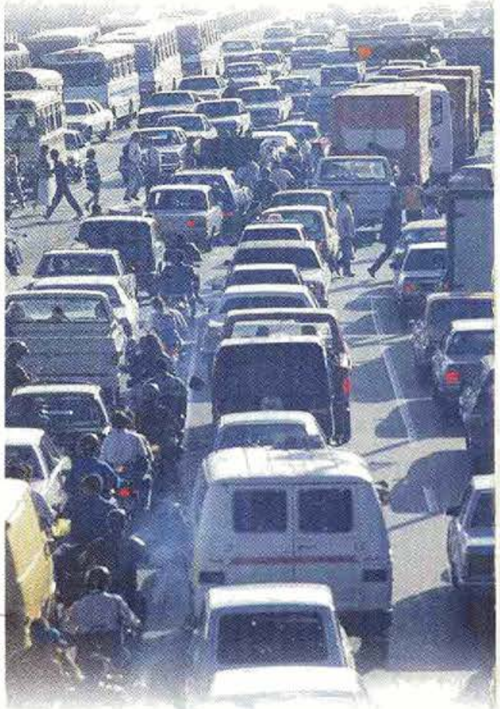
UNEP

Natural Selection

Evolving Choices for Alternative Fuels and Vehicle Technologies



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Foreword

Members of a village cooperative in Mali extract and sell oil from the local jatropha plant to power a local diesel truck. In the U.S. and Brazil, motorists fill their tanks with various blends of ethanol made from corn or sugar cane. Such "biofuels" are examples of cleaner, renewable and available alternatives to non-renewable and polluting fossil fuels.

Alternative fuels are important because motor vehicles fuelled by petroleum are a major source of harmful emissions, including sulphur and nitrogen oxides, carbon dioxide, carbon monoxide, particulate matter, volatile organic compounds and lead (in countries where leaded gasoline is still used).

Further, fossil fuels currently supply 95% of our transport energy, with road transport accounting for half of all air pollution and more than 80% of urban air pollution. Increasing local and regional air pollution is not only affecting land and water resources, they are also making us sick by increasing respiratory diseases, cancer and asthma. These impacts and those from climate change to which transport contributes with about 18% are costing our economies billions of dollars.

Despite some impressive technical improvements to vehicles and numerous government measures to encourage better environmental performance, these impacts continue to worsen. This is due to an ever increasing demand for transport services from a growing world population and rising incomes, particularly with the eastward enlargement of the European Union and the rapid industrial development of countries, such as China and India. Consequently, a sustainable transport sector is now not just desirable, it is *crucial*.

A sustainable transport sector based on alternative fuels, however, can produce more than just environmental benefits. In developing countries, where oil imports often represent a large drain on national budgets, cultivating and processing local biomass into renewable fuels can help ease pressure on national budgets while creating local jobs and restoring degraded agricultural lands.

Of course, biofuels are not the only type of alternative fuel, and the future will most lik bring a mix of fuels that will vary from country to country. Alternatives include liquef petroleum gas, compressed natural gas, electricity and hydrogen.

Despite their obvious benefits and considerable investment by governments and the privat sector, none of the available alternative fuel/vehicle options has yet truly overcome all of the technical, market and policy barriers - mainly because a common policy and strategy does not exist.

Helping overcome these barriers is the purpose of this publication. In the first part, you will find information on different alternative fuels, including descriptions of each alternative fuel technology, current market position, state of development, performance, environmental impact, health and safety concerns, and costs. The second part describes policy options and actions that can be undertaken by governments, industry, and consumers.

I urge you to read this publication carefully and act on its recommendations to develop alternative fuels as a significant and growing element of the global transport sector. It is very clear that if we continue with "business as usual", the massive investments we will make in transport in the coming decades will not produce a sustainable outcome and we will leave our children - and generations to come - with a world more polluted than today.

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Acknowledgements

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A Serious Challenge

The transport sector is crucial to the world's economy and a major contributor to global GDP. An estimate for the U.S. economy, for example, found that one in four dollars was in some way connected to the automotive industry.

The immense benefits the transportation sector provides, however, must be set against the costs of a sector that is over 95% dependent on oil. This dependence on petroleum fuels creates supply risks and produces a range of serious environmental, social and health impacts.

Further, transport is by far the fastest growing energy demand sector. In the next two decades the industrialisation of China, India and other developing countries will create a new growth in the demand for oil that will outpace demand from the developed world.

These trends raise troubling questions and challenge the ability of the world's transport fuels and technologies to deliver sustainable solutions. Can urban centres continue to bear the weight of vehicle tailpipe emissions? Can the global atmosphere safely absorb massive releases of greenhouse gases? How will rising fuel costs impact economies in both developed and developing countries? How will nations meet their increasing energy needs while protecting the global environment – especially in the face of staggering population growth in developing countries.

The question of significance, therefore, may not be when the world runs out of oil, but rather what actions can be taken *now* to deliver sustainable transport.

Drivers for Change

In addition to concerns about the longevity of world oil supplies, there are a number of important dynamics which question continued reliance on petroleum. When former Saudi Arabian Oil Minister Shiek Yamani said, "The stone age came to an end not for a lack of stones, and the oil age will end, but not for a lack of oil", he may have been referring to the impact which energy security, climate change, air quality and other "non oil" factors will have on the future's choice of fuels.

Energy security

The world is not running out of oil – at least not yet. Global oil reserves total more than a thousand billion barrels and new reserves continue to be discovered – often at a pace equivalent to or greater than current production. New technologies are also improving the recovery of reserves in the ground.

Therefore, although 90% of the Earth's oil endowment has already been discovered, present consumption rates mean the remaining bounty could yield plentiful and cheap oil for another 40 years, possibly longer. Some surveys of possible oil discoveries estimate that between 1.4 trillion and 2.1 trillion barrels of oil remain to be produced worldwide, creating a range with a 95% possibility that the world's remaining oil resources could last 63 more years and a 5% chance they will last another 95 years.

Petroleum experts within and outside the industry contest this lifespan. They question reserve estimates and assumptions that the last bucket of oil can be pumped from the ground just as quickly as oil gushing from wells today. Their analyses of the discovery and production of oil fields around the world suggest that within the next two decades, the supply of conventional oil will begin to lose pace with increasing global demand – accelerated by demand in developing countries which is expected to grow three times faster than in the OECD region. With this competition for increasingly limited supplies, prices will almost certainly rise, bringing an end to the abundant and cheap oil on which development and economic growth have depended.

Many countries are also witnessing rapid declines or even the exhaustion of domestic oil supplies, requiring them to increasingly rely on external sources. In the European Union, for example, external dependence on oil is expected to increase to 90% in the next 20 years. Further, the world's remaining oil resources are increasingly concentrated in fewer and fewer countries, which limits the diversity of supply sources, increases vulnerabilities associated with import dependence, and potentially exacerbates political tensions over the increasingly precious status of oil supply.

Climate change

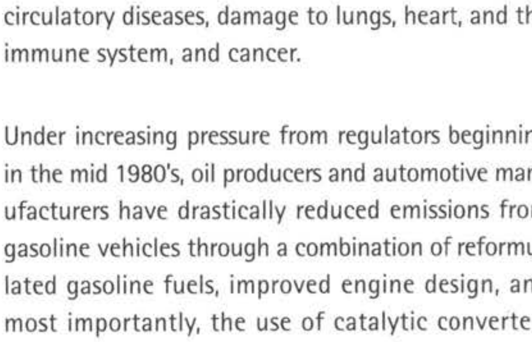
Climate change has steadily risen to the top of the global environmental agenda. This is due to an increasing realisation that current energy production and use account for 80% of anthropogenic (human induced) greenhouse gas emissions, principally carbon dioxide (CO_2). The increased concentration of greenhouse gases is collectively acting to create an enhanced greenhouse effect, increasing global temperatures in a phenomenon known as global warming. The consensus among a majority of climate scientists is that such warming will have serious environmental impacts and lead to changes in climate that include, rising sea levels and increased flooding. These changes will also create sweeping impacts on health, agriculture and ultimately economic development.

Of the 28 billion metric tons of man made CO_2 emitted worldwide every year, 18% comes from cars and trucks – and this fraction is expected to grow. The International Energy Agency forecasts that CO_2 emissions from the transport sector will increase by 92% between 1990 and 2020, generating roughly one-fourth of the global energy related CO_2 emissions. Of this, more than 80% will be emitted from cars and trucks.

Local air pollution

Transportation is responsible for releasing staggering levels of harmful emissions into the atmosphere, especially at the local level where the motor vehicle is the largest single source of toxic emissions (mostly hydrocarbons, nitrogen oxides, carbon monoxide, particulate matter, volatile organic compounds and lead). These emissions account for about 50% of all air pollution and more than 80% of urban air pollution in developed countries. The impacts on human health are considerable and include respiratory and circulatory diseases, damage to lungs, heart, and the immune system, and cancer.

Under increasing pressure from regulators beginning in the mid 1980's, oil producers and automotive manufacturers have drastically reduced emissions from gasoline vehicles through a combination of reformulated gasoline fuels, improved engine design, and most importantly, the use of catalytic converters in exhaust systems. Nonetheless, these advances continue to be outstripped by the escalating number of kilometers travelled by all vehicles. Moreover, many emission abatement technologies are not yet available in developing countries where emissions standards are minimal and fuel quality remains low. This presents an acute human health concern in urban areas of the developing world where the number of inhabitants will double to nearly 4 billion by 2030.



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Role of Alternative Fuels and Vehicles

With sufficient preparation, the transition to a post-oil economy does not have to be traumatic. There are numerous possible paths to alleviate the pressing questions of transportation sustainability. Many of these paths are currently being explored, often collectively, and include: improving fuel efficiency, introducing stricter emissions standards and emissions control technologies, improving conventional fuel quality (i.e. eliminating lead and lowering sulphur levels), and improving vehicle maintenance. Likewise, strategies to encourage better urban planning and behavioural changes, including modal shifts to public and non-motorised transport, can help to create sustainable transport systems.

However, the solution associated with breaking the grasp oil holds on the transportation sector lies mainly with the market's ability to identify a practical substitute. The challenge of squeezing both greater efficiency and pollution reductions from conventional vehicles, however, is leading a continuous search for viable alternative fuels and propulsion systems.

% Change in Emissions from Conventional Gas Vehicle to AFV			
(grams/mile basis)	Dedicated CNGV	Dedicated LPGV	Dedicated Electric Vehicle
Fuel Use Only			
GHGs (total)	-13.28%	-5.25%	-100.00%
VOC	-78.41%	-62.95%	-100.00%
CO	-20.00%	-25.00%	-100.00%
NOx	-10.00%	-10.00%	-100.00%
PM 10	-34.55%	-32.73%	-36.36%
SOx	-98.02%	-100.00%	-100.00%
Complete Fuel Cycle (Fuel Production and Use)			
GHGs (total)	-14.97%	-14.17%	-31.01%
VOC	-82.99%	-63.83%	-90.42%
CO	-20.28%	-25.16%	-98.91%
NOx	-8.68%	-21.03%	-7.19%
PM 10	**467.73%**	-43.35%	**45.36%**
SOx	-88.45%	-80.29%	**342.67%**

Source: U.S. EPA

The list of leading alternative fuels and vehicles includes (but is not limited to) biodiesel, electricity, ethanol, hybrid-electric, hydrogen/fuel cell, liquefied petroleum gas (LPG), and compressed natural gas (CNG). These fuels are largely characterised as "alternative" by their ability to be substitutes for gasoline and diesel fuels made from petroleum, although they may still have associated hydrocarbons, such as in natural gas or LPG. These alternatives are also expected to reduce dependence on imported petroleum and improve air quality. Hybrid electric and fuel cell vehicles are also referred to as "advanced" alternative vehicles because they can run on fuels produced from renewable resources.

Some experience has already been gained with each of the contending alternative fuels. More than eight million LPG vehicles are in operation worldwide while hundreds of thousands of CNG-fuelled vehicles operate in dozens of countries, including Argentina, Italy, India, U.S., Egypt, Venezuela, and China. Brazil has extensive experience with ethanol-fuelled vehicles, and nearly 4 billion liters/year of 10% ethanol-blended "gasohol" are used in the U.S. commercial sector. Battery-electric light-duty vehicles also exist today, primarily in fleets, while 100,000 hybrid electric vehicles have been sold worldwide since their introduction in 2000. Experimental hydrogen fuel cell vehicles are currently being introduced in the U.S., Germany and Japan.

Not surprisingly, each alternative fuel and vehicle technology has advantages and disadvantages. Natural gas engines may have difficulty achieving the anticipated large reductions in vehicular nitrogen oxides emissions; biofuel production may require crop expansion onto vulnerable, erosive lands; and fuel cells may be limited by the ability and cost of hydrogen.

Moreover, a transition to one or more of these fuels confronts a number of barriers that limit the percentage of alternative fuel use and the number of alternative fuel vehicles in national fleets. Limited vehicle range, limited refuelling infrastructure and higher fuel costs, for example, have been major, if not preclusive, barriers. Even after years of legislative inducement in the U.S., alternative fuel vehicles still number only about one million, or 0.4%, of all vehicles. Alternative fuel consumption has not fared better, managing to account for about 0.2% of total vehicle fuel consumption in 2000.

Barriers

Barriers to greater market penetration by alternative fuels are often characterised by the "chicken-and-egg" situation – an insufficient number of alternative fuel vehicles means fuel suppliers are reluctant to invest in refuelling facilities, which deters buyers. Without buyers, automotive manufacturers are not inclined to build the vehicles – at least not at production levels necessary to institutionalise sales and distribution or bring down the price.

Despite various barriers, alternative fuel vehicles are here today and can immediately contribute to significant reductions in oil use, pollution, and carbon dioxide emissions.

Low oil prices and entrenched markets

Today's gasoline prices might be considered expensive by some motorists, but they are not high enough to induce many people to give up their conventional gasoline and diesel automobiles in favour of an alternative. When adjusted for inflation, the price of gasoline has barely risen in the last 40 years. Studies have shown that even a doubling of the price for crude oil would not significantly increase the market share for alternative fuel vehicles.

In addition to fuel cost, the major barrier that most alternative fuels must overcome is the need to compete with the highly developed technology and massive infrastructure that supports the production, distribution, and use of gasoline and diesel fuels. Any new fuel must compete with the ready availability of gasoline and the massive amounts of capital and engineering time continuously invested to optimise performance of gasoline vehicles. As such, consumers' acceptance of gasoline presents a formidable challenge to new fuels that may require a totally new distribution network.

Insufficient refuelling infrastructure

The limited number of refuelling stations for alternative fuels compared with gasoline and diesel stations is often cited as the biggest impediment to alternative fuel vehicles. For conventional fuels, a distribution system and a network of refuelling stations has been established through substantial investment over many decades. Because some alternatives will require significant elements of this infrastructure to be totally replicated, alternative fuel choices are often more expensive and less competitive.

For example, the widespread use of compressed natural gas requires a new routing of pipelines and the construction of compression and dispensing facilities costing $300,000 or more per refuelling station. Similar investments would be needed for hydrogen gas. LPG can be trucked to stations and pumped in similar ways to gasoline, although additional costs are incurred for storage facilities, dispensing nozzles and safety features. Ethanol in low blends requires no additional measures at the refuelling point, but higher blends require the replacement of degradable rubber and certain metals in storage tanks, pumps and vehicle components.

On the positive side, alternative fuels do not necessarily have to be available at the same number of sites as gasoline to give adequate coverage and compete at the same level of consumer convenience. Vehicles operating mainly in urban areas, for example, can often manage with a much smaller network.

Alternative fuels could also be dispensed from the same network or a subset of sites. The cost of a completely new infrastructure can be mainly avoided if existing facilities are used; and these sites are generally conveniently located, purpose-built and well distributed to give effective coverage. For larger sites, the supply of alternative fuels is essentially a question of "adding an extra pump" and fuel storage tanks, which is already happening for LPG. For example, ethanol also has few technical challenges as it behaves much like petrol or diesel.

These technical and cost barriers underscore the point that a refuelling infrastructure will not emerge overnight, or without a clear expectation of returns on investment.

In summary:

- The challenges for the introduction of any alternative fuel are substantial, which means a widespread refuelling infrastructure is unlikely to be developed for an interim fuel that will only be used for a limited number of years or where the presence of a number of alternatives dilute investments in infrastructure;

- The emergence of a "mix" of different alternative fuels being used for different niche areas is a possibility. This is most likely for special-use or "captive" fleets where the alternative has clear technical or cost advantages, or in regions with focussed and sustained incentive programmes.

Range limitations

The generally lower energy density of alternative fuels compared to gasoline reduces driving range and compounds the barrier of limited fuel availability. To counter this problem, some manufacturers have introduced vehicles capable of using both gasoline and alternative fuels by either switching between two fuels separately stored on-board (bi-fuelled vehicles) or mixing fuels together in varying proportions (flexible-fuelled vehicles). Unfortunately, multi-fuel vehicles are generally more costly than specifically built vehicles and offer inferior fuel efficiency, emission characteristics, and performance.

For electric vehicles (EVs), range can be extended using "hybrid" configurations that combine electric motors with small internal combustion engines or fuel cells. Other measures for coping with range problems include a strong emphasis on vehicle fuel efficiency; introduction of high pressure, cryogenic or hydride storage tanks for gaseous fuels; and consumer acceptance of the weight and space penalties required by larger storage tanks.

Cost penalties

Although costs vary, alternative fuel vehicles cost on average more than conventional vehicles – which reduces the incentive for their purchase. For example, a vehicle that runs on gaseous fuels generally costs from $3,000 to $5,000 more than the conventional version of the same vehicle, largely due to the cost of tanks and ancillary equipment. The price of an electric vehicle generally ranges from $30,000 to $45,000. However, ethanol requires only limited extra costs from minor adjustments and some manufacturers are building flexible fuel vehicles using components compatible with both ethanol and gasoline at no additional cost for the consumer. Hybrid electric vehicles are becoming increasingly price competitive in the $20,000 to $40,000 range. Fuel cell vehicles are currently manufactured on a very limited, experimental basis, and leased for $500 to $1,000 per month to special customers with access to hydrogen fuel.

Still, the higher vehicle cost barrier may ultimately be the easiest barrier to overcome as increased consumer demand helps manufacturers lower prices through production economies of scale.

Consumer acceptance

Continued development, promotion and use of alternative fuels contribute to greater consumer awareness of viable options and lay the foundation for future sustainable transportation fuels.

For example:

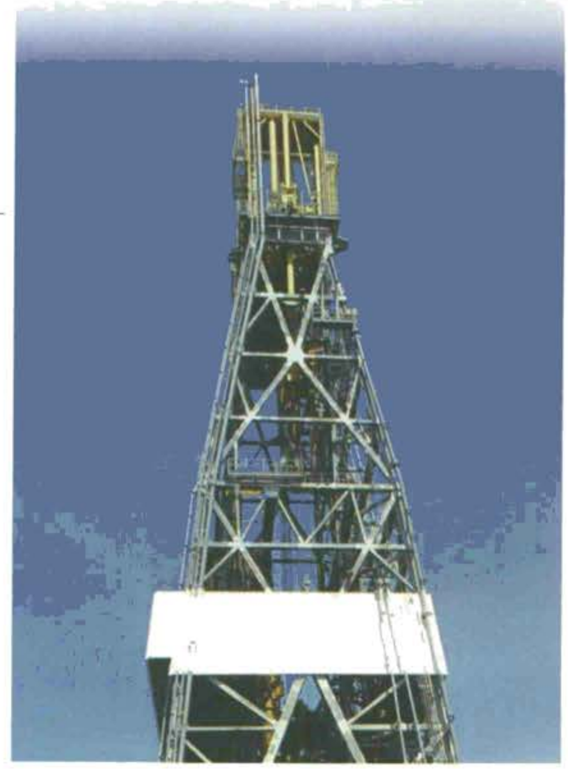
- The use of CNG advances development of gaseous technologies and furthers confidence and experience with gaseous fuels necessary for using hydrogen on a large scale.

- An improved distribution infrastructure can allow alternative fuels to replace gasoline to be used besides electricity in hybrid electric vehicles.

- Continued development of ethanol may be the most direct path to a "renewable" fuel with limited greenhouse gas emissions.

A significant penetration of alternative vehicle technologies and fuels will be dependent on continued technology development, cost-reductions, market deployment and supporting infrastructure. The following sections explore these fuels and vehicle technologies, including market development, performance, environmental impact, health and safety concerns, and costs.

Liquefied Petroleum Gas



Liquefied Petroleum Gas (LPG) is a by-product of natural gas processing and petroleum refining. In its natural state, it is a colourless, non-toxic gas comprised primarily of propane and butane. LPG can be compressed to a liquid at very low pressure and easily stored and transported. In this form, it has similar properties to gasoline and can be used in a standard spark-ignition engine with only minor adjustments. LPG is used for residential and industrial purposes worldwide and readily available from an existing global production and distribution network.

LPG may be the easiest alternative fuel to commercialise when considering performance, cost, range, and emissions. It is a proven and reliable transportation fuel used in automobiles, trucks, buses, and a variety of off-road vehicles since the 1960s. It is clean-burning, high octane, abundant, and relatively clean. Due to these characteristics, it has been widely promoted to reduce urban air pollution. LPG can be used in a wide range of vehicles and holds the largest worldwide market for alternative fuels.

Market

More than 8.3 million motorists worldwide drive LPG vehicles – a trend growing at 12-15% per year. Growing markets include Algeria, Bulgaria, China, the Russian Federation and South Korea. In Europe, a 40% growth is projected through 2005. In these countries, especially the U.K., Italy and France, LPG is gaining market share because it costs less than gasoline and quickly "pays back" the extra costs of converting a vehicle to use LPG, especially for high-kilometre vehicles.

LPG has made a greater penetration of the private vehicle market than other fuels, but is still a stronger alternative for vehicle fleets that can take advantage of the convenience and lower costs associated with central refuelling. These fleets include airport and hotel shuttles, taxis, buses, utility and trade vans, delivery vehicles, rental cars, police vehicles and school buses.

LPG vehicles can access more than 32,000 refuelling sites worldwide, including more than 1,000 stations in mature markets such as Australia, Italy, Japan, Mexico, Poland, South Korea, Turkey and the U.K.

Technology development

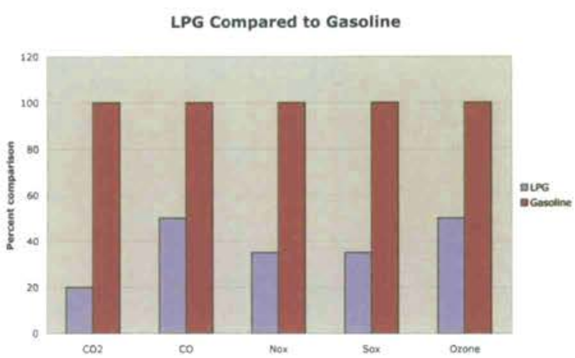
In recognition of public concern and demand for cleaner vehicles, virtually all major automotive manufacturers have introduced LPG vehicles. New engines have been specifically engineered to run on LPG and feature the same driving performance and acceleration consumers know from gasoline vehicles. Fuel systems and electronic engine management systems have been fully adapted with some models also supporting a dual fuel system, allowing the driver to switch from LPG to gasoline, thereby almost doubling driving range. However, the dedicated engine brings the greatest gains in fuel efficiency. For LPG vehicles, manufacturers are designing around the gas tank, placing the tanks under the floor or luggage compartment to maximise valuable passenger space.

Performance

The performance and operational characteristics of LPG vehicles compare favourably to conventional fuel vehicles. Converted gasoline-powered spark-ignition engines tend to run more smoothly because LPG has a higher octane rating than gasoline. The higher octane of LPG also allows higher compression ratios, which can deliver increased engine-power output and better thermal efficiency. These characteristics reduce fuel consumption, emissions, engine wear and maintenance requirements, including the frequency of spark plug and oil changes. LPG produces less soot than both gasoline and diesel fuels, reducing abrasion and chemical degradation of the engine oil. With the latest generation of LPG-fuel systems, acceleration and top speed are comparable to gasoline vehicles. LPG fuel efficiency (measured as liters per 100 kilometers of gasoline equivalent) is about the same as reformulated gasoline. However, LPG has a lower energy density than gasoline and diesel, which has no effect on engine performance but means a larger volume of fuel and a bigger tank are required to achieve the same overall driving range.

Environmental impact

The use of LPG in vehicles offers an immediate and concrete solution to improve local air quality, especially in urban areas. In terms of air-borne emissions of the main regulated noxious gases, LPG is among the lowest of all automotive fuels available today. Compared to gasoline, LPG yields 50% less carbon monoxide (CO), 40% less hydrocarbons, 35% less nitrogen oxides (NOx) and 50% less potential to form ozone.



LPG can play an important role in mitigating climate change, producing on average 20% less CO_2 compared to gasoline on a well-to-wheel analysis and approximately 167 grams of CO_2 equivalent per kilometer (versus 251 grams of CO_2 equivalent per kilometer for a vehicle operating on reformulated gasoline at 8.7 liters per 100 kilometer (l/100km) (Note: this reference point will be used in future sections). Moreover, LPG is non-toxic, non-poisonous and does not contaminate aquifers or soil if spilled.

Health & safety concerns

The safety record of LPG is equal to – and in some cases better than – gasoline or diesel. However, due to consumer concerns about the usability of gaseous fuels, automotive manufacturers upgraded safety features by incorporating improved technologies. LPG fuel tanks, for example, are much stronger than comparable gasoline tanks and new safety valves automatically shut off supply from the tank if a leak occurs in the fuel system.

Moreover, an LPG vehicle has a closed fuel system where fitted valves move the fuel from pump to the vehicle's tank without exposure to the outside environment, which prevents fuel spills and evaporation.

LPG has the lowest flammability range of any alternative fuel and an ignition temperature one-half that of gasoline. If it leaks, LPG quickly evaporates.

Cost

LPG vehicles are more expensive than their gasoline-powered counterparts, costing approximately $2,000 to $4,000 more for light-duty vehicles and $4,000 to $5,000 more for medium-duty delivery trucks. These costs are expected to decrease as more LPG vehicles are manufactured and sold. To promote LPG as a clean fuel, governments usually provide subsidies through exemptions on fuel excise tax, which can make the final pump price one-third to one-half the price of gasoline, depending upon the country. High-kilometre drivers are therefore able to quickly recover the additional higher cost of the vehicle.

Key Facts

- *Industry and consumers have extensive experience with LPG use, storage and transport.*
- *Adequate supplies and distribution of LPG are available at a price competitive with gasoline and diesel fuel. Additional conversion costs are often quickly recovered through fuel savings.*
- *LPG has the highest energy density of the alternative fuels and offers the least compromise in fuel storage, range, and weight*
- *LPG is a liquid at low pressures and therefore can be carried in relatively light-weight tanks.*
- *At normal ambient temperatures LPG vapours are heavier than air, possibly creating pools of flammable vapours in low spots if a leak occurs.*
- *Tanks are pressure vessels and therefore weigh more than diesel tanks, though less than higher pressure gas tanks for natural gas and hydrogen.*
- *LPG requires appropriate handling because it is heavier than air and can cause cold burns to the skin if spilled or used inappropriately.*

Compressed Natural Gas

Natural gas is a mixture of hydrocarbons, mainly methane (CH_4), drawn from natural gas wells or in conjunction with crude oil production. With global reserves greater than petroleum, natural gas is an abundant resource widely used for home heating, cooking, and industrial applications. For vehicle use, natural gas is delivered through pipelines and compressed at the point of fuelling. Natural gas can also be used in a liquid form (LNG), primarily for heavy duty trucks and buses. In limited cases, biogas is produced from decomposed waste in landfills where it is captured, converted, and used to fuel limited numbers of municipal fleet vehicles, primarily on a demonstration basis.

Most existing natural gas vehicles (NGVs) are conventionally-fuelled-vehicles converted to run on compressed natural gas (CNG). The use of natural gas in light and heavy duty vehicles has been extensive due to several factors: its low comparative price to conventional fuels (due to both a lower fuel price and tax incentives); its potential for reduced emissions; and the relative ease of use, with only minor modifications to existing internal combustion engines needed.

Natural gas has several natural advantages as an automotive fuel, including:

- The ability to be mixed with air and burned more cleanly and efficiently;
- A simple structure and the highest hydrogen-to-carbon ratio;
- A low carbon content per unit of energy; and
- Abundant and readily available supplies through a distribution network of pipeline systems in many parts of the world.

Market

There are some 2.5 million NGVs and 5,300 refuelling stations worldwide, primarily in Argentina (720,000 vehicles), Brazil, Italy, Pakistan, India, U.S., Egypt, Venezuela, China, and the Ukraine (35,000 vehicles). However, their use is largely limited to specialised fleets, mainly because:

- Low energy density limits the range relative to conventional fuels;
- Onboard storage of CNG requires bulky and expensive tanks;
- Expensive refuelling infrastructure and expertise is needed; and

- Refuelling is neither as quick nor as straightforward as with liquid fuels.

These factors have significantly limited refuelling infrastructure for the passenger car fleet compared to refuelling infrastructure for gasoline or diesel fuels. However, many of the drawbacks are greatly reduced for certain vehicle fleets (e.g. buses, delivery vehicles, taxis) operating from central refuelling facilities – referred to as "captive fleets". The main advantages of deploying CNG in these fleets are:

- The required range is often limited, and generally predictable;
- Vehicles are parked and refuelled overnight at depots, which increases use and cost-effectiveness of a dedicated refuelling facility; and
- Many of these vehicles are large, so the penalty for using a heavy tank is relatively small and more easily accommodated.

Technology development

Natural gas vehicle technology is considered mature with more than 40 manufacturers worldwide offering NGVs and natural gas fuelled engines. In the last years, manufacturers have produced an impressive array of both dedicated and dual-fuel CNG vehicles, including passenger cars, pickup trucks, school and transit buses, refuse haulers, and heavy-duty trucks. Many of these vehicles operate using the cleanest internal combustion engines ever manufactured.

Two types of CNG fuel systems are on the market: dedicated vehicles operating exclusively on natural gas, and dual-fuel vehicles using both natural gas and gasoline.

Environmental impact

Due to the favourable properties of natural gas as an engine fuel, CNG vehicles produce lower levels of all pollutant emissions than either gasoline and diesel vehicles. Compared with gasoline-powered vehicles, dedicated CNG vehicles can reduce exhaust emissions of CO by approximately 70%, non-methane organic gas (NMOG) by 89% and NOx by 87%. Dedicated NGVs can also reduce CO_2 exhaust emissions by 20-30%, emitting roughly 173 grams of CO_2 (equivalent) per kilometer. However, because methane itself is a potent greenhouse gas, care must be taken throughout the fuel cycle to avoid leakages or venting.

Performance

Because the octane rating for CNG is higher than gasoline, a CNG vehicle with a dedicated engine produces greater power, acceleration, and cruising speed, although dual fuel CNG vehicles can be slightly underpowered. In addition, CNG engines can run more efficiently than a gasoline engine due to the cleaner burning characteristics of natural gas, which can also extend the life of the vehicle.

Although proper training is required for all maintenance personnel working on CNG vehicles, some routine maintenance can be less frequent. The oil in a CNG vehicle, for example, does not need to be changed as frequently because CNG burns more cleanly than gasoline, producing fewer deposits in the oil. Many NGV owners report that oil changes are needed only every 13,000-24,000 km and standard spark plugs last as long as 96,000 km. In heavy-duty vehicles, CNG engines are also generally less noisy than diesel engines.

CNG fuel efficiency (measured as liters per 100 km of gasoline equivalent) is approximately the same as that of reformulated gasoline. Although CNG has a lower energy density than gasoline and diesel, this has no effect on engine performance but does mean a larger volume of fuel and a bigger tank are required to achieve the same overall driving range.

Health & safety concerns

NGVs are as safe as vehicles operating on traditional fuels, such as gasoline. This is due to the structural integrity of the NGV fuel system, and the physical qualities of natural gas as a fuel.

The fuel storage cylinders used in NGVs are much stronger than gasoline fuel tanks. CNG cylinders are subjected to a number of regulations, including "severe abuse" tests, such as heat and pressure extremes, gunfire, collisions and fires. The composite materials used to encase the tanks, however, are more susceptible to physical damage than metals under abusive conditions. For this reason, composite materials on CNG cylinders must always be properly handled and protected. Incidents involving ruptures of natural gas cylinders have revealed that the composite overwrap on the cylinder was subjected to some form of chemical attack or physical damage.

CNG is an inherently safe, non-toxic fuel with a narrow flammability range. It is also lighter than air and will not pool as a liquid or vapor on the ground in the event of a spill or accidental release. CNG disperses rapidly, minimising ignition risk relative to gasoline. Nevertheless, indoor leaks may form a flammable mixture in the vicinity of an ignition source. NGVs have onboard gas detectors and other safety devices, such as tank safety valves that allow fuel to flow only when the engine is operating.

At a CNG fuelling station, the gas is compressed at a very high pressure before it is delivered to vehicles. Although the use of high storage pressures can appear dangerous, high-pressure gases are used safely every day in household, industrial and medical applications. Further, there are stringent safety standards for compression, storage and fuelling of natural gas vehicles.

Cost

Although CNG generally costs 15 to 60% less by volume than gasoline or diesel, converting a vehicle to CNG can cost an additional $2,000 to $4,000 or more. But CNG equipment can be purchased and installed by the fleet owner with training from the conversion companies or conversion kit manufacturers. Alternatively, NGV specialists can do the conversion, which adds about 25% to the vehicle cost. New CNG vehicles can cost $1,000 to $6,000 more than their gasoline-powered counterparts – primarily due to the higher cost of the fuel cylinders. As the popularity and production of CNG vehicles increases, vehicle costs are expected to decrease.

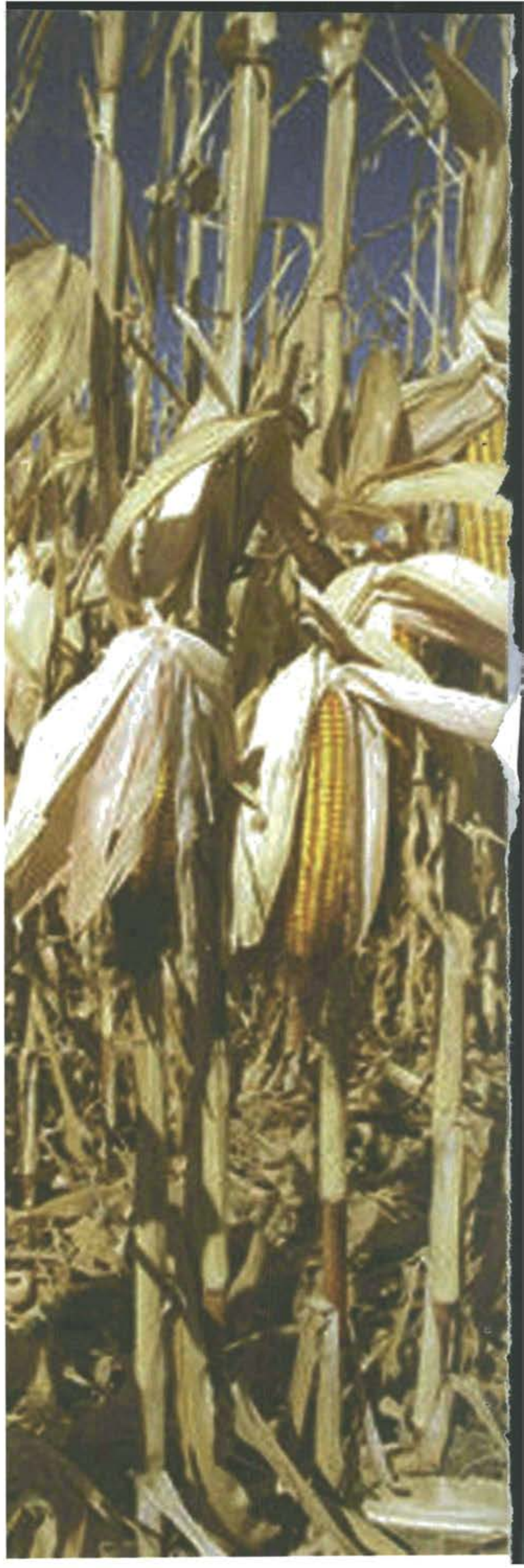
CNG has additional "convenience costs" due to limited range and therefore requires more frequent refuelling. The cost of a typical CNG refuelling station is also higher at between $350,000 to $450,000 – compared to $50,000 to $150,000 for gasoline. These costs are largely attributed to the need for a separate compressor station, specialised equipment and pressurised storage facilities.

Pathway

An additional benefit of CNG is its potential to be a natural "stepping stone" to hydrogen. In this regard, CNG promotes a transition to gaseous fuels because it gives users greater familiarity with a gaseous, rather than liquid, fuel. CNG could also expand the infrastructure for using natural gas as a possible input fuel for formulating hydrogen. The natural gas pipeline system could also be converted to transport hydrogen, though this has yet to be proven as a practical, cost-effective option.

Key Facts

- *CNG has very low tailpipe emissions.*
- *NGVs are becoming more widely available as CNG can be adapted to virtually any vehicle.*
- *Fuel costs are low (even lower with fiscal incentives), which offers excellent economic benefits to fleet operators.*
- *Driving range is limited because CNG energy content per volume is relatively low.*
- *CNG requires expensive, specialised refuelling stations, which limits availability.*
- *Vehicle and conversion costs are currently expensive.*
- *Even small emissions of methane from refuelling can have a significant effect on overall greenhouse gas emissions.*



Source: U.S. EPA

Biofuels: Ethanol & Biodiesel

Biofuels are emerging as a promising renewable source of energy for the transportation sector, particularly for displacing petroleum and reducing, or even eliminating, vehicle emissions of greenhouse gases. Biofuels can deliver increased energy security by improving the diversity of transportation fuel supply sources – with the possibility of replacing petroleum imports with domestic biofuel production.

Compared to petroleum fuels, biofuels typically produce significantly lower well-to-wheels emissions of CO_2 and other greenhouse gases because their CO_2 emissions are "recycled" as part of the fixed carbon cycle. Biofuels also feature air quality benefits, such as lower emissions of carbon monoxide (CO), hydrocarbons (HC), sulphur dioxide (SO) and particulate matter. Biofuels are less toxic than conventional petroleum fuels.

Biofuels take two primary forms: ethanol and biodiesel. Both ethanol and biodiesel can be easily blended with conventional gasoline and diesel fuels and used in today's vehicles. Biodiesel can be blended with diesel in any percentage up to 100% without significant problem, but typical blends range from 5% (B5) in France to 20% (B20) in the U.S. Ethanol can be blended with gasoline up to 10% in conventional vehicles, and a number of studies suggest that conventional vehicles may experience few problems on ethanol blends up to 20% or even 30%. Ethanol blended at higher levels, such as E85 (85% ethanol, -15 % gasoline), have a tendency to degrade some materials and require minor modifications to refuelling station storage tanks, dispensing equipment and engine parts, mostly replacing components made of plastic, rubber, and some metals.

Ethanol

Ethanol is ethyl alcohol made in a process similar to brewing beer. Starch crops such as corn, sugar beets, or cereals are fermented and then distilled into ethanol. Ethanol may also be produced in the future from cellulosic crops, such as switchgrass and short rotation trees, and wastes from agriculture, wood processing, and municipal solid waste.

Low percentage ethanol blends, such as E10, are currently dispensed in service stations worldwide, with little incompatibility of materials and equipment (mainly in older vehicles in some countries).

Market

Fuel ethanol produced from corn has been used as a transport fuel in the U.S. since the early 1980s, and now accounts for 5.7 billion liters or 1% of total annual U.S. motor fuel consumption. In Brazil, production of fuel ethanol from sugar cane began in 1975, peaking at 4.2 billion liters in 1987. Production is lower today but all gasoline sold still contains between 22% and 26% ethanol by volume. In Canada, Mexico, Australia, India and throughout Europe, governments are promoting significant increases in ethanol use because of the energy security and clean air benefits ethanol can provide.

Advanced ethanol feedstocks and conversion processes, including ligno-cellulosic (grasses and woody plants) ethanol, appear capable of much greater reductions in well-to-wheel greenhouse gases than conventional ethanol. Reductions of more than 100% appear possible if co-production of electricity and other products is included. There may also be a much larger potential land base for growing cellulosic crops than grain or other commercial crops.

Technology development

Following on the successful applications of E10, considerable interest is growing to the use of E85. In the U.S., all major vehicle manufacturers have introduced selected models where E85 compatibility is standard equipment and covered under the same warranty, service and maintenance conditions as gasoline vehicles. These vehicles have been dubbed "flexible fuel vehicles" (FFV), looking and driving just like conventional vehicles but providing the driver with the ability to use E85 fuel. Many car owners are unaware that they are actually driving an FFV.

FFVs feature an engine computer that automatically recognizes which fuel is being used and controls the fuel and ignition systems for the optimal mix of fuels by changing the flow rate of the fuel injectors and firing of the spark plugs. Some components in the fuel system (fuel tank, filter, pump, injectors) are also sized differently and made of materials compatible with higher concentration of alcohol, such as a stainless steel fuel tank and teflon lined fuel hoses. FFVs also resolve two critical barriers retarding the market for alternative fuel vehicles: incremental cost and refuelling. Since modifications are standard equipment, there is no additional cost. And because the FFV is engineered to operate on any blend of ethanol or gasoline, it can be refuelled with gasoline should E85 ethanol not be available, avoiding the need for extensive infrastructure.

Environmental impact

Although actual emissions vary with engine design, the potential impacts of ethanol E85 relative to conventional gasoline include:

- Fewer total toxic emissions;
- Reductions in ozone-forming volatile organic compounds of approximately 15%;
- Reductions in carbon monoxide of about 40%;
- Reductions in particulate emissions of about 20%
- Reductions in nitrogen oxide emissions of about 10%;
- Reductions in sulphate emissions of about 80%;
- Lower reactivity of hydrocarbon emissions; and
- Higher ethanol and acetaldehyde emissions.

In a well-to-wheels analysis, ethanol emits roughly 155 grams of CO_2 (equivalent) per km, although more than 75% of these emissions are related to the fuel cycle (harvesting crops, distilling the fuel and transporting it to refuelling stations) and not to tailpipe emissions.

Performance

Ethanol vehicles exhibit the same power, acceleration, payload, and cruise speed as conventionally-fuelled vehicles. In addition, ethanol has a higher octane rating than gasoline, which reduces engine "knock" and can result in higher energy efficiency. Ethanol also absorbs moisture and helps prevent gas-line freezing in cold weather, negating the need to add expensive and possibly harmful fuel additives. In addition, ethanol has some detergent properties that keep engines running smoothly and fuel injection systems clean for better performance. Fuel efficiency for E85 is roughly the same as reformulated gasoline but it has a lower energy density, limiting vehicle range to about 75-90% of the range for comparable gasoline vehicles.

Health & safety concerns

When used as a motor fuel, ethanol is not considered a toxic pollutant at levels likely to be inhaled. It is much less flammable than gasoline, thus accidental fires are less frequent and less severe when spills or releases of vapor occur. Ethanol is safer than gasoline to store, transport, and refuel. Because ethanol is water soluble and biodegradable, land and water spills are usually harmless, dispersing and decomposing quickly, although any gasoline portion of a spill is still a problem in these situations.

Cost and projections

A recent survey indicates that the costs of ethanol are two to three times more than those of conventional fuels and that substantial tax differentials (discounts on biofuels and/or increased taxes on conventional fuels) would be needed to achieve cost competitiveness. Ethanol is predicted to be price competitive with gasoline at world oil prices above $30/barrel.

A key question is whether current research on cellulosic ethanol will produce targeted cost reductions.

Biodiesel

Biodiesel is a methyl ester made in a chemical process (transesterification) that reacts virgin vegetable oils (rapeseed, soybean, sunflower, etc.), used frying oils, or animal fats with methanol and a catalyst such as potassium hydroxide. The reaction produces biodiesel and glycerine. Biodiesel is non-toxic and biodegradable.

Market

Biodiesel has steadily emerged from trial to full industrial production and marketing with wide and increasing acceptance by the diesel vehicle industry. Biodiesel is manufactured in 21 countries with the largest quantities produced and marketed within the European Union, particularly France and Germany where biodiesel is derived from excess agricultural production. Other key countries using biodiesel include Austria, Czech Republic, Italy, Malaysia, Nicaragua, Sweden and the U.S.

Technology Development

Biodiesel blends operate in diesel engines just like petroleum diesel, regardless of engine size. No engine modifications are required and biodiesel maintains the payload capacity and range of diesel. In this regard, there is no need to change vehicles, spare parts inventories, refuelling stations or skilled mechanics.

Environmental impact

Although actual emissions vary with engine design, the potential impacts of a biodiesel blend (B20) and pure biodiesel (B100), relative to conventional petrodiesel, include:

- Reductions in carbon monoxide emissions of 10% (B20) and 50% (B100);

Jatropha plant from which oil can be extracted to power vehicles.

- Reductions in particulate emissions of 15% (B20) and 70% (B100);
- Reductions in total hydrocarbon emissions of 10% (B20) and 40% (B100);
- Reductions in sulphate emissions of 20% (B20) and 100% (B100);
- Increases in nitrogen oxide emissions of 2% (B20) and 9% (B100); and
- Comparable methane emissions for both, B20 or B100.

Performance

One of the major advantages of biodiesel is that it can be used in existing engines and fuel injection equipment with little impact on operating performance. Biodiesel maintains the same payload capacity and range as conventional diesel, and provides similar horsepower, torque, and fuel economy. Biodiesel has a higher cetane number than conventional diesel, which indicates increased engine performance and serves as a high-quality lubricant that can enhance the life of heavy-duty engines.

Biodiesel vehicles can have cold-start problems relative to petrodiesel, but this is more of an issue for B100 than B20 fuels. With high blends of biodiesel, the release of deposits may clog filters initially and precautions should be taken to replace fuel filters until the petroleum build-up is eliminated. This issue is less prevalent with B20 blends, and there is no evidence that lower-blend levels such as B20 cause problems to filters.

Health & safety concerns

Biodiesel is biodegradable, dissipating quickly after a spill and degrading four times faster than petrodiesel. As a non-toxic fuel, it is safe to handle, transport, and store. However, if blends are spilled, the petrodiesel portion is still a problem, but less so than with 100% petrodiesel. Biodiesel has a high flash point and low volatility so it does not ignite as easily as petrodiesel, which increases the margin of safety in fuel handling.

Costs

Biodiesel infrastructure uses the same equipment as petrodiesel to store, transport, and deliver diesel fuel. As such, the primary barrier for biodiesel is the cost of production. B100 can be purchased for $0.50 to $0.80 per liter, depending on the feedstock and the supplier, while B20 costs $0.08 $0.30 more per liter than conventional petrodiesel. Although biodiesel costs more than petrodiesel, fleet managers can switch to biodiesel without purchasing new vehicles, acquiring new spare parts inventories, rebuilding refuelling stations or hiring new mechanics.

Key Facts

Ethanol

- *Flexible-fuel vehicles running on ethanol and/or gasoline are already available at no incremental cost to the customer.*
- *Vehicles running on ethanol exhibit the same power, acceleration, payload, and cruise speed as conventionally-fuelled vehicles.*
- *Ethanol can be used in almost any vehicle and is easily blended with conventional fuels.*
- *Ethanol is a renewable fuel producing low overall emissions, including 'inherently' low CO_2 emissions.*
- *Lack of refuelling infrastructure , limited range and higher costs are barriers.*
- *Vehicle range is somewhat limited.*
- *Emissions benefits are reduced when total CO_2 emissions (associated with harvesting crops, distilling the fuel and transporting it to fuel stations) are considered.*

Biodiesel

- *Biodiesel combusts like conventional petrodiesel fuels and is compatible with conventional petrodiesel engines.*
- *The energy density of biodiesel is similar to petrodiesel, and there are no significant compromises in payload, freight volume, or vehicle range.*
- *Recycling of waste oils, such as used cooking oils, might lower costs compared to biodiesel produced directly from agricultural crops, although available volumes are likely to be small.*
- *Biodiesel is easier to use than other fuels such as compressed natural gas or LPG because it can be blended with conventional petrodiesel fuels.*
- *Current limitations include increased costs and slight reductions in fuel economy.*

Battery Electric Vehicles

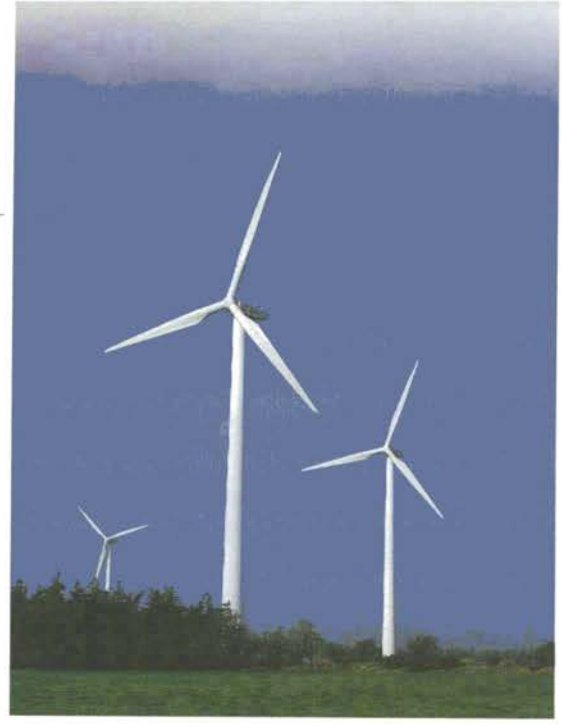
Battery Electric Vehicles (BEVs) have been available for many decades and predate the internal combustion engine. BEVs utilise an electric motor, storing energy in a battery pack that must be recharged from an electric power source. BEVs offer a number of distinct benefits, primarily zero emissions at the point of use and quiet operation. Although vehicles introduced the early 1990s had a driving range of only 80 to 130 km per charge, advances in battery technology have improved range to over 160 km per charge. If renewable power is used to generate the electricity, BEVs have the potential to be emission free. In spite of these benefits, they continue to suffer from major drawbacks in terms of comparable performance, range, recharging times, and availability of recharging infrastructure. Most of these limitations relate to battery performance as research has yet to produce a lighter and more powerful alternative to the lead-acid battery at an acceptable cost.

Source: courtesy NREL

Market

BEVs have been on the market for over a decade. However, despite product offerings from major automotive manufacturers, worldwide production is only an estimated 10,000 vehicles, but statistics on the market are scarce and inconsistent. For example, when converted vehicles, hobbyists' vehicles, and motorcycles are included, the world market reaches 65,000 vehicles. Led by Germany (4,100 vehicles) and France (1,800 vehicles), Europe has led the development of commercial BEVs with about 60% of the market. Outside of Europe, the United States and Japan are the biggest markets, with around 2,000 BEVs each.

Policies requiring zero emission vehicles, such as California's ZEV programme, have the potential to stimulate demand and new models over the next few years with estimates suggesting BEVs will account for about 2% of the U.S. light duty vehicle stock by 2030. In Europe, the European Electric Vehicle City Distribution (Elcidis) project aims to stimulate use of electric vehicles in seven cities. However, as hybrid-electric and fuel cell technologies mature, it now seems likely that BEVs will be rapidly superseded by these electric versions in all but a few niche markets, such as small, specialist vehicle fleets in urban areas. Recent studies indicate that the "electric vehicle" market will be dominated by hybrid electric and fuel cell vehicles, with an estimated potential market of 8.5 million vehicles in the year 2009.



Source: courtesy NREL

Recharging BEVs with clean electricity from renewable energy resources such as modern wind generators eliminates harmful emissions associated with electricity generated from fossil fuels.

Technology Development

With a fully charged battery, BEVs have equal acceleration, speed, and handling compared to conventional vehicles. Unfortunately, the primary technical limitation to BEVs has been the development of a light-weight, reliable, low-cost battery that can deliver a greater driving range. Lead-acid batteries are the primary power source in today's BEVs, which have a driving range of about 100 km and take 8 hours or more to recharge. Advancements in lead acid batteries are aimed at doubling the range and reducing recharge time to 5 hours.

Nickel batteries (e.g., nickel-iron and nickel-cadmium) deliver a range of over 160 km and recharge in 4 to 8 hours. They are currently more expensive than lead-acid batteries but last longer because they can be recharged more times. There are, however, some safety concerns, including the toxicity of nickel and cadmium, particularly if disposed in landfills. A promising battery technology under development is the nickel-metal hydride (Ni-MH) battery, which overcomes the problems of other nickel-based batteries. These batteries contain non-toxic, recyclable materials, have a potential range of about 400 km and recharge in as little as 15 minutes.

Lithium batteries include the lithium-ion (Li-ion), lithium-metal sulphide, and lithium-polymer varieties. Li-ion batteries are still a few years away from mass-production and are very costly to manufacture – making them even more expensive than NiMH or lead-acid batteries.

Each of these technologies is under development, but no major developments are currently anticipated in battery technology. More BEV sales will lead to lower prices. Any advances in battery technology will benefit hybrid vehicles and possibly fuel cell vehicles.

Environmental impact

BEVs are sometimes referred to as "zero-emission vehicles" because no pollution is essentially produced from the tailpipe or through fuel evaporation. This is important, for it means that the use of BEVs could greatly reduce emissions of carbon monoxide and smog-forming pollutants in cities with air quality problems.

While BEVs themselves are clean, generating the electricity to charge their batteries can produce air pollution and solid waste, depending on the power source. Power plants burning conventional fuels such as coal (used for more than half of the electricity generated worldwide) produce harmful emissions including particulate matter, sulphur oxides, nitrogen oxides, hydrocarbons, and carbon monoxide. These same plants also emit substantial amounts of CO_2 which contributes to global warming.

In a well-to-wheels analysis, BEVs using electricity derived from a natural gas power plant emit 136 grams of CO_2 (equivalent) per km – all of which is attributed to the fuel cycle prior to vehicle operation. While this vehicle has lower well-to-wheels CO_2 emissions than any other vehicle with the exception of some fuel cell vehicles, the total emissions are far from zero.

There are several factors that affect this pollution trade-off: it may be easier to control pollution at a power plant than from individual vehicles; and power plants often are located outside major centres of urban air pollution. And while only a fraction of today's power plants use renewable resources, if they eventually do, total emissions could actually be negligible.

Performance

BEV testing has demonstrated that acceleration, speed, and handling can equal that of conventional vehicles when the battery is charged and operating at optimal performance. BEVs are also more energy efficient and produce less noise than gasoline or diesel powered vehicles, particularly in stop-and-go traffic because the engine does not run if the car is not moving. BEVs have fewer moving parts than gasoline cars and require less maintenance. BEVs are extremely efficient, with fuel efficiency approximately three times that of engines fuelled by reformulated gasoline, LPG, CNG and ethanol.

Currently, the main drawback is the limited driving range of BEVs. Depending on battery type, climate, and terrain (battery charge life is shorter in cold weather and when vehicles must ascend), an EV can travel from 64 to 240 km on a single battery charge, and current batteries take several hours to recharge. There are also space considerations because batteries are relatively large and heavy, resulting in less room for cargo or passengers.

Health & safety concerns

BEVs must meet the same safety standards as conventional vehicles. In some instances, research shows they can be safer than gasoline-powered vehicles because they usually have lower centres of gravity, making them less likely to roll over in an accident. The danger of fire in a collision is also substantially reduced because BEVs do not have a gas tank or reservoir of engine lubricating oil.

Potential health or safety risks associated with widespread use of batteries have not yet been fully evaluated. Many vehicle batteries contain toxic elements or produce toxic emissions, which could make battery production, transport and use risky, and disposal a significant solid waste issue. A number of programmes to recycle and exchange batteries currently seek to address the issue of safe battery disposal, but a proportion of batteries ends up in solid waste landfills. The environmental impact of this method of disposal is potentially severe as batteries disposed in landfills can explode or release highly toxic and corrosive chemicals that pollute soil, water and the atmosphere.

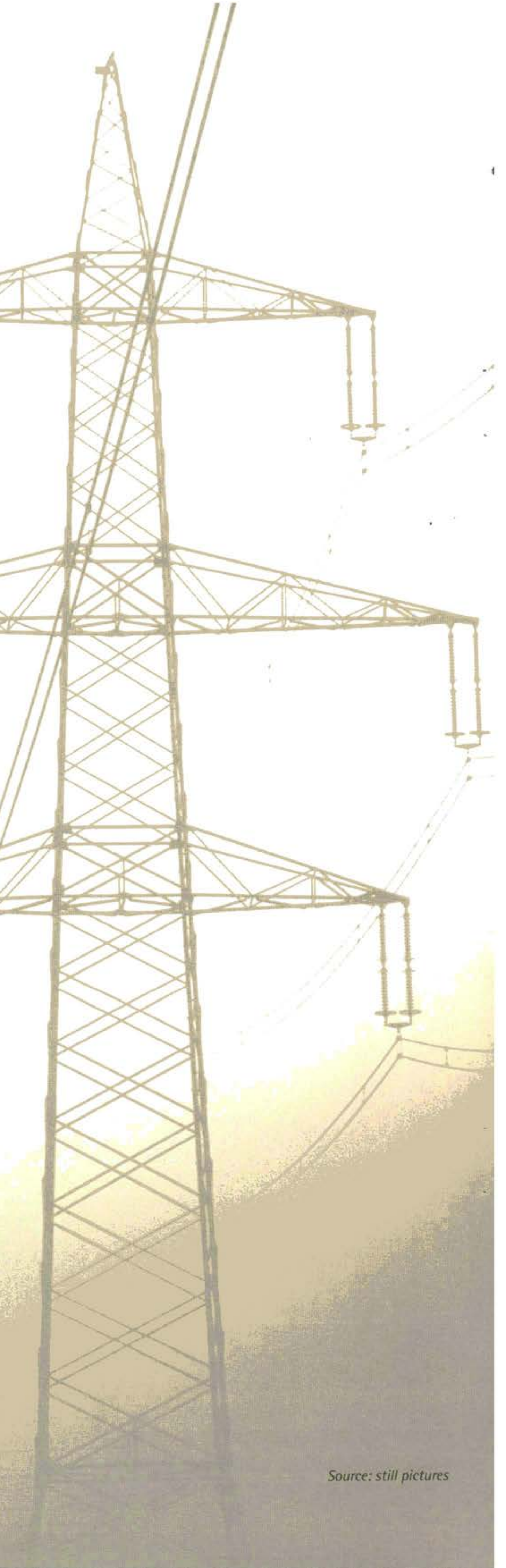
Cost and projections

BEVs can cost significantly more than gasoline vehicles, with prices from $15,000 to $40,000. This is mainly due to the high cost of battery packs and vehicles produced in small volumes. Some manufacturers lease BEVs to stimulate market development and to minimise concerns over maintenance costs and resale values. Relatively higher BEV purchase prices can potentially be offset by lower "fuel" and maintenance costs. The average monthly electricity cost for a typical BEV driver is less than $15, compared to at least $50 for gasoline. Costs can even be lower if BEVs are recharged during off-peak periods (such as overnight) when rates are lower. BEVs can also have lower maintenance costs because they have fewer moving parts than internal combustion engines and do not require tune-ups or oil changes.

One important obstacle to affordability, however, is that lead-acid batteries must be replaced every 3 years at a cost of approximately $8,000 to $10,000. Battery packs have remained expensive because they are only produced in small volumes. As the battery technology matures and the production volumes increase, costs are expected to decline.

Key Facts

- *BEVs have no tailpipe emissions.*
- *CO_2 emissions are significantly reduced per km with 'zero' CO_2 if electricity is generated from renewable resources.*
- *BEVs are quiet, easy to use and perform as well as conventional vehicles.*
- *Limited range and higher costs, particularly for batteries, are significant BEV barriers.*
- *Improper battery disposal can create significant environmental impacts.*



Source: still pictures

Hybrid Electric Vehicles

Today's hybrid electric vehicles (HEVs) typically combine the internal combustion engine (ICE) of a conventional vehicle with the battery and electric motor of an electric vehicle. The combination offers low emissions – similar to electric vehicles – and the power, extended range, and convenient fuelling capability of conventional gasoline and diesel vehicles. This flexibility makes HEVs well-suited for fleet and personal transportation. Light-duty HEVs typically have a small battery pack but are powered primarily by an ICE using conventional fuel. Although they are more efficient, these vehicles are not considered alternative fuel vehicles because they do not use alternative fuels. However, several types of heavy-duty HEVs in use today have engines powered by alternative fuels such as CNG. Additionally, any fuel can be used to power the ICE, including ethanol or LPG.

Not all HEVs are alike and there are many ways to combine engine, motor/generator and battery components. However, there are two basic configurations: "parallel" and "series" hybrid. In a series hybrid, the engine never directly powers the vehicle. Instead, the engine drives the generator which charges the batteries or powers an electric motor that drives the wheels. In a parallel hybrid, the engine, batteries and electric motor all connect to the transmission, so both the engine and the generator/motor can supply power to the wheels, switching back and forth as driving conditions vary. In addition, hybrids can capture kinetic energy lost during braking and return it to the battery in a process called "regenerative braking."

Market

In 1997, Toyota introduced the first HEV Prius in Japan. Two years later, Honda sold the first HEV Insight in the U.S. These two vehicles, followed by the Honda Civic Hybrid, marked a radical change for the automotive industry offering motorists vehicles that combine the benefits of BEVs and conventional gasoline-powered cars and trucks used for more than 100 years.

A number of other automobile companies have announced plans to introduce HEV models over the next several years. Ford will begin selling the HEV Escape sport utility vehicle in 2004. In 2005

Source: courtesy NREL

DaimlerChrysler plans to release the hybrid Dodge Ram pickup, followed by an HEV Mercedes S-class in 2006. GM plans to roll out several new HEV models in the 2004 to 2007 period.

The Toyota Prius has been extremely popular, with worldwide sales reaching 100,000 by the end of 2002, including 60,000 sold in Japan, 35,000 in North America, 3,500 in Europe and another three hundred worldwide. Honda has also succeeded with 10,000 Insights sold. Sales should be boosted further when California introduces its new ZEV standard, with hybrids making up 6% of sales in California from that date – further improving the manufacturing economics and thereby the price to consumers. If current technical targets are met, projected sales of hybrid vehicles in the U.S. could grow rapidly, penetrating 10% of the light duty vehicle stock by 2017, and 24% by 2030. HEVs are estimated to achieve 3% of the European market by 2010 and triple between 2010 and 2015 as high-volume production accelerates. By 2015, the penetration rate is expected to be around 8 to 10%.

Technology development

Hybrid power systems were conceived to compensate for the shortfall in BEV battery technology. Because batteries can supply only enough energy for short trips, designers believed an onboard generator powered by an ICE could be installed and used for longer trips. They also believed that after better batteries were developed, hybrids would probably not be needed at all. But after 20 years of study, it seems that hybrids are taking centre stage and electric vehicles are only being used in niche markets where fewer kilometers are travelled. The principal drawback of hybrid technology is that the vehicle must accommodate two distinct engine technologies, and sophisticated systems to ensure that they work together effectively. This is partly offset by the advantages of using a smaller and simpler ICE. Nonetheless, hybrids must overcome problems of weight, technical complexity and manufacturing cost. Automotive manufacturers currently focus on improving the electric motor and advancing battery technologies.

Hybrids can be an important step for developing and commercialising many of the new technologies that will be needed for fuel cell vehicles and the "electrification" of the vehicle transport. For example, improvements to electronic control systems, electric drive trains, supercapacitors, and batteries are vital elements of both HEVs and fuel cell vehicles. Over the next 10 years, further research and development of the ICE-HEV can advance these components while fuel cell stack technology matures. The fuel cell could then replace the internal combustion engine in the hybrid format.

Environmental impact

More efficient cars offer significant environmental benefits. Although hybrids are more efficient than many alternatives, including conventional vehicles, they will never be true zero-emission vehicles because of their internal combustion engine. However, HEVs are not fuel-specific and hybrid applications have been tested with cleaner input fuels, such as CNG and biofuels.

Compared to conventional vehicles, the first hybrids on the market can cut emissions of greenhouse gases by a third to a half, and later models may do even better. Hybrids can also reduce smog pollution by 90% or more compared to the cleanest conventional vehicles on the road today. In a well-to-wheels analysis, HEVs in combination with reformulated gasoline emit 150 grams of CO_2 (equivalent) per km. As with BEVs, there is still a disposal problem associated with the electric batteries. However, HEV batteries are smaller and, depending upon the number of times a battery is charged and discharged, need to be replaced less frequently (estimated at 7-10 years).

Performance

Hybrids offer similar driving performance compared to conventional vehicles, along with the extended range and rapid refuelling that consumers expect. The combined drive system can yield two to three times more fuel efficiency, giving HEVs the same or greater range as traditional vehicles – up to three times greater depending on vehicle and gasoline tank sizes. Honda's Insight, for example is expected to travel 1,100 km on a single tank of petrol.

Performance also depends on the battery pack as each battery operates over a particular operating range to achieve optimum life and performance. Temperature variations from module to module in a battery pack can reduce performance. Most HEV warranties for batteries typically cover a driving range from 128,000 to 160,000 km, depending on the manufacturer.

Health & safety concerns

HEVs operating on gasoline pose no new or significant health or safety concerns beyond those for existing combustion engines. However, like battery electric vehicles, HEV batteries contain toxic elements that pose safety issues in their production, transport, use, and disposal. (See section on BEVs).

Costs

In general, HEVs command a price premium of about 20%, or around $2,000-$8,000 depending on the vehicle. This premium is not excessive when lifetime fuel savings are considered. However, even at this price premium, manufacturers are subsidising the initial price, as the true manufacturing cost is believed to be approximately twice that of a conventional vehicle at present. Further, costs associated with replacing the battery not under any warranty can range from $3,000 to $8,000. Costs, therefore, remain a significant hurdle, but are expected to fall rapidly both as sales volumes increase and as the technology matures. Hybrids could be fully competitive in only a matter of years, particularly if emissions standards force up the costs of conventional fuels and vehicles.

Key Facts

- *HEVs require no special infrastructure changes because they typically run on gasoline and can be refuelled at any service station.*
- *Fuel efficiency is greatly increased compared to gasoline-only vehicles.*
- *Regenerative braking helps minimise energy losses and recover the energy used to slow down or stop a vehicle.*
- *Total emissions are greatly decreased, with CO_2 emissions significantly reduced by 33% to 50% per kilometer.*
- *HEVs can be designed to run on alternative fuels and thereby further reduce CO_2 emissions.*
- *Purchase price premiums are not excessive and costs are expected to drop with projected and significant increases in market demand.*
- *Technology developments are needed to reduce costs.*
- *HEVs are technically complex and the best storage and conversion systems have yet to be fully developed.*
- *Development of HEV components is advancing the development of fuel cell vehicles.*

Fuel Cell Vehicles

Clean electricity from renewable energy resources, such as sollar cells can be used to "electrolyse" water into hydrogen and oxygen. The hydrogen can then be used in full cells to produce clean electricity with only heat and water vapour as by-products.

During the past decade, the fuel cell has risen in prominence as a clean, efficient and sustainable option for powering motor vehicles. In particular, polymer electrolyte membrane (PEM) fuel cells have emerged as a potential replacement for the ICE. A hydrogen fuel cell vehicle (FCV) looks like a hybrid electric vehicle, featuring an electric motor paired with a fuel cell generating the electricity in the place of the ICE.

Source: Ballard Power Systems

A fuel cell "stack" is part of a fuel cell engine that replaces a conventional internal combustion engine.

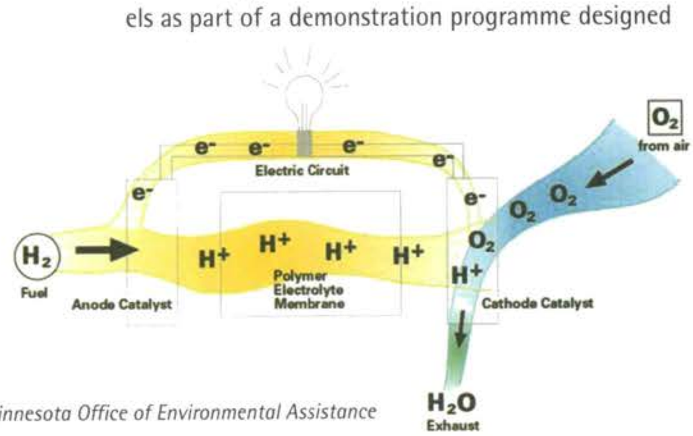
A fuel cell power system has many components, but its heart is the fuel cell "stack," which is made of many thin, flat cells layered together. Each cell produces electricity through a chemical process using hydrogen fuel and oxygen from the air. The combined electrical output of the fuel cells in the stack is sufficient to power the vehicle and deliver the long range, power density, and driving characteristics of a conventional vehicle. Fuel cells are efficient, quiet, and have no moving parts.

FCVs can be fuelled with pure hydrogen gas stored onboard in high-pressure tanks, or with hydrogen-rich fuels such as alcohol, natural gas, or even gasoline. These fuels must then be converted on-board into hydrogen gas by a device called a "reformer."

Tailpipe emissions range from just heat and water if hydrogen is used as the fuel, to some CO_2 and trace quantities of other regulated emissions if other fuels are used in combination with on-board reforming.

Market

Fuel cells have moved remarkably quickly from laboratory to road testing: The City of Los Angeles in the U.S. recently leased the first of five Honda FCX models as part of a demonstration programme designed to generate on-road data. DaimlerChrysler together with demonstration partners is currently testing 60 Mercedes-Benz "F-Cell" A-Class fuel cell vehicles under everyday conditions.



Source: Minnesota Office of Environmental Assistance

A number of the major automotive manufacturers have stated their intention to begin selling fuel cell passenger vehicles during 2003-2005. Honda plans to lease a limited number of its FCX vehicles in the U.S. and Japan by the end of 2003. However, these vehicles will only be available on a lease basis to a few pilot fleets with ready access to hydrogen refuelling stations. Toyota plans to offer about 20 hybrid fuel cell sport utility vehicles based on its Highlander platform by the end of 2004 while Ford Motor Company said it would offer a fuel cell version of the Focus in low-volume production for small fleet operations in 2004. Other FCVs under development include the GM Opel HydroGen 1, the Hyundai Santa Fe FCEV, the Nissan Xterra FCV, the DaimlerChrysler Necar 5, and Daihatsu's Move FCV-K-2.

Predictions vary widely on the timing and penetration of FCVs into the passenger vehicle market, with most automotive manufacturers predicting sometime after 2010 as the market requires at least 5 to 8 years to develop after the introduction of the first commercial vehicles. Projections for the U.S. have indicated that fuel cells could achieve about 7-10% of the light duty vehicle stock by 2030, if current technical targets are met.

Technology development

There are many different fuel cell stack technologies, although the only proven vehicle stack design is the hydrogen-air PEM fuel cell. This technology has made dramatic advancements from 1998 and is the current technology choice of vehicle manufacturers. However, the PEM still needs further development to demonstrate extended durability, minimised fuel cell failure rates, and the capability of low cost manufacture.

Commercialisation of the FCV, however, is not dependent on just the development of the fuel cell stack. There are also many ancillary technologies that require parallel development while the fuel cell matures, including electric drive systems, batteries and battery management systems (if the hybrid design is used), on-board fuel storage, and overall system thermal management.

The truly difficult obstacle to fuel cell commercialisation, however, may be surrounding the fuel, in particular, how hydrogen is generated and stored on board. Provided that on-board storage of hydrogen can be adequately addressed, vehicle manufacturers prefer the options that formulate hydrogen off-vehicle, as this greatly reduces the technical challenges and costs. In contrast, energy suppliers tend to favour on-board reformation of clean gasoline or methanol, as these two pathways require fewer changes to the fuel supply systems than using pure hydrogen gas stored on-board the vehicle.

Off-board hydrogen

A number of different sources can be used if hydrogen is manufactured outside the vehicle and stored on-board as a compressed gas or liquid. These sources include the use of hydrogen from oil refineries or other industrial plants (although this source is limited and not a low carbon option), steam reforming of natural gas (large-scale or local); generating hydrogen from oil or coal; pyrolysis of biomass; and electrolysis of water either at a central facility or at refuelling stations.

Electrolysis offers a promising future scenario where renewable energy sources supply the electricity to separate hydrogen from water—yielding the optimal mix of sustainability and emissions reductions. However, electrolysis from any conventional electricity generation source creates emissions (see section on Battery Electric Vehicles), losses in energy efficiency, and higher costs.

If hydrogen is produced from large central plants, either using electricity from power plants or natural gas in large steam methane reformers, the hydrogen can be delivered by tankers to refuelling outlets in the form of either cryogenic liquid or compressed gas.

On-board hydrogen

The alternative to on-board storage of hydrogen is on-board fuel processing, which reforms various liquid or gaseous fuels (e.g., gasoline, methanol, alcohols, CNG) to produce the required hydrogen for immediate use in the fuel cell. On-board reformation adds significant complexity and involves several processing units that must be integrated into the vehicle for thermal management and load control. These technologies still face significant development challenges, though this option has the advantage of using a distribution infrastructure already in place, particularly for gasoline.

- Gasoline has the advantage of being widely available through the existing fuelling infrastructure. However, it has a complex molecular structure and is more difficult to reform than natural gas, methanol or ethanol. The use of gasoline may also require refiners to introduce a "fuel cell gasoline" that is much purer and likely to be more expensive at the pump.

- Reforming methanol for fuel cell use is simpler and cleaner than reforming gasoline. As with other options to gasoline, however, commercial use requires the development of infrastructure for delivering, storing, and dispensing methanol at retail fuel stations.

- Ethanol is possibly the best near-term renewable fuel source for fuel cells. Ethanol is slightly more difficult to reform than methanol and similar to gasoline, with similar emissions and concerns about reforming at high temperatures. Ethanol can be more easily available at refuelling stations because it can be distributed through existing infrastructure. Ethanol could be viable for certain regions where ethanol production is significant, such as Brazil.

- Since natural gas does not have a significant energy density advantage over hydrogen, it is generally considered as a more appropriate source for off-board rather than on-board reformation.

In other words, if a vehicle is to carry a tank of gas on-board, it should be hydrogen. Natural gas is already the primary feedstock for manufacturing hydrogen for commercial-scale, industrial applications. In cities with good natural gas distribution, it may be relatively easy and cost-effective to deliver the gas to retail outlets, and then reform hydrogen on-site.

Environmental impact

Fuel cells are often characterised as yielding "zero emissions", but this applies only when pure hydrogen is stored on-board the vehicle and used directly, which produces virtually no emissions except water. However, if emissions produced "upstream" in the production of hydrogen are included, the environmental impacts of fuel cells may be greater than zero, depending upon the source of hydrogen and the method of reformulating hydrogen-rich fuels into hydrogen.

For example, if hydrogen is derived from the electrolysis of water using renewably generated electricity, the indirect emissions can be mostly eliminated. However, significant upstream emissions can arise when the electricity is generated from fossil-fired power plants. If hydrogen is harvested from natural gas, the indirect emissions (associated with fuel cell buses) are estimated to be one-half those of diesel vehicles. Emissions can also be very low with on-board reforming. Tests of methanol-powered fuel cell buses with on-board reforming of methanol, for example, indicate minimal emissions of all regulated pollutants, though they do emit substantial amounts of CO_2.

Performance

Fuel cell vehicles are expected to offer the same driving performance, power density, short refuelling time, and range as today's cars and trucks. As with other electric-drive vehicles, fuel-cell vehicles run smoothly and quietly.

Health & safety concerns

There is little awareness of hydrogen safety. Presented with the idea of a hydrogen vehicle, most people express concerns about explosions, often referring to the Hindenburg disaster of 1937 where most deaths were wrongly attributed to hydrogen combustion. Studies indicate that hydrogen storage systems can be engineered to the same safety levels as conventional fuel systems, making it safe as a transport fuel. Consider:

- In its natural form at room temperature hydrogen is a gas lighter than air, and thus dissipates more quickly than other fuels such as gasoline or diesel. Leaks are unlikely to form clouds of flammable gas, but will naturally swirl up and away from a potential victim or flame.

- Hydrogen burns with a clean flame producing little radiant energy. This means that a victim would have to be practically in the flame in order to suffer burning. Testing carried out on vehicular hydrogen tanks, where the tank cap was removed and the contents set alight, found that hydrogen in the tank burned in an upward streaming jet of flames, but raised the temperature inside the car by only a couple of degrees.

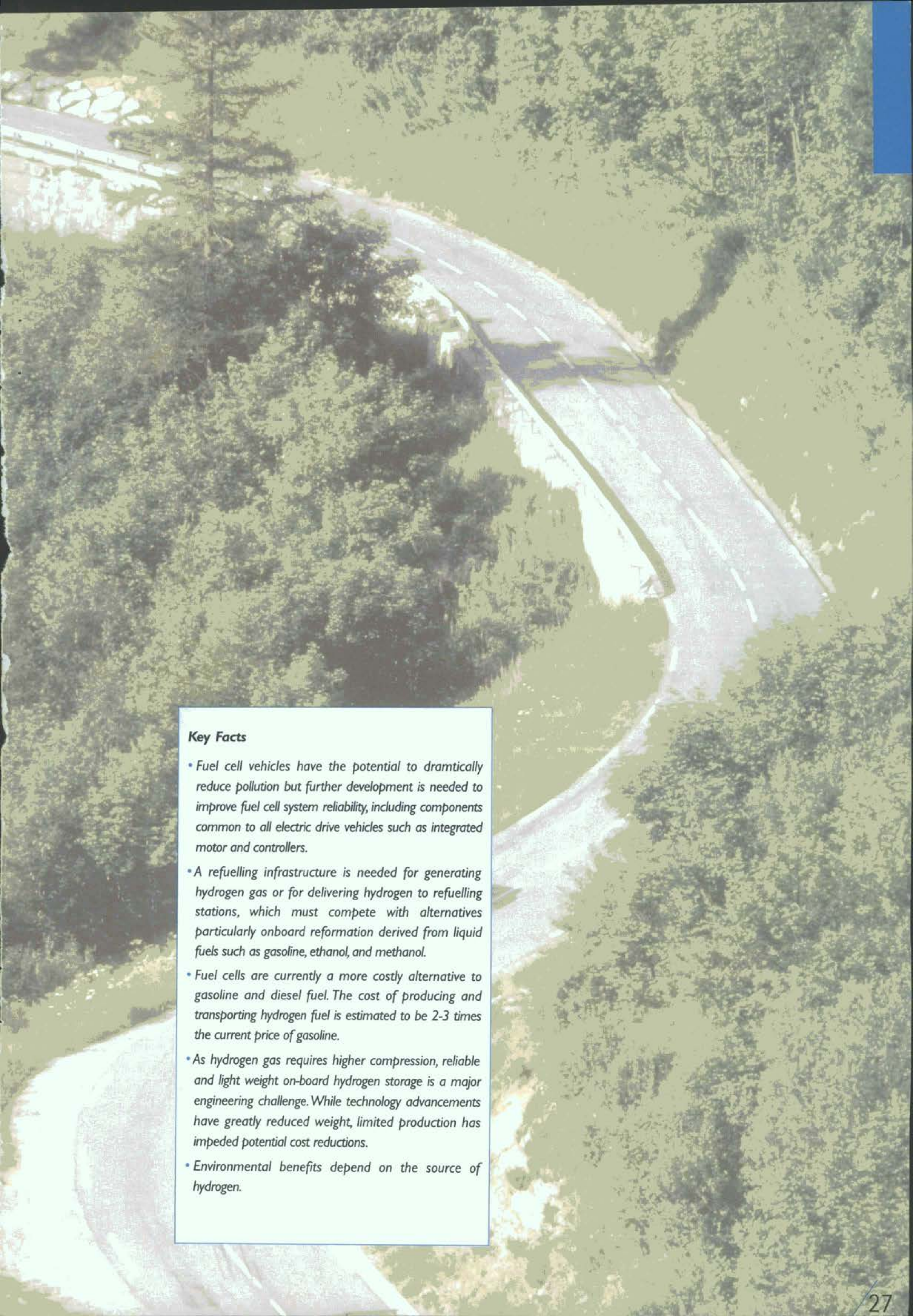
- Advanced composite material storage tanks that form the most protected and strongest part of the car would be used to store on-board compressed hydrogen. These tanks have already been tested against industry standards to withstand high-speed collision damage. Hydrogen gas can be stored and used as safely as natural gas, which is currently piped all over the world directly to industrial sites and residential houses.

Cost and projections

Even though fuel cell vehicles are being made available to limited demonstration programmes, it is too soon to tell how fuel-cell vehicles will be priced on the consumer market. But the interest of automotive manufacturers worldwide in developing these vehicles signals their belief that fuel cells can compete with conventional vehicles. Limited data from the City of Los Angeles indicates that a fuel cell vehicle can be leased at a price roughly equivalent to the lease price of a luxury sedan.

For the most part, costs are high because of the proportion of R&D costs imbedded in each vehicle – which are still manufactured as "one-off" or limited productions. It remains unclear what scale of production is needed to bring costs down and how much of the incremental cost can be eliminated through volume production.

Compared on a well-to-pump basis, the unit cost of hydrogen is likely to be 2-3 times the cost of gasoline. As hydrogen transport and production are the largest components of all the examined pathways, they are the appropriate focus for cost reduction.



Key Facts

- Fuel cell vehicles have the potential to dramtically reduce pollution but further development is needed to improve fuel cell system reliability, including components common to all electric drive vehicles such as integrated motor and controllers.
- A refuelling infrastructure is needed for generating hydrogen gas or for delivering hydrogen to refuelling stations, which must compete with alternatives particularly onboard reformation derived from liquid fuels such as gasoline, ethanol, and methanol.
- Fuel cells are currently a more costly alternative to gasoline and diesel fuel. The cost of producing and transporting hydrogen fuel is estimated to be 2-3 times the current price of gasoline.
- As hydrogen gas requires higher compression, reliable and light weight on-board hydrogen storage is a major engineering challenge. While technology advancements have greatly reduced weight, limited production has impeded potential cost reductions.
- Environmental benefits depend on the source of hydrogen.

Policy Options

The task of balancing energy developments, their inevitable environmental impacts and their ultimate sustainability may be most pronounced in the transportation sector. The nearly absolute dominance of oil as a transportation fuel, combined with the escalating global growth in vehicle travel, the significant impact of resulting vehicle emissions on air quality and climate change, and the vital socio-economic role transportation plays in linking supply and demand presents a complex, if not intractable, challenge for policy makers to identify and implement sustainable transportation policies.

These policies have remained elusive, despite an increasing public awareness of the jeopardy associated with unmitigated reliance on oil and heightened public concerns about the environment, energy security and sustainability. Moreover, despite the many clear, tangible, and presently achievable benefits associated with increasing the use of alternative fuels and vehicles; despite considerable investment in their development and supporting infrastructure; and despite varying government efforts to promote their deployment, no fuel or vehicle technology has yet overcome infrastructure, performance or cost barriers to challenge gasoline and diesel fuel in the marketplace.

Currently, there is no single, coordinated and focused policy addressing alternative fuels. If current scenarios are correct, petroleum fuels will remain the dominant transportation fuels for decades. Combined with the long-term increasing use of vehicles, even if they are increasingly efficient, the situation creates an ever greater imperative to identify and implement a focused energy policy aimed to encourage suitable alternatives to gasoline and diesel fuels.

Needed: concerted action

Governments already have numerous policy options to promote alternative fuels, including incentives, mandates, development of standards, research funding, public education and government procurement. The introduction of these measures will naturally depend upon the importance policy makers attach to the potential benefits and differences in monetary and convenience costs. In this light, action is most effective in a policy environment where fuel suppliers and vehicle manufacturers act responsively and take coordinated and concurrent action to change established markets for gasoline and diesel fuels. Most importantly, consumers need to translate environmental concerns into action, particularly in the acceptance, purchase and use of new technology, vehicles and fuels. It will take a concerted effort by all sectors of society, but a switch to clean, sustainable fuels is viable. The following section explores actions different players can take to overcome barriers impeding alternative fuel and vehicle markets.

Governments can make a difference

Despite the environmental and economic advantages favouring the introduction of alternative fuels, they still face critical barriers to market entry. However, some of these barriers can be addressed and alleviated with incentives and leadership from policy makers. Governments at all levels have a vested interest to encourage the use of alternative fuels due to their inherent environmental and energy security benefits. In particular, their use provides an immediately available solution for reducing smog, particulate matter and health costs associated with urban air pollution. Moreover, they can provide a means for governments to meet greenhouse gas reduction commitments under pressing global and national climate change policies.

Clear and concise long-term government policies are required to expand the use of alternative fuels, enable industry to invest in clean vehicle production, and provide consumers with the choice and the confidence to purchase alternative fuel vehicles. Policy makers also have the opportunity to help consumers understand the longer-term benefits of their vehicle purchase decisions.

Taken together and balanced across economic and environmental concerns, cleaner alternative fuels can provide an ever increasing percentage of transport fuels.

Fiscal and tax measures

Tax incentives can effectively reduce the purchase price premium of alternative fuels and vehicles. Such incentives can "level the playing field" with conventional fuels, particularly in the early years of market development.

Since fuel excise taxes comprise a significant percentage of the price consumers pay for motor fuels, exempting alternative fuels from a portion of this tax burden is an available and powerful tool for leveling the playing field, or in some cases, creating a lower pump price for the alternative fuel. For example,

- The UK has set the excise tax for LPG at roughly 15 pence, equal to about one-third the excise on gasoline and diesel fuel. Despite the relatively higher cost of delivering LPG to fuelling stations, it is roughly 35% cheaper than gasoline. This pump price advantage for LPG is considered the driving force behind development of the UK market for LPG. In just five years, the country's LPG fleet has increased from almost nothing to nearly 90,000 cars serviced by more than 1,200 refuelling points.
- In the late 1980's, New Zealand's fuel tax exemptions on CNG and LPG vehicles stimulated a national car fleet of 100,000 CNG and 50,000 LPG vehicles. In the early 1990's, an excise tax was introduced which substantially reduced the consumption of CNG and LPG. Consequently, the fleet of CNG vehicles today numbers less than 1,000, with LPG vehicles numbering 18,000 to 19,000.

To reduce the sales price premium of alternative fuel vehicles, some governments offer sales tax reductions, exemptions or rebates. For example,

- New York State (U.S.) offers a tax credit for electric vehicles equal to 50% of the incremental cost up to a maximum of $5,000 per vehicle. In 2002, a new provision was added to the tax incentive program that provides a tax credit of up to $2,000 for the purchase of qualified hybrid electric vehicles.
- In Canada, a higher vehicle price carries a marginally higher sales tax. Since the marginally higher price of an alternatively-fuelled vehicle can push the purchase into a higher tax category, the Canadian government discounts qualified vehicles by $7,000 and then applies the associated tax rate.
- In France, tax exemptions for LPG taxis and buses are available. Since 1998, 100% of the value added tax (VAT) paid on LPG can be recovered.
- In India, the government is pursuing a number of incentives to stimulate the market for CNG vehicles, including an exemption from the 12% state sales tax and a 3% low-cost loan option. The Delhi government is currently asking the Finance Department for an excise tax waiver for new CNG vehicles and a waiver from customs duty on imported CNG kits.

Tax deductions (reductions of one's taxable income) and tax credits (reductions in the amount of tax one owes to the government) have been used by a variety of countries to offset the cost differential between a conventional vehicle and a new or converted alternative fuel vehicle. Such incentives need not be a significant drain on government tax revenues until the number of alternative fuel vehicles grows substantially.

Strategic action

A comprehensive strategy for formulating goals and implementing programmes in the area of alternative fuels is needed. Experience has shown that in some cases, legislation has been passed but not enforced. In other cases, programmes were underfunded, outdated or misdirected. For example, taxes on LPG in Sweden in the 1970s were low in order to motivate its use, successfully triggering a demand for new vehicles and substantial investments in LPG infrastructure. Subsequently, the government increased the taxes on LPG to cover the loss of fiscal income due to the transition from gasoline to LPG, and the use of LPG dropped. This shows that governments need to take a long-term approach when promoting new fuels.

- In order to promote clean fuel vehicles, for example, (Natural gas, LPG, hydrogen, and E85) and electric vehicles, the U.S. Federal government offers a one-time income tax deduction of up to $2,000 and $4,000 respectively.

Other fiscal incentives include higher taxes for the more polluting fuels in order to motivate the use of alternative fuel vehicles. Such a "pollution tax" (also being considered as a CO_2 tax) can be an effective stimulant for alternative fuel vehicles in cases where lower emissions result in a lower levied tax rate.

For example,

- To send a clear signal to vehicle manufacturers and purchasers about the environmental impact of the cars they make and use, the UK government has introduced a new tax schedule for vehicles based on CO_2 emissions. Vehicles with a CO_2 emission of 165g/km are subject to a 15% tax, which increases by 1% with each 5g/km rise in emissions. Diesels carry a 3% levy on top of these rates. If the only fuel used by the car is LPG, there is a discount of 1% plus a further 1% for every 20 g/km the car's CO_2 emission level is below that year's threshold. For hybrid cars there is a discount of 2% plus 1% for every 20g/km the CO_2 emission level is below the threshold for that year.
- Sweden, Finland, Norway, the Netherlands, and Slovenia also tax fuels based on their carbon content. In addition to alternative fuels these taxes also favour diesel, since diesel releases less carbon per km than does gasoline.

Environmental Taxes

The idea behind environmental fuel taxes is to make some alternative fuels more attractive by adjusting the margins.

Taxes can be imposed on fuels to reflect the real socio-economic costs of their use, such as accidents, road wear and environmental effects. According to many analysts, it is only the environmental tax component that ought to vary since the number of accidents as well as the amount of the road wear is independent of fuel type. For example, fuels with fewer effects on a local environment (such as lower emissions of sulphur and nitrous oxides) could have a lower environmental tax than fuels with a higher impact. Similarly, fuels with less impact on the global environment (such as lower emissions of greenhouse gases) ought to have a lower tax level than fuels with higher impacts on the global environment. For example, biofuels can be exempted from the carbon dioxide tax, in principle, when the net emission of CO_2 from their use is considered to be zero.

Differentiating the environmental tax component for various fuels presupposes that it is possible to estimate the real environmental costs related to the respective fuels. The uncertainty regarding such estimates, however, is considerable.

Unfortunately, tax policies are often skewed by other issues. For example, diesel fuel often has a lower tax level per liter than gasoline because governments want to reduce the costs for industry and trade – not to reduce emissions. Moreover, although most economists can agree that the level of the gasoline taxes is not sufficient to internalise the social and environmental costs, governments have been reticent to do so as the higher resulting costs could impact consumers.

Regulatory measures

Regulatory measures and mandates can help promote alternative fuel vehicles, although they are unpopular without adequate incentives. Regulatory measures include purchase requirements for fleets; mandates to ban polluting vehicles in cities with air pollution in congested urban areas during certain hours of the day; and requirements upon municipalities. For example:

- In 1992, the U.S. National Energy Policy Act required fleets of more than 50 vehicles (of which at least 20 are centrally fuelled), and light duty vehicles located in metropolitan areas, to purchase "alternate fuelled vehicles" based on a graduated scale and reaching 90% by 2006.
- In Hong Kong, Japan and Korea, government measures encouraging taxis to use clean-burning LPG have resulted in a 90% (and greater) penetration of LPG into the national taxi fleets.
- In 2001, an India Supreme Court ruling mandated the conversion of the entire New Delhi bus fleet to natural gas. Seven thousand transit buses and as many as 2,000 school buses are to be converted or removed from service. Taxis and auto rickshaws must also be replaced with new vehicles running on clean fuels.
- In 1990, the California Air Resources Board (CARB) established the Zero Emission Vehicle (ZEV) program as a measure to meet health-based air quality goals. Since then, several northeastern U.S. states have adopted California's ZEV instead of less stringent federal standards. The ZEV program was designed to catalyse the commercialisation of advanced-technology vehicles that would not have any tailpipe or evaporative emissions. Originally, the ZEV program required that 2% of new vehicles produced for sale in 1998 and 10% of new vehicles produced for sale in 2003 would be zero emission vehicles. The automotive manufacturers convinced CARB that they could not meet the 1998 deadline, and full implementation of the programme was delayed until 2003. In 2002, automotive manufacturers sued the state over the programme and were granted a preliminary injunction barring its implementation pending a final court ruling. In the midst of the ensuing legal debate, the state decided to proceed with revisions; side-stepping the legal challenge with the aim of restoring the ZEV program by 2005.

Innovative measures such as exemptions from city-driving restrictions and reduced (or free) fees for parking alternative fuel vehicles in downtown areas provide significant incentives for motorists to value these privileges over the cost penalty associated with the purchase of an alternative fuel vehicle.

- For example, a newly implemented "congestion-charge" scheme levies a £5 charge on vehicles commuting into the city of London. All passenger and light commercial vehicles which qualify under the government's PowerShift programme receive a 100% discount from the congestion charge.

Some alternative fuel standards have already been developed. But fledgling alternative fuels will require the development of standards for components, and in some cases standards for fuel composition, safety, installation, driving in certain locations (i.e. tunnels), and for other safety aspects (such as indoor refuelling and garaging).

- The European Parliament recently approved the draft regulation of the United Nations Economic Commission for Europe (UN-ECE) concerning uniform provisions for specific LPG retrofit systems for the use of LPG in vehicle propulsion system. This regulation aims primarily to break down the barriers to trade in motor vehicles, while ensuring high levels of safety and environmental protection.

Development of stringent emissions standards can stimulate awareness of environmental concerns among consumers and vehicle manufacturers. The challenge of meeting stringent emissions standards is typically achieved more easily by alternative fuels than by the traditional fuels. Incentives and/or credits can be provided to vehicle manufacturers who exceed current standards. Such standards, implemented on a gradual but steady time schedule, tend to have "technology forcing" motivation on vehicle manufacturers to develop and produce lower polluting vehicles. The timing of adopting more stringent standards, and the degree of stringency, must be balanced carefully to "force" the technology without creating economic dislocation among the very same vehicle manufacturers who will be responsible for creating a generation of alternative fuel vehicles.

Source: Clean Cities Program

Technology development

Through funding of research, development and demonstration projects, governments can substantially advance the development of new vehicles. Assisted by efforts of some manufacturers, alternative fuels have made some progress entering well-established industries and markets. But the alternative fuel vehicle suppliers also need assistance, either through direct funding or through the various national research organisations that can help product and market development. For example:

- The U.S. government recently initiated a $150 million programme to spur the development of both hydrogen vehicles and hydrogen refuelling infrastructure. The project is a demonstration to help research and development efforts and provide insight into issues related to codes, standards, safety and the interface between vehicles and infrastructure. The highly visible project is intended to increase public awareness of hydrogen-powered vehicles and is an important first step to bring energy companies and automotive manufacturers together to solve development issues.
- To build awareness of alternative fuels and vehicles, the Canadian government has implemented a vehicle testing and demonstration programme to evaluate and showcase advanced technology vehicles close to market readiness. Additionally, the government will identify the regulatory regime needed to ensure that advanced technology vehicles are clean, fuel-efficient, safe, and not unnecessarily delayed from entering the marketplace.

Partnership measures

Voluntary agreements with key stakeholders, including city officials, fuel suppliers, vehicle manufacturers, and fleet operators can play an important role in advancing alternative fuels and vehicles, and disseminating the best information about their benefits. For example:

- The U.S. Department of Energy created a "Clean Cities Program", encouraging cities to develop policies and programmes promoting energy conservation, energy efficiency, and improved transportation programmes by stressing the benefits of alternative fuels. To qualify for status as a "Clean City", municipal leaders are required to organise decision makers and other community leaders to create specific plans for introducing alternative fuels, such as voluntary commitments from taxi fleets or local government decisions to use alternative fuels in municipal fleets. This voluntary "partnership" model has considerable potential for replication worldwide. See www.ccities.doe.gov
- The Cairo Air Improvement Program promotes the use of CNG fuel in motor vehicles, including the creation of a public awareness campaign to educate citizens on air quality concerns and the potential solutions offered by CNG. The programme created working partnerships with fuel suppliers, the Cairo Transit Authority and the Greater Cairo Bus Company to switch bus fleets to CNG. See www.caip.com.eg
- The California Fuel Cell Partnership (CaFCP) is a voluntary alliance of some 30 automotive manufacturers, energy companies and government organisations to demonstrate and promote awareness of fuel cell vehicle technology. Specifically, the partnership aims to: (1) Demonstrate vehicle technology by operating and testing the vehicles under real-world conditions in California; (2) Demonstrate the viability of alternative fuel infrastructure technology, including hydrogen and methanol stations; (3) Explore the path to

commercialisation, from identifying potential problems to developing solutions; and (4) Increase public awareness and enhance opinion about fuel cell electric vehicles, preparing the market for commercialisation. See www.fuelcellpartnership.org

- The ZEUS project was designed to help remove market obstacles that hinder the widespread use of zero and low emission vehicles, including the high cost of current vehicles, a lack of infrastructure for fuel and maintenance, and a lack of sufficient incentives to boost early market penetration. The project is concentrated in 8 European cities, where a thousand zero and low emission vehicles will be collectively purchase and used. A wide range of fuels for public and private vehicles is included. In addition, the project will study incentives and initiatives which can support the public use of more energy efficient transport. The ZEUS project is also intended to stimulate transportation by "greener" modes, such as using innovative fuels for public transport and promoting public awareness of the links between transport, energy and the environment. See www.engva.org

- The European Commission is allocating 18.5 million € to the Clean Urban Transport for Europe (CUTE) demonstration project for nine European cities to introduce hydrogen into their public transport system. The cities are Amsterdam (Netherlands), Barcelona (Spain), Hamburg (Germany), London (United Kingdom), Luxembourg (Luxembourg), Madrid (Spain), Porto (Portugal), Stockholm (Sweden) and Stuttgart (Germany). The CUTE project is designed to demonstrate that hydrogen can be an efficient and clean urban power source. Twenty-seven fuel cell powered buses, running on locally produced and refilled hydrogen, will be used to demonstrate that zero emission public transport is possible today when political will is combined with innovative technology. See http://europa.eu.int/comm/energy_transport/en/cut_en.html

- The Electric Vehicle City Distribution System (ELCIDIS) project is a cooperative programme between seven European cities and the European Association of Cities. The partnership was established to explore and promote the use of electric vehicles and to demonstrate the possibilities for hybrid electric vehicles. The deployment of hybrid electric vehicles was common to all cities involved in the project. See www.elcidis.org

Source: ELCIDIS

Source: U.S. EPA

Fuel suppliers

In order to break the "chicken and egg" dilemma, fuel suppliers must commit investments to aggressively develop a widespread network of refuelling facilities. Moreover, they will need to communicate these investments to automotive manufacturers and motorists if they wish to build greater confidence in automotive manufacturers to manufacture and motorists to purchase and use alternative fuel vehicles. The importance of vehicle manufacturers and equipment suppliers as key developmental partners is closely linked with government policies – if governments can be convinced to provide more incentives for motorists to switch to alternative fuels, vehicle manufacturers will be provided with more incentives to develop the technology and increase production.

Source: Shell

Information on the availability of refuelling facilities is key to developing confidence in alternative fuels and vehicles. Fuel suppliers need to develop and disseminate accurate and consistent information to target audiences on the quality and availability of the fuel, including governments (national and local), vehicle industry (manufacturers, equipment suppliers, dealers), fleet managers, finance and lease companies, vehicle and motoring associations, environmental organisations, media and private motorists. Other measures include:

- Investing in a network of refuelling facilities.
- Providing information on fuel availability, such as station locator maps and websites.
- Promoting alternative fuels to automotive manufacturers, dealers, and fleet managers, and engaging them to sell the benefits of the fuel through partnerships to increase the sales of dedicated and dual fuel vehicles.
- Providing policy makers with information on refuelling infrastructure to encourage their continued support for providing fuel and vehicle incentives.
- Allocating resources to ensure fleet managers receive sufficient training on environmental issues.
- Taking a strategic view of the need for alternative fuel refuelling/recharging points within their service areas.

Vehicle manufacturers

Automotive manufacturers, both directly and through their dealers, need to provide customers with more information about the availability and life-cycle costs of alternative fuel models. They can also promote the environmental benefits of different models through their advertising campaigns and by ensuring that their dealers have the information needed to answer questions from buyers about the environmental impacts of different models.
In addition, manufacturers can:

- Demonstrate the emissions benefits of cleaner vehicles on a continuous basis.
- Introduce more low-emission vehicles into the market ahead of regulatory requirements.
- Provide demonstration models for battery electric, hybrid electric and fuel cell vehicles for testing before being made commercially available.

Source: Shell

Governments, vehicle manufacturers and oil producers need to work together to develop the refuelling infrastructure necessary to advance the market for alternative fuel vehicles.

- Communicate the performance and benefits of alternative fuel vehicles and publicise sales of cleaner vehicles.
- Undertake a larger and more concrete production and sales plan, oriented toward providing products to meet customer needs, such as alternative fuel delivery vans in place of diesel models used by regular fleet customers.

Consumers

Informed consumers can make intelligent decisions. Unfortunately, in too many instances the public seems to know very little about alternative fuels, related vehicle technology, their benefits and availability, and their ability to mitigate air quality and climate change problems. More often, it is the barriers to alternative fuel development that the public is aware of. For example, if life-cycle costs are considered, the higher incremental costs of vehicles can often be quickly offset by fuel savings. Consumers are often unaware that manufacturers are building and offering more alternative fuel models, conversions are reliable and cost-effective and range limitations can be overcome by using the right vehicle in the right applications.

Unfortunately, governments, automotive manufacturers, and fuel suppliers have not made marketing and advertising to the public a priority. In many instances, increasing market share for alternative fuel vehicles may simply be a matter of making a convincing case. Motorists have already demonstrated their willingness to pay more for vehicles that offer increased power, size or luxury. By the same token, consumers are increasingly recycling products as a part of their growing sense of civic responsibility. In many ways, a clean fuel choice is a parallel civic choice that needs development and encouragement.

Alternative fuel vehicles can be an attractive choice that makes good economic sense, delivers added benefits for the environment and leads to a better and sustainable future where incremental market barriers can be overcome through the power of the market.

This can be accomplished by:

- Improving the public perception of alternative fuels by positively profiling alternative fuel vehicles in the media and promoting their cost-effectiveness and environmental responsibility.
- Advertising success stories and case studies.
- Promoting greener driving behaviour and better vehicle maintenance.
- Building local involvement and coordinating action with local government authorities.
- Communicating demand to encourage government support and industry investment in refuelling infrastructure and vehicle choice.

Epilogue

We need clean fuels and safe, efficient vehicles. We need them to not only grow our economies, but to reduce the serious damage to the global environment from our current use of petroleum fuels. We need them to diversify our energy supply because the transportation sector is over 95% dependent on oil and by far the fastest-growing energy demand sector. We need them because analyses of global oil discovery and production suggests that within the next two decades, the supply of conventional oil will begin to lose pace with increasing demand. And with a continuously increasing demand in developed countries and the rapid industrialisation of China, India and other developing countries, prices will almost certainly rise.

We need alternative fuels and efficient vehicles to reduce the threat of climate change and improve the quality of our air. We need them because 18% of the 28 billion metric tons of CO_2 emitted worldwide from human activities in 2003 originated from the transport sector – a figure the IEA forecasts will grow by 92% between 1990 and 2020. We need them because 50% of all air pollution and more than 80% of air pollution in certain urban areas is currently caused by vehicle emissions, which impacts considerably on human health.

Alternative fuels and vehicles can thus play an important role in the creation of a sustainable transport sector, along with improved fuel efficiency, stricter emissions standards, improved conventional fuel quality, and inspection and maintenance schemes.

However, none of the available alternative fuel/vehicle options has yet created a significant market niche, despite the many clear, tangible and presently available benefits, considerable investment in their development and various government efforts to promote their deployment.

The reason lies in a number barriers, including limited vehicle range, fuel availability and fuelling infrastructure, and relatively higher alternative fuel and vehicle costs.

There are numerous possible paths to alleviate the pressing questions of transportation sustainability. Therefore, coordinated and focussed policies are needed to comprehensively address alternative fuels. Actions by all relevant players are required. Every stakeholder can play an important role to give existing alternative fuels and vehicle technologies the necessary market or technological boost. With sufficient coordination, the transition to a post-oil economy does not have to be traumatic.

Although cleaner fuels and vehicles can take us a long way on this path, they alone will not take us to the destination of a sustainable transport sector. We also need to develop better urban planning, rethink current transport patterns and manage mobility through increased use of public transport and non-motorised options.

Such shifts will not be easy, but they also represent a great opportunity. In this endeavor, education and information are important, but without the correct economic signals, success will be limited. If governments can create economic frameworks where prices reflect the environmental and social truth, buyers will respond, markets will expand and the development of alternative fuels and vehicles will progress much more rapidly.

ABOUT THE

UNEP DIVISION OF TECHNOLOGY, INDUSTRY AND ECONOMICS

The mission of the UNEP Division of Technology, Industry and Economics is to help decision-makers in government, local authorities, and industry develop and adopt policies and practices that:

- are cleaner and safer;
- make efficient use of natural resources;
- ensure adequate management of chemicals;
- incorporate environmental costs;
- reduce pollution and risks for humans and the environment.

The UNEP Division of Technology, Industry and Economics (UNEP DTIE), with the Division Office in Paris, is **composed of one centre and four branches:**

The International Environmental Technology Centre (Osaka), which promotes the adoption and use of environmentally sound technologies with a focus on the environmental management of cities and freshwater basins, in developing countries and countries in transition.

Production and Consumption (Paris), which fosters the development of cleaner and safer production and consumption patterns that lead to increased efficiency in the use of natural resources and reductions in pollution.

Chemicals (Geneva), which promotes sustainable development by catalysing global actions and building national capacities for the sound management of chemicals and the improvement of chemical safety world-wide, with a priority on Persistent Organic Pollutants (POPs) and Prior Informed Consent (PIC, jointly with FAO).

Energy and OzonAction (Paris), which supports the phase-out of ozone depleting substances in developing countries and countries with economies in transition, and promotes good management practices and use of energy, with a focus on atmospheric impacts. The UNEP/RISØ Collaborating Centre on Energy and Environment supports the work of the Branch.

Economics and Trade (Geneva), which promotes the use and application of assessment and incentive tools for environmental policy and helps improve the understanding of linkages between trade and environment and the role of financial institutions in promoting sustainable development.

UNEP DTIE **activities** focus on raising awareness, improving the transfer of information, building capacity, fostering technology cooperation, partnerships and transfer, improving understanding of environmental impacts of trade issues, promoting integration of environmental considerations into economic policies, and catalysing global chemical safety.

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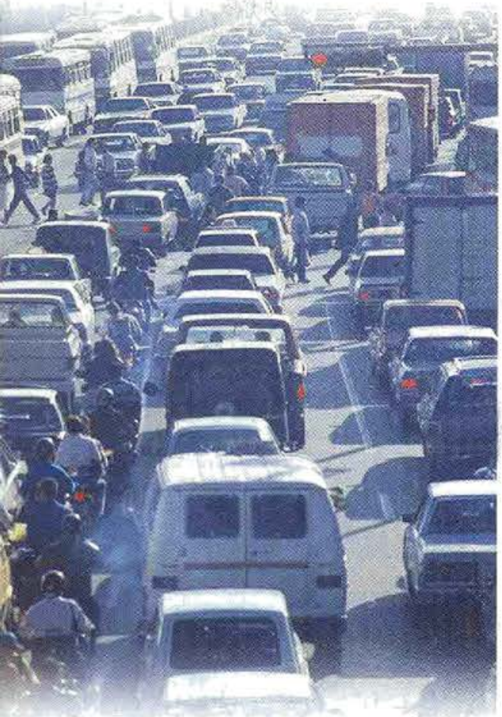

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