RCEM Working Papers

RCEM 2014/03

RESEARCH CENTRE FOR ENERGY MANAGEMENT
AT ESCP EUROPE BUSINESS SCHOOL

TITLE:
An overview of next-generation of fuels for land transportation

Author Name:
Michael Grossmann

affiliated to
CCI PARIS ILE-DE-FRANCE

ESCP Europe Business School,
527 Finchley Road, NW3 7BG, Hampstead, London, United Kingdom.
http://www.escpeurope.eu
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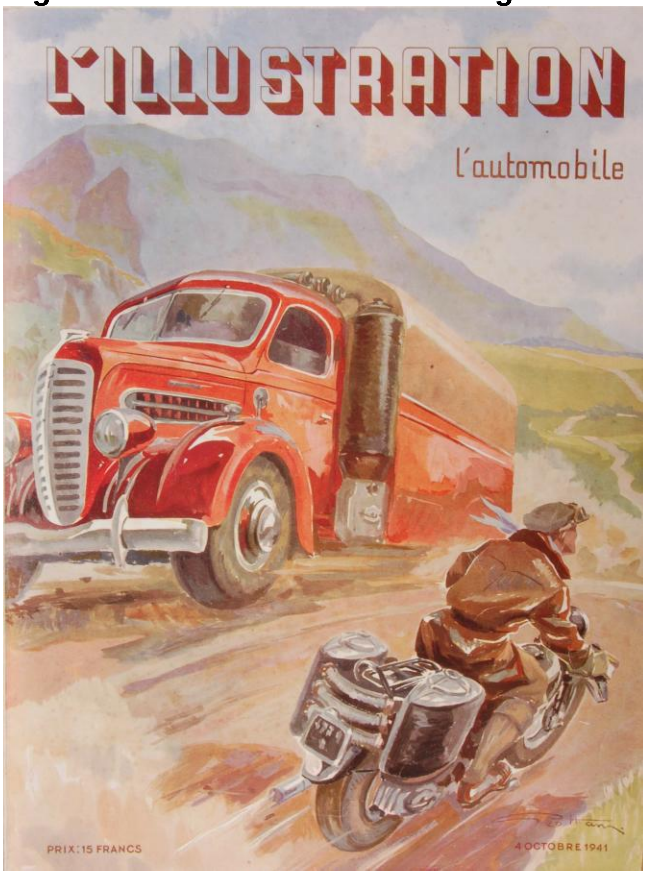
An overview of next-generation of fuels for land transportation

When fuels as versatile as petroleum products are in transports, it is not surprising that several alternative fuels are needed to substitute for different vehicle types and usages. Petroleum products' qualities are their unsurpassed energy and volume density and their ease of handling. Now that we're faced with the prospect of scarcity, global warming and constraints on local pollutants, the transportation sector is required to find alternatives to what has fuelled us for 100 years. Necessity being the mother of invention, several alternative fuels are now emerging. None of them are exactly new technologies (see WW2-era popular science magazine below), but a combination of technical improvements, public acceptance, the establishment of norms, and the deployment of a distribution infrastructure are giving each of these technologies a chance to occupy a niche within road and rail transportation.

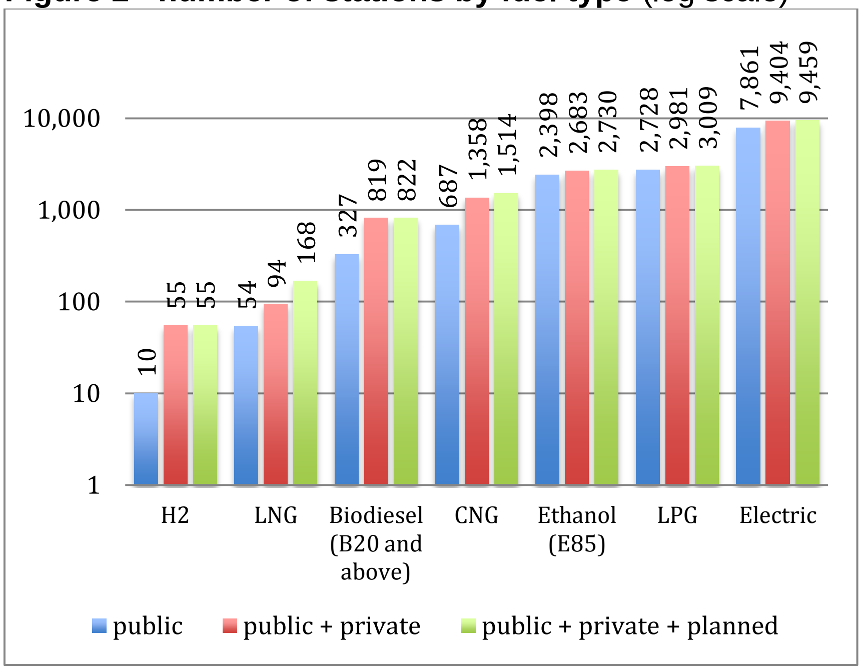
Figure 1 - Alternative fuels during WW2 France



What follows is an overview of each of these new fuels, their characteristics, environmental performance, and cost factors. They share a sparse fueling infrastructure, though some are more affected than others (see figure below). The figures below are to be compared with about 120,000 gasoline / diesel stations in the US. Other considerations to factor in when comparing technological options are:

- the fueling / charging time: it's a matter of minutes for liquid fuels and CNG.[1] For electric vehicles, recharge is best expressed in terms of kilometers per hour of charge.[2] Battery swapping is a way around this issue, but there are vehicle / battery compatibility issues.[3]
- the number of charge cycles: 3000 for latest-generation Lithium batteries for a 10% capacity loss.
- compression or liquefaction energy expenditure: in the case of hydrogen (H2) filling at the up to the 700 bar vehicle standard, the electricity expenditure is a non-negligible 3 kWh/kg,[i] compared to an energy content of 33 kWh/kg. For small-scale LNG plants, there is 5% energy expenditure for liquefaction.

Figure 2 - number of stations by fuel type (log scale)



data source: www.afdc.energy.gov/ accessed on 13/04/2014

LPG

Liquefied Petroleum Gas is a mixture of mainly propane with some butane. For 60% of the supply, it is stripped from associated and dry natural gas, and the remainder is a product of refining. LPG is the most widespread alternative fuel in the automotive sector with more than 23 million vehicles operating worldwide, placing it in 3rd place behind gasoline and diesel.

The success of LPG -or autogas- as an automotive fuel, is explained by the combination of environmental performance and range. Price differentials with the dominant fuels and environmental requirements explain the popularity of LPG in a disparate number of countries.

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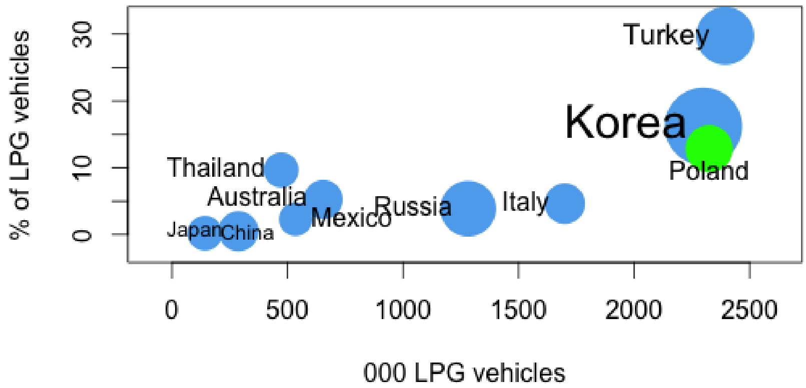
[1] A 60 liter fast fill takes 4 minutes

[2] The Tesla Model S charges half the battery in 20 minutes, or 160 km of range.

[3] As the bankruptcy of car battery rental and recharging network Better Place demonstrates

Figure 3 - LPG vehicles and automotive LPG consumption



Sources: WLPGA (2011) (LPG vehicle numbers), World Bank (overall vehicle numbers), own analysis

Because of the combination of fuel cost savings and range it confers, LPG is popular with taxis in the countries where this fuel is well-established. In Tokyo and Bangkok, almost all taxis run on this fuel. LPG is also well-suited for forklifts because these often have to operate in enclosed environments.

CNG and LNG

Compressed Natural Gas (CNG) and Liquefied Natural Gas (LNG) are the compressed (at the 300 - 350 bar standard) and liquefied (at -162 ^{o}C) forms of methane. In a way, these fuels are a more gaseous extension of LPG motorization, providing greater fuel savings. There is also a cost premium on both the vehicle and the distribution infrastructure. This said, most CNG passenger vehicles are bi-fuel and the shorter natural gas range is not much of a constraint. The table below compares the performance and price of the Audi A3 2014 in its CNG and gasoline variants. The implied kilometric payback starts after about 180 000 km[4]. In an era of declining mileage for passenger cars, the business case is not an obvious one. According to Wood Mackenzie, a consultancy, the mileage of short-haul freight trucks (90 - 150k km/yr) and urban busses (40k km/yr), plus the fact that they may dispose of their own fueling infrastructure makes these vehicles more obvious candidates for CNG motorization.

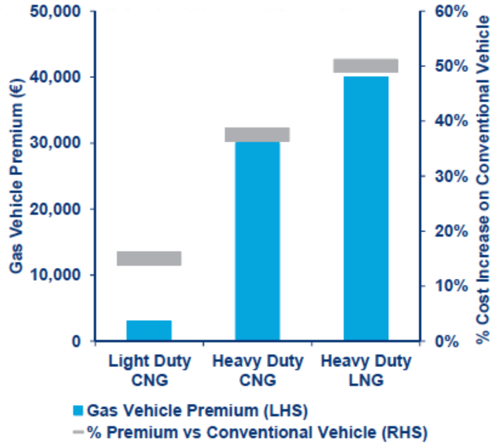
Compared performance of basic and CNG Audi A3 versions	cyldr / cm3	max power	torque (Nm)	1 / 100 km combi	g CO2 / km	range (km)	price (€ incl. VAT)
Audi A3 TFSI manual gasoline	4 / 1.4	77	175	4.9	114	700	21,900
Audi A3 TFSI manual CNG + gasoline	4 / 1.4	81	200	5.3 (3.5 kg)	92 (CNG) 120 (gsln)	400 (CNG) 900 (gsln)	25,900

source: constructor data

[4] Assuming Germany's current gasoline and CNG prices of 1.54 and 1 € / l gasoline or equivalent

Where massive stored energy is important, as with long-haul freight, mining trucks and locomotives, LNG is a feasible alternative to diesel providing a range of 1000 km.

Figure 4 - Gas vehicle premia



Sources: industry sources, Wood Mackenzie analysis

Finally, LPG and NG motorization are less emissive in local pollutants than gasoline / diesel. Under Euro-6 emissions standards, NOx, a lung irritant, will be cut drastically for passenger diesel from 180 mg/km to 80 (it is already at 60 g/km for gasoline). NGVs easily meet this and other local pollutant standards. For greenhouse gasses (GHG), Natural Gas Vehicles (NGV) are about 20% lower than diesel on a tank-to-wheel basis, and they can be as much as GHG-neutral on a well-to-tank basis if the methane is of renewable origin.[5] This is an important consideration for auto manufacturers, whose new fleet average emissions are subject to Euro-6 limits CO2 emissions starting in 2015.

EVs

The performance of electric vehicles is largely determined its battery technology. While traditional acid-lead batteries can reliably deliver the power surge needed to start an engine, they do not contain much energy (30-50 Wh / kg). Lithium batteries provide much better energy density. For the two main electrolyte families, lithium iron phosphate (LiFePO4 or LFP) and metal oxides (NMC, NCA, Cobalt, Manganese), they provide good energy density - 128 and 256 Wh / kg respectively - and reasonable power density - 1000 and 512 W / kg respectively. Lithium-based batteries dominate other types in charging speed and the number of charging cycles with limited capacity loss. Lithium batteries however need a dedicated battery management system to balance the cells and prevent overcharging and to optimize their life span.

[5] Methane can be made from organic matter fermentation, or it can be synthetized from water electrolysis hydrogen using renewable electricity.

Tesla Motors stands out among EV manufacturers in that it now manufactures its own batteries in partnership with Panasonic, allowing it to build Li batteries adapted to automotive needs at a lower cost. While Tesla's original Roadster model used 6830 $LiCoO_2$ or LCO electrolyte cells, the same type that powers our laptops and cameras, the new Tesla Model S uses a $LiNiCoAlO_2$ or NCA electrolyte, packing 60/85 kWh providing a range of 330/420 km. For its 2015 Model S, Tesla plans to use two types of batteries, which the driver can choose depending on the journey's requirements: a classical lithium-ion battery for acceleration and performance, or a newer (and less tested) metal-air battery for range, or a mixture of both.

Fuel Cells. Fuel cells are a device meant to transform a fuel - usually hydrogen - into electrical power. To compare them with the other alternative fuel technologies, hydrogen FC vehicles face the same challenges as natural gas vehicles, but in worse, and the advantages of EVs, but in better. Starting with the challenges, hydrogen is extremely voluminous. One kilogram of H2 contains 120 MJ, versus 43 MJ for gasoline, but it can power a Toyota FCHV SUV passenger car for 110kg.[ii] Fortunately, FC vehicles are extremely efficient with the hydrogen they do carry and their range equals that of gasoline vehicles. HFCVs do need high-power low-energy batteries to smoothen the FC's duty cycle.
Hydrogen in transport faces supply challenges. Most of the hydrogen is consumed in the petrochemical and food industries, and it is produced on site from by methane steam reformation, to reduce logistical costs. Therefore, unlike EVs, CNGVs and LNGVs, hydrogen-FC vehicles cannot tap their fuel off a public grid. The H2 is generally trucked it or sometimes produced from methane.[6] In the future H2 might be made from water electrolysis.[7]
Thus, as with the NGVs and EVs, HFCVs can be powered from renewable sources, if the electricity for the electrolysis is renewable, or if the reformed methane comes from biogas. Audi proposes a payment card to track the methane consumption of its A3 g-tron drivers. It commits to inject into the grid equal amounts of synthetic methane made from renewably produced hydrogen; ironically 95% of the hydrogen produced worldwide is made from methane.

The technologies outlined here promise distinctly lower prices per driven km. In the UK, 60% of the price of gasoline at the pump consists of fuel duty and VAT.[iii] It provided 5.1% of government income in 2010/11. If cars with "fuel" costs of 3.50€/100km as for the Model S start replacing cars with fuel costs of 10€/100km, governments will need to implement distinct automotive electricity taxation schemes to balance their budgets.

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[6] A trailer truck carries 300kg of gaseous H2
[7] The process will need to gain in energy efficiency first. Water electrolysis has an energy efficiency of 65% at best

[i] DOE Hydrogen and Fuel Cells Program Record, Record #: 9013, October 26th, 2009

[ii] Savannah River National Laboratory - STI - 2009 - 00446

[iii] www.racfoundation.org/assets/rac_foundation/content/downloadables/racf_deloitte-uk_fuel_taxation-apr13.pdf