemicals present in coal burning plant emissions, sulphur and metals capable of promoting the oxidation of $SO_2$ to $H_2SO_4$ in the presence of water and hydrogen peroxide are concentrated in the ultrafine fraction of coal ash [23]. Occupational exposure to sulphuric acid has been associated with increased risk of laryngeal and other respiratory cancers in a number of epidemiological studies [24, 25].

Concentration of metals in emissions from coal fired power plants varies according to the composition of the coal. Elements of greatest concern are arsenic, cadmium, beryllium and lead. Chromium and nickel occur at lower concentrations. The concentrations of trace metals increase as the particle size of fly ash decreases [23]. Inorganic arsenic is classified as a human carcinogen, inducing skin and lung tumours in humans [10, 26]. The carcinogenicity of cadmium has been evaluated by IARC [10, 27]. It is classified as a probable human carcinogen, suspected of causing lung cancer in humans. Chromium [VI] is classified as carcinogenic to humans. Increased occurrence of lung cancer and sinonasal cancer in workers employed in chromate production, chromate pigment production and chromium plating industries constitutes evidence in support of this conclusion. Metallic chromium and chromium [III] compounds are not classifiable as to their carcinogenicity to humans [28]. Nickel compounds are carcinogenic to humans. Metallic nickel is possibly carcinogenic to humans. An increased occurrence of nasal and lung cancer has been observed in workers exposed to nickel compounds in the refining of nickel [29]. Occupational exposure to beryllium may lead to increased lung cancer risk; beryllium and its compounds are classified as probable human carcinogens [10, 30]. Inorganic lead compounds also produce tumours in experimental animals. Small and inconsistent increases in risk for cancer were observed in workers exposed to lead. These compounds are classified as possible human carcinogens [10, 31].

Coal contains trace amounts of radionuclides from decay series headed by $^{8}U$, $^{235}U$ and $^{232}Th$, which are emitted during coal combustion. Coal typically contains about 1–2 ppm of uranium and 2–4 ppm of thorium [22]. Even if the total amount of radionuclides is orders of magnitude lower than in the nuclear cycle, the maximum dose to individuals in the vicinity of a coal burning facility may be comparable to that from a nuclear facility; these emissions are not usually monitored around coal burning plants, hampering estimation of the health effects of radioactivity from coal use. In addition to radionuclides in particle emissions, small amounts of radon gas are released during coal combustion and from ash piles. Coal fly ash has shown mutagenic activity [32].

### 2.2. Peat

Peat is used as an energy source mainly in Nordic countries. Its use in energy production yields less sulphur oxides than use of coal or oil. Production of PAHs during peat burning depends on the circumstances; under incomplete burning conditions the amount of these compounds can be substantial (up to 39 μg/MJ) [33]. Peat ash has shown mutagenic activity [34].

### 2.3. Wood and other biomass

The term 'biomass' includes photosynthetically derived materials, which have always been used by humans as a source of food and materials. Wood chips and sawdust are used as energy sources to produce electricity. Burning of wood produces only minimal emissions of $SO_2$, but can produce high emissions of PAHs and comparable levels of other combustion products such as $NO_x$ and hydrocarbons [35] (see Table II). Commercial scale electric power stations use combustion systems which have PAH emissions of the order of 80–700 μg/MJ [33].

### 2.4. Oil

Fuel oils used for electricity generation are mainly of grades 4 to 6, also known as 'residual oils', derived from distillation residues from refinery processing. Residual oils contain high concentrations of PAHs [36]. To a lesser extent, distillate fuel oils are also used for electricity production. Data concerning exposure to fuel oils in humans were considered by IARC to provide inadequate evidence for their carcinogenicity, mainly because the epidemiological studies were not able to discriminate among exposures to various petroleum products. Residual fuel oils are considered to be possibly carcinogenic to humans [36].

The operation of oil refineries results in the emission of large amounts of airborne $SO_2$, $NO_x$, particulates and hydrocarbons, as well as liquid effluents containing, among other compounds, oil and trace metals. Transportation of oil by rail, road or water poses carcinogenic risks comparable to those discussed for coal. Data on air emissions from burning oil to generate electricity (Table II) do not differ greatly from those of burning coal, except that the levels of particulate emission are considerably lower and there is no ash to dispose of [37].

Ten separate, company specific cohorts have been studied in the USA, two in Canada, one in the UK and one in Italy. An IARC Working Group evaluated the occupational exposures in petroleum refining; evidence of carcinogenicity was limited for skin cancer and leukaemia, and inadequate for other cancer sites on which information was available. Given the exposure to benzene and untreated and mildly treated mineral oils, which are carcinogenic to humans, occupational exposures in petroleum refining were considered to be probably carcinogenic to humans [38].

One cohort study examined the mortality of 1109 men working at an oil producing or pipeline location in the USA. The overall mortality was very low and statistically significant deficits were seen also for all the major causes of death. The only significant increase was for thyroid cancer among pumper gaugers [38].

Three small studies on the mortality experience of workers in five Italian coal and oil fired power plants have been published [39–41]. There was a moderate but consistent excess of total and lung cancer mortality in all the cohorts analysed.

## 2.5. Shale oil

Crude shale oils differ principally from crude petroleum in that they contain higher concentrations of organic nitrogen compounds and arsenic. Numerous PAHs are present. In a few countries, shale oil is used to generate electric power. Oil shale also contains significant levels of crystalline silica, a probable human carcinogen [42]. As, Cd, Pb, Hg and Ni are frequent in oil shale. Shale oils are considered to be carcinogenic to humans on the basis of an excess of skin cancer among shale oil workers [10, 21].

## 2.6. Natural gas

Natural gas accounts for about 11% of the global electricity consumption [43]. Exposure to hydrocarbons such as methane, propane and butane may occur during the extraction of natural gas and from pipeline leaks. No data are available on the carcinogenicity of these hydrocarbons. Burning of natural gas usually causes lower levels of emissions of $SO_2$, $NO_x$ and hydrocarbons than use of coal or oil. Particulate emissions, however, are comparable to those of other fossil fuels (Table II).

## 2.7. Nuclear

Direct epidemiological data are available for some parts of the nuclear fuel cycle: uranium mining, refining, enrichment and reprocessing and, to a much smaller extent, for commercial reactor workers [44, 45]. Additional information on the effects of chronic low level exposures to ionizing radiation is provided by studies of workers in defence establishments and in nuclear shipyards [44]. Most of the analyses carried out within these cohorts, by level of exposure, provide little evidence of an exposure related increase in overall cancer mortality; the width of the confidence intervals for estimates of radiation induced risks is such, however, that the estimates are consistent with a range of possibilities, from an absence of a carcinogenic effect to risks several times greater than those on which current radiation protection standards are based (Table III) [44, 46–52].

In most studies, analyses of many specific types of cancer have been conducted. These studies have generally been consistent in not showing significant

TABLE III. ESTIMATES OF THE ANNUAL EXCESS MORTALITY RISK FOR ALL CANCERS IN HUMAN POPULATIONS EXPOSED TO IONIZING RADIATIONS [46]

| Study | Excess deaths ($10^{-6}$ per year/10 mSv) | 95% confidence interval |
|---|---|---|
| *Scientific Committees* | | |
| BEIR V, 1990 [44] | 9.6[a] males | 6.8–15.5[b] |
| | 10.1[a] females | 7.9–14.5[b] |
| UNSCEAR, 1988 [47] | 4–11 | |
| ICRP 26, 1977 [48] | 4.0 | |
| BEIR III, 1980 — linear [49] | 6.0 | |
| — linear quadratic | 2.5 | |
| Atomic bomb survivors | | |
| 1988 DS86 [50] | 10.1 | 8.0–12.4[b] |
| *Nuclear workers studies* | | |
| UKAEA, 10 year lag [51] | 17.4 | −21.7, 62.3 |
| Sellafield, 15 year lag [5] | 17.0 | -30, 70 |
| Hanford, 10 year lag [52] | -29.0 | <0, 26[b] |

[a] Based on a single exposure, and an average lifetime of 80 years.
[b] 90% confidence interval.

increases in risk for exposed workers for most of the cancer types examined, although a few associations have been found. Most notably, statistically significant associations between the cumulative dose from external radiation exposure and mortality from multiple myeloma have been reported in two studies [52, 53]. Although multiple myeloma has previously been associated with exposure to ionizing radiation in the atomic bomb survivors study, the observed excess risk, based on a small number of cases, is not consistent with the estimates obtained from these studies. An association between radiation exposure and mortality from cancer of the prostate has also been found in two studies [51, 54], while non-significant increases in SMR for prostate cancer among nuclear workers as a group were also reported in two additional studies [55, 56]. Statistically significant associations between exposure and cancer of the bladder, as well as with leukaemia, were found in one study [57], and for lung cancer in another among those exposed to radionuclides [58]. Increased SMRs for lung cancer were also found in three additional cohorts [57, 58].

Exposure to the general population from power plants, mines and fuel processing may occur through leaks into the local environment (e.g. tritium in drinking water), leading to contamination of water and air, and accidents which may have much wider scale consequences. Environmental contamination may also occur from accumulated wastes stored in radioactive waste disposal sites.

## 2.8. Geothermal (hydrothermal), wind, hydroelectric and ocean energy

Hydroelectric power plants are responsible for over 20% of the total electricity generation, whereas geothermal, wind and ocean energy cover less than 1% of the total electricity production [43].

Hydrothermal fluids (coming from the interior of the globe) contain gases such as $CO_2$, $SO_2$ and $H_2S$, methane, benzene and radon which may affect the water quality downstream of the geothermal plants [35].

Even if little or no specific cancer risk can be identified in these cycles, occupational carcinogenic exposures could occur in related industries, such as the metal and construction industry, as well as from earth moving and transportation activities. Construction of a dam and a reservoir may create environments for parasitic waterborne diseases, such as schistosomiasis, that have been linked to the development of cancer in humans [59].

Emissions of particulates, $SO_2$ and $NO_x$ per unit of energy from the geothermal, wind and hydroelectric cycles have been estimated. They derive from activities related to materials acquisition, since emissions of these agents during routine operations are negligible, and appear to be one or more orders of magnitude lower than emissions from the coal cycle [35].

## 2.9. Solar

Workers in the device fabrication stage of the photovoltaic energy cycle may be exposed to dusts, fumes and aerosols with large fractions of respirable particles averaging less than 1 $\mu$m in diameter. The three semi-conductor materials that are used are silicon, cadmium sulphide and gallium arsenide. Production of silicon may cause exposure to crystalline silica, a probable human carcinogen [42]. Manufacture of cadmium sulphide cells entails occupational and public exposure to cadmium from smelting, refining and fabrication facilities. Exposure to arsenic for workers and the public may result from copper and lead smelting as well as during photovoltaic cell production. Environmental exposure to cadmium or arsenic may occur as a result of leaks from operating cells and waste disposal after decommissioning of the devices.

## 3. AIR POLLUTION AND OZONE DEPLETION

### 3.1. Carcinogenic risk from air pollution and the contribution of electricity production plants

Estimates of airborne emissions of selected air pollutants from different electricity cycles are presented in Table II. Great caution should be applied when making comparisons between cycles, since the estimates are strongly dependent on assumptions about the composition of the fuels, the technology applied in the plant and other factors that vary with time and space.

Attempts to quantify the human cancer burden due to air pollution have followed two different approaches. On one side, there are examples of quantifications based on low dose extrapolation of the risk from human or animal carcinogens among air pollutants, such as formaldehyde and metals. A recent authoritative example is the estimate made by the United States Environmental Protection Agency (EPA) of the number of cancers in the USA that may be attributable to 90 air pollutants emitted from 60 source categories, among which are coal and oil combustion from utility, industrial, commercial and residential sources. Their overall estimate is 1700–2700 excess cases of cancer per year, or an equivalent of roughly 7–11 annual cases of cancer per million population. The largest single source of excess cancer incidence was motor vehicles, which account for 58% of the total estimated incidence, while large industrial facilities ('point sources') account for another 20% [60].

In particular, the EPA assessed the risks from coal and oil combustion as the source of air pollution, indicating a burden of 11 cases per year, one of which derived from electricity generation [61]. A similar estimate from the UK provided the figure of one death per year per 1000 MW of coal and oil fired plants due to the emission of PAHs and other carcinogens [62].

An alternative approach uses the results of epidemiological studies that analysed the risk of cancer, mainly from the lung, associated with exposure to air pollution. These studies have provided some evidence of an increased risk of lung cancer among individuals who lived in more polluted areas compared with individuals living in less polluted areas. A positive interaction between air pollution and smoking or occupational exposure was indicated by a number of studies [63]. The relative risks were in the range of 1.1–1.5. It should be noted that a relative risk of 1.1, i.e. a 10% increase in the incidence of lung cancer over the background, would mean that about 9% of all lung cancers among exposed individuals are attributable to air pollution. The proportion of cancers in the overall population attributable to air pollution depends on the proportion of people exposed to it. A recent study from Cracow estimated that 4.3% of lung cancer among men and 10.5% among women are attributable to air pollution [64]. These proportions, if applied to US lung cancer incidence, would represent 4386 lung cancer cases per year in males and 5775 cases in women [65]. It is clear that, even assuming that electricity production contributes only 10% to overall air pollution, this approach provides estimates of extra cancer cases which are orders of magnitude higher than those obtained by analysing specific pollutants, as previously described.

In conclusion, in most studies, residence in urban or polluted areas has been found to be associated with an increase in cancer risk, mainly lung cancer. It therefore seems probable that, in heavily polluted areas, air pollution increases mortality from lung cancer, but that the contribution of different sources of pollution, and specifically that of electricity production plants, cannot be accurately assessed. However, estimates based on the effects of selected pollutants, for which both information on air level and models on cancer risk at low doses are available, are likely to underestimate the magnitude of the contribution of air pollution to human cancer.

### 3.2. Transportation

Further contribution of electricity production to air pollution comes from transportation of fuels by road, rail and water. Transportation of coal and oil may represent a substantial proportion of the total traffic.

Exhausts from internal combustion engines have been evaluated for carcinogenic risk. Diesel engine exhausts have been evaluated to be probably carcinogenic to humans and gasoline engine exhausts possibly carcinogenic. Several nitroarenes, which are components of engine exhausts, can cause cancer in experimental animals (Table I); some of them are very potent in various short term tests for genotoxicity [66].

### 3.3. Ozone depletion

There is an awareness that the concentrations of ozone in the Earth's stratosphere have been decreasing for nearly two decades [67]. The concern was mainly about depletion at the high latitudes of the southern hemisphere, but a recent study reported a substantial decrease over the Arctic as well [68]. Ozone plays an important role in the Earth's ecosystem in that it is responsible for absorbing UV radiation from the sun — practically all of it in the UVC range (240–290 nm), and a large proportion in the UVB range (290–320 nm). It is this range of wavelength which can cause DNA damage, and which is therefore important to the viability of terrestrial life forms.

Future models of atmospheric ozone concentrations are complex, and require many assumptions about the trends in emissions of all of these gases. In general, however, there is a consensus that atmospheric ozone will continue to decline for at least the next 40 years, perhaps by some 6–7% on average [69]. As a consequence of the resulting increased exposure to UV radiation, an increase in skin cancers (non-melanoma and melanoma) can be expected. A 1% reduction in ozone levels will increase the biologically effective UV flux by 2%, and it has been estimated that this would increase the incidence of non-melanoma skin cancer by 1–3%, and mortality from malignant melanoma by 0.8–1.5% [70].

## 4. CANCER RISK FROM WASTE DISPOSAL

Few data are available on cancer risk from waste disposal in the electricity cycle. Most industrial processes generate some toxic waste; the carcinogenic risks to workers and the general population living near toxic waste dumps are still badly characterized and are not specific to electricity production.

The carcinogenic risk of most concern is from radioactive waste disposal. At present, the dominant contribution is from low and intermediate level radioactive waste, mainly mine and mill tailings, which account for about three-quarters of an effective dose of approximately 200 person-Sv per GW(e) per year [47]. Most of this dose will be received within about $10^4$ years after waste disposal. This is based on the assumption that intermediate level radioactive waste is stored in 'reasonably' covered engineered disposal facilities, built below the water table and preferably in clay soils, thus minimizing the contamination of local waters [47].

At present, neither spent fuel nor vitrified high level radioactive waste has been permanently disposed of; current assessments of risk from radioactive waste disposal do not therefore take these into account [3, 47]. The disposal of high level radioactive waste and the management of waste sites to prevent future contamination resulting from population settlements, acts of war and geological events for hundreds of years pose great logistical problems. It is therefore not possible to predict what the health risk from the disposal of today's high level radioactive waste is going to be for future generations.

## 5. CANCER RISK FROM ACCIDENTS AND MISUSE

Accidents are not the only source of non-routine exposure to carcinogenic agents, as has been shown with the burning of oil wells during the war in the Persian Gulf. Acts of war, targeted either on oil or nuclear facilities, can lead to extreme levels of environmental contamination with still unclear consequences for humans and the natural environment. The carcinogenic risks entailed by these acts are difficult to assess, as is the likelihood of future events of this sort.

In terms of cancer, accidents in coal mines, dams, refinery fires and oil platforms or tankers entail relatively little risk, while accidents in the nuclear industry can lead to abnormal levels of exposure to ionizing radiation locally, and possibly on a global scale.

Accidents in the nuclear industry can be divided into two types: those that concern only a limited number of persons (mainly workers in a plant or during the transport of radioactive mterials) and those that involve large groups of the general population. Accidents limited to a few exposed persons are much more frequent than accidents yielding global environmental contamination, and may go unreported. Most of the known accidents resulted in relatively high doses to a small number of individuals [47, 71]. At least ten major accidents occurred between 1945 and 1989, mostly before 1965; since then, better knowledge of the relevant parameters has resulted a reduction in risk of such accidents; most of these accidents occurred in research reactors. UNSCEAR has also reported a large number of incidents in connection with the transport of radioactive material or with the loss or stealing of such materials [47, 72].

Accidents at nuclear power plants involving large numbers of individuals are fortunately rare, but they do occur. There have been four known major documented accidents in nuclear power plants: Kyshtym in September 1957 in the southeast Urals; Windscale in the UK in October of the same year; Three Mile Island in the USA in March 1978 and Chernobyl in the Ukraine in April 1986. Detailed reviews of these accidents are available [47, 71, 72]. The consequences of the Chernobyl accident are discussed in greater detail because of its severity.

Many reports have been published on the radiological contamination from the Chernobyl accident and on its health consequences. Predictions range from nearly zero to millions of additional cancers worldwide. Using the more accepted risk coefficients for radiation carcinogenesis derived by national and international risk assessment agencies, the variability is somewhat reduced: Il'in et al. [73] predict approximately 1200 extra deaths from cancer among the 74 million inhabitants of the central regions of the USSR, an excess of 0.011% above the spontaneous level, using the UNSCEAR [47] radiation risk estimates. On the basis of Bengtsson's evaluations, which use the Swedish Radiation Protection Authority risk estimates, 8000 extra deaths from cancer are predicted in the European part of the Soviet Union, and 4000 in the rest of Europe [74]. The United State Department of Energy [75] predicts 6500 extra cancer deaths in the Soviet Union (range: 2000–17000), 10 400 in Europe, excluding the USSR, and 17 400 worldwide. Using a risk estimate for cancer mortality of 0.1/Gy, the Commission of the European Communities predicts 20 000 additional cancer deaths among the 320 million inhabitants of the European Community [76].

Predictions of cancer risk resulting from the Chernobyl accident depend strongly on the assumptions being made regarding dose distributions and radiation risk estimates; the Chernobyl accident resulted in both external irradiation with low linear energy transfer radiation and internal contamination with a number of radionuclides. There are still uncertainties about the effects of protracted low dose exposures to ionizing radiation, as well as about the relative effects of different types of radiation. In particular, little is known about the magnitude of risk from internal contamination with iodine and other radionuclides. Any risk prediction is therefore subject to criticism. Only a careful study of very large populations with well known dose levels could help in assessing the validity of the various risk predictions that have been published.

It is impossible at present to estimate reliably the health consequences of future nuclear accidents, since too few data are available on the probability of occurrence of a major accident, and prediction of its effects remains subject to the many uncertainties outlined above.

## 6. CANCER RISK FROM ELECTRICITY DISTRIBUTION

The methods of transmission and distribution of electricity are similar, regardless of the source from which it is generated. Considerable epidemiological data on occupational and residential exposures to extremely low frequency (ELF) fields have been published in recent years. Human exposure to electric and magnetic fields (EMF) in the ELF range (0–300 Hz) has recently been suspected of increasing the risk of leukaemia and other malignancies, especially in children in relation to residential exposure [77]. There is still no consensus, however, as to whether cancer risk is increased by exposure to EMF arising from electricity distribution systems. Regarding occupational exposure, the results are quite consistent across studies, indicating a relative risk for leukaemia of the order of 1.5–2.0 for 'highly exposed' versus 'less exposed'. Increases in brain cancer risks have also been reported [78].

Recent experimental research on ELF fields has yielded informative results on the mechanisms by which they may induce cancer. In particular, ELF fields appear to interact with phorbol esters, the best known promoting agents in experimental carcinogenesis, at membrane receptor sites [79], and to be able to suppress T-lymphocyte cytotoxicity in murine cell lines [80].

## 7. PROBLEMS IN COMPARATIVE QUANTITATIVE CANCER RISK ASSESSMENT

### 7.1. Limitations in data

Most electricity generating processes entail carcinogenic risks to humans at different steps of the cycle. Some of the risks are well characterized and in a few cases serious attempts to quantify the cancer risk have been made. In general, risks to workers seem better characterized than those to the public, and a few occupational groups related to electricity production have been studied quite extensively. In most instances, however, the agents of carcinogenic concern which result from electricity production are not specific to that industry, exposure levels are imprecisely known, and exposures are spread over large areas, where the same or similar agents from other sources are also present. In such situations, quantification of the cancer burden due to electricity production can be estimated only on the basis of a long list of assumptions, resulting in estimates likely to depend more on the uncertainties than on the data available.

A number of reports has been published in the recent literature [54, 81, 82], raising the question of the adequacy of current risk estimates for low level radiation exposures. The results of these studies suggest that low level chronic exposures may actually entail a greater risk than that which has been estimated until now. Although interpretation of these results is not straightforward, and more studies are needed to confirm or dismiss them, it raises, once again, the question of the soundness of scientific bases for risk extrapolation.

### 7.2. Uncertainties in the assumptions

Uncertainties in the assumptions needed to quantify cancer risk from different energy sources are best exemplified in the case of airborne emissions of chemicals and radiation from the different cycles. Similar considerations, however, apply to the other steps of each power cycle, such as the mining or extraction of raw materials, transportation, waste disposal and accidents.

Estimates of health effects, and specifically carcinogenic risk, of airborne emissions from electricity generation rely on assumptions about a number of factors, including exposures which depend both qualitatively and quantitatively on the compositions of the fuels, the technology of the power plant, the maintenance of key components such as boilers and pollutant precipitators, the atmospheric conditions (wind, temperature and humidity), the interaction with other airborne pollutants and other carcinogenic exposures, the structure of the population living in the area of concern, and factors such as the density, the proportions of subgroups with different susceptibility and the relationship between exposures and diseases. Quantitative estimates of the effects of airborne pollutants or radiation usually present simplified assumptions, such as 'standard' fuel composition and plant operating conditions, and no chemical or biological interaction with other factors. No serious attempt has been made to evaluate in how far estimates would vary if some of these assumptions were modified.

### 7.3. Additional considerations

Any attempt to quantify cancer risk to human populations has to cope with factors which are even more difficult to quantify or predict than those previously discussed. In the case of electricity production, one must weigh fairly short term exposures and short term risks (within the space of an individual's lifespan) against longer term exposures and risks and probabilistic considerations. In the case of coal burning, for example, exposures resulting from the generation of 1 GW/a of electricity can be characterized in space and time, and if the risk assessment models were adequate, the resulting excess number of cancer cases could be estimated. The worldwide ecological modifications resulting from fossil fuel combustion and their influence on the future life of humans and other living species should also to be taken into account, but predictions are at present based only on the available knowledge of the processes. In the case of nuclear fuels, however, much of the risk is probabilistic; during routine operations, the nuclear cycle does not cause very much pollution because of the very strict controls built into it. Most of the risk therefore comes from accidents, from acts of war which cannot be predicted, and from the accumulation of wastes which will need to be managed very carefully for many centuries. Both the carcinogenic risk and the exposure resulting from current production of electricity from nuclear sources must therefore be considered in the very long term, and the risk must be thought of as a risk of cancer in directly exposed individuals and as a genetic cancer risk in future generations. It is unclear how these issues can be put into the frame of a global comparison of effects.

Another aspect of the problem that is also likely to affect any risk assessment is the time and space variation of risk from different energy sources. Data on which to base comparisons are specific to existing facilities in countries where studies have been carried out. It is likely that technological improvements will continue to occur in the future, but it is unclear, for instance, what proportion of the hazardous emissions currently produced by fossil fuelled power plants can be reduced by ameliorating the existing plants. Furthermore, application of sophisticated and highly hazardous technology, such as that used in the nuclear industry, might create special problems in countries where adequate competence is not available.

### 7.4. Conclusions

Very sparse data are available upon which to base a full quantification of the cancer risk to humans from the electricity production industry. Different approaches have provided conflicting data and it would be misleading to compare estimates on widely studied cycles, such as nuclear, with estimates on cycles whose effects are far from clear, such as fossil fuels. More data are needed on exposures and on humans, and risk prediction models must be validated. As mentioned, even predictions on the effects of the Chernobyl accident vary by orders of magnitude.

When quantification of risk is considered not to be feasible, however, qualitative indication of the existence of a carcinogenic hazard should be considered sufficient to implement preventive measures and to operate towards a reduction in the opportunities of exposure. However, no cycle seems to be free from cancer risk to humans; even 'cleaner' technologies, such as hydroelectric or wind power, entail some carcinogenic risks for workers engaged in the acquisition of material. A reduction in electricity consumption, as the global adoption of an energy saving policy, seems to be the best way of diminishing the cancer burden that might arise from this industry. Reduction in airborne carcinogenic emissions, such as metals, PAHs and radionuclides, will clearly be beneficial, although it will be very difficult to quantify the benefit. Prevention of release of contaminants from nuclear plants, both under normal operating conditions and during accidents, will also prevent cancer in exposed populations. It is unrealistic, however, on the sole basis of current knowledge to recommend global adoption of any one energy cycle on the basis of a quantified assessment of the effect of this choice on the carcinogenic risk to exposed human populations.

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# CRITICAL LOADS, REVERSIBILITY AND IRREVERSIBILITY OF DAMAGE TO ECOSYSTEMS

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## Abstract

CRITICAL LOADS, REVERSIBILITY AND IRREVERSIBILITY OF DAMAGE TO ECOSYSTEMS.

The concept of critical loads and levels has been introduced into national and international pollution control programmes over the past few years. The term critical loads is usually applied to elements such as phosphorus, sulphur and nitrogen which are essential building blocks for life but which create ecosystem damage when present in excess amounts or in particular forms. Acidification of surface waters owing to atmospheric deposition of sulphate has been well documented in North America and Europe. Over the past two decades in industrialized countries there have been significant reductions in sulphur dioxide emissions which have resulted in decreased sulphate deposition downwind and improvements in chemical and biological quality of surface waters. Large sulphur dioxide emissions at Sudbury, Canada, have acidified surface waters in that area over the past 100 years. However, significant emission reductions have been achieved since the 1970s and surface waters have shown decreasing sulphate concentrations and increasing pH. In one study lake, lake trout reproduction has recommenced in response to improving lake pH. One study lake in central Canada has shown that the recovery process can be very complex over a number of years as the terrestrial processes adjust to new deposition conditions. Watershed characteristics influence the time and nature of the recovery process. Improvements in lake quality and stream runoff quality are observed as deposition decreases, well before the critical load values are reached. There is strong supporting evidence from experimental manipulations of lake and terrestrial ecosystems that recovery will occur when deposition is reduced. Forest decline has been observed in many areas receiving acid deposition and there is scientific consensus that acid deposition is one stress contributing to the decline. There is evidence also that removing the acid stress will result in restoration of terrestrial systems in badly damaged areas although it would take many decades for a forest to return. Experimental results show that removing deposition from soils results in large changes in the composition of the soil water but recovery of forest decline in the study plot has not yet been documented.

## 1. INTRODUCTION

The use of deposition values or atmospheric concentration objectives, based on environmental effects, has been introduced into national and international pollution control programmes over the past decade [1, 2]. These values, defined as critical or target loads and levels [3], are similar to conventional pollution control objectives, although they introduce a number of important new concepts.

The application of conventional air and water quality objectives for protecting the environment against the effects of toxic pollution has been a standard approach for many decades. A variety of biological test methods is used in setting standards for toxic materials. For example, 'application' or 'safety' factors are applied to short term acute toxicity test results to determine environmental concentrations deemed to be protective of the environment [4]. Specific values for application and safety factors have been determined by comparing experimental toxicity data for known effect and non-effect concentrations. Environmental objectives can be set as low as 0.01% of the $LC_{50}$ concentration [4]. Pollution control measures are applied to ensure that these environmental objectives are met in the environment and it is further expected that all negative effects will be prevented. Since the objectives are applied in the natural environment and not directly to the air or water emissions as they enter the environment, there will be some mixing zones adjacent to the emissions in which the environmental objectives will not be met [4]. However, polices are usually applied to minimize these areas of non-compliance to the greatest extent possible.

For many toxic compounds, such as lead, mercury and cadmium, the desirable objective for concentration in the ecosystem might be zero, but since this may not be achievable in an industrial society, setting and meeting environmental objectives is an alternative approach to achieving environmental protection. Elements or compounds in this category cause measurable biological damage if present in high concentrations and beneficial effects in the environment would not be expected at any concentration.

There are a number of essential elements such as phosphorus, sulphur, nitrogen and carbon which can lead to significant environmental change and damage if present in the environment in excessive amounts or in particular forms. For example, excessive amounts of phosphorus in lakes can lead to major ecological distortion due to excessive algae growth (eutrophication) [5]. The effects of excessive sulphur, in the form of sulphuric acid, can cause environmental degradation due to acidification [6]. Ammonium and nitrates can contribute to acidification as well [7].

There is increasing concern that the concentrations of carbon dioxide in the atmosphere may also lead to changes in global climate [8]. Since the elements in this category are essential building blocks of life, and are naturally present in the environment, it is not possible or desirable to reduce their concentrations in the environment to zero. However, as indicated, these elements/compounds can cause significant environmental changes because of the amounts or forms in which they occur in the environment. In contrast to the effects of the toxic materials, the environmental changes that occur might be deemed beneficial. For example, increasing the amount of nitrogen deposition to forests may increase their overall health and growth rates [9]. Nitrogen deposition may also create a terrestrial ecosystem that is different from the natural ecosystem [3], which for some observers could be a more desirable state, although this is very subjective. Therefore, in setting objectives for these compounds in the environment, it is valid to consider the concept of a critical load or level which is not zero but rather is defined as "the highest load/level that will not cause chemical changes leading to long term harmful effects of the most sensitive ecological systems" [3].

A number of elements, such as selenium and copper, have characteristics of both categories in that they are essential elements to life. Zero concentrations in the environment are not acceptable but at higher concentrations they have toxic effects [4]. Objectives for these compounds are generally established using the same principles as for toxic compounds.

TABLE I. CONTRASTS BETWEEN CONVENTIONAL ENVIRONMENTAL OBJECTIVES AND CRITICAL LOADS

| Conventional objectives | Critical loads |
|---|---|
| Effects generally experienced at the organism level | Effects usually manifested at the ecosystem level |
| Objectives established on the basis of laboratory tests | Ecosystem studies required to establish values |
| Lethality or physiological effects are the usual response used in setting objectives | Ecosystem effects may be via direct (chemical change) or indirect (food chain alterations) mechanisms |
| Compounds considered are not essential to life | Elements or compounds are essential building blocks for life |
| Environmental objectives are set well below known effects to provide some margin of safety | Objectives are set as close to damage levels as possible |
| No beneficial effects are likely to occur in the environment at any level | Changes may occur that are deemed beneficial (such as increased productivity) although such benefits may be very subjective |
| Environmental damage from exceedences is usually observed within a short time | Environmental damage from exceedences may occur over a long time (years–decades) and may be cumulative |

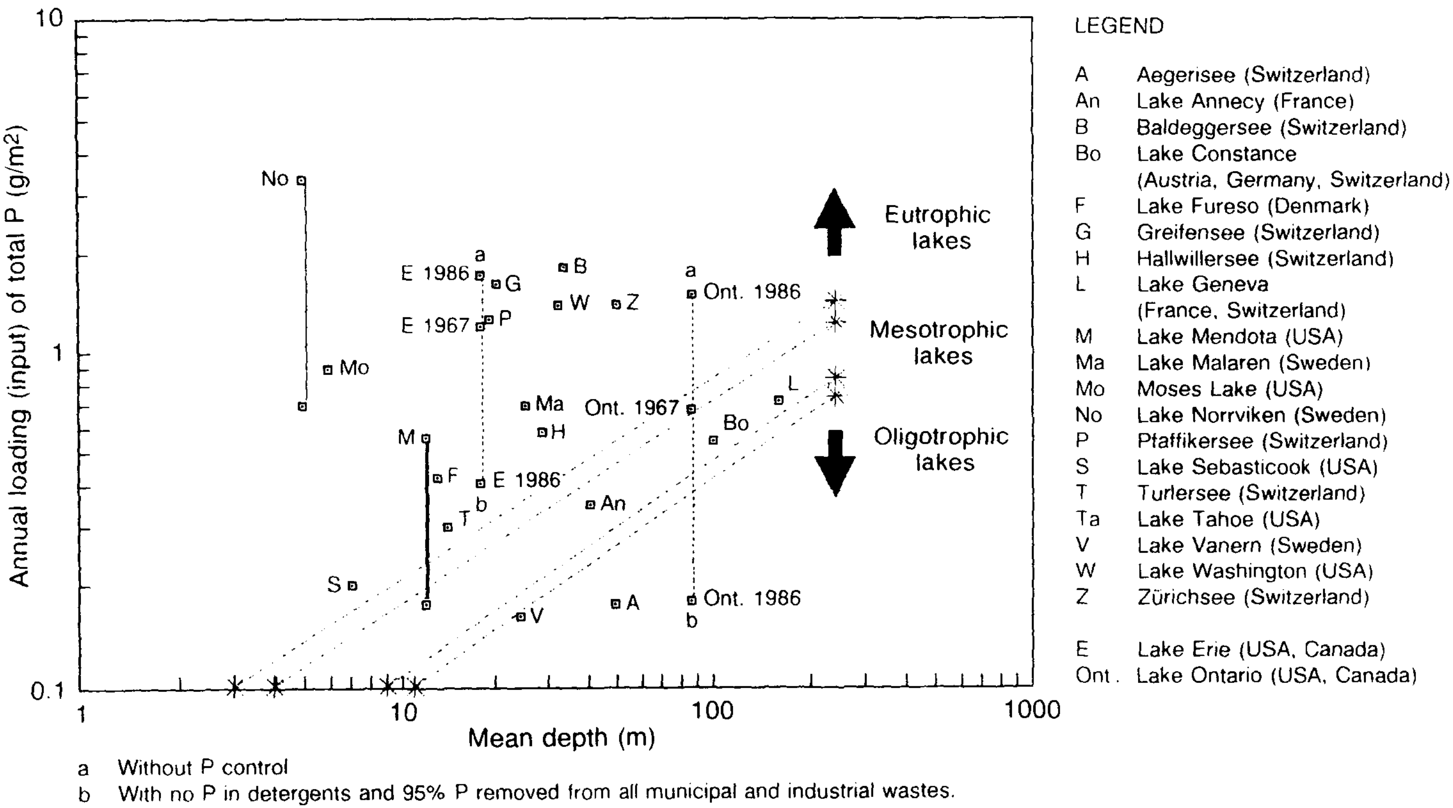


*FIG. 1. State of eutrophication for a number of lakes in Europe and North America [11].*

While conventionally derived objectives and critical loads are both designed to prevent damage to the environment, there are a number of contrasts as summarized in Table I. There is some overlap in some of the characteristics, and critical levels (i.e. concentrations) for some gases such as sulphur dioxide are similar to conventional objectives.

In setting objectives for toxic materials, the concentration is set well below known damage levels, thereby providing a safety measure for the environment [4]. In contrast, the critical loads concept seeks to establish environmental objectives just below the known environmental effects. Since these effects are difficult to define in their entirety over the long term, it is equally difficult to establish critical loads at values that guarantee no changes in the environment over time. Partly to account for such uncertainties, the term target load has been introduced which is defined as an environmental objective (generally higher than the critical load) which accounts for some of the practical considerations such as the economic feasibility of achieving the critical and the societal acceptance of ecological changes and/or damages that may occur or remain at the target loading value [9].

One of the earliest approaches to establishing environmentally based objectives for the essential elements was that of Vollenweider in evaluating the effect of phosphorus on lake productivity [10]. Vollenweider's phosphorus model, as shown in Fig. 1 [11], recognized the role of phosphorus loading to lakes in defining their trophic status. The model allowed environmental managers to design phosphorus control programmes to move eutrophic lakes to a less eutrophic condition and to protect lakes from deterioration. It was successfully applied to pollution control measures in the Great Lakes Basin of North America where eutrophication, particularly of Lake Erie, became a major environmental problem in the 1960s [11]. The Vollenweider model was unique in its approach and influential in subsequent approaches to setting environmentally based objectives [12]. The approach is largely dependent on empirical observations and thus inherently accounts for many environmental factors that are poorly defined or not even known.

In 1982 Sweden proposed objectives for sulphur deposition for their country, on the basis primarily of empirical observations that were supported by model calculations. A total deposition of no more than 9 kg $SO_4 \cdot ha^{-1} \cdot a^{-1}$ was determined to be the critical load for sensitive lakes in Sweden. A value of 15 kg $SO_4 \cdot ha^{-1} \cdot a^{-1}$ was predicted to prevent large scale acidification damage [13, 14].

In 1983, Canadian scientists used a similar approach in establishing a sulphur deposition target load for eastern Canada [1]. A target value of 20 $kg \cdot ha^{-1} \cdot a^{-1}$ of wet sulphate was established using empirical observations in eastern North America, supported by the environmental models available at the time. Figure 2 shows the deposition values for a number of study sites. Data were available to demonstrate acidification damage at all locations with deposition above 20 $kg \cdot ha^{-1} \cdot a^{-1}$ (40 $meq \cdot m^{-2} \cdot a^{-1}$). It was recognized that some damage would likely occur in sensitive areas at less than 20 $kg \cdot ha^{-1} \cdot a^{-1}$ but data were too limited to establish a more

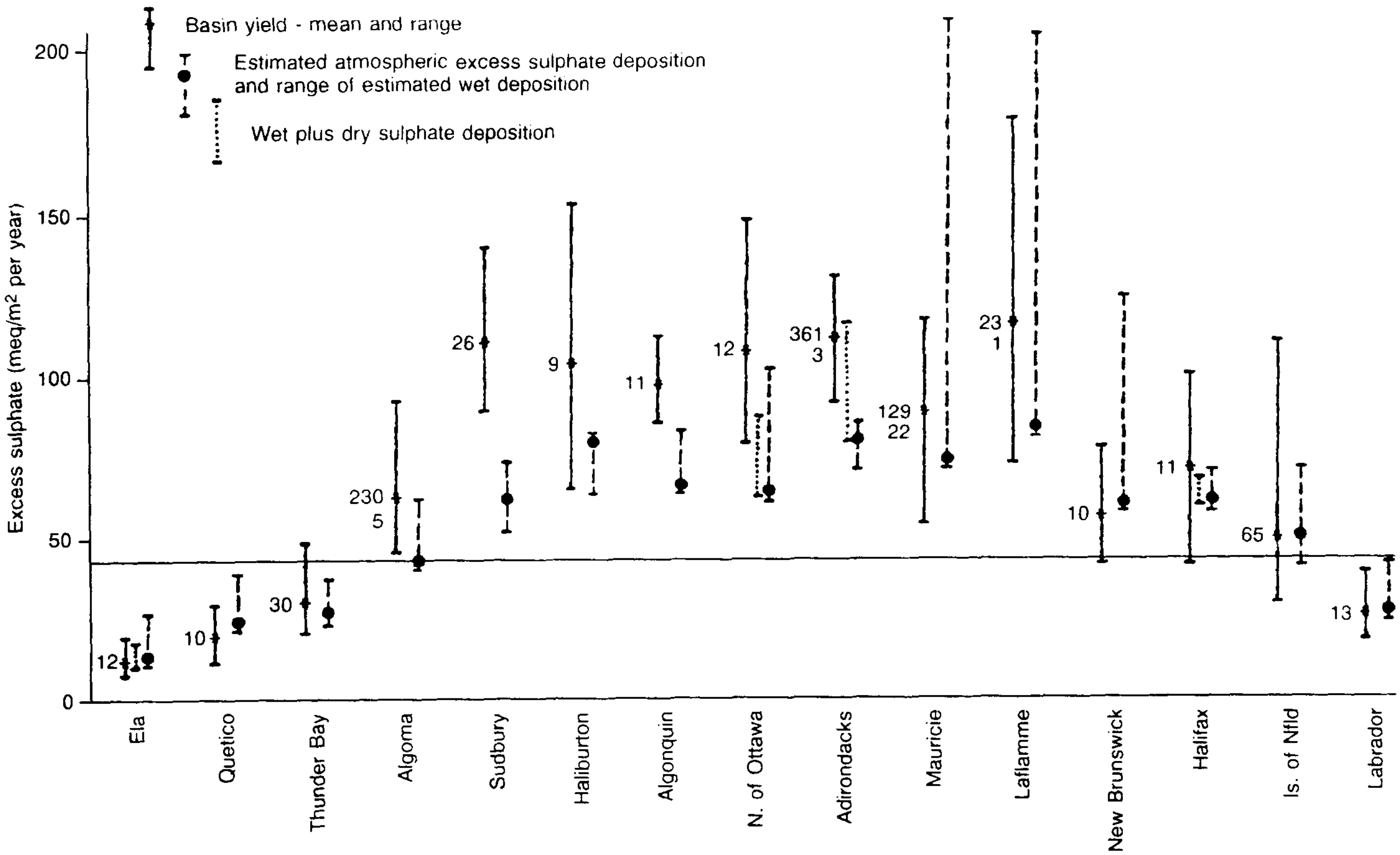


*FIG. 2. Mean and range of the basin specific yield of excess sulphate compared with estimated atmospheric excess sulphate deposition in precipitation for 1980. Also shown are wet plus dry depositions of sulphate calculated from 1980 measurements of $SO_2$ in air at four stations [1].*

precise deposition value. Recently newer and more extensive data in eastern Canada have been used in concert with a more stringent ecological threshold to define critical loads for tertiary watersheds that are as low as 8 $kg \cdot ha^{-1} \cdot a^{-1}$ of wet sulphate [15].

In both the Swedish and Canadian cases, scientists decided that there was insufficient information to establish a similar number for nitrogen; therefore it was assumed tentatively that the effects of nitrogen would either be minimal or at least would not increase in the future as sulphur was reduced. However, recent data have also indicated that nitrogen deposition may contribute to acidification of surface water [16].

Critical and target loads are generally established in areas where the current environmental conditions are unacceptable. The goal is usually to reduce deposition to these values and thus reduce or eliminate the damage. Consequently, an obvious question is the rate and extent of recovery of the ecosystem that will result when the critical or any given target load is met.

It should also be pointed out that it is not necessarily acceptable to allow deposition to increase to target values in areas that are currently below the value. Other factors, such as prevention of significant deterioration (PSD) in pristine ecosystems or meeting national emission objectives, may override the application of a critical load approach.

In this paper attention is focused on the recovery of ecosystems from acidification.

## 2. RECOVERY OF ECOSYSTEMS

Virtually all industrialized countries are at various stages of implementing sulphur and nitrogen control programmes for preventing acidification of terrestrial and aquatic ecosystems. Sulphur control programmes, in particular, have been in place for many years in North America and Europe and as a result, information regarding environmental recovery is available. In addition, there are a number of ecosystem experiments which have provided considerable information on the environmental response to decreasing deposition.

### 2.1. Aquatic ecosystems

#### *2.1.1. Sudbury, Ontario, Canada*

The non-ferrous smelting operations at Sudbury, Ontario, Canada, have resulted in large sulphur dioxide emissions in that area for the last one hundred years; these emissions, in combination with a number of other detrimental forest practices, have resulted in extensive environmental degradation. In the 1970s sulphur dioxide control measures were implemented by two local smelter companies. One of them,

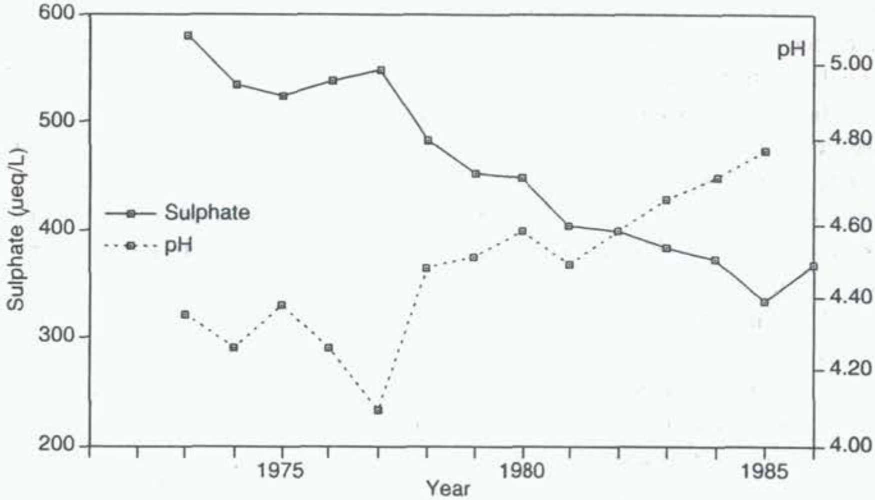


*FIG. 3. Temporal variation in pH and $SO_4$ in Clearwater Lake, 1973–1986 [15].*

INCO Ltd, also built the world's tallest stack (381 m) which was commissioned in 1972 and designed to disperse remaining emissions over a much larger area. The combination of these measures resulted in substantial improvements in the local air quality and decreases in acid deposition to the local ecosystem, particularly of the dry deposition [17]. Results for Clearwater Lake (Fig. 3) [18] show that after very little change was observed in the lake water quality from 1972 to 1977, there was a steady decrease in the concentrations of sulphate and improvement in the lake pH until recently. In the last two or three years sulphate concentrations appear to have stabilized, likely owing to the fact that there have been no further improvements in the deposition since local sulphur dioxide emissions have been fairly constant during this time. It is expected that the improvement will resume again as further sulphur dioxide controls are implemented in Canada and in the United States of America.

Gunn and Keller [19] have reported on the biological improvements that have occurred in lakes near Sudbury. Detailed studies on White Pine Lake, near Sudbury, recorded the appearance of naturally produced young lake trout from the remnant adult population. Young lake trout first appeared in 1982 and became increasingly abundant throughout the rest of the study (Fig. 4). No young fish were taken in experimental netting in 1976 and 1981. Two fish were collected in 1982 and by 1987, 103 juvenile fish were taken in the nets. These results indicate that while some adult fish had survived in the lake, reproduction was not successful until the pH increased above 5.5. White suckers and burbot populations did not respond to the improved water quality, presumably because the adult population was too small by

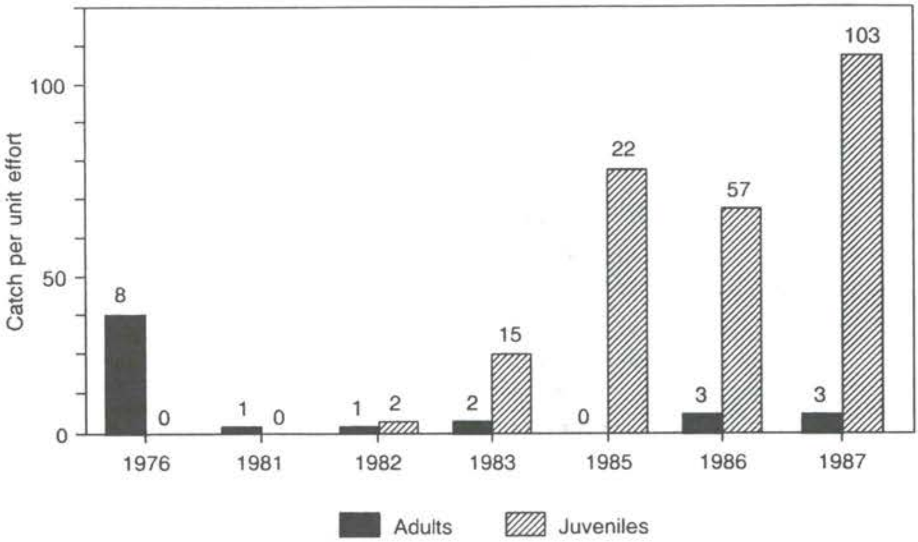


*FIG. 4. Catch of lake trout per unit effort in experimental gill nets in White Pine Lake, near Sudbury, Ontario. The numbers of fish recovered are indicated on the graph [19].*

the time the water quality improved. The authors also identified decreases in the lake trout prey population of perch and decreases in benthic invertebrates in deep areas of the lake occupied by lake trout. Conversely, the density of invertebrates in the shallow areas, normally foraged by perch, increased as the abundance of perch declined. In addition to changes in invertebrate populations that could be related to fish populations, the authors also identified changes that were due to improved water quality in that the total number of taxa increased from 39 in 1982–83 to 72 in 1988; at least five new species were identified in the 1988 survey.

Clearwater and White Pine lakes are not unique examples. Survey data from over 200 lakes in the area also show decreases in hydrogen ion content of about 50% between 1974 and 1976 and 1981 and 1983 [20]. Sulphur dioxide emissions in the area were reduced about 70% from the 1960s to the late 1980s. The total deposition in the early 1970s was estimated to be from 75 to 150 $kg \cdot ha^{-1} \cdot a^{-1}$, mostly as dry deposition of $SO_2$ [21]. The present deposition in this area is about 20 $kg \cdot ha^{-1} \cdot a^{-1}$ [22] and recent studies have indicated that the critical loads for this area should be 9 $kg \cdot ha^{-1} \cdot a^{-1}$ [15]. These results indicate that while the critical deposition has not yet been reached there has already been significant improvement in lake water quality.

The sulphur dioxide emissions and the environmental degradation in the Sudbury area represent very extreme conditions and the recovery of ecosystems has been greatly influenced by local controls rather than by a response to long range transport of air pollutants. However, there are other areas of eastern Canada where recovery in response to changes in long range deposition have been recorded.

In Nova Scotia the export of sulphate from watersheds, as measured by the discharged weight concentrations in river water, decreased by an average of 47% for 12 rivers between the years 1971 and 1973 and 1982 and 1983 (range 38–61%). In Newfoundland, the sulphate export decreased by an average of 44% for eight watersheds (it ranged from one watershed increasing by 10% to a decrease of 71%). There was an increase in the pH for all of the rivers [23]. Sulphur dioxide emissions in the upwind areas have decreased and atmospheric models calculated an expected deposition reduction of 20–25% for this time period [24]. These results are in good agreement considering the expected error in the model calculations and the variability in the sulphate measurements.

Data are also available for lakes in the Algoma area of Ontario located at the eastern end of Lake Superior. Fifty-four lakes have been sampled every three years since 1979. It has been shown that in response to reduced sulphate deposition, the lakes have either increased in pH and alkalinity or decreased in base cation concentrations [25]. White sucker populations were observed in two lakes in 1986 with age classes indicating survival had begun after 1980. When these lakes were sampled in 1979, the pH was less than 5.5 and no fish were found. The authors suggest that the fish invaded from healthier downstream waters when the pH in the study lakes approached 5.5.

The Plastic Lake watershed in south central Canada, just east of Georgian Bay, has been intensively studied for over a decade [26]. The sulphate deposition in the area decreased about 40% from 1976 to 1983 and has been relatively constant for the past 6 years. This is consistent with decreases in eastern North American sulphur dioxide emissions [27]. Current deposition is about 30 $kg \cdot ha^{-1} \cdot a^{-1}$ wet sulphate. The critical load for both the Algoma area and the Plastic Lake is estimated to be over 20 $kg \cdot ha^{-1} \cdot a^{-1}$ in order to maintain less than 10% of the lakes at a pH of less than 6.0 or 16 $kg \cdot ha^{-1} \cdot a^{-1}$ and to maintain less than 5% of the lakes at a pH of less than 6.0, so the deposition is well above the critical load. Protection of the remaining 5 or 10% of the lakes not protected by these critical loads would require much lower deposition values.

The overall Plastic Lake response has been rather complex but some of the main features are as follows. Alkalinity and base cations decreased from 1979 to 1985. The continuing acidification while deposition was decreasing was hypothesized to be due to lake water replenishment time (about 4 years) and to delays in response within the catchment. In recent years, the lake alkalinity has remained constant. Sulphate concentrations decreased over the study period and continued to decrease after the deposition stabilized mainly owing to the time required to reach a steady state within the lake. However, sulphate concentration increases in the most recent years are attributed to the reoxidation and release of sulphate stored in a wetlands area of the watershed. Long dry periods resulted in the water table being lowered in the wetlands, leading to the reoxidation of the sulphate. The alkalinity in an upland stream, which drains only soils, went from negative values (i.e. acidic) to positive values over the study period, but the effect of wetlands in the drainage basin has delayed and complicated the recovery of the lake itself.

### 2.1.2. *Experimental evidence of ecosystem recovery*

Documentation of recovery in natural systems has sometimes been hampered by a lack of historical information since the environmental effects began before acid deposition measurements were made. Studies on the experimental manipulation of ecosystems have provided considerable additional information on the mechanisms of recovery of ecosystems.

At the Experimental Lakes Area (ELA) in northwestern Ontario, Canada, lakes have been deliberately acidified by the addition of sulphuric or nitric acids. Acid deposition is low in the area, about 10 $kg \cdot ha^{-1} \cdot a^{-1}$ wet sulphate [22]. The experiments provide accurately controlled pH changes and the chemical and biological effects are well monitored [28]. Over the past several years the acidification of one lake has been allowed to recover at a controlled rate.

Lake 223 was acidified with sulphuric acid and a loss of biological diversity was observed as the pH of the lake was reduced below 5.8, from its original value of 6.5 to 6.7. All species of fish ceased reproducing at pH levels below 5.2. Beginning in 1984 the pH was allowed to increase by reducing the acid loading. As the

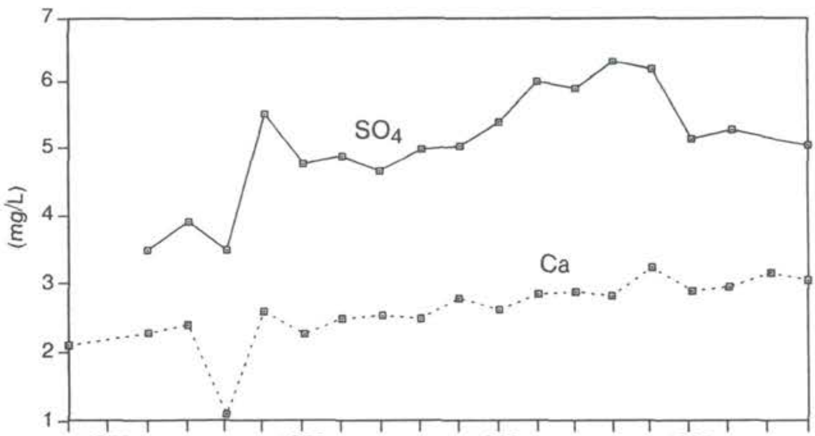


*FIG. 5. Mean volume weighted concentrations of calcium and sulphate in Lake 239 from 1969–1988 [27].*

pH of the lake increased from about 5.0 to 5.8, reproduction of lake trout, white sucker and pearl dace resumed at about the same pH levels where reproduction had been observed to stop during the acidification phase of the experiment [29].

The experimental results are consistent with field observations that failure of fish reproduction is a sensitive response to decreasing pH and that recovery will occur so long as sufficient adult populations remain. Obviously if the adult populations are lost, then restocking programmes will be required.

Schindler et al. [30] have reported on the effects of temperature changes on observed trends and surface waters. At the ELA, the wet sulphate deposition is low ($10\ kg \cdot ha^{-1} \cdot a^{-1}$) and has decreased about 20% over the last 15 years [22]. It would be expected that sulphate concentrations in surface waters would also decrease as has been observed in other areas. In fact, however, the sulphate concentrations almost doubled (Fig. 5). The authors were able to show that this increase was mainly in response to a change in evapotranspiration in the area brought about by an increase in the average temperature of about 2°C over the 20 year record. The decreased runoff contributed to an increase in lake concentration of many constituents. These results clearly demonstrate that comprehensive records of ecological data are essential in making a full evaluation of trends in surface waters.

Field and experimental observations of chemical and biological recovery of surface waters following reduced sulphur oxide emissions and deposition are very encouraging.

## 3. TERRESTRIAL ECOSYSTEMS

Most of the observed improvements in surface waters following changes in sulphate deposition are a reflection of changes in the surrounding watersheds.

Direct evidence of terrestrial responses to changing deposition is provided by the Reversing Acidification in Norway (RAIN) Experiment. The wet deposition of sulphate and nitrate was removed in a one-step fashion when roofs were constructed over two watersheds in 1983. Simulated clean rainfall was applied under one roof while the other was operated as a control with the acidic rainfall applied under the roof. Nitrate concentrations in the runoff decreased by 60% within two weeks after the experiment began, a decrease shown to be a direct response to changes in the input from precipitation. There has also been an overall decrease in the strong acid anion concentrations; this reduction is compensated for by the decrease in the concentrations of base cations (55%) and by an increase in the alkalinity (45%). The systems had not reached a new steady state by 1988 so the true reversibility of the acidification of soil is not yet fully known but the results are encouraging and consistent with data from natural recovering ecosystems [31].

The phenomenon of forest decline became a significant issue during the 1980s but the exact role of acid deposition has not been fully defined. Forest decline is regarded to be a result of a number of stress factors on the forest such as insects, diseases and climate [32]. The key question is whether or not the forest will recover if the single stress of acidification is removed from the ecosystem.

In the Sudbury, Ontario, area, forest regrowth has been observed to begin naturally in areas of extreme vegetation damage about ten years after the severe pollution stress has been removed [33]. It will take many decades, however, before anything that qualifies as a forest is restored. Regrowth of forests in that area is greatly accelerated when the soil conditions are improved by the addition of lime and fertilizer and when trees are planted.

In many areas of forest decline it has been shown that the trees are suffering from nutrient deficiency, most commonly calcium, magnesium, phosphorus and potassium. Many areas of Germany are being treated by the addition of fertilizer that produces revitalization of the forest even though the acid deposition stress has not been completely removed [34]. In Canada, sugar maple decline is quite extensive in the Province of Quebec and experiments have been carried out using potassium fertilizer and lime in various mixtures [35]. At nine study sites there was improvement in foliage transparency and in the incidence of dwarfed foliage. As Hendershot observed, "The most striking improvements were in foliar discoloration where complete elimination of this dieback symptom was observed in three of the nine sites" [35].

Foliar analysis indicated changes in the concentrations of nutrients, particularly potassium, calcium and magnesium. While acid deposition has decreased in the study area, as it has over all of eastern North America over the last decade, there would have been very small changes in deposition during the study period.

A number of experiments being conducted in Europe have resulted in acid deposition being excluded from forest soils and replaced by clean rain, with and without the addition of nutrients. At one study site in the Netherlands, large changes have already been observed in soil chemistry as a result of excluding the deposition but recovery of the forest has yet to be documented [36].

It is hoped that the results of these experiments over the next few years will further clarify the role of acid deposition in forest decline and help determine the rate and extent of recovery from damage.

## 4. CONCLUSIONS

Decreases in sulphur dioxide emissions in a number of industrialized parts of the world have been reflected in decreased deposition downwind and improvements in chemical and biological quality of surface waters.

The improvements in runoff water quality can begin within weeks or a few years after decreases in deposition, although recovery to the original chemical and biological condition takes decades. As water quality improves in lakes, fish reproduction has been shown to recommence if there is a sufficiently large residual adult population.

The chemical changes in runoff from watersheds, following a reduction in deposition, can be quite complex as the various soil processes adjust to decreased deposition. Expected trends in recovery may be altered by other factors such as changes in temperature and evapotranspiration.

There is evidence of forest recovery in areas of severe acidification damage, although the time required to restore a healthy forest will be many decades. The process can be speeded up by the addition of lime and fertilizers and replanting of trees, but it will still be decades before a healthy forest is restored.

Addition of fertilizers and lime to damaged forests can improve vitality and eliminate decline symptoms even though acid deposition remains high. Recovery of forest decline in response to decreased deposition in areas of less severe acid deposition, however, has not yet been well documented.

## ACKNOWLEDGEMENTS

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## SUMMARY OF THE DISCUSSION OF KEY ISSUES

### Topical Session 3

*Chairwoman:* **G. Kibble** (Australia)

*Rapporteur:* **M.J. Chadwick** (Commission of the European Communities) (CEC) *(Consultant)*

*Panellists:* **A.F. Fritzsche** (Switzerland)
**L. Hamilton** (United States of America)
**J. Lochard** (France)
**I. Mintzer** (United States of America)
**B. Wahlström** (International Institute for Applied Systems Analysis) (IIASA)

G. KIBBLE (Australia) *(Chairwoman)* began by highlighting some of the major themes which had emerged from Key Issues Paper No. 3 and the other papers presented during the session. It was clear that there was no single response strategy to deal with the problems of climate change, and that a range of measures would have to be taken to mitigate and adapt to these problems. It seemed likely that greater pressure for stronger environmental controls would develop and that there would be greater demand for public participation in decisions on environmental issues, which would have to be made against a background of considerable uncertainty. Internationally co-ordinated mechanisms would be necessary for the collection and dissemination of data on health and environmental issues and there would be a need for a better environmental assessment methodology with more quantifiable indicators to deal with these issues. However, it must be recognized that the results of assessments and studies could not be applied on a global basis and that appropriate risk and environmental assessments needed to be carried out on a regional scale to deal with local conditions. Finally, it was essential to ensure that the best international institutional arrangements were available to deal creatively with the range of research and other issues in the fields of energy, the environment and health.

K. KING (World Bank) (IBRD) said that the implications of Key Issues Paper No. 3 were far more radical than those of Key Issues Papers Nos 1 and 2. Comparative risk assessment necessarily went beyond the traditional focus of electricity planning in at least three ways. First, since it was essential to include the impacts on health and the environment from the entire fuel cycle, decision making was elevated to at least the level of the overall energy sector, rather than just the electricity subsector. Second, the time-scale of many health impacts, such as cancer, and of environmental impacts, such as irreversible damage to ecological systems, made it necessary to adopt a much longer perspective than the 7–10 year planning horizons generally adopted by power utilities. If a longer time-scale of, for example, 40 years was adopted in examining these impacts, it would also be necessary to look at the dynamics of technology development and not just limit the choice to the power technologies currently available. Third, as illustrated in N. Sundararaman's paper (SM-323/22), there was a global dimension, so that it was necessary to look beyond the energy sector in the decision making process to other sectors, such as the agricultural sector, which made similar contributions to greenhouse gas emissions. These factors therefore entailed a move into rather unfamiliar territory and planning in the electricity sector would be much more complex than ever before.

B. WAHLSTRÖM (IIASA) agreed that assessments in the electricity planning sector would have to take a wide variety of aspects into account. However, it might not be necessary for individual utilities to consider all these aspects for every installation, provided an institutional system could be established where global policies were formulated on a single level and then broken down into national policies to provide the framework for planning at the utility level. The first steps towards this kind of planning have been described in Key Issues Paper No. 4.

A.F. FRITZSCHE (Switzerland) noted that the Symposium had already shown very clearly that the risks associated with electricity production were only one of the aspects which had to be taken into account in electricity planning, although the focus of the current session was on this aspect. Increased public concern about health and safety, at least in developed countries, in all fields, not only in the energy sector, made it imperative to deal with this problem. Comparative risk analysis aimed at providing as rational a basis as possible, given the current level of knowledge, for dealing with this problem.

To be meaningful, any risk comparison of energy systems must necessarily include the various categories of risk incurred by all parts of the corresponding fuel cycles, because all parts of the fuel cycle had their specific and often quite different risks. For example, occupational risk for the large scale production of hydroelectric power was dominated by the risks of dam construction and, in the case of coal, the major risk was incurred during mining. If only the risks involved in actually producing the electricity were considered, they would be very low for hydroelectric power and would account for less than 10% of the occupational risk for the coal cycle.

The time-scale for the incidence of cancer risks was indeed long, but these risks were committed at the time of the decision to build a specific power plant and must therefore be considered at that time. With regard to the dynamics of technology change, although much reasoned conjecture was often possible, even in the case of a traditional energy source such as coal, it was difficult to foresee all such developments and the impacts they could have on health and the environment. However, again, any risks were committed at the time of the decision taking. In other words, decisions were based on the risks of existing technology and not the risks of later, possibly improved, plants which were not yet available on the market.

The greenhouse effect was, of course, quite another dimension, but there it was fairly clear which energy options carried this risk and which did not. A decision on the importance to be attached to this risk was probably more one of basic national or even multinational policy than an element in the decision taken by a utility.

L. HAMILTON (USA) pointed out that, while banks were perhaps considering their investments and payback times over a 7–10 year period, utilities were concerned about the lifetime of the plants in which they were investing; the lifetime of most plants was about 30–40 years. New York State utilities were, in fact, considering the introduction of externalities, in other words, health and environmental costs, into their planning and the inclusion of these externalities in their least cost optimization solution to meet the demand for electricity generation. If the World Bank was interested in the methodologies used by the New York State utilities, he would be happy to make the information available.

I. MINTZER (USA) noted that consideration of the long term impacts might make it possible to improve the efficiency of economic markets in the energy sector by taking into account the full costs of energy supply and use, by making more efficient use of capital, and by reducing long term damage to the environment as a whole.

J. LOCHARD (France) said that the time-scale and global dimension of many of the environmental effects that had been identified over the past decade presented a real challenge for the scientific community. There was still much that was unknown about the real impact of global issues and the final impact, if any, of an increase in average temperature on ecological and human systems. The prevailing attitude was to act with caution so as to avoid any irreversible situations, but it was essential to find out more about the issues at stake as soon as possible in order to avoid any unnecessary long term commitment of large amounts of resources that would be better used in other areas to improve social welfare.

M. KATZ (USA) pointed out that the comparative data in Key Issues Paper No. 3 showed relatively low risk and fatality figures for nuclear power, and yet the main problem associated with nuclear power was one of public acceptance. He wondered how this apparent contradiction could be resolved.

J. LOCHARD (France) noted that the contradiction referred to had been a matter of concern for many years and no real answers had yet been provided. A great deal of work in the field of risk perception and risk communication had attempted to close the gap between the 'objective' and 'perceived' levels of risk. In his view, the proposed solutions of improving public communication and education on these issues had failed because they relied on a model which was too simplistic. If people did not perceive risks as they really were, it was not just a question of irrationality or emotion which had to be corrected but, more fundamentally, the manifestation of certain social and ethical values prevailing at a given level of a society's development. Comparison of the risk of living near a nuclear power plant and the risk of smoking a few cigarettes per day would never have any impact on the attitude of those living near a reactor. There was no easy solution to the problem. Perhaps the social and ethical values should be analysed more carefully. It was also important to remember that risks in themselves were meaningless; risks were always assessed within the framework of some decisional context.

I. MINTZER (USA) noted that there was a tendency to assume that public perception of risk was a function of some quantitative analytical assessment of the probabilistic evaluation of consequences. This was clearly not the case, neither for nuclear power nor for global climate change. It was as much the perception of the uncertainty of the outcome that would dominate the public's reaction. Attempts should be made to assimilate into risk management strategies an evaluation of the relatively low probability, but high consequence, outcome associated with the use of nuclear power and global climate change. In particular, careful consideration should be given to ways of dealing with the uncertainty of the risks associated with the long term disposal of nuclear wastes and with the disruption that might occur several decades hence as a result of global climate change. These two problems were examples of a new type of problem related to environmental impacts in which there was significant scientific uncertainty; a long lag time between the policy decision and the resulting improvement; and considerable separation between those bearing the benefits and those bearing the costs.

L. HAMILTON (USA) said that one of the problems was the confusion of the public, and even among experts, between the use of nuclear power for electricity generation and nuclear weapons production.

A.F. FRITZSCHE (Switzerland) noted that public perception of risks was not just a question of better communication and better information, however important the communication of such information might be. Many scientists, used to logic and rational argument, tended to forget that the irrational element, comprising instincts and feelings, was often much more prominent in the general public. Public reactions to questions of safety and risk were far more instinctive and emotional than rational, and these reactions could only, with difficulty, be influenced by factual information. There was a tendency to agree with information which confirmed previous views and feelings and to disbelieve any information which conflicted with such views and feelings. There was therefore a basic need to understand the psychological process involved. Without such insight, there was little chance for real change and for rationalization of risk perception. Since it was a question of education rather than information, change was likely to take a long time.

B. WAHLSTRÖM (IIASA) said that research had clearly shown that the concept of risk was far more complex than simply the product of probability and costs. Social and cultural dimensions had to be included, involving a communication process where credibility and trust were the most important components. The complexity of the issues associated with nuclear power generation made it difficult for the public to understand them and hence affected its acceptability of nuclear power. Furthermore, the nuclear power industry had, in the past, sometimes given contradictory messages which had not served to promote public confidence. A better understanding was needed of how people responded to different kinds of message and on what they based their beliefs.

P. DASTIDAR (IAEA) said that, given the present rate of human activities, a shift in the concentrations of atmospheric gases was inevitable and even if, as a result of feedback effects, there were no changes in the average global temperature, there would be shifts in local temperature and hence local climates. Since man's economic activities depended on local climates (particularly in the case of agriculture), these economic activities would be disrupted, causing chaotic conditions. He therefore believed that the precautionary principle should be applied to prevent drastic changes in atmospheric gases.

I. MINTZER (USA) pointed out that it was not possible to prevent global climate change. The increase of about 0.4–0.6°C over the past century, as suggested by the scientific Working Group of the Intergovernmental Panel on Climate Change (IPCC), represented a fraction of the climate changes which were expected as a result of emissions during the period from 1880 to 1980. Estimates of the impact of these emissions were of the order of an increase of 1–2.5°C over the pre-industrial level, even if no further emissions of greenhouse gases took place. A further climate change was therefore inevitable and could not be influenced by current policy changes. What could be affected was the rate at which climate change, beyond that which was already inevitable, occurred and measures could be taken to reduce the damage resulting from the unavoidable climate changes.

There would be changes in local temperatures because the climate change resulting from global warming would not be distributed evenly. Estimates suggested that it would be 2–3 times the average at high latitudes in the northern hemisphere, and about 50–75% of the global average in tropical areas. The differentiation would affect the thermal gradient between the equator and the poles and thus alter the thermodynamic heat engine driving the wind and the ocean currents. It was the changes in wind and ocean currents that were likely to alter regional temperatures. In addition to the global average rise in sea level, the most likely effects would be shifts in the patterns of precipitation, as well as the patterns of temperature, and these would affect agricultural production and the frequency and duration of extreme weather events. It was the rate of climate change as much as the magnitude that would determine both disruptions in the ecosystems and the economic impacts.

One element of a strategy that might follow a precautionary principle was to improve institutional competence for dealing with variability in the weather, resulting both from natural fluctuations and from human induced changes. He did not think that mankind was on the edge of a climate catastrophe, but climate change would increase the pressures faced by societies, with or without a buildup of greenhouse gases. By increasing energy efficiency and by shifting the balance of energy supplies from carbon intensive fuels, such as coal, to hydrogen intensive fuels, such as natural gas and ultimately smokeless fuels or renewable energies, the rate at which the risk of climate change increased could be reduced.

G. SANCHEZ-SIERRA (Organización Latinoamericana de Energía) (OLADE) pointed out that 99% of the population in developing countries did not understand the carbon dioxide issue and it was not an important environmental priority. Access to drinking water, availability of food, education, improvement of health, etc. were of much greater importance. Therefore, co-operation was essential in dealing with global problems. Although the channels for implementing the necessary assistance were available through multilateral banks, environmental components of energy projects, etc., there appeared to be a lack of commitment on the part of the main industrialized countries.

I. MINTZER (USA) said that it was clear that risks of rapid climate change would never be accorded the highest priority in either industrialized or developing countries. However, the impact of rapid climate change would make the more imminent policy problems faced by both industrialized and developing countries more difficult. The highest share of the costs of rapid climate change was likely to be borne by developing countries, whether or not they recognized this risk. For example, the rise in sea level as a result of the greenhouse effect would increase the likelihood of damage caused by heavy storms and flooding at the mouths of large river systems. Recent preliminary research carried out at the International Rice Research Institute in the Philippines suggested that the three most widely used cultivars of rice were particularly sensitive to temperature changes during the period in which the rice was flowering. The research suggested that a 4°C increase in temperature during this period would result in a 90% decline in fertility of these three cultivars. A third of the world's population, which depended on rice, could therefore be affected by temperature changes. Similarly, the risks associated with weather related disasters had a much greater economic impact on developing countries than on industrialized countries. If the shared nature of the risk of global climate change were properly recognized, strategies of co-operation and technology transfer could emerge to reduce the rate at which this risk increased.

A. COVARRUBIAS (World Bank) (IBRD) agreed with G. Sánchez-Sierra (OLADE) that there was little concern in developing countries about the global impact of power projects. There was, however, some concern about local and regional aspects. Power projects involved resettlement of the population (for example, in the event of the construction of a large hydroelectric power plant with large reservoirs, or the construction of long power transmission lines and gas or oil pipelines which used thousands of kilometres of land); deforestation; and threats to rare or unique animal and plant species, involving problems of biodiversity. Environmentalists attached great importance to resettlement, deforestation and biodiversity when assessing power projects. Key Issues Paper No. 3 made little reference to these regional and local issues. He believed that international co-operation was needed to develop the guidelines or criteria to be adopted, which would enable power developers to design resettlement and reforestation programmes and programmes to mitigate the impact on biodiversity.

B. WAHLSTRÖM (IIASA) agreed that comparative studies should try to include all the possible effects. There were, however, problems associated with the prediction models, which had to be able to give an accurate account of the consequences; the data needed; and the actual comparison in which several very different indicators had to be compared. It was difficult to select the best alternatives when there were conflicting objectives. In many cases, it was sufficient to make order of magnitude comparisons because the accuracy of the models and data was not likely to be very high. A further problem was presented by the poor level of knowledge that existed. For example, it was not known what other effects, such as effects on the biosphere, $CO_2$ increases might have in addition to climate change.

C. GERBER (World Health Organization) (WHO) noted that the scientific and technical databases on which risk calculations were based were generally quite weak and wondered what R&D should be undertaken to improve these both in the short and long term.

A.F. FRITZSCHE (Switzerland) said that when considering the current knowledge of the data used for quanitification of risks in the energy field, it was necessary to make differentiations. Much of the data on the acute risks of injury and death due to accidents was available in the form of statistics, although often less detailed than one would wish. There was often a need also for more specific data, in other words, for more differentiated statistics.

For late risk resulting from chronic exposure to noxious substances, the situation was quite different and further research was needed in this area. As the paper by Boffetta et al. (SM-323/23) had shown, it was frequently difficult even to determine whether there was a risk at all, since the risk, if any, was often so low that it could not be differentiated from the background of other similar and far greater risks. One might wish that the public, which sometimes showed unreasonable reactions to such real or merely imagined risks, would begin to register this fact. Since the negative effects were sometimes so small, risk comparisons had to be based on models incorporating hypotheses on the cause–effect relationships, which were usually extrapolations from high doses to the low doses of interest. This was, for example, standard procedure for radiation. If such hypotheses were reasonably compatible, limited risk comparisons could be made even in this area, for example, between radiation and chemical pollution.

The situation was also different for severe accidents. Much public attention was devoted to the possibility of a severe nuclear accident. It was not generally realized that severe accidents could occur in most energy cycles, apart from new and renewable energies, such as wind and solar. In fact, severe accidents in the fossil fuel and hydroelectric cycles were relatively common, so that viable statistics existed on a worldwide basis. It was surprising that these statistical data had not yet been systematically processed and this was, in his view, one of the most pressing tasks to be undertaken in the field of energy risk.

A databank of risk information would be very valuable and would bring together a mass of hitherto unaccessible statistical information. The information would consist mainly of statistical data on the acute consequences of all types of accident. In the area of late risks, the data which could and should be collected would probably be confined to emission data. He believed that the establishment of such databases was being discussed within the IAEA, in co-operation with a number of other institutions.

G.P. HALBRITTER (CEC) *(Consultant)* noted that the excellent presentation of Key Issues Paper No. 3 showed that mass pollutants such as $SO_2$ and $NO_x$ were in the process of being controlled. However, northern countries, such as Germany, were experiencing problems of increasing concentrations of photo-oxidants, such as tropospheric ozone, resulting not only from electricity production but also from traffic. He therefore wondered whether there were plans to include those pollutants and specific hydrocarbons, dioxins and furans in comparative risk assessments.

Furthermore, he wondered whether the linear, no-threshold hypothesis adopted for cancer risk, according to which very small concentrations would contribute to the risk, could also be applied to chemicals. He also wondered whether there was a risk assessment methodology to deal with known carcinogenic substances such as dioxins and furans, which showed their carcinogenic potential only in the presence of a further carcinogenic substance.

L. HAMILTON (USA) said that the linear no-threshold dose hypothesis was just a hypothesis. It had been largely used in the area of radiation as a way of providing a convenient ample safety margin for setting recommended limits. In actual fact, even with radiation, there was no evidence either for or against a threshold. One could argue that since repair took place of deoxyribonucleic acid (DNA) molecules affected by radiation, there must be a practical threshold. According to the linear no-threshold hypothesis, the fact that an individual would die as a result of taking 100 aspirin tablets implied that if 100 people each took one aspirin one death would occur. This clearly was not the case. However, regulatory authorities in a number of countries assumed a linear no-threshold hypothesis for a number of known carcinogens for regulatory purposes, even though the risk of cancer from these substances was a multistage process. There was a real need for research in this area of risk assessment. In the case of chemicals, it was necessary to use much better models which reflected the actual pharmacology of these materials in the body and the multistage process of carcinogenesis as demonstrated by molecular studies.

J. VAN DE VATE (IAEA) noted that the report of Working Group 1 of the IPCC had suggested that there was a 'missing sink' of $CO_2$, which some climatologists believed was even larger than the oceanic sink. The missing sink was probably biotic and located in the northern hemisphere. It would be interesting to know how such a large biotic $CO_2$ sink would change the atmospheric residence time of $CO_2$

and, in turn, lower the global warming potential of the greenhouse gases other than $CO_2$.

I. MINTZER (USA) said that, according to current understanding of the carbon cycle, a significant portion of the carbon emitted each year from energy related activities and land use changes remained unaccounted for. Recent isotopic analysis suggested that an unknown portion of the carbon was being taken up by regrowth of biota, particularly forests in the northern hemisphere. This hypothesis remained preliminary and unproven, but it underlined the importance of the interaction between biotic systems and human industrial activity. It did not significantly affect estimation of the residence times or of the global warming potential of other greenhouse gases.

The problem of global climate change should not be regarded just as a $CO_2$ problem, but as a trace gas problem and strategies should be found to reduce the emissions of the group of trace gases identified by N. Sundararaman in his paper (SM-323/22) as contributors to global warming. It was also important to look for strategies which could take advantage of the capability of the biota to take up carbon dioxide by encouraging measures that would sequester carbon both in forests and in soils and by sustaining the primary productivity of the ocean, in other words, by recognizing the link between ozone depletion and climate change. It was important to reinforce efforts to reduce the rate of growth in the concentrations of chlorofluorocarbons, the buildup of which would result in ozone depletion, leading to possible significant impairment of the carbon uptake capability of phytoplankton, which was the principal biotic species that converted atmospheric carbon dioxide to carbohydrates and other organic compounds in the ocean.

M. KATZ (USA) wondered who would pay for the improvements in electricity generating technology which would be required in future to protect health and the environment.

A. DUNCAN (United Kingdom) wondered whether banks were prepared to underwrite the costs of enhanced environmental protection and, if so, how would they judge the point at which these costs became excessive.

B. WAHLSTRÖM (IIASA) said that the process of internalizing external costs, such as environmental and health effects, would result in increased energy prices which would have to be paid by the consumer.

L. HAMILTON (USA) agreed that it was the consumer who would have to bear the costs. However, he believed that the incorporation of health and environmental assessment into the develoment of new electrical generation technology would lead to a reduction in health and environmental costs in about 30–40 years with the replacement of older, less satisfactory technologies.

I. MINTZER (USA) said that users should appreciate the full cost of energy and that the long term cost and the somewhat uncertain environmental costs related to energy supply and use should be included in the price. While it was not appropriate for banks to pay, it was appropriate for banks to introduce policies which would encourage institutional reform so that the choices among investments were made on a least cost investment planning basis.

J. LOCHARD (France) agreed that the price of electricity should reflect the external health and environmental costs and that, in the end, consumers would have to pay. However, the internalization process was not a straightforward one. All effects had to be identified, quantified and evaluated in monetary terms. In the case of intangible effects, there were still many problems associated with cost assessment, but the difficulties involved were no excuse for not tackling the problems.

H. GLUBRECHT (Germany) noted that there was an important difference between providing energy from fossil and nuclear fuels on the one hand, and renewable resources such as sun and wind on the other. In the first case, latent energy which would normally never enter the biosphere was added to the energy balance. In the second case, there was only a redistribution of energy which reached the biosphere.

C. BURNHAM (Canada) pointed out that cancer could take several years to develop. Since fossil fuels had been used for many years, the database related to these fuels was perhaps better developed than that for nuclear fuel. She therefore wondered whether the number of cancers associated with nuclear power might increase with the number of years of operation.

S. LATEK (Poland) noted that Key Issues Paper No. 3 assumed that health and the environment should be compared separately. In his opinion, it would be useful to show the evident influence of environmental degradation on human health. In Poland, for example, there was much evidence to suggest that environmental conditions affected the average length of life, which was shorter than in other countries. Furthermore, mortality (mainly of children) and the number of cancers was evidently higher in the polluted region of Silesia than in the rest of Poland.

J. TUOMISTO (Finland) noted that Boffretta et al. (SM-323/23) concluded that a reduction in electricity consumption was the best way of reducing the cancer burden; he felt that this was an oversimplification. The Nordic countries had attempted to reduce electricity consumption in the 1970s and the result had been a 20% increase in total radiation exposure due to radon, because a decrease in ventilation was an essential element of energy conservation.

# INCORPORATION OF ENVIRONMENTAL AND HEALTH IMPACTS INTO POLICY, PLANNING AND DECISION MAKING FOR THE ELECTRICITY SECTOR

**(Topical Session 4)**

**Chairman**

**J. BOUVET**

France

## CHAIRMAN'S REPORT

# INCORPORATION OF ENVIRONMENTAL AND HEALTH IMPACTS INTO POLICY, PLANNING AND DECISION MAKING FOR THE ELECTRICITY SECTOR

## Key Issues Paper No. 4

**M. Munasinghe**
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The title of Key Issues Paper No. 4 implies an objective that is extremely ambitious, namely, sustainable development of the electricity sector. The techniques of analysis and incorporation are merely tools to achieve this objective. It is clear that attitudes towards the environment have changed and that these changes are affecting the future development of the power sector.

In primitive times, human beings presumably lived in a state of pure symbiosis with the environment. During the Industrial Revolution, attempts were made to master or overcome nature. Several decades ago, as the impacts of human activity, including power generation, on the environment became known, the 'cleanup approach' began to be adopted. In other words, after causing the damage, attempts were made to negate the consequences. We are now in a more proactive mode, and it is this ethos which stimulates the thinking of this Symposium and other conferences. This means that the consequences should be anticipated and efforts made to avoid or mitigate their impact. Sustainable development of the electric power sector signifies that we have some knowledge of what 'sustainable' means, and that it is clear which aspects of the environment and human health we are trying to protect or preserve.

One can identify three basic functions of the environment. First, it is a source of raw material and, as the energy crises of the 1970s and early 1980s demonstrated very clearly for depletable resources, inefficient, hasty exhaustion of such resources may cause serious problems. This is also true of renewable resources, because resources such as hydropower and forests can also be overused and, if stocks are depleted, they can no longer be renewed. Second, in recent decades another important function of the environment has become apparent, namely, the recycling of waste products of human activity, often at zero cost. However, the levels of pollution, whether sulphur dioxide from power sectors or waste produced in urban environments, are now exceeding the recycling capability of the environment. Third, the most recent attribute which has emerged is that the environment also provides life support functions. The importance of the ozone layer and global climate are well known, but there are less tangible aspects such as biodiversity that are global functions which also need to be protected.

It is worth recalling the definition in the report of the World Commission on Environment and Development, which states that sustainable development should meet the needs of the present generation without compromising the interests of future generations. In essence, sustainable development is a process of change in which exploitation of resources, direction of investment, orientation of technology and institutional change all act in harmony and enhance both current and future potential human needs. To achieve this, efficiency and equity are essential. In planning and decision making, it is important to bear in mind the fact that environmental problems tend to have a greater affect on the poor. Whether it is the poor within a country or the poorer countries themselves, it is inevitably these areas that have environments which are more degraded and these people who are at a greater disadvantage. Thus, there is a very important equity dimension to the environmental issues of energy and electricity use.

All the Key Issues Papers stress the need for an integrated methodology and make an attempt to establish general principles and methods for solving problems, rather than trying to provide specific answers. Expert Group 4 recognized that the problems were extremely complex and that a very comprehensive approach was needed, together with a formal and systematic mechanism to solve the problems. Economic efficiency is a key element, because all the contemplated actions involve large amounts of money. Since resources are scarce, efficient use of resources is of top priority. The paper does not attempt to specify single pinpoint solutions, but rather seeks to present a series of options and a mechanism for making trade-offs among the different options in order that different countries and different decision makers can use formal mechanisms to make choices in a rational way.

Before discussing the decision making process itself, it is worth recalling traditional decision making. This type of decision making, which pre-dated the energy crisis of the 1970s, had the tendency of looking at problems in the power sector very much in isolation. The conventional type of approach at that time was to make a demand forecast which was influenced mainly by socioeconomic and other factors. On the basis of this forecast, a least cost plan was prepared which may have included certain technological options, reliability and other technical considerations. A set of prices was then determined from the cost structure. It is true that a number of other criteria were taken into account: economic efficiency, financial viability, certain concepts of basic needs, etc. However, in the early days decision making was more or less confined to the electric power sector. Today, the world is much more complex.

This complexity is not necessarily a result of the environmental crisis. Since the days of the oil crisis in the 1970s, it has been realized that decisions in the power subsector can no longer be made in isolation. In fact, rising oil prices showed that it is necessary to look at energy in a very broad, integrated way, taking into account national economic considerations and environmental aspects.

A number of new developments have taken place in the decision making process. First, concern about the environment has greatly increased the number of interested groups and actors who have an influence on decisions. These range from international institutions, multinational organizations and non-governmental organizations, to very localized interest groups. As a result, there is a need for much greater transparency in the presentation of information and greater consultation in the decision making process. Second, today, in addition to traditional criteria such as economics, finance and social considerations, there are environmental considerations which complicate the decisions in a very major way. This broader set of criteria, against which trade-offs have to be made, means that an integrated multilevel decision making framework is required. Third, the electricity subsector is today much less isolated than ever before. In the past, decisions on supply and demand could be made with a much greater degree of autonomy; now, explicit allowance has to be made for the fact that the electricity subsector is part of the energy sector. It is necessary to look at the interaction between electricity and the fuels used: on the supply side as a means for producing electricity, and on the demand side where electricity can substitute for direct use of fuels. Allowance also has to be made for the fact that the energy sector is part of the overall national economy which interacts with a number of other different sectors of the economy. Energy and electricity are not final end use consumable items such as bread. Rather, electricity is a service which produces other things that meet human needs. Therefore, it is the needs of these other sectors — such as industries and households — which drive the demand for electricity, and it is very important to know what is happening in these other sectors in order to make planning decisions for the electric power sector. The fourth development is that decision making now involves global issues, which complicate matters even further. This is not surprising in the sense that the oil crisis of the 1970s demonstrated that what happens on international markets has a very important influence on decision making within a country.

Environmental concerns, and to some extent global change discussions, mean that in the future there may be a possibility that international discussions will lead to certain agreements which enforce another set of exogenous criteria on decision making at the country level. Decision makers have to be aware of this, and the decision making process has to be both flexible and comprehensive enough to accommodate these changes, since environmental interactions range from the micro level to the global level. This is not unexpected because the environment is pervasive; it is a holistic concept and environmental issues enter into decision making at every level.

Among the important tools that have emerged are environmental impact assessment mechanisms. The paper describes the environmental assessment process at the World Bank. This is not a unique process, but it is a sign that international institutions, development institutions and institutions within countries are now taking environmental impact assessment very seriously, in both industrialized nations and developing countries. This means that, in order to incorporate environmental impacts into the decision making process, it is necessary first to identify the physical impacts and then to attempt to quantify these impacts in economic terms. Evaluation of environmental impacts therefore becomes quite important.

Over the past few decades there has been a great increase in the number of techniques that have been developed to value environmental changes in economic terms. These include changes in productivity, costs to avoid damage and replacement costs. Valuation will continue to be a very important element simply because, in order to make trade-offs, it is necessary to know the economic impact of particular environmental effects. For certain aspects, such as biodiversity and some health impacts, it is not possible to establish the monetary value of the impacts. In such cases, there are other techniques of analysis, e.g. multicriteria decision making processes. Risk assessment sometimes falls into this category because this often involves dealing with loss of human life. The decision making process cannot rely solely on minimization of cost or pure economic numbers but must also be broad enough to accommodate certain other impacts which cannot be valued in economic terms.

Decision makers are now confronted with a whole range of policy instruments, and the environmental process has introduced two main types of policy instrument: economic incentives which use market mechanisms such as pricing, taxes and subsidies; and 'direct controls', or command and control type regulations which rely on limits, e.g. emission limits. It is important to bear in mind that these policy instruments have to be very closely co-ordinated; in other words, pricing and market mechanisms have a very important role to play, but certain norms, regulations and criteria also have to be established. The choice of instrument depends on the level of decision making and will also depend on the institutional framework within a particular country.

However, one should not think that there is a straight forward decision making framework into which one can simply 'feed in' the technologies and all the assumptions and wait for the answers to be produced. It is quite clear that there are formidable impediments to implementation, and one of the issues that was raised by all the Expert Groups is how to make sure that the full potential of different options, such as efficiency improvement, can be achieved. Uncertainties, for example, in technology or in prices, are very important and have been of particular significance since the oil crisis.

One approach to dealing with uncertainty is to keep a broad range of options open in order not to be locked into particular decisions and not to preempt options which may prove to be important in the future. In developing countries, the lack of implementation capability, infrastructure, human resources, etc. make it difficult to deal with economic and environmental issues. In the Soviet Union and Eastern

Europe, development of market type instruments and regulations might be a high priority in order to make progress. In some of the industrialized countries, pluralism — the fact that there is a very large number of interested groups — sometimes leads to paralysis in decision making. This problem has to be solved so as to avoid putting the power sector in the embarrassing position of having to meet growing needs, but at the same time being unable to do anything to meet these needs.

Another important point is that the decision making framework must deal with issues at the global level. The decision making framework is more familiar in the context of a single country, but there is an increasing tendency for environmental problems to be globalized. This leads to the issue of burden sharing. If environmental issues are divided into those that fall within a country and those that fall outside a country, most countries will seek to address the issues that fall within their country. This is clearest in developing countries. Over the past decade, most developing countries were not concerned about the environment, but they now accept that local environmental problems are, in fact, a barrier to development. However, they are still not greatly concerned about global environmental problems such as global warming. A given country is not willing to incur costs in order to solve a problem whose solution benefits some other country. One financing mechanism aimed at resolving this difficulty is the global environment facility, recently set up by the World Bank, the United Nations Development Programme and the United Nations Environment Programme. The idea is to start, on a pilot basis, with about US $1.5 million (a rather small amount of money in relation to the problem) with a view to looking at projects in developing countries which would help to relieve some of the global environmental problems. The funds are made available on a grant basis so that there is no burden on developing countries. In solving global environmental problems, the decision making framework must have a compensatory element, which means that solutions to such problems require mechanisms that go beyond the normal framework of international aid.

# INCORPORATION OF ENVIRONMENTAL ISSUES INTO POLICY, PLANNING AND DECISION MAKING FOR THE ELECTRICITY SECTOR

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**Abstract**

INCORPORATION OF ENVIRONMENTAL ISSUES INTO POLICY, PLANNING AND DECISION MAKING FOR THE ELECTRICITY SECTOR.

The concept of efficient and rational use of energy offers the chance of a joint strategy for energy and environment policy. The energy side benefits from value for money and security of supply by 'saving' energy resources. The environment side benefits because $CO_2$ emissions are avoided and other traditional energy related pollutants are reduced. Three major structural problems of traditional electricity supply are discussed: the lack of attention given to the possible uses of heat arising from electricity production, insufficient use of the decentralized electricity supply from industrial co-generation and from renewable energy resources, and the lack of attention given to the possible ways of reducing electricity demand. To cope with these problems, a comprehensive policy framework is needed which combines all the possibilities for action in planning administrative law and economic incentives, as well as for information and advisory measures, including further education and training.

## 1. INTRODUCTION

Electricity is the most valuable form of useful energy we have. Estimates indicate that the volume of electricity used in domestic economies will continue to increase in spite of, or indeed partly because of, the discernable successes that have been achieved in primary energy conservation. While most industrialized countries have succeeded over the past 30 years in decoupling, to a considerable extent, increases in primary energy consumption from economic growth, consumption of electricity has continued to rise. Figure 1 [1] makes this trend clear, using the Federal Republic of Germany as an example. (The data enumerated throughout the text were compiled before the unification of Germany in October 1990.)

The growing dependence of industrialized countries on electricity for economic development is shown in Table I [2]. It can be seen that the gross electricity production of the most important industrialized countries almost doubled between 1970 and 1988. At more than 10 000 TW·h, electricity production worldwide is today ten times greater than it was in 1950 [3].

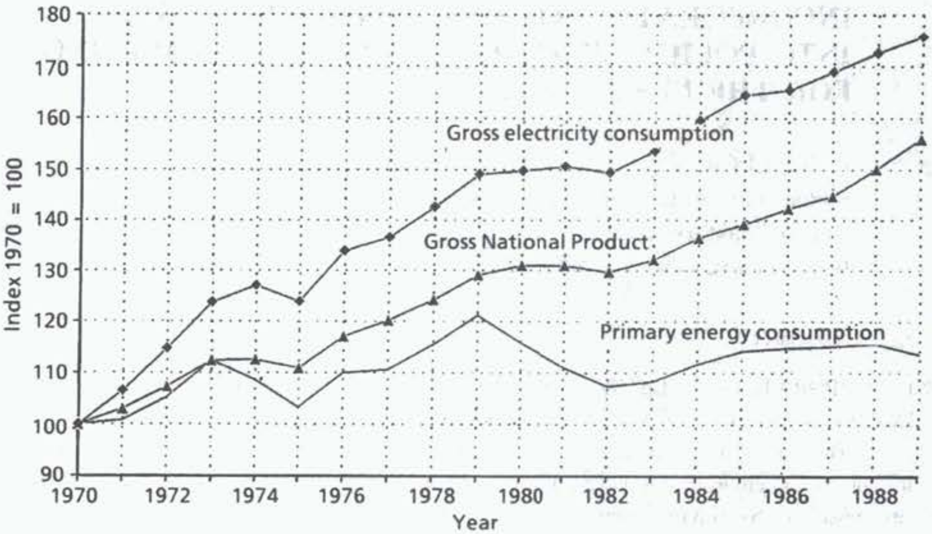


*FIG. 1. Gross National Product primary energy consumption and gross electricity consumption in the Federal Republic of Germany (1970–1989) [1].*

TABLE I. GROSS ELECTRICITY PRODUCTION OF THE OECD, EC AND INDIVIDUAL COUNTRIES
(in $10^9$ kilowatt-hours)
*(Source: Ref. [2])*

| | 1970 | 1988 |
|---|---|---|
| OECD | 3402 | 6468 |
| EC | 929 | 1706 |
| Germany, Federal Republic | 243 | 431 |
| Japan | 360 | 754 |
| USA | 1624 | 2872 |

In future, probable technological developments such as the increased application of microelectronics for control purposes, something which may, on the whole, contribute to greater energy productivity, will also mean a rise in the importance of the electricity sector for domestic economics.

Energy conversion, in general, means that the environment is put under strain and finite resources are consumed. Thus, to use figures for the Federal Republic of Germany as an example, 99% of the nitrogen oxide emissions, 96% of the sulphur dioxide emissions, 92% of the carbon dioxide emissions and 88% of the carbon monoxide emissions are energy related. The electricity share of these emissions is as follows: $NO_x$, 24.6%; $SO_2$, 60.8%; $CO_2$, 35.2%; and CO, 0.5% (all the figures are for 1986; source: Ref. [4]).

Given this situation, I believe that, within an energy and environment policy, it is in our own best interests to work towards ensuring that electricity production and consumption are as efficient and environmentally compatible as possible.

## 2. THE MECHANISMS AND STRUCTURAL PROBLEMS OF AN ENERGY AND ENVIRONMENT POLICY

No one can deny that even in market economy countries it is the job of the politicians and the State to set a framework so that those who wield economic power act in a way that is compatible with the interests of the common good. This is especially true of electricity provision which, for various physical and technical reasons, has in the past developed, to a large extent, structures that resemble a monopoly.

The concept of efficient and rational energy use, meaning saving finite resources and unburdening the environment of energy related pollutants by ensuring the same energy service for less primary energy used in its production, has in the past played too small a role, both in energy policy and in environment policy. Neither policy realized that each of their objectives, i.e. economic efficiency and security of supply on the part of the energy policy, and a reduction in environmental pollution caused by energy production and the conservation of natural resources on the part of environment policy, could be achieved by means of a joint strategy aimed at conserving energy resources to the greatest possible extent. In the 1970s and, to some extent, today as well, the relationship between environment and energy policy was characterized instead by conflicts.

In the environment policy, one cause for these conflicts was the fact that it tried to cope with individual problems of energy related environmental strain — particularly a reduction in emissions of dust, $SO_2$ and $NO_x$ — by applying regulatory instruments and by using add on techniques. Since energy consumption was kept out of play, this approach meant a direct increase in the cost of energy production, thus provoking resistance from the energy policy and the energy sector.

In the same way as those responsible for the environment policy, energy policy makers were fixed solely on the requirements of energy supply. The policies pursued were, in the main, those geared towards optimizing and maximizing the supply of energy produced from each individual fuel, taking into account value for money and security of supply. They went along with considerably increasing the microeconomic

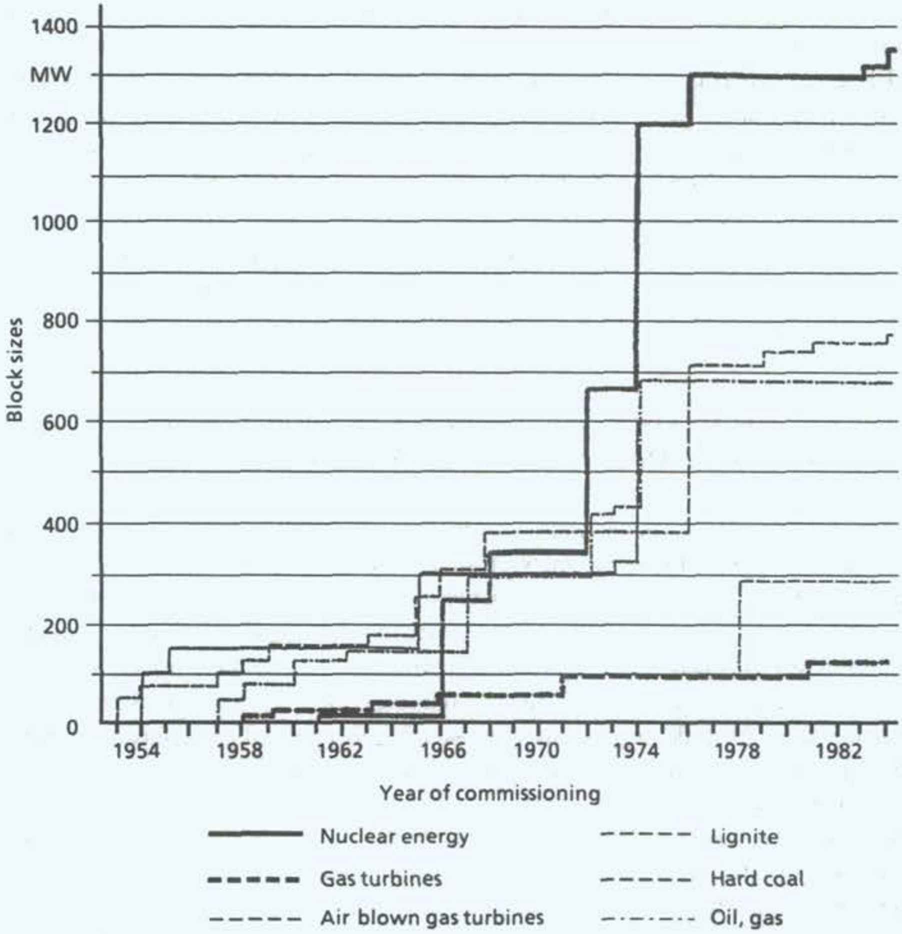


*FIG. 2. Size of power station blocks in the Federal Republic of Germany [8].*

efficiency of energy production and based their actions on the belief that centralization and economies of scale would solve all the supply problems. This can be seen from the following figures for the Federal Republic of Germany:

(a) Between 1950 and 1989, the mean amount of fuel used in Federal German power stations per kilowatt-hour of net production dropped from 0.682 kg hard coal units (HCU)/kW·h to 0.350 kg HCU/kW·h, in other words, by almost 50% [5].

(b) The amount of transmission and distribution losses from the national grid also dropped from 14.1% in 1950 to 4.7% in 1989 [6].

(c) In 1988, 1.7% of the Federal German power stations, each with an output of 1000 MW, provided 35.2% of the total output of the Federal German national electricity grid; 44.6% of the installations (most with a capacity of under 1 MW) provided barely 0.2% of the total output [7].

Figure 2 [8] shows the trend towards ever larger power station blocks observed since the early 1970s in the Federal Republic of Germany. In 1988, over 50 000 km of 380/220/110 kV overhead wires were installed [9].

The success of this supply oriented strategy may be seen from the way electricity prices have developed over the years. Between 1960 and 1989, the average end consumption price of electricity in the Federal Republic of Germany (for special customers as well as those charged at the normal rate) only rose from 10 to 18.5 pfennigs per kilowatt-hour (excluding VAT and the so called equalization levy applied from 1963 onwards) [10]. Thus, the increase in the electricity price was considerably less than the retail price index, which rose by 160% over the same period. This price development is all the more remarkable given the environmental protection measures implemented in the Federal Republic of Germany. In the light of the 1983 Ordinance on Large Scale Combustion Plants alone, power plant operators invested DM 28 billion ($10^9$) in desulphurization and nitrogen oxide removal facilities. The success has been considerable.

Between 1966 and 1989, in spite of increased electricity production, power stations and district heating plants registered a total drop in dust emissions, from 0.48 to 0.03 Mt/a, $SO_2$ emissions, from 1.35 to 0.37 Mt/a, and $NO_x$ emissions, from 0.48 to 0.47 Mt/a. Despite these successes, which certainly have to be improved further, this strategy, based on electricity production and supply, created problems which have to be dealt with today within the framework of a comprehensive energy and environment policy geared towards efficiency and environmental compatibility. A brief outline of three of the problem areas is given:

(a) The lack of attention given to the possible uses of heat arising from electricity production, and this in co-generation plants, i.e. the optimum total energy application of the primary energy used, thus promoting the concentration and centralization purely of electricity production in steam turbine power stations. Up to 1987, only 400 small co-generation plants with an electric capacity of some 220 MW had been built in the Federal Republic of Germany [11]. To these must be added traditional thermal power stations with an electricity output of 2445 PJ (83.4 million tonnes of HCU) and a heat output of 146 PJ (5 million tonnes of HCU).

(b) The lack of attention given to the use of a decentralized electricity supply potential from industrial co-generation and facilities for the use of non-traditional fuels such as the sun, wind, small hydroelectric plants and biomass, and methane energy from dumping sites, sewage gas, pit gas and waste. In 1987, the percentage of electricity generated from co-generation plants in the Federal Republic of Germany was 11.4%, i.e. around 16.5 kW of electric output [12]. In 1988, electricity generation from renewable energy sources covered 5.3% of the energy consumption from the national grid in the Federal Republic of Germany [13]. Because of relatively unfavourable feeding conditions, 96% of the Federal German decentralized block power plants do not feed into the national grid. On the basis of a voluntary agreement between the electricity sector and industry, the cost of electricity produced decentrally and fed into the national grid lay, in 1988, at between 32 and 48% of the price paid by the end consumer. In the United States of America, on the other hand, the cost was between 60 and 100% of the end price paid by the end consumer [14]. The importance of the cost of feeding electricity into the national grid is discussed in Section 3.

(c) The lack of attention given to the possible ways of reducing electricity demand on the part of end consumers. The Enquête Commission of the German Bundestag estimates even today that the technical savings potential for household electric appliances is running at between 30 and 70%, depending on the type of household appliances used [15]. With regard to lighting, energy efficiency could be doubled or even tripled if the systems currently in use were to be replaced by other systems that are already available or are in the development stage [16]. Finally, experts also expect a considerable savings potential because of the forced introduction of more energy efficient electric motors in the trade and industry sector [17].

## 3. RAISING THE ENERGY EFFICIENCY AND ENVIRONMENTAL COMPATIBILITY OF THE ELECTRICITY SECTOR AS A TASK FOR FUTURE ENERGY AND ENVIRONMENT POLICY

Since add on technologies do little to hold back $CO_2$ emissions, the climate problem and the difficulties surrounding $CO_2$ offer the energy and environment policy the opportunity of jointly meeting the challenge posed by the above mentioned structural problems in the electricity sector and in the energy industry in general, as well as by making use of all the technical possibilities available.

I do not adhere to the trenchant comments made by Lönnroth [18], who said:

> "Now environmental pressures make the electricity industry face a juncture: the industry will evolve either towards a large scale expansion of nuclear energy or towards a large degree of diversification and, possibly, decentralization".

I believe rather that the national and international discussions that have taken place over the past few years have engendered a high degree of consensus on the priorities to be set in energy policy. Priority is given to the promotion of efficient and rational energy use, making use of all the possible means that the entire energy sector has at its disposal to increase sufficiency. This includes taking the demand side into account as well as increasing the contribution of renewable energies and energy potential, which has not hitherto been used to the full, for example, in the field of energy generated from waste. A strategy such as this serves the interests of both energy policy and environment policy:

(a) The energy side benefits from value for money and security of supply by 'saving' energy resources and adding new ones

(b) The environment side benefits because $CO_2$ emissions are avoided and other traditional energy related pollutants are reduced.

Implementing a policy that is geared towards energy efficiency and environmental compatibility poses a particular challenge to policy makers, especially in those countries that have market economies:

> "Programs organized to promote more efficient use of energy are inherently more difficult to implement that those organized to sell electricity or alternative energy carriers like natural gas or oil. ..., the patterns of energy use depend on decisions by a large number of consumers, each of whom is continually confronted with having to make scores of decisions relating to major energy using activities. This situation is far more complex than that for the production of energy, which generally involves only a few different energy forms and a relatively small number of producers." [19].

The complexity of the task of policy making demands an intelligent combination of all the possibilities for action in planning, administrative law and economic incentives as well as for information and advisory measures, including further education and training. No blanket cure such as the exclusive use of economic instruments is available. However, all policy making, particularly in market economies, should be designed to ensure that optimum use of market forces leads to those active on the economic and social scene making well aimed decisions on their own authority.

I would now like to give a brief outline of some of the elements of a policy framework such as that applied to the electricity sector. There is hardly any sector of the economy in which reliable, long term planning is as important as it is in the electricity sector. Clear, long term policy objectives have a particularly important role to play, for example, those being discussed at the moment at the international level within the framework of the negotiations for a Climate Convention with complimentary protocols, and indeed those which have already been agreed upon by a number of countries at the national level. Thus, the decision of the Federal German Government to reduce $CO_2$ emissions by 25–30% over the 1987 figures by the year 2005 sent out a signal to the economy. This is bringing home to the economy sector the fact that investments in energy conservation technologies will, in future, be worth the effort. As proof that the signal has been received loud and clear, I would like to quote a comment made on 26 February 1991 by Dr. Heinrich von Pierer, a member of the Board of Directors of Siemens AG at a press conference held on the 1989/1990 Annual Report for Siemens' Kraftwerk Union energy productions [20]:

> "The objective agreed during the Government Coalition negotiations to reduce $CO_2$ emissions by between 25 and 30% by 2005 is increasing pressure on us to achieve an even more efficient and thus more economical conversion and use of energy".

The same long term signals may be given by a State research and technology policy. It is therefore particularly urgent to set clear priorities in research and technology spending that are geared towards rational energy use and the promotion of renewable energies.

One of the most significant preconditions for increasing the use of heat generated during electricity production is to ensure that sites are chosen near to potential users. By using environmental impact assessment, urban and regional planning as well as greater use of the possibilities, within the energy law, of conserving resources, together with the creation of more competition on local and regional electricity markets, it should be possible to work towards a situation where investors take into account the best total energy use of primary energies when choosing sites.

The same effect may also be obtained using economic instruments such as an energy tax or the $CO_2$ levy planned by the German Government. The $CO_2$ Levy Act under preparation in the Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit plans, among other things, to gear the levy to the energy output level of the primary energies used in power stations. This represents not only an incentive to use more and more efficient procedures in energy production but it also gives positive economic impetus to co-generation. The 'steering effect' of the $CO_2$ levy is therefore twofold: on the one hand, the raising of the levy itself is an incentive and, on the other, the money raised in this way is used for specific environmental measures, thus strengthening the incentive even further.

A very interesting economic instrument is the Act on the Remuneration of Private Electricity Producers, which has been in force in Germany since 1 January 1991. This Act obliges utilities to accept electricity generated by third parties into the national grid and to pay them a specific amount for this service. The remuneration for electricity generated from wind and photovoltaics amounts to 90% of the average end price for electricity generated traditionally.

In the case of electricity from small water power stations and installations for use as biomass energy, dumping gas and sewage gas, 75% of the average yield of marketed electricity must be paid for.

This regulation, which, unlike legislation in the USA under the Public Utilities Regulatory Policies Act (PURPA), does not yet include industrial co-generation, has a number of positive effects. It promotes economic interest in decentralized electricity production on the basis of renewable energies or other usable energy resources such as sewage gas and agricultural and industrial wastes. Thus, in practice, this regulation pragmatically internalizes part of the ecological costs of central and exclusive electricity production into the electricity price. The market and the many decentralized agents then have to choose between using self-produced electricity or purchasing it from outside suppliers, and also between the various primary fuels used in electricity production. Decentralized electricity production by third parties also provides the electricity companies with a potentially interesting new market from which they can profit as electricity distributors.

In view of the decreasing electricity demand, the concepts of 'demand side management' and 'least cost planning' are being discussed and, to a certain extent, are also being implemented. These concepts assign a particular role to the electric utilities industry in reducing energy demand and creating more energy efficient consumption structures. Demand side management — taken to mean traditional load management with the aid of a suitable pricing policy and particular agreements regulating when customer groups using large amounts of electricity are withdrawn from the grid — is a tried and tested instrument which serves the aims of short term microeconomic cost optimization. A new addition to discussion on demand side management with the aid of least cost planning is, in particular, the time-scale set for microeconomic cost optimization and the use of other policy instruments over and above pricing measures, taking the form, for example, of an active advisory service, and the granting of premiums and offers to finance ways of reducing electricity consumption on the part of the customer.

In most market economies it is the electricity industry which, given the specific physical and technical conditions of electricity provision, has a special role to play. In view of its status, very often a monopoly, and because of its obligation to supply electricity, the State traditionally developed control measures designed to protect the common good and to avoid the misuse of economic power. I believe that this traditional leaning towards protection of the common good is a good precondition for successfully practising a least cost planning concept aimed at long term cost optimization within the energy sector. Before this can happen, of course, the State regulatory bodies responsible for energy must provide firms with the impetus for optimizing costs in the long term.

Thus, in Germany the relevant energy law is currently being checked for any impediments it may pose and also for possible improvements. In addition to this, there is the internalization of ecological costs into energy prices through a levy, tax and tariff pricing policy, as well as measures in the end consumer sector. It is necessary to complement these actions by improving the information and advisory services for electricity consumers, in particular regarding small and medium sized firms, as well as by improving the education and further training of architects, engineers and skilled manual workers. Labelling systems within the market economy should not be underestimated, as shown by the German experience with the 'Blue Angel'.[1] In the

[1] Blue Angel is the symbol used in Germany to label environmentally friendly products.

light of the technical possibilities available it is possible to promote the comprehensive introduction on to a wider market of advanced procedures and products.

## 4. SUMMARY

In the electricity sector as well as in the energy and environment policy the era of single dimension point solutions is past. Given the increasing importance of electricity as a useful form of energy, it will continue to be necessary to ensure an adequate supply of electricity. However, within the context of other forms of energy provision, electricity production, distribution and consumption have to be optimized into an all round system, including power and heat. This means that the electricity industry will be required to combine, to the highest possible degree, centralized and decentralized solutions by using all the available fuels. It demands optimum total energy use of the primary energies applied and also requires that the potential of new forms of fuel be used to the full and that all the possibilities for lower consumption, using more efficient technologies, be explored.

In market economy systems, with the segmented interests of individual economic sectors in play, particular significance is attached to the regulatory power of the State. This, too, means an optimum combination of State instruments to guide human actions. Traditional administrative law has certainly not lost its importance, but it must be complemented by economic and behaviour oriented instruments to motivate those with economic power to take the required action on their own.

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# ECONOMIC AND ENVIRONMENTAL ISSUES CONFRONTED DURING THE TRANSITION FROM CENTRALLY PLANNED TO MARKET BASED ECONOMIC SYSTEMS

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**Abstract**

ECONOMIC AND ENVIRONMENTAL ISSUES CONFRONTED DURING THE TRANSITION FROM CENTRALLY PLANNED TO MARKET BASED ECONOMIC SYSTEMS.

A more comprehensive electricity planning process is needed to incorporate the health and environmental impacts of electricity generation. One way to do this is to use the identification, assessment and multicriteria assessment of the alternative scenarios of grid system development. Czechoslovakia is trying to pursue this approach, however great effort on the international level is needed to facilitate a more balanced consideration of technical, economic, environmental and health related issues.

## 1. ELECTRICITY PLANNING UNDER CONDITIONS OF UNCERTAINTY

The fundamental problem Czechoslovakia faces while trying to move from a centrally planned to a market based economic system is the uncertainty about future prospects for a wide range of parameters which propel future development in the electricity sector.

Economic, social and political uncertainties affect significantly the appraisal of the demand for electricity. Technological uncertainties remain over the available supply options and environmental protection techniques that could be implemented. Moreover, there are many information or data gaps about environmental impacts, or about behavioural responses to various policy instruments.

This situation makes it necessary to have an adequate decision making process under conditions of uncertainty. It calls for tests and solutions that are flexible enough to accommodate changes in situations and assessments.

The economy of Czechoslovakia is in the process of converting from highly centralized governmental control to a free market economy. It is still very difficult to put the energy future into the proper macroeconomic context and to project the future demand for electrical energy because internal consistency with the country's main social, economic and industrial development objectives and possibilities cannot be fully established at present [1].

Today's electricity demand scenarios differ substantially, depending on the assumption chosen regarding the future picture of overall Czechoslovak economic development. Basically, there are three types of electricity demand projections:

(1) Modest growth during the decade of the 1990s
(2) Zero growth in the first half of the 1990s, modest growth during the second half of the decade
(3) A drop in growth in the first half of the 1990s, but growth during the second half of the decade.

## 2. ENERGY POLICY

The Governmental energy policy document has not yet been finished and approved by the Czechoslovak Parliament. However, it seems reasonable to assume that besides the basic principles being considered, there are also strong environmental concerns about chemical pollutants from burning fossil fuels, which cause severe health and environmental problems (e.g. an increase in the incidence of respiratory diseases as asthma, bronchitis and emphysema, as well as forest decline and crop damage). Also acid deposition threatens indirectly by making several dangerous metals more soluble than usual.

## 3. SCENARIO APPROACH

The incorporation of health and environmental impacts of electricity generation into policy, planning and decision making about electricity generation choices can only be done realistically on the basis of assessment studies providing decision makers with reliable, quantified evaluations of the various impacts from well defined electricity generation systems in the comprehensive energy related framework.

On the basis of the experiences with the Czechoslovak process of decision making and planning in the energy sector, the so-called energy/emission (E/E) scenario approach was adopted to increase insights into the health and environmental consequences of the different electricity production development paths to be followed during the next decades.

The E/E scenario relates to the following main components: (1) electricity demand projection, (2) load diagram projection, (3) power generation technology development strategy, (4) power generation projection, (5) single installations of the electricity generation system and (6) selected pollutant emissions.

Total electricity demand is projected by taking into consideration the anticipated changes in the economic and social situation of the country, the estimated population increase and other relevant factors.

The load diagrams are predicted by means of a model for energy development, MZES (developed by the Institute for Research, Consultancy and Engineering (VUPEK), located in Prague).

In terms of technologies used for the generation of base load electricity, Czechoslovakia at present relies on hard coal as well as brown and lignite coals for conventional power generation and on nuclear fuel for thermal power generation.

The projections of the country's electricity future are divided into two main parts: (1) new power plants (nuclear, hydro and combined cycle) and (2) retrofit programmes of the coal fired power plants.

In considering the characteristics of different new electric power sources, these projections regard nuclear power, which is ecologically acceptable, excellent in economic efficiency and stable in fuel supply, as the main power supply source to meet base demand. Pump and pool types of hydropower will be added to meet peak load demand.

As an option to nuclear power, the use of combined cycle gas turbines could be considered. The viability of this option depends mainly on the efficiency of this system and on the market prices of natural gas.

The retrofit and/or backfit programmes applied to coal fired power plants have two main objectives: to increase the co-generation capability and reduce the emissions. Alternative strategies could include:

(a) Retirement of a substantial lignite fired generating capacity
(b) Retrofitting and/or repowering of appropriate parts of existing lignite fired capacity and installing adequate environmental safeguards
(c) Development of a lignite based replacement capacity for the old thermal plants, using new environmentally benign technologies such as fluidized bed combustion or the integrated coal gasification combined cycle plant
(d) Accelerated introduction of gas fired combined cycle plants, based on natural gas imports from the USSR and/or from the Western European pipeline systems.

Power generation projections are obtained from the MZES calculations. These calculations fill out the projected load diagrams with proposed alternative power plants designed according to the specified criteria and provide an input to the total environmental analysis.

To achieve a deeper insight into the environmental impact of electricity production, the breakdown of an electricity generation system into single installations and locations was introduced. At present, the public electricity generation system consists of:

— 102 coal fired installations: 27 power plants, 32 combined (electricity and heat) power plants and 43 heat plants, which differ significantly in terms both of releases of radioactive and chemical materials and of methods of energy production

— 2 nuclear power plants with 8 PWR WWER 440 units located at two sites in Czechoslovakia: 4 units at Bohunice and 4 at Dukovany.

On the basis of the operating characteristics of the coal fired power plants, as well as the fuel consumption and emission factors estimated for the specific plants or reported in literature, the projection of the relevant air pollutants was made. This exercise has made it possible to reduce the number of the coal fired installations under consideration to 60 (26 power plants, 25 combined power plants, 9 heat plants). This reduction eliminates about 95% of the air pollutants.

In the present phase, the E/E scenarios are focused on air pollutants, as these are to be considered to be predominant in terms both of quantity and of quality of power production. In atmospheric studies, operational routine stack releases of radioactive (U, Th, $^{131}I$, $^{133}Xe$, $^{3}H$, $^{137}Cs$, $^{90}Sr$) and chemical ($SO_2$, $NO_x$, ash, $CO_2$) materials from nuclear and coal plants are covered. The quantification of health and environmental detriment from energy production is based on theoretical considerations relying on model predictions of causal links between pollution sources (radioactive and chemical agents), environmental dispersion and biomedical effects in the systems under consideration.

Power generation leads to largely controlled and measured direct exposure to the work-force, to routine exposures to the public via releases into the environment, and to acute and delayed effects from accidents. All of these exposure paths need different methodologies to assess first dose and then later biological effects.

Within the general scheme of health detriment assessment mentioned above, the following sequence is considered: (1) routine release, (2) environmental transfer models, (3) exposure models, (4) public exposure (temporary and short term), (5) dose effect relationships and (6) health impacts.

Exposure of the public to chemical ($SO_2$, $NO_x$ and fly ash) and radioactive (natural sources and fission products) pollutants was considered. As a risk indicator for radioactive pollutants, the collective committed effective dose equivalent of all persons within the affected population measured in man-Sieverts per year has been used. For chemical pollutants released by energy systems, the 'collective exposure' of the public to the relevant pollutant was applied.

The E/E scenario creates a general context for the assessment and comparison of environmental and health effects and relates to the electricity generation of the public utilities in Czechoslovakia. It also outlines the sources considered for the assessment of the health of the population and the state of the environment. It should be made clear that scenarios are mainly statements of 'what might be' so that the health and environmental consequences of such conceivable future situations might be clarified and evaluated.

## 4. CASE STUDY: POWER PRODUCTION, HEALTH AND ENVIRONMENT

The scenario approach was applied in the case study entitled, Power Production, Health and Environment [2] and was based on projected total electricity consumption and maximum power demand, power generation structure, projected power generation, pollutant emissions during normal operation and a short description of power generation technology for three different electricity development paths for the period from 1990 to 2010.

For the exploration of the space and time distribution of air pollutants in Czechoslovakia, a model for environmental transport, PANDA [3], was used to calculate the concentration of pollutants in the air at ground level in a 3.8 km × 4.8 km grid system at a distance of 40 km from each source.

As a yardstick for comparing the health and environment impacts from different E/E scenarios, the following indicators have been chosen: (1) exposure of the Czechoslovak population to chemical and radioactive pollutants at a distance of 40 km from the source, (2) regional distribution of the public exposure to $SO_2$, (3) the list of the top 10 power plants (in terms of their contributions to public exposure from $SO_2$ and radioactive pollutants).

The following main findings gathered from the electricity production scenarios increase awareness of the public health consequences of atmospheric, operational routine stack releases of radioactive and chemical materials:

(a) In all scenarios the public health consequences of atmospheric, operational routine stack releases of radioactive and chemical materials are decreasing (according to the applicable risk reduction indicators).

(b) It has been determined that the 'worst' districts in Czechoslovakia for health risks are North Bohemia (which contributes about 30% to the electricity production in Czechoslovakia), East Bohemia (5.6%), North Moravia (4%), Central Slovakia (2.7%), West Bohemia (2.3%) and Prague (0.4%).

(c) The E/E scenario with a lower projected total electricity demand (terawatt-hours) has provided the most efficient reduction of public health consequences (according to the applicable risk reduction indicators).

## 5. CONCLUSIONS

Past choices among electric power generation systems and fuel mixes were based mainly on internal cost comparisons of different supply options. A more comprehensive planning process needs to incorporate all of the costs of these systems into the framework of society, including environmental and health consequences. It is necessary to internalize, as far as possible in an analytical framework, the costs and benefits associated with the environmental impacts of electricity generation. To the extent that such impacts cannot be valued economically, the multicriteria decision making process for electricity planning should ensure that non-quantifiable environmental (and also social and economic) matters are considered when choosing among several power generation options.

To increase the importance of the health and environmental impacts of electricity generation on policy planning and decision making within the electrical sector, it is necessary to make the concept workable. One way to do this is the identification, assessment and multicriteria assessment of alternative scenarios of grid system development. Through this approach it is possible to switch from 'ranking' the various 'single' electricity production systems to the concrete grid system where a 'mix' of various electricity sources and fuels is working.

On the international level, great effort is needed to facilitate a more balanced consideration of the technical, economic, environmental and health related issues surrounding electrical production, while defining and assessing strategies for medium and long term planning of electricity sector development.

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## SUMMARY OF THE DISCUSSION OF KEY ISSUES

### Topical Session 4

*Chairman:* **J. Bouvet** (France)

*Rapporteur:* **M. Munasinghe** (World Bank) (IBRD)

*Panellists:* **E. Bertel** (France)
**A.F. El-Saiedi** (Egypt)
**P. Gaudin** (International Confederation of Free Trade Unions) (ICFTU)
**C. Gerber** (World Health Organization) (WHO)
**O. Hohmeyer** (Commission of the European Communities) (CEC) *(Consultant)*
**R. Reinstein** (Intergovernmental Panel on Climate Change) (IPCC)

L. D'ANDREA (Economic Commission for Europe) (ECE) noted that Key Issues Paper No. 4 referred to prices and pricing policies as one of the national policy instruments used to influence and direct decisions in the energy sector and it was argued that energy prices charged to consumers should reflect the total costs to society. He wondered how such a concept could be advocated and applied to developing countries and to countries in the process of economic transition to market economies, which were attempting to promote economic expansion and growth and where energy prices often represented a significant component of their industrial production. In such cases, he wondered whether energy subsidies were a suitable instrument for these countries to reconcile social and economic objectives.

A.F. EL-SAIEDI (Egypt) agreed that pricing of electricity in developing countries was a complex issue. On the one hand, prices could be used to ensure efficient use of electricity; on the other, subsidized prices could be used to promote social and economic development. In Egypt, there was an unbalanced distribution of energy consumption, with the productive use of electricity, such as in industry and agriculture, accounting for less than 50% of the total electricity use. To rectify this situation, the Egyptian Government planned to lift subsidies in the non-productive areas of electricity use, to reduce non-productive consumption and promote conservation, while continuing to subsidize energy in the production sector in order to help boost the economy.

O. HOHMEYER (CEC) *(Consultant)* said that he believed that the argument that energy prices to the consumer should reflect the total costs to society applied even to developing countries. Subsidies should not be given through prices for single commodities, such as energy, nor should they be given at the expense of hidden health or environmental costs. The two approaches gave the wrong price signals, resulting in levels of commodity use or environmental and health damages which were too high. If a certain economic activity needed subsidization for social or developmental reasons, these subsidies should be given directly and not hidden in a commodity, such as energy, since such subsidies would merely encourage wasteful use of the commodity.

G. SANCHEZ-SIERRA (Organización Latinoamericana de Energía) (OLADE) pointed out that, while, in theory, it was necessary to include environmental constraints in power planning, in practice, with a power sector debt of US $46 billion ($10^9$), an annual investment requirement of some US $20 billion and an average annual inflation rate of 1000%, it was hardly feasible for developing countries to assume the additional burden of environmental constraints. Industrialized countries had successfully globalized the environmental problem and it was time for them to globalize the solution.

C. GERBER (WHO) pointed out that when environmental and health protection was taken into consideration in planning new facilities or in the replacement of existing facilities, the additional cost was relatively small in comparison with the costs involved in retrofitting plants. The additional cost served to internalize the costs or benefits of improved public health and environmental protection. The World Bank and other groups providing financing or assistance to developing countries should accept such costs as an integral part of a power plant. In the case of the costs countries were expected to incur in order to avoid or solve regional or global environmental problems, assistance should be provided by those who benefited.

Most international groups recognized that some increase in $CO_2$ emissions would have to be permitted in developing countries, while $CO_2$ emissions would have to be reduced in industrialized countries. A number of measures would have to be taken: each country would need to plan its energy production and use to include environmental and health impacts, giving first priority to its local energy sources; more R&D would have to be carried out by the technically advanced countries to develop more effective and efficient renewable sources of energy, such as hydropower and photovoltaics; assistance and funding agencies should only support energy systems that were efficient and environmentally sound; and technical assistance should be provided to developing countries by the industrialized countries in planning and implementing energy programmes.

A.F. EL-SAIEDI (Egypt) said that while environmental considerations were perhaps an area of low priority in the energy policies of developing countries, given their other more urgent problems, there was nevertheless a growing public awareness of environmental problems in these countries. In Cairo, for example, there was public pressure on the Egyptian Government to reduce the high levels of pollution. He believed that globalization of solutions to improve the environment was possible and could be achieved through conditions on financing set by multinational development banks, through the provision of technical assistance by international organizations or through international conventions and protocols.

R. REINSTEIN (IPCC) pointed out that many actions to protect the environment would not add costs in the longer term, since such actions would lower other costs. Both environmental and health protection were important, not only for ethical and moral reasons but also because of their economic value to society. The environment was in itself an economic resource and poor health reduced the effectiveness of human resources and hence their economic contribution. Almost all countries had come to recognize this fact, although different countries attributed different values to health and environmental protection in comparison with other needs, such as economic development or the need to maximize employment. The results of internalizing these external costs would therefore vary from country to country.

A. de OLIVEIRA (Brazil) noted that the previous sessions of the Symposium had identified several advantages of hydroelectric power: environmental impacts were limited and relatively easy to control; it was a renewable energy source; it did not add to greenhouse gas emissions; and the risks associated with its exploitation were low. It was also pointed out that there were large unexploited hydropower resources in developing countries, where electricity consumption would inevitably increase in the future. In view of these facts, he wondered whether multilateral banks should promote the use of hydropower in developing countries and whether lower interest rates should be provided for such projects.

M. MUNASINGHE (World Bank) (IBRD) began by noting that the environmental impacts of hydropower were not necessarily small. At the local level, there were significant environmental and social impacts, including innundation of land, deforestation, loss of biodiversity, watersheds, resettlement, etc. At the global or international level, poor implementation of hydroelectric power schemes could have serious adverse effects, as in the case of the 200 MW Balbina hydropower plant in Brazil, which had inundated a large area of forests. The methane releases from this flooded land would be equivalent to the global warming potential of a 500 MW coal plant. Low interest financing deprived other deserving sectors, such as health and education, of funds. There was no compelling reason why only hydropower should receive such a subsidy. As all the Key Issues Papers had agreed, there was no single technology which would solve environmental problems. A broad integrated decision making framework should therefore be applied systematically to evaluate all the options and subsequently to determine the priorities.

H. KHATIB (World Energy Council) (WEC) noted that currently in developing countries, which accounted for some 80% of the world's population, as much as one-third, in other words some 1500 million people, had no supply of electricity and the availability of supply to those who did was about half that in industrialized countries. The lack of electricity and commercial energy promoted the use of biomass and deforestation, thereby contributing to global emissions. It would therefore be inappropriate to talk about global sustainable development without addressing these problems.

M. MUNASINGHE (World Bank) (IBRD) noted that poverty and environmental degradation were closely linked. It was not possible to deal with the environmental issue without addressing the issue of poverty. Global sustainable development would require true international partnership and burden sharing. It would require more conventional aid for developing countries to address local environmental and poverty issues and additional compensatory grant funds for developing countries to undertake projects and policies that benefited the global commons.

S. BOYLE (Greenpeace) wondered what level of carbon reductions was possible using carbon or energy taxes alone as a policy tool for controlling greenhouse gas emissions and what other specific policy measures could be adopted. In the context of least cost or integrated resource planning, which was a common approach adopted by utilities in the United States of America and Europe, he wondered why, when such utilities could often make a better return on investment from selling electrical efficiency without the environmental costs, many people in the electricity industry were opposed to this system.

A. STIRLING (Greenpeace) said that there appeared to be broad agreement that the scale of environmental impacts of renewable sources, compared with those of conventional sources, was such that, if the full externalities were effectively incorporated into the price of electricity, renewable energies would rapidly become extremely competitive. Since resource size was not now considered to be a critical constraint on renewable energy, he wondered whether the inclusion of externalities in price could be regarded as the most important determinant of the future structure of electricity supply.

G.P. HALBRITTER (CEC) *(Consultant)* noted that Key Issues Paper No. 4 contained a description of the interesting approach adopted to improve end use efficiency in the USA, whereby utilities were rewarded for energy efficiency investments, and wondered what the practical experience of this approach was. The paper presented by E. Müller (SM-323/25) showed that an attempt was being made in Germany to internalize external costs through the introduction of legislation. In his view, such measures would only be successful when at least the countries of the European Community adopted a similar approach. Furthermore, he wondered whether the proposed $CO_2$ charge would be the appropriate instrument for promoting the installation of co-generation facilities or whether there would be a need for further administrative regulations.

O. HOHMEYER (CEC) *(Consultant)* said that recent calculations carried out at the Fraunhofer Institut für Systemtechnik in Karlsruhe had shown that, depending on the level of carbon or energy taxes, overall carbon emission targets of up to 80% were achievable. However, they should not be the only instruments for carbon emission reductions. In his view, a regulatory framework setting technical performance standards as upper limits, together with a tax incentive scheme for further optimized reductions, would prove to be the most efficient approach to the problem.

Least cost planning, including demand side management strategies were fairly new approaches for many planners in the utility sector, who were used to supply side optimization approaches. It would require considerable efforts to convince them that gains could be made from the new approaches. Appropriate incentive schemes for utilities would also have to be introduced to ensure that vigorous demand side approaches would result in the highest profits for the utilities.

Current research results on external costs suggested that there was some evidence that certain small scale renewable energy technologies, such as wind energy, might gain considerably from the internalization of external costs. How competitive these would then be was a question which could not yet be answered. However, it should not be forgotten that some large scale renewable energy technologies could themselves have considerable external environmental costs.

With reference to the questions raised by G. Halbritter (CEC) *(Consultant)*, he said that the experience had been fairly positive in California, where profits were directly linked to the success of demand reductions, through the utilities' demand side management activities. For example, the annual profits of Pacific Gas and Electric could vary by some US $60–90 million, according to the actual success in demand reductions, which were measured against specific reduction targets. It was estimated that demand side management would take care of a very substantial share of the projected growth in electricity demand. These capacity savings were in the order of several gigawatt for the current planning horizon.

In Germany, legislation had recently been enacted to improve the price paid by the utility for electricity supplied to the grid by car producers based on renewable energies. For wind and solar energy, this was set at 90% of the prices charged to final consumers by the utility (without taxes and transfer payments), while it was set at 75% for electricity from small hydropower and biomass plants. There were signs that countries such as Denmark and the Netherlands may follow this example.

With regard to co-generation, while carbon taxes were likely to encourage the installation of co-generation plants, it was doubtful whether such taxes in themselves would suffice, since basic decisions needed to be taken regarding a decentralized versus a centralized generating structure.

R. REINSTEIN (IPCC) said that most analyses showed that heavy reliance on carbon taxes would require very high carbon taxes, in the order of several hundred dollars per tonne. If such taxes were adopted unilaterally by certain countries, they would have very serious effects on competition among energy intensive industries. Even if they were to be harmonized within the European Community, they would still have fairly major differential effects owing to the different mixes of fossil fuels and nuclear power and would still have quite serious effects on competition. It would be very difficult to adjust to the trade distortions which could arise from high carbon taxes.

Almost all countries now recognized the importance of internalizing the external costs associated with environmental and health protection. However, different countries assigned different relative values to these goals as compared with other goals, such as maintaining employment. The potential of small scale renewable energies depended to some extent on location and on the kind of infrastructure to which they would relate. One of the dangers of subsidizing such energy was that it might promote excess energy consumption. The particular relevance of individual technologies would vary from country to country.

In the area of end use efficiency and co-generation, the experience in the USA had been fairly positive. His colleague, J.C. Geidl (USA), could perhaps provide more details on the success of the Public Utilities Regulatory Policies Act (PURPA).

J.C. GEIDL (USA) noted that PURPA had stimulated the non-utility market extensively in the USA, so that non-utility generation was currently providing about 6% of the total electricity generation in the USA. This share was expected to grow at about 4.7% per annum. About one-third of this non-utility generation was provided by renewable sources, including hydropower, biofuels, wind, solar thermal and photovoltaics. There had been a growth in non-utility solar thermal electricity generation through the sale of high temperature collectors to the non-utility industry in 1990 and progress was expected in this energy source in future.

J. BOUVET (France) *(Chairman)* said that he believed that the least cost planning method should be applied as widely as possible. However, sudden changes in approach were always difficult and, in order to promote the acceptance of such methods by utilities, clear regulations and clear profit notions were necessary.

Byung-Jae LIM (Republic of Korea) said that in view of the huge potential increase in energy demand in developing countries, it appeared that any international effort to reduce greenhouse gases would not be very effective without substantial co-operation from developing countries. However, such countries had little capability for helping to solve global environmental problems and, in any case, considered that most of the existing problems of global warming had been caused mainly by industrialized countries. To make greenhouse gas reduction policies effective, equity issues between industrialized countries and developing countries would have to be addressed properly.

P. GAUDIN (ICFTU) said that the first service which industrialized countries could provide to developing countries would be for industrialized countries to solve problems of pollution in their own countries. Industrialized nations were responsible for more than 70% of $CO_2$ emissions. World economic development based on the current energy consumption model of industrialized countries was not feasible. Development policies therefore had to be formulated and applied which would give priority to a reduction in the energy needed for growth. Technological advances made this possible and would make it increasingly possible. One environmental protection action was to provide financial assistance to developing countries to enable them to use, from the outset, technologies which were less energy intensive and which maintained the ecological equilibrium better.

C. GERBER (WHO) said that a number of studies on energy and environmental issues indicated that in dealing with environmental problems associated with energy production and use some additional growth had to be allowed in developing countries. Given current population growth rates, it would not be possible for them to maintain even their current social and economic status without some increased use of energy. The WHO had recommended that the use of energy be integrated in the planning of all countries and had recognized that developing countries would need increased energy per capita and that developed countries should use less energy per capita. The mistakes that had been made in industrialized countries should not be repeated in developing countries. To promote the necessary transfer of technology, international banks and lending agencies needed to include the question of energy in their planning. No single energy source or system could be portrayed as the most effective for all countries and additional research was needed to develop technologies which would use local resources in developing countries.

R. REINSTEIN (IPCC) said that the technical aspect of the question could be addressed by the IPCC and involved identifying a range of technology options and analysing the technical, economic and market factors to determine their suitability for a particular situation in a particular country. The political aspect related to the mechanism for implementing and financing the technology transfer. This aspect could perhaps be taken up during the international negotiations on a framework convention on climate change being conducted in the Intergovernmental Negotiating Committee.

A.F. EL-SAIEDI (Egypt) said that there was a tendency to make too many generalizations when discussing such issues. It was necessary to specify which developing countries, in terms of installed capacity, one was referring to. In referring to greenhouse gases, emphasis had been placed on electricity generation, although emission of such gases was also attributable to transportation or, in most of the developing countries, to the solid fuels which were used for cooking and heating in rural areas and whose use was difficult to control. Developed countries should first concentrate on curbing the increase in greenhouse gases in their own countries. Once this had been achieved, efforts could be devoted to assisting developing countries through technology transfer, technical assistance to improve the efficiency of electricity generation and use, assistance in proper planning and better use of indigenous resources for electricity generation.

P. DASTIDAR (International Atomic Energy Agency) (IAEA), noting that Key Issues Paper No. 4 placed great emphasis on governmental decision making, pointed out that, in fact, the largest sector in terms of finance, consumption and utilization was the private sector consisting of investors, industry and the consumer. Decisions taken at these levels were the most important and finally determined the impacts on the environment and society as a whole. Further work was necessary in this area.

E. BERTEL (France) said that Expert Group 4 had recognized the importance of the private sector in the decision making process and several members of the Group were, in fact, representatives of the private sector and electricity companies. The paper proposed possible scenarios and solutions, but it was clear that further study of these issues was necessary in order to determine the optimum energy and electricity strategies, taking into account the positions of all the sectors involved.

E. MARSHALL (United Kingdom) felt that the forecasts of growth in energy demand related to growth in population should not be accepted without question. Sustainable development was not compatible with uncontrolled growth in the world's population. The costs of a worldwide population and health control programme should be compared with the costs of environmental degradation and the probably unfinanceable demand for growth in electricity production. The implementation of such a programme could perhaps be considered as an alternative or additional measure to energy conservation and environmental preservation.

C. GERBER (WHO) said that the WHO Energy Panel had recognized that the projected population growth in developing countries could easily overwhelm the available energy sources and continue environmental degradation and human health problems. It had recommended that family planning and education programmes be implemented in countries with high growth rates. At the same time, the Panel had recognized that energy use per capita in the most industrialized countries had to be reduced if the world was to have the energy needed to provide adequate socioeconomic standards in an environmentally acceptable way.

L.A. BOL'SHOV (Union of Soviet Socialist Republics) (USSR) noted that, given the uncertainties associated with decision making, it was necessary to separate the responsibilities of experts, decision makers and the public. Experts should provide decision makers with objective information, which should not be biased by considerations of how the public would accept their assessments. It was then for decision makers to take factors associated with public acceptance into account.

E. BERTEL (France) said that Expert Group 4 was well aware of the problems raised by L.A. Bol'shov (USSR) and the difficulty of implementing an effective decision making process while taking public opinion into account. However, the Group believed that the public should be able to express its views on the proposed options and should be provided with the necessary information to do so. To be implemented effectively, it was essential that any energy strategy should reflect the majority view. The main problems were public information and the adoption of a process which, while taking the wishes of the public into account, could ensure that coherent decisions were taken within an acceptable time-scale.

C. GERBER (WHO) said that more rational decision making could only be expected if R&D activities were increased to improve the scientific and technical data and to reduce the uncertainties underlying risk assessment.

E. MÜLLER (Germany) felt that, in implementing the least cost planning concept, there was a possible danger of concentrating economic power in the hands of the electricity utilities. It seemed that by not only giving advice but also financing energy saving appliances, insulation programmes, energy efficient lighting systems, etc., utilities would be in the position of controlling the relevant market, including the services of the small and medium sized firms needed to install heating installations.

O. HOHMEYER (CEC) *(Consultant)* said that least cost planning, including demand side management, could only be introduced sensibly if the process was efficiently controlled by State and regulatory authorities. Such schemes, as shown in the case of California, could only be successful if precise demand reduction targets were set and substantial penalties and incentives were offered. If the incentives were too low, the utilities would not initiate vigorous action to achieve demand side efficiency improvements. In the case of Germany, it was very important to introduce least cost planning approaches before making decisions on capacity expansion.

J. ESCUDERO (Spain) pointed out that the concept of an electrical tariff for the consumer per kilowatt-hour did not distinguish between the source of the kilowatt-hour and, therefore, before introducing a $CO_2$ tax, it was necessary to ensure that each source supported its own costs and that, for example, hydropower did not support the costs of coal.

R. de MILLAS (Germany) noted that the German Government and the Kreditanstalt für Wiederaufbau, Frankfurt am Main, had adopted appraisal criteria for electric power supply projects. These criteria were based on the following facts: power supply projects as a rule could not directly combat poverty; electricity supply was a prerequisite for sustained economic development, provided it was supplied reliably and efficiently; projects should comply with least cost expansion schemes; the efficient allocation of scarce financial resources should be ensured by correct pricing; and energy conservation, promoted by cost covering tariffs, had a strong effect on environmental impacts and $CO_2$ emissions. The criteria adopted to reach these objectives were: the time ratio availability of existing plants should be higher than 75%; transmission and distribution losses should be lower than 20%; cost coverage by tariff structures should be more than 65–80% of the economic cost; if tariffs were subsidized, the share of non-productive consumption in the increase of supply by the project should not exceed 40%; and German environmental standards should be fulfilled if no applicable local standards existed. Projects which did not comply with these criteria would no longer be implemented. Furthermore, priority was given to projects producing the lowest $CO_2$ emissions and options involving combined cycles or co-generation.

E. ROTH (Germany) agreed with E. Müller (Germany) that the era of single dimension point solutions had passed, but felt that focusing on energy conservation sometimes led to another single dimension point solution. For example, desulphurization of coal fired power plants was clearly a disadvantage in terms of energy conservation but was a correct decision in terms of minimizing environmental impact. Co-generation of heat and electricity naturally was more efficient than solar energy, production by wind generators or photovoltaic processes, but the latter might be preferable options in terms of environmental impact. These two examples showed that even energy conservation should not be considered as a goal in itself. It was only preferable as long as it served to achieve higher goals, such as preservation of a healthy environment. The problem of electricity and the environment was too complex to allow single dimension point solutions.

K. KING (World Bank) (IBRD) noted that Expert Group 4 had developed a good overall decision making framework. The various Key Issues Papers had presented a number of specific methodologies incorporating domestic health and environmental impacts into national planning; however, the Symposium had shown that global impacts defied easy solutions. Therefore, it appeared that, even with vigorous intervention to ensure energy efficiency, the current and likely mixes of energy supply technologies (when coupled with rapid industrialization in developing countries) would not lead to the required reduction in carbon dioxide emissions. It was therefore necessary to establish a specific methodology to help decide among alternative long term (for example, 40 year) visions of the future of power technologies. This would involve producing a serious analysis of alternative R&D agendas, the optimum amount and allocation of energy R&D funds, and the most appropriate types of international R&D co-operation in the area of energy. Only then could one determine which were the best energy options for minimizing greenhouse gases in the future.

H. GLUBRECHT (Germany) felt that the importance of intensive development of renewable energies had been underestimated. He wondered whether it was more reasonable to invest money in improving techniques of burning fossil fuels to reduce $CO_2$ emissions by 20–30% for a period of time which would be limited by the availability of these fuels, or to promote solar and wind technology, which did not require such fuels, did not produce any waste, produced no $CO_2$ emissions and could be implemented for an unlimited period of time.

# LUNCHEON SESSIONS

# NUCLEAR POWER, SAFETY AND THE ENVIRONMENT
## *Keeping the options alive*

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### Abstract

NUCLEAR POWER, SAFETY AND THE ENVIRONMENT: KEEPING THE OPTIONS ALIVE.

The demand for electricity throughout the world continues to grow. Population increases, coupled with rising per capita demands for power, are putting pressures on the generation, transmission, and distribution systems of both developed and developing nations. In the face of this growing demand, existing power production infrastructures are continually ageing. Clearly, conservation, extended use of existing power plants and new production capacity are needed to meet the growing demand. New capacity decisions must be made that reflect a balanced consideration of environmental impacts, safety, technology, economics and demand. These decisions will require a balancing of many risks, uncertainties and competing interests. No single fuel will be able to satisfy all circumstances. Commercial nuclear power is already a significant energy source, today generating more than 17% of the world's electricity. It is a proven electricity generating technology that emits no sulfur dioxide, nitrogen oxides or greenhouse gases. In addition, over 6000 reactor-years of successful operating experience accumulated worldwide have demonstrated that nuclear power plants can be operated safely. With this experience it is believed necessary to maintain nuclear power as a viable option for meeting future energy needs. In the United States of America, the primary issues that need to be addressed to maintain the nuclear option include: continued safe operation of ageing plants, regulatory stability, introduction of new reactor designs and disposal of nuclear wastes (especially spent fuel). Several of these issues are addressed in the National Energy Strategy recently developed by the United States Department of Energy. In addition to these issues, increased public understanding of the risks associated with the complete fuel cycles of different electricity production technologies is vital to a future of nuclear power. Efforts of the United States Nuclear Regulatory Commission to address these issues include: early site permits, standard design certifications, and combined licences; evolutionary and advanced reactor design concepts; nuclear waste disposal criteria; and plant ageing research and licence renewals.

## 1. INTRODUCTION

I am pleased to speak to you today in the midst of your discussions of the critical and complex subject of electricity and the environment. This Symposium can throw new light on the comparative economic, environmental and health effects of different currently practical methods of meeting electricity requirements. Such understanding is needed in all countries to support decisions and plans for the relative contributions these different methods should make to electricity production and use. I look forward to the Symposium outcomes.

There is no question that the demand for electricity throughout the world will continue to grow as populations and the per capita demands for power increase. By contrast, the existing power production infrastructures are continuing to age and will require maintenance, enhancement or replacement. Clearly, conservation, extended use of existing power plants, and new production capacity are all needed to meet the growing demand.

A balanced consideration of environmental impacts, safety, technology availability, economics and demand must be an integral part of the process of making any new capacity decisions. No supply option is totally free from environmental impacts and health risks, and no single fuel will best satisfy all considerations. Therefore a complement of energy supply options should be considered in plans to meet future needs for generation of electricity. This complement of options should include nuclear power, which, I believe, has demonstrated the necessary safety, environmental and economic qualifications.

## 2. GLOBAL NUCLEAR POWER PRODUCTION

Nuclear power is presently a significant energy source, generating more than 17% of today's electricity worldwide. At the end of 1990, 29 countries were operating one or more commercial nuclear power plants, totalling together more than 400 plants. Nuclear power is an electricity generating technology that emits no sulfur dioxide, nitrogen oxides or greenhouse gases. In addition, over 6000 reactor-years of successful operating experience have been accumulated worldwide.

Of course, nuclear power is not without its risks and environmental impacts. While generally good, the safety record of commercial nuclear power plants has been marred primarily by two accidents, Three Mile Island in 1979 and Chernobyl in 1986. In addition, all countries with commercial nuclear power plants are seeking an adequate site and reliable facility design for disposal of the spent fuel from their plants.

It should be encouraging to note that some of the world's best scientists and engineers have been working, with much success over the past 40 years, to further reduce the risks and environmental problems associated with nuclear technology.

However, a gap exists between the confidence these scientists and engineers have in nuclear technology and the views of some governments and some members of the public that nuclear technology presents unacceptable risks and environmental problems. For nuclear power to remain a viable option, it is essential that the risks and environmental problems of generating electricity be explicitly placed in perspective along with those risks and environmental impacts associated with the alternatives.

## 3. STATUS OF THE COMMERCIAL NUCLEAR POWER INDUSTRY IN THE UNITED STATES OF AMERICA

In the USA today, there are 113 nuclear power plants licensed by the United States Nuclear Regulatory Commission (NRC) for commercial operation. In 1990 these plants provided more than 20% of the total electrical demand in the USA. In 1989, the displayed energy contribution from the operating nuclear plants was equivalent to approximately 4.3 billion barrels of imported oil, approximately 1 billion tonnes of coal, and about 6.5 trillion cubic feet of natural gas.[1] Without nuclear power in 1989, US utility emissions of $CO_2$ would have been 18% higher [1].

Three nuclear power plants remaining in construction status will total about 9.3 thousand MW of additional electricity. In addition, several operating plants are beginning to plan for licence renewal for an additional 20 years of electric power production. However, to date no utility has scheduled the construction of a new nuclear power plant to meet the growing need for electricity in the USA. But it is not possible to infer that nuclear power has been excluded selectively from utility plans for new electricity generation capacity. According to information published by the North American Electric Reliability Council, US utilities plan for only 6.9 thousand MW of new generation from coal plants to be constructed between 1990 and 1999 [2]. A majority of the planned new generation is for oil and gas or combined cycle plants. To date the plans for any new generation capacity appear to fall far short of the nation's anticipated need.

## 4. NATIONAL ENERGY STRATEGY

In February, 1991, President Bush released the National Energy Strategy (NES) developed by the United States Department of Energy (DOE) [3]. The NES offers a programme of greater energy efficiency, use of alternative fuels and the environmentally responsible development of all US energy resources. I will leave the

[1] 1 billion = $10^9$; 1 trillion = $10^{12}$; 1 $ft^3$ = $2.832 \times 10^{-2}$ $m^3$.

broader discussion of the NES for P.L. Ziemer, of the DOE with his presentation (Paper SM-323/38), and focus here on the portion of the NES that addresses commercial nuclear power.

On the basis of projections made by the DOE, a substantial new generating capacity will be needed to shore up dwindling reserve margins, sustain economic growth and replace older existing capacity, both fossil and nuclear. Approximately 85% of the additional capacity needs over the next 20 year period will be for base load capacity — the type of generating installation that can operate continuously, year-round and around the clock.

Recognizing the increasing US dependence on imported oil and increased environmental concerns about the long term effects of emissions from burning fossil fuels, the NES identifies an important and growing role for nuclear energy as part of a balanced array of energy sources for meeting the need for additional capacity in the USA.

The NES states that "nuclear power can cleanly and safely meet a substantial portion of the additional base load electricity generating capacity the USA will require by 2030 if (1) the operating lifetimes of existing nuclear plants are extended (where this can be done safely and with appropriate Federal oversight and technical support), and (2) utility executives once again consider the 'nuclear option' technically, politically, and economically feasible when new capacity is planned" [3].

## 5. ISSUES RELATING TO COMMERCIAL NUCLEAR POWER

In the USA, the primary issues that must be addressed to maintain the nuclear option include: continued safe operation of ageing plants, regulatory stability, introduction of advanced reactor designs and disposal of nuclear wastes (especially spent fuel).

Regulatory changes, among other factors, have contributed to construction delays and increased costs for all nuclear power plants completed after the Three Mile Island accident in 1979. Recent NRC reform of licensing procedures and successful implementation of initiatives to standardize plant designs should reduce the time from ground breaking to operation of nuclear power plants and bring the cost of nuclear power into competition with alternative energy sources.

While US nuclear power plants have demonstrated an exceptional record of safety, concerns about the safety of nuclear power increased as a result of the accidents at Three Mile Island in 1979 and Chernobyl in 1986. These concerns may be mitigated through meticulous attention to safety in the currently licensed plants and by the increased safety margins provided in the design and operation of advanced nuclear power plants.

Finally, the USA must demonstrate an effective programme for the disposal of nuclear waste. Much experience has been gained in the handling, storage and transport of all types of nuclear waste (such as spent fuel and low level radioactive wastes) and in the disposal of low level wastes, in the USA and in OECD countries. However, though there is strong scientific agreement on acceptable technical approaches to be used in designing a facility for the disposal of spent nuclear fuel (and other high level wastes), little progress has been made in the actual development and operation of such a facility. In the USA, as well as in other countries, progress to date has been impeded largely by public opposition to siting of nuclear waste disposal facilities.

Successfully addressing these issues should enhance the safety, reliability, economics and environmental acceptability of nuclear power. However, it is also important to recognize that both the lack of public understanding of nuclear technology and the lack of public appreciation for the basic concepts of risk have contributed to the public concern about and opposition to nuclear power.

## 6. ROLE OF THE NRC

I will now discuss what the NRC is doing to address these issues and keep the nuclear option alive.

The mission of the NRC is to ensure adequate protection of public health and safety, of the common defence and security, and of the environment in the commercial use of nuclear materials in the USA. The NRC's scope of responsibility includes regulation of commercial nuclear power plants; research reactors; fuel cycle facilities; medical, academic and industrial uses of nuclear materials; and the transport, storage and disposal of nuclear materials and wastes.

New efforts of the NRC to address these matters include: plant ageing research and licence renewals; early site permits, standard design certifications and combined licences for new reactors; evolutionary and advanced reactor design concepts; and nuclear waste disposal criteria.

### 6.1. Plant ageing research and licence renewals

The NRC has devoted substantial time and resources to identify and evaluate complex technical, policy and legal issues in allowing for the renewal of existing operating licences. On the basis of the condition of the current energy infrastructure, timely renewal of nuclear power plant operating licences is important for ensuring an adequate supply of electricity for the USA during the first half of the 21st Century.

The NRC is developing a regulatory framework to provide for the continued operation of currently licensed nuclear power plants while ensuring the protection of the health and safety of the public and the environment. This framework will meet the utilities' need to understand the regulatory requirements for licence renewal sufficiently early to make timely and informed decisions concerning future generating capacity.

The regulations developed by the NRC will require that each renewal applicant demonstrate that age related degradation of a facility's systems, structures and components has been identified, evaluated and corrected through an integrated plant assessment before a renewed licence is granted.

In addition, the NRC is developing proposed amendments to its environmental protection regulations that will use a generic approach to narrow the number of environmental issues that must be assessed in individual plant licence renewal reviews. Issues that have been assessed in a generic environmental impact statement can be excluded from individual plant reviews.

The decision to undertake this change was based primarily on two considerations. One is that licence renewal will involve nuclear power plants and activities for which the environmental impacts of operation are well understood. The second is that changes in the environment around nuclear power plants are generally gradual and predictable.

The US nuclear utility industry has selected a pressurized water reactor (PWR) and a boiling water reactor (BWR) as pilot plants for testing the licence renewal process. The NRC expects the first application for licence renewal in December 1991 and another dozen or so applications by the turn of the century.

### 6.2. Early site permits/standard design certifications/combined licences

The NRC recently developed a new process for approving new power plant sites; this early site permit process allows for litigation and resolution of site suitability issues in advance of an application for a construction permit or combined construction and operating licence. As part of the early site permit process, the applicant must demonstrate that there are no major impediments to the development of an emergency plan. An early site permit can be issued for up to 20 years.

The nuclear utility industry has recently responded to a DOE offer to assist in demonstrating the feasibility of the NRC's early site permit process. After a comprehensive review of the new regulations, an industry team plans to identify a site for the application of the process.

The NRC is also developing a design certification process that allows for approval of a standard design submitted by a vendor prior to an application for construction by a utility. A utility that wants to build a nuclear power plant could reference the early site permit and standard design certification in their application for the combined construction permit and operating licence application.

A combined licence allows the owner to construct and operate the plant, subject to satisfactory completion of required inspections, tests and analyses. Financial risks associated with constructing a plant are reduced because the design is approved and the site suitability and reactor safety issues are resolved for the most part before construction begins. The owner can proceed with construction with a high degree of assurance that significant changes will not be required and the facility will be allowed to operate after it is constructed.

### 6.3. Evolutionary and advanced reactor design concepts

The NRC is reviewing presently a number of different evolutionary and advanced reactor designs. Some of these reviews should lead to design certifications within the next few years, thus making the benefits of the standard design certification process available to the utilities.

The first group of reactor designs planned for licensing through certification are evolutionary reactor designs. Evolutionary reactor designs have evolved from current US light water reactors (LWRs) and utilize special safety features developed through US operating experience. They have been designed specifically to be resilient to severe accidents. As might be expected, it is these evolutionary designs that are scheduled to go to design certification first, since they do not represent a major departure from the technology used in the current generation of plants.

The next generation advanced reactor designs scheduled for detailed review and eventual certification are referred to as passive reactor designs because they include safety systems utilizing natural processes and/or passive features. Examples of these safety systems include gravity fed emergency water supplies and natural convection cooling processes, instead of systems relying on active elements such as pumps and power driven valves. The passive reactor designs that are now being reviewed at the conceptual stage by the NRC include an advanced PWR, a simplified BWR, a gas cooled reactor, a liquid metal cooled reactor, a Canadian designed heavy water reactor, and the PIUS LWR being developed in Sweden. As all of these designs have safety features that are outside its present licensing experience, the NRC is developing plans to acquire the necessary experimental and analytical information needed to support the certification process for these designs.

### 6.4. Nuclear waste disposal criteria

To dispose of high level waste and spent fuel generated in US nuclear power plants, the DOE is responsible for design, construction and operation of a geological repository; the United States Environmental Protection Agency (EPA) is responsible for establishing standards for the repository; and the NRC is responsible for establishing regulations to assure compliance with EPA's standards and ultimately for licensing of the geological disposal facility. The final disposal of high level nuclear waste in the USA requires a determination of acceptable health and environmental impacts for 10 thousand years.

In 1983, the NRC established regulations for licensing geological repository and is now evaluating potential uncertainties in these regulations in order to provide clarification where needed. In addition, the NRC continues to work with the EPA as they develop standards for disposal of high level nuclear waste and spent fuel. Once EPA's standards are finalized, the NRC will consider changes that may be necessary to conform the regulations to the standards.

The NRC is also conducting pre-licensing consultations with DOE on a proposed repository site at Yucca Mountain, Nevada. With these early consultations, the NRC is providing the DOE with guidance to help ensure that the DOE is proceeding in an appropriate manner and that it will develop an acceptable licence application. According to the DOE's current schedule, the licence application will be submitted to the NRC in the year 2001.

One of the most significant challenges of the high level nuclear waste disposal programme is dealing with uncertainties in evaluating the integrity of a geological repository over the 10 000 years of intended isolation. The need to assess geological processes, climate changes and human activities for thousands of years leads inevitably to uncertainties. The NRC is focusing its pre-licensing consultations with the DOE on acceptable methods for dealing with those uncertainties which will be most significant. The NRC has opened these pre-licensing consultations to the public in an attempt to include all parties in the USA that may be affected by the development of a geological repository.

For the other nuclear wastes generated by commercial nuclear power plants, there are currently three operating low level nuclear waste disposal facilities in the USA. In 1980, with the desire to place the responsibility for disposal wastes generated in different States with those States and to recognize that the operating disposal sites had limited capacity, a Congressional Act was passed that after 1 January, 1996, each State is responsible for disposing of commercial low level waste generated in its boundaries [4]. This Act allows States to form Compacts or to act independently and establishes milestones and penalties to encourage States to develop new disposal capacity.

The NRC's role in this programme is to develop rules and guidance that assist the States and ensure adequate protection of public health and safety in the disposal of these wastes. Many of the rules and much of the guidance are in place and a total of 13 low level waste disposal sites are presently being considered by the States. However, the USA anticipates that only a few new disposal facilities will be operating by the 1 January, 1996 deadline established by the US Congress.

### 6.5. Public acceptance

Ironically, there seems to be no serious issue that has been raised as a problem for nuclear power that does not have a counterpart somewhere else in contemporary industry today. A difference has been that the nuclear power version of the problem has been identified earlier and publicized more fully than the problems in other industries. There is a tendency on the part of the public to regard radioactive hazards differently from other, often more dangerous, hazards.

One of the primary factors contributing to public concern about and opposition to nuclear power has been society's lack of understanding of the general concept of acceptable risk. A. Bromley, the Advisor to President Bush on science and technology matters, has stated that in a technological society such as ours — one which has given us longer, healthier and more comfortable lives than most humans have ever known — some level of risk taking is not only inevitable but desirable [5]. If we were to attempt to eliminate all risks, we would need to give up the present benefits of many technologies and reduce the potential for future advances. Nevertheless, I think everyone would agree that all technological risks should be kept as low as reasonably possible.

In an attempt to clearly define acceptable levels of risk in the operation of nuclear power plants, the NRC developed the Safety Goal Policy. This policy was established in 1986 with two qualitative and two quantitative provisions.

The provisions of the Safety Goal Policy are somewhat complex so I will summarize them. The qualitative provisions are that nuclear power plant operations do not introduce a significant additional risk to life and health of individual members of the public and that the risks to society are comparable to or less than the risks of generating electricity by viable competing technologies.

The quantitative provisions are that: (1) the risk to average individuals in the vicinity of a nuclear power plant of prompt fatalities that might result from reactor accidents should not exceed one-tenth of 1% (0.1%) of the sum of prompt fatality risks resulting from other accidents to which members of the US population are generally exposed; and (2) the risk of cancer fatalities that might result from nuclear power plant operation to the population in the area near a nuclear power plant should not exceed one-tenth of 1% (0.1%) of the sum of cancer fatality risks resulting from all other causes.

The Safety Goal Policy lays out the safety philosophy the NRC is using and will continue to use in licensing and regulation of new and existing facilities, and helps ensure that the risks to the public from nuclear power remain low. I believe that a better understanding by the public of the NRC safety goal policy and how well the goals are met could contribute to greater confidence in the safety of nuclear power.

## 7. CONCLUSIONS

It is important to look closely at the contribution nuclear power can make, in the light of the obvious need for new power generation and the awareness of global environmental problems. However, the basic impediments to nuclear power are well known. They stem from the concerns I have noted about reactor safety, regulatory stability, and waste disposal. These impediments exist on an international scale and involve a tangle of technical, political, social and economic issues.

If nuclear power is to be included in the complement of electricity generating technologies considered in the energy infrastructure of any country, as I believe may be necessary, these impediments must be addressed adequately in a manner that will ensure protection of public health and safety and the environment.

In addition, a greater public understanding of nuclear issues together with the risks associated with the complete fuel cycles of other energy technologies is necessary. Public acceptance of nuclear power depends not only on resolution of its regulatory and institutional impediments, but on the demonstration of continued safe and reliable operation of nuclear power plants, and on an increased credibility of those organizations responsible for design, operation and regulation of nuclear power plants.

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# SWEDISH ENERGY POLICY DURING THE 1990s

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**Abstract**

SWEDISH ENERGY POLICY DURING THE 1990s.

The Swedish energy policy to be implemented in the 1990s has as its main objectives long term stability in energy development, more efficient electricity trade between consumers and producers and more efficient use of energy through investment in new technology and in spreading information about that technology. The Swedish Government believes that through these technologies and new equipment and techniques, such as the stock market system of efficiency bonds, the energy system will be a more environmentally adapted system. Sweden proposes that to meet stringent environmental demands it will be necessary to introduce charges on harmful emissions, establish emission ceilings, develop extensive programmes for wind power, gasification and gasohol and support investments in large scale wind, solar and biofuels programmes. A further step in the Swedish energy policy will be the postponement of the beginning of the phasing out of nuclear power in 1995/1996.

## 1. BACKGROUND

After negotiations during the months of September-December 1990, an energy policy agreement between the three Swedish parties — the Social Democratic, Centre and Liberal — was presented in January 1991. This agreement has become a Bill which will be decided upon by the Swedish Parliament at the end of May 1991.

The main points in the Swedish energy policy to be implemented during the 1990s will be:

(a) Charges and taxes on emissions of $SO_2$, $NO_x$ and $CO_2$
(b) Increased efficiency in the electricity market
(c) Postponement of the beginning of the phasing out of nuclear power in 1995/96
(d) Extensive technology development programme for wind power, gasification and gasohol
(e) Support for investment in new energy programmes such as large scale wind power and solar heating technologies
(f) Measures to promote chlorfluorocarbon production and biofuels
(g) Increased efficiency in energy use through the purchase and demonstration of more efficient technology and information
(h) Increased international contacts to promote competition and co-operation

(i) Establishment of a commission for biofuels which will propose measures for strengthening the competitiveness of biofuels.

In connection with the reports that the Swedish Government and Parliament have ordered as a basis for the present Bill, energy policy questions were also raised which are important to answer during the next few years.

## 2. SWEDISH ENERGY SYSTEM OBJECTIVES

In order to achieve a better functioning market, Sweden believes it necessary to safeguard the buildup and operation of an efficient infrastructure and stop monopolist influences on the markets. To meet stringent environmental demands, it will also be required to introduce charges on harmful emissions, irrespective of where they may arise and to try out on a voluntary basis emission ceilings with transferable emission rights.

In order to achieve a long term perspective and stability in the development of energy, Sweden proposes to avoid using temporary subsidies to control the buildup of specific parts of the energy system. It also sees as a responsibility the duty to explain the principles behind energy policies and the international interdependence of these policies so that changes in the control measures can also be foreseen outside the political sphere.

By a combination of economic and administrative policy measures, together with the RD&D of new and more efficient technology on the supply side, more efficient technology on the demand side, plus changes in market requirements, it is the Swedish Government's judgement that the adjusted Swedish energy system will be geared towards a more environmentally adapted system. This will occur with the knowledge of, and participation in, international development.

Efficient trade, effective energy use and new technology are the three spheres which will be of interest to Sweden during the next few years as the country tries to develop and improve the conditions in the area of energy and the environment.

## 3. MORE EFFICIENT ELECTRICITY TRADE

In order to improve the situation of the consumers, studies are being carried out at the National Energy Administration on how to increase and improve electricity trade between Swedish consumers and producers, and also on how to increase electricity trade between consumers in Sweden and producers abroad.

This will be done partly by submitting proposals to establish an independent organization of the national grid, which has as a starting point, on the one hand, the public interest and, on the other hand, the transmission of power in a technically and economically advanced manner.

Through a Swedish Government owned company or corporation the present obstacles will diminish and possibilities will increase for new and smaller producers to share in this exchange of electricity. Sweden is also going to study how to increase trade/competition on the regional and district grid in order to lower costs. This development has a direct connection with the joint action of the Nordic countries and follows from the discussions in the European Community (EC) regarding transit and the common carrier.

I believe that treating these infrastructure questions will be important in finding efficient and international solutions. I consider it also especially important that the infrastructure is under public control. In the choice between having a government owned company or corporation which runs the trunkline network, or having instead a private company, which besides its activity has the authority to inspect that activity, I consider it a better solution to have a government owned company or an authority where equal treatment, oversight, etc. are built into the framework of the organization.

## 4. MORE EFFICIENT USE OF ENERGY

The other aspect I would like to mention is the more efficient use of energy whereby the Swedish Government proposes an investment worth 1 billion[1] SEK during a five year period[2]. Most of this money will be used to produce new technology in order to ensure the availability of efficient equipment on the market.

This investment implies procuring more efficient technology on the consumption side as well as spreading information about that technology and creating rules for procurement which provide the incentive to think about lifetime costs instead of investment costs alone.

We have also received an assignment from the Swedish Government to try to see if we can develop a stock market system of efficiency bonds on the demand side which will be as straightforward and simple as the new supply technology.

Energy is an input and not a consumer good. There is always an efficiency factor which could be improved, before the end use of energy. If this is accomplished, the consumer will have the same amount of satisfaction, but less input of energy will be required. The rationale behind the need to develop a policy to influence the market is that the market has imperfections. But even in ideal cases, the requirements for a market to operate successfully are very complex. The pricing has to be correct, the customers have to understand the value of the goods, make correct calculations, and know all their alternatives in detail. On the energy market, most of these requirements are normally violated and hence there are good reasons

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[1] 1 billion = $10^{12}$.

[2] 1 SEK = US $0.17.

for activities to move the demand side towards optimality. Price information is handled by individuals who, even with an extensive use of computers, will be limited in their abilities to find an optimal solution that will last for decades.

Systematically we are feeding more and more expensive power generation to inadequate equipment, even though we have the knowledge and the skill to reduce the demand at a cost lower than the cost of increasing supply. Systematically we regard the customers as participants who pay for the new power, though they are never consulted. Even through they could be offered better alternatives, we do not bother to give them that service but instead we merely supply kilowatt-hours. We also systematically disregard the possibility of creating a more mature and a more suitable market.

The market is an excellent institution to distribute goods and to allocate resources, but it needs some minor adjustments to let through goods in the optimal amounts. It is important, however, to look first at the factors having a strategic influence on the market.

If one wants to impose changes on a system such as energy, there are some elements which one has to control to achieve optimality. This can be called energy service which is made up of the following components: planning, technology, market analysis and commercial methods. Brought together in an interdependent system, these components will allow one to create and deliver energy service for the market on the terms that the market can accept.

The agents best positioned to handle such a system are, from my point of view, the electric utility or distributor, for two reasons. Firstly, they have the everyday market contact with the end users and are in many cases regarded by the end users as superior in the knowledge of how to use energy. Secondly, they may have the primary interest in achieving a more efficient system as they might benefit from it themselves. They can benefit either from more efficient use of their equipment for production and distribution, or from involving themselves in selling/leasing the new equipment to the customers. In addition, they could both save and earn money from the monitoring of the market. And most of all, the customers will receive good value for their money.

We would suggest that the organization of the market should be tried in a more business-like manner in order to encourage more parties to take a chance. The establishment of parties controlling opportunities in danger of being lost, organizing a stock market for conservation and the issuing of efficiency bonds could be examples of such business instruments. The bonds should be issued to cover the extra cost the party in question needs to cover in order to obtain a load reduction in excess of what would otherwise be produced.

The producer can decide if the offer is better for him than his options for new power or if it will be better just to postpone the building of new power systems to avoid costs. But mainly the producer could decide which offer is best for him and have the full satisfaction of competition not only on the supply side but also on the demand side. There could be money involved in this also for brokers or for financiers willing to end load their loans.

We think that a more organized stock market for efficiency bonds will have several advantages. It will allow for more actors to participate on each side, and will be far better from a competitive point of view than the mainly bilateral solutions which are being used today.

## 5. ENERGY ALTERNATIVES

Finally a few words about measures to promote new alternatives for heat and power production. Solar and wind power will be supported by 25% of the investment cost. If combined heat and pressure are built, the cost is SEK 4000 per kW·h electricity installed if biofuels are used. There is also an opportunity to get back up to 50% of the investment cost if one develops large wind power plants, gasification plants and gasohol systems on a demonstration scale.

In summary, the Swedish approach to the issue of energy and the environment during the 1990s will be to establish a stable and long term energy policy, more efficient trade, more efficient utilization and more efficient technology.

# POLICY ASPECTS OF ELECTRICITY AND THE ENVIRONMENT

## (General Plenary Session)

**Chairmen**

**C. BANDARA**
Sri Lanka

**P. SILVENNOINEN**
Finland

**Invited Paper**

# PROMOTION OF ELECTRIC POWER POLICIES WHICH CONSIDER JAPAN'S ENVIRONMENT

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## Abstract

PROMOTION OF ELECTRIC POWER POLICIES WHICH CONSIDER JAPAN'S ENVIRONMENT.

Fuelled by the advances of the information oriented society and the increasing desire for a comfortable standard of living, demand for electric power has been growing at a faster rate than the demand for overall energy. To cope with such a strong demand and to supply a stable and adequate amount of electric power, energy conservation and oil substitution policies were implemented, especially since the time of the oil crises, to overcome the weakness of Japan's electric power supply structure, which depended almost entirely on overseas energy supplies. At the same time in order to deal with the environmental problems which surfaced with Japan's economic growth, policies focusing on these problems were incorporated into Japan's electric power policies and were implemented widely. As a result, Japan can be said to have practically succeeded in coping with securing a stable energy supply as well as an environmental preservation programme, at least in the field of electric power. Furthermore, with respect to global environmental problems which have become a prime factor in restricting energy and electric power supply in recent years, Japan has set a goal to stabilize per capita $CO_2$ emissions after the year 2000 and to advance the drive to conserve and use energy efficiently. Japan also is focusing on an energy and electric power policy establishing a supply structure that raises the dependence on power sources that produce little $CO_2$, centring mainly on nuclear power. Now that energy problems have become a concern shared by all countries in the world, it will be important for Japan to use its experience and accumulated technology as a member of the world community and as an industrially advanced country.

## 1. OIL CRISES AND ENERGY POLICIES

Owing to the fact that energy resources are extremely scarce in Japan, the country must depend on energy from overseas in order to maintain its everyday living and promote its economic development. Before the time of the oil crises, Japan enjoyed the benefits of cheap and abudant oil and was able to secure energy easily. However, the oil crises drastically altered the economic picture. Resource constraints, i.e. the problems of rising energy consumption and exhaustion of fossil energy, as well as the difficulty of maintaining a stable energy supply in the face of dependence on an imported fuel supply, have become important concerns. After the two oil crises, Japan concentrated its efforts on energy conservation as well as on diversification of energy and the securing of a stable energy supply. In particular, Japan has pursued energy conservation by increasing the efficiency of equipment and plants and by effectively using waste heat. With respect to diversification of energy, Japan has promoted the introduction of nuclear power generation, coal and liquid natural gas (LNG) from abroad, domestically produced energies such as hydropower and geothermal sources, as well as new energies. Furthermore, in order to achieve a stable supply, and improve energy security, Japan has pushed for the procurement of imported energies from several countries.

## 2. RECENT ENERGY PROBLEMS

In recent years, in addition to the issue of energy security, environmental problems starting with global warming have become an important concern. According to the review of the Advisory Committee for Energy, an advisory council of the Japanese Ministry of International Trade and Industry, global demand for energy from oil in recent years has shown an uptrend and will continue to rise. This surge in energy consumption, particularly the combustion of fossil energy, will cause increasing $CO_2$ emissions into the atmosphere; these releases are believed to constitute roughly one-half of the cause of the greenhouse effect. Despite these disadvantages, energy consumption is closely and inseparably related to worldwide economic activities and civic life. In this connection, as human activities expand, energy consumption rises unavoidably. Global energy and environmental problems can be overcome only by combining the intelligence of mankind with the co-operation of each individual country.

## 3. CONDITIONS SURROUNDING ELECTRIC POWER

The percentage of primary energy used by electric power in the total primary energy supply (electric power ratio) is showing an increase of about 37%. This growth is attributable partly to the progress of the information society. Also, the mounting desire for a comfortable standard of living, as evidenced by the surge in demand for air conditioning in the private sector, encourages the use of household electric appliances. As seen above, the demand for electric power commands a large share of energy. Furthermore, since demand for electric power is growing at a faster rate than that of other power types, there is a substantial concern that future supply and demand will tighten. Electric power has now become indispensable for everyday living and economic activities because it is high quality energy with a high utility value. The stable supply of electric power is being requested strongly. For this reason, it is believed that many difficulties will accompany the attempt to strike a balance between global environmental problems and electric power demands.

## 4. ELECTRIC POWER POLICY WHICH CONSIDERS THE ENVIRONMENT

During the late 1960s in Japan, air pollution and water pollution problems which accompanied the explosive economic growth began to surface and became social problems. As a result, several proposed thermal power plant construction projects failed to obtain the approval of local officials as well as residents and were therefore deadlocked. Having gone through such bitter experiences with regard to electric power policies, Japan has aimed for a cheap and sufficient supply of electric power and the securing of that stable supply, as was emphasized particularly after the oil crises.

To overcome the weakness of Japan's energy supply structure, which is dependent almost entirely on foreign fuels, it is Japan's goal to construct an electric power structure centring on oil substituting power sources such as nuclear power, LNG and coal. At the same time, Japan is promoting actively an environmental assessment system and environmental protection facilities for desulphurization, denitration, etc., and has encouraged research and development of environmental protection facilities and environmental preservation technology. As concrete steps towards implementing such policies, the National Tax System based on the sales volume of electric power and the Special Account for Measures Promoting Power Sources were established in 1971. By using these financial resources, it was possible to devise a scheme for technological development, introduction of facilities, promotion of siting of electric power sources, etc. Within this scheme, measures concerning environmental protection were also implemented. Moreover, a low interest financing scheme from Japanese Government resources and a framework in which this system can be utilized for establishing environmental protection facilities have been established. As a result of such efforts, Japan's dependence on oil, which had reached a peak of 70% as shown in Fig. 1, fell to roughly 20% in recent years. Further, as shown in Fig. 2, the establishment of environmental protection facilities in thermal power plants has also made remarkable progress. Japan is confident that its environmental protection measures have already reached the world standard at least for electric power facilities. For this reason, conventional environmental problems are today no longer major factors that hinder the siting of power plants.

Such electric power policies will not only continue to be carried out but will also incorporate policies that address especially the recent global environmental problems that have rapidly emerged as an international concern.

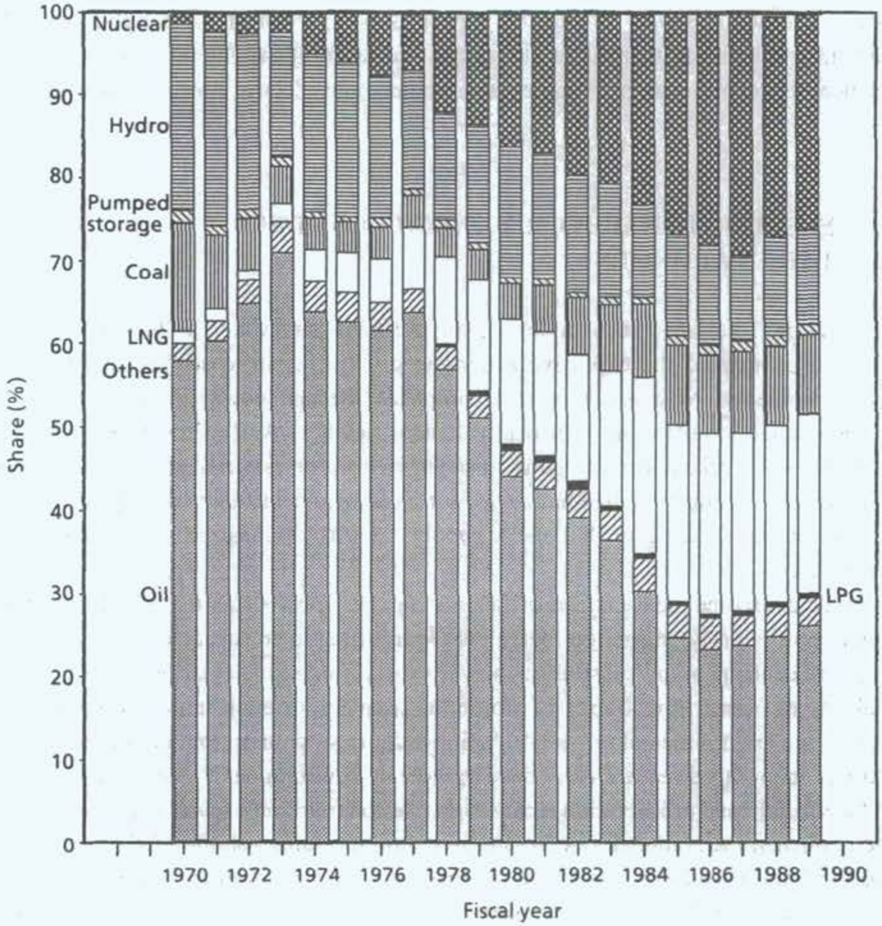


*FIG. 1. Historical profile of electricity generation in Japan.*

## 5. ADDITION OF NEW ELECTRIC POWER POLICIES

As a part of such efforts, to cope with the problem of global warming in the coming years, the Japanese Government devised the Global Warming Prevention Action Plan in October 1990 and set a goal to stabilize the per capita emission of $CO_2$ after the year 2000. It is making serious efforts to achieve such goals. Measures for electric power are also incorporated into the programmes described above.

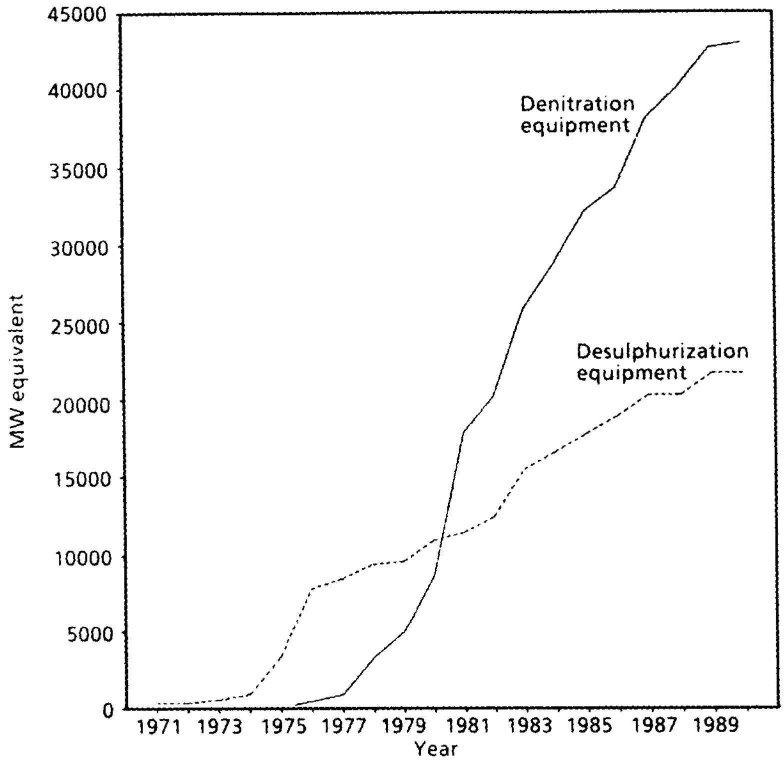


*FIG. 2. Installation of antipollution equipment.*

On the demand side, the basic direction points to a dramatic increase in the efficient use of energy, i.e. energy saving measures. Secondly, the effort calls for measures that increase the importance of power resources which produce minimal $CO_2$ and for the establishment of a supply structure with a high dependence on non-fossil energy, i.e. a structure centring on nuclear power.

With regard to increasing the efficiency of energy use, from 1973 to 1988, as shown in Fig. 3, Japan successfully lowered its Gross National Product (GNP) basic unit of energy consumption by 36%. Japan has also devised a low energy consumption structure that far exceeds the Organization for Economic Co-Operation and Development (OECD) average as shown in Fig. 4. At present, a goal to achieve the same level of energy conservation by the year 2010 is being set. However, the achievement of this goal will be as difficult, so to speak, as wringing a dry towel.

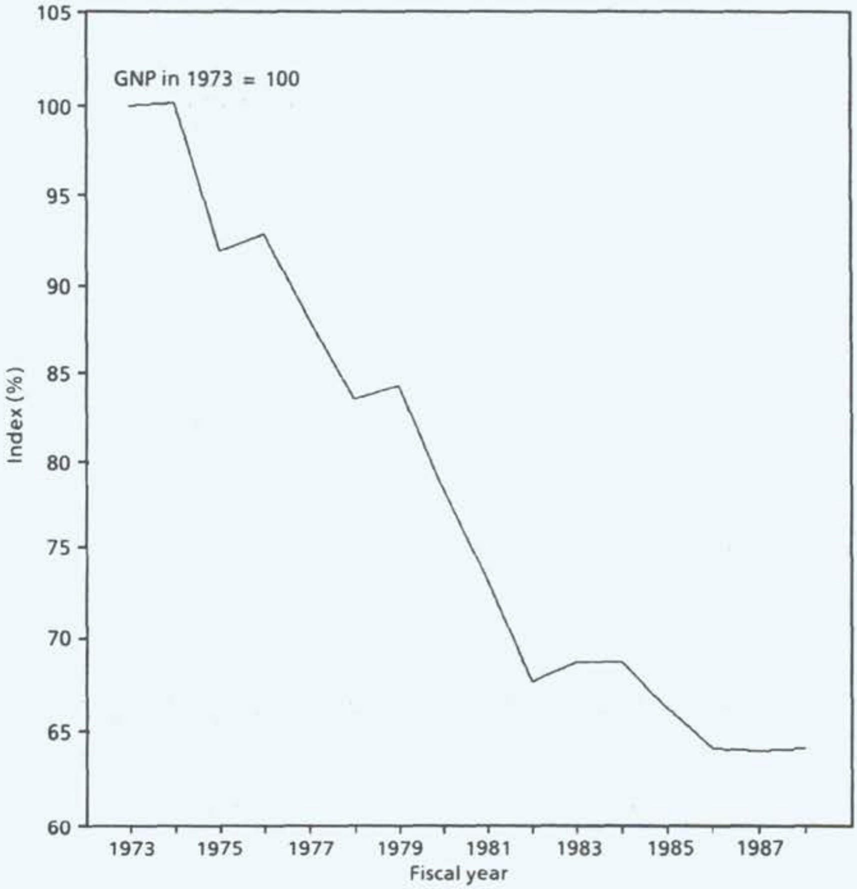


*FIG. 3. Reduction of energy consumption per unit GNP in Japan.*

For this purpose, even in the field of electric power, Japan is making a bid to further increase the efficiency of equipment and plants as well as the specific requirements of the social system. In addition, it is channelling its energies into applying low quality energies that have been thrown away or overlooked, i.e. energy from sea water, from river water and waste heat from city activities such as the operation of a subway transportation system.

Although maximum efforts are being concentrated on the promotion of hydropower, geothermal sources, new energies, etc., supply capability will largely depend on nuclear power. The low per capita emission of $CO_2$ in France is mainly a result of the improvement of the nuclear power ratio in that country. It can be seen that this low emission value contributes significantly to the prevention of global warming. Therefore, Japan considers nuclear power to be the centrepiece of energy

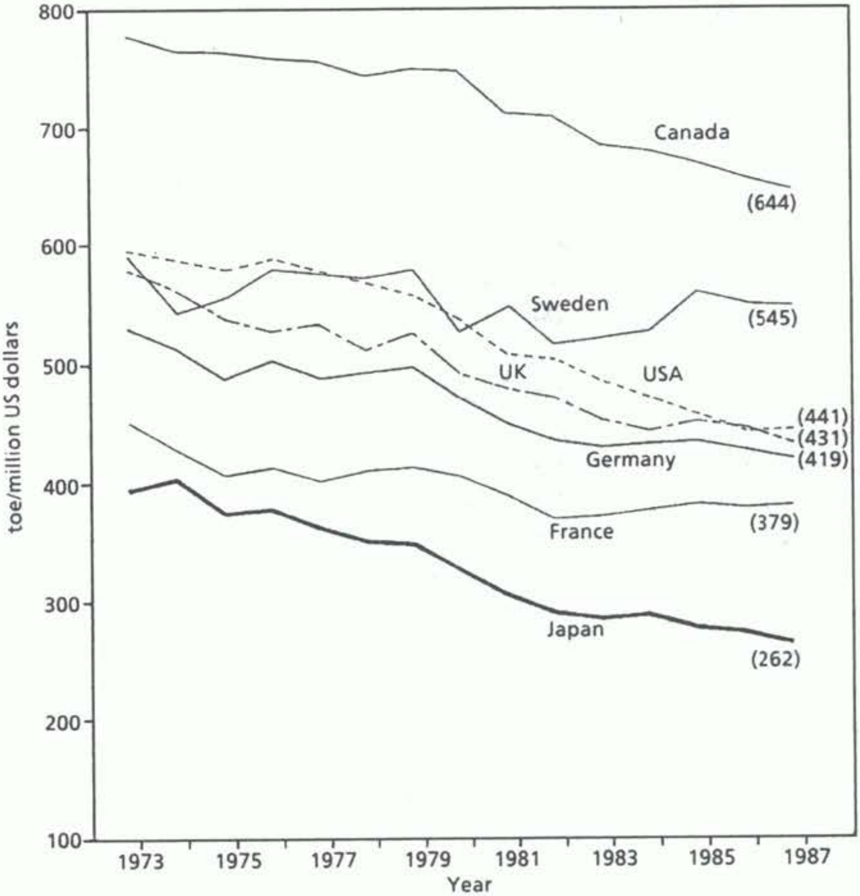


*FIG. 4. Energy consumption per unit Gross Domestic Product (GDP) in seven OECD countries.*

supply and is making serious efforts to develop and utilize such power. By setting a goal to achieve a nuclear power plant capacity of 72 million kW and to increase the share of nuclear power plants to 27% by the year 2010 (see Table I), Japan is diligently making the necessary efforts to achieve this goal. It can be easily seen that the achievement of this objective will hardly be easy in the face of mounting movements against nuclear power not only in Japan but worldwide. Nevertheless, because of the importance of solving global environmental problems, it is a goal that must be attained. With the anticipated rise in demand for energy by developing countries, it can be said that making contributions to the control of $CO_2$ emissions in the future by promoting nuclear power, a technology intensive power source, is the responsibility of industrially advanced countries.

TABLE I. GOAL OF POWER SOURCES

| End of fiscal year | 1988 | | 2000 | | 2010 | |
|---|---|---|---|---|---|---|
| | Total (measured in 10 MW units) | Share (%) | Total (measured in 10 MW units) | Share (%) | Total (measured in 10 MW units) | Share (%) |
| Nuclear | 2 870 | 17.4 | 5 000 | 22 | 7 200 | 27 |
| Coal | 1 112 | 6.7 | 2 960 | 13 | 4 000 | 15 |
| Liquid natural gas | 3 306 | 20.1 | 5 030 | 22 | 5 300 | 20 |
| Hydro: Total | 3 613 | 21.9 | 4 450 | 19 | 5 170 | 19 |
| Conventional | 1 913 | 11.6 | 2 150 | 9 | 2 500 | 9 |
| Pumped storage | 1 700 | 10.3 | 2 300 | 10 | 2 670 | 10 |
| Geothermal | 18 | 0.1 | 100 | 0.4 | 350 | 1 |
| Oil and LPG | 5 563 | 33.8 | 5 120 | 22 | 4 020 | 15 |
| Methanol | — | — | — | — | 100 | 0.4 |
| Dispersed power sources[a] | — | — | 110 | 0.5 | 570 | 2 |
| Total | 16 482 | 100 | 22 770 | 100 | 26 700 | 100 |

[a] Dispersed power sources include fuel cell, solar and wind.

## 6. PROMOTION OF INTERNATIONAL CO-OPERATION

With the advances in the globalization of energy, economy and technology in recent years, coping with energy problems has become a task shared by all countries. From this standpoint, it is important for each country to co-operate actively with each other to resolve such problems. By making full use of its experience in promoting various energy conservation measures, Japan would like to co-operate in devising such new efforts as the application of unused energies. In recent years, the movement against nuclear power has dramatically intensified in Japan. For this reason, siting of nuclear power plants will face serious difficulty. Although governmental and private publicity campaigns concerning nuclear power are being launched, the safety of nuclear power affects not only domestic trends but also attitudes abroad against nuclear power. Therefore, it is necessary to improve safety on a global scale in order to heighten people's confidence in nuclear power. Japan would like to contribute to this effort. Moreover, given the present situation that fossil fuels such as coal will continue to be indispensable in the future, Japan will co-operate in research to increase the efficiency of power generation through pressurized fluid bed power generation technology and combined power generation technology, in order to control the production of $CO_2$. At the same time, Japan would like to share desulphurization and denitration technology designed to prevent acid rain. Development of the revolutionary technology of $CO_2$ stabilization is based on the Global Recycling Program, called 'New Earth 21', which Japan has been proposing for the resolution of the global warming problem. Japan would like to aim for the early realization of this programme through the exchange of information between countries.

## 7. CONCLUSIONS

Having experienced high economic growth and the two oil crises in the past, Japan was almost able to succeed in coping with both the securing of a stable supply of electric power and the usual environmental problems. However, measures to cope with new global environmental problems are still in the early phases. Owing to the fact that global environmental problems are closely related to energy consumption, in order to overcome such problems it is necessary and indispensable to increase the efficiency of energy use, to use non-fossil fuels and recyclable energies as well as to advance broad based measures, including international co-operation. Moreover, the full effectiveness of global environmental measures is demonstrated only if all countries — rather than only a few — join forces and employ such measures. For this reason, as a member of the world community and as an industrially advanced country, it will be important for Japan to make wide ranging contributions to the resolution of this problem on the basis of its previous experience and accumulated technology.

## Invited Paper

# INTEGRATING ENVIRONMENTAL CONCERNS INTO PLANNING TO MEET ELECTRIC DEMAND

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### Abstract

INTEGRATING ENVIRONMENTAL CONCERNS INTO PLANNING TO MEET ELECTRIC DEMAND.

President Bush released the United States National Energy Strategy (NES) in February 1991. The keystone of the strategy is to continue the successful policy of allowing markets to determine energy prices, quantities and technology choices. In the United States of America, most detailed decision making related to meeting energy demand is decentralized and carried out largely by the private sector. Decisions are made generally on a regional rather than on a national basis. Thus, the policy aspects of electricity and the environment involve both broad Government initiatives and private sector implementation. The NES establishes a series of goals and approaches for several energy policy areas. In the area of increasing energy and economic efficiency, initiatives are established for electricity generation and use. The NES also establishes goals and approaches in the area of future energy supplies (for coal, nuclear power and renewable energy resources) and determines methods to enhance environmental quality (e.g. air quality, waste management, water and land use issues and global environmental issues). The US Department of Energy, through its power administrations, supplies electricity to various service territories. The Bonneville Power Administration (BPA), located in the US Pacific Northwest, is used as a case study in the paper. Every two years, the BPA prepares a Resource Program that communicates how it proposes to meet its obligations to serve the power requirements of its customers. Public participation is an important element of the Resource Program. Because the BPA is a Federal agency, the National Environmental Policy Act process is fully integrated into the overall resource planning process. The BPA is preparing a Resource Program Environmental Impact Statement, covering 10–15 years of resource planning, to ensure that it will be able to meet its load demands in a cost effective and environmentally sound manner. The BPA's resource planning process can be used as a model to ensure that environmental protection values are fully considered in planning directed towards meeting electricity demand.

## 1. INTRODUCTION

In February 1991, President Bush released the United States National Energy Strategy (NES) [1]. The document culminates an 18 month process undertaken by the US Department of Energy (DOE) and also involving most Federal executive agencies. The President established the objective of the NES as "achieving balance among our increasing need for energy at reasonable prices, our commitment to a safer, healthier environment, our determination to maintain an economy second to none, and our goal to reduce dependence by ourselves and our friends and allies on potentially unreliable energy suppliers" [1]. He directed that a keystone of this strategy would be to continue the successful policy of market reliance. Wherever possible, the President added, markets should be allowed to determine prices, quantities and technology choices. In specific instances where markets cannot or do not work efficiently, he directed that Government action be aimed at removing or overcoming barriers to efficient market operation.

On the basis of this direction, the NES incorporates the views, data and analyses provided by numerous participants, including energy producers, consumers, developers, conservationists, environmentalists and trade associations. The NES lays the foundation for a more efficient, less vulnerable, and longer environmentally sustainable future. It defines international, commercial, regulatory and technological tools that will substantially diversify US sources of energy supplies and offer more flexibility and efficiency in the way energy is transformed and used. Specifically, it will stimulate more efficiency and competition throughout the energy sector; expand the fuel and technology choices available to the nation; improve US R&D; and support the international leadership role of the USA in developing energy, economic, security and environmental policy.

Because this paper focuses on the policy aspects of electricity and the environment, the discussion will centre initially on the goals and approaches established by the NES in the areas of energy and economic efficiency, future energy supplies and environmental quality enhancement. The remainder of the paper will consider how the DOE, through its power administrations, deals directly with the policy aspects of electricity and the environment, and how it applies some of the principles established in the NES. A case study approach will illustrate how these issues are addressed in the resource planning activities of an individual DOE power administration. The decision making process described is offered as a model for others who need a methodology for considering both environmental and electricity supply questions in planning directed towards meeting load demands.

## 2. THE NES AND ELECTRICITY GENERATION AND USE

The NES emphasizes that the electricity related portion of overall energy use in the USA is steadily increasing. By the year 2010, the DOE projects that 41% of the nation's primary energy will be used to generate electricity, up from 36% today. Accordingly, the NES recognizes the need to generate, distribute and consume electricity as cleanly and efficiently as possible and also forecasts substantial growth in domestic generating capacity [1]. About 700 000 MW of electric generating capacity are installed in the USA today. On the basis of gross national product projections and other economic indicators, the DOE estimates that the USA will need about 200 000 MW of additional generating capacity by 2010.[1] This forecast assumes that energy conservation and efficiency efforts will be pursued aggressively and that the existing capacity will be maintained adequately through refurbishment and replacement [1].

The NES also recognizes that electricity is the most heavily regulated industry in the US energy sector.[1] As such, the Federal–State regulatory regime that governs investment and operational decisions within this industry will influence profoundly which types of new supply- and demand-side resources are developed, who will develop them, what technologies and fuels will be used, and what the full consumer and environmental impacts will be. As will be discussed, the goals and approaches developed by the NES for electricity generation and use take into account specifically this Federal–State influence.

Policy issues of electricity and the environment are examined in three chapters of the NES. In the chapter entitled, ''Increasing Energy and Economic Efficiency'', initiatives are established in the area of electricity generation and use. In ''Securing Future Energy Supplies'', initiatives are proposed to enhance domestic use of coal and nuclear power; also specific legislative and regulatory proposals are introduced to increase electricity generation from renewable energy resources. The chapter, ''Enhancing Environmental Quality'' addresses the air quality, waste management, and water and land use issues associated with energy production as well as global environmental concerns.

## 3. GOALS AND APPROACHES TO NES POLICY AREAS

The NES establishes a series of goals and approaches to meeting the aim of each of the energy policy areas that it addresses. These areas are summarized in greater detail below.

### 3.1. Energy and economic efficiency

For electricity generation and use, the NES establishes two primary goals. The first goal is to encourage efficiency and flexibility in making electricity supply and

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[1] Remarks of L.G. Stuntz, Deputy Under-Secretary, Policy, Planning and Analysis, United States Department of Energy, before the American Public Power Association Board of Directors Reception and Luncheon, Washington, DC, 11 March 1991.

demand choices. The approach to meeting this goal is to promote revisions to Federal and State regulation of the electricity industry to permit more competition as well as more efficient productivity and use of electricity. The second NES goal in this area is to promote diversity of electricity technology and fuel choice by pursuing research, development and demonstration activities to improve performance of electric technologies and to make possible the use of clean, abundant domestic energy resources at competitive costs.

### 3.2. Future energy supplies

The NES also establishes goals and approaches for maintaining coal's competitiveness. About 55% of the nation's electricity is now produced from coal, and this percentage could increase in the decades ahead. As a result, the NES stresses new ways of producing, transporting and using coal that are both environmentally acceptable and economical. The primary NES goal in this area is to maintain coal's competitiveness while meeting environmental, health and safety requirements. The proposed approach to meeting this goal involves promoting development and demonstration of new coal related technologies and clarifying environmental requirements for refurbished generating units.

With regard to nuclear power, the NES focuses on removing existing barriers to nuclear energy production. Since about 20% of the US electricity is generated by nuclear power plants, nuclear fission is second only to coal as a source of electricity. The NES notes that nuclear power is a proven electricity generating technology that emits no sulphur dioxide, nitrogen oxides or greenhouse gases. In addition, nuclear power is a plus for US energy security because it does not rely on fuel whose supply is threatened by depletion or cut-off. To try to capture these benefits, the NES establishes the following four goals in the nuclear power area:

(a) Maintaining exacting safety and design standards
(b) Reducing economic risk
(c) Reducing regulatory risk
(d) Establishing an effective high level nuclear waste programme.

The approaches proposed to accomplish these goals include accelerating of the introduction of advanced nuclear power plant design as well as standard power plant design; reform of the United States Nuclear Regulatory Commission (NRC) licensing process; and the siting and licensing of a permanent waste repository as well as a monitored retrievable storage facility.

The NES also places emphasis on increasing renewable energy resources as a supply base for electricity generation and establishes several goals in this area. First, the NES calls for encouraging environmentally acceptable hydroelectric power through the following:

(1) Eliminating excessive regulatory barriers that add costs and risks to hydropower development
(2) Requiring a continuing review of existing hydropower projects to improve operation and maintenance and to identify improvements in efficiency that can be made economically.

The second goal of the NES in the renewables area is to reduce the costs of, and increase industry confidence in, selecting solar, wind, biomass and geothermal technologies to generate electric power. The approaches proposed in this area include the following:

(i) Increasing the funding for R&D related to renewable energy
(ii) Extending investment credits for solar and geothermal energy technologies and expanding these to wind and certain biomass technologies
(iii) Eliminating regulatory barriers to the development of renewable resources for electricity generation.

A third goal in the renewables area is to support the conversion of municipal solid waste to energy. Proposed approaches include increasing R&D on waste to energy systems as part of a comprehensive waste management programme providing better information on waste to energy systems.

### 3.3. Enhanced environmental quality

The NES places considerable emphasis on issues related to energy and the quality of air, land and water. The overall goal in this area is to improve environmental quality by implementing the proposed NES actions designed to increase energy efficiency and reduce energy demand so that the amount of future emissions is lowered and the use of natural gas, renewable energy, nuclear power, alternative transportation and clean coal technology is stimulated to reduce air, land and water quality impacts. The NES also establishes a goal to increase flexibility in meeting environmental requirements through a number of approaches, including:

(a) Improving analysis of energy impacts as part of rule making
(b) Expanding flexibility and use of market mechanisms, such as emissions trading, to reduce compliance costs
(c) Amending legislation and administrative programmes to allow more flexibility in control practices while maintaining environmental protection
(d) Providing more complete analysis of the environmental impact of competing technologies (total fuel cycle analysis)
(e) Ensuring that environmental concerns regarding emerging energy technologies are considered in advance.

With respect to global environmental issues, the NES establishes four important goals:

(1) Improve understanding of the emissions and processes that could change the global climate, the associated impacts and the possible control and mitigation measures associated with climate change
(2) Improve energy efficiency and effect a shift to energy sources and technologies that emit fewer greenhouse gases
(3) Co-operate with other countries to improve understanding of potential global climate change and its impact, and develop a consensus on appropriate responses
(4) Protect the stratospheric ozone layer through strengthening the current international agreement.

The approaches outlined to meet these goals include various research efforts, US participation in appropriate international panels and implementation of the strategic ozone protection provisions contained in the Clean Air Act Amendments of 1990.

In summary, the NES considers the range of institutional and regulatory barriers as well as intellectual and physical barriers preventing the best use of all US energy resources — supply and demand. As stated above, the implementation of the NES is a shared responsibility. To meet its challenges, the NES calls for action by Federal, State and local governments and by domestic and international energy producers and consumers. But the NES does not provide a detailed blueprint on how individual energy producers should go about meeting these challenges. Within the diversified US energy sector, there is a wide variety of approaches that can be taken. For purposes of this paper, the planning and decision making steps used by an individual electricity supplier are explored in greater detail below.

## 4. DECENTRALIZED DECISION MAKING IN THE ENERGY SUPPLY SECTOR

While the NES establishes a broad framework for national energy policy, as noted above, it emphasizes market reliance as the primary means to determine energy prices, quantities and technology choices. This is in response to the fact that most of the detailed decision making related to meeting energy demand is decentralized and largely carried out by the private sector. For example, the decisions to adopt a new energy technology developed through a DOE demonstration programme or to develop a strategy on where to drill for new oil and gas resources are generally made by private companies. Further, in the area of electricity supply and demand, decisions are generally made on a regional rather than on a national basis.

In the USA, both public and private electric utilities are concerned with meeting the demand for power in their service territories which, at most, cover several States. In addition, these decisions are made under the constraints of a variety of Federal, State, and local regulatory requirements. For example, every State has its own public utility commission which establishes its own requirements dictating how the customers' demand for electricity will be met. Therefore, no single nationwide methodology is used to address the environmental issues raised by the need to meet electricity demand.

## 5. DOE POWER ADMINISTRATIONS AND ELECTRICITY SUPPLY PLANNING

For the most part, the DOE is not in the energy supply business. However, among its many missions, the DOE is responsible for marketing Federally generated power and its power administrations are responsible for meeting electricity demands in their service territories, primarily in less populated areas. Like private utilities, these power administrations must develop load forecasts and resource plans, consider the range of resource types and supplies available to them (e.g. conservation, hydropower efficiency improvements, coal, geothermal, wind) and model their anticipated load growth under different scenarios to develop a flexible resource plan.

Unlike private utilities, the DOE power administrations are subject to the requirements of the National Environmental Policy Act (NEPA) and other laws aimed at Federally marketed power in developing their resource plans, and must integrate environmental protection goals into their overall planning. Consistent with NES goals, and as discussed in more detail below, the DOE power administrations have already begun to take steps consistent with the NES goal to provide a more complete analysis of the environmental impacts of competing technologies by developing total fuel cycle analyses as part of their resource planning. These decisions are even more critical in the light of another NES goal that calls for phasing out debt subsidies to power administrations so that they will begin to sell power at a price that covers the Federal Government's cost of providing it.

## 6. CASE STUDY: BONNEVILLE POWER ADMINISTRATION (BPA) AND THE BALANCING OF ENVIRONMENTAL AND ELECTRICITY SUPPLY CONCERNS

The BPA was created by the US Congress in 1937 to sell and deliver the power from the Bonneville and Grand Coulee dams. Today, it serves about 120 publicly owned utilities, municipalities and co-operatives as well as eight investor owned utilities, seven Federal agencies and fifteen 'direct service' industries, such as aluminium companies. The BPA service territory covers all of the States of Oregon, Washington and Idaho as well as Montana, (west of the Continental Divide) and some adjoining portions of Wyoming, Utah, Nevada and California. The area encompasses about 300 000 square miles[2] and has a population of about 9 million. The BPA system has the capacity to produce over 24 000 MW of power, primarily from hydroelectric and nuclear sources [2].

As noted earlier, the electric industry is the most regulated industry in the energy sector. The Pacific Northwest Electric Power Planning and Conservation Act of 1980 (also known as the Pacific Northwest Power Act) is one of the many legal requirements affecting the way the BPA does business. It requires that any combination of new generation and energy conservation sources that the BPA acquires must be determined to be cost effective. Moreover, the Act specifies that among equally cost effective power sources, a conservation source must be the BPA's highest priority, followed by renewable resources such as hydroelectricity, wind, solar, geothermal and biomass. Waste heat or generating resources of high fuel conversion efficiency, such as co-generation, is to be the BPA's third preference, followed by all other resources, such as nuclear or coal fired plants. In addition, the Act gives the BPA a new role in protecting the fish and wildlife in the Columbia River through measures mitigating damage to these natural resources caused by the construction and operation of Federal dams that generate power in the United States' Northwest. These regulations represent requirements unique to the BPA, and privately owned utilities generally face fewer prescriptive resource related mandates [2].

Every two years, the BPA prepares a Resource Program that communicates how it proposes to meet its obligations to serve the power requirements of its customers [3]. Alternatives are examined, which are composed of different combinations of energy resource types from the BPA resource stack (i.e. the list of resources, ordered generally by cost, that are forecast to be available to meet electric power needs). The BPA planning model relies on this resource stack to simulate regional resource acquisition and to serve as a basis for BPA planning decisions.

In developing its Resource Program, the BPA prepares five load forecasts to reflect the uncertainties it faces in predicting power demand. Next, a range of load/resource balances is prepared by comparing the capability of existing Federal system resources to the range of projected Federal system loads over the next 20 years. Then the BPA develops new resource supply forecasts to plan acquisition of cost effective resources to meet load growth and to assist programme design. Under the most recent medium forecast, the Federal system is now in load/resource balance with sufficient resources to meet BPA needs for the rest of the decade. However, the exact level of future loads is not known. If demand grows faster or if resources do not perform as expected, the BPA could face a deficit. Under high load growth, the BPA could require up to 5000 average MW to meet its load obligations during the planning horizon.

[2] 1 square mile = $2.590 \times 10^0$ km$^2$.

Also important in developing the BPA Resource Program is the element of public participation. Consistent with its responsibilities under the Pacific Northwest Power Act, the BPA made its draft Resource Program plan available to the public and held a series of public hearings. In addition, it published a comment summary that included BPA responses to the input from the public. As evidence of BPA responsiveness to public concern, on the basis of comments received a number of changes were incorporated into the final Resource Program. For example, the final document calls for a greater acquisition of conservation resources than had been planned originally. The BPA has made public participation a key element in its policies related to electricity and the environment [4].

## 7. FACTORING IN ENVIRONMENTAL CONSIDERATIONS AT THE BPA

As part of the DOE, the BPA is a Federal agency, and its actions are subject to certain requirements not always faced by utilities in the US private sector. For example, in the area of environmental policy, the NEPA asks each Federal agency to examine the major actions it has planned to determine if these actions could have significant effects on the quality of the human environment. If the answer is 'Yes', as with BPA's Resource Program, then the NEPA requires that the agency prepare an environmental impact statement (EIS) on its proposed action.

The purpose of the EIS is to ensure that a full consideration of potentially significant environmental impacts is incorporated into the overall project planning process. The EIS must address the significant environmental impact of the proposal and reasonable alternatives to it, any adverse environmental effects that cannot be avoided should the proposal be implemented. It must also consider the relationship between short term uses of man's environment and the maintenance and enhancement of long term productivity, as well as any irreversible or irretrievable commitments of resources that would be involved in the proposal should it be implemented. The EIS must also address the means to mitigate any adverse environmental impacts related to implementing the preferred alternative. Through such analyses, the EIS should inform decision makers and the public of reasonable alternatives that would avoid or minimize adverse impacts or enhance the quality of the human environment [5].

In contrast, privately owned utilities are not required to prepare an EIS on their resource plans. A private utility may address many of the same issues and concerns as does the BPA in developing its resource plan; however, it is *not* required under a law such as the NEPA to integrate environmental considerations into its planning process. Such a plant must obtain all requisite environmental permits (some of which require extensive media specific analyses); however, unless it builds on Federal land or requires certain Federal permits or rights of way, a privately owned electric utility is not required to prepare an EIS on the construction and operation of new capacity.

Thus, the NEPA affords Federal agencies a sometimes unique perspective on the environmental issues associated with planning to meet electricity demand. Further, the EIS is another mechanism that makes public participation an integral part of the planning process. As Federal planning decisions are being made, the public has opportunities for early and continuing involvement from providing input on the scope of issues that should be included in an EIS to attending hearings and comment periods on the draft document.

At the BPA and other DOE power administrations, the NEPA process is fully integrated into the overall resource planning. Environmental concerns are identified and analysed as part of all resource planning activities. By integrating the NEPA values into the overall planning process, consideration of environmental issues becomes inseparable from resource development decisions. The BPA is using its Resource Program Environmental Impact Statement (RPEIS) to ensure that it will be able to meet its loads in a cost effective and environmentally sound manner.[3] Unlike the Resource Programs that are prepared every 2 years, the RPEIS will cover 10–15 years; other, more specific EISs and environmental analyses may be prepared at a later time. The RPEIS will evaluate the environmental trade-offs among the various resource types in the stack and the impacts of adding these resources to the existing BPA system. It will analyse both quantifiable and non-quantifiable effects, including environmental 'externalities'. Consistent with the goals of the NES, this process will enable BPA to consider fuel cycle costs for the various resources it is considering.

In its RPEIS, the BPA approach will be to analyse three alternatives. The first is a 'no action' alternative where neither the BPA nor the region will meet the underlying need for electric energy to meet customers' load growth. The second alternative is a 'status quo' case where the BPA will continue doing business as usual — acquiring resources to meet load based on minimizing total system cost, without taking into account quantified *external* environmental costs and benefits. Under the status quo alternative, the resource types to be analysed are: conservation, hydropower efficiency improvements, transmission efficiency improvements, co-generation, geothermal, hydropower, solar, wind, coal, combustion turbines, fuel switching, nuclear and imports. For each scenario analysed by the BPA, regional supplies of each of these resource types will be forecast.

The third alternative is a 'base case' where the BPA will acquire resources from the resource stack to meet load based on minimizing total system cost, including quantified external costs. The base case will be the bench-mark against which

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[3] United States Department of Energy Memorandum, "Implementation Plan for Resource Programs Environmental Impact Statement", to J.J. Jura, Administrator, Bonneville Power Administration, from P.L. Ziemer, Assistant Secretary for Environment, Safety and Health, 28 March 1991.

all alternatives are compared. Several alternatives will be considered, each emphasizing a different available resource: coal, nuclear, conservation, renewables, co-generation, combustion turbines, fuel switching and energy imports. For example, when the conservation scenario is emphasized, both lost opportunity and discretionary conservation are placed at the top of the BPA resource stack. Two subalternatives will be modelled using the following:

(a) The current BPA regional resource supply forecast of conservation (2300 average MW) at the top of the stack

(b) An increased amount of conservation (3100 average MW) to reflect conservation measures forecast to become cost effective within the planning horizon.

Similarly, when the renewables case is emphasized, hydro, solar, wind and geothermal resources will be moved to the top of the stack and acquired first.[3]

Three BPA models will be used to assist in determining the environmental impact of additions to the existing system. The first model simulates resource decisions by acquiring resources in response to various load forecasts and ways of operating the power system. It then calculates costs, ensuing rates, and BPA revenue requirements and net cash flow resulting from different acquisition decisions. The next model will dispatch these resources, as necessary, in operating the BPA system to meet future load growth. The resulting operation will be evaluated to determine how resource additions might change the operation of the existing system and impact on air and water quality, cultural resources, recreation, land use and fish and wildlife. Finally, EPA approved atmospheric dispersion models will be used to calculate concentrations and exposures to pollution from fossil fuel fired generators. These results will be used to forecast effects on human health risks, crop and forest damage, visibility reduction and materials damage. These effects will be used in quantifying environmental externality costs.

In addition to the above, the RPEIS will focus on a range of specific issues with environmental implications, including global climate warming, polychlorinated-biphenyls (PCBs) in fluorescent light ballasts, indoor air quality in commercial buildings, Northwest Power Planning Council protected areas, and the resource acquisition process.

## 8. WEIGHING ENVIRONMENTAL COSTS AND BENEFITS AS PART OF ELECTRICITY SUPPLY PLANNING AT BPA

In addition to the environmental analysis required by NEPA, the BPA believes that incorporating environmental costs into resource planning is a prudent business practice and that by minimizing certain adverse risks one can avoid future costly activities [6]. It also believes that quantifying environmental costs will help improve its resource decision making. Environmental costs for the utility industry are the economic value of environmental risks not paid for directly by the utility or the utility's customers.[4] These costs are 'external' to the pricing system. Examples of such environmental costs include reduced visibility, adverse human health effects, reductions in crop and timber yields, acidification of lakes and streams, damage to materials and buildings and reductions in fish and wildlife populations. The focus of the BPA environmental cost estimates has been on the environmental effects associated with plant operations. These estimates have not reflected environmental costs associated with the entire fuel cycle. For example, BPA analyses do not include the environmental externality costs associated with fuel/materials production or spent fuel and waste disposal.[4]

The BPA is developing estimates of environmental externality values expressed as real levellized costs, taking into account pollutants such as sulphur dioxide, nitrogen oxides, carbon dioxide and particulates. To date, it has estimated that these costs are an average of 10 mill/kW·h for coal[5], 4 mill/kW·h for combined cycle combustion turbines, and lesser amounts for renewable resources.[4] The BPA environmental cost estimates are being developed in an open, public process with participation from representatives of investor owned and public utilities, state regulatory agencies, Federal agencies, independent power producers as well as and private citizens. The BPA will apply the environmental cost estimates it has derived (and others as they are developed) in its competitive resource acquisition programmes. These environmental cost adjustments will be added to the levellized system cost (along with other adjustments for capacity, seasonality etc.) to determine the cost effectiveness of each resource. The BPA will focus its efforts on effects where there is some meaningful economic cost to society from effects on the environment or risk to BPA ratepayers from future internalization of environmental effects [6]. By incorporating environmental costing into its overall resource acquisition planning, the BPA will be able to base its future decisions on a full accounting of all the costs associated with each resource acquisition decision it makes. As noted above, this approach is consistent with the fuel cycle analysis called for in the NES. In this manner, environmental protection values are never separated from other resource considerations in the BPA decision making process.

## 9. SUMMARY AND CONCLUSIONS

The NES establishes a new framework for energy supply planning within the USA that is designed to lay the foundation for a more efficient, less vulnerable, and

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[4] Bonneville Power Administration, United States Department of Energy Bonneville Power Administration Memorandum, "Environmental Cost and Benefits Briefing", 21 February 1991.

[5] mill = US $\$10^{-3}$ = 0.1¢.

environmentally sustainable future. Using market reliance as a keystone, US Government action under the NES will be aimed primarily at removing or overcoming barriers to efficient market operation. Thus, while the NES establishes a broad national energy policy blueprint by allowing markets to determine prices, quantities and technology choices, it leaves much of the implementation of its goals to the decisions made by the companies within the energy producing industry. With respect to electricity generation and use, the NES establishes two primary goals: to encourage efficiency and flexibility in electricity supply and demand choices and to promote diversity of electricity technology and fuel choices.

These two goals form the context in which the policy aspects of electricity and the environment must be considered. However, because the planning of electricity supply and demand in the USA is primarily accomplished on a regional basis, largely through the efforts of private companies, there is no single model within the USA for addressing these policy aspects.

The DOE, through its power administrations, supplies electricity to certain service territories. Prompted by laws such as the NEPA, the DOE has developed a planning process which integrates environmental issues into overall electricity supply and demand decision making, as evidenced by the efforts of the BPA. This paper has summarized the BPA resource planning process and its methodology for capturing and accounting for environmental externalities. This process is offered as a model for use by others who have the responsibility to ensure that environmental protection values are considered fully in planning to meet electricity demand.

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**Invited Paper**

# ELECTRICITY AND ENVIRONMENT
## *Policy aspects in developing countries*

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**Abstract**

ELECTRICITY AND ENVIRONMENT: POLICY ASPECTS IN DEVELOPING COUNTRIES.

Energy is an essential prerequisite for the economic growth of developing countries and in particular electricity has a steadily expanding share of the energy spectrum. While there is awareness in the developing world of the environmental consequences of power generation, sustaining an adequate power supply with minimum damage to the environment poses a serious challenge to the low income countries of South Asia. Power development in India has been rapid and has depended mainly on the potential of coal and hydro. Renewable energy technologies do not, as yet, make a substantial contribution on account of both technical and commercial limitations. A considerable amount of R&D effort directed at these technologies is, however, under way. The legislative framework and institutional mechanisms for environmental management have been established in India. While necessary safeguards are being provided in new projects, retrofitting in the old projects is making slow progress. However, demand management and energy conservation are now receiving high priority in the Indian power programme. The development of environmentally more benign coal technologies is also being attempted. Every country has to aim at maximum energy self-reliance and given the imperative to alleviate poverty, a country like India cannot compromise its economic growth and development objectives. There are also acute problems in regard to both domestic resources and foreign exchange reserves. These severely constrain the space for manoeuvring in the energy strategy. Nevertheless, developing countries must initiate positive action to control the growth of demand, to use energy efficiently and to integrate energy planning with overall national economic planning. International aid is also needed, especially as many of the environmental problems are global in character.

## 1. NEED FOR ELECTRICITY

On account of the close relationship between the demand for energy and the development process, the energy requirements of developing countries such as India are increasing at a faster rate than those requirements of developed countries. Energy has a dual function; it is a factor of production in agriculture and industry, whereas in the household sector, it functions as a consumer good and an input to the quality of life. However, because of continuous technological improvement, the energy–

Gross Domestic Product (GDP) elasticity has been declining over time. Especially in the last 15 years since the oil price increase of 1973, structural changes in the economy and concerted technical effort to improve efficiency of energy use have reduced the elasticity to less than unity in advanced industrial countries. But, the nexus between the two is still strong in developing countries. The high rate of population growth itself contributes to increased energy demand. The increase in the GDP has to come mainly from the widening of the agricultural, industrial and transport sectors of the economy, which are relatively energy intensive. Besides, there is a steady process of substituting traditional sources, namely fuel wood, animal dung and crop residues, with modern fuels such as oil, coal and electricity. Developing countries therefore face the challenge of having to provide increasingly large energy supplies to sustain their economic development. As the Brundtland Report has stated, "A safe and sustainable energy pathway is crucial to sustainable development; we have not yet found it" [1].

Whether in industrialized or developing countries, electricity commands a steadily expanding share of the energy spectrum. Being low entropy energy which can be used with high efficiency, it is replacing less efficient fuels. The ease with which it can be transported over long distances and the wide range of its applications make electricity the preferred fuel in many areas of consumption. Electricity is also amenable to generation from several renewable and non-renewable sources. In industry, the use of electricity has made possible the development of new cost effective energy efficient technologies. This phenomenon of the increasing importance of electricity in the energy economy is visible in developing countries also.

As the role of electricity has grown more ubiquitous, there is a growing awareness that the conventional technologies for electricity generation give rise to varied environmental problems, some of which impact on the immediate neighbourhood, while others affect wider areas. Such awareness is fairly widespread in India, which has a large well informed segment of the population. But in seeking solutions as to how the need for augmenting electricity supply can be reconciled best with environmental protection, we should appreciate that all developing countries cannot be placed in one basket. In the first place, the 'developing' category encompasses a large income range. Secondly, oil rich countries are relatively well placed in charting their growth strategies and in making technology choices. Their oil importing counterparts are in a much more difficult position. Even within this subcategory, the energy resource endowments differ from country to country. Thus the low income overpopulated countries of South Asia face formidable problems in providing adequate energy supplies to sustain their economic development.

## 2. PRESENT STATUS OF POWER DEVELOPMENT IN INDIA

When India attained independence in 1947 there was only a skeleton of a power supply industry. The total installed generation capacity in the entire country was

TABLE I. GROWTH OF INSTALLED CAPACITY IN UTILITIES

| Plan period | Total capacity addition (MW) | Installed capacity at the end of Plan period (MW) | | | |
|---|---|---|---|---|---|
| | | Hydro | Thermal | Nuclear | Total |
| First Plan (1951-1956) | 1 100 | 940 | 1 755 | — | 2 695 |
| Second Plan (1956-1961) | 2 250 | 1 917 | 2 736 | — | 4 653 |
| Third Plan (1961-1966) | 4 520 | 4 124 | 4 903 | — | 9 027 |
| Fourth Plan (1969-1974) | 4 579 | 6 964 | 9 059 | 640 | 16 663 |
| Fifth Plan (1974-1979) | 10 202 | 10 833 | 15 207 | 640 | 26 680 |
| Sixth Plan (1980-1985) | 14 226 | 14 460 | 27 030 | 1095 | 42 585 |
| Seventh Plan (1985-1990) | 22 310 | 18 566 | 44 598 | 1565 | 64 729 |

TABLE II. DEMAND MET DURING VARIOUS PLAN PERIODS [2]

| End of Plan | Actual demand met | | Annual compound growth rate during Plan | |
|---|---|---|---|---|
| | (MW) | (million kW·h) | Peak (%) | Energy (%) |
| 1st (1955-1956) | 1 683 | 8 270 | — | — |
| 2nd (1960-1961) | 3 312 | 16 385 | 14.5 | 14.7 |
| 3rd (1965-1966) | 5 605 | 30 540 | 11.1 | 13.3 |
| 4th (1973-1974) | 11 408 | 64 052 | 7.3 | 7.3 |
| 5th (1978-1979) | 17 028 | 96 652 | 8.3 | 8.6 |
| 6th (1984-1985) | 24 971 | 145 296 | 6.7 | 7.0 |
| 7th (1989-1990) | 37 380 | 231 861 | 8.4 | 9.8 |

TABLE III. SECTORAL CONSUMPTION OF ELECTRICITY (1987–1988) [3]

| Sector | Percentage of consumption |
|---|---|
| Household | 13.00 |
| Agricultural | 18.95 |
| Industrial | 56.49 |
| Transport | 2.21 |
| Others | 9.35 |
| Total | 100.00 |

hardly about 1360 MW and the supply was mostly confined to large towns and cities. Since then there has been a vast expansion of the power system, with a distribution network spread across the country and touching 85% of India's 550 000 villages [2]. Tables I and II give an idea of the growth of installed capacity and energy generation. Impressive as these figures are, in relation to the country's population of about 840 million, the per capita consumption of electricity is quite low (a little over 200 kW·h/a). But, significantly, the growth rates have remained consistently high.

The sectoral consumption of electricity may be seen in Table III. Unlike advanced industrialized countries where domestic consumption is high, in India the industry sector accounts for the largest share of electricity consumption [3]. While Indian agriculture still depends mainly on animal energy, electricity for irrigation pumping has shown rapid growth and there are over eight million electrically operated pump sets. The extension of irrigation through the use of such pump sets has been established clearly as a contributory factor in the country's increased crop production.

The pattern of growth of electricity generation in India has naturally been determined by the available energy resources. India is relatively well endowed in hydropower potential and there are substantial reserves of coal. The total hydro potential is estimated to be of the order of 600 TW·h of firm annual energy, which is equivalent to 125 000 MW of firm power at 40% load factor. Of this, only about 21% is currently being trapped. According to the latest assessment data, coal reserves in India are of the order of 180 000 Mt. It is therefore natural that coal fired thermal power and hydropower account for the overwhelming bulk of energy generation in the country.

Some resources necessary for nuclear power are available in India. The total reserves of uranium are estimated at 70 000 t, an amount sufficient for only 10 000 MW of generation in conventional reactors. But, there are thorium reserves

(363 000 t) which may be utilized eventually in breeder reactors and therefore are of special significance in meeting the country's long term energy requirements.

India has only limited hydrocarbon resources; as of 1 January 1990, the balance of recoverable reserves were 757 Mt of crude oil and 686 billion ($10^9$) $m^3$ of natural gas. As a matter of policy, the use of oil for power generation has been discouraged for the last several years. The exploitation of natural gas is relatively recent and, with increased availability, gas based power generation has started in a limited way in the country.

As would be apparent from the data presented in Table I, renewable resources of energy do not as yet appear in the picture. This situation is, of course, not peculiar to India. Leaving aside futuristic possibilities (such as fuel cell and hydrogen) and technologies for which there is limited potential (such as geothermal and tidal), electricity generation through direct exploitation of solar (thermal and photovoltaic routes), wind and biomass energy are of interest to India. These technologies offer several advantages; they can be located close to the areas of consumption, thereby reducing distribution losses, they have a relatively short gestation period, the maintenance requirements are not demanding, capacities can be built up in a modular fashion and they are generally more environment friendly than conventional large scale technologies. In spite of these favourable factors, their market penetration has not been substantial for the following reasons:

(a) New technologies cannot cater to large or bulk requirements. In India, urban and industrial loads account for 70% of electricity consumption. Such loads would have to be catered to by conventional large scale power generation.

(b) In the case of grid supply of power, the capital investment right up to the point of consumption is made from the public exchequer. However, the investment in the decentralized energy supply device has to be made by the private individual, even though society benefits in the process. To some extent, the gap between the economic and financial returns can be bridged by subsidies, but the inherent difficulty remains, particularly as the new technologies are characterized by high capital cost (though maintenance costs are low).

(c) There are some technical limitations also. If a decentralized electricity source operates in the stand alone mode, the reliability of supply will be low and the capacity utilization will remain poor. Solar energy and wind energy based devices may require a backup system because of the variability of the primary source. This will make the system quite expensive. Nevertheless, if the decentralized sources are linked with the grid, maintenance of grid stability will pose problems when the proportion of aggregate decentralized capacity becomes significant.

(d) As decentralized sources, the new technologies should find ready application in rural areas. But, at present they are relatively expensive and beyond the reach of most sections of the rural community.

(e) Technologies such as solar thermal and wood based power generation are land intensive. The common property resources in the rural areas have traditionally provided support to the poor through the provision of fuel and fodder free of cost. Even as it is, because of the growing pressure of population, encroachment by powerful landlords, etc., there has been a steady erosion of such resources, thereby aggravating the problems of the poor. To deprive the poor of what little is left to generate electricity to be consumed by the affluent sections of the village community is clearly not desirable.

It is, however, recognized that from the long term perspective, it is essential to develop new technologies which have potential in the local context. The economics of new systems vis a vis the conventional technologies are also bound to improve over time. In recent years, considerable effort has gone into research, development and demonstration of solar thermal and solar voltaic devices for various applications. A national demonstration project on wind energy is in operation in India. The viability of biogas technology for meeting domestic cooking energy needs has been established and over a million family owned plants have been installed. The prospects of using the new technologies for meeting heat and mechanical energy requirements are encouraging and as these constitute the bulk of rural energy requirements, the efforts in this direction are being accelerated. But, as far as electricity generation is concerned, viewed from the macroangle, the prospects do not appear promising.

## 3. MEASURES FOR ENVIRONMENTAL PROTECTION

Environmental conservation has to be the collective responsibility of the society as a whole. Nevertheless regulatory intervention by government is necessary to ensure compliance with prescribed pollution limits and to lay down procedures for prior examination of the environmental consequences of new developmental activities. Indeed, the Constitution of India enjoins upon the Indian Government and all the citizens to protect and improve the environment. The following statutes have been enacted in India for purposes of environmental management:

- Wildlife Protection Act, 1972
- Water (Prevention and Control of Pollution) Act, 1974, with amendments in 1988
- Air (Prevention and Control of Pollution) Act, 1981, with amendments in 1987
- Forest (Conservation) Act, 1980, with amendments in 1988
- Environment (Protection) Act, 1986
- Mines and Minerals (Regulation and Development) Act, 1957, with amendments in 1986.

TABLE IV. MINIMUM NATIONAL STANDARDS FOR THERMAL POWER STATIONS [4]

| Parameters | Maximum limiting concentration |
|---|---|
| **Condenser cooling water** (once through cooling system) | |
| pH | 6.5–8.5 |
| Temperature | Not more than 5°C higher than the intake water temperature |
| Free available chlorine | 0.5 mg/L |
| **Boiler blowdown** | |
| Suspended solids | 100.0 mg/L |
| Oil and grease | 20.0 mg/L |
| Copper (total) | 1.0 mg/L |
| Iron (total) | 1.0 mg/L |
| **Cooling tower blowdown** | |
| Free available chlorine | 0.5 mg/L |
| Zinc | 1.0 mg/L |
| Chromium (total) | 0.2 mg/L |
| Phosphate | 5.0 mg/L |
| Other corrosion inhibiting materials | Limit to be established on case by case basis |
| **Ash pond effluent** | |
| pH | 6.5–8.5, preferably greater than 7.0 |
| Suspended solids | 100.0 mg/L |
| Oil and grease | 20.0 mg/L |
| No limits for heavy metals given for the present | |

Under the provisions of these statutes, minimum national standards have been set for various activities. The standards for water pollution prescribed for thermal power stations are shown in Table IV. As regards air pollution, a limit of 150 mg per normal $m^3$ has been determined for particulate emission from large power stations [4]. Sulphur dioxide emission standards, based on pollution control equipment in thermal power plants, have not been enacted because of the low sulphur content of Indian coal (less than 1% by weight) and the small size of thermal power plants set up in the past. Since 1984, stack height requirements have been set for

TABLE V. STACK HEIGHT IN THERMAL POWER STATIONS [4]

| Boiler capacity (MW) | Stack height (m) |
|---|---|
| 200 < 500 | 220 |
| 500 and more | 275 |
| <200 | $H = 14\ Q^{0.3}$ [a] |

[a] H = stack height measured in metres; Q = sulphur dioxide emission measured in kilograms per hour.

proper dispersion of the oxides of sulphur and nitrogen. The stack heights prescribed for different boiler capacities can be seen in Table V [4].

In certain areas where a large installed capacity of thermal generation is planned, installation of flue gas desulphurization (FGD) is being insisted upon to lower the level of sulphur dioxide [5]. In a 500 MW unit at Bombay, an FGD plant of 25% capacity using sea water has been installed.

The problem of dealing with greenhouse gases is more difficult. According to one estimate, out of the total global carbon emissions, the burning of fossil fuels in developing countries accounts for 19%, of which India's share may be 2.2% [5]. This amount is not large and only reflects India's low share in the world's total power generation. As future development in India will be largely coal based, there is bound to be a corresponding increase in the generation of carbon dioxide. To what extent the proportion of thermal power generation can itself be limited and to what extent technologies which may avoid or reduce carbon dioxide production can be adopted are discussed later. It may not be inappropriate to recall here the Declaration adopted at the Noordwijk Conference on Atmospheric Pollution and Climatic Change in 1989 [6], which called for:

(a) Industrial countries, which are mainly responsible for greenhouse gas emissions, to take the lead in terms of domestic action
(b) Recognition that targets for emission reduction by developing countries not compromise the economic growth and objectives of these countries
(c) Priority to be given to actions, such as energy conservation, that are also clearly justified on the basis of economic criteria [7].

Apart from setting legal standards for air and water pollution, procedures have been established for environmental impact assessment of new projects. As power generation in India is almost wholly in the hands of the Union and the State Governments, environmental clearance has been made a mandatory prerequisite for investment approval. Apart from satisfying the local statutory authorities regarding projected arrangements for keeping air and water pollution within permitted limits, the environmental clearance procedure covers wider aspects such as impact on soil and water, land use, health, tourism, fauna; also included in the procedure are arrangements for rehabilitation of families which may be displaced by the project and treatment of catchment areas (in the case of hydro projects) etc. If the project involves loss of any forest area, additional statutory approval by the National Government is necessary. Applications for environmental clearance are examined by the Environmental Appraisal Committees constituted by the National Ministry of Environment and Forests. Vigilance is also maintained by voluntary groups composed often of persons affected by environmental pollution, who highlight the adverse ecological consequences of the new project. Seeking judicial intervention in such matters is also not uncommon.

All the nuclear power stations in India are federally owned through the Nuclear Power Corporation and function under the overall control of the Indian Atomic Energy Commission. The Commission has set up the Atomic Energy Regulatory Board which is entrusted with the responsibility of maintaining requisite safety standards in the nuclear power industry. The Board has three main objectives:

(1) Preparation of safety codes, guides and standards as well as technical regulations relating to nuclear and radiation safety
(2) Supervision of the authorization process and specifications for each basic nuclear facility and granting of authorization at different stages, namely site evaluation, construction, operation, final shutdown and decommissioning
(3) Surveillance of facilities both in construction and in operation.

Passing of the necessary statutes and establishment of institutional mechanisms for environmental assessment do not mean, however, that the environmental issues connected with power projects have been resolved satisfactorily in India. Barring projects taken up during the last 10 years or less, the older projects were built at a time when environmental considerations did not figure prominently in project design. What we now see from hindsight as mistakes or omissions in hydro projects would generally not be amenable to corrective action at this stage. In the thermal power projects, there is scope for retrofitting pollution control equipment. In this case, the approach is to give reasonable time for installing necessary equipment. As of 1990, out of 65 thermal power plants located in India (excluding 3 closed plants), only 21 plants met fully the requirements of the regulations. There was partial compliance in 20 cases [8]. The situation with regard to water pollution was even more unsatisfactory. Given the high ash content in Indian coals, the accumulation of fly ash in a thermal power station reaches large proportions, requiring huge amounts of land for storage, thereby creating underground and surface water pollution. Efforts being made to use fly ash for making bricks and other construction materials have not met with encouraging results so far. In the case of nuclear power stations, there is a widely held view that the regulatory authority should be completely outside the umbrella of the Atomic Energy Commission.

## 4. IMMEDIATE PERSPECTIVE

As stated earlier, coal and hydropower will continue to be the main sources of electricity in India during the next 20–30 years, supplemented by nuclear and gas based power generation. Between thermal and hydropower generation, the former is growing at a faster rate. New hydro projects run into strong opposition, as they invariably involve loss of forest area (which is already low in India) and involuntary resettlement of large numbers of families. Within the next 30 years, it is hoped that the renewable energy technologies will be in a position to provide a sizeable proportion of the electricity requirement.

In the past, attention has been concentrated almost wholly on augmenting supply. However, the high capital intensity of the power sector and the scarcity of capital for investment have highlighted the need for equal attention to be paid to demand management and energy conservation. Admittedly, India's performance in this area has been weak and halting. Raising the efficiency of existing power stations is now considered as a matter of first priority. One of the tasks of the newly created financial institution, the Power Finance Corporation, is to encourage balancing investments for improving plant availability. It is also recognized that more systematic action is needed for flattening the load curve which requires modifications in the electricity tariff so as to differentiate between peak and off-peak hours. Reduction of system losses, integration of power stations into regional grids and the encouragement of co-generation have been identified as other measures to be taken by the utilities. At the consumer end of the conservation issue, fiscal concessions announced by the Indian Government and the availability of soft loans from financial institutions for energy saving equipment are expected to minimize inefficient use of electricity. Moderation in the growth of electricity demand will, besides reducing the requirement of investment capital, partially ease the environmental problems.

Since coal will be the main source of primary energy in the coming years, action has been initiated to develop environmentally more benign coal technologies. The directions in which this effort is being attempted are as follows:

(i) Cost effective technologies of beneficiation of coal are under development. Improved performance of power stations because of availability of a better grade of coal, reduction in emissions and saving in transportation costs are seen as the benefits.

(ii) A pilot project to examine the suitability of Indian coals for slurry transportation is under construction. If this proves successful, it would have both technical and enviromental advantages.

(iii) A few fluidized bed combustion boilers have been installed. Presently because of their limited size, they are suitable for captive power generation. Some R&D work is in progress to explore the possibility of widening their use.

(iv) An experts group has examined the feasibility of establishing a combined cycle power plant based on coal gasification. The technoeconomic suitability of Indian coals having high ash and high ash fusion temperature is to be established.

(v) An experimental 5 MW magnetohydrodynamics plant has been commissioned. The operational parameters and design improvements are being studied.

In case there is a breakthrough in the design of a viable gasification combined cycle plant, it will be possible to secure a double benefit improvement of thermal efficiency and reduction in the environmental emissions. Beneficiation of power grades of coal would be another major step in controlling the problems associated with ash disposal.

It is only in recent years that organizations vested with the responsibility for monitoring the environment have arisen in India; the same situation applies to the involvement of universities and research organizations in environmental studies. Systematic collection of relevant data is only just getting started. It will take some time before a clear picture is established regarding the movement of wastes and the influence of seasonal air currents.

## 5. FINANCIAL IMPACT OF ENVIRONMENTAL MEASURES

It is now accepted that for any new project the cost of environmental protection should be regarded as an integral component of the project cost. As universally recognized, there are still some problems in the methodology of estimating in financial terms the cost of 'externalities'. However, to the extent possible, all quantifiable elements are being taken into account. Recent experience indicates that in hydroelectric projects involving storage of water, the cost of compensatory afforestation and a well conceived programme of settling those members of the population who suffer involuntary displacement can add as much as 20% to the capital cost of the project [9]. There is still an unresolved issue pertaining to the treatment of the catchment. Such treatment has multiple benefits and the extent to which the cost of the treatment should be allocated to the power project remains a matter of debate.

On the issue of making FGD equipment mandatory in new large power projects, there is a sharp division of opinion. As most Indian coals have low sulphur content and in relation to the country's area, the scale of power generation in India is low, there is an opinion that dispersion of emission of oxides of sulphur, by having stacks of a sufficient height, is adequate and that to increase the capital cost by about 25% to incorporate FGD equipment is not justified. Where there is a concentration of power plants or a large plant, such equipment may eventually have to be made mandatory.

## 6. POLICY ASPECTS

The concept of sustainable development is relatively recent. Even in industrially advanced countries where the per capita draw on global natural resources and the contribution to environmental degradation have remained high, determined remedial action is not yet visible. It should therefore not be surprising that in developing countries where the per capita consumption levels are low, environmental concerns appear to be muted. It is not that the people in these countries are less protective of their natural heritage. Indeed, in most of these countries, the economic pattern and social customs still display strong ties to nature. But, in attempting to balance between the imperatives of development and the unquestioned need for environmental preservation, these people face formidable problems involving certain basic considerations:

(1) International oil developments in the last two decades have clearly established that energy self-reliance has to be a major goal of a country's energy policy. With their fragile economies, oil importing developing countries do not have the strength to withstand repeated oil crises. Most of these nations have serious balance of payment difficulties and some are in deep debt. To minimize dependence on imported energy, every country will have to exploit its own energy resource endowments to the maximum extent. Thus, the extent of indigenous endowments and the outlook on the balance of payments will determine the choice of technologies for power generation. Stated differently, for most developing countries, the fuel switching options would be limited. Within the framework set by the two major factors mentioned above, the environmental aspects will have to be taken into account and every effort made to minimize the adverse impact.

(2) Per capita consumption of energy has to go up in low income developing countries in order to raise the low levels of productivity and income and to improve the quality of life for large segments of the population. Poverty alleviation has to be at the heart of the development effort. Provision for the basic human needs of safe drinking water, elementary education, health care and shelter has to be accorded high priority. If the economic conditions in low income countries do not improve and if the disparities widen even further, the political stability in these countries will be impaired.

(3) It is generally agreed that the combination of pervasive poverty and high population pressure is the most important contributing factor to the degradation of the environment in countries such as India. Viewed from the angle of environmental deterioration, power generation and industrial growth could be regarded as of secondary importance. Alleviation of poverty and control of population growth, linked as they are with the total developmental process and deep cultural factors, will take considerable time.

(4) Low income developing countries face the perennial problem of lack of capital resources. Given the many demands on available resources and the economic realities facing the country, it is not easy for the leadership to achieve a finely tuned balance between short term and long term goals.

(5) Developing countries depend largely on industrialized nations' technologies, which are not always available to them on favourable terms. If developing nations have to pay well above cost for environmental protection technologies, the adoption of these methods will be delayed further.

This is not to suggest that the developing world should absolve itself of any responsibility to minimize the deterioration of the global environment. What needs to be emphasized is that their capabilities are severely constrained by a variety of factors. These constraints notwithstanding, the energy policy framed by a developing country should encompass the following:

(a) Demand management and energy conservation should receive high priority. There is ample evidence to show that in all sectors of the economy, there is scope for energy conservation. There should be well designed incentives to encourage the adoption of energy efficient technologies. To the extent possible, the development strategy itself should be designed to contain the growth in future energy requirements. Both demand management and energy conservation require rational tariff policies.

(b) Within the constraints imposed by the indigenous availability of energy resources and the capacity to import energy, there has to be an optimal mix of generation technologies. In order to arrive at such an optimal situation, one should evaluate the costs of each available option, taking into account also the environmental costs.

(c) The energy policy of a country cannot be divorced from its overall development strategy; the two interact closely with each other. The process of development makes new demands of energy, and the availability of energy influences the direction and content of development. In India, where the country's development has been regulated under successive five year plans, it has always been accepted that energy planning should be fully incorporated into the process of national economic planning. Though it has not been possible to maintain a match between availability and requirement, this attitude has undoubtedly helped the country to maintain some coherence in its energy policy.

In recent years, efforts have been made to forge global policies to combat environmental problems. While some headway has been made in regard to control of chlorofluorocarbons, the greenhouse problem is proving more intractable. Clearly there is a need for international aid to developing countries to enable them to cope with the environmental challenges. In the last 15 years, there has been a marked worsening of the international aid situation. The credibility of international action has to be fully established in the perception of developing countries, if effective results are to be achieved.

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**Invited Paper**

# POLICY ASPECTS OF ELECTRICITY AND THE ENVIRONMENT IN THE EUROPEAN COMMUNITY

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**Abstract**

POLICY ASPECTS OF ELECTRICITY AND THE ENVIRONMENT IN THE EUROPEAN COMMUNITY.

The paper provides a comprehensive survey of the activities of the European Community as it aims to reconcile electricity demand, which continues to increase, with the protection of health and the environment. The option of adding economic and fiscal instruments to the more traditional command and control measures is mentioned specifically.

## 1. EUROPEAN COMMUNITY TREATIES

The European Community has been established under a succession of Treaties, ranging from the establishment of the European Coal and Steel Community in 1951 to the founding of the European Atomic Energy Community and the European Economic Community in 1957. This latter Treaty, the central feature of the Community, established common approaches to, amongst other activities, the free movement of goods, persons, services and capital, as well as agriculture, transport competition, economic and social policies.

It is important to note that the Treaties provide extensive legal powers to enforce both the rules of the Treaties and the measures decided upon by the Member State Governments in Council under the provisions of the Treaties.

Perhaps reflecting the development of political priorities, the issue of the environment was not mentioned until the latest revision of the European Economic Community Treaty in 1985 (the Single Act). Energy policy is still not specifically mentioned in that Treaty, leaving aside, of course, the two sectoral Treaties just mentioned.

The following Community objectives for environmental policy are therefore now inscribed in Article 130r of the European Economic Community Treaty of 1958:

(i) To preserve, protect and improve the quality of the environment
(ii) To contribute towards protecting human health
(iii) To ensure prudent and rational utilization of natural resources

The Article goes on to note that action relating to the environment should be based on the principles that preventive actions should be taken, damage should be rectified, wherever possible at the source, and the polluter should pay. Especially significant is the requirement that environmental protection should be a component of the Community's other policies, including, of course, its energy policy. Furthermore, the Community and the Member States will co-operate with countries which are not Community members and with relevant international organizations in environmental matters.

Thus the Community's environmental policy objectives and means of action are clearly established. In the energy sector, although similar specific mention of objectives is not made in the Treaty, it does provide the means for actions to be taken.

## 2. ELECTRICITY PRODUCTION IN THE COMMUNITY

What, then, are the characteristics of the electricity sector in the Community? Primary energy use for electricity production accounts for over one-third of total primary energy requirements. Electricity demand, amounting to 1700 TW·h in 1990, has increased by an average of 2.9% per year over the last five years and it seems likely that this rate of increase will be sustained, at least in the medium term.

The structure of electricity production varies widely between the Member States. For the Community as a whole, in 1990, 9.5% of electricity production was from hydro sources, 34.7% from nuclear and 55.5% from conventional thermal. The majority of the production from conventional thermal sources was from hard coal, amounting to 31% of the total production, 7.0% from lignite, 8.5% from oil, 6.0% from natural gas and the remainder from other sources.

The Community has imposed only two limitations on the fuels which may be used for electricity production. These were in the form of two Directives, adopted in 1975 after the first oil crisis, limiting the use of oil and natural gas, respectively, in power stations. The Directive limiting the use of natural gas was revoked in early 1991, following a review of the supply position of natural gas and in the interests of the contribution of natural gas to limiting undesirable atmospheric emissions. This action could signal an increase in the use of natural gas for electricity production.

It is clear that, given the differing structures of electricity production in the various Member States, Community environmental protection measures have differing consequences in terms of both overall effects on the environment and on electricity production costs.

## 3. ACID EMISSIONS

The first wide ranging issue of continental concern arose in the late 1970s and was linked to the acidification of precipitation, which caused widespread damage in natural ecosystems (lakes, forests, crops) and in man-made structures (corrosion of monuments, building materials).

Acid emissions from fossil fuel burning ($SO_2$, $NO_x$) were identified as the main cause of this damage and legal measures have been taken since to limit such emissions from major sources including power plants, industrial boilers, domestic heating appliances and road traffic. 'End of pipe' solutions, which are available or in the process of being developed, allow for the reduction of $SO_2$ and $NO_x$ emissions before, during or after combustion. These techniques act on the sulphur content of certain fuels, on the combustion technology itself (fluidized beds, low $NO_x$ burners, etc.) or treat the flue gases after combustion (flue gas desulphurization, catalytic converters for power plants and motor vehicles).

To a lesser extent, the successive Community programmes on the rational use of energy also brought about some relief in the rate of acid emissions as well as that of $CO_2$ emissions. Thus, better performing car engines, household appliances with less (electric) energy consumption and modifications of industrial production processes allowed a steady increase in performance and comfort without using proportionally more energy and creating more air pollution.

Despite this promising beginning, much more needs to be and can be done in the field of energy economy which, in the absence of efficient $CO_2$ abatement technologies, has been identified as the currently most promising route towards stabilizing and curbing emissions of $CO_2$ and other greenhouse gases in the Community nations and in other industrialized countries.

The acid rain issue gave birth to the 1979 Convention on Long Range Transboundary Air Pollution, signed under the auspices of the United Nations Economic Commission for Europe and to which the Community as such is a Party together with all its Member States.

## 4. COMMUNITY PROTOCOLS

Successive Protocols have been added to the Convention, establishing specific obligations to reduce by at least 30% total national sulphur emissions or their transboundary fluxes (Helsinki Protocol, 1985) and to stabilize total national $NO_x$ emissions or their transboundary fluxes (Sofia Protocol, 1988) by given dates. The latter Protocol also requires the application of national emission standards to major new stationary and mobile sources and source categories on the basis of the best available technologies which are economically feasible. The Protocol also makes it obligatory to introduce control measures for major existing stationary sources.

The Community has taken its own internal legal steps to limit and reduce $SO_2$ and $NO_x$ emissions from the major sources burning fossil fuels, but at a somewhat different rate so that the target date of the $SO_2$ Protocol could not be met (Directive 88/609 on large combustion installations will achieve the 30% overall reduction rate but at the beginning of the next century only). Moreover Community legislation in the field of emissions control for new installations is based on the principle of using the best available technology which does not entail excessive cost and on the obligation to retrofit major existing stationary plants to those standards when necessary.

The measures concerning large combustion installations relate principally to power stations. New installations and retrofitting of flue gas desulphurization equipment involve both capital and operational costs and reduction in transformation efficiency. These factors change the economics of electricity production and tend to favour the use of less polluting fuels, such as natural gas.

Work is in progress, at the request of the French Government, to further limit in the Community the total sulphur emissions from the production and use of liquid fuels throughout the whole chain of processes, including the refinery operation itself and also the treatment of heavy residues.

With the recent decisions of the Council of Ministers strengthening substantially the control of $NO_x$ (and other) emissions from all new motor vehicles (passengers cars and lorries) being marketed within the Community, the Community will be in a position to join the above mentioned Sofia Protocol on the stabilization of total $NO_x$ emissions by 1994.

Thus, following the initiatives of successive Environment Programmes, the Community has put in place legal requirements for both air quality standards and emission standards. These demonstrate the ongoing nature of the Community's approach to the protection of the environment and also the progressive impact of environmental concerns on the electricity sector.

The results of these and future legal actions, which aim at further control of emissions into air, water and soil from specific industrial sectors, will help the Community to play an active role in the formulation of the next steps of the Protocols mentioned above. These would be based on a target oriented view called 'critical load approach'. The same view is taken for another Protocol in progress on volatile organic compounds emissions.

## 5. CLIMATE CHANGE

It is now appropriate to discuss the new challenge the Community and the world are facing — the greenhouse effect and the possibility of climate change.

This is not the place to engage in a scientific presentation or in a discussion on the extent of scientific proof of possible climate change. It is well known that major uncertainties continue to exist. Nevertheless, the Intergovernmental Panel on Climate Change, the largest group of scientists ever to have worked on global warming, did conclude that "the greenhouse effect is real: infra-red absorbing gases in the atmosphere make the surface of the Earth warmer than it would otherwise be" [1]. The emissions of these gases are forecast to increase at a rate faster than previously thought. So it is accepted that the danger is great enough to develop some countermeasures.

As regards $CO_2$ emissions, which are presently thought to be responsible for slightly more than 50% of the greenhouse effect, the situation is very complex. Firstly, there are no economical abatement technologies available, therefore the amount of $CO_2$ emissions in the Community will be a direct result of fossil fuel use. Secondly, the greenhouse effect is a global problem which cannot be solved at the Community level; at present the Community contributes 13% (i.e. 2750 million t) of total world $CO_2$ emissions.

Under the Community's two conventional Scenarios up to the year 2010, $CO_2$ emissions in the Community could increase by 14–26%. Such a development would be in contradiction to the Community's objective of stabilizing total $CO_2$ emissions by the year 2000 at 1990 levels in the Community as a whole as adopted at the joint Energy and Environment Council on 29 October 1990. It is only under Scenario 4 "High Prices" that such a stabilization target would be achieved. This Scenario assumes substantial improvements in energy intensity, moderate economic growth and higher end user prices.

The Community's $CO_2$ stabilization objective has to be regarded as a first step towards the reduction of $CO_2$ emissions in the longer term. It is now the Commission's responsibility to propose a precise strategy on how to achieve stabilization of $CO_2$ emissions by the year 2000. In an initial working paper presented to the last Environment Council in December 1990, the policy options at the Community's disposal were presented.

## 6. COMMUNITY POLICY

The Community's strategy will have to rely on a mix of several policy instruments as there is no single, miracle solution available. The first element in such a mix must certainly be the effort to further improve energy efficiency and energy conservation. The Commission has recently proposed, in the form of the SAVE Initiative, a significant Community contribution for improving energy efficiency and limiting $CO_2$ emissions. The second element of the strategy consists of R&D efforts for energy and the environment and the development of renewable energy sources. These two elements will yield significant net benefits, but they are unlikely to be sufficient in themselves to achieve the stabilization objective.

Consequently, in addition to the more traditional 'command and control' elements, economic and fiscal instruments seem to be necessary to achieve $CO_2$ stabilization in the Community — some Member States have already studied or are in the process of studying the introduction of such instruments. Apart from the modification of existing energy and transport taxes, which could yield positive effects, interest focuses today on the fiscally neutral introduction of new taxes.

The essential political policy options for specific taxes consist of:

— Taking the carbon content as the base ($CO_2$ or carbon tax)
— Taking all (except renewable) energy sources as the base (general energy tax)
— A combination of these two options.

With regard to these options no final decisions have been taken by the Commission up to the present. However, in view of the pros and cons of the various possibilities, the Commission favours a combination of a $CO_2$ tax with an energy tax. It considers this to be a good synthesis of advantages without presenting major risks, especially regarding energy security.

Therefore as a first general conclusion, it can be stated that stabilization of $CO_2$ emissions by the year 2000 does not seem to be an impossible task. However, by no means can this be regarded as an easy job. It will require substantial policy efforts and intervention. Within these global stabilization strategies, two sectors are of special concern: transport and electricity.

At present, power generation represents some 31% of Community $CO_2$ emissions. These emissions may increase up to the year 2000 by more than one-third as the attractiveness of electricity is still increasing.

While between 1980 and 1988 some 65 GW of nuclear capacity came on stream and helped to limit the Community's $CO_2$ emissions, this increase will not happen again in the decade ahead. The nuclear outlook for the 1990s is for 7–11 GW additional capacity only; coal use in power generation, however, is expected to increase. The task to stabilize $CO_2$ emissions by the year 2000 in the electricity sector is therefore extremely difficult and would require a very substantial increase of natural gas in power generation.

Gas appears as the swing fuel of this decade, compensating for a reduced nuclear contribution and replacing coal as the principal alternative in meeting incremental demand. Additional gas volumes may be of the order of up to 75 million tonnes of oil equivalent. However, seeking these additional gas supplies should neither expose the Community further to greater vulnerability to energy insecurity, nor increase prices substantially. Meeting these challenges will require the implementation of the internal energy market for gas.

As indicated earlier, increased efficiency in both the production and end use of electricity can make a real contribution to reducing the environmental impact of the electricity sector.

A further area of environmental concern of a completely different nature is that of nuclear energy. Chapter 3 of the Euratom Treaty of 1957 provides that basic standards of protection from ionizing radiations shall be laid down, both to protect workers and to ensure safe levels of radioactivity in air, soil and water. The Community's approach to this question involves not only the definition of standards, in which the recommendations of the International Commission on Radiological Protection are followed, but also includes advice as to how these standards may be achieved. Such activities are supported by R&D programmes, which are developed under Chapter 1 of the Euratom Treaty.

The question of the consequences of a nuclear accident is a matter of public concern. The Community and the Member States are signatories of the Vienna Convention, established following the Chernobyl accident. In addition, the Community has its own rules for the reporting of all significant nuclear incidents and for supplying information to the public on health protection measures taken or planned by the national administration.

Like other environmental pollutants, radioactive emissions do not respect national frontiers. International co-operation is essential and, of course, exists within the Community which co-operates closely with interested organizations such as the International Energy Agency and the International Atomic Energy Agency. An R&D co-operation agreement will be negotiated with the USSR and measures to enable close co-operation on radioprotection matters are being proposed. These efforts would provide surveillance of the environmental and health effects of the disposal of radioactive wastes similar to that already provided in Article 37 of the Euratom Treaty.

The Community already supports projects directed towards early validation of the concept of deep geological disposal of nuclear wastes and also encourages international co-operation on all aspects of the transport and disposal of wastes.

The safe operation of nuclear power stations is a vital aspect of environmental protection as well as an important element in improving public confidence in nuclear energy. The Community is developing means of extending experience in this field to central and eastern European countries through consulting activities and the 'twinning' of nuclear power stations in these countries with those in the Community.

This discussion has provided an overview of the development of those aspects of environmental policy in the Community which impact especially on the electricity sector. As the Community goes forward with development of the internal energy market and with continued emphasis on protection of the environment, energy and environment policies must continue to be closely linked.

## Invited Paper

# ENVIRONMENTAL IMPACT OF ELECTRICITY IN HUNGARY

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### Abstract

ENVIRONMENTAL IMPACT OF ELECTRICITY IN HUNGARY.

An investigation was carried out on the risks to society of the different electricity supply options in Hungary. It revealed that a considerable number of such risks originate from electric shocks, half of which occur in the household, resulting in several dozen fatal accidents every year. Concerning the technological procedures, from the extraction of fuel to the generation of electricity, most of the risks stem from accidents and occupational diseases among operational personnel. Environmental hazards endangering the population play a less significant role. According to data collected over the past two decades, calculated risks grow in the following order for the different energy supply options: natural gas, nuclear, oil, open cast mining of lignite and deep mining of coal. The growing social opposition to various activities in the energy field stems, in the majority of cases, from the fact that much of the population cannot distinguish between real and imaginary dangers and believes that it is subjected to environmental hazards without it having any control over the matter. The energy industry has reduced emissions of ash from coal fired power plants to the internationally required level. Owing to structural changes in the fuel consumption of power plants, $SO_2$ pollution has also been reduced, in accordance with the Geneva Convention, but further progress is still necessary. The $NO_x$ output of power plants is of no trouble and various emissions from the Paks Nuclear Power Plant are far below the permitted levels, sometimes by several orders of magnitude. Protection of the environment is a determining factor in the energy field and, together with the technical and economic aspects, public acceptance is becoming an essential requirement for the industry.

## 1. INTRODUCTION

Protection of the environment has become increasingly important in Hungary over the past few years. Because of the political changes that have taken place in the country, open expression of public concern has been made possible. The population's opposition to all industrial activities and facilities that are considered environmentally dangerous has become very strong. Although protection of the environment has been a crucial issue in taking decisions in the energy field, it has now become the focus of criticism and dissent. Over the past few years protest movements have interrupted the construction of a hydropower project on the Danube River, prevented the founding of a storage facility for low and medium level nuclear wastes, enforced the rerouting of a high voltage transmission line, etc. Decisions on the type and location of future power stations have become particularly difficult, because every option is opposed strongly, either by green movements or by local representatives. Because none of the political parties in Hungary has yet formed a definite policy on these questions, governmental decisions have had to be postponed.

## 2. THE SOCIAL RISKS OF ELECTRICITY

In many cases, the reason for opposition to various activities in the energy field is that the community cannot distinguish between real and imaginary dangers, since it lacks the necessary information. Therefore, it is essential that an objective picture be provided as to which hazards society will be prepared to accept if it wants to use electricity. Without doubt, a very low standard of living, without electricity, would result in a much higher risk.

The risks resulting from electricity supply were investigated [1] on the basis of Hungarian data accumulated over the past two decades. These calculations covered the technological procedures used, from fuel extraction to electricity for the consumer, taking into consideration the most important types of power plant in Hungary. The technical features of three electric power supply alternatives are shown on a simplified flowsheet (Fig. 1). The products and services of other branches of the national economy which are necessary for creating and operating the technologies represented in each block cause additional risks. These can be estimated by using the input–output model of the national economy. In most cases, such

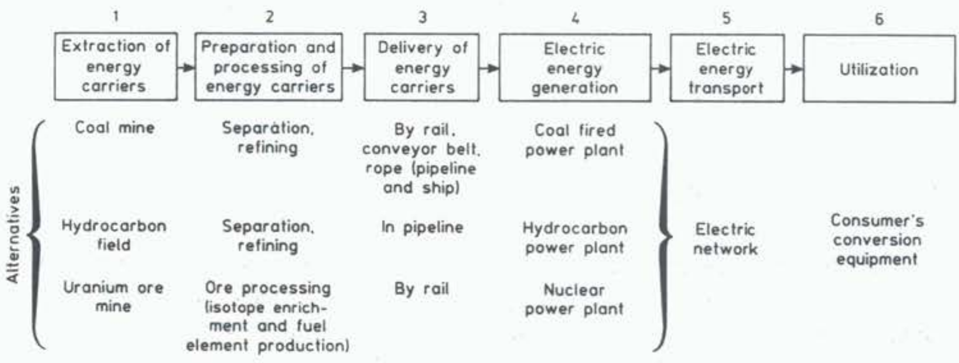


*FIG. 1. Electric power supply alternatives (the processes in parentheses do not exist in Hungary).*

TABLE I. POSSIBLE UNFAVOURABLE ENVIRONMENTAL EFFECTS OF ELECTRICITY

| Nature of consequence | Main types | Possible results |
|---|---|---|
| Direct physiological harm to human beings | Accidents (trauma, burns, electric shock, radiation damage)<br>Diseases (occupational and environmental harm), effect of toxic and radioactive substances, electromagnetic radiation (?), carcinogenic substances and effects, harmful substances in the food chain, psychological effects, noise, offensive odour, deterioration in landscape<br>Genetic mutation | Death, reduction in life span, disablement, chronic diseases, permanent or temporary disabilities, hereditary disturbances |
| Damage to the technical environment | Corrosion (buildings, technical facilities)<br>Disturbances (effect of electromagnetic and radioactive radiation on the means of communication, the limitations in reception, etc.), soil movement (collapses, dam bursting), explosions and fire | Dilapidation of buildings, bridges, roads, machines, etc., faulty operation or damage in communication devices (computers, television sets, radios, telephones, etc.) |
| Damage to the natural environment | Heat contamination (warming up of surface waters, climatic changes), chemical contamination (of plants, waters, soil; acid rain, smog, ozone hole, greenhouse effect, dangerous wastes)<br>Radioactive contamination (direct effect, inhalation, incorporation, accumulation)<br>Disintegration of the Earth's crust (open cast mining, tectonic effects, hydrological changes, biological consequences)<br>Others (insolation, deforestation, changes in atmospheric and ocean currents, etc.) | Extinction of populations, degradation or elimination of the supporting ability of waters, degradation of soil fertility, Earth movements, microclimatic changes, erosion, global climatic changes, degradation in the living conditions of human beings (drinking water sources, unfavourable changes in flora and fauna) |

analyses have only slight influence, but use of some renewable energy sources may result in costs that are several times higher because of the large amount of construction material needed as a consequence of the low power density.

In examining the risks, it is necessary to clarify which unfavourable environmental impacts should be determined. Table I demonstrates the wide variety of possible approaches. Obviously, the importance of each possibility differs, as does judgement of the consequences over time; however, these do not always depend on objective knowledge. Frequently, scientifically unjustified concerns emerge which are then enlarged out of all proportion by irresponsible members of the media. The result is that people become frightened. Professional organizations as well as the media have a significant role to play in ensuring that objective information is gathered and circulated. It is in the interests of society to eliminate real damages, instead of having the population live in dread of imaginary dangers; it is also necessary to gain public acceptance for the necessary energy options.

Most of the risks — expressed as risk indices of the different hazards — do not stem from environmental harm to residents, but rather from accidents and occupational diseases among operational personnel, particularly in the deep mining of coal. The high percentage of electric shocks is astonishing. Annually, they cause several dozen fatal accidents, half of which occur in the household. This is approximately five times as high as the fatal consequences shown in phases 1–4 in Fig. 1. No information is available on less severe casualties.

Risks in natural gas fired and nuclear plants are low, whereas those in power plants based on oil and on the open cast mining of lignite are considerably higher. The risks resulting from the deep mining of coal are much higher.

In Hungary, the annual risks from generating electricity are a few dozen fatalities per gigawatt peak load and the number of irrevocable consequences is one order of magnitude higher; for temporary injuries and diseases the risk is one to two orders of magnitude higher. These figures are shocking, but other statistics such as those from the use of chemicals or fatalities from traffic accidents are even worse.

## 3. ENVIRONMENTAL EFFECTS

The population appears to have less interest in industrial damages than in environmental hazards, strengthened by the belief that the latter are dangers to which it is subjected without it having any control over the matter. An exact examination of environmental hazards is not possible because knowledge of the health effects is very limited, but the upper limit of possible consequences can be estimated.

The Hungarian energy industry has achieved some success but it still faces many difficult environmental problems [2]. Before the 1960s, the energy economy was built up on coal, and flue ash emissions created unbearable conditions in some settlements around the power plants. This problem was solved by incorporating elec-

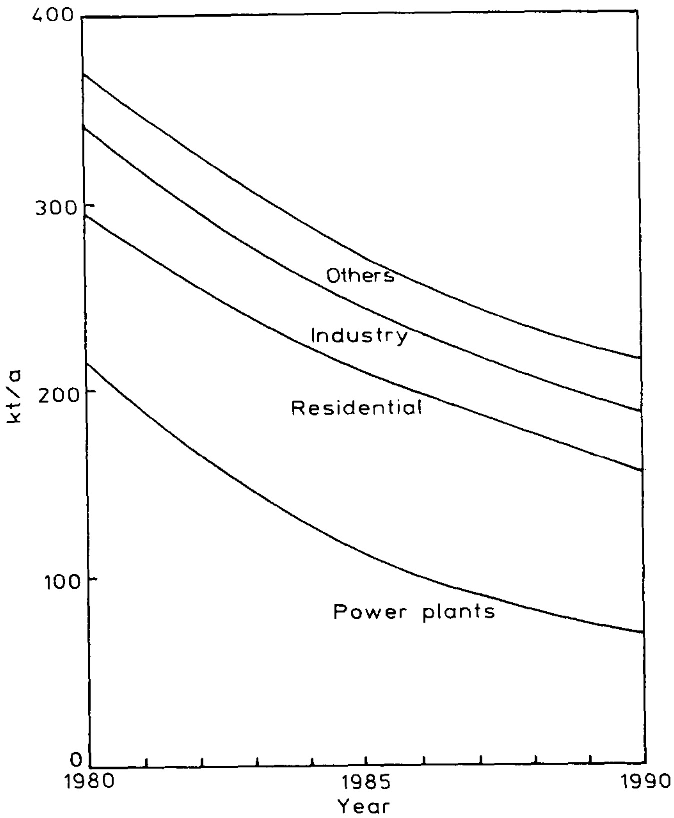


*FIG. 2. Emission of solid contaminations originating from firing.*

trostatic precipitators into the plants; these had a separation efficiency of 98–99%. Figure 2 shows that emissions from power plants have been reduced by about 70% over the last decade.

This spectacular change was partly due to flue gas cleaning and partly to a decrease in coal usage in power plants (in line with the increase in nuclear electricity generation). Currently, only a few old (and small) units with dust separating cyclons are in operation; their total elimination is a task for the future. Their annual average immission value is satisfactory, but the local maximum requirements are not always met. In the coming years, further reduction is expected because of a decline in coal combustion and the shutting down of old units.

Figure 2 also demonstrates that radical changes have not been achieved in those sectors in which flue gas cleaning is seldom economically feasible. Substitution of coal with natural gas and improvements in the energy economy show some success. (Energy is responsible for only about half of the total amount of solid emissions.)

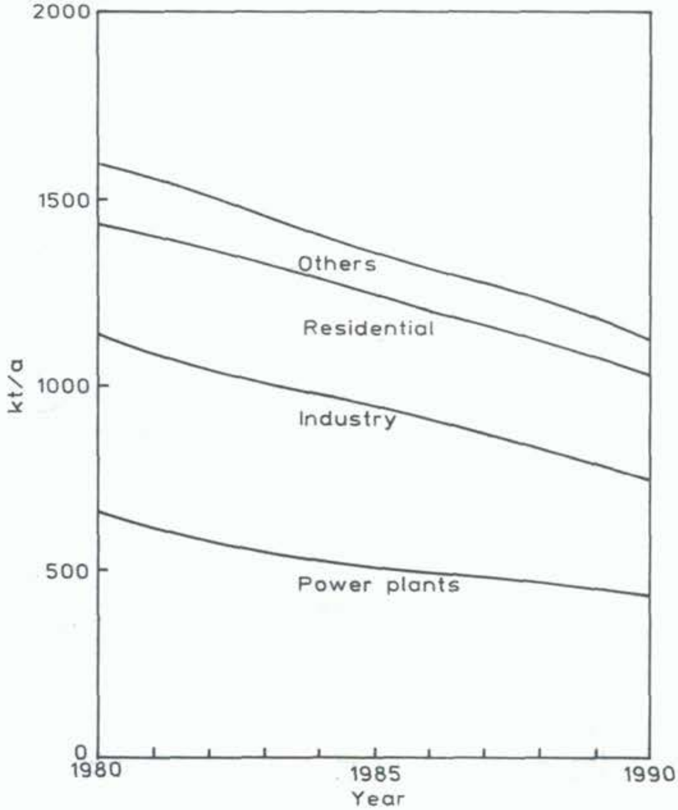


*FIG. 3. $SO_2$ emissions from firing equipment.*

Figure 3 shows that there has been a remarkable reduction in the $SO_2$ emissions of power plants over the past 10 years. As a result, in 1990 Hungary had already curtailed the 1980 value by 30%, in accordance with the Geneva Convention assumptions for 1993. As can be seen in the figure, the reductions made by other sectors are not significant.

The reduction in $SO_2$ emissions resulted from the increase in nuclear power generation over the past 10 years, as shown in Fig. 4. Most of the nuclear energy was generated to satisfy base loads, whereas conventional power plant production shifted towards covering medium and peak loads. As a result, consumption of fuels with high sulphur contents, mainly coal and heavy oil products, has been reduced.

In spite of the significant improvements made, the local emission and immission maxima are unfavourable, exceeding the prescribed limits for almost all of the fossil fuelled power plants. The situation of coal plants is particularly troublesome, since the $SO_2$ concentration in flue gas is higher by several orders of magnitude than the permitted value, because of the high sulphur content of the fuel. Therefore, technical interventions at individual plants are unavoidable, since the global reduction in pollution is insufficient. Some progress has already been made.

Some small and medium capacity atmospheric fluid bed boilers have been put into operation, with satisfactory results. A Hungarian hybrid system [3] appears to be promising, also with larger capacities. It can be used to retrofit old boilers at greatly reduced investment costs. This system combines the advantage of fluid bed combustion, i.e. retention of sulphur in the bed (slag with or without a limestone additive), with the possibility of adding pulverized coal firing in peak load periods. Experiments on injecting limestone or other additives into the combustion chamber of large boilers have been carried out, but they have not proved to be economically

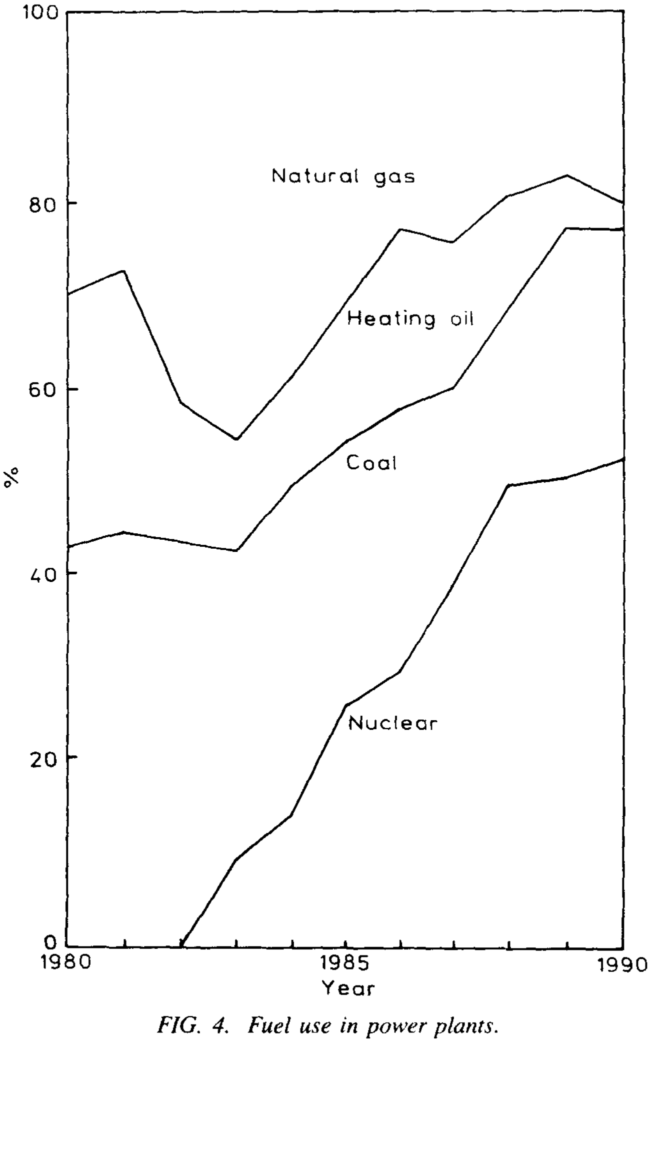


*FIG. 4. Fuel use in power plants.*

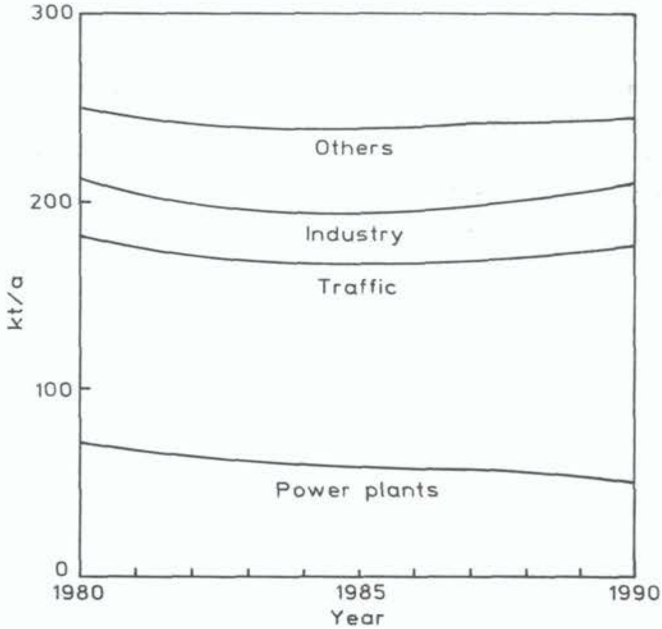


*FIG. 5. $NO_x$ emissions in the energy field.*

feasible. Large units should be retrofitted with desulphurization facilities, but such projects have been hindered by the lack of capital. It is evident, however, that new coal power plants cannot be built without flue gas desulphurization. Problems connected with the disposal of the dangerous by-products of the desulphurization process will also have to be taken into account.

In the coming years, great changes are not to be expected in fuel consumption. However, slight modifications can be anticipated because of the shutdown of a number of old units, the setbacks to the coal mining industry as a result of the high extraction costs and the increasing use of natural gas. Growing constraints will enforce efforts to reduce $SO_2$ pollution in power stations. A high priority for the power industry is to acquire the necessary financial resources for this purpose; international support would be very useful in this regard.

The slight decline in $NO_x$ emissions in power plants (Fig. 5) also depends on changes in fuel consumption. The figure also indicates that most of this contamination emanates from the traffic sector. $NO_x$ emissions, and the resulting immissions of power plants, only occasionally exceed the requirements, and even then not significantly. Further improvement is expected after modernizing the burners and from fluid bed firing because of the low operating temperature. $NO_x$ emissions need special attention, since gas turbines (operating at a high temperature) will come into operation in the combined cycle in the near future.

Research work is in progress which will clarify the share and the role of other pollutants in the flue gas (heavy metals, volatile organic compounds, etc.).

Because of the greenhouse effect, increasing attention is being given to $CO_2$ emissions. As shown in Fig. 6, the total $CO_2$ release has been constant over the past decade: only emissions from power plants are declining because of the reduced use of fossil fuels. Although only 25% of the $CO_2$ comes from power plants, major reductions are expected from this sector by virtue of the large amount of power concentrated in the equipment. Smaller improvements may be achieved by using less fossil fuel or by substituting it with natural gas, and by better energy efficiency. An essential solution can only be expected if the role of nuclear power is increased. Although use of new and renewable energy sources (geothermal, biomass and some solar) is being encouraged, these will probably not influence the energy balance greatly, especially the electricity supply, over the next one or two decades.

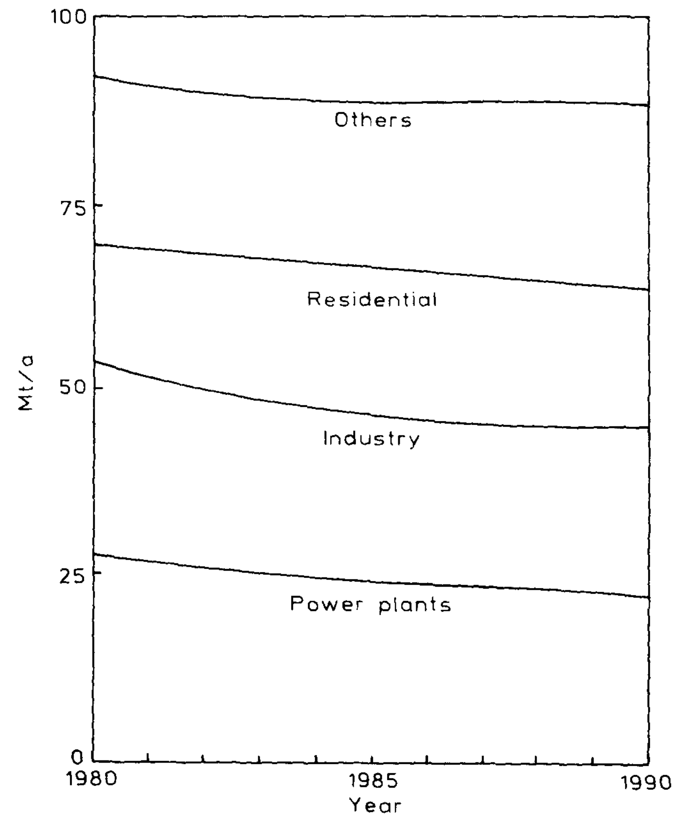


*FIG. 6. $CO_2$ emissions from energy equipment.*

The experience gained over the past 10 years on the environmental effects of the Paks Nuclear Power Plant (four units, 440 MW PWR blocks) is favourable [4]. A monitoring system, consisting of numerous measuring and sampling sites, controls the radioactivity in air, water, soil, vegetation and the animal world, as well as in the food produced, within the 30 km zone around the plant. The radioactivity released has been far below the permitted values for every component. The amount of noble gases emitted (mainly argon and xenon) has not exceeded 3.5%, and other gas components (e.g. iodine) and aerosols have remained below 0.1% of the limits set by the authorities. The isotopes emitted into the Danube River (mostly activation products) measure up to a few per cent; only tritium is about 50% of the permitted value.

Emissions from Paks are significantly lower than the international average for emissions from PWR reactors. The increase in radiation (background) is lower than the error of the measuring instruments, therefore it can only be computed. The individual dose increment, calculated on the basis of the effect mechanism for processes in the 3–5 km range around the power station, is 0.3 $\mu$Sv/a. This is four orders of magnitude less than the dose of natural background radiation and three orders of magnitude less than the permitted value.

The risk to operating personnel is low because of the high degree of automation and remote operation, strict quality control and disciplined operational action. The number of industrial accidents is very small; the collective dose obtained by personnel during maintenance (200–700 mSv) is also low by international standards. The same is true for the specific value (less than 0.1 mSv/GW·h); individual doses rarely reach one-fifth of those permitted.

Paks exercises considerable influence on air pollution; if this plant were to be substituted by fossil fuel based power plants, the $SO_2$, $NO_x$ and $CO_2$ emissions of the power industry would double.

Power plants release only small amounts of chemical waste into surface waters; however, the heat contamination they produce is considerable. Extensive and widespread investigations [5] had to be carried out to clarify the hydraulic, thermal and biological conditions of the rivers used for fresh water cooling. In how far these rivers can be used for cooling power plants, and what measures should be taken to prevent their dangerous overheating in the summer period or in the event of a low flow rate also have to be considered.

## 4. OUTLOOK

The planning of a new facility involves not only economic calculations and technical planning but also meticulous studies on how to eliminate environmental hazards using appropriate measures and technical equipment. Old facilities still in operation have to be retrofitted step by step in order to minimize the pollution they cause.

The most generally accepted concept of the Hungarian energy policy is to conserve energy. This is very important for several reasons, e.g. to increase economic efficiency, to make rational use of natural resources, to save investment capital, to improve the balance of payments, etc. Protection of the environment is also of significance. However, only by improving the efficiency of technology, eliminating large scale consumption in utilities and regressing some energy intensive industries will a balance be found to offset the increasing trends in comsumption; these may also alleviate the burden on the environment, but only temporarily.

Owing to the uncertain development of the Hungarian economy, it is extremely difficult to forecast consumers' demands. Therefore, the power industry needs a flexible strategy which is able to adjust to the actual changes in consumption. The general lack of capital necessitates low cost investments. For these reasons, gas turbines will be installed over the next few years with unit capacities that fit well to the annual increments in peak load. They should be installed rapidly, and at a reasonable cost. To increase economic efficiency, they will be operated in combined cycles; if possible, electricity generation will be coupled with heat supply. In the case of gas turbines, the problems of a reduction in $NO_x$ emissions (caused by the high combustion temperature) and protection against noise have still to be solved.

In the long term, construction of new power plants is unavoidable if the base load is to be covered. Three options, nuclear energy, the open cast mining of lignite and the importing of hard coal, have been considered. Public acceptance is a very important consideration in decisions taken on each alternative. In the case of nuclear power, operational safety and a solution to the radioactive waste disposal question are determinant factors. A reduction in $SO_2$ emissions and in the consequences of open cast mining is essential for the second variant, and elimination of pollution for the third. To overcome the lack of capital, joint ventures would be welcomed with companies in other countries, where the payback system could be solved by exporting electricity. Elaboration of the legal mechanisms and procedures to enable the participation of members of society in any decision making has started, but we are aware that this will not be an easy, clear cut task.

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**Invited Paper**

# ELECTRIC SYSTEM EXPANSION PLAN AND THE ENVIRONMENT IN THE REPUBLIC OF KOREA

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**Abstract**

ELECTRIC SYSTEM EXPANSION PLAN AND THE ENVIRONMENT IN THE REPUBLIC OF KOREA.

A stable supply of energy has been one of the most important decision making criteria in establishing the Electric System Expansion Plan (ESEP) in the Republic of Korea; less attention has been paid to the environmental issue. Since environmental protection is now of global concern, the country is facing energy, economic and environmental problems. Under these circumstances, policies were reformulated in order to reduce emissions; the changes were then incorporated into the new ESEP. Specifically, a target plant mix has been restructured so that the coal plant share is reduced and the nuclear power share increased. Furthermore, future coal fired power plants will have to be equipped with flue gas desulphurization. Although liquid natural gas power generation is not economically competitive, more such power plants are to be constructed; the total generation capacity in the year 2006 is expected to reach 17%. Because of these measures, a reduction in emissions in the electricity sector is expected. Also, since the country is actively carrying out a nuclear power development plan, the rationale for nuclear power is discussed.

## 1. INTRODUCTION

The Republic of Korea has experienced remarkable economic growth over the past few decades. Energy consumption has increased in parallel with this growth, showing an average increase of 8% per year in terms of primary energy consumed. However, at the same time the average increase in electricity demand was 15% per year. Since natural energy resources are scarce, the country depends heavily on resources from abroad. Under these circumstances, the main concern in supplying energy was quantitative rather than qualitative. However, after the two oil crises in the 1970s, the most important factor that had to be considered in establishing the Electric System Expansion Plan (ESEP) was a stable supply of energy.

Because the standard of living has reached a very high level, the desires of the people are now shifting from sufficient quantities of energy to good quality energy that is environmentally benign. Since environmental protection is now of global concern, the Republic of Korea is facing energy, economic and environmental problems.

## 2. ENERGY SOURCES FOR POWER GENERATION

The only conventional resources that the country possesses are hydropower and anthracite coal. The total potential of the former is about 3500 GW, of which 40% is utilized; the rest is economically unviable at present because of the limited and poor conditions for development.

The anthracite coal reserves are about 600 million tonnes; these could last for 20 years, based on the current consumption level. The calorific value of this coal is quite low (about 3400 kcal/kg), and the percentage lime is high. Furthermore, the mining costs are very high because the mines are deep. Accordingly, large scale consumption of such coal is impossible from the environmental and economic points of view. The capacity of anthracite coal power plants is 1000 MW, which is 4.7% of the total generation capacity, or 27% of the total coal fired power plants. The remaining 73% is bituminous coal, all of which has to be imported.

TABLE I. RELIANCE ON IMPORTED ENERGY

| Year | Reliance ratio[a] (%) | Reliance ratio[b] (%) |
|---|---|---|
| 1981 | 73.4 | 75.0 |
| 1982 | 72.2 | 74.3 |
| 1983 | 70.1 | 74.5 |
| 1984 | 69.9 | 75.3 |
| 1985 | 68.8 | 76.2 |
| 1986 | 66.7 | 78.2 |
| 1987 | 65.5 | 80.0 |
| 1988 | 67.9 | 83.2 |
| 1989 | 71.0 | 85.5 |
| 1990 | 73.3 | 87.6 |

[a] Nuclear regarded as domestic energy.

[b] Nuclear regarded as imported energy.

Oil has not yet been discovered in the country, therefore it has to be imported. Dependence on oil is so great that the economy is affected by any changes in the international oil market. After the two oil crises in the 1970s, decision makers in the electricity sector were compelled to devise an energy policy that was not based on oil. The most effective way of realizing such a policy was to introduce nuclear power. As a result, its development was accelerated and the first nuclear power plant went into commercial operation in 1979. Further plants have been constructed and at present eight PWRs and one PHWR are in operation, two PWRs are under construction, one PHWR has been contracted, and two PWRs and two PHWRs are planned.

The energy supply structure is very vulnerable. The country depends heavily on foreign countries for its energy resources; in 1990, about 85% of the total resources had to be imported. Table I shows the trend of energy reliance upon foreign countries.

An unstable electricity supply could result from the vulnerable energy supply structure. To depend heavily on a single energy source is a high risk matter; if problems arise in the main energy source, the supply of electricity could be interrupted. Thus, diversification of the energy sources is the policy that has been elaborated with a view to securing a stable supply of electricity.

## 3. ELECTRIC SYSTEM EXPANSION PLAN

### 3.1. Establishing ESEP procedures

A series of ESEPs has been formulated in connection with the 5 year Economic and Social Development Programme, formerly the 5 Year Economic Development Programme. It was only in the late 1970s that an ESEP was formulated with the participation of many experts in various fields, in addition to the government and the Korea Electric Power Corporation, the only utility in the country. The ESEP is subject to revision in order to cope with any unexpected changes in economic progress or electricity demand. Formulation of the new ESEP was completed in early 1991 and is currently awaiting final approval by the government.

In drawing up an ESEP, the first step is to forecast the electricity demand; this is done by expert groups. Then a final forecast is determined, after several meetings have been held to make a comparative review and analysis of each forecast. This is followed by decisions on the proper input values of the WASP computer model, e.g. the construction costs, fuel costs, discount rates, etc. WASP is then executed and the results are reviewed and modified, taking into consideration the qualitative factors that cannot be dealt with by WASP. This modified version then becomes the official, final ESEP.

In the 1980s, one of the most important decision criteria in establishing the ESEP was the stability of electricity supply and economic competitiveness. Since environmental protection has become a global issue, the environmental factor has been considered in the ESEP.

## 3.2. Environmental considerations in the ESEP

### *3.2.1. Revision of the target plant mix*

To realize the diversification policy, a target plant mix approach was adopted in the late 1980s. A target plant mix is determined by combining the Delphi method with the optimization method. The target plant mix set for the year 2006 is 35:35:30 for nuclear, coal and others (oil, hydro and liquid natural gas (LNG)). The current ESEP was determined on the basis of this combination. The target plant mix for the forthcoming period has been revised in order to cope with regulations that are expected to become more stringent in the near future. The revised target plant mix for 2006 is 40:30:30 for nuclear, coal and others.

### *3.2.2. Installation of flue gas desulphurization (FGD)*

Existing coal fired power plants are equipped with environmental protection facilities such as low $NO_x$ burners, electrostatic precipitators, high stacks, etc.

TABLE II. $CO_2$ EMISSIONS FROM THE ELECTRICITY SECTOR

| | 1990 | 1995 | 2000 | 2006 |
|---|---|---|---|---|
| *Total $CO_2$ ($10^3$ t)* | | | | |
| Current plan | 47 | 80 | 104 | 132 |
| Revised plan | 47 | 77 | 95 | 106 |
| *$CO_2$ per capita (t)* | | | | |
| Current plan | 0.92 | 1.79 | 2.21 | 2.72 |
| Revised plan | 0.92 | 1.72 | 2.02 | 2.17 |
| *$CO_2$/GNP (t/million won)*[a] | | | | |
| Current plan | 0.30 | 0.44 | 0.42 | 0.40 |
| Revised plan | 0.30 | 0.42 | 0.38 | 0.32 |

[a] 720 won = 1 US dollar.

However, none have FGDs, but recent government policy is that such plants should be equipped with FGDs in the future. The first plant of this type is scheduled to go into commercial operation in 1993.

*3.2.3. Expansion of LNG power plants*

In 1985, LNG was first used for power generation, primarily in line with the power source diversification policy. Increasing concerns about environmental protection provided impetus to the expansion of LNG power plants. According to environmental regulations, from 1989 power plants located in the Seoul metropolitan area had to use LNG.

Several new satellite towns are now being constructed in the metropolitan area. Since most of the power stations are located a long way from Seoul, the loading centre where use of LNG is compulsory, co-generation plants are being constructed to satisfy the electricity demand of these new towns. The current share of LNG power capacity is 12%; it is expected to rise to 17% by the year 2006.

## 4. REDUCTION IN EMISSIONS IN THE ELECTRICITY SECTOR

### 4.1. Reduction in $CO_2$ emissions

Table II compares the estimated reduction in $CO_2$ emissions in the revised ESEP and the current ESEP. The estimation for the electricity sector is 20% in 2006. The $CO_2$ emissions per capita of the revised plan show a slower rate of increase than the current plan. For $CO_2$ emissions per unit GNP, the two plans show a decreasing tendency from 2000.

### 4.2. Reduction in $SO_x$ and $NO_x$ emissions

As shown in Table III, the $SO_x$ emissions of the revised ESEP are 50% those of the current ESEP for 2006. Two-thirds of the reduced emission is because of the change in plant mix, that is, a reduction in coal consumption, and one-third can be ascribed to FGD. The $NO_x$ emissions of the revised ESEP are 60% those of the current ESEP (see Table IV). Of the reduced $NO_x$ emissions, 40% are because of the change in plant mix and 60% because of selective catalytic reduction (SCR).

## 5. NEW AND RENEWABLE ENERGIES

Renewable energies can play an essential role in diminishing emissions. However, in spite of the environmental advantages, so far their contribution has been

TABLE III. REDUCTION IN $SO_x$ EMISSIONS (in $10^3$ t)

| | 1990 | 1995 | 2000 | 2006 |
|---|---|---|---|---|
| Emissions of current plan | 370 | 719 | 708 | 726 |
| Emissions of revised plan | 370 | 646 | 500 | 367 |
| Total reduction in $SO_x$ | 0 | 73 | 208 | 359 |
| due to plant mix | 0 | 20 | 64 | 149 |
| due to FGD | 0 | 53 | 144 | 210 |

TABLE IV. REDUCTION IN $NO_x$ EMISSIONS (in $10^3$ t)

| | 1990 | 1995 | 2000 | 2006 |
|---|---|---|---|---|
| Emissions of current plan | 67 | 138 | 175 | 221 |
| Emissions of revised plan | 67 | 122 | 130 | 137 |
| Total reduction in $NO_x$ | 0 | 16 | 45 | 84 |
| due to plant mix | 0 | 4 | 12 | 35 |
| due to SCR | 0 | 12 | 33 | 49 |

TABLE V. OIL RELIANCE RATIO IN PRIMARY ENERGY CONSUMPTION

| Year | Reliance ratio (%) | Year | Reliance ratio (%) |
|---|---|---|---|
| 1976 | 58.6 | 1983 | 55.9 |
| 1977 | 61.7 | 1984 | 51.8 |
| 1978 | 63.3 | 1985 | 48.2 |
| 1979 | 62.8 | 1986 | 46.4 |
| 1980 | 61.1 | 1987 | 43.7 |
| 1981 | 58.1 | 1988 | 47.0 |
| 1982 | 57.6 | 1989 | 49.6 |

insignificant because of economic inferiority. In 1989, their share was as low as 0.26% of the total primary energy consumption.

The Substitute Energy Development Promotion Law was promulgated in 1987; it enumerates ten types of alternative energy source: solar thermal, photovoltaic power, bioenergy, waste solid energy, coal utilizing fuel, small hydropower, wind power, hydrogen energy, fuel cells and ocean energy.

On the basis of the provisions of this Law, in 1988 the Substitute Energy Development Master Plan was formulated with the aim of raising the share of alternative energy to 3% by the turn of the century. The specific goals for the particular fields of technology are: MW class coal gasification, 1 MWp[1] class solar power generation, 1 MW class solar battery and 200 kW class phosphoric acid fuel cells.

Installation of an alternative energy facility will be financed by the government. It is also currently conducting a study on reforming environment related laws and environmental administration. It has been suggested that the government support both the manufacturers and users of alternative energies. Above all, it should place greatest emphasis on improving the economic competitiveness of alternative energies so that an effective substitute energy policy can be realized.

## 6. THE ROLE OF NUCLEAR POWER

The nuclear power development programme is actively being carried out. The rationale for nuclear power is based on three factors.

First, nuclear power is the most promising alternative form of energy at the present moment from the point of view of current energy technology and from the natural and geographical situation of the country. As mentioned earlier, the Republic of Korea has very few natural energy resources and has to import the greater part of its energy resources from foreign countries. Moreover, its aim is to preserve the economic growth achieved over the past few decades. Hence, a stable supply of energy has been, and will continue to be, one of the most important decision making criteria in policy formulation. The strategies adopted to secure the stability of electricity supply are oil substitution and power source diversification. Developing alternative energy forms will take a relatively long time in comparison to the rapid increase in electricity demand being shown in the country. It is expected that the share of alternative energy will be, at most, 3% of the total primary energy in 2000. Nuclear power is a technology intensive form of energy and far less resource exhaustive than fossil fuel burning. Therefore, it is inevitable that the nuclear policy will be developed aggressively. Nuclear power has made a substantial contribution towards an abatement in oil use, as shown in Table V.

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[1] p is the peak power that can be produced from a light intensity of 1000 $W/m^2$.

TABLE VI. ACTUAL GENERATION COSTS BY FUEL TYPE (won/kW·h)[a]

| Year | Nuclear | Coal |
|---|---|---|
| 1984 | 29.7 | 32.0 |
| 1985 | 27.3 | 32.1 |
| 1986 | 29.4 | 32.1 |
| 1987 | 27.4 | 32.8 |
| 1988 | 26.6 | 24.3 |
| 1989 | 23.6 | 24.9 |

[a] 720 won = 1 US dollar.

Second, nuclear power has an economic advantage over fossil power generation. According to a recent study, the costs of nuclear power generation are 6% lower than those of coal. Also, according to actual costs over the past few years, nuclear power is economically more advantageous than coal, as shown in Table VI.

Finally, nuclear power also has an environmental advantage over coal fired plants since it has little impact on air pollution. In the Republic of Korea, siting is going to be a very serious problem. Because 70% of the country is mountainous, most of the suitable sites for power plants are found in the mid-western part of the country or along the southern coast of the Korean Peninsula. Power station sites could be located in coastal areas if the following requirements were provided:

(1) A quayside along which vessels of the tens of thousand tonne class can be anchored, as well as the necessary unloading facilities for bituminous coal
(2) A large area for the storage of coal and ash.

Sites for coal plants should also be suitable for other industries. As far as the environmental and geographical conditions are concerned, nuclear power plants are preferable to coal fired power plants.

For the Republic of Korea, nuclear power is a necessity rather than an alternative form of energy, therefore every effort is being made to develop nuclear energy because 'nuclear' is 'new clear'.

# SUMMARY OF DISCUSSION

## General Plenary Session

*Chairman:* **P. Silvennoinen** (Finland)

*Panellists:* **S. Boyle** (Greenpeace)
**C. Burnham** (Canada)
**C.-E. Lundgren** (Denmark)
**A. Mongon** (France)
**V. Thorpe** (International Confederation of Free Trade Unions) (ICFTU)

L. D'ANDREA (Economic Commission for Europe) (ECE) noted that A. Mongon's paper (SM-323/33) appeared to indicate a contradiction. On the one hand, it was stated that available quantities of natural gas were limited and attention was drawn to the fact that it emitted $CO_2$ when burnt. On the other, it was stated that obstacles to the penetration of gas should be removed. He wondered how this apparent contradiction could be resolved.

A. MONGON (France) said that L. D'Andrea (ECE) was correct in observing an apparent contradiction. However, the intention was to indicate that while gas was one of the best fuels for energy production and was helping to solve many environmental problems, it was a fossil fuel which existed in limited quantities. It therefore had to be used as efficiently as possible.

O. HOHMEYER (Commission of the European Communities) (CEC) *(Consultant)* noted that industry had an impressive record of improving energy efficiency in the area of production and that these improvements had been achieved despite the fact that a return on capital within 18–24 months had been required for energy related investments. He wondered what the effect would be if this requirement were brought in line with the level of return on capital required for general investment in industry, namely 5–7 years.

A. MONGON (France) said that if the period for return on investment was increased from 18 months to 5 years, the potential for energy saving would obviously be greater. However, this type of investment conflicted with other, more important, production investments which made industry globally more competitive. Nevertheless, he agreed that every effort should be made to improve energy efficiency in industrial processes and to use the available capital for the necessary investments.

O. HOHMEYER (CEC) *(Consultant)* pointed out that the adoption of a 5 year period for return on capital would not make industries less competitive, but in fact more competitive, since overall costs were likely to be considerably lower, even if investments were financed entirely on a credit basis.

L. HAMILTON (United States of America) said that in the production of photovoltaic cells in the USA and, to some extent, in Italy, knowledge of the health and safety of the materials to which the workers were exposed was an integral part of the production process. This knowledge was shared not only with workers inside the production facility but also with the local community and local health and safety authorities, so as to minimize the impact in the event of an accident. The introduction of new technologies, in which health (occupational and public) and environmental considerations were taken into account during their development, would solve the problems associated with the historical hazards of the old technologies on which V. Thorpe (ICFTU) had focused.

V. THORPE (ICFTU) said that it was true that, as a result of trade union pressure, the health and safety standards applied to many industrial operations in developed countries had been improved greatly. However, his organization had members in some 75 countries around the world and, regrettably, in the majority of these countries the standards of health and safety were not on a level with the standards described by L. Hamilton (USA).

S. LATEK (Poland) noted that Nordel had considerable experience and success in reducing the environmental impacts of energy. He wondered whether Nordel was considering crossing other borders and sharing its experiences with very polluted countries in Eastern Europe, such as Poland.

C.-E. LUNDGREN (Denmark) said that the Nordel Development Programme was not only considering internal measures but also connections with countries outside Nordel, in particular with Baltic countries, including Poland, with which Nordel was quite prepared to co-operate and share its experiences.

E. CORRAN (Australia) noted that C. Burnham's presentation (SM-323/30) had illustrated how a utility could involve the community in the process of deciding what options should be adopted to meet electricity needs. However, such public participation was limited by the time at which the enquiries were made, by the choice of intervenors who were subsidized and by the choice of the individuals resolving the issues at the end. He therefore wondered whether, in the long run, the community accepted the results as a democratic choice and also whether the approach was used in less well educated communities.

C. BURNHAM (Canada) said that it was important for planners to be prepared to make changes to plans in order to accommodate public interests. It was evidently not possible to satisfy everyone, but one could at least enable people to participate in the process. In Ontario, an independent Board Member decided which intervenors should be funded and at which level. In societies that were less well educated, public consultation programmes appropriate to the region would have to be designed.

R.A. JAMES (Canada) said, by way of clarification, that Ontario Hydro played no part in deciding to whom or in what amounts funding was provided for the public hearings on Ontario Hydro's long term plan. With regard to public participation, he believed that it was unreasonable to assume that all complex technological issues could be resolved by reaching a public consensus. As far as efficiency was concerned, there was little doubt that everyone favoured the more efficient use of energy, and the discussion should therefore focus on the likely success of conservation measures, not whether they were good or bad. In considering the negative impacts of electrical generation, one should not forget the substantial benefits, such as life extension, health and quality of life, derived from the availability of electricity.

H. FUCHS (Switzerland) wondered what precautionary measures had been taken by Ontario Hydro to prevent a distortion by the mass media of the results of the public participation process. Although there was a long tradition of democratic participation in Switzerland, the mass media could influence public voting by distorting or giving a biased presentation of the facts.

C. BURNHAM (Canada) said that utility spokespeople should be prepared to provide honest details about their programmes themselves, as opposed to leaving it to the media to be the exclusive source of information. Active media participation tended to be discouraged by the fact that formal public hearings generally lasted months, even years. Public consultation and feedback programmes should be designed to arrange information meetings with utility planners and interested parties in small groups designed to minimize confrontation and encourage open information exchange on issues.

In answer to a question whether Ontario Hydro had received requests for photovoltaic and other alternative systems from people who wished to be disconnected from the grid or from people living in remote areas where it was expensive to extend the grid, C. BURNHAM (Canada) said that Ontario Hydro had developed a wind/diesel hybrid power plant in which the wind turbine generated power when wind speeds permitted and the diesel generator operated as needed. A 60 kW wind/diesel facility had been operating in Ontario's northernmost community since 1987. A 10 kW photovoltaic system had been installed in another remote community in 1986. Ten individual 180 W photovoltaic systems and batteries provided electricity for a few lights, radios, televisions and telephones at other remote settlements. Ontario Hydro had not yet helped customers to install technologies such as solar heaters which would make them completely independent of electricity supply.

K. KING (World Bank) (IBRD) requested clarification on the distinction made by S. Boyle (Greenpeace) in his intervention between the 'precautionary principle' and the 'no regrets policy' and the decision making implications involved.

S. BOYLE (Greenpeace) said that the no regrets policy involved studying issues, such as global warming, which might turn out not to exist. The precautionary principle involved looking at the range of risks associated, for example, with climate change and lowering the level of risk, although it might or might not be economic to do so in terms of the existing definitions. The precautionary principle often required greater investment than a simple no regrets policy.

E. MARSHALL (United Kingdom) noted that estimates of the benefits of curbing carbon dioxide emissions were still very controversial. It had been suggested in the USA by W. Nordhaus that the measurable gains might be small and that the estimated cost of halving greenhouse gas emissions may be US $200 billion per year or 1% of the global output, if done slowly. Population reduction programmes might be the most cost effective environmental protection measure in a world where sources of finance were limited and where all sources of energy were valuable. She wondered why Greenpeace was not devoting any attention to population reduction.

S. BOYLE (Greenpeace) said that he did not accept W. Nordhaus' analysis for a number of reasons. The analysis focused exclusively on the USA, although any such analysis should take other countries into account. For example, any significant reduction in grain production in the USA, resulting in the disappearance of the surplus which many countries depended on, would affect other countries and overall economic growth globally, which would in turn affect the USA. W. Nordhaus had pointed out that agriculture accounted for only 3% of the Gross National Product (GNP), the implication being that a slight reduction would not affect economic growth significantly. However, while this may be true, it was still necessary to eat. Furthermore, if one did not control greenhouse gas emissions, there was no guarantee that development would continue in a linear fashion. The reason why Greenpeace had not focused on limiting population growth was that it was a very complex issue which required further study. He agreed with E. Marshall (UK) that the pressure of population growth was a driving factor for many environmental problems and that the issue did need to be tackled.

F.H. HAMMAD (Egypt) pointed out that public acceptance in energy matters was much easier than public acceptance in the area of birth control, which involved a number of aspects such as culture, attitudes, religious beliefs, education levels and family income. Some Asian countries had adopted aggressive birth control policies, some of which had succeeded, but the majority of which had not. In Egypt, a more moderate approach had been adopted and family planning centres provided free medication and medical advice. In Cairo, the average number of childen in high income families, enjoying higher standards of living and the benefits of electricity, was 2–3; in low income areas there were 5–10 children per family. He therefore believed that problems of population growth could be solved by improving standards of living and by providing developing countries with more power plants to generate more electricity.

J. GRIFFITH (USA) noted that in his intervention S. Boyle (Greenpeace) had wondered how nuclear power would have been viewed in the 1960s if it had been treated in the same way as some of the renewable technologies were being treated at present. It should be recalled that nuclear power had been viewed as a very promising technology in the 1950s and 1960s. It had often been suggested that it could produce electricity too cheaply to be metered. This optimism had faded as problems were encountered and solved. However, as these problems were solved and their costs largely, if not totally, internalized, nuclear power had remained an economically viable electricity option. In the case of renewable energies, it appeared that certain renewable technologies were unable to produce significant amounts of economic electrical power, even though not all the problems were understood and the consequent costs had not been internalized. In his view, renewable technologies and nuclear power had been treated similarly and the results provided some insight into what future directions were possible.

T. KANOH (Japan) agreed with S. Boyle (Greenpeace) that demand side energy efficiency was essential. However, there was a difference between energy demand and electricity demand. The GNP of OECD countries had increased by 50% between 1973 and 1988, whereas energy demand had increased by only 14%. The same was true in Japan, where the GNP had increased by 90% since 1973, while energy demand had increased by only 20%. However, during this period, electricity demand had increased steadily and rapidly with the requirements of an information, software oriented society. In the case of the OECD, electricity demand had increased by 55% and, in Japan, by 70% since 1973, despite energy conservation efforts. Electricity was needed even for energy conservation measures, such as the recovery of waste heat.

S. BOYLE (Greenpeace) said that although energy conservation measures had been successful in Japan, there were areas where there was significant scope for improvement. The majority of the efficiency improvements had taken place in the industrial sector, with a number of innovations in the area of R&D, grants and the introduction of a law making it mandatory for energy managers in companies above a certain size to receive appropriate training. However, there was a significant potential for increased efficiency in the residential sector, although it accounted for only a relatively small proportion of the overall energy demand. The level of insulation in houses was so poor that it increased the use of air conditioning and the amount of heat needed in cold periods, owing to the low thermal mass of buildings. Furthermore, there had been significant technological improvements in the area of efficiency until about 1984 or 1985 when, with a fall in energy prices, less emphasis had been placed on technological improvements and efficiency standards. Refrigerators, for example, had not been upgraded, although the best available technologies in areas such as refrigerators and lighting indicated that there was a great potential for efficiency in these areas. T. Kanoh (Japan) was correct in pointing out that the trends in energy demand and electricity demand differed. However, it was very difficult to decide whether electricity was the best option in terms of environmental impact and efficiency for all of the service areas. A great deal of additional research was necessary.

C.-E. LUNDGREN (Denmark) noted that the Union des producteurs et distributeurs d'énergie électrique (UNIPEDE) and the World Energy Council

(WEC) had been working in the area of energy conservation for the past 20 years. Electricity supply companies were in fact unique in teaching their customers how to use less of their marketed product. He also pointed out that, in comparing electricity consumption and GNP, it was important to take into account the consumption profile (light or heavy industry, the effect of depression or growth, etc.).

C. BURNHAM (Canada) said that, in the Ontario programme, it had been found that electricity consumption was fairly evenly divided between the residential, commercial and industrial sectors and that efforts were being undertaken to understand the specific uses in each of these sectors.

H. KHATIB (WEC) said that he believed that the views of S. Boyle (Greenpeace) regarding the possibilities for less use of electricity were unrealistic. Historically, there was a continuous link between energy use and economic growth. The ratio had decreased by almost half over the past 20 years and was now being maintained at approximately 0.4:0.6. Since most economic growth was taking place in developing countries, where there was still a very close link between electricity use and economic growth, he believed that it was likely that there would be a 1:1 link between electricity use and economic growth in future. A distinction should be made between increased energy usage and economic growth, on the one hand, and emissions of greenhouse gases on the other. In alleviating certain environmental problems, increased electrification would help, since some economic activities were being carried out using environmentally harmful fuels.

S. BOYLE (Greenpeace) wondered what assumptions were being made when suggesting that the ratio between electricity use and economic growth was going to be 1:1. He did not believe that electricity was necessarily the appropriate option for all areas, such as transportation or heating. It was also important to consider technologies of direct fuel use, which might, in some instances, be a more appropriate option than electricity.

H. KHATIB (WEC) pointed out that the world's population was increasing at a rate of 1.7% per annum and in developing countries it was higher than 2%. Consequently, 2% more consumers were entering the market each year. At present, some 1500 million people in developing countries were without electricity. Given the fact that these people would gradually be provided with electricity and electrical services and the fact that developing and developed countries were increasing their economic activities at a rate of 3–4% per annum, growth in electricity demand was inevitable. Attention should therefore be focused on making a distinction between growth in electricity demand and growth in greenhouse gases.

J. VAN DE VATE (International Atomic Energy Agency) (IAEA) pointed out that, in order to have significant end use energy saving, a fundamental change in public attitudes towards new energy saving equipment was necessary. Such changes required time. In his experience, in the case of electricity saving lighting, there was a tendency for lights to be left on for longer than with conventional lighting. One might also point out that if conventional lighting was used, less space heating was required.

S. BOYLE (Greenpeace) said that it was true that it took time for people to become accustomed to new lighting systems. However, many of the newer designs could look remarkably similar to incandescent light bulbs, and improvements in lighting balance and colour tinting made them much more acceptable than earlier designs. The effect of such lights being left on for longer had been taken into account in the assessment of the efficient lighting programmes. It had been assumed that people would use the new lights 50% longer than conventional ones, but there was still a significant saving, since the lights were 4–5 times as efficient. In his experience, electricity saving lighting was actually fairly popular among the public.

C. BURNHAM (Canada) confirmed public support for such programmes and noted that Ontario Hydro had implemented an efficient lighting programme and had been surprised at the results. The efficient light bulbs had been marketed by a supermarket, and Ontario Hydro had offered a rebate if customers sent in a completed form. Within 2 weeks, 20 000 light bulbs had been sold and over 175 000 had been sold so far. The light bulb packaging material provided information on the energy savings and the reduction in greenhouse gases achieved by using such light bulbs.

V. THORPE (ICFTU) said that customers were clearly interested in consuming less energy and it was for the technicians to produce solutions to enable consumers to do so.

L. McCONNELL (Canada) noted that there appeared to be unanimous agreement on the need to improve generation and end use efficiency, but disagreement on what efficiency improvements could be achieved in the future. In discussing efficiency, it was important to clarify what type of efficiency improvements were being referred to. Most of the enormous improvements in efficiency which had taken place during the 20th Century were the result of market driven improvements. There were also information induced improvements, where attempts were made to influence people's attitudes towards using more efficient technologies. Load forecasts made by utilities in North America already included the expected market and information driven efficiency improvements. When utilities in North America referred to efficiency improvements, they were referring to financially induced improvements, where money was provided by the utility in some form to accelerate the adoption of efficient technologies.

S. BOYLE (Greenpeace) noted that in the USA the percentage improvement in energy intensity, which was a very crude measure of efficiency improvement, had been increasing at about 1% per annum over the past 80 years and at a somewhat higher level during the mid 1970s and 1980s in response to prices and a range of government programmes. When referring to efficiency improvements, he was referring to efficiency improvements which would occur over and above these naturally occurring improvements. He believed that the rate of efficiency improvements could be increased to 2–3%, provided the utilities received real financial incentives to improve efficiency and to make significant investments in end use efficiency.

E. ROTH (Germany) felt that there was a certain bias in the discussion, which was concentrated on efficiency. Everyone regarded efficiency as important and attention should therefore be focused rather on ways of producing, in as environmentally benign way as possible, the additional energy which was still needed.

C. BURNHAM (Canada) noted that many conferences discussed ways of preventing or mitigating the environmental effects of electricity generation and transmission. It would be useful to assemble the experts again to discuss specific techniques for avoiding pollutant discharges, processes which produced fewer pollutants, the best available control technologies for pollutants, and ways of improving energy transmission and generation efficiency.

C.-E. LUNDGREN (Denmark) commented that engineers were often criticized for proposing new plant types and his own company had been criticized for distributing low energy bulbs to its private consumers free of charge.

P. SILVENNOINEN (Finland) *(Chairman)* agreed that most of the attention had focused on energy saving aspects and that there was general agreement that all cost effective measures should be taken to improve energy efficiency. However, there had perhaps been a tendency to neglect end use efficiency in the past and this may account for the prominence given to it at the Symposium. While there was agreement on the importance of efficiency, there was disagreement on how to produce energy with the minimum environmental impact.

## Invited Paper

# ELECTRIC POWER PLANNING
*The people decide*

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**Abstract**

ELECTRIC POWER PLANNING: THE PEOPLE DECIDE.

The most important element of contemporary electric planning is public involvement. This is especially true when considering the environmental trade-offs which are inevitable since all forms of electric generation have some effect on the environment. Addressing these dilemmas will pose some difficult questions. These are choices to be made by members of the public, not technical problems to be solved by engineers. Winning approval for major utility projects is essentially a political process. The astute planner will recognize this and start building a role for the public at the earliest stage of planning. The development of Ontario Hydro's 25 year plan included extensive public outreach programmes, attitude research and reviews by Ontario's Government. The plan is now being considered by the Provincial Government's Environmental Assessment Board, a quasi-judicial panel with the force of law behind its decisions. This process includes extensive public participation, much of which is funded by Ontario Hydro. In today's world it is not enough to be right if one lacks public support. Nevertheless, if one can get a broad enough social backing for an initiative, it is amazing what one can do.

## 1. BACKGROUND

One of the realities of the environment is that we only have one. All of us must share it. If we ruin it we cannot escape. We cannot trade it in and it does not have a warranty. Everything we plan and every station we build have an effect on the environment.

Consideration for the environment must be part of planning from square one. If we ignore this part of our duty as electricity planners then the environmental damage that results may well exceed the benefits of the energy we provide.

Planning for the environment is first and foremost about people, not technology. The same applies to electricity planning. We have to constantly remind ourselves that serving people is the end, and technology the means.

In order to plan our electric future effectively, the public must be involved. Electric planning can no longer be done by a utility alone. Even if planners did have infinite wisdom, any plans and any environment decisions are going to involve trade-offs. The necessary public acceptance of the inevitable hard choices will not occur unless members of the public have participated in the decision process.

As has been stated many times in this Symposium, any new electricity supply will have environmental effects. I do not think it is appropriate from an environmental viewpoint to pit one type of generation against another. Each has its own advantages and disadvantages, technically, environmentally, economically, socially and regionally. Of the three conventional centralized forms of power station each comes with its unique set of problems, and each should be designed to prevent and/or mitigate effects on humans and the environment.

Fossil fired generation produces greenhouse gases, among other effects. This situation applies even to plants with upgraded pollution controls. Nuclear energy brings with it the still to be resolved questions of waste disposal, and public concerns about safety remain even where the record is as excellent as that one compiled by the CANDU reactors. Hydroelectric projects can flood large areas, displacing human settlements and altering animal and fish habitats.

## 2. PUBLIC INVOLVEMENT

Addressing these supply choices poses some difficult questions. These are choices to be made by members of the population, not technical problems to be solved by engineers. Utilities are being swept up in the broad social change which sees environmental concerns pervading every facet of our lives. That change necessitates bringing the public into what was once a relatively closed planning process.

Furthermore, involving the public does not mean marketing a fait accompli. The assumption that planners know best and the public is uninformed is no longer acceptable. People today are much more active and knowledgeable than they used to be. They are much less inclined to put blind faith in the experts. This is true even if the experts, in the final analysis, turn out to have been right all along. Just because people lack specific scientific or technical training does not mean that they are uninformed or irrational.

It is now important to discuss the Ontario Hydro process of environmental consideration, rather than the technology we use. I will describe a learning process that sees us striving for consensus rather than for quick and easy answers.

Let me hasten to add, I will not be talking about perfection, but we are trying to learn. First, let me put Ontario Hydro on the map. Ontario is Canada's most populous Province with more than nine million people. It is Canada's industrial heartland with a gross Provincial product exceeding 230 billion[1] Canadian dollars[2].

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[1] 1 billion = $10^9$.

[2] US $1.00 = Canadian $1.17.

We operate 70 hydroelectric, 8 fossil fuelled, and 3 nuclear generating stations. Our installed dependable peak capacity in 1990 was over 30 000 MW. We supplied over 136 million MW·h to our customers in 1990 — 44% from nuclear generation, 27% from hydroelectric and 20% from coal.

Meeting demand has been straining our capacity and much of our existing plant is wearing out. Load forecasts point to an increase in demand of from 60 to 100% by the year 2014. The options for meeting that demand carry capital and environmental price tags of considerable amounts. Paying the price requires public understanding and consensus.

Developing that consensus is just as important as getting the technical answers right. Our approach may be of interest to those of you who confront similar planning problems.

Winning approval for major utility projects is essentially a process involving people. The astute planner will recognize this and start building a role for the public at the earliest stage of planning. In December 1989 we issued our 25 year plan for the demand and supply of electricity in Ontario. Involving the public in the development of this plan began back in 1984 when we initiated the preliminary stage of long term planning, our so-called Demand/Supply Options Study. We set out to investigate all of the possibilities for both generating and saving electricity. Part of that investigation involved actively seeking input from the many different segments of Ontario's population.

We held workshops with Provincial organizations, community leaders, major hydro customers and municipal utilities. The organizations represented agricultural, industrial, religious, labour, native, recreational and, of course, environmental interests. In all, 58 interest groups participated and 35 presented written submissions.

Along with this community outreach programme, we were taking the largest sampling of our customers' opinions in Ontario Hydro's history. In 1986 we conducted over 2000 one-on-one interviews with residential, commercial and industrial customers. We wanted to determine the priorities of our customers relative to electric planning. We asked people about their preferences in terms of technology and then outlined the environmental effects of those various technologies. Then we asked again about their preferences.

We found that customers valued reliable service above all else. Tied for second place on the list of concerns was the issue of the environment and rates. We found that, for the most part, our customers did not connect their use of electricity with environmental effects. We learned that people were willing to accept higher prices if it would help the environment.

We repeated the study in 1988 and in just two years environment had advanced to be even with reliability in first place as a customer concern. Pricing concerns had fallen to third place.

## 3. PLANNING STRATEGY

After we had examined all the options and the public input, we developed a planning strategy which set forth our five planning priorities and which tried to reflect the interests that had been expressed by our customers:

(1) Upgrading and refurbishment of our existing generation and transmission facilities consistent with high standards of environmental protection.
(2) Aggressive pursuit of energy conservation to reduce load growth, recognizing that the most effective way of reducing the impact of electricity generation on the environment is to reduce generation requirements. We recognized that we had to have the co-operation of customers, municipal utilities and Ontario's Government for this to be effective.
(3) The encouragement of non-utility generation, giving special preference to options using renewable resources and high efficiency co-generation.
(4) Orderly development of our remaining hydroelectric potential.
(5) Keeping our major new supply options open to replace retiring facilities and meet load growth, thus ensuring reliable electricity service into the next century. The major supply options are CANDU nuclear, fossil and firm purchases from neighbouring Provinces.

These priorities led to our 25 year plan which is now being reviewed in public hearings by the Provincial Environmental Assessment Board.

We reviewed the supply options considered in the plan to ensure that they met the environmental regulations and we compared their advantages and disadvantages. Environmental considerations were high on the list of reasons why demand management, non-utility generation and hydroelectric development have such prominence in the final product.

We have some ambitious targets for these areas. By the year 2015 we project 3300 MW of non-utility and 3000 MW of new hydroelectric capacity. We hope to have cut 4800 MW from our load through conservation. That adds up to three nuclear stations that we will not have to build, a total of 12 reactors we will not have to clean up after or pay for.

Even if we meet these targets, our task is not finished. Our medium load forecast indicates demand will increase from a present peak of about 24 000 MW to more than 37 000 MW by the year 2015. Besides that we have 8700 MW of current capacity which will need replacement.

We concluded that we were still going to have to build some new generating capacity. If the public is going to support the plan, it must agree with this basic premise. There is not much point arguing about technology and sites until this question of the need for additional supply is resolved. We hope that the Provincial Environmental Assessment process mentioned earlier will be the central mechanism for doing this.

The Environment Assessment Act passed in 1975 requires that any major undertaking of public sector entities, such as Ontario Hydro, be evaluated and approved by the Provincial Environmental Assessment Board. Generally undertakings are defined as specific generation or transmission projects. This is the first time that a plan has been submitted under the Act.

The Environment Assessment Act requires the proponent to provide funding for some of the interest groups participating in the hearings. We will be providing more than twenty million Canadian dollars to interveners who qualify. This allows them to hire experts and lawyers so that they can participate meaningfully in the hearing process.

By submitting the 25 year plan, we have separated the long term strategic planning, the question of need, from individual construction projects. The individual projects will eventually be subject to their own environmental assessment, but only after we have discussed the broad plan.

In the 25 year plan we have defined our undertaking as an integrated programme for providing electricity services. We are asking the Board to first consider the broad plan and to accept our case for need. We are also describing, in a general way, the environmental effects of the different technologies for meeting that need. Of course key to the plan will be an examination of the costs of the various options.

We have to show the Board and the public that we are doing everything we can to restrict demand and to exploit private supply. In the end, we hope to draw their attention to the fact that even after doing all of that, we will still need to build new supply.

We have taken this approach partly because of public frustration. Environmental assessment was always an afterthought, with assessment happening only after the fundamental decisions about need had already been made.

Such assessment is necessary for our 25 year plan even if it adds another few years to the process. We hope that the time spent forging support rather than pouring concrete will work out best in the long run. Most environmental issues are issues of the long run. The long term benefits of informed public support should outweigh whatever time is lost in construction schedules in the short run.

In today's world it is not enough to be right if one does not have public support. Nevertheless, if one can get a broad enough social backing for an initiative, it is amazing what is possible.

However, first we have to establish a public consensus concerning the need for new supply. Only then can we deal with the question of the source of this supply and the impact on the environment of the various options.

Even if the Board approves the overall plan, we will still have to have environmental hearings on the individual projects. However we should not have to reinvent the wheel every time nor should we have to reconsider the general alternatives, the load forecasts and the generic environmental effects for each project.

We have to respect public opinion because it is the most powerful force which bears on the planning environment. It will make itself heard whether we like it or not. Last year the voters elected the first Social Democratic Government in Ontario's history. The new Government has imposed a moratorium on development of new nuclear power stations and our plan calls for three new stations.

The new Provincial Government understands the importance of public involvement. It has decided to allow the Environmental Assessment hearings to continue. It needs the answers from those hearings as much as we do.

This is just one more example of the new reality of planning — there is no longer any entity, private or public, capable of making plans unilaterally and then imposing them. There are those who lament that under these conditions nothing is ever going to get done. Even if this pessimistic view is accurate, it is no use charging at windmills, so to speak. Like it or not this is the new order.

We must, in very practical and specific ways, provide opportunity for the public to understand and to contribute to our work. We must balance the needs and concerns at the local level with the economic needs of the whole Province and the technical limits we face.

Delivering benefits to people — it should be remembered — is the objective of all our work. We must be prepared to accept changes to our plans if the public does not agree with the balance that we have proposed between demand management, new supply and the proposed technologies.

I would like to close with the same message I presented in the opening of my paper, except in closing I am quoting from the words of a great North American Indian leader, Chief Seattle when speaking in 1854 to an assembly of tribes preparing to sign treaties with the white men who had overrun their lands:

> "The air is precious to the red man for all things share the same breath — the beast, the tree, the man, they all share the same breath.... Whatever befalls the Earth, befalls the sons of the Earth. If men spit upon the ground, they spit upon themselves.
>
> "Where is the thicket? Gone. Where is the eagle? Gone. And what is it to say goodbye to the swift pony and the hunt? The end of living and the beginning of survival.
>
> "What is man without the beasts? If all the beasts were gone, men would die from a great loneliness of the spirit. For whatever happens to the beasts, soon happens to man. All things are connected."

## Invited Paper

# ENERGY AND ENVIRONMENT
## *The position of European industrial consumers*

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### Abstract

ENERGY AND THE ENVIRONMENT: THE POSITION OF EUROPEAN INDUSTRIAL CONSUMERS.

The paper presents the position of the International Federation of Industrial Energy Consumers (IFIEC) Europe, the European arm of the IFIEC, on the issue of $CO_2$ emissions and global warming. It has been claimed that the amount of carbon used in the industrial, transport and domestic sectors may be a major contributing factor to the atmospheric buildup of $CO_2$. According to this thinking, a carbon tax has been proposed which would induce consumers to switch fuels or conserve energy, thereby reducing emissions on a global level. The IFIEC Europe does not believe that using taxes to resolve such environmental problems would be effective, nor does it hold that such a tax would have a real impact on the global reduction of $CO_2$. Instead IFIEC Europe sees the need for further scientific research to find lasting cost effective solutions to the problem. The paper discusses the role of industry, energy use policies and a combined heat and power system as some steps towards alleviating environmental problems. IFIEC Europe sees the importance of technology transfer and co-operation between decision makers in dealing with the problems. Key adjustments in energy policies are suggested and the conclusion is drawn that until scientific research can more clearly describe the cause/effect phenomenon of $CO_2$ emissions and in the absence of international agreements, IFIEC Europe believes energy conservation and efficiency to be effective and relatively low cost responses to the global warming problem.

## 1. BACKGROUND

It is claimed that the amount of carbon used in the industrial, transport and domestic sectors may be a major contributing factor to the atmospheric $CO_2$ build-up which is thought to have repercussions on global warming, i.e. the greenhouse effect. According to this thinking, creating a carbon tax proportional to the amount of carbon burned or $CO_2$ emitted would induce consumers to change their behaviour patterns in a significant way through fuel switching or energy conservation so that overall $CO_2$ emissions would be reduced on a global level. Despite the fact that carbon taxes would raise revenues which could finance government environmental policies or could offset taxes elsewhere in the economy, there seems to be a growing interest in the use of market based measures to deal with environmental issues.

## 2. POSITION OF THE INTERNATIONAL FEDERATION OF INDUSTRIAL ENERGY CONSUMERS (IFIEC) EUROPE

IFIEC Europe, the European arm of the IFIEC, believes that using taxes to resolve environmental problems would not be very effective; in particular, IFIEC Europe does not believe that a carbon tax would have a real impact on the global reduction of $CO_2$ emissions. Besides that, there are still so many scientific doubts and divergent opinions today about $CO_2$ effects that it would be difficult to set up a mandatory policy based on taxation, without allowing for exemptions which, in turn, would be a source of unfair market conditions. Addressing a global issue with unilateral and heterogeneous policies will lead first to economic distortions, but may not, in fact, achieve the desired effect of changing fossil energy consumption patterns in a permanent way. However, we would like to draw attention to the fact that changes in the composition of fossil energy input diminish $CO_2$ emissions only, and do not solve the total problem; available quantities of natural gas are limited, and its burning also emits $CO_2$.

IFIEC Europe feels there is a clear need for further scientific research to learn more about the $CO_2$ problem in order to find lasting, cost effective solutions. This, of course, promises to be a medium to long term challenge. In the absence today of scientific consensus on this issue, IFIEC Europe would like to focus its attention on the measures that might be undertaken in the immediate future.

## 3. ROLE OF INDUSTRY

To begin with, it is important not to forget the active role that industry has played in past years to protect the environment. Industry has a good record in improving energy efficiency and in switching to safer fuels. It is estimated that the global $CO_2$ emissions in industry have decreased by 10% in the European Community (EC) countries over the past 10 years (see EC statistics in this respect), with an improvement as high as 60% in the British chemical industry over the past 30 years. These efforts have had the double advantage of lowering operating costs while reducing emissions.

Industry today contributes to no more than 30% of global emissions, with the remaining emissions being almost equally shared by the transport and domestic sectors. Drawing from its past experience, industry can propose pragmatic low cost solutions for reducing $CO_2$ emissions even further.

### 3.1. Policy of national energy use

Priority should be given worldwide to the development of an ambitious policy of rational use of energy; government policies should be oriented towards encouraging greater efficiency in energy use and increased investment in alternatives to fossil fuels and high performing technologies. Incentive measures that allow greater flexibility in financing and that reward energy consumers for their efforts should be offered.

### 3.2. Combined heat and power system (CHP)

The CHP system offers the most efficient form of power generation, because it makes possible the production of electricity with a consumption of primary energy considerably lower than that of conventional power plants. This fact has an important impact on environmental protection, because for the same output of power, the quantity of any pollutants emitted by CHP is considerably reduced. Development of CHP should be encouraged through the removal of administrative and commercial obstacles. In particular, effective rights to purchase, exchange or sell energy based on 'open access' to the gas and electricity transmission grids in the international European market could attract new investments in CHP.

### 3.3. Technology transfer

Much has been said about the importance of introducing energy effective technologies to developing countries as they renovate and replace obsolete industrial plants. Practical measures should be taken to facilitate such technology transfers. For example, creative financing schemes which offer attractive lending terms in exchange for environment friendly investments might be set up.

### 3.4. Co-operation in decision making

The EC Commission and Member States are presently reviewing their energy policies to take into account new objectives for the next century. IFIEC Europe believes that closer co-operation between the various decision makers will be essential in moving towards the use of energy resources which emit less $CO_2$. For example, key adjustments in energy policies should be made in the following areas:

(a) There should be further and faster removal of obstacles to the penetration of gas into the energy market.

(b) Conditions should be created which allow gas price setting and competition between gases.

(c) Use of gas for power production should no longer be banned according to EC regulations.
(d) Use of non-competitive coal should comply with EC regulations.
(e) Taking of a realistic approach to nuclear energy, starting with the resolution of technical problems relating to fuel and decommissioning of wastes. Nuclear energy may be able to provide a key contribution to future energy and environmental needs once the public is convinced of its overall safety.
(f) Recognition of the enormous potential for conservation in the EC transport and domestic sectors. However, government intervention may be required to stimulate action, for example, through the introduction of new energy saving incentives. Tremendous efforts have yet to be made in both of these sectors before they catch up with industry's record in this field.

## 4. CONCLUSIONS

It is industry's experience that real progress can be made towards achieving cost effective energy conservation when step by step measures are taken and are based not only on a solid determination to associate economic goals with environmental considerations, but also on the possibilities open to industry to 'shop around' for market oriented solutions.

Industry is willing to pursue its active role in working towards a sustained environment, but it would not like to be penalized by policies and measures, such as a carbon tax, that would not be adopted universally or which would not provide specific remedies to emission problems such as $CO_2$.

In the absence of international agreements, and until scientific research can more clearly describe the cause/effect phenomenon of $CO_2$ emissions, IFIEC Europe is convinced that a strong case should be made for energy conservation and efficiency as an effective and relatively low cost response to the global warming problem.

**Invited Paper**

# NORDEL AND THE BRUNDTLAND REPORT

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**Abstract**

NORDEL AND THE BRUNDTLAND REPORT.

Nordel is a co-operative organization formed by the electricity producers in Denmark, Finland, Iceland, Norway and Sweden. Its purpose is to produce and transmit needed electricity as efficiently, economically and securely as possible. The organization is an example of voluntary collaboration without directives or control bodies. Differences in the production systems and demand patterns in the individual Nordic countries provide the basis for such a power exchange, beneficial to both the economy and the environment. In the paper Nordel, the Nordic organization of the electricity industry, is held up as an example of co-operation across national borders and regions. Such co-operation could be fruitful in managing the impact of electricity generation on the environment, and of mutual benefit to the economies involved. Nordel's more than 25 years of experience proves this fact. To further reinforce the co-operation and intensify competition, Nordel has begun a major development programme to use available resources and capacities even more efficiently. This programme provides a framework for incorporating environmental consequences into the policy and planning of the electricity sector. The Nordic electricity companies carry out R&D on several environmental topics, including the the issue of $CO_2$ emissions. The main fields emphasized are energy efficiency in electricity production and utilization, use of $CO_2$ free fuels and other ways to reduce $CO_2$ emissions. The initiatives discussed in the paper are crucial steps towards international co-operation in the electricity sector.

## 1. INTRODUCTION

While Nordic countries and their electricity companies have only limited impact on the environment, globally, regionally or locally, environmental questions, nevertheless, claim top priority on the agenda for political discussions in the Nordic Parliaments.

The energy sector plays an important part in these discussions which find expression in the ways and the extent to which the individual Nordic nations, their Governments and authorities emphasize the environmental and health impacts of energy production and use. Measures taken to ensure this concern include taxes levied on energy and $CO_2$, targets set for reduction of $SO_2$, $NO_x$ and $CO_2$ emissions and restrictions imposed on the extension of hydropower plants.

The Nordic power companies observe national and international legislation, rules, regulations and agreements concerning environmental topics, and are striving to be even more effective.

Strategies for reducing the environmental impacts of electricity production and use are crucial elements in the policy of the electricity industry in the Nordic countries. Nordel — the organization for co-operation in the field of production and transmission of electric energy — encourages efforts in this area.

## 2. NORDEL

### 2.1. Nordic model for co-operation within the electricity industry

Nordel is a co-operative organization formed by the electricity producers in Denmark, Finland, Iceland, Norway and Sweden to produce and transmit needed electricity as efficiently, economically and securely as possible.

In fact, a common market serving the 23 million inhabitants and their industries in the Nordic countries has operated for more than 25 years through transborder transmission lines and cables, where electricity is marketed every hour throughout the year. The first Nordic power network began in 1915 when the interconnection across the Øresund Strait between Sweden and Denmark was put into operation.

As in every market, an agreement is made when differences occur, most often when prices are different. (There are always buyers for the cheapest product.) Within Nordel it is agreed that the seller and the buyer define their respective prices according to certain ground rules. When an agreement is made, the seller and the buyer split the difference evenly.

This agreement works both ways and ensures the maximum use of exchange opportunities. In this way, an interconnected system comprising a total of 5565 MW is operated efficiently and economically. At the same time, it provides maximum security of supply within the limits of production and transmission capacity. However, the system will only work in an atmosphere of mutual trust and common goals.

The operation of the interconnected electric power system in the Nordic countries is an example of voluntary Nordic collaboration which works very well. It is governed by mutually agreed upon recommendations and principles, and is directly managed by national operation managements bodies. There is no need for directives or control by any superior body and no overall Nordic operation management.

However, the Swedish power company, Vattenfall, acts as co-ordinator and is responsible for frequency control and sudden demands on operating reserves. Each individual national operation management body is responsible for its own part of the interconnected Nordel system and thus responsible for power exchanges with neighbouring systems. This co-ordination takes place through bilateral agreements between the respective operation management bodies.

## 2.2. Electric power generation in Nordel

The total electricity production in the Nordel countries is about 335 TW·h/a. The large Nordel system embodies a variety of plant types, of which the greatest number by far is of the non-polluting types. In 1989 the total electricity production within Nordel was composed of:

−60% hydro
−25% nuclear
−14% coal
<1% other: wind, geothermal, etc.

The production systems in the different countries have been built to meet each nation's individual domestic needs. Hydropower has been exploited wherever it is topographically, economically and politically possible. Of course, the varying geographical conditions of the countries have led to great differences in the utilization of hydropower. The use of nuclear power also differs greatly, mainly for political reasons.

Consequently, Norway has an entirely hydro based system, Denmark an entirely fossil fuel based system, and Finland and Sweden have a mix of hydronuclear and fossil fuelled power. Electricity production in Iceland is based on hydro- and geothermal power. Iceland has no interconnection with the other Nordic countries. These major differences in the production systems provide an important basis for the very valuable and profitable power exchange between the power systems in the four Scandinavian countries.

At the same time, the environment also benefits from this power exchange. The total man-made $CO_2$ release in the Nordel countries is in the range of 250 million t/a, of which about 70 million t come from electricity production. Every terawatt-hour of electricity produced on a $CO_2$ free basis (i.e. instead of by coal)

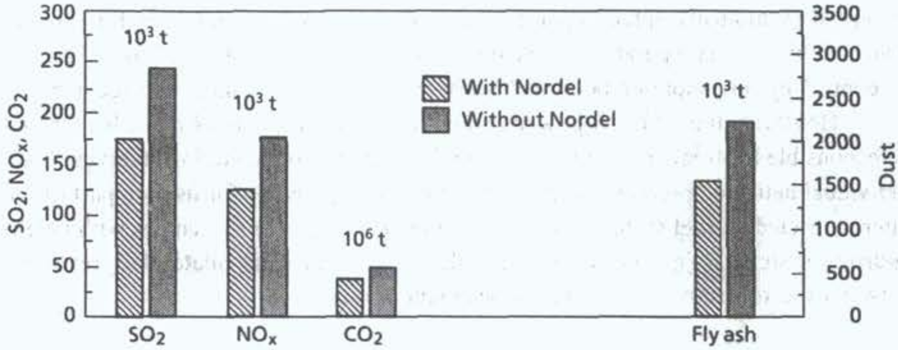


*FIG. 1. Residual products from electricity production in the Nordel area (1990).*

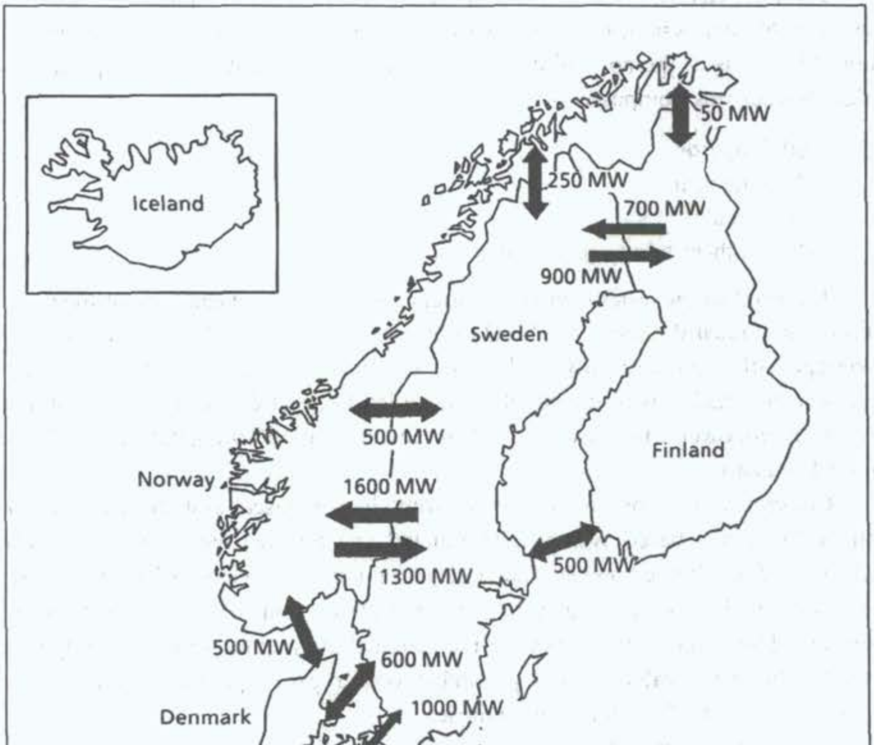


*FIG. 2. Transmission capacities on the interconnections (1990).*

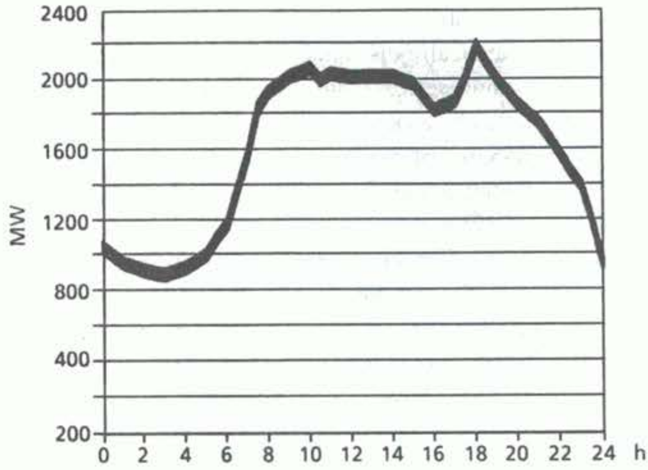


*FIG. 3. Elkraft system load during a 24 h period (13-10-1988).*

saves about 1 million t of $CO_2$ emissions. In 1990 through the exchange of electricity within Nordel, the environment was spared from receiving:

-70 000 t $SO_2$
-50 000 t $NO_x$
-12 million t $CO_2$.

## 2.3. Electric transmission in Nordel

Today the total Nordel installed capacity is about 85 000 MW (Fig. 1). The national networks are linked by a total of 22 tie-lines. Under normal conditions, these have sufficient capacity for the Nordic electric power system to be regarded as a single power system that can utilize the combined production resources and thus ensure an overall economy with acceptable limitations.

The backbone of the national networks and the strong interconnecting link consists of 400 kV lines and stations. In Finland and Sweden, the predominant transmission needs are from North to South, that is from the hydropower plants on northern rivers to the industrial and population centres in southern areas. In southern Norway, the predominant transmission needs are from West to East. The transmission lines in Denmark are shorter, but large thermal power units on the system and the interconnections with Germany, Norway and Sweden have motivated the creation of 400 kV networks in the eastern and western regions of Denmark (Fig. 2 shows the transmission capacities on the interconnections in the Nordel system).

The Nordel system constitutes a combined hydro and thermal capacity which supplies an uneven geographically distributed load. The hydropower resources are located largely in the northwestern region of the system, the thermal power in the southeastern. The transmission capacity between these regions is very large. During years with normal availability of hydropower, mainly nuclear and fossil fuelled power is used for the additional energy production. Higher than normal runoff will reduce fossil fuelled production.

Figure 3 illustrates how Nordel co-operation affects the electricity production, and shows a typical 24 h load curve for electricity production in the eastern part of Denmark. At night, transmission of electricity goes from Denmark to Sweden. In the daytime, the Danish power plants are relieved of some production by transmission of electricity from Sweden to Denmark.

## 3. NORDEL DEVELOPMENT PROGRAMME

### 3.1. Background and scope

Nordel has recently embarked on a major development programme to further intensify co-operation among members. The development programme has several purposes. One is to save money invested in production facilities which so far have been determined mostly by needs and energy policies set down by the individual Nordic nations. Another purpose is the need to form a coherent view on energy, the economy and the environment, put forward by growing concern about the environmental aspects and consequences of electricity production. Special emphasis in this programme will be placed on the environmental issue. Gro Harlem Brundtland — the present Norwegian Prime Minister — was chairman of the United Nations committee which in 1987 issued the report on energy balance in the world, Our Common Future, which made a strong plea for help in dealing with environmental issues for the benefit of all [1].

### 3.2. Contents

The aim of the Nordel development programme is to reinforce co-operation and intensify competition so that available resources and capacities can be used most efficiently.

The basic principles of the development programme are to:

(a) Extend the production capacity and control the electric system in Nordel in order to minimize the environmental impact on the region as a whole, regardless of borders

(b) Develop optimum utilization and distribution of electricity

(c) Utilize fully the internal Nordel system and the external interconnected power systems vis-à-vis the EEC. Co-operation within Nordel should always observe EEC standards and directives.

A number of statements are being prepared and will form the basis for discussions on a reorientation of the Nordel co-operation. These statements concentrate on: models for co-operation, production, transmission and interconnection of power systems and electricity demand. To implement the findings of the statements and the conclusions of the discussions, policies need to be reconsidered. Both national authorities and power producers need to rethink old policies and actions based on national sovereignty. The old idea of one's own power in one's own country is no longer adequate.

It will take some tough political rethinking to allow, for example, Denmark to build and operate a hydropower plant in Norway. But coal and gas fired Danish power plants could then cut down their production and emit fewer pollutants. However, it would be equally difficult to get permission to produce electricity in Danish power plants and export it to Eastern European nations. Obviously, there are simpler approaches. Long term contracts could be made which maintain ownership but retain most of the benefits.

## 4. OTHER NORDEL RESPONSES

### 4.1. $CO_2$ R&D

The Nordic countries support the battle against $CO_2$, which was so heavily begun with the Brundtland Report, through:

(a) Energy economy at the point of end use
(b) Improvement of production efficiency, both with improved process technology and co-production of heat and electricity
(c) Use of fuels which cause less $CO_2$ formation
(d) $CO_2$ free electricity production: hydro, nuclear, biomass, wind, etc.
(e) R&D in the fields of efficient electricity production and use, $CO_2$ free electricity production (biomass, wind energy, etc.) and methods to filter $CO_2$ from flue gases for later reuse.

#### *4.1.1. Energy economy in the end use sectors*

Electricity companies in the Nordel countries have for several years supported and spread information on energy efficiency in the end use sectors. Results can be seen now as a stagnation, or even decline, in electricity consumption in the domestic and industrial sectors. Still, there is room for a further increase in energy management and efficiency and consultant schemes must be strengthened in the future.

*4.1.2. Improvement of production efficiency*

Fuel used in thermal power plants must be used efficiently in order to reduce losses as much as possible. The efficiency of electricity production was previously about 35%, but today at the newest power plants it is 42–45%, and the power companies expect it to increase within the next decade to reach about 50%. New technologies such as coal gasification, pressurized fluid bed and fuel cells might reach even higher rates (above 60% has been mentioned).

The use of combined heat and power (CHP) has for many years been common in the Nordel countries. Grids for district heating cover practically all the major cities in Denmark, Finland, Iceland and Sweden. These grids make possible a widespread use of CHP and a considerable increase in the total efficiency of the fuel, which at the newest plants is today 91–92%.

Co-produced heat's share of the total heat consumption has increased considerably over the last 10 years, and there is room for a further increase. In Denmark, for example, CHP covers 22% of the total heat demand, and in the next 10 years this share is expected to increase to 45%. As a result, the total efficiency (i.e. utilization of the fuel), which in 1989 was 56%, is expected to reach 70–75% after the year 2000.

The ratio between output of electricity and output of district heating is today a factor of 0.6, but could be increased significantly in the future, whereby a higher percentage of the electricity production would result from combined production. Consequently, a smaller amount of fuel would be used. Both the environment and the economy would benefit from this, and demands would then be made on the co-operation within Nordel.

In a situation in which a large proportion of electricity production is related to heat demand, there is a need for regulation, for instance at night when electricity demand is low, but heat demand is high. The co-operation between the Nordel countries makes such regulation possible. Hydroproduction is cut back, and surplus electricity — the so-called 'runover' — from CHP plants is used both for pumping water back into water reservoirs and for serving electric boilers in district heating systems.

*4.1.3. Use of fuels producing less $CO_2$*

When natural gas is used instead of coal or fuel oil in a condensing power plant, less $CO_2$ will be produced per output of electricity. In this way, natural gas can reduce the $CO_2$ emissions from the actual power plant by 40%, compared with the emissions from coal firing. Switching from fuel oil to natural gas may then give a 20% reduction in $CO_2$. Add to this the fact that combined cycle power plants are more efficient than conventional condensing power plants and the use of natural gas could theoretically halve the emission of $CO_2$ from a power plant.

However, methane leaks from the natural gas grid must be kept below 3–4%, otherwise the benefit of $CO_2$ reduction would be counterbalanced by the greenhouse effect caused by greater methane losses.

Other important parameters that must be taken into account are the economy and security of supply which differ from country to country. Investments in infrastructure (grids) are necessary to ensure a sufficient security of supply. Seen in this full perspective it is clear that natural gas can only be a piece in the puzzle of $CO_2$ reduction.

### *4.1.4. $CO_2$ free electricity production*

Nuclear power, hydropower and other renewable sources of energy — wind energy and use of refuse and biomass (straw, wood chips and biogas) — are all important elements in future electricity production. These sources should be used to the greatest extent while keeping an eye on the environment and economy.

As stated before, more than 85% of the electricity in the Nordel countries is produced on a $CO_2$ free basis. A considerable increase in this share is not likely, owing to environmental and economic restrictions. Nordel studies have shown that through retrofitting existing hydropower plants production could be increased by about 5%. Development of new techonologies for nuclear power production could create the basis for extension of the nuclear capacity and meanwhile, existing nuclear plants could be upgraded and their lifetimes extended.

Biomasses are, to some extent, used already, primarily in district heating systems. However, there is a potential for a substantial increase in their utilization. The same can be said for wind energy, even though Denmark at least has already carried out a comprehensive programme for wind turbines. Nearly 3000 wind turbines with a total installed capacity of 330 MW are in operation. Their production is limited, however, and covers less than 2% of the electricity demand in Denmark.

### *4.1.5. Nordel R&D*

Electricity companies within Nordel will continue their co-operation with industries and research institutes in research, development and demonstration areas aimed at energy generation with a minimum of $CO_2$ production and environmental impact. The electricity companies in the Nordel countries are involved in a number of projects concerning the use of wind energy, biomass and other $CO_2$ free energy sources.

In the field of wind energy, data and experience are collected and analysed in order to establish a sound basis for a further increase in utilization, and for technological development. Utilization of biomasses for electricity production involves subjects such as fluid bed combustion, gasification, growing of fuel crops, etc., and, of course, analysis of the environmental impacts of these technologies.

Researching and developing ways to filter out $CO_2$ from flue gas for later reuse are carried out in the Nordel countries as well. Internationally no breakthrough has been seen yet, but it is important to keep an eye on this frontline in order to ensure a swift implementation of results.

## 5. CONCLUSIONS

Co-operation across national borders and regions could be a fruitful way of managing the impact of electricity generation on the environment, and at the same time could be of mutual benefit to the economies involved. Nordel's more than 25 years of experience proves this fact.

Today, environmental subjects and questions have top priority in political discussions worldwide. If we really want to incorporate environmental impacts into policy, planning and operation within the electricity sector, greater international co-operation is needed. We must leave customary thinking behind, and eliminate all 'sacred cows'. It is time for governments and power producers alike to start all over again and rethink their policies.

In the EEC, common carrier principles directed towards a market oriented electricity sector have been seriously discussed, and measures to ensure further progress will be taken. The Nordel development programme is a step in the same direction. It will form the basis for a reorientation of the co-operation in the Nordic countries and at the same time create a framework for incorporating environmental impacts into the policy and planning of the electricity sector.

## REFERENCE

[1] WORLD COMMISSION ON ENVIRONMENT AND DEVELOPMENT, Our Common Future, Oxford University Press, Oxford (1987).

## Invited Paper

# POLICY ASPECTS OF ELECTRICITY AND THE ENVIRONMENT
## *A trade union view*

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### Abstract

POLICY ASPECTS OF ELECTRICITY AND THE ENVIRONMENT: A TRADE UNION VIEW.

Workers have a personal interest in safe and healthy working and living environments. Jobs in new, pollution free energy production and utilization systems are likely to offer greater long term security and better working conditions. Planning for a sustainable energy future requires organizational reappraisal as well as technological expertise. This task is more suitable for social institutions than for scientific ones. Workers' organizations have pioneered for democratic intervention in industrial decision making. The right to know and the right to decide are citizens' rights as well as workers' rights and trade unions have negotiating experience which should be tapped to cope with the new tasks of consensus forming which lie ahead. In the paper suggestions are presented for action to be taken at the local level to support the necessary international co-ordination of environmental efforts. These include: raising the best prevailing standards of environmental protection, collecting and publicizing information about and regulating new processes, maintaining strict environmental accounting and auditing records, encouraging rapid growth of new technologies and finally adopting new approaches to debt and development problems.

## 1. BACKGROUND

It is a short step for members of trade unions to take from the defence of workers' health and safety in the plant to a concern for the protection of the wider community from the environmental effects of industrial operation. Workers have long and bitter experience in their daily exposure to industrial pollution. In many cases workers have been the frontline troops (many would say the 'guinea pigs') in providing a defence against the spread of industrial hazards to the general population. Many of the data implicating substances and processes as generally hazardous have been accumulated from the experience of workers personally affected during the industrial process.

Employers have often sought to exploit a commonality of interest with the workforce in resisting strong regulation of polluting emissions. They have sometimes done so effectively on the grounds that such controls pose a risk to employment. But experience with the process of technological development over the last two decades has shown that *planned* industrial change can be more beneficial to the workforce of a given industry than a kind of Luddite opposition, which is in any case doomed to eventual failure.

The simplistic formula of pollution = jobs/pollution control = job losses disregards the positive role trade unions have played in promoting manpower planning and retraining. This formula also fails to recognize that social and economic support programmes are necessary components of the industrial change required to maintain competitive performance. In the electricity generating industry, in particular, there is a much more secure future for new employment in the production of new energy efficient equipment and in developing new, non-polluting energy industries than in holding onto unhealthy jobs in filthy production facilities until public demand finally closes them down before there is time to plan alternatives.

In the words of the Report of the World Commission on Environment and Development, "The time has come to break out of past patterns. Attempts to maintain social and ecological stability through old approaches to development and environmental protection will increase instability. Security must be sought through change" [1]. The role of trade unions in bringing about the necessary changes in policy and approach is a crucial one that involves international co-ordination. Trade union intervention is also essential to ensure that the interests of workers are not sacrificed in the process of change.

## 2. POLICY APPROACHES TO ENERGY USE

This paper is not the proper place for a technical debate that should be pursued in this Symposium by those better competent to discuss probable levels of future electricty demand and the technologies required for meeting it. It should be pointed out, however, that the collective memory of workers is haunted by the daily experience of planning exercises, which, though designed by industrial experts and exact in every detail, have lacked the practicability that a framework of common sense would have contributed. When practice proves the errors of such unimaginative planning, it has always been the workers who have paid the price in lost jobs and in disruptions to their careers and lives.

Change is necessary not only in the technology required to develop sustainable energy industries for the future, but also in planning for that future. Straight line planning which sees the future as a logical extrapolation of the past would lead us to conclude that a vast expansion of electric power consumption is necessary to achieve the development goals of industrializing nations and that expansion in such countries will inevitably mean reliance upon fossil fuel primary resources in those regions. It would also predict that if developed nations are serious in their declared intent to reduce polluting emissions — and especially if they are to reduce $CO_2$ emissions — then they must accelerate their reliance upon the only currently available $CO_2$ free technology, nuclear power generation.

Whether this prediction is correct or not, it is based on the same major flaw that has created present energy problems. It considers the future in terms of the past and does not comprehend the development of new means to reach desired ends. Aside from public fears of nuclear energy as a technology, the key problems which are the focus of current concern over environmental degradation from electric power production are the result of accumulated burdens of poisons and wastes throughout 200 years of industrial activity. The emission of $SO_2$ and $NO_x$, responsible for the bulk of acid precipitation problems, was similarly a problem for urban dwellers at the very start of the Industrial Revolution. In fact, the buildup of atmospheric $CO_2$, contributing significantly to global temperature rise and resulting climatic change, is as old as fire itself.

Despite the dazzling history of technological advancement in this 200 year period, the parallel history of pollution has, indeed, been marked not by the rapid advance of technology, but by a notable failure to change industry's primitive approach to waste disposal. When the fumes from factory chimneys began to choke an unacceptably large number of inhabitants in the industrial cities, causing widespread respiratory and other diseases, the industrial response was not startling in its ingenuity. Factory chimneys were simply built higher to push the polluting gases further up into the atmosphere for dispersal to and by the wind. This has remained the approach to the problem in most countries until very recent times. However, now the industrial fallout poisons the forests (and people) hundreds of kilometres away in neighbouring nations.

This short-sighted approach has transferred the real costs of pollution to society at large and onto future inhabitants of the planet. It is necessary to try now to repay this two century tax holiday within a single generation. How foolish it would be therefore to continue planning for the future by initiating actions which simply levy present costs on developing nations or which rely heavily on technologies for which safe long term waste disposal methods are not available. Would it not be better to employ our limited reaction time in perfecting and installing energy saving equipment and non-waste producing energy technologies?

One common factor in all the key problems of occupational and environmental health is the relatively long lead time required before the problem is discovered. By the time the impact of poor planning is felt or recognized, a substantial deficit has already been established within the environment or within the workforce, making it inevitable that the situation will worsen before it improves, even if urgent arresting action is taken. The problems of global warming and the diminishing ozone layer are prime examples of that 'time bomb' process in action. The wave of response now issuing from every responsible organization makes it inevitable that great changes will occur in production as a result of the strong expression of political will. These changes involve substantial impacts on employment and manpower requirements. The concern of labour during this transition period will be that the sacrifies which they will be asked to make during this transfer shall not simply lead up a blind alley.

## 3. INSTITUTIONAL STRUCTURE

Government institutions and the global corporations which control energy production and policy inevitably create large scale, centralized energy solutions which mirror their own structures. Trade unions, too, are traditionally happier with large production facilities where mass membership is easier to obtain and to service than in many dispersed locations. It has suited all parties to concentrate their enthusiasm on technologies which reflect and best serve their organizational cultures. The high capital cost of such large scale facilities has proved an effective barrier to competition and to the development of alternative energy technologies. Under the prevailing organizational circumstances, it would seem that solar energy is unlikely to become a serious option until the corporations have found a method to put a screen around the sun and to meter out its energy at so much per kilowatt-hour!

As a result, society is now poorly served with a limited range of ideas from which to choose to attain the desired objectives of lower energy use and cleaner energy production. To reverse the tendency to production centered gigantism and to develop rapidly energy use solutions, which may well be decentralized in nature, will require a determined effort to overcome these structural constraints. Trade unions, too, may need to come to terms with opportunities for developing decentralized networks among a larger dispersed workforce installing and servicing new end used equipment, rather than continuing the easier option of static one site memberships. The challenge of sustainable energy production is therefore less of a technological problem than an organizational one.

This social basis of industrial decision making needs urgent attention before new unsatisfactory solutions prevail. Technology needs to be put back under social control — not the other way around. In this process, social organizations such as trade unions are crucial because of the valuable experience they can bring to the matter of negotiating policies for social change.

## 4. WORKERS' RIGHTS ARE CITIZENS' RIGHTS

Trade union demands for improved standards of health protection on the job have focused particularly on the assertion of certain key rights: the right to know what techniques and substances are being introduced into the factory and what their known health effects are, and the right to decide whether to accept any potential risk inherent in working with such substances or processes.

Workers are citizens too and more often than not it is they and their families who live in the shadow of the factory chimneys. It is not surprising, therefore, that the struggle for the right to know and the right to decide within the factory should be contrasted by trade unionists with the absence of such rights in the wider community. Information and control are the two areas in which industry has resisted most strongly the workings of democracy. These are also the areas in which trade unions have the most negotiating experience. This experience can therefore serve society as a whole particularly well in the process of reaching broad social accord in establishing desirable industrial and environmental development goals, in enforcing regulations and in monitoring to achieve them.

Whatever the regulatory response may be to the need to limit the polluting effects of energy growth, it is at the industrial level where the solutions will have to be worked out. Workers in the electrical energy generating industries and in the downstream and upstream industries share the natural concern of the population at large over environmental matters and their impact on the direction and type of future industrial development. The more direct role of the workers within the industries, however, requires that the workers themselves also become more involved in the practical business of substituting new, low polluting forms of electricity production for the old and take a more active part in the economic and social dialogue which must accompany this process.

Strategies directed not at solving environmental problems themselves, but at damping down the upsurge of public concern for reasons of economic or political expedience do not serve the long term interests of workers in these industries any more than they meet the needs of society as a whole. These approaches will tend to delay action until an emergency situation arises which forces the political administration to act precipitously without the necessary planning for industrial investment and retraining of workers.

To be able to lend their strength to the change process, trade union representatives need to gain direct and equal access to international decision making fora on environmental matters. There are many different forms of international co-operation by which trade unions can contribute to the decision making process.

## 5. INTERNATIONAL RESPONSE

Environmental hazards are generated locally but experienced globally; transboundary air pollution links production in one country with acid deposition in another; global temperature rise and thinning of the ozone layer result from many individual acts of pollution down to the domestic level, but the results affect everyone. International, too, are the industries and many of the companies that are the originators of most of this pollution. This fact alone can often inhibit the willingness of officials of the national government to impose the necessary strict regulations, because they are mindful of the threat of runaway production being transferred to less well regulated countries. A deadly game has ensued in which the last country to impose restrictions stands in hope of inheriting the dirtiest industries.

Given these circumstances, the creation of an internationally effective mechanism for regulation and control becomes vitally important. Despite their obvious and noted shortcomings, the recent United Nations accords on Transboundary Air Pollution and on the Protection of the Ozone Layer [2] have set very important precedents for negotiation and settlement on environmental issues at the international level. National laws and regulations also affect environmental control, but their application is very uneven on a worldwide scale.

Major differences in standards of environmental protection from one country to another are as undesirable from a trade union point of view as are differences in working conditions and trade union rights. No worker should have to compete to maintain low levels of occupational and environmental health in order to keep his or her job.

It is common for a Symposium such as this to conclude that the global environmental challenge requires global environmental action. The practical control of pollution, however, must be supported by local agreement, inspection and action. There is no excuse for delay at the local level while discussions grind slowly on in international fora. A number of key areas for integrated action at the international and national/local levels are evident and are outlined below.

### 5.1. Harmonizing and raising the best prevailing standards

Trade unions at the international level have considerable experience with and knowledge of multinational companies which play the perfect employer in countries where regulatory action or trade union organization are strong, but which take full advantage of weakly regulated and organized countries to operate plants that are hazardous both to the workers and the wider environment. Despite the internal cost justifications which companies may devise to defend this situation, there can be no moral justification why standards that can be met for plant operation in Germany or the United States of America, for example, should not also be met in plants producing identical products in Brazil or Malaysia.

### 5.2. Collecting, publicizing and regulating new processes

Any meaningful programme of energy planning for a sustainable future needs a firm basis of analysis and agreement to support its decisions and to monitor its progress. Public accord with the purpose of such a programme also requires greater openness in presenting the environmental facts. The dearth of reliable statistics at every level of the environmental debate is one of the first problems to address.

In 1988 for the first time the United States Environmental Protection Agency published detailed statistics showing a Polluters' League Table illustrating that just 100 firms are responsible for 64% of all toxic releases in the USA. The companies were named. The result of this public exposure was most positive in that it led many of these firms to re-examine their total waste disposal strategies and to adopt proactive approaches to environmental affairs. Statistics also suggest strongly that concentration on the operations of the biggest multinational companies will have the greatest effect on cleanup of the environment. Small scale industry may be dirtier and more difficult to monitor on an individual basis than larger enterprises, but the sheer size of the major corporations means that they are the leading polluters on a consolidated basis, and it is from them that the improvements must come.

### 5.3. Environmental accounting and auditing

Each new environmental revelation tends at present to be treated as an ad hoc emergency — be it ozone depletion, acid rain, nuclear waste disposal, or leaded petroleums. As a result, no overall integrated policy on environmental protection has emerged and no philosophy of response exists to guide regulators in coping with future emergencies or in studying longer term issues for pre-emptive action. The scale and seriousness of the environmental challenge make it essential to establish a forum where discussion can remain current and well informed and can involve co-operation among all parties concerned, with a view to constructing a framework for logical and integrated action.

A system of environmental accounting and auditing needs to be devised on an internationally agreed upon basis which will have force equivalent to the importance of the accounting principles which companies are expected to maintain in respect to their capital wealth. Just as financial accounting is governed by strict regulation and backed by law, the social responsibility of the corporation in environmental matters must also be mandated. In the light of experience in other areas of social concern, only the incurably naive or the intentionally dishonest would believe that this transformation in favour of the environment could be effected without the compulsion of public accountability.

The involvement of workers in monitoring the correctness of such environmental accounts will be essential, for it is often only the workers who know where the company has been dumping its unrecorded wastes or when it has been falsifying its returns. The right to act as a public 'whistleblower' in this context should be a protected and supported right.

### 5.4. Encouraging rapid growth of new technologies

Stricter regulation itself has already been identified as a prime motivator for developing the new processes and products required to clean up the environment and to move energy growth to a fresh, sustainable path. Opportunities for expansion into these socially desirable forms of production need to be identified quickly as a positive part of regulatory action and given high priority in energy development programmes. At the same time, it will be essential to plan and to encourage the movement of workers into these new sectors through greatly enhanced transitional programmes of training and socio-economic support. Demands for ongoing education within a constantly changing work context need to be reinforced.

The move to new, clean energies needed to power the balanced ecological development of future industries is not a foregone conclusion. With the appearance of a 'carbon tax' on the political agenda to 'claw back', i.e. require environmental cleanup costs from fossil fuel users, a great deal of money is being spent on solar and other alternative energy options. The most difficult barrier still remains, however, and that is the tendency of energy providers to look for centralized generating solutions where revenues can be drawn down from metered consumption.

Photovoltaic technology, for example, can be viewed as a mass collection facility, located in space or in the desert, with its power output carried or beamed to user networks far away. The time and capital needed to develop this scenario are likely to delay severely the likelihood of its being seen as a realistic part of the solution. Such alternative technology could also be seen, however, in an alternative pattern where collection takes place on a distributed basis — implying that profits will need to be built into the equipment itself rather than into the distribution mechanism. For workers who are looking ahead to future career planning, recognizing this difference is vital in negotiating early manpower training requirements.

### 5.5. New approach to debt and development

It is unlikely that international calls for environmental protection will be heeded by developing countries until some serious concern is shown by the industrialized world over the more immediate economic plight of third world nations. Well fed and housed populations of the developed countries bemoan the loss of tropical forests in faraway places, but live themselves in the relative luxury created from years of industrial pollution which has spread to the rest of the world. The economies of the developed countries also have long relied upon third world economies to sustain their growth. The latest manifestiation of this phenomenon is the scale of third world debt. Until this situation is challenged, no call for restraint in approaching environmental questions is likely to be taken very seriously.

One Brazilian observer has commented that if the tropical forests are the lungs of the Earth, debt is its pneumonia. The most important single contribution to developing a sustainable energy future is likely to be an agreement on the ways and means of transferring cleaner technologies to developing lands at prices they can afford. This is also perhaps the thorniest problem of all.

This framework for controlling change implies some rather far reaching modifications in current practice. These are likely to prove much less disruptive than the turmoil (both environmental and social) that would eventually result from the failure to take planned social action to meet the powerful destructive forces that neglect has already unleashed. The most secure basis for effecting such policy changes is an informed and concerned democracy.

Trade unions do not limit their area of intervention only to what happens inside the gates of the power station. Democracy implies and includes the assertion of common ownership rights over the natural environment, rights which have been violated in the past by industry without discussion or consultation. Within the processes of collective bargaining for change in industry as well as in the social and political institutions where long range energy futures are hammered out, these rights will be asserted by the trade unions as essential elements of progress towards a sustainable electric power industry.

## REFERENCES

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# SUMMARY OF STATEMENT

**S. Boyle**
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In his statement the author noted that since the opportunity to address the Symposium had been given to him at such short notice, he was unable to present a detailed paper which did justice to Greenpeace's research. Instead, he intended to restrict his remarks to a few observations on the analyses and discussions at the Symposium and Greenpeace's perspective on some of the elements of a truly sustainable energy future.

Concern about the environmental consequences of utilizing large quantities of finite fossil and other fuels prompted Greenpeace to support the precautionary principle in dealing with energy and pollution issues. There was, in his view, a clear distinction between the precautionary principle and the no regrets policy, which a number of governments, including that of the United States of America, had adopted. The precautionary principle went much further than the no regrets policy. As several speakers and panellists had confirmed, the 'business as usual' scenario was totally unacceptable and fundamental changes in approach and thinking were needed among energy industries and governments.

He was both surprised and somewhat disappointed with some of the apparent consensus views which had been presented at the Symposium, particularly those presented from the perspective of the electricity industry. While mention had been made in general terms of the demand side issue, there had regrettably been no detailed consideration of studies such as Energy for a Sustainable World by Goldemberg et al., the eight nation case studies by the Battelle Memorial Institute covering OECD and former countries of the Council for Mutual Economic Assistance, the electricity technology assessments by the Rocky Mountain Institute, and the very detailed analyses on both the potential and the realized savings by a large number of utilities in North America and Western Europe.

End use efficiency had been referred to only as a means of slowing down the apparently inevitable increase in electricity demand. The improvement in efficiency suggested was of the order of 10–20% over the next few decades, which was considerably below the actual technical potential, as indicated by E. Müller (Germany) in her presentation (SM-323/25). One example demonstrating the success of end use efficiency was a recent assessment of 45 efficient lighting programmes, under which 2 million energy efficient light bulbs had been installed in Europe, which had indicated that the total cost to society was 2.1 US cents per kilowatt-hour. It seemed to be assumed that only a small proportion of the technical potential could be realized in practice, although some of the better designed and better marketed demand side management programmes in the USA were, in fact, proving very successful in this area.

It should be remembered that electricity was just a subsector of the energy sector itself. Discussions at the Symposium had largely ignored the wider energy context by elevating electricity to the most important sector, and by generally assuming that it would grow to dominate the whole energy sector in future. It was, however, not yet clear whether electricity was the most suitable means, in terms of efficiency and environmental impact, of providing a wide range of energy services. If sustainable development was to have any meaning in relation to the electricity industry, electricity consumption would have to stabilize or be reduced. However, no electricity demand scenarios and projection curves to achieve this in either industrialized or developing countries had been presented at the Symposium.

The cost effectiveness and the scale of the electricity contribution to be made by the range of renewable energies had, with only a few exceptions, been inadequately represented. Generally, the contribution to be made by renewable energies had been dismissed as minimal, accounting for only a few per cent of electricity demand in the period up to the year 2010. However, if the time horizon was extended beyond the year 2010, if hydropower was included in the analysis, and if at least some element of externalities was introduced the picture was very different, as A. Zervos (Commission of the European Communities) (CEC) (Paper SM-323/21) and O. Hohmeyer (CEC) *(Consultant)* had noted. He personally wondered how nuclear power would have fared in the 1960s if it had been analysed and treated in the same way as renewable energies were at present. The relatively environmentally benign nature of many of the renewable sources, linked to more appropriate financing schemes for the technologies in order to take into account their high capital cost, could allow rapid deployment of renewable energies over the next few decades.

The methodology of many of the analyses at the Symposium had been to base electricity demand and technology projections for the future on past experience and the role of end use efficiency and renewable energies had been almost entirely considered in terms of inherently high projections of increasing electricity demand. In contrast to this approach, the 'bottom up' type of analysis of end use service needs was not locked into the past, but considered the potential technology and policy solutions to specific problems and allowed directly comparable economic analysis of both supply and demand side options.

The view had been expressed that the electricity industry was only a small part of the problem. Although in most countries electricity provided less than 15% of final energy demand, electricity consumed 25–40% of primary energy, usually constituted the largest single source of $CO_2$, sulphur dioxide and radioactivity emissions, and absorbed a large proportion of the available investment capital. The industry therefore needed to bear a proportionate share of the responsibility for environmental problems.

The availability of cost effective efficiency and renewable technologies was such that an immediate start could be made towards reducing the reliance on fossil fuels and nuclear power. The major barriers to a future free of fossil fuels and nuclear power were not technical or economic, but social, political and institutional. There was evident resistance on the part of the electricity industry and unwillingness to adopt least cost integrated resource planning and demand side management. Governments should therefore provide financial incentives to encourage utilities to make such transitions. In addition to least cost planning, other policy options involved inclusion of externalities in the costs, imposition of energy taxes, removal of subsidies, establishment of minimum efficiency standards, preparation of extensive information programmes, substantial increases in and rationalization of all energy R&D programmes and, above all, a commitment by governments and utilities to act.

## SUMMARY OF DISCUSSION

### General Plenary Session

*Chairman:* **C. Bandara** (Sri Lanka)

*Panellists:* **F. Caccia Dominioni** (Commission of the European Communities) (CEC)
**Young-Gun Lee** (Republic of Korea)
**J. Mukai** (Japan)
**R.S. Chandran** (India)
**G. Vajda** (Hungary)
**P.L. Ziemer** (United States of America)

F.H. HAMMAD (Egypt) wondered what the future prospects were for nuclear power in Hungary.

G. VAJDA (Hungary) noted that Hungary was undergoing the difficult transition from a planned economy to a market economy, with the resulting decrease in industrial output, Gross Domestic Product, electricity consumption and living standards, and an increase in unemployment. In view of the uncertainties of the situation, a flexible energy policy was necessary. Combined cycle gas turbines of 100–150 MW would be put into operation over the next few years and, where possible, would co-generate heat and electricity. Three options for a base load power station were currently being considered, namely, a nuclear plant, a conventional plant based on open cast mined lignite and a coal fired plant based on imported hard coal. Public acceptance would play a fundamental role in the decision. Experience with nuclear power plants was very good. There were currently four 440 MW units with pressurized water reactors. They offered high reliability, a good level of safety and the generating costs were the lowest of all the sources of electricity production in Hungary. However, the future of the nuclear option was uncertain owing to problems of public acceptability.

J. MARECKI (Poland) wondered whether the reduction in $SO_2$ emissions from power plants over the period 1980–1990, as indicated in G. Vajda's paper (SM-323/29), was largely attributable to the growing share of nuclear energy in Hungary's total electricity production, or whether it was the result of installing special desulphurization equipment in conventional coal fired power plants.

G. VAJDA (Hungary) replied that the sharp decrease in $SO_2$ emissions had resulted from the increased use of nuclear power, which currently accounted for half of the indigenous electricity production. Older conventional power plants had consequently been reduced to medium and peak loads, with a resulting lower fuel consumption.

L. D'ANDREA (Economic Commission for Europe) (ECE) said that J. Mukai (Japan) had indicated that nuclear power was the 'centrepiece' for Japan's future energy requirements. However, there was strong opposition to the siting and further development of nuclear power plants. He therefore wondered what energy alternatives Japan would consider if constraints were placed on nuclear power.

J. MUKAI (Japan) said that at present no other alternatives were being considered. In establishing the target for the future contribution of nuclear power to electricity production in Japan, the feasibility of new plant construction and the maintenance of existing capacity had been taken into account. Public opposition to nuclear power would make it difficult to achieve this target, but the importance of global environmental problems would make it essential to achieve it. In promoting nuclear power, emphasis was placed on the establishment of a programme for the disposal of high level radioactive waste, vigorous efforts to provide accurate information about nuclear power, expansion of government assistance for safety reviews and control, and international co-operation on safety.

J. GRIFFITH (USA), noting that nuclear power appeared to be classified as both a domestic and an imported energy source in Japan and the Republic of Korea, wondered what criteria were used to decide whether it was a domestic or imported energy source.

Young-Gun LEE (Republic of Korea) said that nuclear energy was usually classified as an imported energy when referring to consumption. However, in terms of the supply structure, nuclear energy could, to some extent, be regarded as a domestic energy source. To be more precise, one could call it a semi-domestic energy source.

J. MUKAI (Japan) said that nuclear power was also regarded as a semi-domestic energy source, since nuclear power plants could continue operations for some 2–3 years after any abrupt cessation of nuclear fuel imports. This projected operating time was based on the lifetime of the fuel assemblies, the significant amount of nuclear fuel in fuel assemblies in the country and the fact that energy production from existing nuclear fuel could be increased by reprocessing.

T. KANOH (Japan) said that he would be interested in hearing about the future role of electricity in the transportation sector in the USA and the Republic of Korea. Transportation was a sector where energy consumption had been increasing and would continue to increase, not only in relative but also in absolute terms. It was also a sector in which fuel switching had not yet taken place. He wondered what the prospects were for the introduction of mass transportation systems, such as high speed commuter trains, and the introduction of electric cars.

P.L. ZIEMER (USA) said that the national energy strategy included incentives and involved R&D in the area of transportation. Other fuels, such as natural gas, were beginning to be used for government cars and, more generally, within the context of a free market, use of various alternative means of transport was encouraged through a number of strategies.

Young-Gun LEE (Republic of Korea) said that decision makers in the electricity sector had given little attention to the transportation sector, since its share of energy consumption was quite small. However, with the rapid increase in cars, the transportation sector would have to be given more attention in the future in terms of energy conservation.

T.R.S. CHANDRAN (India) agreed that a distinction had to be made between developed and developing countries and even between developing countries at different stages of development. For example, recently industrialized countries were in a better position to adopt new, environmentally more benign technologies for electricity generation than low income countries where supply of energy at minimum cost was an essential consideration. In India, a massive 'social forestry' programme had been initiated with the main objective of meeting local fuel and fodder needs in rural areas. If it also helped to reduce $CO_2$ levels, this would be an additional advantage. However, land in India and other countries of South Asia was not plentiful and village common lands providing free fodder and fuel for the rural poor were becoming scarcer. Use of such lands for commercial energy forestry to generate electricity for the rural elite would only worsen the position of the poor.

J.M. KINDELAN (Spain) said that in his view undue emphasis was being given to the importance of the $CO_2$ problem in all meetings on energy and the environment. It was true that the increase in the $CO_2$ percentage in the atmosphere was a cause for concern. However, by presenting the problem as a future ecological threat, one only served to encourage the nuclear sector, which was regarded as a major world polluter. As T.R.S. Chandran (India) had pointed out, developing countries first had to combat more urgent priorities associated with poverty before dealing with problems of $CO_2$ emissions. Although it seemed certain that the $CO_2$ level in the atmosphere had increased over the last 100 or 150 years, $CO_2$ emissions resulting from industrial activities and transportation represented only 3–5% of the total exchange between the atmosphere and the biosphere. Attention should continue to be paid to the $CO_2$ problem, but without taking revolutionary practical decisions which made no economic sense and which would be a crime against developing countries.

F. CACCIA DOMINIONI (CEC) said that while he basically agreed that developing countries had more pressing priorities, this was no reason for industrialized countries to remain passive. In his view, the European Community had adopted an effective and balanced approach to the problem of $CO_2$ emissions. It had also refrained from fixing objectives which were too ambitious and, consequently, unrealistic. It was important to note that representatives of certain developing countries at the Symposium had not ruled out making some contribution.

E. MÜLLER (Germany) noted that the differences in commitment to targets for stabilizing or reducing $CO_2$ emissions appeared to be based on different assumptions concerning energy consumption forecasts. In Germany, for example, it was expected that, as a result of efficiency improvements, economic growth would not lead to increased energy consumption and that, with a business as usual scenario, $CO_2$ emissions could be reduced by 4% by the year 2005. Other countries seemed to think that economic growth was inevitably linked to an increase in energy consumption. It was important to clarify the different assumptions in this area and she wondered what the attitudes to the problems were in the USA and Japan.

P.L. ZIEMER (USA) said that if no measures were taken, an 80% increase in $CO_2$ emissions could be expected by the year 2030 in the USA. However, the national energy strategy planned to reduce this rate of growth in $CO_2$ emissions to 38%. If one considered all the greenhouse gases, rather than just $CO_2$, it was expected that emissions could be maintained at the current levels for the foreseeable future.

J. MUKAI (Japan) said that the policy on $CO_2$ emissions provided for a stabilization on a per capita basis at about the 1990 level by the year 2000 through implementation of a wide range of measures to be adopted by the Japanese Government and by private sectors.

L. McCONNELL (Canada) said that the target set at the Conference on the Changing Atmosphere, held in Toronto in 1988, was a 20% reduction in $CO_2$ emissions by the year 2005 in all developed countries. He wondered whether a 20% reduction in $CO_2$ emissions could be achieved in the electricity subsector.

J. MUKAI (Japan) said that there were no official estimates of $CO_2$ emissions specifically for the power generation sector. The latter was at a disadvantage inasmuch as other sectors could reduce $CO_2$ emissions by switching to electricity. He believed that, provided the shift to electricity by other sectors was not too large, the target of stabilizing per capita emissions of $CO_2$ by the year 2000 at the 1990 level was feasible.

P.L. ZIEMER (USA) said that the set of actions outlined in the national energy strategy aimed at stabilizing all future greenhouse gas emissions at or below the 1990 level for the period up to the year 2030.

F.H. HAMMAD (Egypt) noted that the Symposium had devoted a great deal of attention to the $CO_2$ emissions and health and environmental impacts resulting from the burning of fossil fuels. However, he wondered whether any calculations had been made on the amount of $CO_2$ released and the health impact and contribution to global warming of the oil wells which were burning in Kuwait and which would continue to burn for almost a year.

F. CACCIA DOMINIONI (CEC) said that as far as he knew no such calculations had been made. Nevertheless, the CEC had promoted actions to extinguish the burning oil wells in Kuwait as quickly as possible. In his view, the situation was more serious in energy terms, in terms of the loss of millions of tonnes of oil, rather than in environmental terms.

P.L. ZIEMER (USA) said that his understanding was that all the calculations showed that the amount of $CO_2$ being emitted from the burning oil wells was extremely small and was not thought to have any significant impact on global climate change. The major concern was the local effects, particularly the impacts on the health of those living in the area.

O. HOHMEYER (CEC) *(Consultant)* wondered whether it was correct that over the last 5 years electricity consumption had decreased in California, while it had increased by some 2–3% per annum in most other states in the USA. During the same period, California had enjoyed similar economic growth rates as the rest of the country. If these facts were correct, he wondered whether the differences could be explained by radical differences in the energy policy instruments employed. It appeared that in terms of least cost planning and demand side management practices, California could be regarded as having the leading edge in developments in the USA, while the United States Department of Energy (DOE) appeared to be the trailing edge. Given a projected growth of 38% in $CO_2$ emissions from sources in the USA by the year 2030, he wondered whether there was no concern in the USA that developing countries might demand equal $CO_2$ emission rights per capita.

P.L. ZIEMER (USA) said that energy policy varied from state to state within the USA, but pointed out that under the national energy policy an attempt was being made to address the issues in a coherent way. There might well be incentives for other states to adopt policies that worked successfully in California. With regard to the issue of greenhouse gases, it was the DOE's view that $CO_2$ was not in itself an issue, but that a multitude of greenhouse gases were involved, and the objective of the national energy strategy was to keep the total level of greenhouse gases fairly constant.

G.P. HALBRITTER (CEC) *(Consultant)* said that after hearing earlier in the Symposium about the interesting concepts for future energy planning in the USA, such as least cost planning, internalization of external costs and new tariff structures, he was shocked to hear P.L. Ziemer (USA) refer to a projected additional capacity of 200 000 MW by the year 2010. He wondered what the justification for such an expansion was, particularly in view of the fact that the USA had the highest per capita energy consumption in the world.

P.L. ZIEMER (USA) said that the figure of 200 000 MW was based on an 18 month study carried out by the DOE, which had collected information from many sectors in the USA and had then attempted to integrate that information into a coherent overall strategy. The strategy also included measures to reduce the rate of increase in total energy consumption which might otherwise be expected on the basis of present usage.

H. KHATIB (World Energy Council) (WEC) noted that P.L. Ziemer (USA) had indicated that under the new energy policy, markets would determine prices and technological changes and that the economic value of environmental risks would not be paid for directly by the utility or by the consumer. He wondered how such a view could be reconciled with the view emerging from the present Symposium and other international forums that electricity and energy prices should increasingly be influenced by social costs and by local and global environmental costs, rather than by market forces.

P.L. ZIEMER (USA) said that the policy in many cases was not necessarily to mandate, but to make it attractive for power producers to adopt certain approaches. For example, the national energy policy had certain built in incentives to encourage the private sector to invest in renewable energies and to promote conservation. The fact that reliance was placed on the market place did not mean that environmental goals were being ignored. In fact, the national energy strategy had very definite priorities regarding environmental issues.

K. KING (World Bank) (IBRD) wondered about the practicality of the internalization of external costs in a situation where tariffs were heavily influenced by social (i.e. non-cost related) factors. In many countries, power was made available to agricultural consumers for water pumping at highly subsidized rates for social reasons. If the external costs could not be passed on to the final consumers for social reasons, the utilities had to absorb them, thereby increasing their financial deficits, which in turn had to be underwritten by State governments. In other words, what governments took in one hand in the form of environmental taxes was returned with the other in the form of increased subsidies to utilities. As a result, there was no change in behaviour by either the utility or the consumer. He wondered how T.R.S. Chandran (India) could claim that environmental costs were being internalized in such a situation.

T.R.S. CHANDRAN (India) agreed that internalization of external costs would not be effective unless the costs were reflected in tariffs. It was also true that the existing tariff structure in the various power utilities in India did not conform to economic principles. Nevertheless, it was necessary to include the environmental costs of generation in order to evaluate options for new generating capacity and to make the environmental implications of a new investment decision clear to the government and to the public. There had been calls in India for tariff subsidies to be overt and to be provided by the government in line with their policy objectives. It was evident that the finances of the utilities had to be put in order if they were to raise the capital funds needed to increase the electricity supply.

H. GLUBRECHT (Germany) said that he was surprised that only two of the papers presented at the morning's session had made more than a passing reference to renewable energies. It was true that production of electricity from these sources was only competitive in special cases and at particular sites. However, one should bear in mind that more than 50% of primary energy was used for thermal energy, such as heating of buildings, process heat for industry, hot water, etc. For such applications, solar energy had become much more competitive than it had been and active programmes for its further development were being implemented in all developed and in many developing countries. As far as he was aware there had been considerable success in this area in India and Japan.

T.R.S. CHANDRAN (India) said that the renewable energy sources which had long term potential in India were solar, including thermal and photovoltaic, wind and biomass. Of these, the biogas programme had been fully proven from a technical and economic point of view. There were currently about 1.2 million family owned biogas units functioning in different parts of India. They were not intended for electricity generation, but primarily for providing heat energy for domestic cooking. Solar and wind energy programmes were still at the R&D stage. A large number of photovoltaic units had been set up in order to assess their viability for various applications, but as yet they were prohibitively expensive. Wind speeds were generally low in tropical countries, although there were some locations where wind energy could be exploited. In India, greater attention was being given to use of wind energy for irrigation pumping, where variability of output was not a serious problem.

J. MUKAI (Japan) noted that part of Japan's energy policy was to improve energy independence by having an adequate mix of oil substitute sources such as nuclear energy and coal, new energy sources and dispersed power sources such as fuel cell, solar and wind, which were expected to account for 2%, or 5700 MW, by the year 2010.

# KEY ISSUES AND FINDINGS
## and
## ROUND TABLE
## on
## *Challenges for International Co-operation*
## (Closing Session)

**Chairman**
**N. DESAI**
United Nations Conference
on Environment and Development (UNCED)

# SUMMARIES OF REPORTS

## Energy and Electricity Supply and Demand
### *Implications for the Global Environment*

**Key Issues Paper No. 1**

K. LEYDON (Commission of the European Communities) (CEC) *(Chairman of International Expert Group 1)* said that a major factor impeding planning and hampering decision making was the considerable uncertainty that existed in a number of areas. First, the scientific uncertainty of the nature and dynamics of the phenomenon of global warming and the impacts which it would have on particular regions; second, the uncertainty regarding the cost of handling these problems since, although there had been some major progress in research and analytical work, no hard and fast conclusions had been reached; and third, the problem of policy uncertainty since, if the exact nature and extent of the problem were not known and if it was also not known how it could be solved technically, it was very difficult to define a policy mix that could be described as anywhere near optimal. The wide range and enormous number of actors involved also had to be considered.

Much had been said about $CO_2$ in the Symposium, but not as much about methane or chlorofluorocarbons. The $CO_2$ problem was perhaps more difficult to define than the problem of chlorofluorocarbons had been. It was a problem involving all countries of the world and affected areas ranging from power generation to rain forests in Brazil. The uniqueness of the problem, at an international level or even at a national level, made it a unique management problem, and the difficulties of its solution should not be underestimated.

Expert Group 1, which had looked at the relatively smaller problem of supply and demand at a global level over a period of 20-70 years, clearly could only identify some key points. These focused on three main themes: the quality of life; the financial needs and the conflicting objectives; and options in the energy and environment debate.

It would appear that there was a consensus that economic welfare and growth were not incompatible with a healthy environment. In developing countries, electricity services had been regarded as a tool for supporting industrialization, increasing productivity throughout the economy and improving living standards. However, in general, the electricity supply industries in developing countries, which had not fully recovered from the oil shocks and the major depression in world economic growth in the 1970s and 1980s, were not well placed financially to face the needs of the 1990s. A priority in reconciling development needs was to reconcile the financial needs so as to alleviate the financial crisis being faced by electricity supply industries in developing countries. It was not for the present Symposium to establish the policy for doing so, but discussions on this issue would include the problems of the transfer of aid, debt restructuring, adaptation of the financial terms and sharing of exchange rate risks. These were problems faced not only by developing countries but also by countries in Eastern Europe. In both cases, issues of financing, capital transfer and technology transfer would have to be given priority. However, in Eastern Europe the situation was somewhat different, since it was a region with high per capita use of energy and electricity but low service quality. With increases in generation and end use efficiency, there was a good chance that energy demand and the consequent emissions in this region could be stabilized.

There were three main general aspects which needed to be considered: whether the social consensus on global warming was sufficient to induce the public to accept the costs and societal changes required in meeting the challenges; the policy options, and the policy mix, for coming to terms with the problem; the basis for a long term strategy to reduce $CO_2$.

Although there was divergency between the developing world and the industrial world and, within the industrial world, divergency of emphasis between one grouping and another grouping, perhaps the major constraint at present was divergence between the actions that experts judged to be necessary and the way in which the policy makers, and indeed the general public, perceived the problem. There might be a broad directional consensus among the experts, but the question was how this consensus could be transmitted from experts to the general public and policy makers. The problem was most evident in developing countries, where priority was understandably given to economic and social development. As far as environmental issues were concerned, developing countries and countries in Eastern Europe focused primarily on problems of the local environment. Although global climate problems were recognized by experts, they were unlikely to figure prominently at the local level. One of the advantages of the present unique Symposium was the possibility of helping to establish a process in order to develop a broader social consensus. The main need was to find more common ground between public opinion, politicians and experts. This should perhaps be taken as a challenge by the organizations that had co-sponsored the Symposium. They should join together to promote a more effective dialogue between energy and environmental experts on the one hand, and the broader policy making environment on the other.

The second aspect concerned ways of determining the correct policy mix. Perhaps the first step in dealing with long term problems should be to focus on existing problems such as urban congestion in Mexico City, or atmospheric pollution in Silesia or in Czechoslovakia. In doing so, confidence could be built to deal with the long term problems. While the Symposium had focused on discussions about electricity and the environment, it should be remembered that the demand for energy was derived — energy was not an end in itself. Other energy sectors such as the transportation sector, the industrial sector and domestic users should not be neglected. It would, in fact, be wrong to expect the energy industry to solve the global warming problem alone. Complementary policies had to be implemented in other sectors and there had to be harmony between the actions that were taken in the energy or the electricity sector and those that were applied more widely. There were considerable differences of opinion about the real costs and impacts of different options and strategies. The organizations sponsoring the Symposium might, therefore, consider whether they could contribute to the development of a consensus on this very important issue of costs, particularly on the demand side.

Experts in the electricity supply industry should be aware of the widely held belief in the enormous potential for savings to be made in the end use of electricity, even if industrial experts thought that such savings were not, in fact, technically feasible. In determining the policy mix, consideration should be given to efficiency and the adaptation of investment programmes to meet different needs in different regions. To avoid a breakdown in communication between the problems of the day to day world and the abstract world of the economist or politician, there must be a real understanding of the usefulness of investment programmes and market instruments. Market instruments could include fiscal measures, incentives, adjustments to the taxation system, and innovative new mechanisms to promote financial assistance for appropriate actions in developing countries and in Eastern Europe. Such actions could constitute no regret policies.

The third important aspect concerned the necessary long term strategies. It was important to consider global population growth and new technologies which might ultimately have to replace traditional energy systems. Even with the best current no regret policies and some of the scenarios that had been presented, including those in Key Issues Paper No. 1, with optimistic assumptions about the role of renewable energies, it was evident that $CO_2$ emissions would continue to grow and that this was a problem which required a long term strategy.

## Energy Sources and Technologies for Electricity Generation

### Key Issues Paper No. 2

S. GARRIBBA (International Energy Agency) (IEA) *(Chairman of International Expert Group 2)* said that Topical Session 2 had covered five main points: the status and prospects of generating technologies; ways of achieving environmental objectives; the economics of power generation technologies; the barriers to market development; and the mechanisms to improve access to technology.

Most of the participants in the Symposium had recognized the absence, in the area of power generating technologies, of imminent technological breakthroughs likely to show significant penetration in the near future. In the case of power generation technologies, there was a long lead time in the technology innovation cycle and there were also concerns about energy security. The longer term prospects for the next 30 years included: increasing options for the upgrading and refurbishing of old types of power plant; advances in the conversion efficiency of coal fired power plants; expanded use of natural gas; performance improvements and the possibility of evolutionary design improvements for nuclear power plants; and integration into the grid of new renewable energy sources for base load. In terms of the open issues, substantial new capacity would be required, even with significant improvements in end use and electricity generating efficiency. It was therefore necessary to consider how governments should ensure that adequately diversified generating capacity was available.

With regard to the technologies for achieving environmental objectives, three aspects should be borne in mind: technologies for dealing with conventional pollutants were clearly available, although they might not all be adopted by all utilities in all countries; nuclear power plants in market economies operated with a very high degree of safety; and the large land use requirements for several of the new renewable energy sources. Over the next 30 years one could expect: an integrated approach to total waste minimization in fossil fuelled power plants; implementation of nuclear waste disposal and decommissioning for nuclear power plants; and total life cycle impact analysis for new renewable power systems design. As far as the open issues were concerned, there were two approaches to the problem of climate change: the interim technology strategy or no regrets policy, and the immediate action plan or precautionary strategy. Under the interim technology strategy, which was the reference strategy for the Symposium, those technologies for power production would be adopted which were cost effective and immediately deployable, such as the upgrading of fossil fuel power plants to increase efficiency, expanded use of natural gas, increased adoption of nuclear power and exploitation of renewable energy sources whenever feasible. In the meantime, investments in R&D would prepare new and more effective options for the future.

There were critical parameters in the area of the economics of power generation technologies, such as the type of application of the plant (on grid, off grid) and the load regime. The cost depended on the reference values, including the discount rate and the escalation rate and, in general, new renewable energy sources could only compete for base load on grid production in local situations, so there was no general competition on the basis of costs. Over the next 30 years, a comparatively higher capital investment per kilowatt in next generation power plants and a decrease in costs through power plant standardization could be expected. The open issue to be considered was whether total or social costs (including externalities) should be used as a basis for comparison among power plant options and what type of methodology should be adopted. In particular, the time and space boundaries of the energy systems and the values for externalities should be defined so that they did not prevent free trade practice.

With regard to barriers to market deployment, several constraints limited the spectrum of available power options, including the economic and financial aspects of utilities, regulatory and institutional frameworks, utility requirements and resources, and public acceptance. Over the next 30 years it was likely that there would be: a progressive separation of the vertically integrated electric utility industry in some countries, to increase the scope for competition; fewer impediments to electricity trade, both within countries and among countries; and tariff structures reflecting costs in those countries undergoing economic restructuring. The open issue was to consider how governments should address public opposition to the siting of new electric facilities that would otherwise limit the availability of future generating capacity.

Finally, there was the question of mechanisms to improve access to technology. No single technology was the best choice for every situation, since the cost and availability of energy sources varied on a regional and national basis. It was important also to remember that there were significant differences in the performance records of utilities in the same country and of utilities in different countries. Over the next 30 years, there was likely to be increased inter-utility co-operation to share experience and best practices and co-ordinated action by governments and regulators to give utilities clear long term signals. The open issue was to consider how international co-operation in R&D and technology transfer could promote implementation of the most efficient power generating systems. In this context, it would appear advisable to consider the case of transitional economies separately from the case of developing countries. Possible approaches included equity investments, clearing house mechanisms and special funds. However, it had become clear during the Symposium that there were no second grade or second class technologies for the developing world and that there was a move towards what might be called a globalized technology in response to global problems.

## Comparative Environmental and Health Effects of Different Energy Systems for Electricity Generation

### Key Issues Paper No. 3

M.J. CHADWICK (Stockholm Environment Institute/CEC) *(Consultant)* *(Chairman of International Expert Group 3)* said that four points had emerged from

Key Issues Paper No. 3 and the ensuing discussion. The first point was that comparative environmental and health risk assessment would play a major role in the decision making process in the area of electricity generation planning and would complicate this process in a number of ways.

First, consideration of the environmental and health effects of the entire fuel cycle would elevate the decision making to at least the level of the overall energy sector. Second, the time-scales for many impacts — both health and environmental — were seen to be much longer than was previously thought, and so the traditional 7–10 year capacity planning horizon for power utilities needed to be extended to perhaps a 40 year horizon. This longer planning horizon would require a different view of the dynamics and the determinants of technology change, since it was no longer just a problem of choosing the optimal mix of currently available power technologies, but emerging new technologies would also have to be considered. Third, the global environmental dimensions of electricity generation made it necessary to go beyond even the energy sector, since other sectors were obviously related to many of the impacts and effects.

To deal with the complexities involved, there was a need to establish an authoritative, co-ordinated international database on the health and environmental risks for different energy sources, including the establishment of appropriate mechanisms for the collection, assessment and dissemination of data. There was also a need for a co-ordinated R&D effort to qualify environmental indicators and to develop related methodologies for comparative environmental risk assessment. Furthermore, there was a need to ensure a formal co-ordination and liaison mechanism among the various international organizations with an interest in health, environment and energy issues, so that it would be possible to deal creatively with the range of research policies and other issues.

While Key Issues Paper No. 3 did not consider the question of risk perception in detail, it was acknowledged that there were discrepancies between quantitative estimates of risk, as reviewed in the paper, and the public perception of such risks. Public fears about nuclear power were just one of many examples and such fears could not just be dismissed as unfounded. Comparative risk assessment could provide a useful input to assist in addressing public risk perception issues. Presentation of quantitative numerical risk estimates in isolation would probably be of limited benefit. It would be more helpful to explain the assessment process itself and the range of impacts and the uncertainties involved.

The second point was that there would be a demand for greater public participation in decision making on matters concerning health, environment and energy, and there was a need, in many cases, to re-examine current practices of public participation, with the aim of developing more efficient mechanisms. The usefulness of comparative risk assessment studies could be maximized within this broad framework of public participation. Indeed, one of the major features of public perception of risk was associated with uncertainty, and risk perception was very often dominated by personal experience and by the supposed uncertainties. Furthermore, where there was a large disparity between those who stood to gain and those who stood to lose, there also tended to be a larger disparity between the risks as perceived by those on the outside and the risks as evaluated by the comparative risk assessment procedures.

The third point was that some of the major actions aimed at dealing with the risk of climate change resulting from increases in radiatively active trace substances (greenhouse gases) were also actions that could be recommended purely on the basis of good practice. In spite of the uncertainty, and the generally recognized implications of this uncertainty, the increase in atmospheric concentrations of carbon dioxide and other radiatively active trace gases over the course of the past four decades was a cause of concern. Rises in the concentration of these gases gave the potential for global warming and the many changes that may result from this. In spite of the commitment that had already been incurred, climate change control or adaptive responses had to be considered and their implications evaluated. Adoption of the precautionary principle could not prevent some climatic modification, but could reduce it. It was possible to make investments that would be prudent in any case, such as the promotion of energy conservation and encouragement of the efficient use of high grade fuels. It was natural that responses to possible climate changes were not regarded as high priorities in many developing countries. However, many of the environmental impacts discussed at the Symposium would be borne disproportionately to the disadvantage of developing countries, where the related catastrophic events tended to be much more serious. The costs of controlling carbon dioxide emissions and of adapting to global climate change would eventually have to be met by the consumers. The process of identifying full costs needed to be encouraged, so that the costs could be carefully evaluated and eventually internalized. In many respects, this would tend to make electricity generating decisions more realistic and result in more efficient practices, but it would complicate the process of reaching decisions.

The fourth point was that it was necessary to analyse accidents more closely within the overall risk assessment procedure, particularly in order to identify and highlight the key features of accidents in particular fuel cycles. All major fuel cycles in electricity generation systems in routine operation and fitted with state of the art technology were able to deliver electricity with relatively low risk to health. However, most energy systems had a potential for severe accidents. It was necessary to take account of the longer term effects that were likely to become evident and to consider mortality and morbidity statistics through close analysis and assessment. For all accidents, distinctions needed to be made between the occupational and public health effects, both in their assessment and in their presentation. The key features of the fuel cycles in energy systems also needed to be given prominence in the presentation of data on long term effects. Long term environmental effects, including those that are irreversible, or the bias of particular fuel cycles to long term rather than immediate accidental effects needed to be highlighted. For the whole range of accidents related to electricity generating systems, a complete and accessible database was required so that common analyses could be made in order to provide a solid comparative foundation for decision processes and to reduce the frequency of accidents.

## Incorporation of Environmental and Health Impacts into Policy, Planning and Decision Making for the Electricity Sector

### Key Issues Paper No. 4

M. MUNASINGHE (World Bank) (IBRD) *(Chairman of International Expert Group 4)* said that the overall thrust and main themes presented in Key Issues Paper No. 4, particularly the decision making framework, had generally been supported in the discussions during the Symposium. Some specific implications and modifications had been highlighted in the discussions and had provided useful additions. A few remaining key issues could be selected for further exploration.

The first issue related to the financial requirements and the global financial implications of various technology options and scenarios. The electricity sector was very capital intensive and had macroeconomic and debt implications, and the financial needs would be very dominant in terms of pricing policy and resource mobilization. The second issue was that of financial sources and mechanisms for mobilizing adequate funding. The third issue concerned the allocation of priorities. For example, in setting R&D priorities it was necessary to consider whether it was plausible to think of a future with only renewable energy sources, or whether more money should be spent on particular fossil or nuclear technologies. Exploration of these aspects needed to take other sectors into account, because many environmental problems involved a significant contribution by other sectors.

Another important area which was discussed was burden sharing and equity. The issues to be considered included the criteria for global and domestic burden sharing, such as the affordability of different measures and the ability of different countries to pay. For developing countries and some of the countries of Eastern Europe and the Soviet Union, the ability to address environmental problems at both domestic and global levels would be constrained by the affordability of response measures. There were economic efficiency criteria, based on the polluter pays concept, which had to be included, such as taxes on carbon emissions and other pollutants to bring market mechanisms into play. The principle of equity and fairness had been touched on and perhaps needed to be explored further, including whether responsibility for past pollution had a bearing on the discussion of burden sharing. There was a clear need for industrialized countries to show leadership in addressing the problems and in assisting other countries to do so. For local environmental problems, increased conventional aid would be required. In the case of global environment issues, a system of compensatory grants was necessary, so that if less wealthy countries had to incur costs in tackling global problems they would be entitled to receive compensation.

The energy crisis of the 1970s had highlighted the need for greater energy efficiency and the need for higher prices, but despite the clear and compelling evidence, many countries had not taken the necessary action. Increased concern about the environment only served to complicate the matter still further, since it was a global problem and also involved unfamiliar costs. Furthermore, environmental analysis tended to focus on natural or biological systems such as land systems, water systems, natural habitats and air pollution. However, the real world was organized according to socioeconomic structures, such as national economies and sectors such as energy, transport and industry within national economies. A single issue such as air pollution was affected by contributions from a number of these sectors. Therefore, in analysing air pollution one could not single out the electricity sector either for analytical purposes or for policy implementation. Instead, it was necessary to gather data from a range of sectors and to co-operate with those working in other sectors to establish a comprehensive policy framework.

Another problem was the problem of valuation. It was very difficult to translate values from one domain into another. One approach was to apply environmental impact assessment and environmental economics, in which an attempt was made to assign values or weights to environmental degradation and then to incorporate these into the sectoral decision making process. However, there were formidable problems associated with this approach, including problems of valuing environmental impacts and the impossibility of valuing impacts such as the loss of biodiversity or rare species, the value of a human life and certain health risks. It was therefore necessary to use other techniques such as multicriteria analysis in order to incorporate this weighted trade-off mechanism into the decision making framework.

The techniques used in the power sector for traditional least cost planning, pricing, etc. were among the most sophisticated in any sector. As a result, the electricity sector was probably better equipped than most other sectors to cope with the additional problems of the environment. The electricity sector should show leadership in responding to the environmental challenge and in actively looking for solutions.

Finally, it was important to consider follow-up actions to the Symposium. One proposal would be to organize a set of regional workshops for senior decision makers at the ministerial level or heads of power companies in four or five regions; the organizations sponsoring the Symposium may then relate the findings of the Symposium to the regional priorities which would emerge. After the United Nations Conference on Environment and Development and after the proposed regional workshops, it might be worthwhile, at the end of 1992, to reconvene at least some of the experts from the Symposium to review the situation and to see whether some of the findings and discussions had, in fact, been incorporated into the decision making process, and to consider what further steps should be taken.

# SUMMARY OF ROUND TABLE

## *Challenges for International Co-operation*

*Chairman:* **N. Desai** (United Nations Conference on Environment and Development) (UNCED)

*Members:* **F. Caccia Dominioni** (Commission of the European Communities) (CEC)

**R. Cibrian** (CEC)

**L. D'Andrea** (Economic Commission for Europe) (ECE)

**B. Semenov** (International Atomic Energy Agency) (IAEA)

**A. McKechnie** (World Bank) (IBRD)

**S. Garribba** (International Energy Agency) (IEA)

**B. Wahlström** (International Institute for Applied Systems Analysis) (IIASA)

**G.H. Stevens** (Nuclear Energy Agency of the OECD) (OECD/NEA)

**S. Tarkowski** (World Health Organization) (WHO)

**L.E. Olsson** (World Meteorological Organization) (WMO)

F. CACCIA DOMINIONI (CEC) said that Key Issues Paper No. 1 had indicated that electricity demand was going to increase, not only in developing countries but also in industrialized countries. Efficient generation and use of electricity was therefore of crucial importance. The European Community had recently adopted important initiatives which, while focusing on the efficient use of electricity, did not neglect the promotion of greater efficiency in electricity generation through the development of appropriate technologies. These Community initiatives were aimed not only at Community Member States but also at international organizations and countries outside the Community, particularly those in Central and Eastern Europe, the Soviet Union, as well as developing countries. In his view, the efforts made by these countries in the short and medium term should focus on the transfer and promotion of better technologies for electricity generation.

The second main issue raised in the Symposium concerned the substitution of other less polluting energy sources for fossil fuels. Use of economic and fiscal instruments to promote this substitution would probably be indispensable, even if it was likely to create certain problems. It was clear that gas was playing an increasing role in electricity generation. However, its development should be studied carefully so that its role did not become so large as to affect the security of supply. In the area of nuclear power, the work done by the Community on the safety of nuclear power plants and waste management was well known. It was to be hoped that increased co-operation among electricity producers, designers, safety authorities and institutes, research centres and others working in the field of the peaceful uses of nuclear energy would result in improved safety, which would in turn lead to better public acceptance of nuclear power. This would be of particular benefit to Central and Eastern European countries, the Soviet Union and those developing countries which had the necessary infrastructure to promote this complex technology. The Community was also working actively in the area of renewable and new energy sources. However, while it was true that there were not the same political difficulties as in the nuclear field and while these new sources should not be neglected, it seemed that unless there were spectacular technological developments these sources could only serve to top up supplies. As Expert Group 2 had indicated, "as stand alone alternatives to fossil or nuclear plants, these [renewable energy] technologies would require energy storage which significantly increases the costs".

On the subject of the third topical session, he fully supported the point made by Expert Group 3 concerning the need to establish a comprehensive, internationally co-ordinated database on the environmental and health effects of different energy systems, and he would recommend the establishment of such a database to his authorities.

Finally, Expert Group 4 had noted that there was a degree of paralysis in a number of countries regarding decisions on investment in the electricity sector. As K. Leydon (CEC) had pointed out, it was essential to find more common ground between the public, politicians and experts in order to develop a broader social consensus. The organizations co-sponsoring the Symposium should take up this challenge. The Symposium itself was a start since, as far as he was aware, it was the first time that a symposium on such an important subject as the interface between energy and the environment had been organized jointly by such a large number of organizations. Further initiatives should be taken, since by coming to concerted conclusions the international community would have a much greater chance of being heard by the public and by political authorities.

R. CIBRIAN (CEC) said that he believed that it was appropriate to draw attention to the assistance and co-operation programmes managed by the Commission on behalf of Community Member States. In addition to the bilateral programmes between Community Member States and all the developing countries of the world, the Commission managed a Community programme, which had been focused in the past on countries of the African, Caribbean and Pacific (ACP) regions which were party to the Lomé Convention between ACP States and the European Economic Community. This programme was currently being expanded gradually to include all Asian and Latin American countries. A significant percentage of the Community's global budget was, and would continue to be, set aside for assistance. Although there would be no reduction in the assistance provided to developing countries, the social, political and economic developments in Central and Eastern Europe made it necessary to pay particular attention to these countries, for which the Commission had established specific assistance programmes. While the Commission and Community Member States had ideas about the priorities on which these programmes should be based, these programmes would reflect the wishes of the recipient countries. In view of the expected growth in the demand for electricity and energy, it was important to give priority to the technological possibilities for improving efficiency.

In addition to bilateral co-operation, a continuing process of political and economic integration was taking place, which would lead to a genuine, stronger European Community. The Commission would undoubtedly acquire more responsibilities during this process and it intended to expand its co-operation at the multilateral level with all international organizations. For example, in the area of nuclear safety there had been a very significant increase in recent years in co-operation between the CEC and the IAEA.

With regard to specific environmental concerns, the Commission's major target was to stabilize $CO_2$ emissions at the 1990 level by the year 2000. The Commission would focus its efforts on this target and try to influence the policies of its Member States. Achievement of this target would involve greater use of gas and some expansion of nuclear power, or at least completion of the nuclear power plants under construction. Renewable sources would also make a by no means negligible contribution, since estimates made by the Commission suggested that these sources would cover 2–3% of the future electricity supply in the Community and account for about 20% of the total reduction in $CO_2$ emissions needed to meet the Community's target. Research and development efforts in the area of renewable energy sources would continue to be given prominence.

As far as the nuclear option was concerned, it currently represented nearly one-third of electricity production in the Community, and was likely to remain at this level. He personally regretted that it would not be possible to increase its share owing to the failure to address satisfactorily certain problems, some of which were of a technical nature but most of which were of a political nature. To strengthen the potential of nuclear power, it was necessary to increase international co-operation in the area of nuclear safety, to make progress in the area of radioactive waste management and to develop and promote new advanced reactors. It was also important to focus efforts on public information, to explain exactly the nature of the risks associated with nuclear power and to respond to the considerable amount of non-factual information which continued to be disseminated on the subject.

L. D'ANDREA (ECE) explained that the ECE was one of five regional United Nations commissions. It was established in 1947 and its basic mission was to promote co-operation among its Member States, comprising countries in Eastern and Western Europe, the United States of America and Canada. Since none of the ECE's decisions carried any force of law, a consensus process had to be developed for governments to agree on the work to be done and the methods to be employed.

One of the findings of the Symposium was the importance of energy efficiency measures in the electric power sector. The ECE Secretariat was currently implementing a project, involving national and international organizations, called Energy Efficiency 2000, which was designed to promote energy efficiency and environmentally sound technologies. Estimates made by the ECE's senior advisers on energy suggested that measures to improve energy efficiency in countries currently undergoing economic transition could save as much as 540 million tonnes of oil equivalent by the year 2000 and could reduce $SO_2$ and $CO_2$ emissions by as much 20–25%. More detailed information on the project was available from the Energy Division of the ECE in Geneva.

In the area of natural gas, the ECE was making an assessment of methane emissions resulting from natural gas operations. In this connection, he believed that information being published on the scale of methane emissions worldwide should be read with caution, since more precise measurements needed to be made. A study was also being conducted to find ways of integrating and extending the natural gas grid of Europe in order to supply countries in Eastern Europe, such as Albania, Czechoslovakia, Hungary and Poland, which had, in the past, tended to rely exclusively on the Soviet Union for their natural gas imports.

The ECE was also active in a number of other areas. It was striving to reduce emissions resulting from coal combustion. Symposia were being organized in Yugoslavia and in the Soviet Union on energy efficiency measures in industry. New concepts in electrical tariffs and gas tariffs for countries in transition were being developed and introduced. Efforts were also being made to promote public awareness in order to encourage the public to have a better appreciation of the importance of energy. A symposium was to be held in Warsaw on this subject. Activities were also being carried out by the environmental divisions of the ECE and protocols had been signed by governments on $SO_2$ and $NO_x$ emissions.

Although all these activities tended to focus on regional concerns, the ECE emphasized that it was very important that the activities of its various working bodies should be carried out in an international context and in co-operation with international organizations in order to achieve common objectives and interests. For their part, representatives of the ECE attending the Symposium would of course submit the results of the Symposium to the appropriate subsidiary bodies of the ECE for their consideration. At the same time, he urged other participants to inform their respective government organizations about the results, so that common objectives could be achieved with a view to providing reliable and safe electric power to consumers.

B. SEMENOV (IAEA) noted that the major topic of the Round Table was challenges for international co-operation. The Symposium itself was probably the best example of international co-operation, gathering together as it did all of the most important international organizations dealing with electricity and the environment. Since most of the international organizations dealing with the subject of the Symposium were rather specialized, it was only by combining efforts that really objective and acceptable suggestions and ideas could be produced.

In the case of nuclear power, one of the major problems was acceptance of nuclear power, both by the public and by decision makers. For this reason, the IAEA was, perhaps more than any other international body, interested in joining efforts to produce objective information to serve as a basis for comparisons of different energy sources. More effective dialogue between experts, policy makers and the public was therefore of great importance.

One very interesting idea which had been raised was the establishment of an international database on the environmental and health effects of different energy systems. For many years, the IAEA had been studying the economics of different energy sources and in 1991 a comparison of the health and environmental impacts of different energy sources was included in the programme known as Subprogramme X. This programme envisaged the establishment of a databank, the creation of methodologies for comparison and the introduction of economic, health and environmental factors into energy planning. The IAEA had already developed a computerized methodology for assisting its Member States in energy and electricity planning and, in future, factors not only of economic but also of environmental and health impacts would be included. The IAEA would welcome the participation of other organizations in any of its programmes associated with energy and the environment.

Another very interesting suggestion concerned the need to establish a formal co-ordinating and liaison mechanism for the continuation of the type of co-operation which had been involved in the Symposium. It would be very useful for some organizational structure, similar to, but not necessarily the same as, the Joint Steering Committee responsible for the preparation of the Symposium, to be established in order to review progress, to consider the problems of the international organizations involved, to discuss future issues and to co-operate in areas of mutual interest.

Many other interesting ideas had been raised, such as the establishment of an accident databank, jointly agreed upon methodologies for comparison, and joint efforts in R&D on advanced technologies. The IAEA was, of course, active in R&D in the nuclear field, but it would welcome co-operation with other international organizations.

In conclusion, since there was no global international energy organization and since the problems involved extended even beyond the scope of energy and the environment, it was clear that the objectives which had been discussed at the Symposium could only be achieved through international co-operation. For its part, the IAEA was very willing to participate in such a co-operation effort.

A. McKECHNIE (World Bank) (IBRD) noted that the work of the World Bank was concerned in particular with developing countries and Eastern Europe, where the environmental priorities were local and where emissions of greenhouse gases were considered less important than more immediate air quality problems, such as particulates, sulphur dioxide and nitrogen oxides. However, these countries were likely to be affected disproportionately by the impact of global climate change.

As the Symposium had shown, energy efficiency was an essential part of any strategy to address environmental issues. Improving efficiency at the macroeconomic as well as at the sectoral level was one of the main focuses of the assistance provided by the World Bank. Experience had shown that policies to promote efficiency should rely on and be supportive of markets. Policies which relied on administrative methods or direct interventions by government or other agencies had proved to be less effective, particularly when they served as a substitute for market signals. To improve efficiency, it was necessary to apply not only the energy related policies mentioned in the Symposium, such as correct price signals, consumer information, demonstration projects and minimum standards, but also broader economic reforms to ensure that enterprises and households had incentives to use not only energy but all inputs efficiently. It was interesting to note that restructuring of the economy had led to large savings in energy and emissions in some of the countries mentioned in papers presented at the Symposium.

A recurrent theme at the Symposium had been the great potential of energy efficiency and of certain renewable options coupled with the difficulty of realizing this potential. First and foremost, utilities should be encouraged to price electricity at its marginal cost and ultimately to include environmental externalities. The World Bank was currently evaluating its power sector policies and it seemed likely that wide ranging institutional reforms would be called for in order to make utilities more autonomous and accountable and to remove barriers to non-utility generation, to enable competition, and to eliminate tax exemptions and financial subsidies. A growing view within the World Bank was that the traditional power utility would serve a diminishing share of the market for electricity services. It seemed likely that electricity would increasingly be generated by separate enterprises, smaller renewable or co-generation plants would supply electricity under non-dispatched arrangements, and other institutions and energy service companies would promote end use efficiency. Elimination of existing implicit or explicit subsidies to public utilities was an essential step towards a more competitive market structure.

The uncertainties involved in formulating an energy–environmental strategy was another theme of the Symposium. In addition to the usual uncertainties about demand forecasts, fuel prices, construction costs, etc., there would be additional uncertainties in the future related to environmental standards, the impact of demand side management and the penetration of non-utility generation. He was, therefore, somewhat sceptical about the usefulness of more long term planning and integrated least cost planning models. The essence of the problem was to adopt the right policies and to develop flexible strategies to adjust to changing conditions.

There were two types of environmental project. The first concerned local or national environmental problems, which countries could finance through normal sources, such as the World Bank. The second produced benefits which were incurred outside national borders, for which the principle of compensatory grants had been established for developing countries. The global environmental facility described in Key Issue Paper No. 4 was funded multilaterally and administered by the United Nations Environment Programme (UNEP), the United Nations Development Programme (UNDP) and the World Bank. The future role of the World Bank in these projects was likely to be that of an intermediary for implementing global projects funded by budgetary contributions from donor countries, rather than as a source of funds itself, since the World Bank borrowed most of its resources from international capital markets.

A striking aspect of the Symposium was the fact that no estimates had been made for the cost of reducing emissions in the power sector. Some improvements and operating procedures had virtually zero cost and these 'no cost' or 'low cost' measures should clearly be adopted as a first priority. In the longer term, there was a need to quantify the environmental impact of alternative strategies as opposed to the traditional project oriented environmental impact assessment. This was an area in which the World Bank would be interested in co-operating with, for example, the IAEA on country case studies. There was a danger that many low priority projects would be undertaken in the name of the environment. The technologies that had been discussed during the Symposium essentially substituted capital for energy and the debt crisis was partly a consequence of such substitution of capital for energy in the 1970s.

The World Bank was working in several areas related to the Symposium. First, it had a group of 16 senior staff who were preparing the World Bank's contribution to the United Nations Conference on Environment and Development. Second, the widely disseminated World Development Report for 1992 would focus on the environment and the results of the Symposium would be made available to those involved in the preparation of this report. In addition, the Symposium would help the World Bank to be more effective in the power sector and in preparing technical assistance programmes, especially through the joint UNDP–World Bank energy sector management assistance programme. The World Bank was a decentralized institution which had co-operated with many of the organizations represented at the Symposium and with many countries. Such co-operation would continue, particularly in the area of specific country focused activities to strengthen the management and efficiency of the power sector, as well as more general exchanges of information. The World Bank would, in principle, be willing to participate in any follow-up workshops identified at the Symposium.

S. GARRIBBA (IEA) noted that the IEA would be holding its meeting of energy ministers on 3 June 1991 and that a number of the issues which had been raised during the Symposium would also be discussed by the ministers at the meeting.

All aspects of the global warming issue had to be considered. The IEA's work on the subject included a study to evaluate the economic implications of different response strategies. A model, developed in an effort to understand the role which carbon taxes might play, showed that in the case of a carbon tax of US $300 per tonne of coal or about US $10 per barrel of oil, it was likely that carbon dioxide emissions would still increase. Two strategies for coping with climate change were being discussed within the IEA and had been discussed at the Symposium. One strategy could be called a no regrets strategy, according to which all options would be adopted which were financially attractive. The other strategy was a more forceful one involving immediate action. There was undoubtedly no easy solution to the problems of climate change.

Another topic raised at the Symposium concerned decision making and public acceptance. The IEA was very much concerned about the power options for the next 20–30 years. In quite a few cases, power options that were in principle available to the market were not adopted. Under what had been called the least cost plan at the Symposium, which he preferred to call optimum resource allocation or efficient resource allocation, the polluter pays principle had to be adopted and all the environmental implications had to be clear.

It was very important to note that a number of actors were involved in the electricity system, such as governments, regulators, utilities and industry. Governments should promote more co-operation among these actors. With regard to technology transfer and international co-operation, it was clear that the development of relations between industrialized countries belonging to the IEA and other countries was becoming increasingly important as a result of energy security concerns, the global nature of the environment and global trade. The IEA and member countries proposed free market principles, according to which tariffs should reflect the actual cost, and there should be a growing degree of free trade. Under such conditions, it might be easier to solve the technology transfer issue. It was becoming increasingly evident that technology transfer involved not transfer of products or equipment but the transfer of know how. However, it should be clear that there was a price to pay for technology. In this context, a useful role could perhaps be played, as had been suggested, by the establishment of an agency for renewable energy sources.

In conclusion, given the fact that the international organizations involved in the preparation of the Symposium had different mandates and different areas of activity, the Symposium was an excellent example of international co-operation and the ideas which had been raised at the Symposium would certainly be taken up by the IEA.

B. WAHLSTRÖM (IIASA) noted that IIASA was a small non-governmental institution comprising only about 60 scientists. Its total budget was of the order of US $15 million, the major share coming from the contributions of its 15 member countries. In future, much of IIASA's work would be focused on global questions, applied research and mathematical modelling. It was likely that emphasis would be placed on patterns of possible surprise rather than on the refinement of models to ensure increasingly better predictions. While IIASA would certainly be involved in developing databases and models, it would be unable to maintain them in the long run and would therefore have to pass on the results of its work to other international organizations. The Key Issues Papers presented at the Symposium had provided excellent summaries of the problems in the various fields and the opportunity to be involved in any follow-up activities would be welcomed by IIASA.

The Symposium had highlighted a growing awareness that the business as usual scenario was not a feasible one. There was also evidence of a growing urgency for decisions to be taken, although there was not yet a clearly mapped path to provide guidance in making these decisions. It was necessary to consider the interactions between all parts of the global system, such as the environment, social development, technology and economy. It was clear that the realities of an interconnected world did not allow for mistakes and the squandering of resources. In this context, there might be a need to establish international institutions which would have the power to prevent national foolishness.

The future was uncertain and mankind was in fact conducting a global experiment with high stakes. One of the problems to be solved was to assess the real impact of carbon dioxide releases. If it were proved that the consequences were large, there would be a greater willingness to act. It seemed that the only feasible route was to try to internalize the external cost of environmental damage in the price of energy. This process could take time but, with the experience of industrialization and internalization of social costs, it ought to be possible. Planning within the electricity sector would then be easier.

International co-operation was necessary to generate the background material to build policies for the future. Such co-operation would also be needed to promote the diffusion of the best technologies. Furthermore, international co-operation was needed in order to establish targets and action programmes, and international negotiations would also be required before the necessary consensus could be reached on suitable actions and a fair distribution of the burdens associated with these actions.

G.H. STEVENS (OECD/NEA) pointed out that nuclear energy was not the only area where there was a lack of public acceptability. There was a lack of public acceptability associated with site acquisition for almost all energy forms, the introduction of efficient end use technology and family planning. The member countries of the NEA had widely differing views about the need for nuclear power and took the view that it was for governments to present the issues as they saw fit and to canvas support for their policies. Public acceptance was not therefore an area in which the NEA could play a direct role.

One of the roles of the NEA was to provide, on as objective a basis as possible, information about the nuclear power option to assist governments in the formulation of their policies. This work was conducted in close co-operation with other parts of the OECD, with the IEA, the IAEA and the CEC. Another role of the NEA was to act as a co-ordinating body for projects which any group of its members wished to pursue.

A considerable proportion of the NEA's resources was devoted to technical exchanges on various aspects of nuclear safety, on waste management, particularly high level waste and spent fuel, and on radiation protection. A number of reports of high technical calibre prepared on these issues had contributed to a better understanding of the risks, the health effects and the environmental effects associated with nuclear energy. As a result, the hazards associated with nuclear energy were perhaps better known than in other energy supply options. This work would obviously be continued and the NEA would take part in the further development of databases to improve the modelling of energy options and to assist policy makers.

The NEA had a considerable amount of expertise in the area of probabilistic risk assessment and it was natural for the NEA to continue its close collaboration with the IAEA in this area. The Environment Directorate of the OECD was trying to develop better ways of cataloguing and quantifying environmental impacts and to make its work available for the United Nations Conference on Environment and Development. The NEA had also pioneered the international dissemination of analysed information on nuclear accidents through the Incident Reporting System, which was a confidential service for the benefit of regulators, and through the International Nuclear Events Scale. Both of these systems had become joint activities with the IAEA. A number of seminars had already been organized on the difficulties of communicating with non-specialist groups about doses, dose rates, committed doses, increment over background levels, etc.

With regard to the internalization of externalities, there was an evident need for further work in this area. A start had been made and the NEA hoped to be closely involved in future developments in this multidisciplinary field and expected to work closely with the IEA, the IAEA and the CEC. Another issue which had been raised was that of the acceleration of technology development. A traditional role of the NEA had been to assist in the establishment of joint R&D projects and there were still a number of such projects being implemented in the area of safety and waste management. In conclusion, there was a wide variety of areas in which the NEA could play a role in international co-operation.

S. TARKOWSKI (WHO), referring to the comments made by M.J. Chadwick (CEC) *(Consultant)* on the comparative environmental and health effects of different energy systems for electricity generation, noted that they not only reflected the spirit of the discussions at the Symposium but also the views of WHO expressed in the report of the Energy Panel of the WHO Commission on Health and the Environment, as well as in the European Charter on Environment and Health, adopted by the Conference of European Ministers of Health and the Environment, organized in 1989 by the WHO Regional Office for Europe.

One important issue deserved particular attention. There was a general consensus that all fuel cycles within the electricity generating system involved environmental impacts and health risks, and public concern in this area and demands for cleaner technology for electricity generation were well justified. The short and long term environmental and health considerations therefore had to be taken fully and systematically into account in energy planning and development. As the European Charter on Environment and Health stipulated, environmental considerations and the health of individuals and communities should take clear precedence over considerations of economy and trade.

Public authorities responsible for policy, planning and decision making in the electricity sector were obliged to take into consideration the potential environmental and health impacts of the chosen system of electricity generation and such decisions should be based on an adequate assessment of the environmental and health risks. There was a need to improve further the process of health risk assessment in order to reduce the level of uncertainties which were serious impediments to the decision making process. Not all the potential health effects were sufficiently well recognized. They therefore needed to be investigated further and improved research tools had to be applied. Information making it possible to identify emerging new problems and to monitor the success of policies and control measures was essential for the effective management of environmental health programmes. Conflicts of judgement caused by inadequate information on the nature and extent of the environmental and health problems could be damaging in political and social terms. In this connection, the recommendation to establish an internationally co-ordinated database on environmental and health effects was welcome.

The European Regional Office of WHO had initiated the development of an environmental health information system based on a regional network for environmental epidemiology. Given the multidisciplinary nature of the assessment of health and environmental impacts and the need to provide comprehensive information to decision makers and to the public, this programme was open to wide international co-operation. Public attitudes towards the risks associated with environmental pollution reinforced the need for a prudent environmental and health protection policy. However, protection policies were expensive and, therefore, prudence in the area of environmental health had to be balanced with financial discretion.

L.E. OLSSON (WMO) recalled that many of the scientists who had met in Stockholm in 1972 had already been convinced at that time of the serious environmental impacts and consequences of energy production. Air pollution, acidification and even the potential risks for climate change had been discussed at the meeting. At that time, air pollution disasters had already occurred and significant man induced climate changes had been observed, particularly in urban areas, but also at the regional level owing to changes in land use practices, as a result, for example, of deforestation. Much had happened in 20 years. Nobody questioned the seriousness of air pollution, the impact of acid precipitation on water, soil and forests or the tragic consequences of drought and desertification and no serious scientist denied the greenhouse effect or the potential changes that could result from continued change in the composition of the atmosphere. The Symposium had illustrated that there was now a dialogue between scientists, technologists and decision makers and there appeared to be a readiness to face the consequences of man's intervention even in large scale natural processes. The question of burden sharing had been raised and he believed that it was important that industrial nations should set an example to developing countries.

The main objective of the WMO's World Climate Programme, initiated in 1980, was to obtain a better understanding of climate, its variation and change — both natural and man made — with the ultimate goal of being able to predict future climates, in other words, climates as a resource base in a socioeconomic sense. The World Climate Programme set out to develop internationally co-ordinated databases for climate and impact assessment, climate system monitoring and climate change detection projects, methods for applying climate information and knowledge and methods to assess the impact of climate on socioeconomic development. One consequence of the work under the World Climate Programme was the establishment of the Intergovernmental Panel on Climate Change in 1988. There were, of course, uncertainties regarding the regional impact of climate change and how it would affect various socioeconomic activities. However, it should be remembered that the changes involved were changes in the radiative forcing of the Earth's climate system, which were comparable to what had occurred in geological times.

Finally, he was convinced that the WMO, within its mandate as a specialized United Nations organization, would continue to work closely with the IAEA and other international agencies in seeking solutions to the many pressing issues related to environment, energy and development. The results from the Symposium and from the preparatory process that had led up to it, would be one important step in the work on a framework convention on climate change and a contribution to the United Nations Conference on Environment and Development.

N. DESAI (UNCED) *(Chairman)*, noting that all the Members of the Round Table had spoken, invited comments from the floor.

C. BANDARA (Sri Lanka) noted that during the Symposium the most salient point that had been discussed was public acceptance of the decisions that would be made ultimately by the policy makers. To promote public acceptance, the impact on the environment of $CO_2$ and $SO_2$ emissions resulting from electricity production should be understood. It was important to continue the work of the Symposium and the suggestion made by M. Munasinghe (World Bank) (IBRD) that regional meetings should be organized to strengthen public awareness of the environmental problems of electricity production was a very useful one. Sri Lanka would be very willing to host an Asian regional meeting, if a decision to hold such meetings was taken.

F.H. HAMMAD (Egypt) said that he believed that the Symposium had created a genuine spirit of international co-operation. All the Key Issues Papers contained sections on the importance of international co-operation. For example, in Key Issues Paper No. 1 it was stated that "effective international co-operation will be needed to realize the potentials for impact reductions ... The pace and ultimate magnitude of impact reduction will depend heavily on the effectiveness of international partnerships — treated not as North to South 'assistance' but as true international collaboration — to facilitate adaptation and transfer of technologies, access to financial resources and co-operation in institutional development''.

Efforts should be focused on two areas. First, the environmental impact should be as low as reasonably achievable taking social, economic and global factors into consideration. Second, an environmental protection culture should be spread at national, regional and interregional levels to promote environmental awareness. It would be useful to establish a joint group on energy, health and the environment representing all international organizations working in the area. The functions of this group would be to establish an international database and information system, including information on energy and electricity supply and demand, on energy sources and technology, and on environmental and health impacts; to co-operate with all United Nations agencies and other agencies in areas of technology transfer, infrastructure development and training, including regional or interregional courses or symposia on the environment, planning, risk analysis, environmental impact assessment and technology development; to set up assessment teams to travel, upon request, to any developing countries to review the energy environment situation and to recommend courses of action; and to develop energy environment standards to harmonize standards worldwide. The proposed creation of a global environmental fund could also be used to promote technology transfer.

L. McCONNELL (Canada) noted that the Symposium had emphasized the need for improved integration and improved co-operation, improved analysis, more R&D, better processes, better public understanding and better data. However, there was one item which had not been adequately emphasized, namely, the threat of continued paralysis. All the problems involved and improvements needed should not be used as an excuse for failing to make timely decisions so that the electricity sector could continue to contribute to an improvement in the environment and an improvement in public health.

H. KHATIB (World Energy Council) (WEC) said that he strongly supported the suggestions made by M. Munasinghe (World Bank) (IBRD) regarding the establishment of regional workshops and the convening of a meeting to review the results and to monitor the worldwide dissemination and implementation of the suggestions made at the present Symposium and at the later United Nations Conference on Environment and Development. In response to comments made by B. Semenov (IAEA) that there was no global international organization responsible for energy, he wished to remind him of the WEC, which was a non-political worldwide organization set up to deal with some of the issues he had mentioned.

J. MURRAY (The Uranium Institute) noting that the Symposium had brought together an immense amount of valuable data in a reasonably coherent form, said that she would like to request the 11 co-ordinating organizations to ensure that the material was disseminated further, not just to governments but also to academic and research institutions and other relevant bodies. The establishment of regional seminars to further the work of the Symposium was also a very useful idea.

N. DESAI (UNCED) *(Chairman)* noted that the Symposium had been a great success and would provide useful input for the 1992 United Nations Conference on Environment and Development. As one looked to the future, it seemed likely that the international community would have to evolve ways and means of developing a scientific consensus on technical issues to serve as a basis for political decision making. Symposia such as the present one would play an increasingly important role in the process of achieving a consensus across disciplines and across regions on the critical issues on which political decisions would have to be taken. The scientific community should also examine its structure, particularly with regard to boundaries between disciplines and the frameworks it used for technology assessment so as to avoid problems such as those posed by chlorofluorocarbons, which had first been promoted as very safe chemicals owing to their stability and had subsequently proved to be an environmental problem owing to their very stability. In conclusion, reliable, independent scientific advice and information would be a crucial basis for decision making in the future.

S. IMMONEN *(Liaison Officer, Government of Finland)* thanked the co-sponsoring organizations for giving Finland the opportunity to host the Symposium. It was clear that there were no easy answers to the problems that had been discussed, particularly in view of the different political, economic and social values in different countries. Nevertheless, he was sure that the Proceedings of the Symposium would make a very valuable contribution to the further discussion of the problems and issues involved.

B. SEMENOV (IAEA) *(Chairman of the Joint Steering Committee)* expressed the hope that the Symposium's work would promote fruitful international co-operation and, in closing the Symposium, thanked all the international organizations involved in its preparation, the scientific secretariat, the chairmen and members of the four working groups, the participants who had contributed to the fruitful discussions, the conference staff and interpreters and, in particular, the Government of Finland and the City of Helsinki.

## CHAIRMEN OF SESSIONS

| | | |
|---|---|---|
| Opening Session | H. BLIX | International Atomic Energy Agency (IAEA) |
| Topical Session 1 | Z. NOWAK | Poland |
| Discussion of Key Issues | G. SANCHEZ-SIERRA | Organización Latinoamericana de Energía (OLADE) |
| Topical Session 2 | Y.I. PETRYAEV | Union of Soviet Socialist Republics |
| Discussion of Key Issues | P.U. FISCHER | Switzerland |
| Topical Session 3 | J.M. BORGOÑO | Chile |
| Discussion of Key Issues | G. KIBBLE | Australia |
| Topical Session 4 | J. BOUVET | France |
| Discussion of Key Issues | J. BOUVET | France |
| General Plenary Session | C. BANDARA | Sri Lanka |
| | P. SILVENNIONEN | Finland |
| Closing Session | N. DESAI | United Nations Conference on Environment and Development (UNCED) |

## RAPPORTEURS OF SESSIONS

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| Topical Session 1 | K. LEYTON | Commission of the European Communities (CEC) |
| Topical Session 2 | S. GARRIBBA | International Energy Agency (IEA) |
| Topical Session 3 | M.J. CHADWICK | Stockholm Environment Institute/CEC *(Consultant)* |
| Topical Session 4 | M. MUNASINGHE | World Bank (IBRD) |

## SECRETARIAT OF THE SYMPOSIUM

| | | |
|---|---|---|
| Chief Scientific Secretary: | L.L. BENNETT | Division of Nuclear Power, IAEA, Vienna |
| Scientific Secretaries: | S. HADDAD | Division of Nuclear Safety, IAEA, Vienna |
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