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ROAD TRANSPORT | WHICH ARE THE ALTERNATIVES TO GASOLINE AND DIESEL OIL?

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The author | A Belgian national with a Master's degree in Electrical and Mechanical Engineering, a degree in Physics and Nuclear Chemistry and a baccalaureat in Economics from the Louvain University (Belgium), Jean-Pierre SCHAEKEN WILLEMAERS began his career as a Lecturer at the faculty of applied sciences of this University. He thereafter joined the Tracetebel and Suez-Tracetebel group. Within this group, he was Head of Trade and Marketing and a member of the Tracetebel Engineering Executive Committee. He was thereafter appointed Executive Vice President and member of the executive committee of Suez-Tractebel EGI (Electricity and gas international), and Director of Powerfin. He was in charge of investments in Europe, Russia and the Middle East in the fields of electricity production, transmission and distribution as well as the transportation and distribution of natural gas by acquisition or project development. In this capacity, he was appointed Chairman or Director of several subsidiaries of this group in Europe and Central Asia. He was also Vice President of the Brussels Chamber of Commerce and Judge at the Brussels Commercial Court. In 2000, he founded a centre for high technology start-ups of which he is still a board member. Today, he is a board member of several industrial companies. He is Chairman of the Energy, Climate & Environment Department of the Thomas More Institute a also member of its Advisory Board.

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Jean-Pierre SCHAEKEN WILLEMAERS

For more than 10 years, the European Union is pursuing a program of reduction of anthropogenic carbon footprint. This policy involves a more efficient use of energy resources and the development of renewable energies. As far as road transport is concerned, the EU has set the goal to have 10% of renewable energy by 2020. In this context, an industry of alternative fuels and vehicles (without gasoline and diesel oil) emerged, although not without difficulty. The question is: which alternatives could meet such a challenge and when?

1 | Biofuels

Thanks to generous incentives linked to this European policy, a large biodiesel and bioethanol industry has been created in Europe. However such biofuels are not as sustainable as they should be. Indeed:

- some of them displace food production and consequently lead to increasing corresponding food price;
- they contribute to a net increase in CO_2 emissions when, for example, displacing forests or fallow fields with lower carbon emissions.

The consequence of such indirect land use change (ILUC) has prompted the Commission to draft proposals to regulate that market by, to start with, capping, in 2020, biofuels from food crops at 5% of overall transport fuel demand in the EU[1]. However, the European Parliament has set, on September 11, 2013, a ceiling on the use of biofuels from food crops at 6%, instead. The EU governments have to finalize their common position. If there is no conclusions by April 2014, European Parliament elections scheduled for May could push back the law until 2015. Actually, the purpose of the cap on biofuels from food crops is to move the biofuels market to biofuels that do not compete with agriculture (advanced biofuels) such as the ones from agricultural waste, wood or algae. But is the second generation of biofuels from ligneous source that better in terms of footprint on the environment? A study carried out by researchers of the British university of Lancaster on biofuels from ligneous biomass, stresses that production of biofuel from willows, poplars and eucalyptuses emit more isoprene than other plants during their lifetime. This molecule combined with other atmosphere gases such as nitrogen oxide, generates ozone, a health hazard. Ozone also affects crops yields.

In the biofuel share calculation, advanced biofuels can count for four times conventional biofuels towards the renewable energy directive's 10 % renewables in transport target. In October 2012, however, the Commission dropped the emission penalties per crop category to account for ILUC. If they are still mentioned, it is only for reporting fuel emissions, not for calculating progress to 6% GHG emission reduction target for road fuels that fuel suppliers must meet by 2020. With such a decision, fuel suppliers will continue to drive demand for biodiesel. This is the consequence of hasty incentive decisions for biofuels prompting investments in the first generation biofuel industry which can hardly be reversed because of big investments and job losses.

"Around two-thirds of European road transport runs on diesel, one third on gasoline. The EU Commission is making an effort to change this with its proposal to reverse the EU's energy taxation directive to force member states to tax diesel more than gasoline. But the European parliament has rejected this idea[2]… If the EU is serious about advanced biofuels, it needs to introduce incentives for farmers and foresters to collect residues…Waste will probably still need to be better defined if it may be used to generate biofuels"[3].

What is sure is that first generation biofuels is not an energy of the future in Europe even though some feed stocks (sugar based) are better suited for alcohol manufacturing like sweet sorghum (sorgo). It requires less water and fertilizers compared to sugarcane for instance and their crop cycle is only 3.5 to 4 months i.e. two to three cycles are possible from the same piece of land annually. Another alternative to petroleum based fuels is biofuels derived from algae and cyanobacteria, although not an immediate possibility[4]. The advantage of producing biofuels from algae includes rapid growth rate, a high per acre yield (algae can grow 40 tons per acre against 8

[1] Almost all biofuels today are made from food crops.
[2] It is worth reminding that a diesel car emits about 20% less CO_2 than a comparable gasoline car. Reversing the fuel split will thus slow down the overall CO_2 emission decrease.
[3] Sonja van Renssen, *European Energy Review*, October 25, 2012.
[4] Right now algae is too expensive to produce. They are expected to be commercially viable between 2017 and 2022, this latter date according to the Obama administration.

tons for corn)[5] and such fuel does not contain sulfur, is not toxic and is highly biodegradable. In particular some species of algae are ideally suited to biodiesel production due to their high oil content, topping out near 50%. Other advantages are that algae do not displace human food, do not require fresh water for its production and algae fuel is relatively harmless to the environment if spilled. Algae can produce up to 300 times more oil per acre than conventional crops such as rapeseed, palms, soybeans and the like[6]. As algae have a harvesting cycle of a few days, several harvests are possible in a very short time frame. Algae require primarily three elements to grow: sunlight, CO_2 and water which could be waste water (after being processed by bacteria, through anaerobic digestion) or ocean water.

Most of the current development involves growing selected strains of algae in open ponds or in closed photo-bioreactors (PBR)[7]. However one of the biggest problems with algae biodiesel is the high cost for implementing the technology. Another obstacle to a successful commercial technology is to identify a steady and reliable source of CO_2. Every unit of algae biomass produced requires twice that amount in CO_2 to sustain commercially viable productivity levels. Ambient absorption of atmospheric CO_2 would not be sufficient. Additional source could be CO_2 emissions from stacks of coal fired power plants. The production of biofuels from algae goes through four steps:

- Selection of algae with high oil content;
- Culture in open pond or in photo-bioreactors;
- Collecting and extracting of oil through various methods (centrifugation, solvent treatment and so on);
- Conversion of oil into fuel through trans-esterification or catalytic hydrogenation followed by hydrocracking. The former bio-diesel can mixed with diesel up to 10-15% in volume whereas the latter can be incorporated in diesel oil or kerosene in much higher quantities.

Among others, American universities are investigating the possibility to produce liquid fuels from abundant and affordable feedstocks. Columbia University (USA) is using CO_2 from ambient air, ammonia an abundant chemical, and a bacteria called N.europaea to generate liquid fuel. The Columbia team is feeding the ammonia and CO_2 into an engineered tank where the bacteria live. The bacteria capture the energy from the ammonia and then use it to convert CO_2 into a liquid fuel. When the bacteria use up all the ammonia, renewable electricity can regenerate it and pump it back into the system. Harvard is engineering a self-contained, scalable electro-fuel production system that can directly generate liquid from bacteria (shewanella), water, CO_2, and sunlight. In this case it is the power generated by solar panels that gives the bacteria the energy they need to process CO_2 into liquid fuel. Both Columbia and Harvard are developing other processes to produce liquid fuels.

2 | Natural gas and electric powered vehicles

A | Electric powered vehicles (EVs)

The full electric vehicle industry is not yet mature! Its development will require big investments in EVs development to cut costs and to increase driving range, in charging infrastructures (normal, wireless inductive or battery swap) and in power storage technologies[8]. Actually, the market is still testing electric drive technology, waiting for the price premium for EVs compared to conventional cars, to narrow. Up to October 2012, only about 5.8 million hybrid electric vehicles have been sold worldwide of which 2.5 million in the US with Prius as the top selling.

[5] Todd Becker, CEO Green Plains, Renewable Energy.

[6] Studies have shown that the production of bio-oil from corn is around 145kg/h/year, while spirulina microalgae and diatom algae can produce up to 18,000 and 43,000 kg/h/year respectively.

[7] A PBR is a closed equipment which provides a controlled environment and enables high production of algae. It facilitates better control of culture environment such as carbon dioxide supply, water supply, optional temperature, efficient exposure to light, culture density, pH levels and so on.

[8] The European Commission "Clean Power for Transport Package" proposes a plan to roll out a large scale distribution network of charging points as well as, by the way, of LNG, hydrogen and CNG refueling stations (see below). This initiative could solve the chicken and egg problem of investors waiting for the infrastructure before further developing alternative cars and TSO postponing the investments in the required infrastructures waiting for the large scale introduction of electric cars on the European market.

What about President Obama declaration that "with enough federal aid, we can put a million electric cars on the road by 2015"? His administration invested about USD 5 billion in grants, guaranteed loans- including USD 465 million for Tesla- and tax incentives to buyers. Yet Americans bought just 71,000 plug-in hybrid or all electric vehicles in the past two years according to GreenCarReports[9]. The Obama administration's clean energy policy faced failures and successes. As far as the car industry is concerned, the failures include, among others, the USD 200 million in government loans for hybrid car development to Fiskar Automotive, which has recently laid off most of its employees to avoid bankruptcy. However, the Fisker fiasco will not spell the end of alternative vehicles. Spending on alternative vehicles will increase by 75% in 2014, to USD 575 million. There would be an annual USD 200 million fund to boost research in this sector.

In Europe, according to a new report from Pike Research, electrical vehicles- including electrically assisted hybrids- will play an increasingly important role in the European market, growing from 0.7% of the market in 2012 to 4% in 2020. While that is still a small portion of the market, it represents more than 827,000 vehicles sold annually in the region. The popularity of diesel has prevented hybrids from achieving the success that they have in North America, where the contrast with large V8 vehicles is important to consumers, according to David Alexander, senior research analyst with Pike Research. In China "for the next 10 years, generally plug-in hybrids have a much better chance to become a relevant volume in comparison to just fully electric cars", said Jochem Heizman, head of Volkswagen in China. In spite of generous subsidies, Chinese consumers bought only 11,375 electric cars in 2012 against a total vehicle sales of 19,3 million according to China Association of Automobile Manufacturers. That's a long way from Beijing's goal to have 500,000 hybrid and electric cars on Chinese roads by 2015 and 5 million by 2020.

Even innovative sales schemes failed to meet sales expectations. This is the case, for instance, of the Israeli firm "Better Place". Founded by Israeli entrepreneur Shai Agassi in 2007, Better Place developed a system where electric-car owners could drive their vehicles into a network of stations around Israel and replace the car's battery with a new one in about the same time it takes to fill a gasoline tank on a regular car. The quick drop system[10] was supposed to remove one of the main obstacles to adoption of electric vehicles, namely the several hours it takes to recharge a flat battery. In 2012, Better Place said it hadn't sold as many cars as expected and around the same time, M. Agassi left the company.

Some car manufacturers are reconsidering their strategy. Toyota, for example, "has scrapped plans for widespread sales of new all-electric mini-car, saying it had misread the market and the ability of still emerging battery technology to meet consumer demand"[11]. Moreover "the current capabilities of electric vehicles do not meet society's needs, whether it may be the distance the cars can run, or the costs, or how it takes a long time to charge"[12]. Even Nissan which got USD 1.4 billion US loan guarantee, is facing disappointing sales. Car manufacturers tend to concentrate, for the time being, on hybrid gas-electric models, obviously a temporary solution!

However, in spite of the fact that full electric cars sales are not yet taking off, all car manufacturers are displaying their new models of electric cars at the 2013 Francfort "Internationale Automobil-Austellung" (IAA).

B | Natural gas powered vehicles

Today, natural gas vehicles (NGV) are the most prevalent on-road alternative fuel vehicles in the world.[13]. Recent margins between the pump prices for petroleum fuels and compressed natural gas (CNG)[14] or liquefied natural gas (LNG)[15] have never been better in many countries…The future global NGV market is even more auspicious given

[9] Charles Lane, *Washington Post*, February 14, 2013.
[10] Lack of standardization of batteries and battery location in vehicles prevent the development of a profitable quick drop network that could have been shared by a majority of brands and models.
[11] Yoko Kotuba, « Toyota drops plan for widespread sales of electric cars », Reuters, September 24, 2012.
[12] Takishi Uchiyamada, Toyota's Vice-Chairman, September, 2012.
[13] NGV is a "clean diesel" or a "fuel efficient gasoline" car.
[14] CNG is typically stored in steel or composite containers at high pressure (205 to 275 bar). However CNG can be stored at lower pressure, in a form known as ANG (Adsorbed Natural Gas), tank at 35 bar in various sponge like materials such as activated carbon and metal-organic frameworks. The fuel is stored at similar or greater energy density than CNG.
[15] LNG storage pressure is typically around 3 to 10 bar. At atmospheric pressure, LNG is at temperature of -162°C. LNG is far denser than even the highly compressed CNG. Vacuum insulated storage tanks are typically made of stainless steel.

the potential of shale gas and other conventional natural gas deposits to boost regional gas production around the world. "The worldwide market for light duty NGVs (natural gas vehicles) will grow steadily over the next 7 years, reaching 3.2 million vehicles sold in 2019. This will result in a cumulative total of 24.5 million light duty NGVs on the road by 2019[16]. This Pike Research also reports that light-duty vehicles make up about 97% of the total natural gas vehicle market, or 2.08 million out of 2.15 million vehicles, as of 2012.

At the end of 2011, there were about 15 million natural gas vehicles worldwide. The Asia-Pacific region lead the world with about 7 million NGVs[17], followed by Latin America with 4.2 million vehicles (35% of the world wide NGV fleet). In the latin American region amost 90% of NGVs have bi-fuel engines, allowing these vehicles to run on either gasoline or CNG.

The world gas consumption in transport is expected to increase from 20 bcm in 2010 up to 40-45 bcm (billion cubic meters) in 2030. The coming decades will show the dramatic growth of use of liquefied natural gas and liquefied biomethane.

Despite its advantages, the use of natural gas vehicles faces several limitations. Natural gas must be stored in cylinders, whether it is CNG or LNG and these cylinders are usually located in the vehicle's trunk, reducing the space available for other uses, particularly during long distance travel. This problem can be solved in factory-built cars that install tanks under the body of the vehicle thanks to a more rational position of components, leaving the trunk free. As with other alternative fuels, other barriers for widespread use of NGVs are natural gas distribution to and at fueling stations as well as the low number of stations selling CNG.

Such a situation can be explained by the fact that consumers are unwilling to purchase NGVs before a refueling infrastructure is built, but business will not invest in natural gas refueling stations until there is consumer demand. Each would be better off if the other side acted first, but neither is willing to move without the other.

"Medium duty, single trucks are estimated by the US Federal Highway Administration at 8.3 million (2 axles, 6 tires, weight ≥ 10,000 lbs) […]. Buses and garbage trucks represent a limited market with only 68,000 transit buses and 480,000 school buses and somewhat 136,000 refuse trucks […]. Currently there are about 12,000 natural gas fueled transit buses in operation […]. There are about 2.6 million registered combination trucks (with one or more trailers) […]. Natural gas in its energy-dense form (LNG) is really the only option beyond diesel for heavy-duty applications. These trucks are large enough to serve as economical platform for the equipment needed to deliver LNG to the engine […]. Currently, the US is considerably behind other countries such as Argentina, Brazil, Italy and India"[18].

Although the US benefits from a gas boom thanks to technological breakthroughs that lead to a considerable drop in gas prices, NGV penetration in the US has been limited, to the most part, to small market niches-medium to heavy-duty fleet vehicles, such as buses, trash trucks and single unit delivery truck fleets In Europe, "the market share in 2011 of CNG (compressed natural gas) and LNG (liquefied natural gas) vehicles is still rather small, now making up close to one million vehicles […], which is making up a market share of only 0.4% of the total running park. Today practically all vehicles using methane as a fuel are propelled by CNG […]. But LNG heavy duty trucks (dedicated or dual fuel) are becoming more and more popular as trucks are Europe biggest road polluters and only very few options to replace diesel exist so far. LNG has a high energy density than CNG and is therefore a real and affordable way to replace diesel on medium and long distances (LNG blue corridors) […]. The diversity of national strategies has led to a very fragmented development of methane refueling. What it needs is a harmonized strategy to develop methane refueling across Europe […]. In total there are only 2,700 refueling points (public and private) in Europe"[19].

"The European transportation market is significantly different from other regions […]. Thanks to fuel prices that are significantly higher than in North America, small, efficient gasoline-and diesel engine cars have led European sales figures for many years. Today, the market is still testing electric drive technology, waiting for t he price premium for EVs compared to conventional vehicles, to narrow, and in some cases waiting for electric charging infrastructure to become established"[20]. Europe's largest light-duty natural gas vehicle market is Italy, where 2012

[16] Pike Research report, part of Navigant's Energy Practice, July 10, 2012.

[17] Against worldwide sales of hybrid electric cars of 4,500,000 as of June 2012 of which 2,180,000 in the US and 1,500,000 in Japan according to *Statistic Brain, Hybrid*, US Department of Energy, September 2012.

[18] "Will natural gas vehicles be in our future?", Alan J. Krupnick, *Resources for the future, Issue brief*, May 2011.

[19] NGVA Position Paper: Minimum infrastructure needs for methane refueling across Europe, May, 2011.

[20] David Alexander, *Pike Research report*, July 10, 2012.

sales reached more than 159,000 vehicles according to Pike Research report. It's followed by Ukraine. Both countries will see slowed growth over the next few years while Germany and Sweden- comparatively small markets today - will have steady growth, the report says.

MEPs approved a draft law setting out rules for achieving the 95g target[21] (rapporteur Thomas Ulmer, EPP, DE), by 47 votes to 17 with 1 abstention, but also added indicative targets for post-2020 CO_2 emissions: a range of 68 to 78 from 2025. These emissions limits are the average maximum allowed for car makers registered in the EU. Makers producing fewer than 1,000 cars a year should be exempted from the legislation. Car makers would therefore have to produce, in addition to older, heavier or polluting models, enough cleaner ones to achieve a balance of 95g in 2020, on pain of penalties. To achieve this, makers could use "super credits", which assign favorable weighting to cars that emit less than 50g of CO_2[22]. Actually, "MEPs agreed in November 2013 to a limited one-year phase-in period. Under the deal, 95% of new car sales will have to comply with the target in 2020 and 100% in 2021. The compromise would also expand the super credits scheme, which allows electric cars to count more towards the fleet average"[23]. The corresponding plenary vote is expected to take place in December 2013.

Germany wants the super-credits scheme to be expanded to benefit the larger, heavier cars made by many German companies. France and Italy, which specializes in smaller, lighter cars, have always been opposed to such a move.

Although NGVA Europe welcomes the prospect of improved efficiency expected as a result of the European Commission's proposal to limit CO_2 emissions to an average of 95 g/km for cars and 147 g/km for vans by 2020, the super credit would give a big advantage to electric cars because, as for now they are the only ones that would qualify for the scheme, giving a monopoly for that type of cars. In contrast, lax regulations in Russia have already provided a foothold for natural gas cars. "Natural gas has been adopted by lower income and rural drivers, along with farmers and operators of light-duty trucks […]. The whole sale price for natural gas at the Henry Hub in Louisiana was 3.33 per million British thermal unit in February 2013; the government-set domestic natural gas tariff in Russia this year is expected to average 3.87 for the same quantity […].This is about a quarter of the wholesale price of natural gas in other industrialized countries like Britain and Germany […]. The biggest issue in Russia, as it will in any other country that tries a conversion, is where drivers can refuel[…]. Russia with a population half of the US, has only 267 NG filling stations and an estimated 86,000 NGVs according to a fact sheet prepared by Gazprom"[24].

3 | Hydrogen powered cars

Hydrogen is theoretically a convenient energy vector. Its combustion in a fuel cell generates electricity with high yield and without pollutant exhaust, water being the sole reaction product. However, currently, its production through water electrolysis is expensive because of catalyst (platinum) cost and much more expensive than hydrogen from steam cracking, but this technology is not considered as "green". The replacement of platinum with inexpensive materials is critical.

Inspired by natural processes, whereby hydrogenases, enzymes present in microorganisms, using iron or nickel are a catalyst to produce hydrogen, researchers of the university Joseph Fourier in Grenoble, are developing a new type of electrolysis with synthetic hydrogenase-like catalyst without noble and costly metal catalysts. Those synthetic enzymes are as efficient as platinum, but they do not have the drawbacks of natural enzymes, for instance their sensitivity to oxygen. They are placed on carbon nanotubes which enable to graft a great deal of such catalysts per unit of electrode surface. However with the same voltage, the catalysis speed is 10 to 100 times lower than with platinum.

The improvement of noble-metal free cathode catalyst will require another 10 to 20 years, according to Vincent Artero[25]. Among the leading fuel cell types, the polymer exchange membrane fuel cell (PEMFC) is one of the most

[21] 95 g CO_2/km.
[22] European Parliament/News, Car CO_2: Mapping the route to 95 g and beyond, Press release-Environment, April 24, 2013.
[23] European Voice, Dave Keating, November 28, 2013.
[24] *New-York Times*, Energy & Environment, Andrew E. Kramer, April 11, 2013.
[25] CEA Grenoble Research Scientist, Project Leader of Hydrogenases Modelisation.

promising fuel cell technologies. It consists of four basic elements:

- The anode (negative side) where the hydrogen is oxidized (loss of electron) and turned into a positively charged ion and where negatively charged electrons are freed and make their way to the cathode through an external circuit , creating the electric current;
- The electrolyte (in this case the polymer exchange membrane also called the proton-hydrogen ion-exchange membrane which allows hydrogen ions to pass through whereas electrons are blocked and are travelling to the external circuit. The membrane must be hydrated requiring water to be evaporated at precisely the same rate that it is produced. If water is evaporated too quickly the membrane dries, resistance across it increases and eventually it will crack, creating a gas short-circuit. If the water is evaporated too slowly, the electrodes(anode and cathode) will flood preventing the reactants from reaching the catalyst and stopping the reaction;
- The cathode (positive side) where hydrogen (travelling through the electrolyte to the cathode) and oxygen ions from oxygen fed into the cathode side, are recombined to form water;
- The catalyst that facilitates the reactions of hydrogen and oxygen. It deals with a substance that increases the rate of reaction without being consumed. The catalyst lowers the activation energy required, allowing the reaction to proceed more quickly or at a lower temperature. It is usually made of platinum powder which very expensive. Research is underway to develop new catalysts that reduce the amount of platinum required, but an effective catalyst that uses no platinum at all remains elusive.

A most promising candidate could the cobalt, graphene and cobalt oxide material, the first non-precious metal close to matching platinum's properties. This catalyst proves to be more stable degrading much more slowly than platinum over time. Cobalt is an abundant metal, readily available at a fraction of what platinum costs.

A single fuel cell produces only about 0.7 Volt. To get this voltage up to a renewable level, many separate fuel cells must be combined to form a fuel cell stack which, in theory, can weigh less than batteries. Fuel cell cars are more efficient than internal combustion engines. They can fill up in minutes at a hydrogen pump and drive several times the range of a battery car, which needs anything from 30 minutes to 8 hours to charge.

Now what about the lead time to launch fuel-cell vehicles? It varies from 5-10 years to decades according to manufacturers and surveys as well as to the assumptions regarding the refueling network. Some manufacturers are very optimistic. This is the case, for instance, of the joint venture of Daimler, Ford and Nissan which plan to develop and launch fuel cell cars within the end of 2014. Daimler hydrogen powered car technologies are very advanced but also very expensive, although conceivable for top-of – the-range cars. This is one of the reasons why it has decided to pool investment with its Japanese and American partners. "By spreading development costs- and using Ford and Nissan's sales volumes to help cover them- Daimler is giving some of its lead on the technology for faster development and a stronger business model". Toyota and BMW (liquid hydrogen technology) announced the launch of their fuel cell cars around 2020.

However there is an infrastructure issue, in particular, investments in hydrogen filling stations. In that respect, fuel cells face a chicken and egg problem. Indeed buyers (and to some extent, manufacturers) are reluctant to invest in hydrogen cars as long as the refueling network is not sufficiently developed and infrastructure investors are waiting for the vehicles to become widespread first.

4 | Compressed air cars

Cars powered by nothing but compressed air[26] are not without drawbacks: air cars have a relatively low range. The distance that an air car can cover without refueling is limited to about 150 km. More usual range of more than 500 km would require larger size storage tanks at the expense of other equipment or space for passengers. The maximum speed is currently limited to about 70 km/h.

In case of accident, compressed air tanks could be dangerous but still safer than hydrogen tanks. To reduce this hazard, air tanks are made of carbon fiber and are designed to crack rather than shatter in a crash. This crack

[26] Compressing air is a way to store excess green power.

would allow the air to escape harmlessly in the surrounding air. Manufacturers fear that air escaping from one end of the tank could produce a rocket-like effect and propel the car on a jet of air. The valve on the car's fuel tanks has been placed on the side to minimize this effect. Compressed air contains only 12% of the energy in lithium-ion batteries and 1% in that of gasoline.

To address above concerns, manufacturers are developing hybrid cars that operate on a combination of compressed air and gasoline. For example, Peugeot Citroën is developing an hybrid with a normal internal combustion engine running on gasoline or air or a combination of the two. Air power would be used solely for city use, automatically activated below 70 km/h and available for 60 to 80% of the time in city driving. At speeds above70 km/h, the car uses a standard 3-cylinder gasoline engine with an automatic transmission and when the driver slows down below 70 km/h as in typical city driving, the car uses compressed air to power hydraulic motor, allowing the gasoline engine to shut down. When climbing a steep hill or accelerating, the two power trains work together to give the car the extra-complement it needs. The company predicts that, by 2020, the cars could be achieving an average of 2 liters/100 km.

The air compression system can re-use all the energy normally lost when slowing down and braking. In the regenerative braking, the car's compressed air storage tanks are refilled with air by harnessing the energy created every time the driver brakes, energy that's usually just dissipated as heat. The motor and pump are in the engine bay, fed by a compressed air tank underneath the car, running parallel to the exhaust.

Such a system is a competitor to hybrid electrical cars, its price being about 1,200 euros cheaper to buy. The hybrid tank would only add about 220 pounds to the car, compared to the 400 pounds batteries of hybrid electrical cars.

Moreover air cars are designed to be lighter than conventional cars. The aluminium construction of these vehicles will keep their weight under about 900 kg which is essential to making these vehicles fuel efficient and will help then go faster for longer period of times.

According to Peugeot's chief executive, this system can be installed on a normal family car without altering its external shape or size or reducing the boot size provided the spare wheel is not stored there. From the outside, air-powered car will look identical to a conventional vehicle.

Peugeot's hybrid air car is currently a concept vehicle but the company expects to have the vehicle available for production by 2016. In the US, Zero Pollution Motors-the American arm of MDI and the company likeliest to produce the first air car for the US market- aims to have a car available soon, able to travel between 800 to 1000 miles on one tank of air plus 30 liters of gasoline. In India, Tata's high tech "Air Pod" is being built with the help of MDI, a Luxemburg-based company which has been pushing the compressed air engine for years. Tata still has no solid production plans yet, nor do any of the other companies working on air cars. In Japan, Honda also released an air car concept in 2010, but as with Tata, no production models have yet hit the road.

Both technologies are in the developing phase, manufacturers currently concentrating on hybrid systems. Air cars appear to offer some advantages over electrical cars. Can both systems co-exist or will one of them displace the other one?

5 | Conclusions

The question is: which alternatives to gasoline and diesel oil are sustainable as regards environmental impact and competitiveness, and at which term? As far as conventional biofuels are concerned, their first generation does not appear as an energy of the future. But is the second generation from ligneous source a better bet? It is doubtful not only because of its footprint on the environment but also because it is already a raw material for other more appropriate uses such as the wood industry, heating and power stations and the feedstock is limited.

Biofuels derived from algae could be, in principle, a serious alternative. However a number of obstacles will have to be overcome before commercializing this type of biofuel, such as the high cost for implementing the technology and the identification of a steady and reliable source of CO_2 necessary for its production although this latter concern could be considered as an opportunity to dispose of large quantities of this gas generated by the industry

(for instance, by coupling a coal fired power station with an algae derived biofuel plant)

By the way, CO_2 could also be the feedstock for processes to produce liquid fuels like the ones developed, among others, by American universities. Electricity is a promising technology for vehicle propulsion although this industry is not yet globally mature to compete with current conventional combustion engines. Its development will require big investments in infrastructure, vehicles and power storage technologies. Hybrid cars (combination of fuel and electricity) instead can compete and are likely to play some role in the European market until fully electrical cars will be economically available.

With the foreseen expansion of urbanization, politicians and regulators could be tempted to impose very stringent regulations in terms of CO_2 emissions in the center of big cities or even of medium European towns. That would give a serious boost to electrical cars and in particular to small, extra light mini cars with 200 km range. A "Samsonite type" battery on wheels could easily be brought back home for night recharging.

What about compressed air cars? As for electrical vehicles, compressed air cars are in the developing phase, manufacturers currently concentrating more on hybrid systems. Air cars appear to offer some advantages over electrical vehicles. Can both systems co-exist?

Today, natural gas vehicles (NGV) are the most prevalent on-road alternative fuel vehicles worldwide. However, NGV growth also faces problems of investments in infrastructure and storage. Although NGVs and electrical vehicles share some similar problems, these latter are more in line with the European de-carbonization policy and therefore in the mid-term, they could significantly increase their share of the market.

Hydrogen is theoretically a convenient energy vector. However, currently, its production through water electrolysis is expensive, in particular because of the cost of the catalyst. The improvement of noble metal free cathode catalyst will require another 10 to 20 years according to CEA[27]. There is, as for gas and electrical driven vehicles, an infrastructure issue, in particular in hydrogen filling stations.

It results from this paper that diesel will remain, for a while, the preferred fuel for road transport in Europe and that it is unlikely to attain 10% renewable resources in the road transport energy consumption fixed by the European Commission as a target by 2020.

Jean-Pierre SCHAEKEN WILLEMAERS

[27] Commissariat à l'énergie atomique et aux énergies alternatives, France.