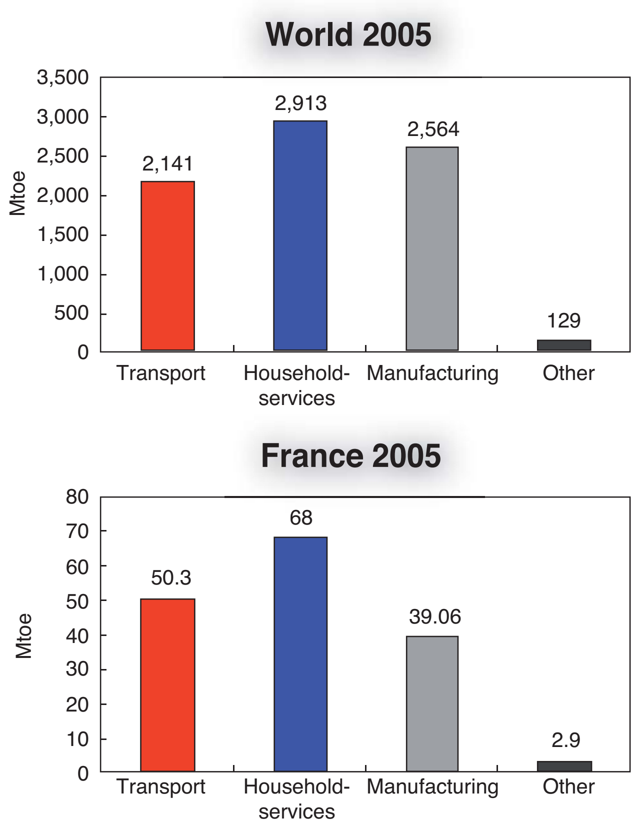
Transport energies: advantages and disadvantages

More than 98% of all transport fuels are petroleum-based, but there has been a multiplication of alternative energies driven by high motor fuel prices and the need to mitigate greenhouse gas emissions. Many pathways are contenders in the quest to choose replacements for petroleum-based motor fuels. What are the pros and cons of the energy sources under consideration for use in the near or distant future?

The transport sector is extremely energy-intensive. In 2005, world transport consumed the equivalent of 2,141 million tons oil equivalent (Mtoe). In France, transport is the second-ranked sector for energy consumption, with 31% of the total (Figure 1).

Fig. 1 - Energy consumption per sector in 2005



Sources: IEA & General Directorate for Energy and Raw Materials, France

The transport sector currently depends very heavily on oil, but there are many possible alternatives such as other fossil resources, biomass, renewable energies and nuclear power (via electricity production), which could all have transport applications by yielding different types of fuel for different types of vehicle. Figure 2 shows the four main vehicle categories, including vehicles powered by internal combustion engines, the most common, as well as the new hybrids just reaching the market.

On what basis should solutions be preferred? What methods should be implemented to evaluate alternative motor fuels and establish the pros and cons of using them in terms of economic viability, environmental performance and resource availability?

Today, the transport sector is heavily dependent on conventional petroleum-based motor fuels

Conventional petroleum-based motor fuels currently cover the vast majority of demand for energy to ensure the mobility of passengers and goods.

Gasoline and diesel represent 98% of the energy used in the global road transport sector. In Europe, they account for 96% with biofuels covering a scant 1.5% and natural gas only 1% (Figure 3).

Energy consumption in the road transport sector is climbing by nearly 2% a year. Conventional motor fuels have already undergone various improvements, both technical (octane and cetane numbers) and environmental (*e.g.* lead and sulfur content), to meet more stringent specifications. Yet further improvements are required to

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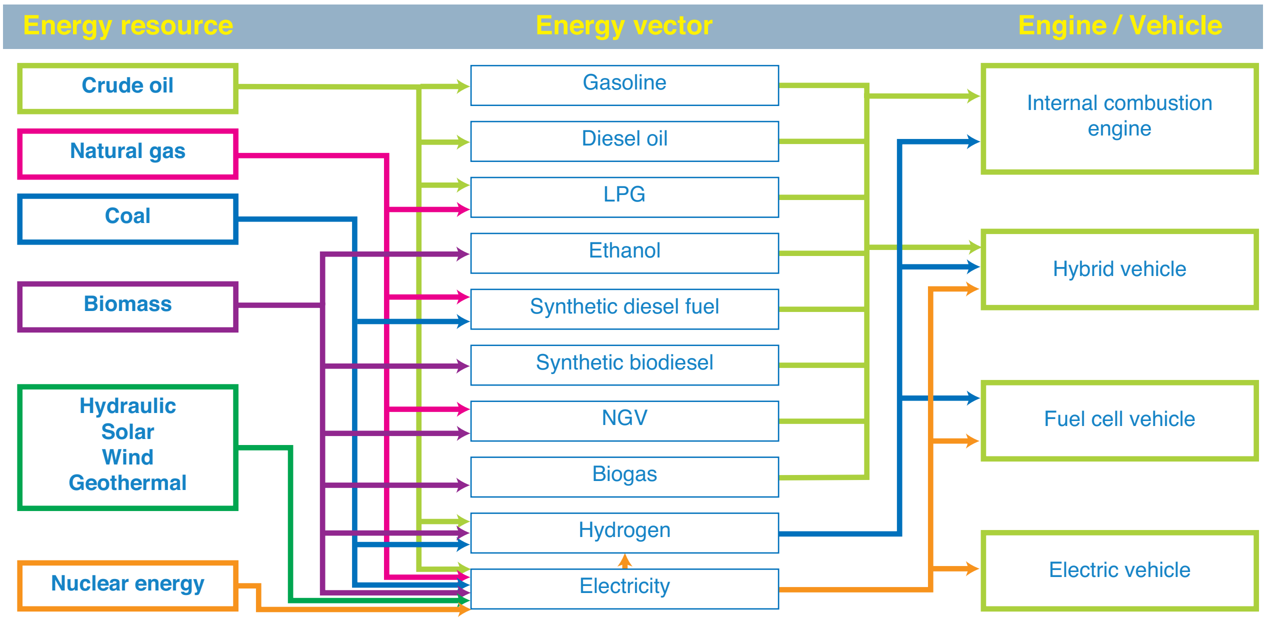
Fig. 2 - Energy pathways



Source: IFP

meet the even stricter regulations scheduled to come into effect. It is likely that new standards will be implemented by 2020 to meet future EU air quality targets and/or specifications for any new engine combustion techniques.

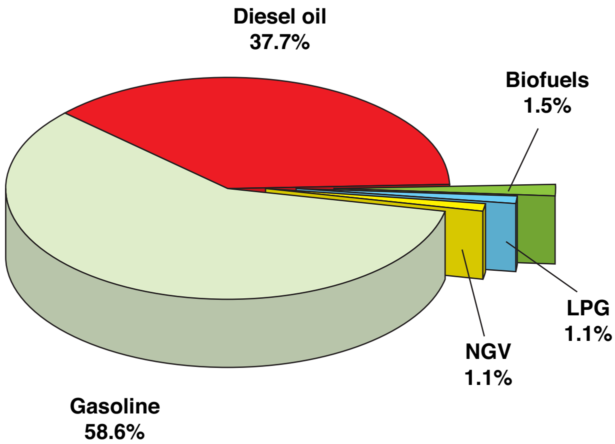
The air transport sector is even more dependent on oil. More than 99.9% of jet fuel is petroleum-based. Some types of small aircrafts still use a type of fuel that is very much like gasoline, but this is a very marginal case.

As for maritime transport, it is 100% dependent on petroleum hydrocarbons (except methane carriers), but the consumption of the world fleet is more evenly balanced between gasoline, heavy fuel and light marine diesel. The latter, the equivalent of domestic heating oil, is in most widespread use (Figure 4).

What is most likely to change in future are the specifications governing the sulfur content in the fuels contained in ship bunkers.

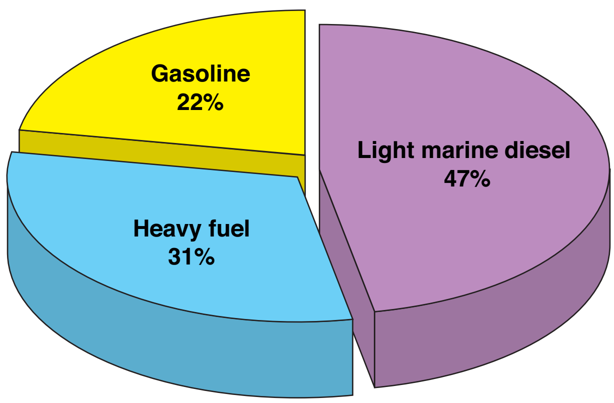
The rail transport sector has been slightly more successful in weaning itself from petroleum energy sources. This is because some countries have electrified a substantial portion of their respective rail networks.

Fig. 3 - Energy consumption in the Word road transport sector in 2007, by type of motor fuel



Source: Based on statistics from the OECD

Fig. 4 - Fuel consumption in the maritime sector in 2006, 18.8 Mtoe



Source: Based on statistics from the OECD

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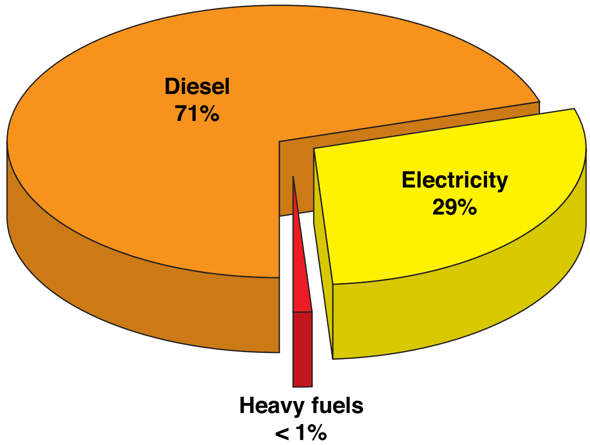
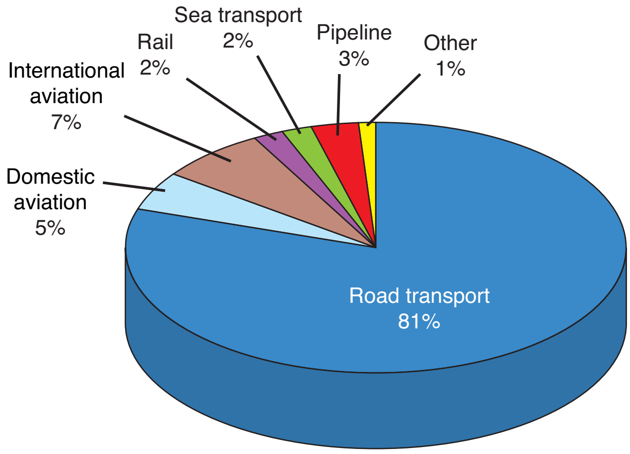
Fig. 5 - Energy consumption in the world transport sector in 2006, 28 Mtoe



Source: Based on statistics from the OECD

Fig. 6 - World transport-related CO_2 emissions in 2005



Source: Based on statistics from the OECD

Nevertheless, the global transport sector still relies on diesel to cover 71% of demand and electric power only accounts for 29% (Figure 5).

Liquid fossil fuels offer big advantages for transport applications. Their high energy density allows a motor vehicle to travel more than 600 km and they can be refined using tried and tested techniques at low cost (excluding the cost of supply).

The fact that the most common transport modes depend so heavily on petroleum raises complex problems. From an economic standpoint, the use of a rare (non-renewable) resource, from which many developed economies are largely dependent, and exposed to the volatility of crude oil prices, is a source of energy vulnerability. From the environmental perspective, the carbon content to be found in petroleum products as well as the GHG emissions and local pollutants associated with refinery operations and combustion engines are major issues at a time when the concept of sustainable development is gaining ground.

Efforts to influence demand (for instance, by changing driving behaviors and travel habits) and diversify motor fuels in the transport sector can be key levers in the reduction of CO_2 emissions (Figure 6) and the consumption of non-renewable resources.

The current status of alternative motor fuels

LPG

Historically, liquefied petroleum gas (LPG) was the first true alternative motor fuel. A mix of butane and propane, LPG is derived from oil refining (40% of the world total) and natural gas processing (60%).

In 2006, LPG consumption for European OECD countries stood at 5.7 Mtoe, up 6% year-on-year, largely due to the emergence of LPG fleets in Eastern Europe. By way of an example, the Polish fleet of LPG vehicles went from 470,000 in 2000 to nearly 2,000,000 at year-end 2007.

In contrast, the LPG fleet in France is small and its growth is apparently stagnating. There are only 140,000 vehicles in France compared to 200,000 in Germany and a million in Italy, despite the fact that 2,000 service stations cover 98% of the French motorway system.

When LPG motor fuel is used in a properly equipped vehicle, it has advantages over conventional motor fuels, particularly environmental benefits:

- CO_2 emissions are 10% lower than for vehicles running on gasoline (but higher than for diesel vehicles),
- NOx emissions are lower than for gasoline vehicles and much lower than for diesel vehicles,
- no soot particles are emitted,
- the octane number is high, which should improve engine efficiency,
- it costs less at the pump than diesel in France, due to tax incentives.

However, there are also disadvantages that explain why the LPG pathway has encountered only limited success:

- for a given model of vehicle, the LPG version costs about 15 to 20% more than the diesel one,
- the size of the distribution network is still small, especially in areas remote from major highways,
- a close relative of oil and natural gas, LPG is a limited resource that does not really help diversify energy sources,

- it does not make much of a contribution to the fight against climate change.

NG motor fuels

Much more attention is being paid to NG motor fuels, because of the development of the natural gas market and the assumption that natural gas will take longer to reach depletion than oil.

Even so, the consumption of NG motor fuel remains quite low. In 2006, it amounted to 0.55 Mtoe (data for European OECD countries). Italy, which began to develop this pathway in the 1930s, is the leading market.

In France, consumption barely exceeded 60 ktoe in 2006 and the NG fleet numbered about 10,000 vehicles in mid-2007. Many of these vehicles have a fixed refueling point where they can fill up at night, for instance.

An NG vehicle offers several environmental benefits compared to a gasoline or diesel vehicle:

- it emits 20 to 24% less CO_2 than a gasoline or diesel vehicle,
- its NOx emissions are lower than for a diesel vehicle,
- it does not emit particulates and the overall toxicity of its tailpipe emissions is significantly lower,
- it offers good resistance to engine knock, which improves efficiency through turbosupercharging.

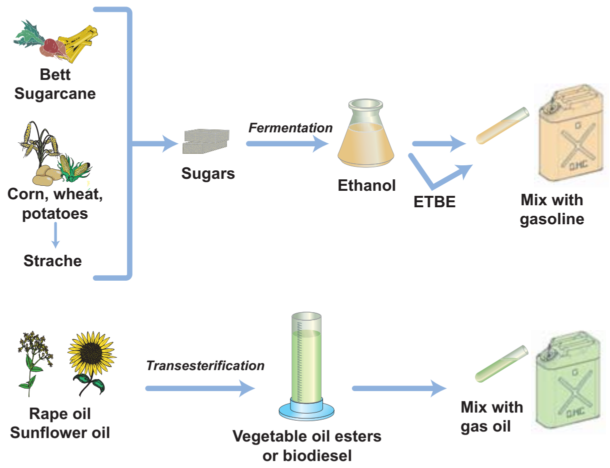
These benefits do not yet outweigh the disadvantages of this pathway, still fairly recent:

- the distribution network has yet to be installed in France,
- this type of vehicle presents larger constraints pertaining to on-board storage and range,
- advances in technology are needed to improve the engines of dedicated NG vehicles as well as their emissions control equipment, which must be compliant with future emissions standards,
- the added cost of NG vehicles is still high, but using monofuel instead of bifuel vehicles would reduce the bill.

Biofuels

There are two main types of biofuels: ethanol and methyl esters of vegetable or animal oils (biodiesel). Used in gasoline engines, ethanol is made from sugar-producing plants, such as sugar cane and sugar beets, or starch-producing plants like wheat and corn (Figure 7). Both types, especially ethanol, have already served as motor fuels in the past.

Fig. 7 - First-generation biofuel pathways



Source : IFP

In volume terms, more bioethanol is consumed than any other biofuel. In 2006, 20 Mtoe were produced worldwide, mostly in Brazil and the United States. During the same period, global biodiesel output reached 4.9 Mtoe, with Germany ranking as the top world producer (41% of the total) and French production standing at 0.49 Mtoe.

The biggest advantage of biofuels is that they can be blended with gasoline or diesel and distributed via the conventional systems. Furthermore, there is no need for major technology breakthroughs in the area of engine design.

The downside is that the resources must be divided up between food and energy applications. A comprehensive management system should be established to determine how to meet both types of demand. Furthermore, although the CO_2 balance for biofuels seems to be encouraging and some of their impacts are well known—especially global impacts like the greenhouse effect and the depletion of fossil energy resources—much less is known about other impacts (*e.g.* on the water and soil), especially at local level.

Electricity

The case of electricity, which is an energy vector and not a primary energy, is slightly different compared to the energies already mentioned. Vehicles today are already equipped with electricity and, as its role in hybrid vehicles expands, their reliance on it will grow. A commercial success, the Toyota Prius became the standard-bearer for a new generation of hybrids and marked the advent of a new era. Most auto manufacturers have announced the addition of new hybrid vehicles to their range.

Today's hybrids operate as electric machines, but do not need to be plugged in: their batteries recharge during coasting or braking, then discharge to propel the vehicle at low speed or provide extra acceleration.

Increasingly, it appears that the next step will be a plug-in hybrid electric vehicle that recharges its batteries by connecting to the grid. This would give the electric motor a more important role. It would also improve eco-performance if the vehicle is recharged with low-CO_2 electricity, in other words, if low quantities of CO_2 are emitted throughout the entire production cycle.

Last but not least is the all-electric vehicle equipped with batteries and an electric motor. It can travel a respectable distance (100 to 200 km) and does not generate any tailpipe emissions. Auto manufacturers are back at work on projects for electric vehicles and new models are expected to reach the market by 2010.

As usual, the electric battery is the only obstacle. A great deal of progress is needed to reduce its on-board weight and volume to cut costs and improve performance. This is a prime objective for many R&D teams and the number of recent projects announced offers hope for big strides forward in the years to come.

The alternative motor fuels of the future

Looking to the medium term, one can expect to see liquid motor fuels derived from other fossil resources besides oil (natural gas and coal) and also from biomass.

Synfuels

There are two steps involved in the production of synfuels, irrespective of the feedstock used. First of all, the raw material is converted to synthesis gas (hydrogen and carbon monoxide). Then the Fischer-Tropsch process is used to obtain liquid products to make diesel and jet fuels. This pathway yields motor fuels, especially diesel, of very high quality (cetane number > 60-65, no aromatics, no sulfur). Naphtha is the principal process co-product.

The feedstock can be natural gas, coal or biomass. The term XtL is used to refer to the conversion of different feedstock to liquids. The advantages of each pathway and its associated costs, whether environmental or economic, largely depend on the type of feedstock involved.

For fossil fuels, there are two options: gas to liquids (GtL) and coal to liquids (CtL). The GtL pathway is especially attractive for countries with large natural gas reserves. However, many projects that were in the planning stage in the early 2000s have been postponed, further to a steep rise in investment costs. Major advances in process performance and significant increases in project size—up from about 10,000 barrels per day in the early 1990s to about 30-75,000 bbld today—have been more than neutralized by a rise in construction costs since 2003 (*e.g.* that of engineering and building materials). Building a GtL unit today requires about US$60,000/barrel/day in capital expenditure, compared to US$20-35,000 in the early 2000s.

Most of the projects undertaken or under development are located in Qatar and Nigeria.

In addition, Petronas has also committed to a GtL project in Uzbekistan. Alliances have also been announced between developers of GtL and refining technologies (*e.g.* Rentech and UOP). Shell and Airbus are conducting tests on the use of synfuels in the air transport sector (Table 1).

Table 1

Projects to build new GtL units

Project	Partners	Capacity	State
Oryx (Qatar)	Qatar Petroleum and Sasol	34 000 b/d	Started in 2007
Escravos (Nigeria)	Sasol - Chevron	34 000 b/d	Starts in 2009
Oryx (Qatar)	Qatar Petroleum and Sasoil	65 000 b/d	Ongoing
Pearl (Qatar)	Qatar Petroleum and Shell	140 000 b/d	Ongoing

As far as environmental performance is concerned, there is room for improvement. For the entire chain of production and vehicle life, the total CO_2 emissions are—at best—equivalent to the conventional refining pathway; usually, it compares unfavorably, because its energy efficiency is so much lower (less than 60%). It would take very specific conditions to improve the CO_2 balance, *e.g.* using flare gas or developing CO_2 capture and storage.

Using the CtL pathway to produce synfuels from coal is another possibility. This alternative is of interest to countries with substantial coal resources, such as India or China, which anticipate an upsurge in energy consumption in the decades to come.

Right now, South Africa is the only country equipped with a CtL production unit (capacity: 190,000 bbld). However, many CtL projects have taken shape in the last three years, because the profitability of CtL technology increased with every hike in the crude price. Another reason is concern over security of supply. The new projects are at different stages in the decision-making process and it is probable that not all of them will be carried out (Table 2).

Table 2

Projects to build new CtL units

Project	Partners	Capacity	State
Shenhua (Chine)	Shenhua	20 000 b/d	Started in 2008
Shenhua (Chine)	Shenhua	50 000 b/d	Planned for 2015
H&WB (Philippines)	H&WB	50 000 b/d	Construction from 2009
Sasoil (South Af. or India)	Sasol	80 000 b/d	

China has announced its intention to build a number of projects by 2020 for a total capacity of 700,000 bbld. At least six coal liquefaction projects are planned in the United States (aggregate capacity: nearly 150,000 bbld). Some are already at the stage of applying for a permit from the competent authorities, others still at the feasibility stage.

The CtL option has two significant disadvantages. First of all, it requires about US$125,000/bbl more in capital expenditure than a GtL unit. Secondly, it turns in a poor performance regarding GHG emissions. In practice, it is almost impossible to consider implementing CtL without CO_2 capture and storage technology.

The GtL and CtL pathways have the same problem: their CO_2 emissions are higher than for conventional pathways. One possibility would be to capture the CO_2 emitted by GtL or CtL units and store it in geological formations, which would improve eco-performance but only at additional cost.

Last but not least, biomass (including waste) can be used to produce synfuels via the biomass to liquids pathway. BtL has not reached the same stage of technical maturity as GtL or CtL: it is still in the R&D phase. A few demo plants have been built, particularly as part of European projects. Their purpose is to optimize the collection, preliminary processing and gasification of biomass, as well as the purification of synthesis gas.

There is only one pilot demo unit in operation, located in Frieberg, Germany. Its purpose is demonstration and to facilitate the sizing of a future BtL production plant which should produce 200,000 t/yr of motor fuel from one million tons of dry biomass. The estimated cost of the unit would come to €800 million and that of the biomass supply would be €180-280/toe.

There is also research underway on the use of BtL jet fuels.

Second-generation biofuels

The BtL pathway relies on the indirect thermochemical conversion[1] of biomass to produce synfuels, which is also true of the technologies based on DME (dimethyl ester), methanol, syngas or ethanol obtained using gasification. BtL is one of the pathways that yields second-generation biofuels.

Extensive research programs have been developed to explore the biochemical conversion of lignocellulosic biomass into ethanol. The idea is to produce ethanol to replace conventional gasoline by fermenting the sugars in the lignocellulose.

The industrial viability of producing ethanol from lignocellulosic biomass has yet to be demonstrated. Taking this process to industrial scale would raise a number of questions pertaining to the optimization of each step (preliminary processing, hydrolysis and fermentation), especially from the economic standpoint.

The first pilot lignocellulosic plants dedicated to ethanol production were built in North America in 2006. There are now about a dozen pilot and commercial units operating in the United States, with large subsidies from the U.S. government providing a healthy stimulus. These units are primarily funded by ethanol or enzyme manufacturers and agribusiness or food companies. This year, Petrobras brought Brazil's first pilot unit onstream; several other projects are slated for 2009-2010. In Japan, a pilot plant has also started up. Six pilot projects have been announced in Europe, including Futurol, which is supported by a number of French industrial firms, financial institutions and research centers, including IFP.

In the long-term future, it may be possible to use marine biomass (algae) to produce many biofuels for motor vehicles. At present, researchers are concentrating on producing biodiesel from algal oils.

Hydrogen

In the long term, it may be possible to use hydrogen to fuel internal combustion engines, either directly or blended with natural gas (up to 20%). Used pure in a fuel cell with an electric motor, it could be viewed as an alternative to the direct storage of electricity in batteries.

Today, industry accounts for 99% of all hydrogen consumed. At global level, refining is the most hydrogen-intensive sector (51%), followed by the manufacture of ammonia (34%) and the production of other specialty chemicals (14%). The energy sector—thanks to the

(1) There is also a direct liquefaction process, used to convert biomass into biocrude without requiring a gasification step. This is called hydrothermal liquefaction.

space industry—only represents 1% of world hydrogen consumption, in volume terms. Fossil fuels are the most common energy sources used to produce hydrogen. Today, steam reforming of natural gas is the technology most commonly used to produce large quantities at low cost. The conversion of biomass to produce hydrogen seems like an attractive alternative, but needs a great deal of R&D. Finally, despite its cost (currently very high) and its mediocre energy efficiency, the electrolysis of water is the preferred pathway for producing hydrogen from non-fossil sources. This being said, the environmental benefit actually derived from its use will depend on the mode of electricity production. It is important to stress that, looking to the long-term future, the choice of hydrogen implies the installation of heavy infrastructure (pipelines, intermediate storage facilities, on-board storage units), accompanied by technical difficulties and large additional costs. Today, there are about forty hydrogen service stations in the world, fairly equally distributed between Europe, North America and Japan.

In conclusion, the transport sector will continue to be heavily dependent on petroleum products. The most commonly used alternative motor fuels at global level are biofuels, LPG and NG motor fuel. Biofuels offer a clear environmental benefit with respect to the CO_2 content.

In the medium term, synfuels derived from natural gas (GtL), coal (CtL) and biomass (BtL) and for which pilot plants or industrial facilities already exist, should come into increasing use. Their profitability in comparison with fossil-based motor fuels will depend on the crude price.

The role of electricity will be increasing, no matter what the level of vehicle electrification might be. In a more distant future, it may be possible to consider hydrogen a replacement fuel if certain technical and economic challenges are overcome.

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