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TITLE:

Natural Gas for Vehicles - drivers behind the success of  
natural gas in transports

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## Natural Gas for Vehicles - drivers behind the success of natural gas in transports

Michael Grossmann - 28 March 2014  
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At a time when, in the West, people drive fewer miles and the number of gasoline and diesel retail stations is on the decrease, Compressed Natural Gas (CNG) is bucking the trend. The original justification for using CNG in transports despite its greater bulk is its low cost, on an energy basis. Oil prices have been largely stable since 2011, but natural gas-powered transportation is continuing its progress on both sides of the Atlantic, largely driven more by environmental considerations. The price differential of CNG-to-gasoline is similar in the US and in Europe on average. Within Europe, this differential is extremely variable from one country to another, and so is the rate of Natural Gas Vehicle (NGV) penetration in each country. Italy has among Europe's most expensive gasoline, and it has the most NGVs in Europe. However, fuel economics are far from being the only factor behind the success of CNG as a fuel. Clean air standards, domestic resource utilization, and in certain developing world countries, fuel subsidy substitution are equally important reasons why CNG has been promoted by governments.

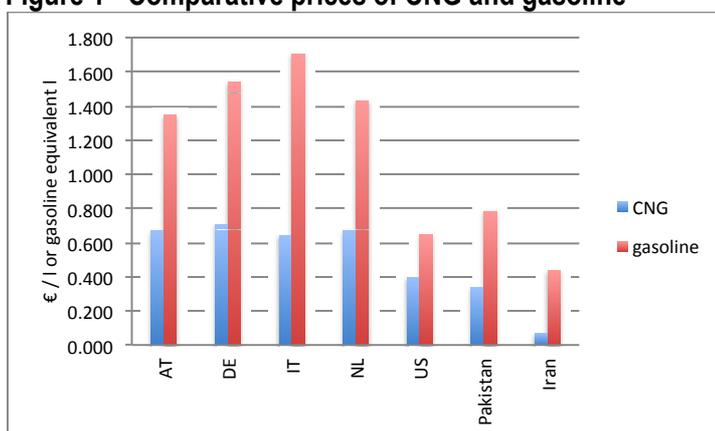
### A NGV refresher

The advantages and drawbacks of natural gas over petroleum products for the transport sector are well established. The table below summarizes the factors in favor and against CNG and Liquefied Natural Gas (LNG), relative to liquid petroleum fuels and alternative fuels, currently and in perspective :

	<b>Pro NGVs</b>	<b>In perspective</b>
<b>Price</b> vs. liquid fuels	The retail price of residential natural gas is far lower, on an energy basis than liquid fuels. See Figure 1 below. The US average price of a gallon is of \$3.40 for gasoline, \$4.00 for diesel (Feb. 2014). A gallon equivalent of gasoline of CNG costs \$2.11, and less than that if refilling on one's own premises. <sup>1</sup>	The price differential will depend on liquid fuel prices. NG retail prices are stable because a significant portion of the cost is in regulated distribution tariffs.
<b>Emissions</b> vs. liquid fuels	Automotive natural gas combustion emits about 25% less CO <sub>2</sub> on a well-to-wheel basis, <sup>2</sup> and produces no CO, volatile organic compounds or fine particles.	NGVs and other "clean vehicles" will increasingly benefit from dedicated lanes / parking during pollution peaks.
<b>Security of supply</b> vs. crude oil	Resources / production ratios for natural gas are of 55-60 years, versus 40-45 years for oil. <sup>3</sup> Because the natural gas resource is better distributed worldwide than oil, it is thought to have better security of supply qualities.	This geo-strategic argument will gain in importance as oil reserves deplete and it is increasingly directed toward applications where it is technically hardest to replace (aviation, petrochemicals).
<b>Fast fill</b> vs. Electric Vehicles	The fast fill of a light CNG vehicle takes under 5'. There is however a penalty to fast fills. The compression heats up the tank and reduces its capacity by about 30%. For an EV, a 20' fast charge powers a vehicle for 100-130 km in the best of cases (DC charging). <sup>4</sup>	Battery technology may improve and battery swap infrastructure may be developed, giving EVs an edge.
	<b>NGV neutral</b>	<b>In perspective</b>
<b>Exiting gas infra-structure</b>	Natural gas already has a number of industrial, commercial and residential applications. As with electricity, it already	The effect of gas demand from NGVs will be negligible in terms of

	has its dedicated distribution network.	transportation & distribution infrastructure.
	<b>Anti NGV</b>	<b>In perspective</b>
<b>Sparse distribution infrastructure vs. liquid fuels</b>	The public distribution infrastructure for vehicles is sparse, compared with liquid fuels. This, and the heat dissipation and volume loss from quick fills, explains why fleet vehicles have their own time fill stations. Part of the reason is that CNG stations are much costlier than liquid fuel ones because of the gas needs to be dried, filtered, compressed and stored. The equipment cost of a quick fill CNG station is \$800k, versus up to \$200k for a gasoline station. <sup>i</sup>	With economies of scale and experience, the cost of CNG stations can be expected to fall. Then, there is the option of refilling one one's own premises.
<b>Energy density of CNG vs. liquid fuels</b>	Compared with regular vehicles, CNG vehicles are hampered by the bulk and weight of their tank. On light passenger vehicles, half the trunk can be taken by the fuel tank. This is less of an issue for heavier vehicles.	As manufacturers propose more OEM CNG vehicles, the need for CNG conversions will diminish.

**Figure 1 - Comparative prices of CNG and gasoline**



sources: CNG Europe, US DoE, paktbiz.com, Zawya  
note: AT - Austria, DE - Germany, IT - Italy, NL - Netherlands

Natural gas is emerging as an alternative to gasoline and diesel, alongside with Electric Vehicles (EVs), hybrids EVs and hydrogen fuel cells, collectively known as Alternative Fuels. In transportation as in power generation, the introduction of natural gas was initially driven by economics. In doing so, it is displacing a dirtier incumbent fuel, petroleum products for transportation, coal for power generation.

#### The pricing of CNG versus traditional fuels

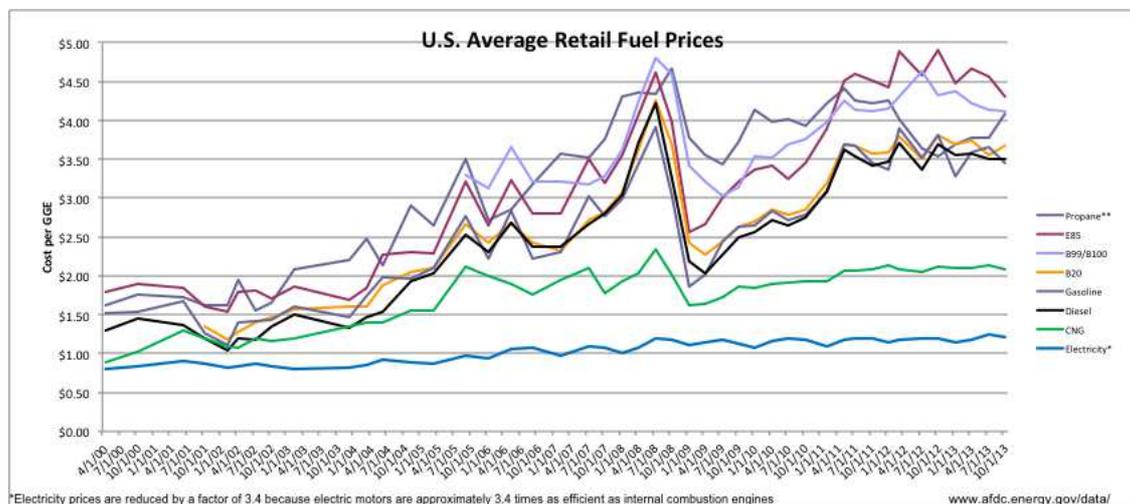
The price differential of CNG to gasoline is comparable on both sides of the Atlantic. In the US, CNG costs currently \$2.11 per gallon in gasoline equivalence (or **0.40 € / l**). This is 62% of the gasoline price at the pump. In the EU, the CNG prices range is of 1.00 - 1.20 € / kg,<sup>5</sup> or **0.66 - 0.79 € / l** of gasoline equivalent. In the EU countries with a significant CNG infrastructure, the CNG price as a percentage of E95 gasoline ranges from 38% in Italy, to 50% in Austria. Unsurprisingly, Italy is by far the country with the greatest CNG penetration in the EU. So, while natural gas prices

<sup>i</sup> For the CNG station, includes: NG dryer, compressor, 3 pressure vessels, 1 two-hose fast-fill dispenser. Components: \$500k, Installation: \$300k. For gasoline or diesel: storage tank, pump, dispenser and installation (source NREL 42390): up to \$200k.

are lower in the US than in Europe, so are gasoline and diesel prices. The cost discount of CNG to gasoline is less in the US than in European countries with a developed CNG infrastructure. This may explain CNG's historically lower penetration in the US. Going forward, two factors will boost the fortunes of CNG on both sides of the Atlantic, but perhaps more so in the US:

1) Price increases at the pump : following the financial crash of 2008 and economic recession, a trough in gasoline prices was reached in 2009 Q1. Prices have crept back by about 75% in the US, and 40%, to reach a plateau in 2011 Q3. In contrast neither the shale gas revolution in the US, nor the economic recovery, seem to have had a noticeable effect on CNG prices at the pump (comparable time series data is available for Europe). The net effect is a widening price differential of CNG to gasoline / diesel.

2) A sense of natural gas abundance : confidence in the fuel's long-term availability will encourage investment in distribution infrastructure, including natural gas distribution lines to fueling stations. Gas lines have an accounting life of 15-20 years and an economic life of over 50 years.



Extending the distribution network has two positive effects for potential NGV owners:

- lower entry barrier : more public CNG refill stations means fewer NGV owners will need to buy in their own refueling pump. For a LDV, a time-fill pump costs about \$5000. It also means NGV ownership will not be limited homeowners / businesses with garage space.
- less range anxiety for CNG-only vehicle owners. It also gives confidence to opt for CNG-only engines (most NGVs are dual-fuel). CNG-only engines are optimized in the compression ratio are more efficient than bi-fuel CNG engines. Furthermore, clean vehicle incentives in certain states extend usage benefits to dedicated CNG vehicles, such as the use of high occupancy vehicle highway lanes, and dedicated parking spots.

#### Where CNG makes sense

For a passenger car buyer, the decision to opt for CNG motorization is not a straightforward one. In the US, the 2014 Honda Civic CNG costs \$2000 more than its Hybrid equivalent, after federal tax breaks. Its 250 bar tank delivers an autonomy of 350 km. This is less than its gasoline equivalent, but far more than any existing pure electric vehicle (EV) on the market now. The CNG Honda manages 27 City / 38 Highway miles per gallon (MPG) of equivalent gasoline gallons. This is respectable, but it is less than the 44 / 47 MPG of the Hybrid Civic. At current fuel prices, the CNG

model would need to be driven on 120 000 miles of highway to make up for the price premium. The payback is quicker if one refuels on one's own premises, or if one takes into account fuel credits provided by manufacturers. For delivery vans, utility trucks and long-haul trucks, the "payback mileage" offsetting the higher investment is expected to be reached sooner than for private vehicles.

Average driven distance per vehicle is another factor that sets the US and Europe apart. In the US a private vehicle is driven more than 21 000 km / year, versus 8 200 km / year in the UK and 12 000 km / year in Germany.<sup>6</sup> So, although US automobilists pay on average less per mile driven, they are more directly affected, as they drive longer distances than their European counterparts. The trans-Atlantic fuel price difference and average driving distance just about cancel out in generating an incentive to invest in fuel economy in road transports.

Driving -measured per licensed person, household or vehicle- has peaked in the mid-noughties on both sides of the Atlantic. Road transport consumption in Europe's top 7 economies is down 9% in the 5 years to 2012.<sup>7</sup> In the US, it is down 9% in the 5 years to 2011.<sup>8</sup> While this trend was amplified by the recession, it is also the result of long-term lifestyle shifts such as telecommuting, car-sharing, online shopping, as well as socio-economic factors such as urbanization, durably higher oil prices and higher fixed costs of vehicle ownership (insurance, parking and getting a driving permit). This shift is probably a durable one, and this would make the cost premium of NGVs and EVs harder to justify economically for vehicles driven less over their lifetime. Utility vehicles, busses and fleet vehicles will thus continue to be the main drivers for the gasification in transports.<sup>9</sup>

#### The effect of emission standards

One would expect that energy efficiency standards and emission limits would generally favor CNG vehicles over gasoline and diesel ones. After all, CNG offers a favorable (i.e. high) hydrogen to carbon (H/C) ratio that presents the potential of 20-30% tailpipe reduction in CO<sub>2</sub> emissions, relative to gasoline for passenger cars. If one considers the well-to-wheel cycle, the reduction in greenhouse gas (GHG) relative to petrol engines is only 6-11%, due to methane leaks during production.<sup>10</sup> In the EU, cars manufacturers are obliged to ensure that their new car fleet does not emit more than an average of 130 grams of CO<sub>2</sub> per kilometer (g CO<sub>2</sub>/km) by 2015 and 95g by 2020. This compares with an average of almost 160g in 2007 and 135.7g in 2011. Standards for heavier vehicles are more permissive. In the US emission standards for new vehicle fleets are slightly less stringent. They are expected to result in levels of 163 grams CO<sub>2</sub> /mile (101 g/km) in model year 2025. This is equivalent to 54.5 miles per gallon (mpg) if achieved exclusively through fuel economy improvements. Today's CNG engines combined with hybrid technology could probably meet these future GHG emission standards. Introducing more CNG models alongside HEVs and EVs will allow car manufacturers to meet CO<sub>2</sub> emission standards.

Emission standards also cover regional pollutants such as oxides of nitrogen (NO<sub>x</sub>), oxides of sulfur (SO<sub>x</sub>), and local pollutants such as particulate matter (PM), carbon monoxide (CO), and various volatile organic compounds (VOCs). In the US, upcoming Tier 3 standards starting 2017 emphasize a reduction in SO<sub>x</sub> emissions, an area in which existing CNG excel.<sup>11</sup> Tier 3 standards have sub-standards applying to each motor type, and the ones for CNG engines are not finalized at this time. However, it is clear that CNG vehicles will easily meet the general sulfur emission limits. In the EU, the passage from Euro-5 to -6, emission standards, expected for September 2014, emphasizes a reduction in NO<sub>x</sub>, a pollutant more associated with current diesel engines. The

upcoming NOx standards require adaptation of the combustion system as well as extensive adjustments to the exhaust gas after-treatment system.

Under current EU standards, maintain NOx emission levels within standards by applying lean-burn combustion (i.e. with air input in excess of stoichiometric burn) concepts without the use of exhaust gas after-treatment systems. With the new EURO-6 standards, CNG engine compliance will become more complicated because of the limits on emissions of NOx and methane.<sup>ii</sup> The concurrent Tier-3 US standards, with their emphasis on SOx limits, give CNG engines a head-start over other gasoline and diesel. On all other pollutant criteria - fine particulates, CO, VOCs, natural gas comes out ahead of liquid fuels, provided it is properly treated.

#### The time of fiscal reckoning will come

Fuel taxes are an important source of revenue for state budgets in the US and the EU. In the US, the federal take is US¢18.3 / 24.3 per gallon for gasoline / diesel or 13% of the price at the pump.<sup>12</sup> On top of this are state and local taxes, bringing the percentage to 28%. Revenue from fuel taxes represents only 1.3% of federal revenue. This tax is applied to finance interstate highways, among other things. In Europe, fuel taxes a far more significant source of state revenue than in the US. Tax rates differ between countries, but EU-wide threshold levels has been agreed for diesel at 0.34€ and 0.33€ / l for gasoline and diesel respectively,<sup>iii</sup> and some EU states apply up to double these amounts. Automotive NG is taxed lightly in the countries where it is available. In Italy, CNG is taxed 239 and 179 times less, relative to gasoline and diesel respectively, on an energy basis. In Germany, the ratios are 5.2 and 3.4, while in the US alternative fuels have a \$0.50 / gal. fuel tax credit.<sup>13</sup> To be fair, CNG should be taxed more lightly than liquid fuels on an energy basis because it is more bulky and expensive to distribute. Natural gas and electricity are undifferentiated energies with many applications.<sup>iv</sup> Applying a specific tax on refueling at home or on private premises will be technically challenging, and perhaps open to legal challenges.

#### Technological options within the transition away from oil in transports

At times of innovation, standards struggle to keep up with industry practice. Standards are particularly important in network industries to ensure inter-operability, safety and compliance, and economies of scale. Forty ISO standards cover CNG and LNG as an automotive fuel. NGV1 and NGV2 are de-facto world standards for the fuelling interface, for light and heavy vehicles respectively. Automotive natural gas can be stored either in compressed or liquefied form. Compressed natural gas (CNG) technology is by far and away the most widespread globally, but the automotive LNG technology is developing as an alternative both in the US and Europe. Both technologies have their advantages and their drawbacks. Motor LNG has 85% (60%, if you include the insulated tank<sup>14</sup>) of the energy density of diesel, its nearest competitor, and it is refilled conveniently as a liquid. It enjoys a \$1.20 - \$1.35 / gal (¢ 32-36 / l) cost advantage over diesel.<sup>15</sup> Being a gas cooled at minus 162 °C, it has a "use it or lose it" characteristic; left unused it boils off and should be vented. Both NGV technologies have natural niches. While CNG vehicles tend to be used by lighter vehicles running scheduled routes out of a depot, LNG propulsion is better suited

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<sup>ii</sup> With lean-burning of natural gas, there is a trade-off between NOx and CH4 emissions from uncombusted fuel. The Greenhouse Gas Potential (GWP) of methane is 21 times that of CO2.

<sup>iii</sup> expressed in \$ / gal for comparison with US levels., EU threshold fuel taxes are at 1.80 for gasoline and 1.66 for diesel

<sup>iv</sup> Natural gas for NGVs needs to be of higher purity than network gas. Home refilling may void the guarantee of the Honda Civic, but in practice, network gas is suitable.

for applications where range and power are required, such as long-haul trucks, locomotives, or ships.

The rationale for LNG is economics for trucks and railway, but it is more likely to be environmental for shipping. In the case of trucking, an 18-wheeler tractor cost \$170k - 200k, versus \$100k for its diesel equivalent.<sup>16</sup> The cost premium is due to a largely manual assembly process due to small production volumes. In rail transportation, Russia has built the world's first LNG gas turbine-powered locomotive, to make use of its abundant gas reserves.<sup>17</sup> Until recently, maritime shipping was immune from emission controls in high seas. It could burn inexpensive (and untaxed) but highly polluting bunker fuel. LNG is only marginally less expensive, but its main attraction is environmental. The International Maritime Organization has a mandate to reduce to 0.5% the sulfur content of bunker fuel on a global basis by 2020. The issue for ship owners and operators is how to find alternatives to economically meet the SO<sub>x</sub> and NO<sub>x</sub> emissions imposed by International Convention for the Prevention of Pollution from Ships (MARPOL) Annex VI. The options to meet these emission limits are expensive Ultra Low Sulfur Fuel Oil, and LNG. Ports are often blamed by the cities they serve for soiling the local air with fine particulate matter. Auxiliary power units on berthing ships and the tractor trucks are the main sources of emissions. To address this problem, the San Diego Port Authority requires all trucks entering the port to run on natural gas. Local air regulations also mean ships at berth will either need to be cold-ironed, or they will generate their power from LNG.

Natural gas also can compete directly with diesel through Gas-To-Liquid technology. There is nothing new to GTL. The Fischer-Tropsch process has been discovered in the twenties in Germany and used a petroleum-starved Germany in the last years of WWII. This technology has been much improved on over the years through better catalysts and operational experience in South Africa and in gas-rich Qatar and Malaysia.<sup>v</sup> The diesel yielded from F-T GTL is of high quality (<5 ppm sulfur) and it can be blended to lower-quality diesel to meet EU or US specifications. However, despite the sustained deficit of high-quality diesel in Europe and lower gas feedstock prices, GTL projects are not economically justified under current market conditions.<sup>vi18</sup>

Finally, Natural Gas can also be an input for ethanol production. Unfortunately, renewable energy policies worldwide in their present form mandate plant-based ethanol as a fuel additive.<sup>19</sup>

#### Political vision required

NGVs have real economical, environmental benefits and, in countries with abundant natural gas resources, they also provide supply security. For countries where automotive fuels are subsidized, substitution for natural gas reduces the strain on government budgets. This and urban air quality are the rationale for state support for CNG in gas-rich Iran, but also in gas-poor India. While EVs have the same environmental and fuel-substitution benefits, NGVs do have distinct usability advantages in terms of autonomy and speed of refill, at the current state of technology. Economics alone will not bring a wholesale substitution of NGVs for traditional vehicles. If economics ruled alone, homes in the developed world would be heated with natural gas or wood pellets where possible, not with electricity. As it stands, NGVs account for about 1% of world natural gas demand.<sup>20</sup> Seen from the perspective of wholesale gas suppliers, this is a minuscule market when

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<sup>v</sup> The original large-scale GTL was pioneered by Sasol in South-Africa using coal and coalbed methane as feedstocks. Other large projects are Shell's project at Bintulu, Malaysia, and the QatarGas / Sasol's project at Ras Laffan, Qatar.

<sup>vi</sup> The US Energy Information Agency suggests that large-scale GTL plants require an oil price above \$110/bbl and natural gas feedstock prices below \$4/MMBTU

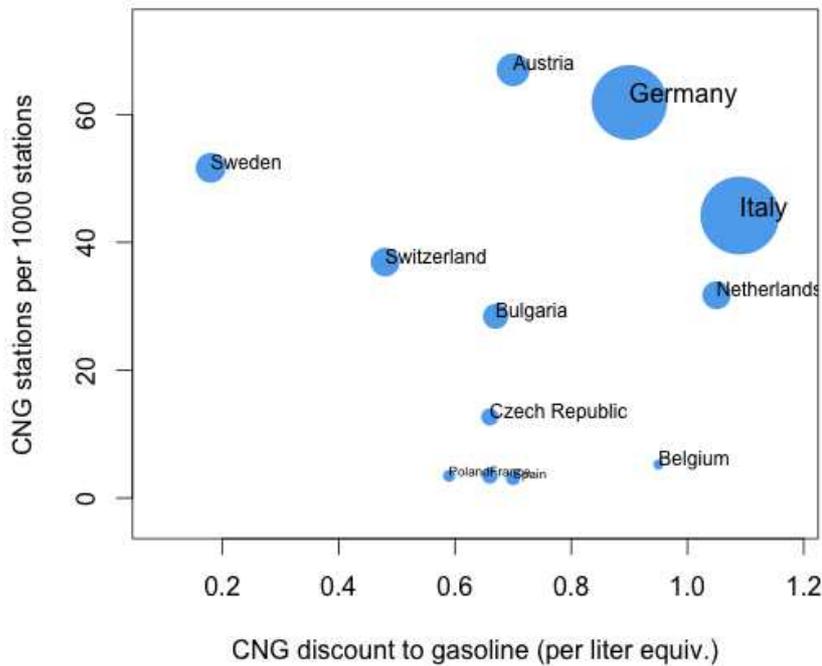
compared with the heating market and industrial applications. Explicit policies in favor of NGV are needed, and it is for transportation and infrastructure authorities to take the lead. Unlike EVs, this needn't take the form of vehicle purchase price subsidies. In fact, policies in favor of alternative technology vehicles may have adverse effect. In the US, bi-fuel CNG/gasoline vehicles receive a lesser tax-credit than solely CNG vehicles and most state-level incentives are for CNG-only vehicles.<sup>21</sup> This discourages potential buyers of CNG vehicles who are currently not within range of refill stations. Because of confusion with LPG, bans on underground parking can also unfairly apply to CNG NGVs. The main barrier to NGVs entering the mainstream in most countries is the lack of refueling infrastructure.

The US has 118 000 refueling petrol stations,<sup>22</sup> but about 1000 natural gas stations in operation, half of which are open to the public.<sup>23</sup> Europe has 3200 stations, but penetration rates in Europe differ widely: the UK, Europe's largest gas market and a former exporter, hardly has any CNG stations. Germany has 930 refill stations, while Italy, which has no domestic gas resources, easily leads Europe with 1200 CNG stations. At the end of 2013, the country had 750 000 CNG-powered passenger vehicles on the road, or 2.3% of the cars in circulation.<sup>24</sup>

#### Key success factors

Navigant Research expects NGVs will grow from 2.3 million vehicles in 2014 to 3.8 million in 2023.<sup>25</sup> Making a quantitative forecast is difficult, as it depends not only on the economics of CNG versus incumbent fuels, but also on government fuel taxation, emissions regulation, zonal restrictions for CNG pumps, and entrepreneurial decisions from fuel retailers and vehicle manufacturers. Visualizing the state of CNG penetration by country, it is clear that many such non-economic factors are at play. The graph below shows the number of CNG stations per 1000 refueling stations, as a function of the retail price discount of CNG (expressed in gasoline liter equivalent) to gasoline.<sup>26</sup> The circle size relates to the country's number stations. The sample covers EU countries with at least 10 CNG stations. Paradoxically absent from this sample are two countries with sizable gas resources and networks, the UK and Norway.

**Figure 2 - CNG station ratio vs. CNG price discount to gas**



As the summary table of countries with high NGV penetration rates show, the success factors for NGV are very much country-dependent.

**Preponderance of NGVs in countries with high NG usage in transports**

Country	Nb.stations	# NGVs	NGVs' share	Possible reason behind CNG market share
Armenia	345	244 000	58%	Embargo from Azerbaijan Inexpensive gas from Russia Well-developed gas distribution network
Iran	2000	3 500 000	38%	Substitutes subsidies on petroleum products US-led embargo Inexpensive + abundant NG Well-developed gas distribution network
Pakistan	3000	2 790 000	22%	Petroleum product import substitution Well-developed gas distribution network
Argentina	1932	2 345 148	19%	Substitutes subsidies on petroleum products Inexpensive + abundant NG
India	900	1 800 000	13%	Substitutes subsidies on petroleum products
Ukraine	324	388 000	6%	Heritage of Soviet Central planning / fuel shortage Well-developed gas distribution network
Italy	1200	823 000	2%	One of Europe's highest gasoline retail price / low CNG price

Data: NGV Journal, World Bank, own analysis

Petrol-driven engines have price and autonomy going for them, and given the state of today's technological alternatives and resources, this makes them irreplaceable for many personal and

commercial uses. A number of conditions need to stack up for alternatives such as CNG engines to reach their potential share of the transportation market.

- **The distribution infrastructure must be developed.** Natural gas entrepreneurs should see in NGVs a niche that deserves to be developed, and distribution utilities should see in CNG a new market for natural gas. Some gas distribution companies in the US provide gas credit to Honda Civic CNG buyers.<sup>27</sup> New entrants such as Clean Energy Fuels Corp in the US are developing CNG and LNG networks. Since 2009, there has been an 11% annual increase in the number of public CNG stations in the US.<sup>28</sup> Of the oil majors, only Shell is betting on natural gas as an automotive fuel in the US. It will build up to 100 LNG refill stations for heavy-duty vehicles across the US.<sup>29</sup> Currently, the US has only 49 LNG refill stations.
- **Manufacturers should add more CNG vehicles** to their catalog. Until 2012, Honda was the only manufacturer proposing a passenger car to the American public, and only in 4 states.<sup>30</sup> The Civic CNG is now available throughout the US, but it remains the only dedicated CNG LDV. Other bi-fuel vehicles on offer in the US are all bi-fuel vehicles. GM offers 2 pick-up trucks and a van, and Ford, 2 pick-ups.<sup>vii</sup> In Europe, 22 CNG bi-fuel versions of passenger cars are on offer, including 6 from Fiat, 8 from VW, and 3 from GM through its Opel subsidiary. The cost differential for OEM vehicles is an acceptable 20% excluding subsidies, 10% after subsidies, and in OEM vehicles the fuel tanks are optimally placed to reduce the capacity loss. A wider choice of OEM vehicles is needed for NGVs to enter the mainstream.
- **CNG and LNG vehicles should be given full credit for their environmental qualities.** The devil lies in the details. CNG engines fare worse than others on emissions of methane, a powerful GHG. This, however can be addressed by catalytic conversions. On all other environmental criteria, natural gas dominates gasoline and diesel as an automotive fuel. Technological advances in internal combustion engines can benefit CNG vehicles as well (lighter materials, regenerative braking, exhaust heat recovery). LNG will be the sole contestant to fuel applications such as long-haul transport and sector-specific applications such as marine, mining, drilling and rail. In heavy duty applications now dominated by diesel, technological advances CNG/diesel dual fuel<sup>viii</sup> and LNG will also make inroads.

Developments in Lithium-ion battery technology are potential game-changer in the passenger car segment of AFVs. If the latest Tesla Motors' 2013 top-of-the-range Model S represents a trend, EVs could equal CNG passenger cars on range. The Silicon Valley manufacturer claims its range reaches an impressive 300 mi. / 480 km under standard cycle conditions, and 450 mi. / 720 km under ideal conditions.<sup>ix</sup> The Nissan Leaf by comparison manages a range of 120 km. EVs are however a newer technology, for better or for worse. In the light vehicle category, the EV-CNG contest, no technology has currently a clear advantage :

- EV recharge times are not compatible with long trips. One hour of charging provides energy for 92km on the Tesla Model S. In comparison, a CNG tank can take 75 liters of gasoline equivalent in 5 minutes.
- Electricity is ubiquitous, whereas natural gas is not. In sparsely populated rural areas, it is not economical to extend the natural gas distribution network.

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<sup>vii</sup> from GM: Chevrolet Silverado 2500 and GMC Sierra 2500 HD, Dodge Ram 2500 CNG, and Cargo vans; from Ford, the F250 and F350

<sup>viii</sup> for CNG/diesel, see Westport's High Pressure Direct Injection technology to substitute 60% of diesel with NG on average [www.westport.com/news/2014/westport-demonstrates-proprietary-gas-enhanced-methane-diesel-technology-westport-gemdi](http://www.westport.com/news/2014/westport-demonstrates-proprietary-gas-enhanced-methane-diesel-technology-westport-gemdi).

<sup>ix</sup> for EVs ideal conditions mean keeping the batteries neither too hot nor too cold, using neither the A/C nor the heater, and driving at 30-40 km/h

- In the future, the cost advantage that NGVs technology enjoys over EVs can be expected to shrink when battery cells designed exclusively for EVs are mass-produced.<sup>x</sup> At present however, NGV production can be scaled up in a way that EV production cannot.
- For shipping, rail and mining applications, tighter environmental regulation may impose LNG by default. It is the only fuel that is both clean and economical for high-power applications. Hydrogen fuel cells (FC) vehicles can provide gasoline-like autonomy, but challenges in distributing hydrogen and the expense of FC power generators prevent this technology from going mainstream.

### Toward a more complex transportation ecosystem

Looking further out into a future where alternative fuel vehicles were to become widespread, these technologies will need to gain acceptance on their environmental, and unsubsidized economic merits alone. On the environmental criteria, technology-specific rebates, often implicitly aimed at favoring national manufacturers, will lose their justification as "alternative" motorization becomes mainstream. The nature of the environmental regulations affecting transports will play a direct role in shaping the motoring landscape. If the emphasis on greenhouse gas emissions persists, NGVs will not be much advantaged compared with high-efficiency hybrid vehicles. If however regional and local pollutants are also taken into account, then NGVs will dominate even hybrid vehicles on all criteria environmental, save perhaps NOx. On economic criteria, natural gas and electricity for transportation will lose their tax rebate relative to liquid fuels. Extending excise fuel taxes to home refueling will be challenging and potentially intrusive.

The emergence of alternatives fuels vehicles mean that the duopoly of gasoline and diesel will be broken to make place for a more complex oligopoly of fuels. A break-through in battery capacity, recharge speed, or hydrogen storage technology could simplify the technological landscape again in a more distant future, but in the meantime, the world will live in an uncertain state where several technologies will become entrenched in some niches, and compete in others. This is not unlike the situation at the turn of the XX<sup>th</sup> century, when the challengers to horse-drawn carts were petrol engines, electric cars and steam cars.

### SOURCES

<sup>1</sup> [www.eia.gov/petroleum/gasdiesel/](http://www.eia.gov/petroleum/gasdiesel/) and [www.cngnow.com/](http://www.cngnow.com/)

<sup>2</sup> The Contribution of Natural Gas Vehicles to Sustainable Transport, Michael Nijboer, IEA, 2010

<sup>3</sup> Resources to Reserves, IEA, June 2013

<sup>4</sup> US Department of Energy, Alternative Fuels Data Center

<sup>5</sup> <http://cngeurope.com> . Note that Sweden's CNG price is an outlier, at 2.11€ / l gasoline equivalent

<sup>6</sup> US Department of Transportation, Federal Highway Administration online database; UK National Travel Survey: 2012, revised 19 Sept. 2013 ; [www.focus.de](http://www.focus.de)

<sup>7</sup> Eurostat table tsdtr250

<sup>8</sup> EIA [www.eia.gov/forecasts/aeo/MT\\_transportationdemand.cfm](http://www.eia.gov/forecasts/aeo/MT_transportationdemand.cfm)

<sup>9</sup> [www.eia.gov/forecasts/aeo/MT\\_transportationdemand.cfm](http://www.eia.gov/forecasts/aeo/MT_transportationdemand.cfm)

<sup>10</sup> Full fuel cycle assessment: well-t-wheels energy inputs, emissions, and water impacts; prepared by TIAX LLC for California Energy Commission, June 2007

<sup>11</sup> [www.epa.gov/otaq/tier3.htm](http://www.epa.gov/otaq/tier3.htm)

<sup>12</sup> [www.transportation-finance.org/funding\\_financing/funding/federal\\_funding/motor\\_fuel\\_taxes.aspx](http://www.transportation-finance.org/funding_financing/funding/federal_funding/motor_fuel_taxes.aspx)

<sup>x</sup> Tesla Motors announced in February 2014 its plans to build its "Gigafactory" in Fremont, California to ramp up its battery production capacity from 35 000 vehicles / year to 500 000.

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- <sup>13</sup> [www.afdc.energy.gov/fuels/laws/3253/US](http://www.afdc.energy.gov/fuels/laws/3253/US)
- <sup>14</sup> [www.cleanfuelsconsulting.org](http://www.cleanfuelsconsulting.org)
- <sup>15</sup> NGV USA – Industry Leaders’ Thoughts, FC Gas Intelligence, February 2014
- <sup>16</sup> <http://online.wsj.com/news/articles/SB10001424052748704740604576301550341227910>
- <sup>17</sup> [www.railjournal.com/index.php/locomotives/russia-develops-lng-traction.html](http://www.railjournal.com/index.php/locomotives/russia-develops-lng-traction.html)
- <sup>18</sup> Gas to Liquids, a viable alternative to oil-derived transport fuels? Craig Brown, Oxford Energy Institute, May 2013
- <sup>19</sup> <http://www.forbes.com/sites/christopherhelman/2012/04/03/ethanol-minus-the-corn-it-could-fuel-america-if-it-werent-illegal/>
- <sup>20</sup> The Contribution of Natural Gas Vehicles to Sustainable Transport, Michael Nijboer, IEA, 2010
- <sup>21</sup> [www.cngnow.com/vehicles/financial-incentives/Pages/information.aspx](http://www.cngnow.com/vehicles/financial-incentives/Pages/information.aspx) and [www.westport.com/products/automotive/bi-fuel-cng/tax-credits-and-incentives/](http://www.westport.com/products/automotive/bi-fuel-cng/tax-credits-and-incentives/)
- <sup>22</sup> The Economist, May 27th 2013
- <sup>23</sup> Natural Gas Vehicle Market Whitepaper USA 2013-2014, FC Gas Intelligence
- <sup>24</sup> [www.omniauto.it/magazine/24416/auto-a-metano-29-nel-2013](http://www.omniauto.it/magazine/24416/auto-a-metano-29-nel-2013)
- <sup>25</sup> [www.navigantresearch.com/research/light-duty-natural-gas-vehicles](http://www.navigantresearch.com/research/light-duty-natural-gas-vehicles)
- <sup>26</sup> sources: CNG station numbers and CNG prices: [www.metanoauto.com](http://www.metanoauto.com); regular filling stations: 2012 Europa annual report; gasoline prices: [www.fuel-prices-europe.info](http://www.fuel-prices-europe.info) ; exchange rates match the month of the price data
- <sup>27</sup> [www.oklahomanaturalgas.com/saveenergyandmoney/naturalgasvehicles/cngrebateprogram.aspx](http://www.oklahomanaturalgas.com/saveenergyandmoney/naturalgasvehicles/cngrebateprogram.aspx)
- <sup>28</sup> <http://anga.us/blog/2013/10/23/natural-gas-vehicles-fueling-stations-becoming-increasingly-available-to-public>
- <sup>29</sup> [www.shell.us/aboutshell/us-media-center/news-and-press-releases/2013/04152013-lng-travel-centers.html](http://www.shell.us/aboutshell/us-media-center/news-and-press-releases/2013/04152013-lng-travel-centers.html)
- <sup>30</sup> [www.autotrader.com/research/article/car-reviews/162700/2012-honda-civic-natural-gas-new-car-review.jsp](http://www.autotrader.com/research/article/car-reviews/162700/2012-honda-civic-natural-gas-new-car-review.jsp)