Alternative Motor Fuels Today and Tomorrow

Today, petroleum products account for 97% of the energy consumed in road transport. The purpose of replacing these products with alternative energies is to reduce oil dependence as well as greenhouse gas emissions. The high price of oil has promoted the use of "conventional" alternative motor fuels (biofuels, LPG, NGV) and also renewed interest in synfuels (GTL, CTL, BTL) that have already given rise to industrial and pilot projects.

Over the next thirty years, the most rapid increase in energy demand is expected to come from the transport sector (+2.1%/yr versus 1.7%/yr for total demand). At present, this sector relies almost exclusively on petroleum products, which raises two key issues: oil dependence and the reduction of greenhouse gases.

This leads to a more general question about alternative fuels: What volume is available and to what extent can it cover demand, present and future?

Alternative Motor Fuels Today...

Petroleum-based motor fuels account for 97% of the energy used in road transport worldwide. These fuels have already undergone substantial improvement. In addition to the specifications already scheduled for implementation, new ones may be enforced between now and 2020 to account for EU air quality targets and/or new modes of combustion in spark ignition and diesel engines (*e.g.* CAI and HCCI).

Beyond this time horizon, alternative fuels offer a solution to reduce greenhouse tailpipe emissions while retaining the internal combustion engine. Some biofuels came into use years ago, often to decrease oil dependence and at the same time exploit a specific resource (*e.g.* Brazil).

In 2003, the transport sector consumed 1,500 Mtoe worldwide. Alternative motor fuels — natural gas for vehicles (NGV), liquefied petroleum gas (LPG) and biofuels — only represented about 40 Mtoe, less than 3% of the total.

Other solutions are under study; for some of them, pilot units have been developed. In the short and medium term, it may be possible to exploit synfuels (GTL, CTL and BTL) produced from natural gas, coal and biomass. In the longer term, hydrogen may provide a breakthrough.

Biofuels

(cf. Panorama paper: *Biofuels Worldwide*)

There are two main types of biofuels, which will undoubtedly undergo intense development in coming years: ethanol, used in gasoline engines, and vegetable oil methyl esters (VOME), used in diesel engines:

- Ethanol is the most prevalent. In 2003, worldwide production totaled about 19 Mt, with Brazil and the United States accounting for the lions share.
- About 1.6 Mt of VOME were produced worldwide in 2003, primarily in Europe.

Ethanol, the foremost biofuel in terms of consumption, has also become the worlds leading alternative energy.

Since the oil shocks of 1973 and 1979, ethanol has primarily been used to replace premium gasoline in Brazil and, to a lesser extent, in the United States. In European countries, ethanol is not generally used directly as a motor fuel; its ether form, ETBE, obtained from isobutylene and ethanol, is blended (up to 15%) with gasoline.

Up to 5% of VOME can be incorporated in motor fuels for distribution at the pump in a manner that is perfectly transparent to the user. Some French refineries add it to commercial motor fuels in proportions varying from 2 to 5%.

One advantage of biofuels is that, blended with conventional motor fuels, they are compatible with the existing distribution system; major vehicle modifications are not required. On the other hand, ***their cost is one of the key factors inhibiting more generalized use, even if their environmental balance, especially with respect to CO_2 emissions, tends to be positive.***

Liquefied Petroleum Gas (LPG) Motor Fuel

A blend of butane and propane, **LPG has two origins**: ***it can be obtained directly in operations to remove hydrocarbon liquids at the field, in which case it is obtained directly or from crude oil refining***. Refining accounts for nearly 74% of the LPG motor fuel produced in France, 60% in California and 40% worldwide.

LPG motor fuel presents certain environmental advantages:

- high octane number, ensuring good resistance to engine knock;
- zero sulfur, lead and benzene emissions; low evaporative emissions;

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– for dedicated vehicles, a reduction in the polluting emissions regulated in gasoline (HC = –73%, NOx = –79%, CO = –87% compared to the 2005 standards);
– on the other hand, the CO_2 emissions balance is slightly higher for LPG than diesel fuel.

It also has disadvantages: the need to develop a distribution network, the high additional cost of vehicle purchase and product availability.

The global LPG fleet has grown 25% in 3 years, up from 7.5 million in 2000 to 9.5 million in 2003, which corresponds to consumption of 16.5 Mt.

In 2003, the largest LPG passenger car fleet was to be found in South Korea (1.7 million units), ahead of Italy (1.2 million), Poland (1.1 million) and Turkey (1 million).

In Japan and South Korea, taxis are the biggest users of this propane/butane blend, because their conversion from diesel to LPG has been subsidized.

In Europe, LPG motor fuel was first used in the 1950s, especially in Italy and the Netherlands, which offered tax incentives making it more attractive. In both of these countries, the domestic fleet remained fairly stable between 2000 and 2003. In Eastern Europe, LPG fuel consumption is on the rise, especially in Poland, whose LPG fleet increased threefold during the period 2000-2003.

Since 1996, France has implemented a series of tax relief measures to make LPG less expensive than diesel fuel. Even so, LPG has not really been able to break into the market. Due to technical problems in the late 1990s and the inadequacy of the market offering, the size of the fleet has decreased.

Table 1
GPL motor fuel worldwide in 2003

Country	Fleet (thousands)		Consumption 2003 (kt)
	2000	2003	
Italy	1,234	1,220	1,202
Netherlands	323	290	435
Poland	470	1,100	1,070
France	200	180	166
Czech Republic	150	145	68
Bulgaria	120	195	258
Lithuania	100	125	120
South Korea	1,214	1,723	3,740
Japan	290	290	1,528
Australia	590	492	1,213
United States	180	190	730
Mexico	350	700	1,200
Russia	400	550	780
Turkey	950	1,000	1,260
World	**7,504**	**9,416**	**16,445**

Source: WLPGA *IFP/Economics Studies/2004*

In the United States, the use of LPG fuel in the transport sector rose in the 1970s and 80s. The biggest consumers were captive fleets (taxis, post office vehicles, buses or delivery trucks).

The LPG motor fuel saw its share of the world transport market increase marginally from 6.6% to almost 8% between 1990 and 2003. It seems improbable that LPG will come into fleet-wide use, due to problems relative to local/regional availability or distribution networks.

Nevertheless, the worldwide volumes available for transport applications may increase in the future, because ***LPG can be obtained at the end of the refinery process and during gas production at the field***. To some extent, the use of LPG motor fuel would help diversify the transport energy supply while exploiting local resources, which may be present in abundance.

Most LPG vehicles are sold with bifuel systems (gasoline and LPG motor fuel) to compensate for the small number of filling stations. In France, less than 10% of service stations offer LPG fuel. One drawback: with a bifuel system, neither fuel can achieve optimum performance.

When the Euro 4 standards take effect in 2005, existing bifuel vehicles may require a major conversion. For bifuels, like conventional motor fuels, specific technological development will be necessary to ensure compliance with polluting emissions standards.

Natural Gas for Vehicles (NGV)

Since the early 1990s, gas applications have been booming, particularly in the electricity sector. As a result, NGV (usually in its compressed form) has been attracting interest all over the world. A number of countries have undertaken ambitious development programs. Domestic tax incentives have been implemented to encourage its use. NGV motor fuel helps attain objectives relative to energy diversification and the security of supply, in that proven reserves of natural gas are superior to those of oil, expressed in the number of years of production.

In 2003, the world numbered 3.6 million NGV vehicles (cf. breakdown in Table 2).

Latin America saw rapid growth as a result of government legislation promoting the development of NGV, especially in Argentina, Venezuela and Colombia, all of which have large gas reserves.

Argentina leads the world in this technology, with close to 1.2 million vehicles. Nearly one-third of the worlds motor vehicles running on compressed natural gas (CNG) are in Argentina, which has 1,100 filling stations. CNG vehicles represented 17.5% of Argentinas total fleet in 2002.

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Table 2
NGV worldwide in 2003

Country	Motor vehicle fleet (thousands)	Consumption (Mtoe)	Number of filling stations
Italy	400	0.36	463
United States	130	0.35	1,300
Canada	20	0.04	222
Japan	18	not given	226
Germany	19	not given	337
Ireland	10	not given	10
France	7	0.02	102
Argentina	1,243	1.7	1,105
Brazil	740	0.8	860
Pakistan	540	not given	574
India	159	not given	166
China	69	0.05	270
Venezuela	50	not given	140
Egypt	52	not given	79
Ukraine	45	not given	130
Russia	36	0.024	218
Bangladesh	32	not given	68
World	**3,649**	**3.81**	**7,180**

Source: IANGV/AIE *IFP/Economics Studies/2004*

Argentina began to promote this motor fuel with a plan to develop CNG vehicles in the early 1980s, when its assets included large natural gas reserves and good gas pipe infrastructure. More recently (2001), an economic slump and the devaluation of its currency accelerated the conversion of the domestic fleet to CNG as the price of petroleum products doubled.

In Europe, Italy was the first country to make significant use of NGV in the 1930s. Although the Italian market is the largest in Europe with 400,000 vehicles, it is not really growing. ***In the United States***, close to 130,000 vehicles run on natural gas.

The use of NGV for transport represents a very low percentage of total consumption of natural gas (mainly used for electricity production and heating) and of the world automobile fleet. The need for high-pressure storage and relatively heavy infrastructure limits large-scale development. Its greatest potential is concentrated in captive fleets of vehicles (*e.g.* buses and trucks) that make many short runs in downtown areas. A few “private home distribution” experiments (*e.g.* by the French utility GDF) have demonstrated the technology through the installation and use of small compressors. Naturally, this does not obviate the need for a distribution network to cover the requirements of vehicles for longer-range trips.

In terms of environmental impact, this technology out-performs liquid hydrocarbon fuels provided that the engine is optimized for its use:

– there are no odors, black fumes, particulates, soot or evaporative emissions;
– CO emissions are reduced by 90% and NOx by 60%;
– if the engine is optimized to run on natural gas, CO_2 emissions can be cut by 5 to 10% compared to the diesel engine.

For the commercialization of NG vehicles, like LPG vehicles, future technology development will be necessary to ensure compliance with emissions levels and the 2005 Euro 4 standards. In the past, a basic conversion sufficed to improve emissions control for regulated pollutants. Now, major optimization work will be required to achieve compliance with mandatory 2005 levels. This may challenge the bifuel concept.

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In the medium term, it can be expected that liquid fuels (gasoline and/or diesel fuel) will be produced from natural gas, coal and biomass as well as from oil.

Gas to Liquids (GTL)

Based on Fischer-Tropsch synthesis, GTL technologies offer new possibilities using natural gas to produce high-grade petroleum-type products (cetane index > 60-65, no aromatics and free sulfur). In recent years, the cost of this type of installation has steadily decreased. Projects that would have required capital investment of over $50,000/bbl/day in the early 1990s now cost between $20,000 and 35,000 bbl/day. There has been substantial progress in process performance and the scale of projects is larger (12,000 bbl/day in the early 1990s versus 30,000 to 75,000 bbl/day today), which has lowered the unit cost of investment.

In 2004, world GTL capacity totaled about 51,000 bbl/day produced by two units that were built in the early 1990s in South Africa and Malaysia.

Table 3
GTL units worldwide (2004)

Company	Capacity	Location
Petro S.A.	47,000 bbl/day	South Africa (1991)
Shell	14,700 bbl/day	Malaysia (1993)

Source: IFP *IFP/Economics Studies/2004*

The South African company Sasol and Qatar Petroleum plan to launch a unit (34,000 bbl/day) in 2006.

Looking to the future, Qatar seems to be the driver of GTL development. Planned projects call for total capacity of 800,000 bbl/day and include the following:

– Shell and Qatar Petroleum have finalized a conversion unit project to produce synfuels from natural gas. Capital expenditure: $5 to 6 billion. The plan is to build 2 units by 2009 (capacity: 2 x 70,000 bbl/day).

– The Sasol-Chevron consortium has signed a memorandum of understanding concerning three GTL projects worth a total of $6 billion. Two units are to be completed by 2009 or 2010 (130,000 bbl/day and 65,000 bbl/day).

– ExxonMobil has entered into a preliminary agreement bearing on the construction of a GTL unit by 2011 (154,000 bbl/day). Cost: $7 billion.

In Nigeria, Chevron and the national company NNPC may undertake a project to bring a GTL unit onstream by 2007 (34,000 bbl/day).

At a time when the number of projects is increasing, we should point out the cooperative agreement established by Shell (oil company) and Volkswagen (motor company). Within the framework of a research program, they are testing vehicles placed at the disposal of public authorities that run on GTL synfuels.

Coal to Liquids (CTL)

Similarly, the CTL technology is a possible solution. Although it costs more, it is technically feasible. This alternative is attractive for countries possessing coal in abundance. World coal reserves, which can ensure production for more than 200 years at the present rate, are concentrated in countries like China and India, which should see sharp growth in their energy consumption in the years to come. By way of an example, let us consider China. The cost of extracting coal is low (about $12/t), therefore the CTL solution may prove competitive compared to conventional solutions provided that the price per barrel stays higher than $40/bbl for a very long period. Since little research was done in this area over the last 20 years, significant advances can be expected in the future.

Only one coal liquefaction facility is in current operation. Located in Secunda, South Africa, it is run by the South African company, Sasol. It uses an indirect liquefaction technology to obtain liquid motor fuels from syngas using the Fischer-Tropsch process. Built between 1955 and 1982, its three units (Sasol 1, 2 and 3) produce a total of 175,000 bbl/day. Its current products are fuels, motor fuels and chemicals.

Sasol is also working on two feasibility studies bearing on the development of coal liquefaction units in two regions of China: North Shaanxi province and the autonomous region of Ningxia.

For the moment, there is only one project under construction, located at a coal mine. This direct liquefaction project (HTI slurry; design: Axens) undertaken by Chinas biggest coal producer, Shenhua, will cost an estimated $1 billion. The first train (a series of 2 reactors) is expected to start operating in late 2006 or early 2007. This facility will produce 20,000 bbl/day of gasoline, kerosene and diesel fuel (one-third gasoline; two-thirds kerosene and diesel fuel) from 6,000 t/day of low-sulfur coal.

But CO_2 emissions are higher for GTL and CTL than for conventional technologies. To improve their GHG balance, consideration may eventually be given to capturing the CO_2 emitted by these units and storing it in geological formations, but this would cost an additional $10 to 20/bbl.

Biomass to Liquids (BTL)

Biomass (BTL) can also be used to produce petroleum-type liquid motor fuels. Like GTL and CTL, two stages are involved. First, collected raw materials are transformed into synthesis gases, then into liquid products, using the Fischer-Tropsch process to obtain diesel fuel and kerosene (jet fuel). For these products of vegetable origin, the cost expressed in euros per tonne of diesel fuel equivalent are still very high, about €700-800/toe. This alternative, not as technologically mature as GTL or CTL, is still in the R&D stage. Projects have been implemented to demonstrate the technology, notably within the framework of European programs. Objective: optimize the collection-gasification stage.

In Freiberg (Germany), a pilot BTL production facility is in service. This demonstration unit is dedicated to producing biodiesel and methanol from vegetable and organic waste. Born of a 2002 cooperative agreement between DaimlerChrysler and Choren Industries, this project was allocated a budget of €11 million, including €5 million from federal authorities and €1 million from DaimlerChrysler.

In Varnamö, Sweden, a project to use wood pulp to generate syngases for conversion to methanol and DME is under consideration.

Hydrogen/Electricity

In the long run, the internal combustion engine may eventually be able to run on hydrogen, used directly or with natural gas in blends containing up to 20% hydrogen. Combining a fuel cell (pure hydrogen) with an electric motor may provide an alternative to direct storage of electricity in batteries, especially for hydrogen produced by electrolysis.

In volume terms, 99% of the worlds hydrogen is used as an industrial gas: ammonia production consumes 50%, refining

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37%, methanol synthesis 8% and the production of other specialty chemicals the remainder. Only 1% of world volume is used for energy purposes in the space sector. Fossil energies are the energy sources most often used to produce hydrogen. To produce large quantities at low cost, natural gas steam reforming is the most commonly used method. The concept of transforming biomass to produce hydrogen is attractive, but a great deal of R&D still needs to be done. Despite the fact that its present cost is very high and its energy efficiency mediocre, the electrolysis of water is the principal pathway for the production of hydrogen from non-fossil sources. However, its "environmental" benefit will depend directly on the mode of production of the electricity used.

In the long term, the use of hydrogen would require heavy infrastructure (pipe transport, intermediate storage, on-board storage) entailing technical difficulties and high additional costs.

There are about forty hydrogen filling stations worldwide, distributed fairly evenly between Europe, North America and Japan.

In a less remote future, electricity may play a larger role via hybrid technologies, making it possible to reduce specific demand for liquid hydrocarbon motor fuels by about 30%. This option is being developed in the United States, which should further inhibit diesel penetration on the US market (cf. Panorama technical report: *The Future of Hybrid Vehicles*).

The alternative motor fuels most in use in the world today are biofuels (ethanol and VOME), LPG (liquefied petroleum gas) and NGV (natural gas for vehicles).

In the medium term, the synfuels produced from natural gas (GTL), coal (CTL) and biomass (BTL) for which industrial or pilot projects exist should come into greater use. In a more distant future, hydrogen may position itself as a replacement fuel provided that certain obstacles are overcome, particularly that of cost.

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