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ENVIRONMENTAL ASPECTS OF THE MOTOR VEHICLE AND ITS USE

- a technical review -

UNITED NATIONS ENVIRONMENT PROGRAMME

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INTRODUCTION

It is generally recognised that the motor vehicle in its various forms - cars, buses, trucks, motor cycles and mopeds - makes a significant contribution to society throughout the world, because of the exceptional mobility it provides and the vital part it plays in economic growth in every sector of activity. It also contributes to the overall development of the less privileged members of the world community in at least two ways - it improves access and transport facilities and it creates a wide range of employment opportunities.

Conversely, it is also recognised that the mounting volume of motor traffic, especially in areas without adequate infrastructures, is associated with certain negative environmental impacts, such as air pollution, noise, congestion and accidents, adversely affecting certain aspects of the quality of life.

Although no way has yet been found of quantifying the motor vehicle's undoubted benefits or its disadvantages, including the social aspects and costs, or of weighing them against each other, an attempt is made in this booklet to provide technical experts in government and industry with an analysis of the various issues that arise in relation to the motor vehicle, the general goal being that society should acquire and enjoy the benefits of technology in optimum conditions from the standpoint of the environment and the conservation of natural resources.

1. STRATEGIES AND TECHNOLOGY FOR AIR POLLUTANT EMISSION CONTROL AND NOISE ABATEMENT

1.1. Emission Control

a) Since the early 1950's, particularly in the industrialised countries, the air pollution and noise caused by motor vehicles has attracted increasing attention as more and more vehicles have come onto the roads and as public pressure has mounted because of a growing realisation that certain aspects of motor vehicle use impair the quality of life. In view of this adverse environmental impact, which is especially acute in areas where urban infrastructures and integrated transport systems are inadequately developed, many countries have enacted legislation aimed at reducing the air pollution caused by motor vehicles; as for noise abatement, significant progress has already been made as the result of competition among manufacturers themselves, silent running being one of the demands of the motorist.

b) Under the Clean Air Act in the United States and legislation in European and other countries, including Canada and Australia, regulations relating to motor vehicle emissions and setting maximum CO, HC and, in some cases, NO_X and black smoke emission levels, have gradually been introduced. Prior to the 1970's, these requirements could usually be met by improved lean burn combustion (improved combustion chamber, carburation and ignition, and changes in ignition timing) and crankcase gas recirculation, neither development involving any major changes in engine design. The emission control levels enforced in various European countries are set out in UN/ECE Regulations No. 15 for Otto spark ignition engines and No. 24 for diesel engines.

c) During the 1970's, two events made the problem of emission control more complicated.

- The passing of the 1970 Amendments to the United States Clean Air Act and the stiffening of the Californian regulations (going back to 1963) because of the worsening levels of photochemical oxidant air pollution caused by hydrocarbons and nitrogen oxides reaching the atmosphere in certain meteorological conditions.
- The 1973 fuel crisis which obliged practically all countries, particularly those dependent on imported oil, to conserve their energy supplies in general and hydrocarbons - the most convenient fuel for motor vehicles - in particular.

d) The purpose ot the US government in calling for reductions in emission levels that were, at that time, not simultaneously attainable with existing technology (maximum emission levels for private cars down to 0.41 g/mile for hydrocarbons, 3.4 g/mile for carbon monoxide and 0.4 g/mile for nitrogen oxides by 1978, using the US Federal urban driving cycle test procedure) and in later setting targets to be met by industry for the energy consumption of future vehicles was - apart from other things - to stimulate and further motor vehicle technology and power plant design. Japan, in a similar position, followed suit though setting different control levels and using different test procedures to suit the local Japanese situation. Though leaving CO and HC emissions at their 1976 level (2.1 and 0.25 g/km respectively), the Japanese Environment Agency requires that, by 1978, the NO_X emission level be set at 0.25 g/km for Japanese vehicles with spark ignition engines, measured by the Japanese "10 modes" test procedure. The rule will apply to imported cars as from 1 April 1981. The 1976 and 1977 NO_X levels were 0.60 and 0.85 g/km for motor vehicles of under and over 1,000 kg kerb weight respectively. Amendments 01 and 02 made by the UN/ECE WP 29 to Regulation No. 15, and Amendment 03, now in preparation, take a less stringent line because of conditions in Europe and also in view of the smaller average size and weight of European vehicles and the attention already paid to fuel economy in European countries. Countries applying the UN/ECE WP 29 emission limits for private cars are now about to introduce the following reductions, recommended in Amendment 03, as from 1 October 1979 : 35 % and 25 % of the initial limits in the Regulation before amendment for CO and HC respectively, and 15 % of the limit set by Amendment 02 for NO_x. This further stage means that the reduction of the emissions of pollutants as compared with those of non-controlled vehicles will now be 60 %, at least for CO and HC.

The motor vehicle market being worldwide, industry has made considerable efforts to research and develop short and medium-term technologies to meet the more stringent US and Japanese regulations and standards - at the expense, in some cases, of work on longer range solutions and innovation.

e) A number of difficulties have been encountered in attempting to comply with the more stringent emission standards envisaged :

- Exhaust gas recirculation and lean burn techniques minimize CO and NO_x formation, but may tend to increase HC emissions.
- Although efficient in reducing CO and HC emissions, oxidation catalysts and, to a minor extent, 3-way catalysts (which also reduce NO_x emissions) produce H_2SO_4 emissions. These would, however, appear to be of negligeable importance.
- Certain techniques for stringent and simultaneous control of CO, HC and especially NO_x emissions may result in increased fuel consumption.
- The addition of lead compounds to motor vehicle fuel is a cost-effective means of increasing spark ignition engine compression ratios and therefore efficiency. Lead, however, is an atmospheric contaminant and poisons catalytic equipment used for pollution control.
- When developed, advanced emission control systems, including 3-way catalysts, which use scarce and very costly materials such as platinum and rhodium, combined with air/fuel metering, exhaust gas sensors, could increase the cost of air pollution equipment by about US $ 300-400 as compared with its cost in 1977. In addition it may be necessary to replace the equipment from time to time as its efficiency declines, since there is no evidence yet that 3-way catalysts last the life of a vehicle. The new equipment and the need for periodic catalyst replacement could well mean a steep increase in the cost of buying and maintaining small, popular cars whose price should be kept at the lowest possible level for social and economic reasons.

f) The conflicting situations referred to in (e) above, and the interaction between them, need further technical and economic investigation; but apart from this shorter-term action to reduce pollutant emissions from conventional engines, research and development should continue on new and less polluting power plants with improved thermodynamic efficiency, and on the use of alternative fuels, two subjects examined in more detail in Section 3 below. In general, any evaluation of environmental measures should take into account the need both to reduce air pollution and to save energy. When conflicting situations cannot be solved, policy rulings will be necessary to decide on priorities.

This implies the need for co-operation between governments and industry. As far as emission control is concerned, industry should bear in mind, from the R & D standpoint, that stringent standards could be required for HC and NO_x emissions in areas where they could react in the atmosphere to give photochemical oxidant air pollution. This is illustrated by Figures I and II below reproduced from "Should we have a new engine" by the Jet Propulsion Laboratory (Californian Institute of Technology - August 1975). These graphs show, for various standards, the projected air quality in the Los Angeles basin for oxidants and nitrogen dioxide respectively, and the share contributed by various sources.

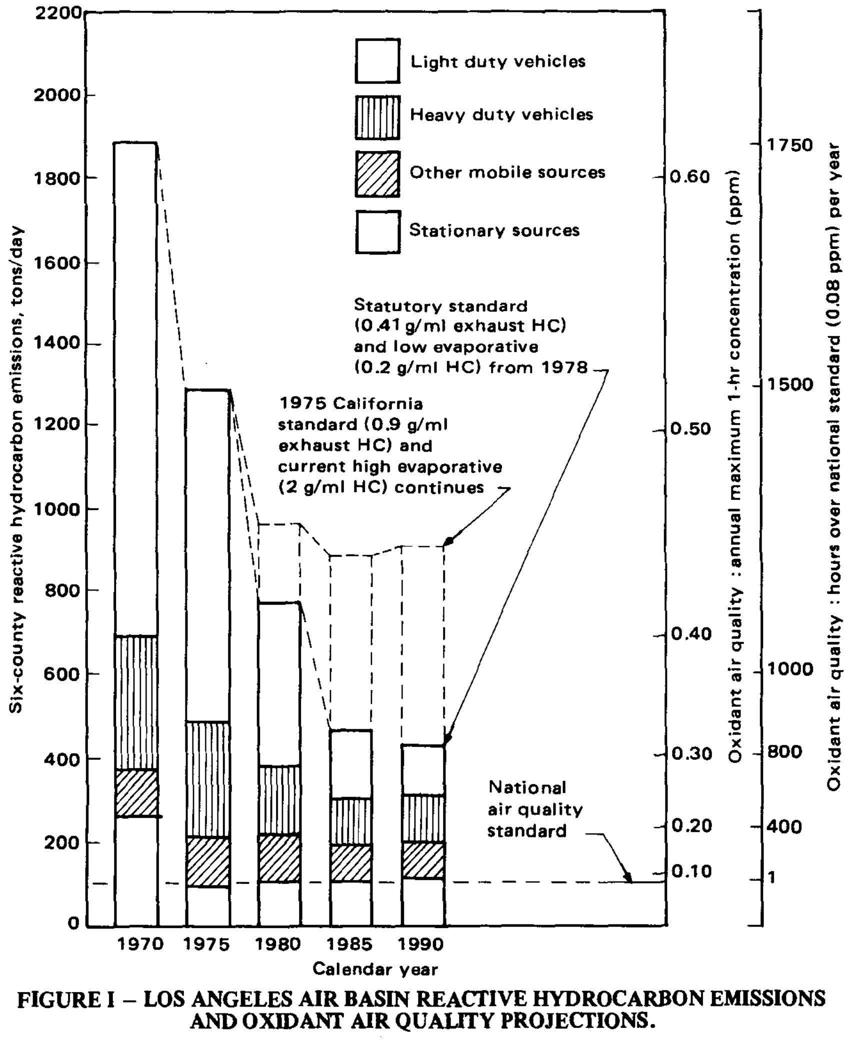

FIGURE I – LOS ANGELES AIR BASIN REACTIVE HYDROCARBON EMISSIONS AND OXIDANT AIR QUALITY PROJECTIONS.

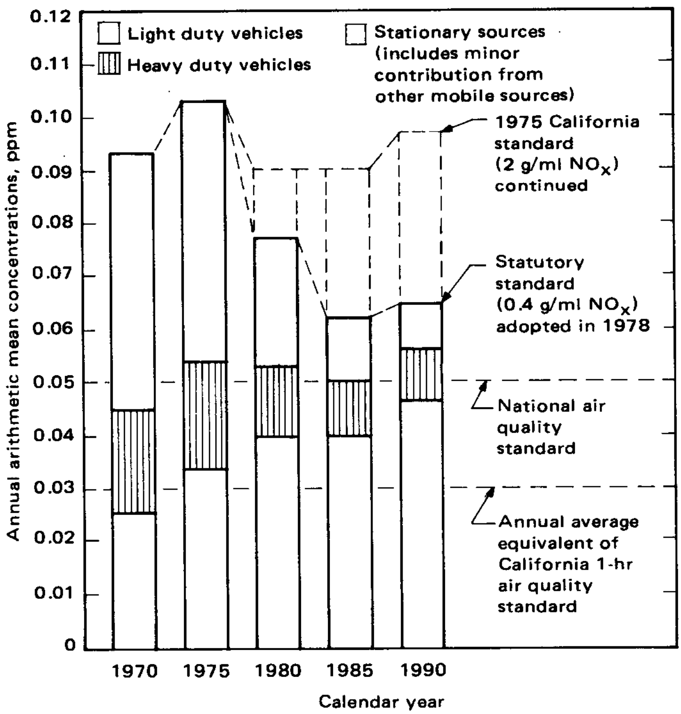

FIGURE II – LOS ANGELES AIR BASIN NITROGEN DIOXIDE (NO_2) AIR QUALITY PROJECTIONS.

1.2. Noise

a) Although significant progress has been made in the last 30 years in silencing exhausts and in reducing mechanical noise, motor vehicles are still regarded as one of the major sources of noise, mainly because of the increasing number in use and the resultant traffic density in most industrialised countries. Noise affects the senses more than any other environmental nuisance and is therefore the most evident, concrete threat to the quality of the environment. This is particularly true in the industrialised and urbanised countries where "peak noise" of varying intensity may combine with "background noise", generally of a lower intensity (between 50 and 70 dBA).

b) Standard methods for measuring maximum noise levels produced by motor vehicles, defined by the ISO R362 procedure or recommended by the Society of Automotive Engineers (SAE), have existed for many years. The principle is to measure the maximum noise level generated by the vehicle as it passes at a given distance from a microphone under specified driving conditions. Although convenient for measuring the noise made by an individual vehicle, and especially its "peak noise" under maximum acceleration, such methods do not reproduce normal urban traffic conditions and do not constitute a sound basis for regulations on urban traffic noise. In this respect, the Environment Protection Agency (EPA) and a number of motor manufacturers associations are presently reviewing various procedures including those prepared by the Committee of Common Market Constructors (CCMC). This would therefore be a good time for industry and national environment, urban planning and transportation authorities to get together in international organisations like UN/ECE (WP 29) and ISO, in order to compare views and develop new international test procedures based on valid vehicle noise criteria, with particular reference to urban traffic noise. A particularly valuable report in this context, for both governmental and industry experts, is the WYLE Laboratories "Study of the Effect of Environmental Variables on the Measurement of Noise from Motor Vehicles" which was commissioned by the American Motor Vehicle Manufacturers Association and contains a comprehensive assessment of environmental and site variables, each link in the vehicle noise generation, radiation and propagation chain being examined singly and in relation to the whole (WYLE Research Report WCR 74-18, El Segunds, California).

c) The complex problem of motor vehicle noise must be seen from three angles :

1) Noise generation by the propulsion system and associated auxiliary equipment ;

2) Its radiation into the surrounding atmosphere ; and

3) Its propagation from the immediate vicinity of the vehicle.

Whilst point 3) above is the exclusive responsibility of urban planning and environment authorities and covers a large number of issues ranging from land-use to traffic flow (fast roads, tunnels, fly-overs, etc.) and including road profile and surface, building insulation and sound barriers on urban highways, vehicle designers should make every effort to reduce noise generation and radiation, priority being given to heavy diesel trucks and motor cycles, and the following facts being borne in mind.

1) Firstly as regards the engine : vibration in the engine structure and in particular in the crank-case block unit is caused by the pressure generated in the combustion process, additional vibrations being set up by mechanical components such as the valve train (camshaft, rockers and valves). This vibration radiates sound waves. Noise is also associated with the

flow of air and gas through the engine. Inlet and exhaust noise are both related to mass flow through ambient and acoustic impedance, but inlet noise, aerodynamic in nature, results from turbulence and is a function of inlet flow and physical configuration whereas exhaust noise is generated by pressure waves arising as exhaust valves open and being then propagated through the exhaust system to the tailpipe. Radiation cannot be easily dissociated from generation for inlet and exhaust noise, and the two phenomena may therefore be considered together in most cases.

2) Secondly as regards the vehicle and vehicle system : noise unrelated to engine combustion pressure comes from various working parts such as the cooling fan (a specific problem in air-cooled engines), alternators, transmission systems and tyres in contact with the road. In all these cases, noise generation and radiation have to be considered together, particular attention being given to the various spectra of noise emissions and to the fact that the walls of office and residential buildings are rarely effective noise filters in the low frequencies.

3) Every possibility of reducing all these aspects of noise generation and radiation should be explored. The following are some important considerations to bear in mind.
   - In air-cooled engines, if no special precautions are taken, the fan is responsible for 30-50 % of the overall acoustic energy generated by the vehicle at cruising speed.
   - Engine encapsulation could reduce noise emission by a few dBA, but the engine and cooling system would, in most cases, have to be redesigned.
   - Rolling noise on smooth and dry road surfaces ranges from 60 to 80 dBA at a speed of 40 mph (65 km/h), depending on type of motor vehicle, heavy trucks being the worst offenders. These figures apply to vehicles equipped with radialply tyres which are slightly noisier than conventional cross-ply tyres but improve fuel consumption.

Several countries, including the United States and Japan, are planning to reduce the maximum noise levels allowed by their regulations. By 1980, some of the European countries represented on WP 29 will be introducing maximum noise levels ranging from 80 dBA for cars with up to 9 seats to 88 dBA for heavy trucks (measured by the present ISO procedure). These noise levels may be different if the revised ISO procedure is used.

2. ROAD SAFETY STRATEGIES AND TECHNOLOGY

Each year, according to World Health Organisation (WHO) sources, road accidents worldwide claim about a quarter of a million killed and several million injured. During the last few years, however, most industrialised countries have succeeded in reducing their accident and casualty figures to a considerable degree as the result of technical progress in vehicle design and construction and in road infrastructure, coupled with the introduction of legislation and regulations on vehicle safety performance, vehicle inspection, traffic conditions and driving behaviour, including the wearing of seat-belts. In the developing countries the situation is less favourable, road accidents in some cases rivalling traditional diseases in the fatality figures, mainly because of the fast-growing number of vehicles in use, inadequate road infrastructures, lack of good vehicle maintenance and absence of public education in matters of road safety. In this respect, "Road Accidents as a Cause of Death in Developing Countries", a study carried out in 1977 by the Transport and Road Research Laboratory (TRRL - United Kingdom), may be of interest.

2.1. Motor Vehicles

As far as the motor vehicle itself is concerned, developments in design and legislation have followed somewhat different lines in the United States as compared with Europe and Japan, as the result of the dissimilar geographic and economic conditions - and the different living standards. In the United States, with its modern roads and predominantly large cars, the accent has been placed on protecting the car's occupants and research has centred on restraint systems and energy absorption in the event of collision. In Europe and Japan, where vehicles are generally smaller and the majority of roads and cities have often an irregular pattern inherited from the past, **priority** has been given to accident prevention by improving vehicles' road-holding, handling and breaking characteristics, and their lighting and visibility.

a) The two approaches were, in fact, complementary and comprehensive regulations covering both accident prevention and personal protection have now been adopted in most industrialised countries. Exchanges of information at international meetings such as the Experimental Safety Vehicle (ESV) Conferences and in international organisations has helped to bring this about. The regulations, with their test procedures and measurement methods, are now being extended and gradually harmonized in the UN/ECE WP 29 Group of Experts on the Construction of Vehicles, enlarged on a voluntary basis to include non-European countries, and also through the directives issued by the European Economic Commission (EEC).

b) Accident prevention and, more generally, the protection of road users must be based on accurate information and efforts should therefore be made to improve road accident statistics. The attention of industry experts is also drawn to the need for further work in the following fields :

   - The protection of pedestrians and cyclists : low front grilles and inclined windscreens, together with the elimination of any projecting parts, can help to reduce the effects of a collision for both pedestrians and cyclists;
   - Restraint systems, particularly the special models for young children, and the problem of the interaction between motivation and design factors and its resolution in terms of increasing the use of seat-belts without any sacrifice in performance ;

- Energy absorption technology, with particular reference to small vehicles which are handicapped by their relatively low energy absorption capacity and crushing performance in front and side collisions ;
- The provision, in co-operation with biomechanical specialists, of improved information on relationships between vehicle deformation or crushing and the severity of injuries suffered by occupants ;
- Improvements to braking systems at acceptable cost (e.g. anti-skid systems) ;
- Design and accessibility of essential safety equipment, for ease of inspection and low cost maintenance ;
- Protection of vehicles' safety equipment against damage in low speed collisions in urban traffic ;
- Provision of safety equipment, including braking and suspension systems, tailored to suit local conditions in the case of vehicles supplied to developing countries.

In exploring these fields, industry experts should aim at reconciling improved safety and fuel economy, bearing in mind the fact that vehicle weight is the largest single factor affecting fuel consumption (see Section 3 and Table 2 below).

2.2. Road Infrastructure

Finally, road infrastructures need to be adequately developed and modernised. In this context, government experts involved in road research and development should co-operate, when possible, with motor industry experts in road design and ensure that the kind of materials and equipment that increase road safety are in fact used. The provisions of the 1968 International Convention on Road Signs and Signals and the 1973 Protocol on Road Markings should be taken into account and priority should go to improving driving conditions at night and in adverse weather conditions, and to improving the ways in which information is communicated to drivers. In this respect, the OECD report "Adverse Weather, Reduced Visibility and Road Safety" (1976) is a valuable reference for governmental and industry experts.

3. TRENDS IN VEHICLE AND ENGINE DESIGN IN RELATION TO THE ENVIRONMENT AND NATURAL RESOURCES

Trends in motor vehicle design are currently dominated, and will remain so for many decades, by the twofold need to protect the environment, particularly in urban areas, and to conserve resources, particularly oil. When the two objectives are in conflict (see Section 1.1. (e) above) then policy decisions will have to be taken in the light of local conditions. Attitudes will no doubt vary from government to government, but it seems reasonable to assume that trends in vehicle design should be viewed against a background of gradual progress in the harmonization of cost-effective and technically feasible regulations and of the test procedures and measurement methods they imply, particularly in relation to air pollution, the very stringent standards being confined to special cases (e.g. heavy traffic combined with meteorological conditions calling for extremely low levels of HC and NO_X emission). However this may be, optimum solutions in situations of conflict between environmental protection and resource conservation requirements, and the priorities to be decided for government action, will continue to concern government and industry experts and condition trends in vehicle design for many years.

3.1. Vehicle Design

a) Fuel saving and emission control

Since big reductions in fuel consumption and in the weight and volume of pollutants (which simplifies emission control problems) can be achieved by reducing the weight of a vehicle, more and more lighter cars will come onto the world market. This development will probably take the form of a trend towards smaller size cars, particularly in the United States, and also :

- The gradual substitution, wherever possible, of lightweight materials such as high-strength, low-alloy steels (HSLA), aluminium alloys, plastics and ceramics, for cast iron, steel, copper and zinc. The use of aluminium for vehicle components is expected to double within the next 10 years.
- An increase in the use of front-wheel drive or rear engine systems, which make a weight reduction of 2 to 5 % depending on car size.

Table 1, taken from Jet Propulsion Laboratory sources (Californian Institute of Technology) shows in percentage terms that weight savings possible through vehicle improvements may range from 8 to 22 % in the short term and 15 to 31 % in the long term, the smaller figure in each case applying to cars imported into the United States (European and Japanese) and the larger to large American cars.

Table 2 from the same source gives estimates of the corresponding percentage savings in fuel consumption possible as a result of these weight reductions and other modifications including :

- Lower aerodynamic drag, related to the C_X penetration coefficient - currently often higher than 0.4.
- Improvements in the efficiency of transmission and accessories, including air conditioning.

Table 2 shows that fuel consumption by motor vehicles in the United State could be reduced by 14 to 35 % in the short term and 26 to 45 % in the longer term, the lower and higher figures in each case applying, as before, to European and Japanese type cars and US type cars respectively.

A further general point is that design trends mainly concerned with improving restraint systems and providing better energy absorption performance in the event of collision and better pedestrian and cyclist protection are unlikely to reduce vehicle weight and fuel consumption to any great extent.

TABLE 1 - WEIGHT SAVINGS POSSIBLE THROUGH VEHICLE IMPROVEMENTS (%)

Source of weight saving	Vehicle Class					
	Small (imports)	Subcompact			Compact (all U.S.)	Large (all U.S.)
		(Imports 20 %)	(U.S. 80 %)	Average		
1. Exterior size reduction	5	5	10	9	10	15
2. Materials : HSLA* and plastics	3	3	3	3	4	5
3. Design details	0	0	2	2	2	3
4. V-6 Engine	–	–	–	–	4	–
Intermediate overall effect	8			13	19	22
5. Materials : aluminium (additional to item 2)	6	7	7	7	7	7
6. Front-wheel drive	2	3	5	4	4	5
Longer-term overall effect	15			26	28	31

* High-strength low-alloy steels.

TABLE 2 - COMPOSITE FUEL CONSUMPTION REDUCTIONS FROM VEHICLE IMPROVEMENTS (%)

Source of reduction	Vehicle class			
	Small	Subcompact	Compact	Large
1. "Intermediate" weight reduction	6	10	15	18
2. 4-speed automatic transmission with lockup	3	6	7	8
3. Reduced acceleration*	2	2	5	10
4. Lower aerodynamic drag	3	3	3	2
5. Improved accessories and drive	1	1	2	3
Overall effect of intermediate improvements	14	20	29	35
6. Longer-term weight reduction (replaces item 1)	12	21	23	25
7. Continuously variable transmission (CVT) (replaces item 2)	10	13	14	15
Overall effect of longer-term improvements	26	35	40	45

* Assumes an increase in 0-60 mph acceleration time ranging from 1 second for the small car class, to 3 seconds for the large car class.

b) Alternative fuels

It has already been seen that, as a way of saving oil, the local situation may warrant the use of alternative fuels, either undiluted or mixed with petrol, but that their large-scale use was not possible. The attention of industry engineers is therefore drawn to the possible social and economic advantages of alcohol blending, particularly where alcohol can be produced from crops grown on otherwise unused land (e.g. sugar cane and cassava). The composition of the blended fuel should be laid down by regulation and the necessary steps will need to be taken to adjust vehicle engines to suit the alcohol/petrol ratio specified in the regulations concerned.

Research should also continue into other possible fuels such as :

1) Methanol and ethanol/gasoline blends, taking into consideration firstly :
   - their high octane rating, providing an increase in octane number of ~ 3 (RON) when using a 10 % concentration ;
   - their lower NO_X emission ;

   and secondly :
   - their corrosive effect ; and
   - their affinity for water.
2) LNG (liquefied natural gas) and LPG (liquefied petroleum gas) ;
3) Ways and means of improving the use of hydrogen in motor vehicles and its on-board storage (compressed or solid and using metal or exothermal reactions) particularly since hydrogen may eventually be a by-product of future electricity generating techniques.

c) Saving raw materials

Besides the gradual substitution of light and more abundant materials, and even those that are independent of natural resources, for heavier and scarce materials, referred to in Section 3, the recycling of scrap from old vehicles will steadily increase. A number of technical factors that have emerged since the beginning of this decade are affecting the present situation and will probably continue to do so for it is still unsatisfactory both economically and environmentally. Present techniques (using fixed or mobile shredders) are already capable of recovering more than 90 % of ferrous and non-ferrous metals and 80 to 85 % of the non-metallic material including polyurethane. Industry should assist this development, which saves both materials and energy, by designing vehicles with recyclability in mind, not only by selecting easily recyclable materials but also, where possible, designing vehicle parts with easy shredding capability.

3.2. Engine design

During its long career, the Otto cycle engine has developed high qualities of operational flexibility, reliability and endurance at an acceptable cost in mass production conditions. Figure III shows its flexibility in delivering the power needed for a small car (900 kg) in various driving conditions at 48 and

80 km/h assuming 100 % transmission and power system efficiency. Its emission characteristics and noise level will continue to determine its environmental acceptability, and its fuel requirements, in type and quantity, will condition the impact of the motor vehicle on the consumption of natural resources.

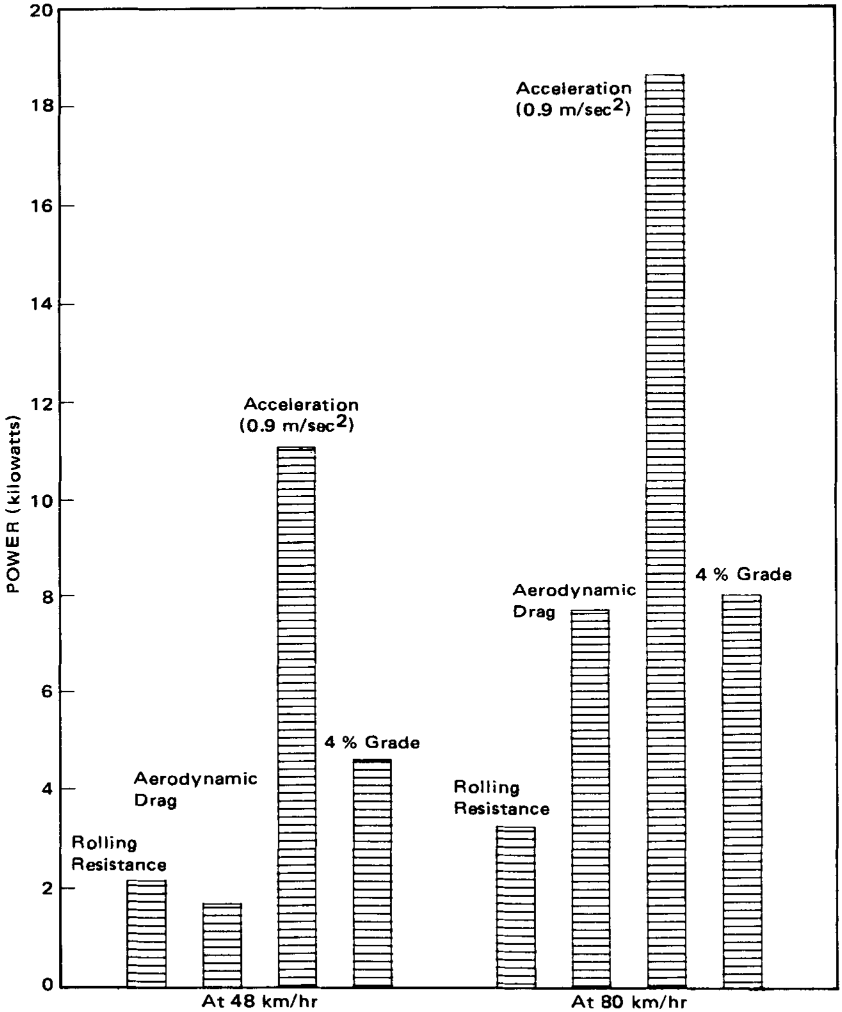

FIGURE III – POWER REQUIRED FOR 900 kg AUTOMOBILE AT 48 AND 80 km/h

(from the report "The Automobile and Air Pollution" published by the US Department of Commerce, 1967).

a) Spark ignition Otto engine

In the short term, this engine, in its present configuration but incorporating recent advances such as electronic fuel injection and some other technological improvements now at development stage, is likely to give the highest performance that reciprocating engines can offer. For the rotary engine, it is generally held that more development time will be required to solve certain outstanding problems (e.g. high HC emission). Technologies now being developed for spark ignition engines have the very significant advantage of tackling the causes of motor vehicle emissions and, in some cases, low fuel efficiency, rather than concentrating on the removal of pollutants in the exhaust manifold. The following technologies for improving carburation and combustion, including air/fuel lean mixture, may produce significant gains in the short term :

1) **Prevaporisation** - Giving a completely uniform air-fuel mixture by preheating, using exhaust or radiator heat, and resulting in :

   - 50 % reduction on average for CO and HC emission, and
   - a slight improvement in fuel consumption.

   The development of preevaporative systems still has to overcome various difficulties including vapour lock.

2) **The sonic carburettor** - Which improves mixture quality by fuel atomisation. Sonic velocity (~ 800 ft/s) is obtained at the throat ; this increases to supersonic levels downstream of the throat, and then instantly becomes subsonic again, creating a shock wave at right angles to the flow in the barrel. The fuel droplets are broken up and mixed with air as they cross the shock wave. Improved mixture quality allows the engine to be operated on the leanest possible mixture - a condition conducive to reduced pollutant emission and higher efficiency. Laboratory tests have shown that :

   - HC and CO emissions are reduced by approximately 50 % as compared with a conventional carburettor, and
   - fuel consumption is said to be reduced by 15 %.

   However, various problems have yet to be solved :

   - altitude compensation,
   - gasket durability in sonic/ultrasonic conditions, and
   - cold start problems.

Table 4 shows in broad outline the salient features of evolving Otto configuration as assessed by the Jet Propulsion Laboratory (Californian Institute of Technology, August 1975). The use of ceramics for the block and rotor of the advanced configuration rotary engine (date unspecified) is worthy of note.

TABLE 4 – SALIENT FEATURES OF EVOLVING UC OTTO CONFIGURATION

Characteristic	Configuration		
	Present	Mature	Advanced
Type	Reciprocating	Reciprocating	Rotary
Fuel/air mix preparation	Conventional carburetor	Advanced carburetor, (ultra) sonic ; preheat	Advanced carburetor (ultra) sonic ; preheat
Speed range	700 to 4500 rpm	700 to 4500 rpm	1000 to 10000 rpm
Block/housing	Ferrous	Ferrous	Ceramic
Pistons/rotors	Aluminium	Aluminium	Ceramic
Induction/exhaust	Valve-in-head	Valve-in-head	Side and peripheral ports
Cooling system	Conventional	Conventional	(None)
Emission controls	EGR ; air pump ; oxidizing catalyst ; quick-heat mani-fold ; quick pulloff choke ; etc.	Advanced carburetion and induction system with aftertreat-ment* of exhaust gas.	Advanced carburetion and induction system with aftertreat-ment* of exhaust gas.

* Alternative aftertreatment systems include :

1) 3-way catalyst/FB control or dual catalyst/air pump or thermal reactor/reducing catalyst/airpump (either may need EGR) to meet 0.41/3.4/0.40 (g/ml $HC/CO/NO_x$)
2) Oxidation catalyst or thermal reactor only, with EGR/air pump or with lean burning, to meet 0.41/3.4/1.-2. (g/ml $HC/CO/NO_x$).

3) **Stratified-charge Otto engine** - This is broadly similar to the conventional spark ignition engine, the major differences being in the cylinder head, piston crowns and induction system, which are especially designed to effect and exploit charge stratification. The stratification is obtained by preparing the fuel/air charge in such a way that burning starts in a fuel-rich mixture and spreads to the rest of the mixture, which may be leaner in fuel. There are three types of stratified-charge engines :
   - prechamber 3-valve carburated (HONDA CVCC engine) ;
   - prechamber indirect injection ;
   - open-chamber direct injection (PROCO engine).

   In its current configuration, under US Urban Federal Driving Cycle conditions, the 3-valve carburated stratified-charge engine (HONDA CVCC) has produced the following emission limits for a four-cylinder car :

HC	CO	NO_x
0.30	2.90	1.70 g/mile

   with a slight improvement in fuel consumption (~ 10 %).

The potential problem with the stratified-charge engine as regards H_2SO_4 emissions is similar to that with the conventional spark ignition engine ; if both are equipped with oxidation catalysts.

Stratified-charge engines present valuable potential for the short and medium term because complex exhaust emission treatment is unnecessary - or less necessary - and fuel consumption is slightly improved which could perhaps offset its higher cost.

b) Diesel engines

Present-day diesel engines are of the piston type. They require compression ratios over twice as high as for Otto spark ignition engines, the reason for their inherent NO_X emission and noise problems. On the other hand, because of their higher thermodynamic efficiency and associated fuel economy, and low CO and HC emission levels, diesel engines will continue to be used, in increasing numbers, for trucks and buses and to some extent for cars. For cars, however, it is important that vehicles of similar performance, size and carrying capacity are considered when comparing diesel and spark ignition engine efficiency. High NO_X emission and noise levels may be lowered by using a prechamber or swirl chamber to reduce peak pressure during combustion.

Table 5 lists salient features of evolving diesel trend configurations, as assessed by the Jet Propulsion Laboratory (Californian Institute of Technology, August 1975). The use of ceramics as cylinder head, block and piston material is worth noting, although no tentative lead time is indicated.

TABLE 5 – SALIENT FEATURES OF EVOLVING DIESEL CONFIGURATIONS

Characteristics	Present configuration	Mature configuration	Advanced configuration
Type	Prechamber or swirl chamber	Swirl chamber	Swirl chamber
Represented by	Mercedes, Peugeot	(Conjectural)	(Conjectural)
Induction system	Naturally aspirated	Turbocharged, IMPM* wastegate	Turbocharged, IMPM* wastegate
Fuel injection system			
Timing	Automatic centri-fugal	Automatic centri-fugal	Automatic centri-fugal
Delivery	Throttle-position modulation	Throttle-position, inlet-manifold-pressure and engine speed modulation	Throttle-position, inlet-manifold-pressure and engine speed modulation
Compression ratio	Fixed, 18:1 to 22:1	Fixed, 18:1 to 22:1	Fixed, approx. 15:1
Cylinder head/block material	Ferrous	Ferrous	Ceramic
Piston material	Aluminium	Aluminium	Ceramic
Cooling system	Conventional	Conventional	None
Emission controls	Retarded injection timing	Retarded injection timing, EGR	Retarded injection timing, EGR

* IMPM = intake-manifold-pressure-modulated.

c) New power plant design

In the longer term, Otto engines of the conventional, stratified-charge and diesel types may be replaced by new power plants offering higher thermodynamic efficiency and lower pollutant emission. R & D on these new power systems will certainly continue, but it is too early yet for any firm prediction about when any power plant would be ripe for mass production or about the type that this would be. Many years of work will be necessary before any decision involving industry in considerable investment cost can be taken. New power plants now being researched are of three types : internal combustion (Brayton cycle), external combustion (Stirling and Rankine cycle) and electro-chemical (batteries and fuel cells).

1) **Brayton cycle** - This is an open cycle, continuous internal combustion engine, with partial exhaust heat recovery. Hot combustion gases are ignited and expanded through a gas turbine to provide power. The ideal Brayton thermodynamic cycle consists of :

– isentropic compression ;
– constant pressure heat addition, partly regenerative ;
– isentropic expansion ;
– constant pressure heat rejection, partly regenerative.

The Brayton gas turbine, in laboratory conditions at least, meets the initial 1978 US Federal emission standards (HC, CO and NO_x) and is a light and vibration-free engine with a multi-fuel capability and a slightly higher cycle thermal efficiency at full load (~ 33 % for a mature Brayton turbine) than the conventional Otto spark ignition engine (~ 27 %, compression ratio 8 : 1).

This higher efficiency and the consequent fuel saving depend on peak gas inlet temperature, but the higher this is, the more difficult the material requirements. The high cost of the alloys or ceramics needed for turbines and the highly specialised manufacturing processes involved will affect future development of Brayton cycle gas turbines and the extent of their future application to motor vehicles at acceptable cost.

2) **Stirling cycle engine** - In terms of pollutant emission, the Stirling cycle engine (like the Rankine) offers the advantages of continuous external multi-fuel combustion, which can be more easily controlled than intermittent combustion. Tc produce power, a working fluid (hydrogen or helium) is alternately cooled during compression and heated during expansion. A rotary air preheater is generally incorporated to recycle some of the residual energy in the combustion chamber. The emission levels of the Stirling cycle engine when developed may be low enough to meet the initial 1978 US Federal Standards, allied with the best thermal efficiency ever obtained for a heat engine, namely :

– ~ 36 % for a mature configuration, as compared with
– ~ 27 % for a mature Otto engine configuration (compression ratio 8 : 1) and
– ~ 32 % for a mature diesel engine configuration.

Stirling cycle engines, however, have not yet been produced in large quantity and their operating characteristics in the hand of the general public have not been established. Moreover, there are problems of high cost and complexity. Special alloys will have to be used to withstand the high temperatures, and the heater head, involving a large number of small tubes in the present design, may present problems of bulk and manufacturing difficulties in high volume production. Even when developed, this problem may price the Stirling engine out of the small and medium-size car market.

3) **Rankine cycle engine** - This is a closed cycle engine which uses the change in phase of a working fluid between liquid and vapour to convert heat furnished from an external fuel combustion system into mechanical work. The ideal Rankine thermodynamic cycle consists of :

- constant pressure heat addition ;
- isentropic expansion ;
- constant pressure heat rejection ;
- isentropic compression.

Classically, water has been used as the working fluid, but organic fluids have also been used in several experimental engines to avoid the freezing problems of water-based engines.

Rankine cycle engines have demonstrated their ability to meet very low emission levels (e.g. initial US 1978 Federal limits) but, in the experiments that have so far been carried out, the major difficulty has been fuel economy, a direct consequence of the engine's low thermal efficiency, even at high expansion inlet-temperatures of over 600°C. Efficiency averages :

~ 24 % for a mature (water-based) Rankine engine, compared with

~ 36 % for a mature Stirling engine and

~ 32 % for a mature diesel engine.

Efficiency decreases if organic fluids are used in place of water. The low efficiency coupled with engine housing problems and cost, could rule out the use of the Rankine cycle engine in motor vehicles even in the long term and mean its "a priori" exclusion from any assessment of trends in vehicle engine design.

4) **Electro-chemical systems** - These can be classed under two headings :

- Batteries (accumulators), where the fuel is usually stored in the conversion device that includes the electrodes ;
- Fuel cells, where the source is separate from the power conversion system.

a) **Battery systems** - The major problems with battery-powered vehicles are the limitations on their range and weight due to the low specific energy levels of the types of battery that are currently available, and the difficulties in the way of developing and marketing high specific energy systems. One way of assessing the financial implications is to assume a maximum allowable cost per kilowatt/hour of energy to be stored on the vehicle and to work out an allowable cost for the battery materials on that basis.

The material costs listed in Table 6 are based on an assumed cost of $ 20 per kWh of storage capacity and reasonable estimates for cost distribution, profit, and so on.

TABLE 6 – IMPLICATION OF DOLLARS 20/kWh ON SPECIFIC ENERGY AND ALLOWABLE MATERIAL COST OF THE BATTERIES

Specific energy (Wh/kg)	Allowable material cost (dollars/kg)*
22	0.29
44	0.57
66	0.86
88	1.14
110	1.43
220	2.86

* Dollars 20/kWh battery wholesale price material cost : 80 % of factory cost G & A 11 %, profit 11 %.

(Taken from YAO, N.P. and BIRK, J.P. "Battery Energy Storage for Utility Load Levelling and Electric Vehicles : A Review of Advanced Batteries" 1975).

The present trend is to develop more efficient batteries than the lead-acid and nickel-iron types whose capacity restricts their use to vehicles of limited performance and range (delivery and utility trucks, buses) and on well-established routes. These new types include :

- Nickel-zinc, with specific energies of ~ 70 Wh/kg.
- Silver-zinc, having a high specific energy of ~ 110-130 Wh/kg, but also the drawbacks of short life and high cost.
- Zinc-halogen, with high specific energy, but posing the difficult problem of storing halogens (bromine or chlorine).
- Metal-air batteries, having some attractive features such as low weight and reasonable specific energy but marred by the need for metal regeneration. Advanced lithium-air and zinc-air batteries have been developed, the latter having attained a specific energy of 150 Wh/kg (in US). Improved zinc regeneration has also been achieved (in France).
- Fused salt electrolyte batteries, using lighter metallic elements (lithium, sodium etc.) combined with elements such as fluorine, chlorine, bromine, sulphur and oxygen. The lithium-sulphur combination could give energy densities of 150 Wh/kg at what might well be a reasonable price, but batteries of this kind would have to be operated at temperatures of over 400°C.
- Solid electrolytes, such as sodium-sulphur, with very attractive power and energy densities at relatively low cost.

b) **Fuel cells** - Although having the advantage of being immediately rechargeable, fuel cells are limited in specific power (cf. Crowe, B.J. "Fuel Cells, a Survey", NASA 1973).

To bring the problem into perspective, it should be noted that it will be difficult for electro-chemical systems to achieve widespread automotive use with an acceptable energy balance in the next 15-20 years, with the exception of utility vehicles. But their ability to generate energy from a variety of materials and particularly their almost pollutant and noise-free potential is so attractive, especially for vehicles used in urban areas, that their development must be encouraged now precisely because it will take so long to perfect them.

4. MOTOR VEHICLE MANUFACTURE

4.1. External Environment

Where the advanced techniques now available for controlling most emissions and effluents from motor manufacturing plants are applied, it is generally recognised that vehicle manufacture is not inherently a highly polluting process. Where there is no adequate legislation covering industrial plants or where it is not enforced, specialists on both sides, government and industry, should co-operate in framing the necessary instruments and industry should comply by installing the necessary equipment for :

- Effluent treatment to remove harmful quantities of hydrocarbons, suspended particulate matter, metals, cyanides, acids, alkalis, and soluble oils, using separation, filtration and neutralisation techniques as appropriate ;
- Adequate dust removal ;
- Treatment of odours and removal of harmful quantities of solvents in paint spraying.

Industry engineers should also be encouraged to intensify efforts to minimize potential environmental problems by appropriate modifications to manufacturing processes and improvements to products.

4.2. Working Conditions

The introduction of mass production techniques, which transformed the motor vehicle from a luxury reserved for the privileged few into a general consumer product, at least in the developed countries, could not have taken place without a radical change in working conditions. Technical skills and versatile operatives have been replaced by automated machines manned by a large and less expert workforce and involving repetitive movement that could be a source of monotony and lead to stress. Many successful work improvement schemes have recently been launched in Europe as a countermeasure and the pioneering work done by the motor industry in attempting to improve working conditions and thereby reduce absenteeism, especially in new plants, is recognised. Apart from this, many countries have brought in legislation governing working conditions in plants and workshops. Efforts to improve the working environment should continue with emphasis on the following :

a) In those countries where adequate legislation does not exist, specialists in the administration and engineers in industry should co-operate in the preparation and adoption of minimum uniform standards regarding safety, lighting, heat, noise and ventilation in the working environment, taking due account of the activities of the International Labour Organisation (ILO) which include studies on working conditions and the working environment, and proposed standards.

b) Experience as regards improving working conditions is not necessarily transferable from country to country or from plant to plant, and experts, in co-operation with the bodies concerned, should continue their efforts to improve working conditions, particularly as regards safety, heavy manual labour, noise and health. Specific aims should be to eliminate hazardous substances such as lead, asbestos, etc., to reduce repetitive and boring tasks by innovations in work organisation, to stimulate interest by increasing personal responsibility and to improve human relationships. A useful reference here is the International Programme for the Improvement of Working Conditions (PIACT) recently launched by ILO.

c) When transferring motor vehicle manufacturing technology and assembly plants to foreign countries, and especially to developing countries, industrial managements and engineers should ensure that the technology and installations involved comply with the industrial legislation in those countries, should it exist, and if it does not, then with the applicable legislation in the country of origin.

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