



ENERGY 2020: TRUCKS TRAINS & AUTOMOBILES

Start Your Natural Gas Engines!

Citi GPS: Global Perspectives & Solutions

June 2013



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ENERGY 2020: TRUCKS, TRAINS & AUTOMOBILES

Start Your Natural Gas Engines!

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Four new trends, each building momentum and reinforcing one another, virtually guarantee that natural gas will make inroads into petroleum's monopoly hold of the transportation fuel market. What's more these trends are somewhat independent of still other new factors that also challenge the role of petroleum in global vehicle fleets and the growth rate of oil demand. What's unclear is the pace of growth of natural gas and the extent of the inroads that can be made.

The four base trends fostering the natural gas challenge are: 1) the accelerating growth rate of natural gas availability globally, with newly booked gas reserve bookings now consistently about double new oil reserves; 2) the breaking of the traditional link between wellhead oil and gas prices – especially in North America – and the overwhelming economic incentives to develop mechanisms to change the link breakage into a cost advantage in the transportation fuel market; 3) the ability of governments, especially in emerging markets with abundant gas resources, to cap natural gas prices at levels that allow compressed natural gas (CNG) and perhaps liquefied natural gas (LNG) vehicles to be more attractive to vehicle owners; and 4) the popular and growing concerns about environmental damage associated with petroleum product use, leading to tightening specifications of petroleum products that open the door for natural gas (via CNG or LNG) to play a growing role in the marine transportation, heavy duty truck and rail transport markets.

These trends are building momentum and mutually reinforcing one another at the same time that new engine and battery technologies are emerging that rely on non-hydrocarbon propellants, including electricity, both as supplements to gasoline and diesel and as fuel sources that can supplant them. And, coinciding with all of these factors is a different monkey wrench – massive improvements in automobile and truck fuel efficiencies, which while reducing the pace of petroleum product demand growth, can also limit the attraction and pace of development of natural gas use in the transport fuel market.

Equally significant is the impact on the oil market. After decades of robust growth in oil demand, the broad consensus in the oil industry and the analytic community is that oil demand will continue its inexorable rise through to 2030.

This consensus in turn underpins the belief that oil prices will have to stay high versus historical norms to bring forth enough supply to meet this ever-rising demand. The only matters seemingly up for debate are how fast oil demand will grow and how high prices will need to be to sustain supply growth. Several developments in fact give reason to question the consensus and raise the possibility that the tipping point for oil demand may come much sooner than the markets are expecting.


Looking across the various sectors for which there are clear opportunities for natural gas to substitute for oil – specifically bunker fuel for ships, natural gas vehicles (NGVs) replacing primarily gasoline-powered light duty vehicles (LDVs), heavy duty trucks both in and ex-US, power generation, petrochemicals and various industrial processes – we model the progressive substitution using fairly conservative assumptions and the resulting impact on oil demand growth, which comes in at a formidable 3.5-mb/d by 2020. Taken together, the improvement in global fleet efficiency and the substitution of natural gas for oil could be enough to put in a plateau for global oil demand by the end of this decade.


Oil to Natural Gas Switching by the Numbers

■ PROJECTED GAS DEMAND FOR TRANSPORTATION (BCF/D)

■ PROJECTED OIL DEMAND DISPLACED (MB/D)

ON-ROAD VEHICLES		2015		2020		2025		2030		2040	
	US	0.2	0.0	1.8	0.3	4.5	0.8	6.7	1.2	12.3	2.1
	EU	0.3	0.0	0.5	0.1	0.7	0.1	0.8	0.1	1.1	0.2
	Asia	3.8	0.6	6.0	0.9	8.1	1.2	10.1	1.5	14.2	2.1
	South America	1.2	0.2	1.4	0.2	1.6	0.2	1.8	0.3	2.2	0.3

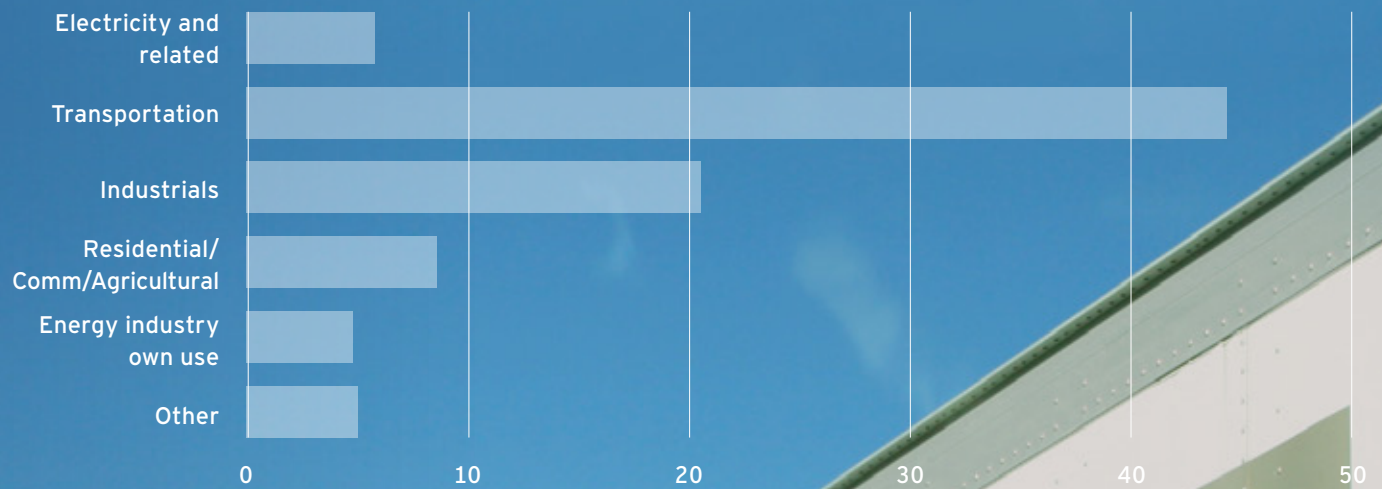
INTERNATIONAL MARINE		2015		2020		2025		2030		2040	
		0.0	0.0	0.1	0.0	1.1	0.1	1.7	0.2	4.4	0.5

OTHER US (RAIL & MARINE)		2015		2020		2025		2030		2040	
		0.1	0.0	0.4	0.1	0.9	0.1	0.9	0.2	1.0	0.2

TOTAL		2015		2020		2025		2030		2040	
		5.6	0.8	10.2	1.6	16.9	2.5	22.0	3.5	35.2	5.4

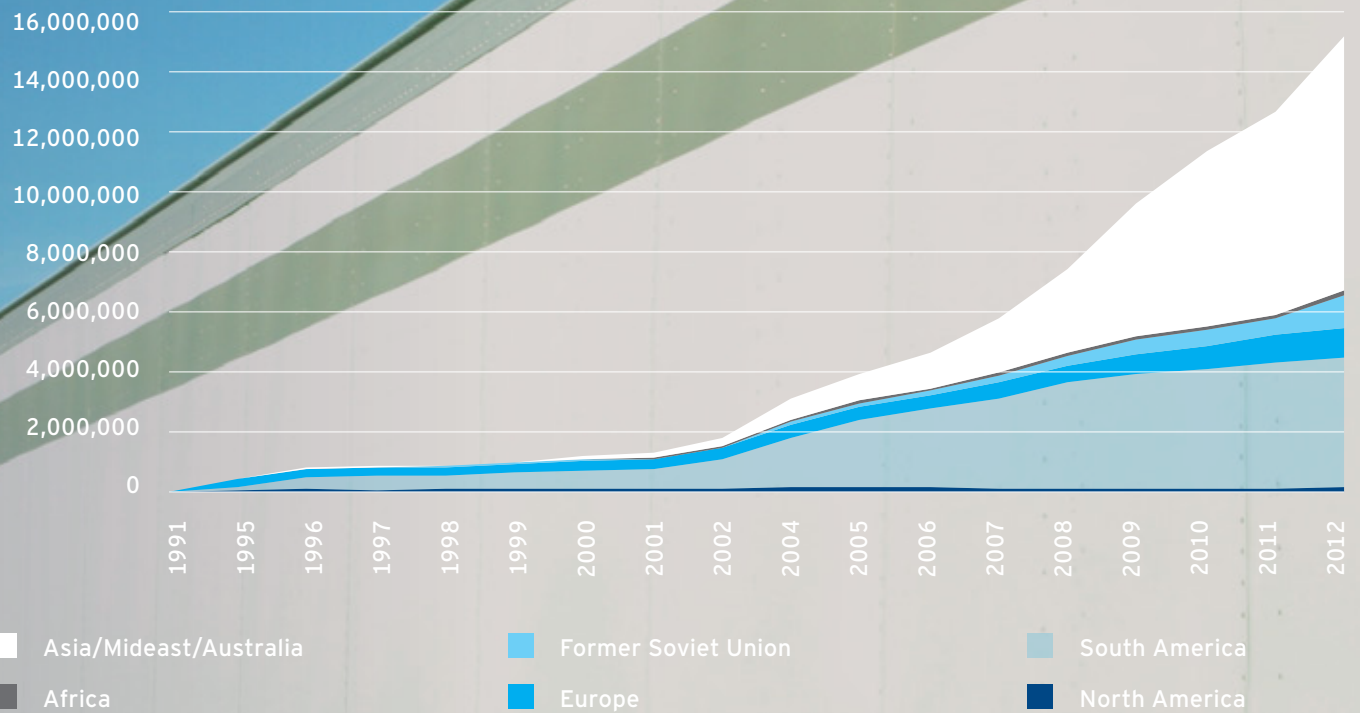
Source: IEA, Lloyd's Register, TOTAL, Citi Research

TOTAL WORLD OIL DEMAND – MILLION BARRELS PER DAY (MB/D)



Source: IEA, Citi Research

GLOBAL SURGE OF NATURAL GAS VEHICLES (1991-2012)



Source: NGV Global, Citi Research

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1. Natural Gas in Transportation Overview

An Overview on Global Oil and Gas Supply

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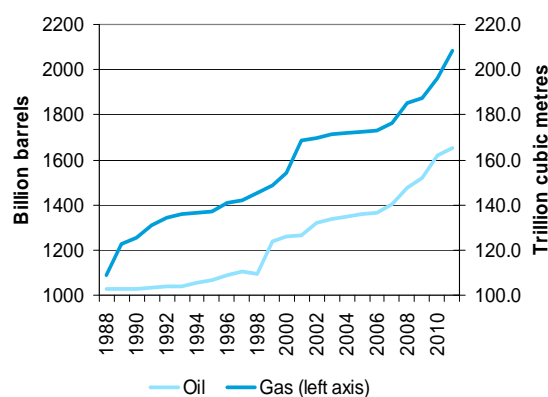
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The world is very gas prone. Between 1988 and 2011, global proved gas reserves have grown 92%, climbing significantly in recent years because of the shale gas revolution and other offshore discoveries. In contrast, proved oil reserves only rose by 61% in the same period.

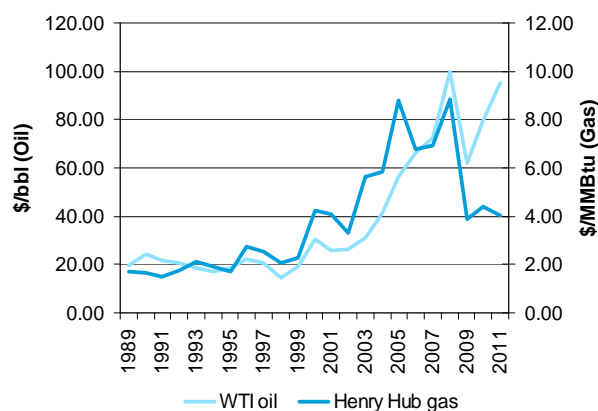
North America has thus far seen the strongest natural gas production growth benefiting from the shale gas revolution, but shale is also present in many places globally. As the source rock of hydrocarbons in conventional reservoirs that have served as the bedrock of global oil and gas production, shale formations are being tapped, with advances in technology – mainly hydraulic fracturing and horizontal drilling – unlocking vast amounts of gas as well as oil.

Figure 1. Global Proved Oil and Natural Gas Reserves, 1988-2012



Source: BP, Citi Research

Figure 2. Oil (WTI) and Natural Gas (US Henry Hub) Prices Since 1989



Source: BP, Citi Research

Oil and gas are typically trapped together in rock formations underground. The geophysical environment sometimes makes one more prevalent than the other at certain locations. However, natural gas tends to appear when the hydrocarbon molecule is "overcooked," breaking down oil or liquids molecules into natural gas, hence at times favoring the discovery of gas. In addition, natural gas is often produced alongside oil, but the difficulty in shipping the fuel limited its use historically – certainly until oil prices surged enough that finding a substitute for oil became critical.

The search for new fields and innovation in technology has driven gas prices lower

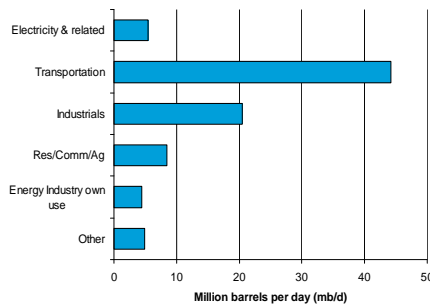
High natural gas prices in the U.S. and Europe, just as oil prices were rising rapidly over the last decade, spurred the search for new fields and innovation in technology. With the development of shale gas, North American gas prices entered a new era, away from the \$8 to \$12/MMBtu world towards a new \$4 to \$6/MMBtu era. Elsewhere, new discoveries – particularly off the coast of East Africa – as well as trapped resources in Russia, plus shale potential globally (even in Saudi Arabia and China), and the export of gas from North America – are making gas reserves more abundant. The growth in gas supply should lower global gas prices from current levels, mitigate future price increases due to higher demand and the de-linking of natural gas and oil prices, now prevalent in North America, should spread around the world.

Size of the Gas-for-Oil Substitution Market in Transportation

Transportation accounts for 44-mb/d of global oil demand, almost 50% of the total

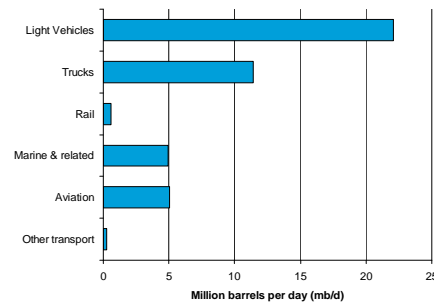
Transportation accounted for about 44-mb/d of global oil demand in 2010. Some 5-mb/d for electricity generation and 20-mb/d for industrial use are also ripe for gas-for-oil substitution. Within transportation, oil demand for light vehicles accounts for over 20-mb/d, trucks for more than 10-mb/d, marine and aviation each uses about 5-mb/d, and the rest is in rail and other transportation. Most regions worldwide, other than Africa, already have some presence of NGVs. The trucking, marine and rail sectors, as well as certain light vehicle markets, should be sizeable market opportunities for natural gas.

Figure 3. World Oil Demand by Sector (2010)



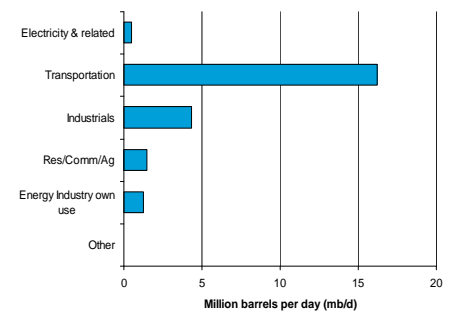
Source: IEA, Citi Research

Figure 4. World Oil Demand for Transportation (2010)



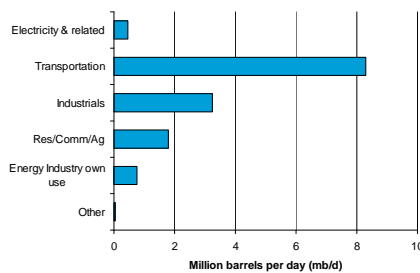
Source: IEA, Citi Research

Figure 5. North American Oil Demand by Sector (2010)



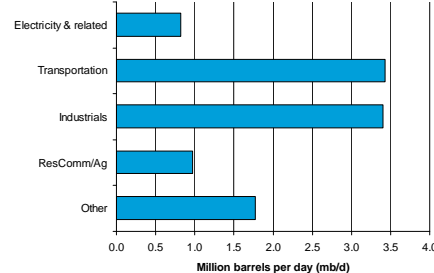
Source: IEA, Citi Research

Figure 6. OECD Europe Oil Demand by Sector (2010)



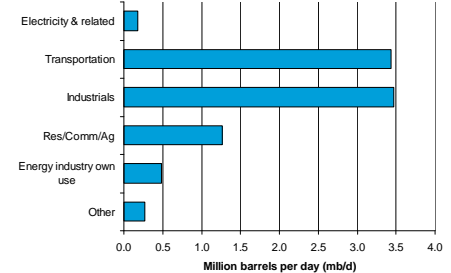
Source: IEA, Citi Research

Figure 7. Asia (ex-China) Oil Demand by Sector (2010)



Source: IEA, Citi Research

Figure 8. China Oil Demand by Sector (2010)



Source: IEA, Citi Research

Figure 9. U.S. Diesel Demand by Sector

Sector	mb/d	Bcf/d
Trucking	1.96	10.26
Rail	0.26	1.37
Mining	0.13	0.68
Drilling	0.07	0.34
Marine	0.48	2.5
Total	2.89	15.2

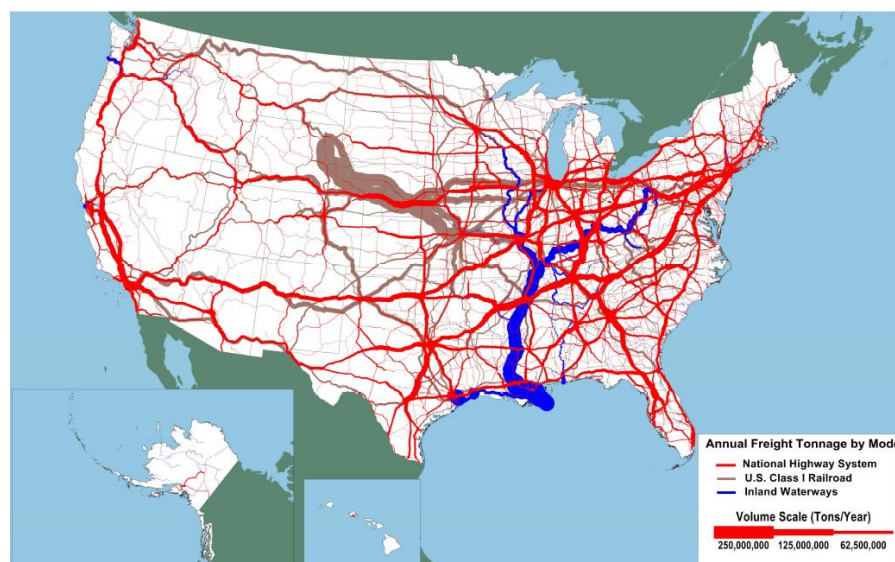
Source: EIA, Citi Research

North America uses about 16-mb/d of oil for the transportation sector. With low natural gas prices, all but the aviation in the transportation sector provide attractive opportunities for natural gas. In particular, the ability to cope with larger fuel tank size and other infrastructure considerations in order to use natural gas make the trucking, rail and marine markets particularly vulnerable for oil as these are the same markets that use the most diesel fuel. LNG pump systems are capable of delivering 650kg of fuel at 4000 psi in an hour. Fuel tank size is an important consideration and 1000 gallon LNG tanks are in development for this purpose. Natural gas could also become a fuel in the off-road market. Westport and Caterpillar are in joint-development of engine and other related technology.

Infrastructure costs could be helped by starting with main corridors

The infrastructure needed to capture a sizeable portion of the market could be smaller than commonly thought. The map below highlights the major trucking, rail and marine barge corridors, with the thickness of the corridors showing the size of the tonnage involved. There are certain key routes across the country, which dominate freight traffic and these routes should be pursued first. Major truck routes with the heaviest traffic are mostly in the Eastern half of the country along several key highways, as well as a couple of routes from West to East and along the West Coast. Hence, targeting these trucking, rail and marine routes can capture a majority of the market. Within the trucking sector, LNG could make inroads in the class 7 and 8 trucks, while CNG can also capture part of the class 3 to 7 segment. Light-duty trucks in the class 1 and 2 portion could also convert from oil to natural gas, particularly for fleet vehicles or ones that have convenient access to CNG refueling stations.

Figure 10. Tonnage on Highways, Railroads and Inland Waterways – Dominated by a Few Key Routes (2007)



Source: US Department of Transportation

Figure 11. NGV Count and Refueling Stations (2011)

Region	NGVs ('000)	Natural gas refueling stations
North America	137	1,080
South America	4,344	4,685
Europe	966	2,577
Former Soviet Union	1,109	1,189
Africa	159	131
Asia/Mideast/Australia	8,478	8,540

Source: Citi Research

Europe consumes more than 8-mb/d of oil in transportation. Environmental issues, fuel economics and the push by Russian gas company Gazprom, among others, are also encouraging a partial switch to natural gas as a fuel. In particular, truckers who use natural gas can benefit from a similar type of cost savings as in the U.S., as diesel prices in Europe are even higher than North America, partially mitigating the concern with higher natural gas prices there. As in North America, most of the truck freight traffic also centers around certain locations, easing the need for massive infrastructure build. Europe already has a greater number of natural gas refueling stations than North America.

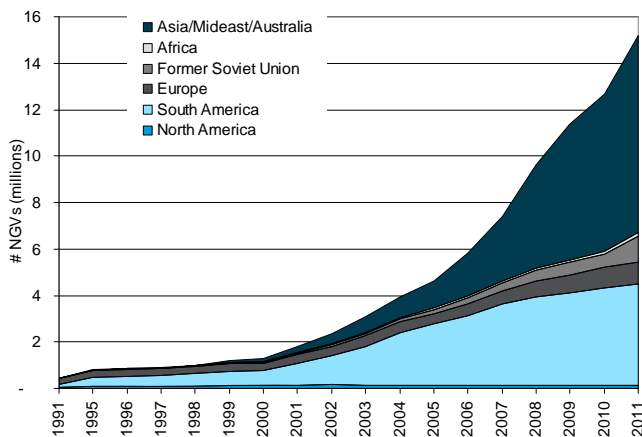
The **former Soviet Union** is another region with growth potential. European gas demand, a traditional market for Gazprom – the largest Russian gas producer – has fallen and Asian buyers have not been active in purchasing its gas. In search of more gas demand for its gas supply amid rising competition from other Russian oil and gas producers, Gazprom is pushing the use of natural gas in transportation to raise "base load" gas consumption.

Asia is currently the largest NGV market

Asia over the past decade has grown to become the largest NGV market, led by Pakistan, Iran and India, with China surging ahead. Favorable fuel economics between oil and natural gas, national security and environmental factors, in part or in full, drove the adoption of natural gas vehicles. Asia, including China, now consumes more than 7-mb/d of oil for transportation. For **China** specifically, the much cleaner burning attributes of natural gas amid pollution problems in the country, and the current favorable price of gas vs. oil, along with fuel diversification factors, are propelling the country forward in the use of gas in transportation. China is way ahead of the U.S. in the deployment of NGVs and related infrastructure.

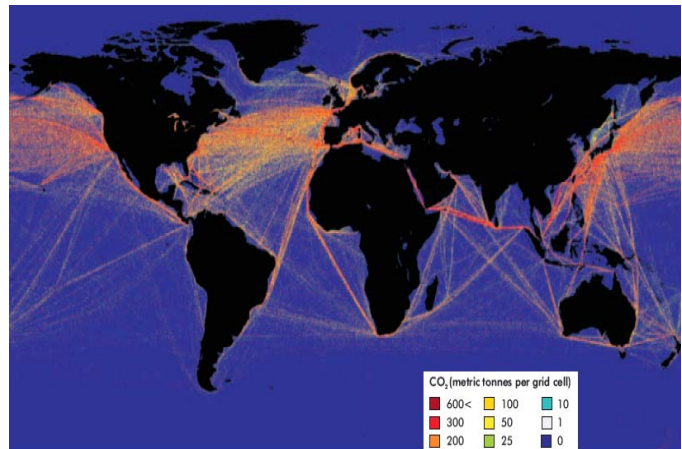
South America has a significant presence of NGVs in both Argentina and Brazil. Argentina, for example, has over 2 million NGVs on the road. The NGV industry grew with limited government intervention or support. Instead, high gasoline taxes, rich natural gas resources and a well-established pipeline system fostered the adoption of NGVs. The government has since encouraged the development of the NGV industry, especially CNG vehicles, due partly to the number of jobs that the industry creates.

Figure 12. Number of Natural Gas Vehicles by Region (1991-2011)



Source: NGV Global, Citi Research

Figure 13. Global Maritime Traffic and CO₂ Emissions (2001)



Source: IEA

Maritime conversion to gas could be helped by regulation

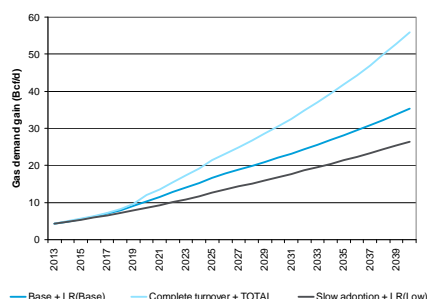
Maritime transport consumes about 5-mb/d of oil globally. More stringent emission regulations (MARPOL Annex VI to be discussed in a later section) along the coasts of Canada and U.S., the North Sea and the Baltic Sea should lead to a change in energy source from fuel oil to either marine diesel or LNG. Potential new Emission Control Areas (ECAs) off the coast of Japan and Mexico, with the addition of the Mediterranean and the Norwegian Sea, could force more fuel-switching. As the global maritime traffic map above shows, several routes dominate major ocean-going and container shipping, easing the infrastructure build hurdle. Regionally, in the U.S., the heavy domestic barge traffic along the Mississippi River is also a prime target – one that Shell is aiming at with its construction of two natural gas liquefaction facilities. Opportunities in this sector are discussed in a later section.

Impact of Gas-for-Oil Substitution on Natural Gas and Oil Demand

Natural gas-for-oil substitute could lead to the displacement of oil demand

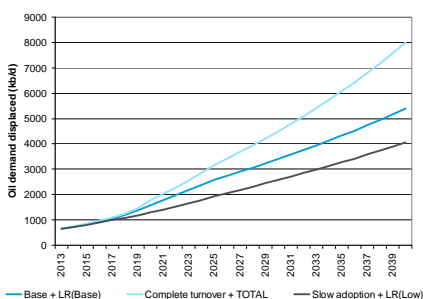
Natural gas-for-oil substitution in transportation could have a far-reaching impact on the oil market¹, particularly as fuel substitution and fuel efficiency curb demand growth amid rising supply globally. Although the pace of substitution could be modest in the next couple of years as various kinks in the natural gas-for-transportation supply chain are being worked out, by 2020 between 1.3- to 1.8-mb/d of oil could be displaced. This is nearly 5% of the current oil consumed for transportation. If the economics are compelling the percentage could be higher.

Figure 14. Projected Gas Demand in Transportation (Bcf/d)



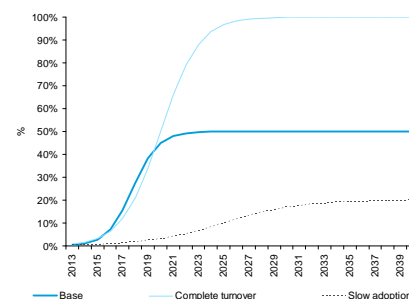
Source: IEA, NGV Global, Poten, TOTAL, Citi Research

Figure 15. Projected Oil Demand Substituted (kb/d)



Source: IEA, NGV Global, Poten, TOTAL, Citi Research

Figure 16. Estimated NGV as % New HDV Sales in the US



Source: Citi Research

We look at three scenarios for NG HDV adoption – a base case, complete turnover and slow adoption

The adoption of natural gas as a fuel could follow an S-curve, with the use of natural gas accelerating as more consumers switch over to the fuel. By 2025, along with the implementation of maritime emission rules in Emission Control Areas (ECAs as governed by MARPOL Annex VI to be discussed below), between 2- to 3-mb/d of oil demand for transportation could be displaced. The base case assumes that about 50% of new heavy-duty truck/vehicle (HDVs) sales in the U.S. would be natural gas-powered, in addition to growth of NGVs and natural gas-powered marine transport elsewhere globally. The low-end estimate assumes that natural gas-powered heavy-duty trucks/vehicles (NG HDVs) will only make up 10% of new truck sales by 2025; this is a rather modest rise in market share but the oil demand impact is still sizeable. The high-end estimate assumes that eventually 100% of heavy-duty trucks (HDVs) in the U.S. would be natural gas-powered. Sustaining this shift from oil to gas is the compelling cost savings and sharp reduction in emissions.

Here comes the inflection point in the “S-curve”, depending on the market penetration of NGVs and natural gas-powered ships in the U.S., China and elsewhere. Citi has constructed three cases for NG HDV sales. (1) If NG HDV sales in the U.S. peak at 50% of total new sales, then combined with gains elsewhere globally, 3.4-mb/d of oil could be displaced by 2030. This could rise to 5.4-mb/d by 2040 due to the growth of the vehicle stock, including NGVs, and an increased use of natural gas in maritime transport. (2) However, if NG HDV sales in the U.S. were to follow historical precedents in fuel switching and reach 100% market penetration, as seen in the complete switch-over from gasoline-powered to diesel-powered trucking in the 1960s to 1970s, and the steam-to-diesel electric shift in the rail sector in the middle of last century, the displacement of oil demand for

¹ See Citi's report, “Global Oil Demand Growth: The End Is Nigh” (March 26, 2013). <https://ir.citi.com/czDLrcphHyo01RfAN9sCKnlZbDCOsMjLzj7mao%2Bmn89zj3H%2BiA2eA%3D%3D>

Oil demand growth may be topping out much sooner than the market expects

transportation could reach 4.5-mb/d by 2030 and 8.0-mb/d by 2030. To put this into perspective, they could be equivalent to 10% to 18% of current oil demand for transportation. (3) If NG HDV sales in the U.S. were to take up a slow adoption as described above and only reach 20% market penetration by 2040, the displacement of oil demand for transportation would be still be impactful at 4.1-mb/d globally.

The combination of an accelerating push to substitute natural gas for oil and ongoing improvements in fuel economy are enough to mean that oil demand growth may be topping out much sooner than the market expects. The shift from oil to gas is already underway in the U.S., where the shale gas revolution is giving a large economic incentive to make the switch. As the U.S. shift gains pace, a combination of politics, greater natural gas availability and environmental concerns are facilitating the trend into the global market, more than compensating for the narrower gas-oil spread.

The ratio between global oil demand growth and GDP growth is falling

Higher prices, the removal of many fuel subsidies and rising fuel economy mandates have dramatically improved the outlook for fuel efficiency in global automotive and truck fleets. The rise in oil prices over the last 10 years has already resulted in a lowering of the ratio between global oil demand and GDP growth from just below 0.6% in 2000-2005, to 0.3% over the last five years. Even given Citi's fairly rosy outlook on global GDP of 3.5% growth per annum from 2014 onwards, this would still only translate into about 1.2% per annum growth in global oil demand. This is also only slightly below the observed average over the last 10 years. Higher oil prices are having more of an impact on consumers as subsidies have been removed in many key consuming countries, and the fallback for oil bulls, China, has already seen a step change reduction in its oil demand growth. In a pattern similar to the abrupt slowdown in demand growth seen in the Asian Tigers in the 1990s, Chinese demand growth has slowed to a more tepid 3-5% rate as compared to the double-digit growth seen in the early 2000s.

One of the many unforeseen ripple effects of the U.S. shale revolution is a push to substitute natural gas for oil. This is set to accelerate with LNG already challenging diesel's heavy duty truck use globally but especially in China; bunker's seaborne market and CNG are set for exponential growth not only in markets such as Brazil, Egypt, Iran and India, but in Russia and the US as well.

The structural oil bull market of the previous decade was a result of surging global oil demand and consistently disappointing non-OPEC supply growth, compounded by a collapse in Iraqi and Venezuelan production. The outlook for each of these factors has now reversed.

Oil demand displacement has a similar path to the increase in natural gas demand

The increase in natural gas demand follows a similar path as oil demand displacement, with demand in the initial years modest in comparison with the global gas market. Current demand in transportation for natural gas is estimated to be around 4-Bcf/d, up from about 3-Bcf/d in 2010 as reported by the IEA. Non-OECD countries make up much of the current natural gas demand for transportation. But transportation merely makes up about 1% of the 315-Bcf/d gas market globally, so that surging gas production worldwide should more than offset this demand gain and keep prices in check. Gas demand for transportation is expected to reach between 9- to 12-Bcf/d by 2020, putting transport demand at around 3% of global gas supply, forecast to be around 375-Bcf/d. Much of this demand can be absorbed by the pipeline gas market in the U.S., Asia and Europe.

Global LNG markets are tight for now, with LNG prices in Asia at times trading well over crude oil equivalence this past winter. Tightness started with the demand impact of the Fukushima nuclear disaster in Japan, which absorbed the considerable surplus in Qatar. The lack of abundant incremental supply and robust demand growth boosted by the proliferation of floating regas vessels look set to keep markets tight for the next few years, absent a significant nuclear re-commissioning in Japan. Once the next wave of LNG export projects comes to market, global LNG markets should loosen materially. This raises the prospect of lower spot prices, and a greater incentive for gas for oil substitution to spread and accelerate globally: hence the assumption that substitution outside of the US starts to accelerate later in the decade.

Oil displacement due to oil-gas switching could range from 2.6-mb/d to 4.5-mb/d

The tables below present the projected gas demand increase and oil demand displacement as a result of natural gas-for-oil substitution in the transportation sector. These tables are broken out in four sections: "On-Road Vehicles," "International Marine," "Other U.S." and "Total Demand." In the "On-Road Vehicles" section, in addition to projections for Europe, Asia and South America, three cases are constructed for the U.S. In the "base" case, NGVs as a percentage of new heavy-duty truck sales will reach 50% in 10 years; in the "complete turnover" case, NGVs as a percentage of new heavy-duty truck sales will reach nearly 100% in a little more than 15 years, following similar fuel-switching patterns as outlined in the next section. In the "slow adoption" case, NGVs as a share of new sales would not reach 20% until 25 years later. In the "International Marine" section, projections from Lloyd's Register and TOTAL, SA are used. "Other uses in the U.S." include rail and domestic marine transport (e.g. barges). Finally, three cases of total demand are presented to show the range of possible impact: (1) the base case consists of the U.S. NGV "base" case and Lloyd's Register's "base" case in international marine transport; (2) the high case is made up of the "complete turnover" case in U.S. NGV adoption and TOTAL, SA's scenario for marine transport; (3) the low case is composed of the "slow adoption" scenario in U.S. NGV and Lloyd's Register's "low" case.

Figure 17. Projected Gas Demand for Transportation (Bcf/d)

	2013	2015	2020	2025	2030
On-road vehicles					
U.S.					
Base	0.1	0.2	1.8	4.5	6.7
Complete turnover	0.1	0.3	2.2	5.9	9.8
Slow adoption	0.1	0.1	0.3	1.1	2.5
EU	0.2	0.3	0.5	0.7	0.8
Asia	2.9	3.8	6	8.1	10.1
South America	1.1	1.2	1.4	1.6	1.8
International Marine					
Lloyds Register (High)	0	0.1	0.3	3.2	5.1
Lloyds Register (Base)	0	0	0.1	1.1	1.7
Lloyds Register (Low)	0	0	0	0.4	0.6
TOTAL*	0	0	1.5	4.4	7.1
Other U.S. (rail + marine)					
	0	0.1	0.4	0.9	0.9
Total Demand					
Base + Lloyds Register (Base)	4.3	5.5	10.2	16.7	22.1
Complete turnover + TOTAL*	4.4	5.6	11.9	21.4	30.6
Slow adoption + Lloyds Register (Low)	4.3	5.4	8.6	12.7	16.9

Source: IEA, Lloyd's Register, TOTAL, Citi Research
* TOTAL, SA

Figure 18. Projected Oil Demand Displaced (mb/d)

	2013	2015	2020	2025	2030
On-road vehicles					
U.S.					
Base	0	0	0.3	0.8	1.2
Complete turnover	0	0.1	0.4	1	1.7
Slow adoption	0	0	0	0.2	0.4
EU	0	0	0.1	0.1	0.1
Asia	0.4	0.6	0.9	1.2	1.5
South America	0.2	0.2	0.2	0.2	0.3
International Marine					
Lloyds Register (High)	-	0	0	0.3	0.5
Lloyds Register (Base)	-	0	0	0.1	0.2
Lloyds Register (Low)	-	0	0	0	0.1
TOTAL*	-	0	0.2	0.5	0.7
Other U.S. (rail + marine)					
	0	0	0.1	0.1	0.2
Total Displacement					
Base + Lloyds Register (Base)	0.7	0.8	1.6	2.6	3.4
Complete turnover + TOTAL*	0.7	0.9	1.8	3.2	4.5
Slow adoption + Lloyds Register (Low)	0.6	0.8	1.3	1.9	2.6

Source: IEA, Lloyd's Register, TOTAL, Citi Research

Natural gas has a low concentration of sulfur dioxide and nitrogen oxides leading to lower emissions

Impact on Emissions

Nearly all forms of emissions should fall by substituting oil-based fuel with natural gas. Excluding emissions due to upstream production, emissions of sulfur dioxide and nitrogen oxides, which contribute to smog and acid rain, would fall by using natural gas instead of diesel or gasoline as a transportation fuel, because natural gas from the wellhead typically has a very low concentration of those pollutants. Natural gas also generally passes through processing plants before entering pipelines or liquefaction. Processing plants also strip out most impurities in gas.

This is also what inspired the implementation of the Emission Control Areas (ECAs) in maritime transport, based on the MARPOL Annex VI protocol. This protocol imposes sulfur dioxide and nitrogen oxides emission levels of near minimal levels. If a ship were to burn intermediate fuel oil, it has to install expensive scrubbers and other equipment to curb emissions. Alternatively, it could burn low sulfur diesel in the form of marine gasoil or marine diesel, or switch to LNG.

But substitution of oil products by natural gas also awakens other environmental concerns. The use of natural gas is not without risks, particularly given concerns of water contamination and greenhouse gas emissions, but promoting best practices should mitigate most risks.

Natural gas has its share of environment issues: water contamination from fracking, methane emissions and pipeline leaks

Above and beyond environmental concerns associated with fracking and other techniques for finding and exploiting the resource base, methane emissions on pipelines and in use for transportation raise other concerns, especially related to minimizing pipeline leaks and capturing LNG boil-off, for methane, a lethal greenhouse gas, can be released into the air through leaks at the wellhead or pipelines. Detecting leakage, sealing cracks and improving aging infrastructure can all help to reduce these fugitive emissions. The industry should be able to partially recoup the cost by monetizing the natural gas captured. LNG boil-off is also being recaptured, usually as a fuel, to power LNG tankers and vehicles that carry the LNG. Capturing boil-off can both significantly reduce methane emissions and the need for another fuel as an energy source onboard.

The U.S. Environmental Protection Agency, the U.S. government agency responsible for environmental protection, published a report in April 2013 that sharply lowered the estimate of fugitive methane emissions. In its report entitled "Inventory of U.S. Greenhouse Gas Emissions and Sinks," the EPA indicated that tighter pollution controls by the industry resulted in a reduction of emissions despite the growth of gas production by 40%. With better data collection and analysis, the EPA estimated that CO₂ emissions, instead of rising from 190-MM metric tons in 1990 to 215-MM metric tons in 2010 as stated in the report from a year earlier, fell from 161-MM tons in 1990 to 144-MM tons in 2010.²

Historical Parallels – Rapid Transition Possible

Transitions driven by fuel economics over policy changes typically follow an "S" curve

Historically, fuel substitution in the transport sector typically follows an "S" curve as discussed earlier, which features a rapid transition period once some critical mass has been reached. This is particularly the case if fuel economics were the principal driver of the substitution rather than a policy-driven change. The beginning of such change is typically marked by significant technical barriers, infrastructure constraints and hesitation from potential adopters, leading to the classic chicken-and-egg problem. As a result, the initial switch seems slow, prospects uncertain and long-term growth projected at the time usually very modest. Once technical barriers are

² <http://www.epa.gov/climatechange/ghgemissions/usinventoryreport.html>

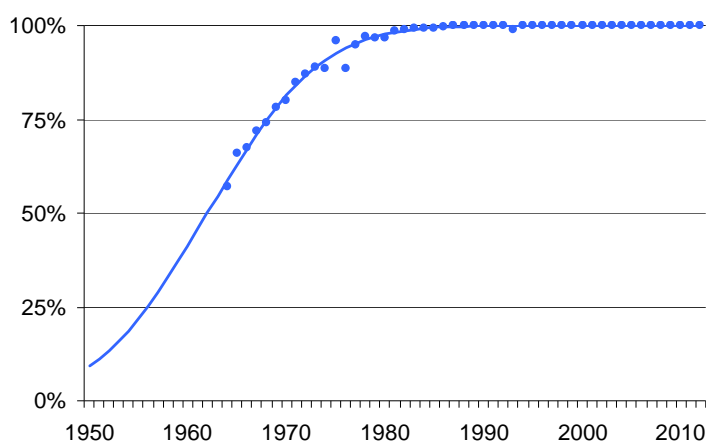
overcome, attractive fuel economics often propel the switch from one fuel to another quickly, thus entering the steep part of the "S" curve. The adoption of new technologies/ fuels snowballs as consumer preference increasingly favors the new fuel. New production and sales gravitate toward the new fuel. As the manufacture of new technologies accelerates, economies of scale lower costs further, making the new technologies even more attractive.

Trucking: From Gasoline to Diesel

A key technology breakthrough in 1953 drove the adoption of diesel in trucking

A prime example of classic "S"-curve adoption is the diesel-for-gasoline substitution that began in the late 1950s through to the 1970s. Although diesel engine was available even back in the 1890s and production of diesel-powered cars began in the 1920s, the mass production of diesel trucks did not emerge until the key technical breakthrough was made in 1953 on Turbo-diesel. As the fuel-economics of diesel over gasoline became increasingly favorable, the market moved quickly in adopting low-cost diesel fuels. The market share of diesel-fueled heavy-duty truck went from the 10% range in 1950s to more than 80% in the 1970s, taking up a majority of new sales in merely 20 years.

Figure 19. Diesel's Share of New Sales of Class 8 trucks in the US (1950-2010)



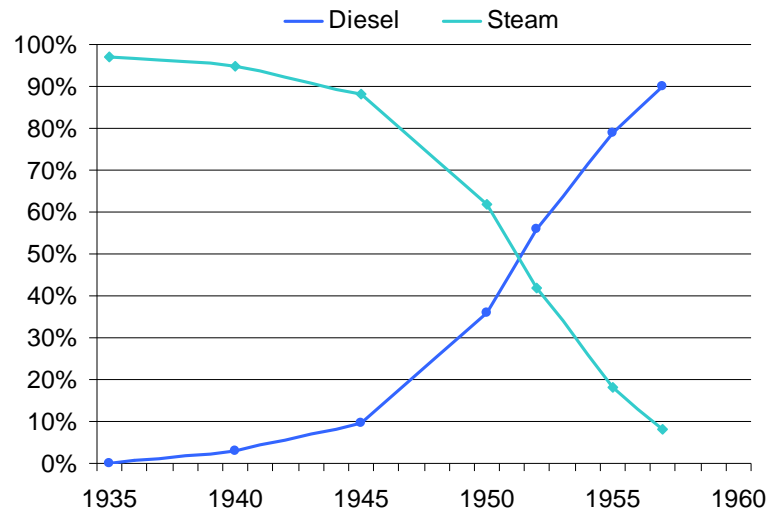
Source: MacKay, Wards Auto, Westport, Citi Research

Locomotives: From Steam to Diesel-Electric

Locomotive transition from steam to diesel-electric took just 20 years

A similar example is the transition of locomotives in rail transport. In the early mid-20th century, electric and diesel-electric locomotives were developed, which had a higher efficiency and lower requirement for manual labor vs. steam locomotives. As labor costs surged during and after World War II, the superior fuel economics of diesel-electric over steam were apparent, driving the quick transition from steam to diesel. Within 20 years from 1940 to 1960, the total market share of diesel-electric locomotives rose from 5% to 95%. By the end of 1970s, most of western countries had completed the replacement of steam locomotives.

Figure 20. Diesel Powered Locomotives in North America (1935-1965)



Source: Ayres-Ayres-Warr, Westport, Citi Research

Natural gas-for-oil substitution in the transportation sector could very well follow these transitions. Superior fuel-economics that natural gas has over oil and lower emission levels – a major policy concern in many countries – should drive the adoption of NGVs.

Energy 2020: Equity Analysis

2. Natural Gas Vehicles in the U.S.

Can Transportation Leverage Shale Gas in the U.S.?

Christian Wetherbee

U.S. Airfreight, Surface Marine

Transportation Analyst

Timothy Thein, CFA

U.S. Machinery Analyst

Itay Michaeli

U.S. Auto & Auto Parts Analyst

With multi-year breakeven periods, investors may see little benefit in the early years following adoption

It is not a question of “if” but a question of “when and how much.” In this section we explore the theme of natural gas as a transportation fuel and its potential impact on various modes of domestic freight transportation. Currently natural gas (compressed “CNG” and liquefied “LNG”) has a low penetration rate in the domestic freight truck market, likely in the low single digits. However, by 2020 we expect penetration to rise to 25%, which will begin to have a noticeable impact on the cost structure of trucking. We do acknowledge that certain applications, like buses and refuse trucks, are well down the path of adoption (for example, 80% of Waste Management’s new truck purchases in 2012 were natural gas powered). There are several barriers to wider spread adoption of the alternate fuel source, which we examine in this report, but there appear to be clear applications in which natural gas makes sense and adoption rates should be solid.

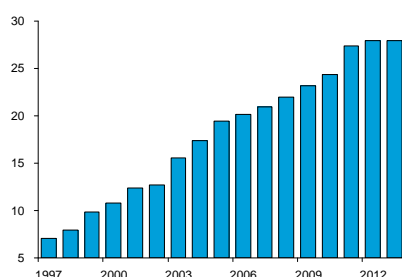
Taking the theme of natural gas as a transportation fuel to the next step of investable ideas may be more challenging. We note that within the coverage universe of freight transportation, machinery and autos, game changing returns from natural gas application opportunities may not materialize over the foreseeable time period while in other cases the scope/ potential penetration may be limited, making the potential benefit small relative to the companies. Further, as the economics lean toward multi-year breakeven periods for the new, more expensive equipment, investors may see little benefit within the first years following adoption. Without incremental government subsidies or lower production prices, initial returns are likely to be challenged and heavy capital spending may not take priority over shareholder returns (buybacks and dividends).

In the following pages, we outline the playing field for natural gas adoption within transportation, including the technologies and applications across domestic freight trucking and rail, as well as the passenger vehicle market.

The Opportunity Is Potentially Large

In our view, the potential conversion to CNG or LNG fuel is quite large, as the domestic freight truck market stands at over ~6.5 million tractors, which together generate approximately 525 billion miles per year. With average fuel efficiency of just over 7 miles per gallon, the market consumes ~25 billion gallons of fuel annually. To put some rough numbers on the potential opportunity for cost savings, it helps to look at the potential cost differential between diesel and CNG and LNG. Assuming a cost differential of \$2/gallon between utilizing natural gas and diesel, the annual savings from switching amounts to nearly \$50 billion of cost savings. While utilizing natural gas as a transportation fuel presents numerous operational and financial challenges that may limit the addressable market, we believe that gas powered trucks are positioned to grow in market share for the foreseeable future.

Figure 21. U.S. Nat Gas Vehicle Fuel Consumption (Tcf)



Source: EIA

Figure 22. Addressable Truck Market

	2008	2009	2015	2021
Truck Population ('000)				
Class 8	2,416	2,340	2,383	2,658
Class 6/7	2,091	2,042	2,162	2,376
Class 3-5	1,910	1,939	2,168	2,434
Total	6,417	6,321	6,713	7,468
Avg Miles per Year				
Class 8	44,934	43,712	43,745	43,937
Class 6/7	16,432	16,008	17,980	20,142
Class 3-5	15,122	15,340	16,390	18,140
Total	76,488	75,060	78,115	82,219
MPG (Miles per gallon)				
Class 8	6	6	6	6
Class 6/7	7	7	7	7
Class 3-5	11	11	11	11
Total	7.2	7.2	7.3	7.3
Gallons Consumed (Bn)				
Class 8	18.1	17	17.4	19.5
Class 6/7	4.9	4.7	5.6	6.8
Class 3-5	2.6	2.7	3.2	4
Total	25.6	24.4	26.2	30.3
Cost Savings @ \$2/gallon Cost Savings (\$Bn)				
Class 8	36.2	34.1	34.7	38.9
Class 6/7	9.8	9.3	11.1	13.7
Class 3-5	5.3	5.4	6.5	8
Total	51.3	48.8	52.3	60.6

Source: Citi Research; ATA; Center for Transportation Analysis

Current LNG/ CNG Engine Applications

The natural gas engine market is currently dominated by Cummins and its joint venture partner Westport Innovations, which specializes in retrofitting the current Cummins engine platform with natural gas components. Together the two companies, through the Cummins Westport JV, produce the most widely used LNG/ CNG commercial vehicle engine — the spark ignited 8.9L engine (ISL G), introduced in 2007. Today, the ISL G engine is primarily used in refuse trucks, buses and medium-duty commercial vehicles running ring and stop-and-go routes, and accounts for a little over half of Cummins Westport's on-road vehicles. It operates 100% on natural gas, and can be powered by either CNG or LNG, one of the key differences compared to the Westport 15L engine, which only runs on LNG. The ISL G engine can be used in heavy-duty applications, although it is limited on power with 320hp and 1025ft lbs of torque relative to 380hp and 1300ft lbs of torque for its diesel counterpart, reducing its effectiveness in long-haul applications. Some fleets have begun to use the ISL G model in heavier/ more strenuous applications, but have done so with caution, as this tends to accelerate the maintenance cycle.

Introduced just over one month ago, with great anticipation by many in the trucking community, the Cummins Westport ISX 12G engine will be the first natural gas product to be used in heavy duty applications, with the performance differential in horsepower and torque only 5% and 12%, respectively, less than its diesel counterpart. The ISX 12G is geared towards regional-haul, vocational and refuse applications, amongst others. This new technology introduced by Cummins Westport is expected to alleviate some of the previous barriers/ concerns regarding

Figure 23. Class 8 Truck & CNG Tank



Source: Company Reports

New heavy duty engine just introduced is geared towards regional-haul, vocational and refuse operations

natural gas engines, allowing for both manual and automatic transmission, as well as engine braking. Our recent checks with a range of North American truck market participants, as well as commentary at the Mid-American truck show in March, suggest there are significant degrees of pent-up demand for the ISX 12G engine, which will be offered by all of the major OEMs, across in a wider range of models (Freightliner, Volvo, Mack, Peterbilt, Kenworth, etc.) and “bridges the gap” between the Cummins Westport 8.9L and Westport 15L. Westport has noted publicly that it is already sold out for 2013 deliveries, and market participants like Clean Energy have outlined some fairly significant growth potential numbers beyond 2013.

Westport 15L engine is third option but low penetration partially due to limited availability

The Westport 15 liter engine is the third option currently available for heavy duty commercial vehicles. Westport uses Cummins ISX 15 engine as the base for their proprietary 15L engine, which is sold in North America as a Westport-branded LNG option on four Paccar (Kenworth and Peterbilt) heavy truck models. Outside of areas with higher elevation (like the Rockies region), usage of Westport’s 15L model has remained relatively low. In addition to the high up-front cost, and somewhat older truck technology, we believe its low penetration is also due in part to its limited availability in Paccar’s Kenworth and Peterbilt models, which tend to have a higher share amongst smaller fleets and owner operators (who, on the whole, are arguably less likely to pay the significant up-front premium for a NG truck). Also, as an LNG-only option, it restricts carriers to routes in which the infrastructure is available (and therefore less relevant for carriers with less-defined routes).

Conversion kits are also available taking diesel engines to natural gas

Finally, Eco Dual offers natural gas conversion kits for the 2004-2009 Cummins ISX 15L engine, with initial costs typically ranging from \$25K to \$40K. We do note, however, that the cost has come down significantly in recent years, and was as high as ~\$135K initially. These kits utilize 60-80% natural gas, with the option to revert back to 100% diesel operation at any point. One limit to greater adoption for conversion kits has been acceptance from the EPA, which often stands in the way of approval of the kits.

Figure 24. Commercial Vehicle Tank Specifications

Fuel Source	Tank Size & Configuration	Usable Fuel (DGE)	Range	Full Fuel Weight (incl. after treatment if needed)	Added Cost
Diesel	75 Gallon Side Mount	75 DGE	450 miles	1,200lbs	\$0
CNG	5x 15 DGE Behind Cab	68 DGE	367 miles	2,050lbs	\$27,000
CNG	2x 41 DGE Side Mount	74DGE	400 miles	1,650lbs	\$35,000
LNG	1x 119 DGE Side Mount	60 DGE	324 miles	1,200lbs	\$22,000
LNG	1x 150 DGE Side Mount	75 DGE	405 miles	1,400lbs	\$26,000
LNG	2x 150 DGE Side Mount	150 DGE	810 miles	2,800lbs	\$45,000
LNG (Westport HD 15L)	1x 119 DGE Side Mount	58 DGE	365 miles	1,600lbs	\$70,000

Source: National Energy Policy Institute

Notes: Assuming 6mpg and 10% spark ignited penalty for CNG, no penalty for LNG compression; 2) Usable fuel incorporates LNG venting volumes, reducing usable fuel base; 3) Diesel weigh includes tank, fuel, and after treatment system; and 4) Westport model assumes HPDI engine, hydraulic pump and 45 gallon diesel tank.

Going forward, we expect more options to become available, as more competitors enter the market. For example, Volvo has announced the development of an LNG based engine, utilizing its D13 12.8 liter engine platform and Westport’s HPDI technology. Volvo’s D13 natural gas engine is expected to reach production in 2014 and will use diesel after treatment systems similar to the current WPT 15L offering, with slightly smaller/ lighter equipment.

Figure 25. Class 8 Truck & LNG Tank w/
Vertical Mounted After-treatment



Source: Company Reports

Different characteristics of CNG and LNG
make it more suitable for different end
markets

Engine Technology: Spark Ignited vs. Compression

Natural gas engines can either be spark-ignited or compression-ignited with pilot injection of diesel fuel, with each providing relative advantages in specific features. As we discuss below, the two main players – and partners - in the market today (Cummins and Westport) are each placing their bets on a particular technology, with Cummins going the spark-ignited route, and Westport emphasizing its HPDI technology.

Compression engines, like the 15L high pressure direct injection (HPDI) engine offered by Westport, utilize a two tank system, wherein a small amount of diesel fuel acts as a pilot ignition source for the LNG fuel source. HPDI/ compression systems allow the engine to maintain similar compression relative to diesel equivalents, injecting a small amount (~5%) of diesel fuel at the end of the compression stroke, preserving horsepower and fuel efficiency. Compression based engines operate solely on LNG, with constant pressure needed in the common rail system. Compression engines are typically as efficient as their diesel counterparts, but despite operating on a fuel source that is roughly 30% cleaner burning, still require after treatment solutions found in diesel systems (diesel particulate filters and selective catalytic reduction). Westport has begun to focus its attention and R&D budget on its 15L HPDI engine platform, with the expectation of greater penetrating the long-haul and heavy haul segments of the market.

Spark-ignited engines use spark plugs similar to a gasoline engine, and are able to utilize either CNG or LNG. Cummins Westport spark-ignited engines are cleaner burning relative to diesel and LNG HPDI applications, eliminating the need for after-treatment and upwards of 500lbs of additional equipment. However, spark-ignition engines reduce the compression ratio to burn fuel at a richer mixture, thereby reducing the performance. The lower compression ratio preserves the engine by preventing pre-ignition, which incurs a fuel penalty of about 10% (said to be improving).

There are characteristics of CNG and LNG that make each one a more suitable alternative for certain end markets. For example, CNG tends to be a good choice for return-to-base fleets, in light and medium duty vehicles in cases where:

- Space for numerous tanks is available on the vehicle;
- Fuel consumption is low (i.e. less than 65 gallons/ day);
- Vehicle weight is not important; and
- The time to refuel is not a concern (i.e. trucks can refuel overnight).

Conversely, *LNG* tends to be a good option for longer haul class 8 trucks where:

- Maximum available range is needed;
- The wheelbase needs to be kept as short as possible;
- Fuel consumption is high (+65 gallons per day); and
- Time to refuel is an important factor.

The operating cost differential between the two engines currently favors CNG technology

In recent studies, diesel particulate filters found in compression engines have added ~\$.04-\$.05 per mile in additional maintenance costs and the need for specialized fuel filters add an additional ~\$.01 per mile, depending on labor sources (\$.009 internal vs. \$.014 external). The additional costs associated with compression based engines are mostly offset by the more frequent maintenance requirements of spark ignited engines, notably spark plug replacement, valve adjustments and specialized oil, adding roughly \$.03 per mile. Thus, the operating cost differential between compression and spark-ignited engines is primarily a function of the fuel penalty incurred by the spark-ignition engines, fuel price differential between LNG and CNG and the availability of fuel sources, which currently favors CNG technology.

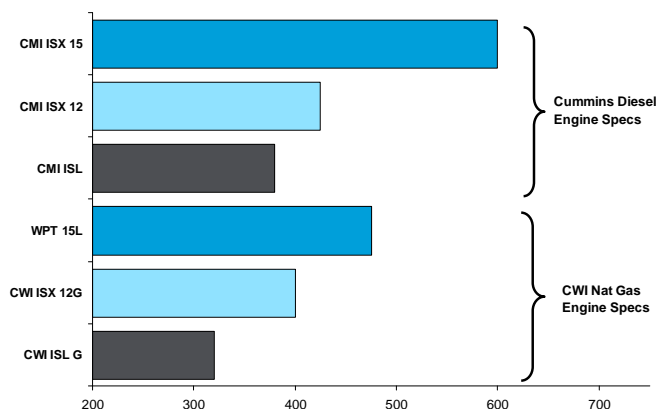
Figure 26. HPDI vs. Spark Ignited Engines: Pros and Cons

Spark Ignited Pro's	HPDI Pro's
<ul style="list-style-type: none"> - Lighter Weight - Lower SCR maintenance and operating expenses - Engine braking and manual transmission available in 11.9L - CNG and LNG capabilities 	<ul style="list-style-type: none"> - Higher compression ratio and increased fuel efficiency - Similar diesel maintenance intervals - Increased horsepower range - Engine braking and manual transmission capabilities
Spark Ignited Con's	HPDI Con's
<ul style="list-style-type: none"> - Lower compression ratio, reducing fuel efficiency 7-10% - Engine braking not available in 8.9L engine - Automatic Transmission Used in 8.9L engine more expensive - Increased fuel system maintenance expenses 	<ul style="list-style-type: none"> - Dual tank system increases weight, partially offsetting gains in fuel efficiency (~400lbs) and limits fuel capacity at ~116DGE - Requires fuel aftertreatment system (~500lbs) reducing payload availability - \$20-40K more expensive than SI, ~\$70K more expensive than diesel - LNG only, currently unavailable with CNG

Source: National Energy Policy Institute

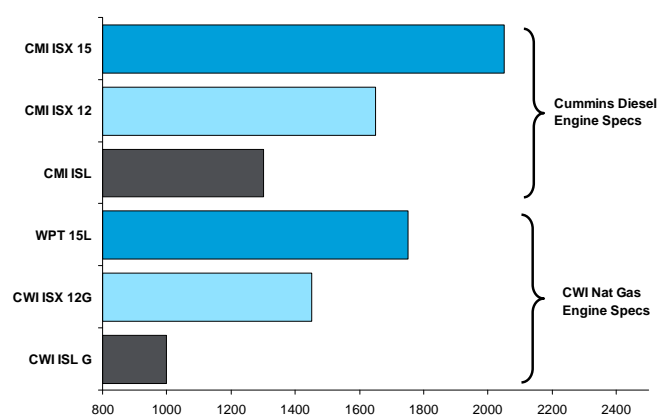
Note: SCR = Selective Catalytic Reduction, DGE = Diesel-Gallon Equivalent

Figure 27. Engine Horsepower Comparison



Source: Company Reports

Figure 28. Engine Torque Comparison



Source: Company Reports

What Can Work and What Can't

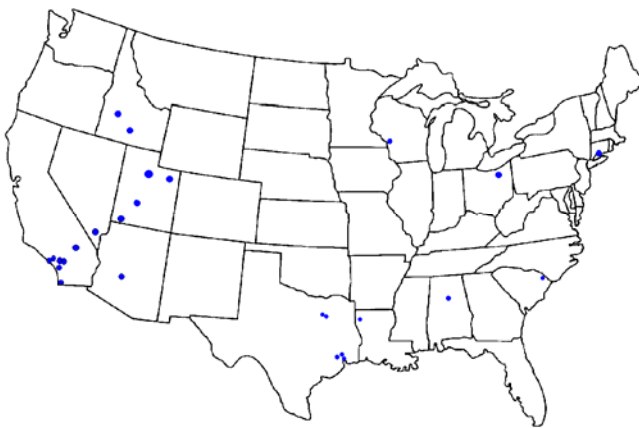
The total addressable market for natural gas trucking applications is a bit difficult to assess, however, there are certain characteristics which clearly qualify certain hauls for conversion much better than others. Principally, we think the following factors are key for conversion to natural gas fuel applications:

1. **Short-Haul** – Given restrictions on fuel carrying capacity and fuel mileage, the ideal CNG/LNG haul should be 400 miles
2. **High Annual Mileage** – Trucks need to be utilized well in order for the economics to work, and despite the shorter length of haul, tractors need to average more than 100k miles a year
3. **Access to Terminal Fueling Infrastructure** – Refueling natural gas tanks takes longer than diesel, requires more safety procedures and precautions, and fueling stations are ideally placed next to pipelines or other natural gas feeder facilities, with limited density currently

Given today's technology, roughly 25% of the truck market has the ability to convert to natural gas by 2020

In summary, while it is difficult to assess precisely the adoption within the total addressable market based on the previous conditions, we estimate that given today's technology, roughly 25% of the truck market has the ability to convert to natural gas by 2020, which coincides with the National Private Truck Council's estimate for the dedicated Class 8 market (both public and private), and includes a small amount of penetration from the at-large, long-haul fleet. We believe that the more dense freight corridors of the United States such as in the northeast (Boston-NYC-Baltimore), southern California, and Texas, are the prime areas where diesel trucks can convert in the near term.

Figure 29. Existing LNG Stations



Source: US Department of Energy

Figure 30. Heavy Traffic Truck Corridors



Source: US Department of Transportation

Non-Class 8 Trucks Also a Significant Opportunity

In addition to Class 8 conversion, we believe there may be an even larger opportunity in percentage terms within the lower classes of trucks, such as straight trucks (fire trucks, utility vehicles, refuse trucks, etc.), and package trucks such as those utilized by UPS and FedEx. These vehicles are more naturally disposed to adopting natural gas given that they tend to operate in a local area, which eliminates or at least reduces the length of haul and terminal fueling issues.

Figure 31. Class 3-5 and 6/7 Population and Mileage

	2008	2009	2015	2021
Truck Population				
Class 6/7	2,091	2,042	2,162	2,376
Class 3-5	<u>1,910</u>	<u>1,939</u>	<u>2,168</u>	<u>2,434</u>
Total	4,001	3,981	4,330	4,810
Avg Miles per Year				
Class 6/7	16,432	16,008	17,980	20,142
Class 3-5	<u>15,122</u>	<u>15,340</u>	<u>16,390</u>	<u>18,140</u>
Total	31,554	31,348	34,370	38,282
MPG				
Class 6/7	7.0	7.0	7.0	7.0
Class 3-5	<u>11.0</u>	<u>11.0</u>	<u>11.0</u>	<u>11.0</u>
Total	8.9	9.0	8.9	8.9
Gallons Consumed (Bn)				
Class 6/7	4.9	4.7	5.6	6.8
Class 3-5	<u>2.6</u>	<u>2.7</u>	<u>3.2</u>	<u>4.0</u>
Total	7.5	7.4	8.8	10.9

Source: Citi Research

Scale and resources of independent owners could limit adoption

Small Fleet, Long-Haul or Non-Dedicated Operator Doesn't Work Yet

One of the stronger headwinds to more widespread adoption of natural gas technology is the fact that a large portion of the over the road truckers are independent owner operators who do not have the scale or resources to invest in natural gas applications. The Owner Operator Independent Driver's Association (OOIDA) estimates that 97% of all U.S. fleets consist of 10 trucks or fewer and 50%+ of all fleets are one truck operations. Additionally, OOIDA estimates that owner operators spend 151-300+ nights away from their homes per year, a metric that indicates that this part of the trucking population is less disposed to dedicated hauls or defined routes, critical components of natural gas adoption.

Growth in adoption likely limited to large fleets that can leverage existing natural gas infrastructure

Penetration Likely Limited Over Next 5 Years, but Could Scale by 2020

Because of the previously mentioned financial and operational impediments of implementing natural gas trucks, we believe that uptake of the technology will be limited to regional adoption, particularly over the next 5 years. We believe that most of the growth will be relegated to large fleets that can leverage existing natural gas infrastructure, mainly refueling stations, while employing the tractors on short-haul dedicated freight lanes. Considering this, we believe that adoption rates for Class 8 tractors, will range from 5%-15% over the next 5 years, but by 2020, given the potential for natural gas equipment costs to lower and for infrastructure to be built, we believe that penetration could rise to 25% by 2020. We have applied these adoption rates to the American Trucking Association's Class 8 tractor forecast for both 2015 and 2021.

Figure 32. Potential for LNG Class 8 Truck Penetration

	2008	2009	2015	2021
Class 8 Population	2,416	2,340	2,383	2,658
Class 8 Mileage Per Truck	44,934	43,712	43,745	43,937
Total Mileage (Bn)	108.6	102.3	104.2	116.8

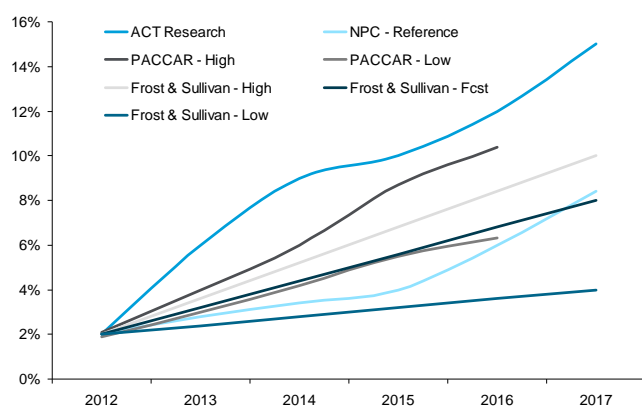
LNG Class 8 Truck Penetration (000s)			
1%		24	27
5%		119	133
15%		357	399
20%		477	532
25%		596	665
30%		715	797

Source: Citi Research

Adoption rates will be constrained by lack of infrastructure but higher growth can be found in the dense freight corridors

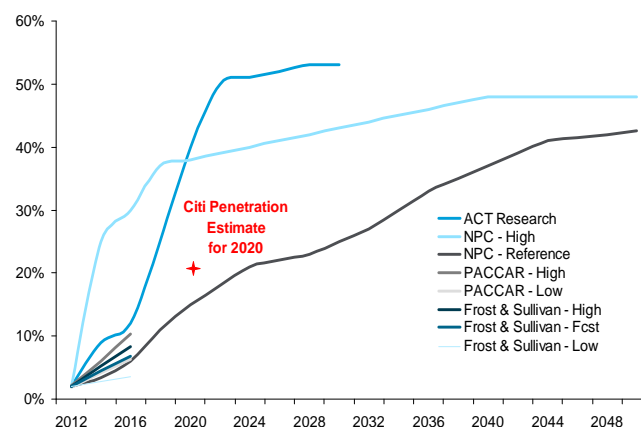
We believe that LNG and CNG applications will continue to increase their share within the Class 8 truck market. Ultimately, we think it's likely that a large portion of the freight market could utilize LNG and penetration rates could ultimately top 40%. However, the pace of adoption will likely remain constrained by lack of infrastructure, and over the next five years, we believe adoption rates in the 5%-15% range are realistic. We believe that much of this growth will come from dense freight corridors near major population centers. Additionally, we also forecast the pace of adoption to resemble more of a hockey stick growth profile rather than smooth, upward trending linear growth. We believe this trajectory is more likely given that the willingness of carriers to adopt the technology depends on first developing greater supporting infrastructure, cheaper technology, or both.

Figure 33. Near-Term Class 8 Natural Gas Penetration Forecasts



Source: Citi Research

Figure 34. Long-Term Class 8 Natural Gas Penetration Forecasts



Source: Citi Research

Running the Numbers

Economics Begin to Favor Natural Gas at \$4/Gallon Diesel

While there are many factors that can heavily sway the profitability of switching to natural gas fuel from diesel, for the standard fleet with access to LNG/CNG fueling facilities, and running with the right length of haul, we believe that cost savings becomes compelling at \$4/gallon diesel. As Figures 35 and 36 highlight, the cost savings compared to diesel can vary significantly, even just considering one variable such as the type of engine; however, the fuel savings typically amount to roughly \$25k a year running at 125k miles per year, according to Ecodual, although we note this forecast may be aggressive, particularly given that LNG/CNG trucks are more likely to be employed in shorter length of haul scenarios, which may prevent them from achieving 125k miles a year).

Figure 35. Comparing Natural Gas Options for Heavy Trucks

Fuel/Engine Type	Incremental Cost Over New Truck	Effective MPG	Blended Cost per Gallon	Yearly Fuel Cost	Range Before Refueling (miles)	Weight of Fuel System (lbs.) Including Fuel
100% Diesel	\$0 with two 100 gallon diesel tanks	6	\$4.00	\$80,000	1,200	1,600
100% CNG with Cummins - Westport ISX12 G - Spark Ignited	\$51,500 with two 42 DGE CNG tanks	5.1	\$1.80	\$42,352	420	1,000
100% LNG with Cummins - Westport ISX12 G - Spark Ignited	\$41,500 with single 79 DGE LNG tank	5.1	\$2.90	\$68,235	383	1,088
Dual Fuel 95% LNG/5% Diesel with Westport 15L HD	\$120,000 with two 32 DGE LNG tanks	6	\$2.96 (dual fuel with average 95% LNG)	\$59,100	375	1,680 (including 40 gallons of diesel)
Dual Fuel 65% CNF / 35% Diesel with EcoDual System	\$29,500 with single 46 DGE CNG tank	6	\$2.57 (dual fuel with average 65% CNG)	\$51,400	872 (420 on dual fuel / 452 on 100% diesel)	1,335 (including 100 gallons of diesel)

Source: Ecodual

Figure 36. Lifetime Diesel Vs. Natural Gas Comparison

	Diesel	Natural Gas
Lifecycle Mileage	800,000 miles	800,000 miles
Miles per Gallon	5.5 mpg	4.7 mpg
Gallons Consumed	145,000	170,000
Price per Gallon	\$4.00	\$2.50
Total Fuel Cost	\$580,000	\$425,000
Fuel Savings		\$155,000
Truck Cost	\$110,000	\$160,000
Other Costs		\$12,000
Total Truck + Fuel + Other	\$690,000	\$597,000
Net Savings		\$93,000 - 11.6 cents/mile

Source: Citi Research; Cummins Westport Presentation

Garbage truck penetration is high, but may not be extrapolated to other types of trucks

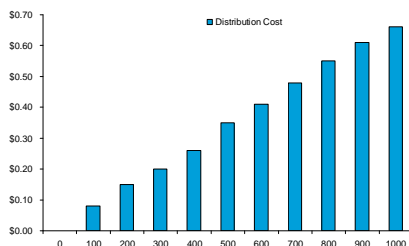
Challenges and Limitations

While utilizing natural gas as a source of fuel is not new (it has actually been powering trucks since the 1920s), using it efficiently and effectively is still a challenge, and there are legitimate headwinds to overcome. As we mentioned earlier, transit buses and garbage trucks are two of the big earlier adopters. The penetration in garbage trucks, for example, has gone from almost zero in 2007 to upwards of 50% (with some estimates even higher) today. One of the benefits to operators (i.e. waste management companies) is the ability to forward purchase natural gas, helping to reduce volatility (and offer fixed price contracts to cities / municipalities / etc). However, there are important distinctions to be made here, which make it less appropriate to extrapolate this opportunity across the traditional over-the-road market. For one, a garbage truck may cost upwards of \$300K, thus the high cost of a tank (the most expensive part of a NG system) is much less meaningful on a percentage basis. Second, there is plenty of room on a garbage truck or a transit bus to store the tanks. Also, because these vehicles don't travel very far each day, there is no real need for refueling infrastructure. Importantly, the adoption of natural gas in garbage trucks may not be a benchmark for adoption in the over-the-road market as garbage trucks tend to be owned and operated by refuse companies or ports for nearly their entire lives, essentially until they fall apart. As such, there is very limited data/ experience on residual value of a 3-4 year old natural gas truck, which is an important data point for an over-the-road operator given their much shorter trade cycles.

Looking specifically at the long-haul market, a lack of engine options has been one of the biggest impediments to adoption heretofore. This should be resolved, however, by the recent launch of the Cummins Westport 12L engine. There are other factors that have served as a barrier to greater adoption thus far, including the following:

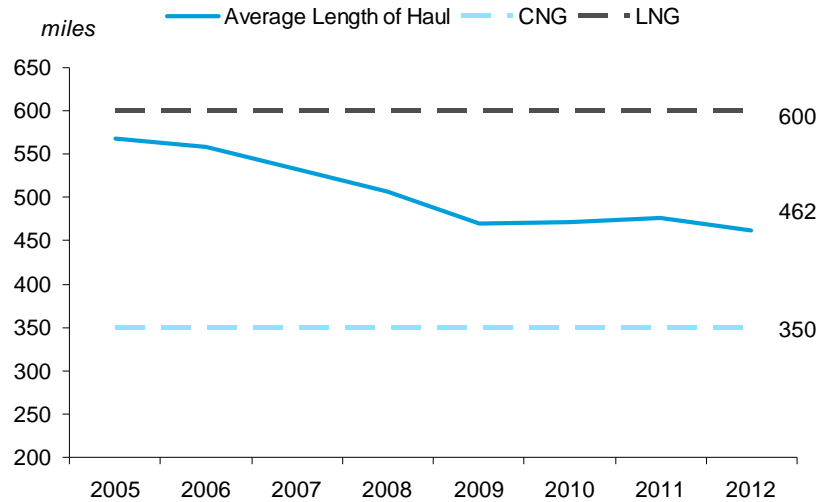
1. **High Upfront Cost** – While the engine costs are roughly comparable (between diesel and NG), high costs for components and fuel tanks can add upwards of \$100K to the cost of a truck.
2. **Limited Refueling Infrastructure** – Refueling can be an issue for the willingness to adopt LNG technology as some carriers are adverse to even refueling diesel outside of their company's facilities. Refueling can pose a significant challenge for utilizing LNG, particularly outside of dedicated operations, as there are several issues that may prevent efficient fueling such as:
 - a. Proximity to natural gas fueling stations
 - b. Physically it takes longer to refuel, particularly for CNG, as slow fill systems (1-8 hours) allow for maximum capacity. Fast fill systems cause an increase in temperature, leading to a penalty of as much as 5 – 10% in lost capacity.
 - c. More dangerous / technically difficult to refuel and requires additional safety steps
3. **Range** – Range is one of the more significant barriers to adopting LNG technology, as even the dual tank configuration range is only <600 miles. However, with railroads taking market share, the average length of haul has consistently trended downwards over the last 15+ years, and the average length of haul for the public companies under Citi coverage is 462 miles, within the dual tank configuration's limits.

Figure 37. One-Way Distribution Costs (\$ LNG / Gallon)



Source: Citi Research; Vehicle Technologies Market Report

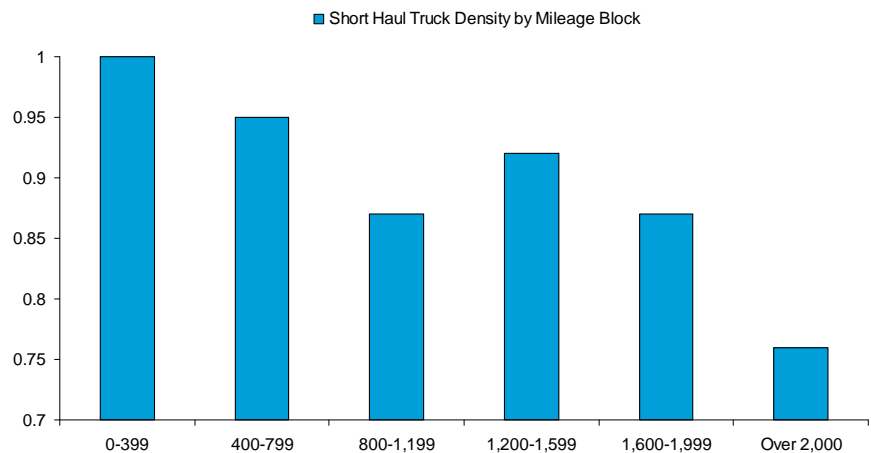
Figure 38. Range Limitations of Gas Exist but Industry Length of Haul Trending Lower



Source: Citi Research

4. **Density** – Truck density is inversely correlated with average length of haul and in the shorter haul lanes (<400 miles) trucks are the primary sources of transportation, commanding approximately 100% of the market. This relationship addresses natural gas' range limitations as average length of haul continues to decrease and trucks are better equipped to handle shorter distances. Further, a larger portion of shorter haul moves are dedicated, which are more susceptible to natural gas transition.

Figure 39. Truck Density Higher at Shorter Lengths of Haul

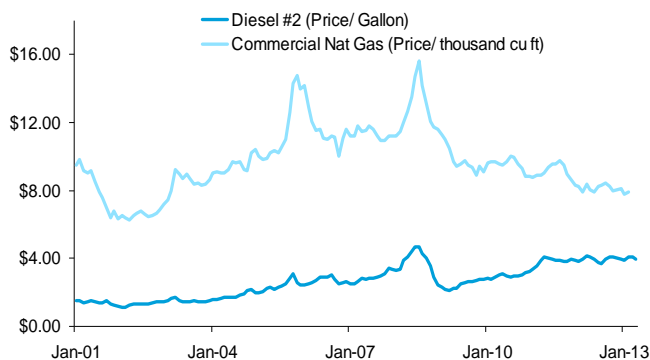


Source: Citi Research

5. **Geography** – Feasibility of moving natural gas to fueling stations may be difficult for some regions such as the southeast (pipeline infrastructure is not possible given terrain restrictions) and other areas where infrastructure is less prevalent. Additionally, other geographical barriers may prevent adoption of LNG from a driver perspective, such as crossing the Rocky Mountains where altitude and weather sap horsepower and may decrease safety.

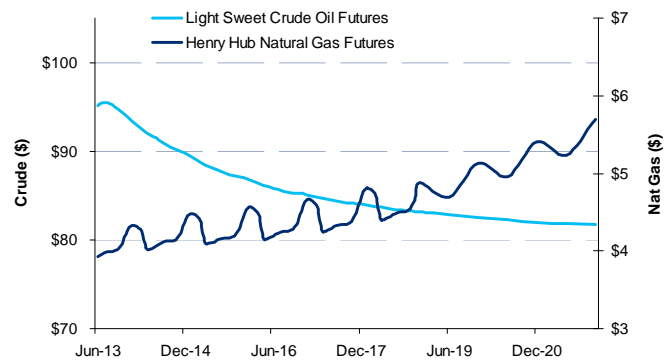
6. **Regulatory** – While the current administration is receptive to alternative fuels, and provides significant tax breaks for investment, this may change under future administrations. Additionally, LNG does present some public and political perception risk, which could be an impediment to operating efficiently in or through certain cities, townships, etc.
7. **Tangential Costs of LNG** – Insurance companies may be less willing to insure drivers with LNG technology, and at a minimum, will likely charge a higher rate. Additionally, finance companies may have a more difficult time financing LNG equipment due to uncertainty in residual values, higher investment and higher risk in the tractor as collateral.
8. **Uncertain Fuel Price Differential** – With the current price differential between diesel and natural gas ~\$1.50 DGE (diesel gallon equivalent), the long-term spread between natural gas and diesel fuel prices remains uncertain. Payback period, which is the primary yardstick carriers use to analyze the applicability of LNG/ CNG commercial vehicle applications, will vary with fluctuating fuel prices. Despite the potential variability in natural gas prices (per futures price expectations), LNG/ CNG pump prices are unlikely to vary greatly relative to underlying commodity demand. Currently the underlying price of natural gas represents 20-25% of total cost at the pump vs. 60% for diesel. Accordingly, the remaining 75-80% in natural gas pump prices is tied to transportation, liquefaction, compression, taxes and other factors. With natural gas infrastructure still in the infant stages of development, a \$1.00 increase in the price of natural gas increases prices at the pump \$0.14-\$0.15, supporting our view of a stable demand scenario for natural gas commercial vehicle applications for the foreseeable future.

Figure 40. Price Differential Diesel #2 and Commercial Nat Gas



Source: EIA, Citi Research

Figure 41. Futures Prices (Nat Gas and Crude Oil)



Source: EIA, Citi Research

Current Progress on LNG and CNG

Early adoption phase currently for natural gas but once proven, adoption should increase

We believe natural gas is still in the early adoption phase for transportation companies as the infrastructure continues to ramp up. Three Truckload companies, one Less-than-Truckload company, and both domestic small package companies have invested in exploring natural gas fuels. We believe that more companies could participate once technology is proven by these early adopters, and price of fuel remains relatively lower than that of diesel.

We note that Truckload carriers have most potential because their fuel costs are the highest relative to their respective cost structures. Of the carriers who have invested in natural gas, Werner and Swift seems to have the largest upside given their estimated fuel margins (28.1% and 30.1% of revenues, respectively).

Figure 42. Natural Gas Transition – TL, LTL, Airfreight

	Fuel Margin	Op Margin	Recent Shifts Towards Natural Gas
Truckload (TL)			
JB Hunt	--	10.5%	Started converting fleet on a small scale
Swift Transportation	28.1%*	9.6%	3 Test Projects: Cummins 8.9-liter (dedicated), Cummins 11.9-liter, and mixing CNG with Diesel
Werner Enterprises	30.1%*	8.4%	(2012) 3 trucks that use natural gas - one with LNG and two with CNG.
Less-Than-Truckload (LTL)			
Con-Way Inc.	--	4.0%	(2012) Launched 2 CNG powered vehicles
Airfreight			
FedEx Corp	--	7.6%	FedEx is testing 2 LNG and 2 CNG trucks and if trial works out, FedEx will consider switching more of its 90,000 vehicles to natural gas
United Parcel Service	--	13.1%	\$18 million investment in fleet expansion planned, upwards of 700 LNG vehicles is expected to be added by 2014

Source: Citi Research

Note: Fuel margin is defined as fuel as a % of total revenues.

NGV: Light Vehicle Outlook

Regulatory & Consumer Demands Create Need for Alternative Solutions

Global regulatory requirements and consumer demand driving change

For the past few years, global automakers have been witnessing a convergence of regulatory and consumer demands around improving fuel economy, striving for energy independence and reducing emissions. After much back and forth, global regulatory requirements are now largely enacted through the middle of this decade, and it's clear that proposals through 2025 call for even greater stringency, likely requiring a greater mix of non-conventional technologies such as alternative fuels, electrification and perhaps even hydrogen fuel-cell. Our work over the years has concluded that, as of now, there is no clear "winning" path for technology choices, making it all the more interesting for investors.

The choice of technology is difficult because goals may conflict, consumers change priorities and product cycles are long

For the automakers, the decision to implement one technology over another is complex. For one, choosing a technology package to achieve one goal (say, improving MPG) may not necessarily mate perfectly with achieving another (say, energy independence or improving well-to-wheel emissions). The consumers themselves are also an issue, as U.S. demand for fuel efficiency has historically tended to rise/fall with gas prices (at least in the short-term), yielding a conundrum where high gas prices damage the very affordability needed to adopt newer technologies. More recent surveys have shown that consumers have begun to consistently label fuel economy as a top consideration regardless of present day gas prices, but there's no question that gas price volatility adds complexity to the decision making (the debated issue of gasoline taxes comes to mind). Third, long automotive product cycles essentially force automakers to make large bets on a few chosen technologies a number of years before market implementation. This makes overnight game-changers less unlikely as automakers carefully spread their investments over the years. This is why monitoring up and coming companies is critical, as they are arguably more capable of introducing technologies faster than large volume automakers, at least in the initial phase. One last issue worth noting is

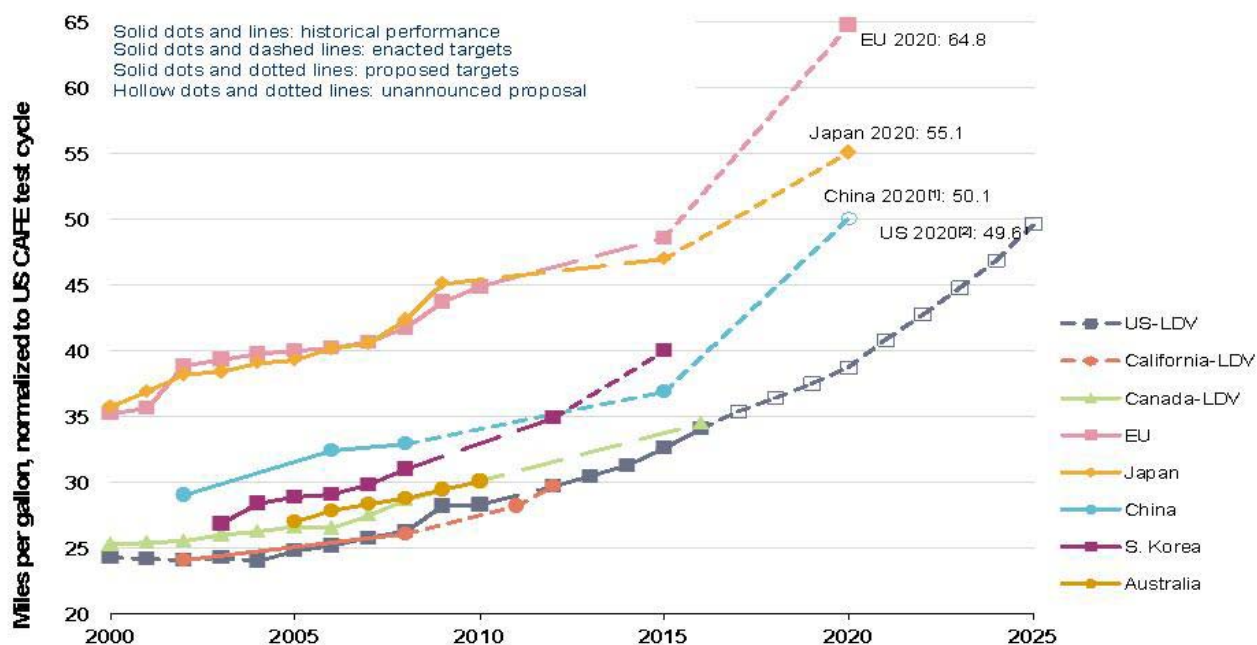
Successful technology package must have reasonable cost and payback, preserve performance and be strongly branded

that global automakers are increasingly looking to achieve global scale through common parts and global platforms, so one region's regulatory hurdle may influence product decisions in another where the regulatory framework may be different.

So far, it appears that automakers are adopting different strategies & pathways towards satisfying regulatory and consumer demands. Part of this stems from varying competitive advantages (Europeans with diesel, Japanese with hybrids) and part simply stems from different thinking around consumer acceptance. What's become clear to us is that a successful technology package must meet the following criteria:

1. **Reasonable costs & payback:** The majority of U.S. consumers purchasing new and used vehicles plan to hold on that vehicle for under 5 years. Outside surveys have shown that, while consumers are willing to pay a premium for fuel economy, they also tend to require a ~3-year payback. This attitude is unlikely to shift to the right anytime soon in light of recent controversies questioning "real-world" vs. "rated" MPG. For this reason, affordable packages such as GDI/turbo, engine timing, stop/start, advanced transmissions, aerodynamics and weight reduction have proven most popular thus far. Advances in these technologies should allow them to continue penetrating the market for years to come, but at some point automakers will likely require even more advanced combinations to satisfy 2025 regulatory standards. CNG's greatest appeal lies in lower emissions and energy security—issues that are of undoubtedly greater importance the post-great recession era. Thus, if CNG vehicles are able to achieve a similar cost/payback as technologies that shine less in the categories of energy security & emissions (hybrids, diesels, advanced gasoline), the probability of strong consumer acceptance would rise dramatically. But no matter how green or energy independent a technology is, consumer acceptance ultimately requires a compelling payback for a big ticket item. This isn't evident in today's CNG vehicle offerings.
2. **Preserve (or enhance) performance:** The success of engines like the Ford EcoBoost can be attributed not only to their ability to improve MPG, but also their ability to enhance performance. Providing a boost to performance greatly enhances the consumer value proposition and helps ensure the automaker earns a reasonable variable margin on sale. This is also a key advantage for Electric Vehicles. CNG vehicles, when compared to conventional gasoline vehicles appear to come out neutral to slightly negative in this regard, although arguably in-line with hybrid offerings.
3. **Strongly Branded:** The best example to illustrate here is the painfully slow pace of diesel acceptance by the U.S. consumer. Traditional cost-benefit analysis often points to diesels as ranking amongst the more compelling technologies for the U.S. market—mainly because of appealing payback, compelling performance and the greater mix of U.S. highway driving (hybrids, for instance, tend to return best in city driving). However, diesel technology simply doesn't have a strong reputation in the U.S. (at least not yet) and often does not score well in outside opinion surveys. Although we do expect diesel penetration to increase in the coming years, automakers will need to educate consumers who may have a negative bias towards the technologies. Diesels aren't the only ones to stand out here: Electric Vehicles too have to fight the tape every time an incident occurs (no matter how minor) or a start-up company restructures. In this regard, we believe CNG could have an edge given the appeal to U.S. energy security and resulting broad economic gains.

Figure 43. Global Regulatory Outlook



[1] China's target reflects gasoline fleet scenario. If including other fuel types, the target will be higher.
 [2] US and Canada light-duty vehicles include light-commercial vehicles.

Source: ICCT

A Menu of Options — Where Does CNG Fit In?

Figure 45 provides “cheat sheet” for various popular fuel saving technologies. Over the years, we’ve come to appreciate that there is no perfect technology at the moment — each carries its own pros & cons and is listed in the table below.

So where do NGVs fit in?

We focus on the Honda Civic NG

Today, there are only a few dedicated NGV offerings in the U.S. market, led by the Honda Civic NG and the General Motors Express/Savana vans. We’ll focus on the Honda Civic NG since it is best representative of a retail vehicle. Another popular offering is the bi-fuel vehicle, which can shift between CNG and conventional gasoline to maximize range and minimize dependence on infrastructure. Bi-fuel vehicles are a particularly popular configuration within heavy-duty pickup trucks where a greater share of fleet ownership exists (allowing for greater miles driven and better access to infrastructure). Another option for consumers is retrofitting existing vehicles into either dedicated NGV or bi-fuel. Retrofitting costs can range from \$12-18k and can depend on desired fuel tank capacity.

Compressed natural gas (CNG) vehicles possess a number of advantages and challenges.

Key advantages include:

+ Energy security: The most obvious advantage is making great strides towards reduction in foreign oil dependency and the resulting gains in U.S. energy security. We believe consumers have become more appreciative of this issue in light of geopolitical conditions and the number of oil spikes observed in recent years with their immediate impact on consumer confidence.

+ Low fuel cost vs. gas or diesel: On an apples-to-apples basis, CNG as a fuel is 30-50% less expensive than gasoline or diesel fuel. More stable, too.

+ Lower emissions: A 20-30% reduction in CO₂ emissions and a 75-95% reduction in NO_x, compared with older gasoline vehicles. Arguably not the greenest but arguably green enough.

+ Bridge to FCV: Lastly, it has been argued that CNG is an ideal bridge solution towards the eventual deployment of future fuel-cell hydrogen vehicles.

The most glaring challenges include:

- Infrastructure: There are currently about 1,300 CNG fueling stations across the U.S., a small percentage of the number of gasoline stations. While the list is growing, only about 50% of the stations are open to the public. Refueling at home is one solution to this, but it's unclear to what extent. Note that Honda does not recommend Civic NG customers refuel at home as moisture and other contaminants risk harming the fuel system, placing a customer's warranty at risk of being denied. We believe that this is a clear issue that must be addressed.

- Energy density: Lower energy density means a lower MPG rating, the necessity for a larger tank (compromising space in the vehicle) and a partial offset to the lower cost of the fuel. Going back to the diesel example, it's also a slight consumer education hurdle as auto dealers would need to reconcile to customers the high cost premium against the lower MPG equation. Consider that the Civic NG is rated 7% lower in city/highway MPG than the Civic HF.

- Large cost premium: Current premiums on NGV range from \$7-\$12k, which is higher than advanced gasoline engines (EcoBoost), most diesels and close to many hybrid vehicles. We believe this is too expensive for mass consumer acceptance.

Figure 44. CNG Gas Station Locations



Source: Citi Research

Figure 45. Fuel Economy Cheat Sheet

	Traditional ICE Downsizing & Boosting	Diesels	Full Hybrids	Plug-in Hybrids (PHEV)	Electric Vehicle (EV)	CNG
Fuel efficiency gains	15-20% better mileage. Turbocharging preserves performance. Future advancements promise another 20% improvement. Stop/Start can add 5-12% too.	35-40% better mileage. Superior to many full hybrids in highway driving, which is more prevalent in the U.S.	25-50% improvement in today's NiMH hybrid systems. Advantage over diesels in city driving. Less so in highway driving.	40-100+% improvement with all electric drive (10-40 mile range).	100+% improvement with zero tailpipe emissions. (Renewable sources can drive well-to-wheel (WTW) gains over time).	Significant emissions reductions, but somewhat lower energy density vs. conventional ICE.
Appeal to performance & adoption hurdles	High - 20% superior torque typically. No real adoption hurdles.	High - 50% higher torque and "fun to drive". Consumer acceptance an issue in the U.S.	Medium - Performance compromised somewhat but low adoptability hurdles. Consumers perceive it as "Next Gen" technology.	Medium - Dual motor/battery lessens battery anxiety risk for consumers.	Medium - "Fun to drive" factor of EVs partially offset by potential battery range anxiety, with the latter likely to be addressed by infrastructure and improving battery range (or switching).	Medium - No major performance give but need for refueling infrastructure (unless able to refuel at home).
Appeal to environmental and national goals	Low - Not an environmental "game changer". Stricter proposed regulations beyond MY20 might make these technologies less impactful.	Developing - Recent marketing in U.S. with old stigma of diesels starting to diminish, but environmental appeal remains a challenge.	High - Emission reduction and lower dependency on foreign oil. Great environmental appeal particularly in large cities.	High - Pure electric range offers breakthrough from conventional hybrids. Less infrastructure anxieties.	Very High - Reduces emissions and dependency on foreign oil. Lithium battery recycling are debatable issues but don't represent an issue. Some promise in solid-state batteries and lithium air.	High - Lower foreign oil dependency. WTW greenhouse gas (GHG) improves over gasoline
Cost	Reasonable. Technologies exist and logistics manageable. Ideal choice for capital constrained auto industry and strained consumer.	High - Similar to slightly below typical hybrids, better durability adds to value proposition. A more expensive option than traditional GDI-turbo.	Higher than diesel but payback improves with higher gas prices and greater city driving. In the U.S. where highway driving exceeds city, diesel makes more sense at present gasoline prices.	High - but more affordable with government credits/incentives. Battery cost reductions key over time.	High - But more affordable with government credits/incentives. Key is reduction in battery cost over time and creative ways to unlock the consumer value proposition (i.e. Better Place model).	High - CNG vehicles carry \$7-\$8k price premium, more than diesels for less "fun to drive" factor.
Challenges	Squeezing more MPG savings to meet increasingly stricter global standards.	Emissions costs and consumer perception.	Costs, safety, and potential changes in consumer demand.	Costs, safety and infrastructure.	Costs, safety and infrastructure.	Infrastructure and less zero tailpipe emission appeal as EVs.
U.S. exposed companies	Borg Warner, Delphi	Borg Warner, Delphi, Tenneco	Johnson Controls, Participating OEMs	Johnson Controls	Johnson Controls, Participating OEMs	Possibly Borg Warner with turbo technology

Source: Citi Research, Kenworth Presentation

Head to Head: Honda Civic NG vs. the Competition

Honda Civic NG is okay but economics for CNG light vehicles need to improve

To best understand the pros and cons of CNG versus competing technologies, we ran a simple comparison between the Honda Civic NG and comparably sized vehicles including the Civic HF, the Ford C-Max hybrid, Toyota Prius-C and Prius-V (larger variant) and the VW Jetta Diesel. The conclusion is fairly straightforward: The Honda Civic NG beats its competitors in annual fuel cost (assuming 15k miles with 51.3% highway), but the vehicle's premium appears expensive relative to the savings, particularly in light of a consumer's typical ~3-year desired payback period. When considering performance, the comparisons are arguably even tougher for the Civic NG particularly relative to the C-Max and the VW Diesel. And we haven't even yet discounted the Civic for infrastructure anxieties plus some reduction in trunk space resulting from the larger CNG tank. So the Honda Civic NG offers slight fuel cost savings versus a Ford C-Max hybrid for a comparable price but with somewhat worse performance (per 3rd party reviews) and infrastructure dependence.

What can we conclude? That the economics for CNG light vehicles must still improve or consumer's desire for U.S. energy security/independence must be a top consideration to overcome less than obvious economic benefits.

Figure 46. Honda Civic NG vs. Competing Vehicles

	Price	MPG	Annual Fuel Cost
Honda Civic NG	\$26,305	27/38	\$993
Toyota Prius C (hybrid)	\$19,080	53/46	\$1,004
Toyota Prius V (hybrid)	\$26,650	44/40	\$1,179
Ford C-Max (hybrid)	\$25,200	47/47	\$1,050
Honda Civic HF	\$19,605	29/41	\$1,446
Volkswagen Jetta (Diesel)	\$24,090	30/42	\$1,690

	Price	MPG	Annual Fuel Cost
Prius C	(\$11)	\$7,225	Similar
Prius V	(\$186)	(\$345)	Similar
C-Max	(\$57)	\$1,105	Worse
Civic HF	(\$453)	\$6,700	Similar
Jetta Diesel	(\$697)	\$2,215	Worse

Source: Citi Research

Bi-Fuel Pickup Trick Economics More Appealing

The Detroit 3 automakers all offer bi-fuel options for their respective pickup truck offerings. For the purpose of this analysis, we'll focus on the General Motors offerings on the Silverado and Sierra 2500HD pickup trucks.

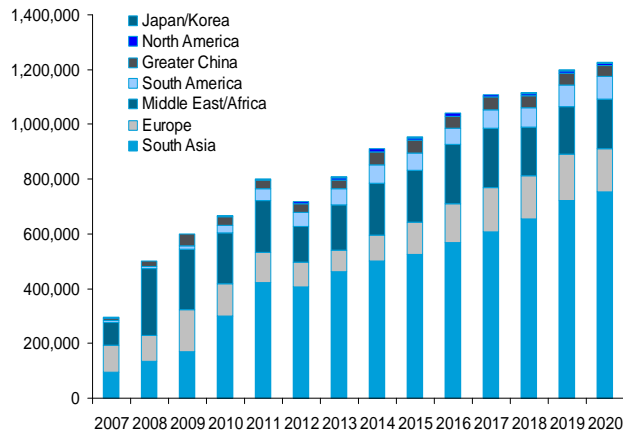
GM's Bi-fuel trucks combine a 17 gas gallon equivalent (GGE) CNG tank with a 36 gallon gasoline tank to claim a range of more than 650 miles. The key selling point is the elimination of range anxiety through the gasoline tank, though usage of gasoline would clearly lengthen the payback period. The bi-fuel option is priced at an \$11,000 premium. GM has claimed that cumulative savings over 3-years can amount to \$5,000-10,000, depending on driving habits. Like the Honda Civic NG example above, the 3-year payback period isn't obvious. However, the advantage of the pickup truck offering is that fleet customers and/or other "work truck" operators are both more likely to drive greater miles than a conventional car and more likely to own the truck for a longer period of time, thereby improving the return dynamics. But also like the Honda Civic NG, the larger CNG tank does compromise some bed space (as much as 25%). Sales of the GM bi-fuel trucks have been fairly low (in the low thousands).

Light Vehicle NGV Penetration Outlook

Estimates for LV-CNG adoptions are very modest, to 1.1% of global auto production by 2020

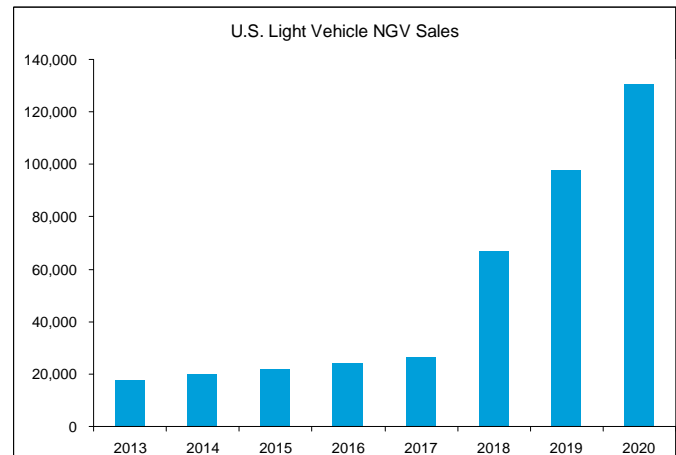
Considering some of the challenges mentioned above and the small product offering in the U.S., renowned 3rd party forecasters have yet to anticipate strong penetration gains of CNG vehicles, albeit demand should growth over time. Forecasting firm IHS estimates that global CNG (both dedicated and bi-fuel) are likely to grow from 0.9% of global auto production to 1.1% by 2020. A more optimistic U.S. scenario outlook, which assumes breakthroughs in 2018 coupled with incentives in supportive states, suggests that U.S. sales for CNG vehicles could surpass 100,000 by 2020.

Figure 47. Global CNG Vehicle Outlook



Source: Citi Research

Figure 48. U.S. NGV Sales Outlook (More Constructive Scenario)



Source: American Clean Skies Foundation Citi Research

What Needs to Happen?

Reduced costs: No matter how green or how impactful to energy independence, consumer payback must be part of the equation. We believe the current premiums on CNG vehicles, ranging from \$7-\$11k, need to come down closer to \$2-\$3k. This will take time and the path is uncertain, but greater penetration of CNG vehicles in heavy trucks could be a first step in eventually bringing down the costs for light vehicle consumers.

Better infrastructure: Infrastructure availability is already improving and home refueling solutions could be made more feasible over time. Thus, this hurdle is less of a concern to us over the medium term.

CNG vs. EV: The Race to Disrupt — What Has to Happen and Who Will Win?

Electric Vehicles: From an operating cost perspective, electric vehicles remain superior with a fuel cost per mile of only \$0.04, even superior to CNG at \$0.07 and of course far superior to conventional gasoline (\$0.15). Besides energy costs, EVs offer maintenance savings from the absence of required oil changes and other functions. Performance also tends to be superior thanks to unique torque characteristics. And despite debates over well-to-wheel emissions, the zero tailpipe emission selling points are nonetheless powerful to both consumers and regulatory bodies. Costs, long charging times and infrastructure are the greatest barriers to mass adoption, even when contemplating federal tax credits. Lower-priced electric vehicles offering limited range (~75 miles), such as the Nissan Leaf, have been met with lackluster demand of <10,000 units (up only 1.5% in 2012). Extended-range EVs like the Chevrolet Volt have done better (23k sales), but have also fallen short of initial expectations. Skeptics will point to these figures as well as the slow pace of battery technology advancements (since the great optimism of 2008) as proof that EVs may only be suitable for luxury buyers. We disagree, and while we have never been in the camp calling for an overnight shift to EVs, the outlook for these vehicles remains bright, in our view. First, despite slow advancements in traditional lithium-ion chemistries, the pipeline of promising technologies is far from dry (solid state, lithium-air). Second, innovative battery switching methods (such as that pioneered by Better Place) offer a way around range and depreciation anxieties, vastly

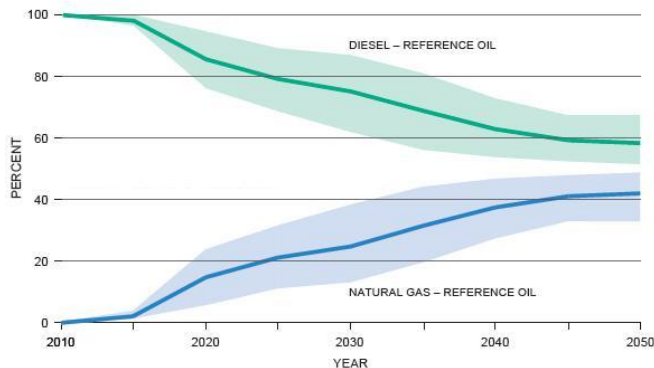
improving today's EV equation for consumers. **What's the tipping point? A 200-250 mile EV in the mid-\$20k range**, possibly with either an efficient fast-charge mechanism (but one that doesn't degrade the battery and jeopardize residual value) or a battery switch capability. Tesla's CEO, Elon Musk, recently expressed his belief that a 200+mile EV costing \$30k (in 2013 dollars) may be 3 to 4 years away. That would be a pretty good start.

CNG: Like EVs, CNG vehicles also face the task of reducing vehicle premium costs by as much as 50%. Where CNG has some advantage is through not having to deliver additional range versus today's offerings, though this assumes consumers accept some reduction in trunk space. The other advantage for CNG is a less dramatic adoption/education curve than EVs—it's a familiar powertrain that's just powered by a different fuel. Economies of scale should deliver some savings over time, but a dose of government incentives may be required to speed up the process. Once CNG vehicles become more competitive than hybrids, diesels and advanced gasoline vehicles, we believe the drive for greater U.S. energy independence and economic investment could provide CNG with a powerful branding message.

U.S. NGV Market: National Petroleum Council Outlook

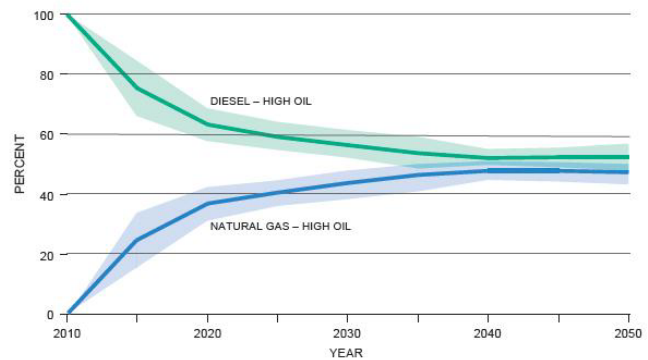
The National Petroleum Council (NPC) recently completed a two-year study of the future of transportation fuels.³ The NPC is a powerful advisory committee to the U.S. Secretary of Energy. NPC assessed the economics, obstacles and the possibility of technological advancement and commercial availability of various vehicle technologies. It studied the fuel/vehicle supply chain pathways and supporting infrastructure.

Figure 49. Changes in Market Shares of Diesel- and Natural Gas-Powered Trucks (Class 7 and 8; Reference Price Case)



Source: NPC

Figure 50. Changes in Market Shares of Diesel- and Natural Gas-Powered Trucks (Class 7 and 8; High Oil Price Case)



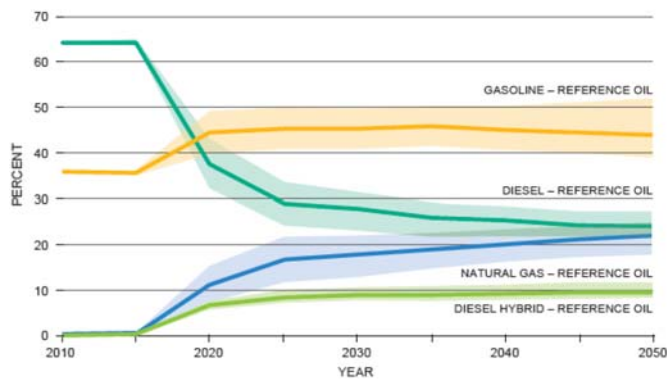
Source: NPC

The NPC projects that NGVs can capture just under 40% of the heavy duty (Class 7 and 8) trucking market by 2020 in a high oil price case and nearly 50% of the market by 2040. Even in the reference case, NGVs market penetration in the heavy-duty truck segment could reach around 15% by 2020 and just under 40% by 2040. The main driver of this abrupt substitution from oil to natural gas is fuel economics and the continued improvement in refueling infrastructure, with the switch starting from the LNG side.

³ The NPC uses oil and gas price forecasts presented in EIA's 2010 Annual Energy Outlook

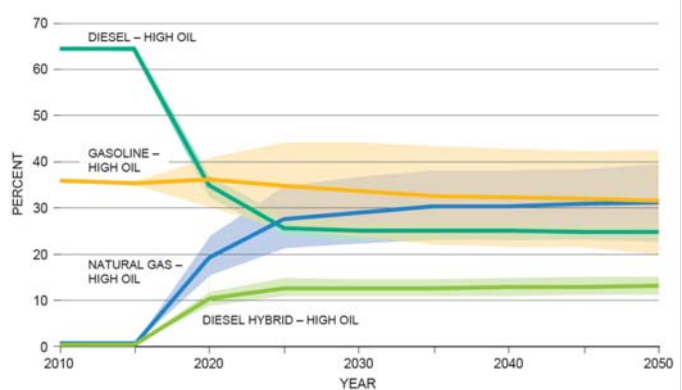
The medium duty (Class 3 to 6) trucking market could experience strong growth in the years to come. Although superior fuel economics are harder to come by, spark ignition engines' switch over from gasoline to CNG, or hybrid-fuel options can help drive gas-for-oil substitution.

Figure 51. Changes in Market Shares of Diesel- and Natural Gas-Powered Trucks (Class 3 to 6; Reference Price Case)



Source: NPC

Figure 52. Changes in Market Shares of Diesel- and Natural Gas-Powered Trucks (Class 3 to 6; High Oil Price Case)

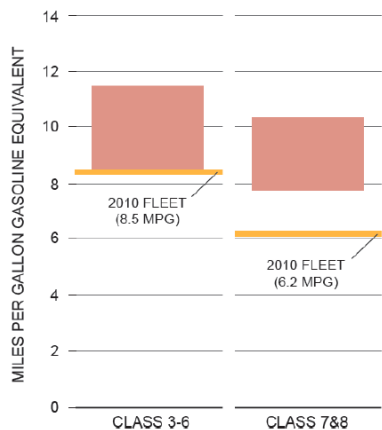


Source: NPC

Economics and performance are the major hurdles to NGVs, not technology

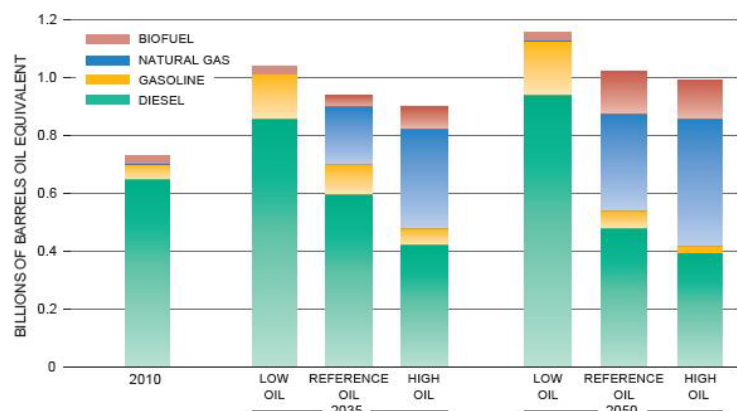
The report asserts that technological barriers are not major issues in the further adoption of light- and heavy-duty natural gas vehicles, but the economics and performance of these NGVs can improve further with continued technological and design advancements. Multiple factors can drive further improvements in cost and performance: cost reduction and design improvement in CNG and LNG storage tanks, optimizing combustion systems in spark ignition and direct injection gas engines, improved aerodynamics, engine downsizing and downspeeding, advanced and optimized combustion systems, exhaust heat recovery (turbo compounding) and turbocharger enhancements. In fact, existing technology can boost fuel efficiencies by up to 100% with a positive return on investment.

Figure 53. Range of Medium- and Heavy-Duty Vehicle On-Road Fleet Fuel Economy in 2050 (all oil prices)



Source: NPC

Figure 54. Fuel Consumption in Class 3 to 8 Trucking Segment in 2010, 2035 and 2050

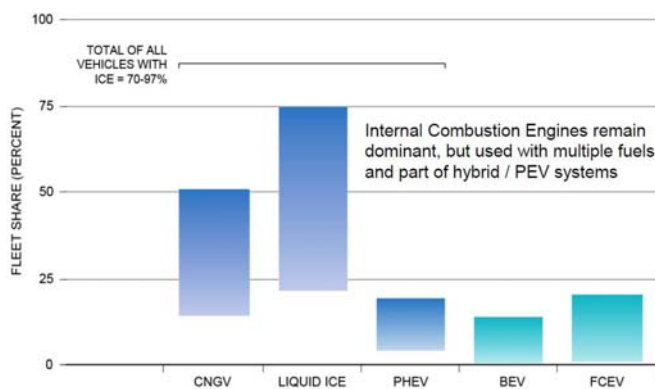


Source: NPC

Opportunities are also present in natural gas-powered light-duty vehicles (NG LDVs). As the powertrain architecture is common in gasoline and natural gas-powered LDVs, advances in gasoline-based technology can be applied to NGVs. A variety of advances can come from applying direct injection technology, highly boosted engines, improvements in transmission and modification in the chassis through weight-reduction and/or more aerodynamic design. The concern that trunk space is limited can be mitigated by optimal placement of CNG tanks during the design process.

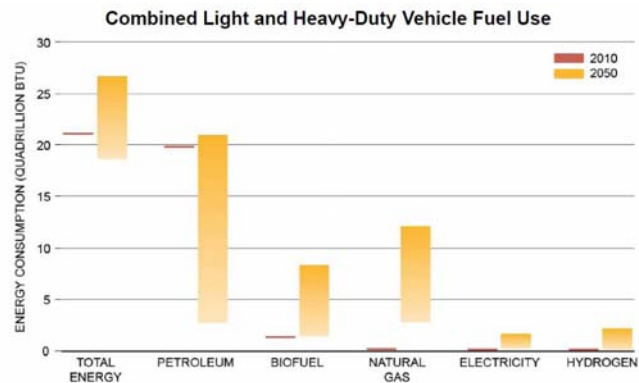
Conversion should begin with fleet and pickup trucks due to their high fuel consumption. Although infrastructure can be a challenge, the wider-adoption of NGVs by fleets and the increased number of refueling stations initially targeting the natural gas-powered HDV segment could extend a refueling network that accommodates the growth of NG LDVs.

Figure 55. Range of Light Duty Vehicle Fleet Shares in 2050



Source: NPC

Figure 56. LDV and HDV On-Road Fuel Use in 2050 Assuming All Alternatives are Successfully Commercialized



Source: NPC

Gasoline demand could fall from current levels of around 18-quadrillion Btu/year (~8.5-mb/d) to 3-quadrillion Btu/year (~1.4-mb/d), if all alternatives are successfully commercialized. Natural gas consumption in transportation could rise from the current negligible levels to between 2.5- and 12-quadrillion Btu/year (~7 to 33-Bcf/d).

Consumer Acceptance

Lack of understanding hurts customer acceptance

A lack of understanding could be the reason why it comes as a surprise that natural gas could replace oil as a transportation fuel. This happens despite the fact that the technology is mature and the fuel is available. In a University of California-Davis study in 2007, when new car buyers nation-wide were asked what could replace gasoline or diesel as a fuel, most people pointed to hydrogen, ethanol or electricity, with between 16 to 22% of the respondents choosing each of those fuels. Only 3.5% chose natural gas. Availability of infrastructure and vehicle selection, along with superior fuel economics, should begin to convert typical consumers.

Figure 57. Choice of Fuel to Replace Gasoline or Diesel, Based on a 2007 Survey of New Car Buyers in the U.S.

	49 States	California
Electricity	22.0%	27.5%
Solar	0.2%	0.6%
Ethanol	16.6%	11.5%
Bio-diesel	7.3%	7.8%
Other bio-fuel	0.2%	0.0%
Hydrogen	17.1%	18.0%
Natural gas	3.5%	7.3%
Propane	1.8%	0.9%
Multi-fuel	0.6%	0.3%
Other	0.3%	0.7%
No idea	25.4%	22.6%
Nothing	4.9%	2.8%

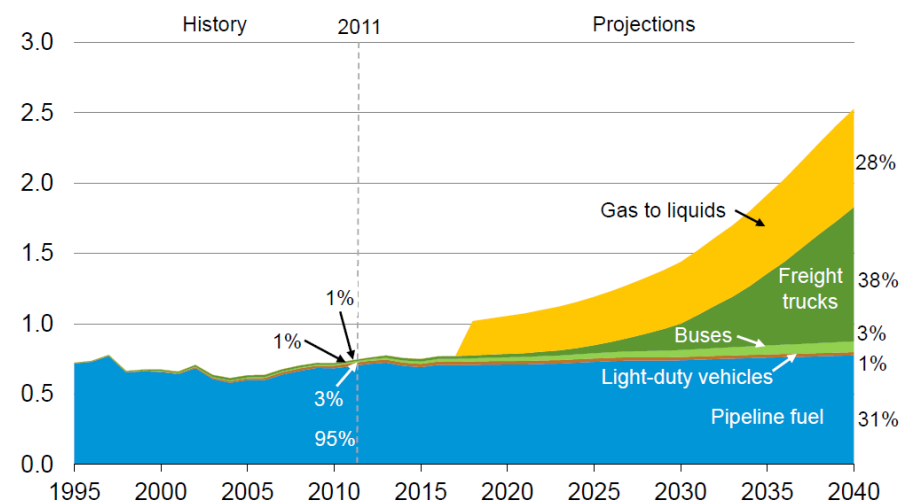
Source: UC Davis, Citi Research

None of the current barriers to gas-for-oil substitution in natural gas vehicles requires ground-breaking technology or an insurmountable amount of investments (e.g. ~trillions USD). Current barriers include a lack of refueling infrastructure, higher first cost of the vehicle, high maintenance cost due to a lack of parts, qualified technicians and service centers, few vehicle choices and a lack of storage space.

Although a CNG passenger car currently costs around \$7,000 more than a conventional gasoline-powered vehicle, fuel-savings can be substantial, as CNG only costs around \$2.30/gallon for fuel savings of between \$1.20 to \$2/gallon.

Conventional wisdom may also grossly underestimate the rapid growth of natural gas demand in transportation. Even the NPC's own report points to a much stronger acceleration in demand. Energy Information Administration's (EIA) latest annual energy outlook (2013) shows its projection of gas demand for transportation, but strong adoption of NGVs by various fleets and major logistics companies is poised to surpass these estimates:

Figure 58. U.S. Natural Gas Consumption (quadrillion Btu) – as a Comparison, Pipeline Fuel in 2011 Uses ~2-Bcf/d of Natural Gas



Source: US EIA

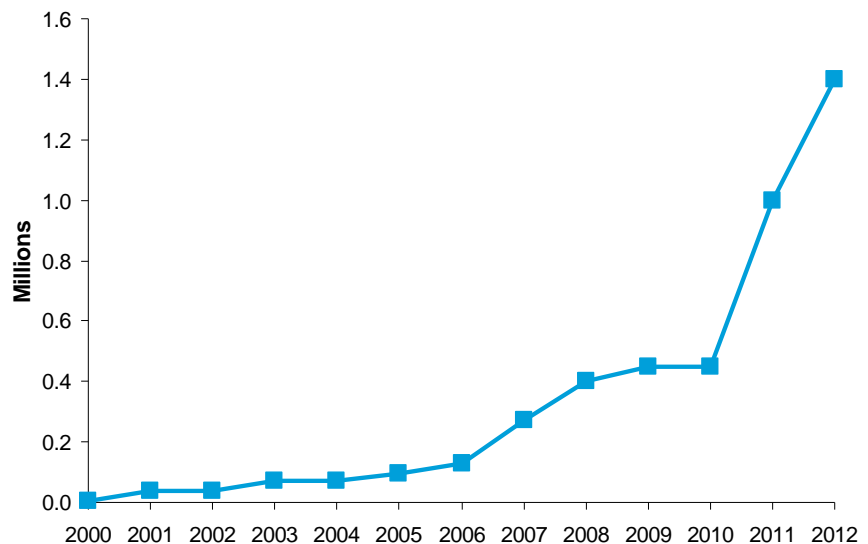
Graham Cunningham
Head of Asia Oil & Gas Research

3. NGVs in China

We expect natural gas vehicles to grow rapidly in the coming years in China, albeit off of a small base. While the economic incentive to switch to CNG/LNG in China is not as strong as in North America, due to higher gas prices, we see stronger government support. According to the 12th Five-Year Plan for Natural Gas Development, China's natural gas consumption should reach 230bcm by 2015 (~8% of primary energy consumption), up from 145bcm in 2012 (5% of total primary energy consumption). The government is attempting to encourage gas consumption in applications which 1) offset oil demand and 2) reduce urban pollution.

According to the China National Petroleum Corporation (CNPC), there were 1.48m natural gas vehicles (about 1.6% of total vehicles) operating in China by the end of 2012 which increased by 48% year-on-year. Of this, LNG vehicles were slightly more than 70,000. Historically, CNG vehicles have been prevalent in provinces with upstream natural gas production such as Xinjiang and Sichuan. More recently companies like Kunlun Energy have begun to develop a market of LNG use in larger commercial vehicles and buses.

Figure 59. Count of NGVs in China since 2000



Source: NGV Global, CNPC, Citi Research

Pricing and Economic Incentive

State owned enterprises (SOEs) like PetroChina and Kunlun Energy as well as private companies like ENN are building gas refueling stations to promote NGVs not only because of government policies but also because of higher gas sales prices for vehicle applications. For example, in Beijing, the price of CNG is Rmb4.73/m³ (US\$21/mmbtu), while residential city gas customers are charged Rmb2.28/m³ (US\$10/mmbtu) and Rmb2.84/m³ (US\$13/mmbtu) for commercial and industrial users. This serves as a strong incentive for city gas utilities to develop vehicle filling station infrastructure.

For consumers, fuel prices are generally 35-40% lower than diesel. Normally the LNG price per cubic meter is 40-45% lower than diesel per liter resulting in a 35-40% fuel savings (based on a conversion of 1m³ LNG to 0.94L of diesel). The price to convert a typical taxi from gasoline to CNG in China is ~Rmb3,500 (US\$560).

The payback period is ~2 months based on an Rmb7.8/L (US\$1.26/L) gasoline price and Rmb3.9/m³ (US\$18/mmbtu) CNG price. According to ENN, a leading natural gas distributor, the cost to convert a large diesel commercial truck to LNG is ~Rmb80,000 (US\$13k), making it more expensive than a diesel truck. Based on a diesel price of Rmb7.5/L (US\$1.21/L) and Rmb4.6/m³ (US\$21/mmbtu) LNG price, it takes 10 months for payback.

Figure 60. Payback Calculation of a CNG Taxi

Average gasoline price	Rmb/L	7.8
Average CNG price	Rmb/m ³	3.9
Gasoline consumption per km	L	0.05
CNG consumption per km	m ³	0.06
Cost saved per km	Rmb	0.156
Average driving distance	km/day	400
Daily average savings	Rmb	62.4
Monthly average savings	Rmb	1,872
Conversion fee	Rmb	3,500
Monthly maintenance cost	Rmb	175
Payback period	months	2

Source: ENN, Citi Research

Figure 61. Payback Calculation of a New LNG Truck

Average diesel price	Rmb/L	7.5
Average LNG price	Rmb/m ³	4.6
Diesel consumption per km	L	0.4
LNG consumption per km	m ³	0.5
Cost saved per km	Rmb	0.7
Average driving distance	km/day	400
Daily average savings	Rmb	280
Monthly average savings	Rmb	8,400
Price difference between LNG truck and diesel truck	Rmb	80,000
Monthly maintenance cost	Rmb	150
Payback period	months	10

Source: ENN, Citi Research

Strong Government Support

Central Government

Government forecast are for gas consumption in the transport sector to hit 30bcm by 2015, up from 5.9bcm in 2010

In the 12th Five-Year Plan for Gas Development in Urban Areas, the government targets gas consumption in the transportation sector (including LNG, CNG and LPG) of 30bcm by 2015, up from 5.9bcm in 2010. In its Natural Gas Utilization Policy (2012 version), the government includes LNG vehicles under prioritized use for the first time, as well as the NG-fueled shipping vessels in inland rivers, lakes and coastal area. The policy highlighted that the massive replacement of the vehicle fleet with NGVs, especially LNG vehicles, should reduce carbon emissions significantly.

The Ministry of Finance released two batches of “special funds for energy conservation and emission reduction in transportation” in 2012 totaling Rmb478m (US\$77m), 34% (Rmb161m or US\$26m) was granted to NGV-related projects.

Local Governments

The pressure to improve urban air quality is a drive for local governments for switching

We believe the strongest support for NGVs currently comes from local and provincial governments, which are under pressure to improve urban air quality. As environmental protection is included in the assessment of the performance of local government officials, converting public transportation to natural gas from oil represents an easy win. Many provinces have announced plans for LNG and CNG vehicles (Figure 62). Even for provinces/ cities without formal plans yet, governments are active in promoting NGVs. For example, Beijing plans to add 3,155 LNG buses to its public transport fleet this year.

Environment concerns and emissions reduction could become dominant drivers of NGV adoption in the future. Favorable fuel economics of natural gas over diesel have been a key factor in boosting NGV use in China. However, the natural gas price reform currently underway in selected provinces will raise prices, thereby cutting into the fuel price spread between diesel and natural gas. This erodes NGVs' competitive advantage in fuel economics.

As smog in big cities becomes a pressing concern, local governments could increasingly turn to natural gas as a transportation fuel for emissions reduction. Hence, government policy is likely to be key to the future growth of the NGV industry. Fuel-switching could be one of the ways in which the country transitions into a "low carbon society." In its 12th Five-Year Plan of Energy Development, the country is expected to increase the share of natural gas in the energy mix to 8% by 2015 and reduce carbon emissions per capita by 17% from 2010 levels.

Figure 62. Local Governments' Plans on LNG and CNG Vehicles

Province/ municipality	Latest status	Plans
Tianjin	Currently has 18,000 LNG and CNG vehicles, 3 LNG stations, 5 CNG mother stations and 33 CNG stations	LNG and CNG vehicles to reach 25,000 by 2015 and 32,000 by 2020. Total gas refueling stations will reach 74 by 2015 and 132 by 2020.
Jiangsu	Had 31 CNG main stations and 96 CNG secondary stations by end-2010.	To build 11 CNG main stations, 250 CNG secondary stations and 50 LNG stations from 2011-2015. By 2015, there will be 42 CNG main stations, 350 CNG secondary stations and 50 LNG stations. 2015 natural gas consumption for vehicles will reach 1.4-2.0bcm, accounting for around 6-7% of total natural gas consumption.
Anhui	Had 18 CNG main stations and 86 CNG secondary stations by end-2009.	To build 23 CNG main stations and 138 CNG secondary stations from 2011-2015. By 2015, there will be 41 CNG main stations and 224 CNG secondary stations.
Fujian	Had 10 gas refueling stations by end-2010.	To build 203 LNG stations from 2011-2015 with a total investment of Rmb3.2bn. Number of LNG stations will reach 356 by 2020. LNG consumption for vehicles will be 1.3bcm by 2015 (or 930,000 tons).
Jiangxi		To build 15 CNG main stations and 100 CNG secondary stations from 2011-2015. CNG consumption will reach 675mcm by 2015.
Shandong	Had a total of 227,500 CNG vehicles by end-2010. There were a total of 302 CNG stations and CNG consumption was 635mcm in 2010, 13% of total natural gas consumption. There were six LNG stations and LNG consumption in 2010 was 12.8mcm.	By 2015, Shandong plans to consume 1.3bcm CNG with 90% of taxis and buses using CNG, plus 400,000 social vehicles adopting CNG. LNG vehicles will reach 59,200 and LNG consumption will reach 1.484bcm. By 2020, CNG consumption will reach 3.2bcm with 95% of taxis and buses using CNG, plus 1mn social vehicles adopting CNG. LNG vehicles will reach 178,000 units and LNG consumption will reach 3.6bcm.
Hubei		By 2015, Hubei will build 105 onshore LNG stations, 12 offshore LNG stations, four LNG storages and one LNG plant. LNG sales will reach 865.8mcm.
Gansu	Had 39 CNG stations in operations and another 18 approved by end-2010.	Gansu plans to add 11 CNG main stations, 161 CNG secondary stations and 33 LNG stations by 2015. Natural gas consumption for vehicles will reach 490mcm by 2015.
Ningxia		In the east Ningxia energy and petchem base, it will add six LNG stations, three CNG secondary stations, one CNG main station (including a standard station) and convert six gasoline stations into oil/gas stations. By 2020, it will add another 13 LNG stations and four CNG stations.

Source: Government plans, Citi Research

How Big is the Potential NGV Market in China?

We believe hitting the government's 30bcm/year vehicle gas demand target depends mainly on how quickly LNG vehicles are adopted.

Kunlun Energy, PetroChina's downstream gas distribution subsidiary, targets 140,000 LNG vehicle customers by 2015 and market share of 30-40%, which implies a total market size of 350,000-470,000 LNG vehicles. LNG consumption for 10,000 LNG vehicles is about 0.5bcm/year. Therefore, total LNG consumption in 2015 could be around 17.5-23.5bcm. We believe Kunlun's targets are aggressive. However, considering the company added ~28,000 LNG vehicle customers in 2012 (the first year the company began marketing to fleet customers), thereby putting the end-of-2012 number at ~31,000, the target could be achieved if new customer additions go well in 2013.

Key Industry Players

The upstream and midstream segments in China's natural gas industry are dominated by the big three SOE oil companies, PetroChina, Sinopec and CNOOC, with PetroChina controlling around 70% of upstream resources and 75% of national pipelines. The downstream segment is more fragmented with both SOEs and private gas distribution companies competing for city gas projects, which are usually granted on 25 to 30 years concessions. Unlike city gas projects, as long as operators can secure gas supply and obtain government approval they can run gas refueling stations. There are around 600 LNG stations in China currently (Figure 63).

According to CNPC, China had an LNG processing (liquefaction) plant capacity of 7.35bcm per year by end-2012, more than double that of 2011. There are 52 projects under construction or planning with a total daily capacity of 40.23mn m³ (14.7bcm per year). Most of this processing capacity is located in western China, near upstream production.

Figure 63. China's LNG Refueling Stations



Source: LNGche, Citi Research

Major operators of LNG stations include Kunlun Energy, Guanghui Energy and ENN Energy (Figure 64).

- Kunlun Energy is a 58%-owned subsidiary of PetroChina and is PetroChina's flagship in the downstream natural gas business. The Company's strategy is "gas in substitution of oil". Kunlun was operating 177 LNG stations by end of 2012, up from just one station in 2009. The company added 130 stations last year alone, and it has 297 LNG stations under construction.

The Company had around 31,000 LNG vehicle customers at end-2012, and it plans to add 50,000 customers this year and targets 140,000 LNG vehicle customers by end-2015. Based on 1 LNG station per 150 LNG vehicles, Kunlun will need close to 1,000 LNG stations by 2015.

Kunlun had LNG processing capacity of 4.53mn m³/day (1.65bcm per year) at end-2012 and it targets 20mn m³/day (7.3bcm per year) capacity by 2015.

- Guanghui Energy, Shanghai-listed, is headquartered in Xinjiang and focuses on western China. It had 103 LNG/ L-CNG stations in operation at end-2012 and developed 1,800 LNG vehicle customers last year. The Company plans to add 908 LNG/ L-CNG stations from 2013-2017 and reach around 1,000 stations by end-2017.
- ENN Energy is a major private city gas project operator in China. Apart from its major business of selling piped natural gas to residential, commercial and industrial users, the company also had 244 CNG stations and 86 LNG stations in operation at end 2012. It also has five LNG plants with a total capacity of 1,610,000m³/day (0.6bcm per year) of which three are operating and two will be operational in 2013.

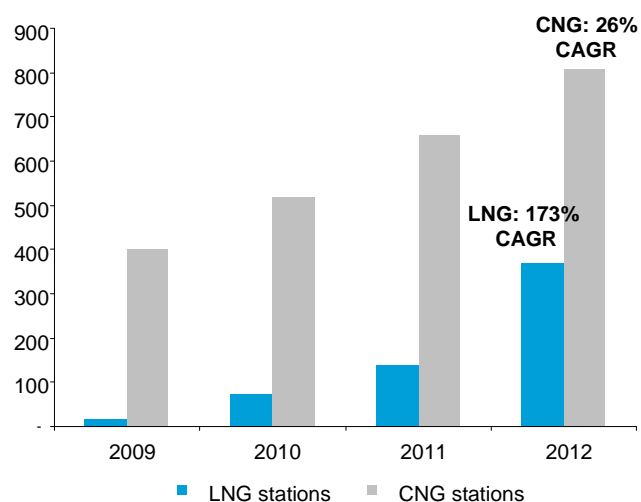
Figure 64. LNG and CNG Stations by Major Operators (2009-2012)

In operations	2009	2010	2011	2012
LNG stations				
Kunlun Energy	1	10	47	177
ENN Energy	-	-	19	86
China Gas	-	-	-	2
Guanghui Energy *	17	64	75	103
Total	18	74	141	368
Growth		311%	91%	161%
CNG stations				
Kunlun Energy	109	141	190	242
ENN Energy	162	192	219	244
China Gas	91	105	133	165
CR Gas	38	82	116	158
Total	400	520	658	809
Growth		30%	27%	23%

Source: Company data, Citi Research

* Guanghui's stations include both LNG and L-CNG

Figure 65. LNG is Growing Faster from a Lower Base (2009-2012)



Source: Company data, Citi Research

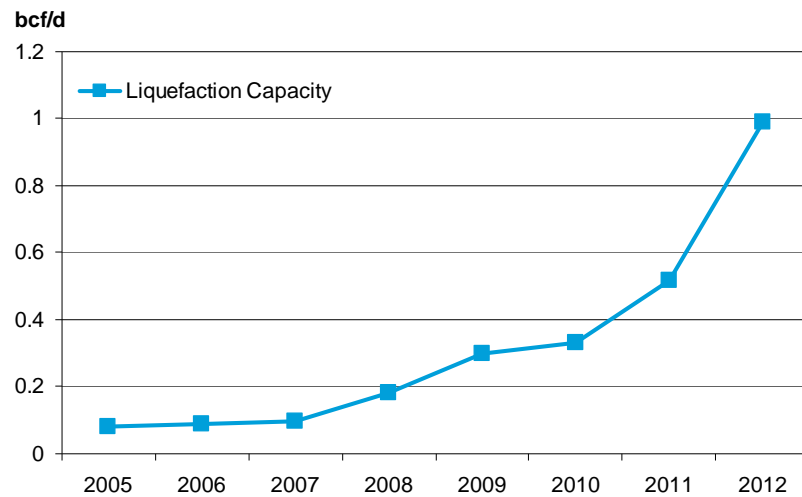
Production of natural gas, distribution networks and LNG liquefaction facilities are all key

Availability of Natural Gas Supply

As in the U.S., gas supply is crucial to the growth of NGVs, particularly the availability of LNG. If domestic production falls short, then imports have to rise to meet demand, which also suggests that the level of overall gas supply could be a constraint on NGV growth. In addition, much of the discussion of the rise of NGVs and refueling stations neglects to mention where the gas supply could originate. Besides upstream production or gas imports, the construction of gas distribution networks and LNG liquefaction facilities affect fuel availability.

The development of liquefaction facilities and growth of LNG production is critical in fuel availability. The country completed 17 additional LNG liquefaction plants in 2012 to put the total number of facilities at 63. The government has encouraged the construction of small-scale LNG plants for peak-shaving purposes and these same plants could be used to produce the LNG needed for NGVs.

Figure 66. Liquefaction Capacity Increase in China (2005-2012)



Source: China LNG, Citi Research

Further downstream, government support of NGV development led to a build-out of 385 LNG filling stations by the end of 2012. The number of LNG stations is expected to double year-on-year. CNPC, as the major supplier of natural gas, is making large investments in the refueling infrastructure as well.

Ronald P Smith
Russian Oil & Gas Analyst

4. NGVs in Europe

LNG-for-diesel substitution in Europe enjoys a smaller price incentive at the wholesale level than that seen in the U.S., but a much larger tax advantage that boosts its competitiveness substantially at the retail level. In total, we estimate LNG to be \$2.80 per equivalent gallon cheaper than diesel in Europe before distribution and retail costs, with ~2/3 of that difference coming from tax policy. Even if the additional distribution and retail costs are substantial, this underlying economic incentive, when combined with the solid environmental policy advantages LNG offers over diesel, could put Europe at the forefront of LNG-for-diesel substitution.

Drivers of LNG vs. Diesel Economics in Europe

We see 6 major economic drivers of LNG-for-diesel substitution: 1) The favorable tax treatment on-road LNG is granted relative to diesel; 2) The pricing gap between a gallon of diesel and the equivalent amount of LNG per unit of energy; 3) The additional cost of an LNG truck relative to a similar diesel-powered truck (the upcharge); 4) The truck's inherent efficiency (miles per gallon); 5) The truck's intensity of use (miles per year); and 6) Absolute oil prices, which can expand or shrink the pricing gap between LNG and diesel.

1. Tax Treatment of On-Road LNG

Our research shows that European countries generally provide generous incentives for on-road LNG use imbedded in their on-road fuel tax regimes, an average of \$1.75/gal, we estimate. Additionally, if VAT treatment in Europe is uniform with that seen in the UK and Germany, with VAT getting charged on the excise tax, then the gap could be as high as ~\$2.10/gal.⁴

Over time we would expect European tax policies to harmonize and the effective tax subsidies to be decreased – fuel taxes are a key revenue source for most European governments, and the erosion of that tax base represented by widespread conversion from diesel to LNG would, we think, probably lead European governments to begin to narrow the preference given to LNG with time. However, we think this would likely only occur years down the road after the cost of the technology has come down substantially and after LNG penetration to the European on-road fuels market has hit a critical mass.

Over the longer term, we'd expect some modest support for LNG for diesel substitution to remain in European tax policy for both economic and environmental reasons.

- On the economic side, displacing diesel with LNG should lower the overall unit cost of on-road energy for Europe by 15-20%, the discount that LNG trades at to ultra-low sulfur diesel on a \$/MMBtu basis.
- On the ecological side, trucks using LNG (methane) as a fuel will emit considerably less pollutants (sulfur, particulates, etc) and CO₂ than a comparable diesel-fuelled truck, and should make it easier for truck makers to meet the upcoming stiff Euro-6 requirements.

⁴ We could be underestimating this, as we are not assuming a uniform treatment of VAT as seen in Germany and the UK – i.e., a tax on a tax. This is likely more widespread than just in these two countries, and if so we are undershooting by a modest amount the tax advantage LNG has over diesel by maybe 20% x \$1.75/gal = \$0.35/gal.

Tax subsidies likely to be reduced in the long term, but remain materially in favor of LNG, we think

Tax treatment varies across Europe, but is supportive

Across Europe the tax treatment for on-road LNG relative to diesel varies, but provides natural gas with substantial effective subsidies almost uniformly.

Belgium, the UK, Italy, France, the Netherlands and Sweden are the most supportive regimes

The most supportive regimes are found in Belgium, the UK, Italy, France, the Netherlands, and Sweden, where excise taxes for on-road natural gas use averages \$2.20 per gallon equivalent lower than those levied on diesel in the same country. Towards the bottom of the league table the effective subsidies are still material, at \$0.90/gal in Poland and \$1.30/gal in Finland. Only in Denmark, where the excise tax on natural gas is a relatively modest \$0.3/gal lower than that charged on diesel, is on-road LNG use not meaningfully supported by tax policy. All other major European countries we examined provide at least \$1.50/gal of tax advantage to on-road LNG usage over diesel.

In general, at the wholesale level and after taxes, LNG in Europe for on-road use will be about \$2.80 cheaper than diesel on a gallon-equivalent basis (Figure 67), with the tax advantage providing almost 2/3 of that difference.

Citi's assumptions: In our optimistic scenario we assume that the effective tax subsidy of on-road LNG remains around the \$1.75/gal equivalent seen today, leaving aside the VAT add-on for the time being. In our pessimistic scenario we assume the tax advantage drops to \$1.00 /gal (see Figure 69 for a full presentation of our sensitivity analysis).

Figure 67. European Diesel vs. LNG Costs

\$ /MMBtu	Wholesale	Tax	Total
Diesel	\$20.51	\$16.54	\$37.05
LNG	\$13.00	\$3.87	\$16.87
Difference	\$7.51	\$12.67	\$20.18

\$ / gal equiv	Wholesale	Tax	Total
Diesel	\$2.83	\$2.28	\$5.12
LNG	\$1.80	\$0.53	\$2.33
Difference	\$1.04	\$1.75	\$2.79
Breakdown	37%	63%	100%

Source: Citi Research

A closer look at the UK tax regime

In the UK on-road LNG is taxed at £0.2470/kg.⁵ Converted at the current exchange rate, that comes to a seemingly-high \$7.8/mmbtu. However, it is only about 32% of the equivalent diesel excise tax of £0.5795/liter, which works out to about \$24.10 per MMBtu.⁶ Converted into a per-gallon equivalent, the combination of the more favorable excise/fuel tax treatment and the initial lower cost of the wholesale diesel price gives on-road LNG a \$2.30/gallon head start over diesel.

There is an additional advantage in that in the UK VAT is charged on excise taxes as well as on the cost of fuel – a tax on a tax – which adds another 20% to both and provides another \$0.45/gal of indirect subsidy. Finally, VAT on the lower wholesale price of LNG will another \$0.10-\$0.20/gal lower tax than that levied on diesel.

⁵ <https://www.gov.uk/fuel-duty#rates-of-fuel-duty>

⁶ There have been proposals in the UK government to raise diesel duties to £0.6097/liter and LNG duties to £0.2907/kg. While both rates would be higher than today, they maintain the current gap in per-btu duties, so for our purposes we are indifferent if or when that increase is finally implemented.

While some of that advantage will undoubtedly be eroded by the presumably higher cost of transport, storage, and handling – which we assume reduced the LNG advantage by \$0.50/gallon – the total gap of \$3.80 per gallon equivalent discount is very significant. If sustained for any length of time, we would expect the UK to begin to see a substantial increase in penetration of LNG into its road fuel market, likely a leader in the trend in Europe.

Figure 68. UK On-Road LNG vs. Diesel Prices

USD/GBP	1.52
Oil, \$/bbl	\$100
Diesel, btu/gal	138,095

	\$/gal	\$/MMBtu	LNG advantage, \$/gal	Notes
Landed ULS diesel	\$2.80	\$20.50		20.5% slope
Excise	\$3.30	\$24.10		£0.5795/liter
VAT	\$1.20	\$8.90		20%
Diesel pump price	\$7.40	\$53.60		
Landed LNG	\$1.90	\$14.00	\$0.90	14% slope
Excise	\$1.10	\$7.80	\$2.30	£0.247/kg
VAT	\$0.60	\$4.40	\$0.60	20%
Shipping, retail margin*	\$0.50	\$3.90	n/a	15%, Citi estimate
LNG pump price*	\$3.60	\$26.20	\$3.80	
LNG-diesel gap	\$3.80	\$27.40	100%	51% discount to diesel
o/w from taxation	\$2.90	\$20.90	76%	
o/w from pricing	\$0.90	\$6.50	24%	

Source: Citi Research

Notes: 1) The retail margin is a (very) roughly estimated additional margin necessary for shipping, storing, and handling LNG relative to diesel; 2) Although European spot prices have been lower over the last 3 years due to the LNG glut, we assume LNG is landed at the current going Asian price for new long-term contracts of c14%.

2. LNG Cost Advantage over Diesel

Although not as large an advantage as seen in the U.S., LNG is still relatively cheap in Europe relative to ultra-low sulfur (ULS) diesel. The extent to which competing LNG projects drive down LNG pricing relative to oil on a global basis (the entry of the U.S. into the global LNG market could conceivably do this), or the extent to which rising LNG demand and rapidly escalating costs for large LNG projects drive up pricing (Australian projects have been plagued by rising costs) will have a noticeable effect on the attractiveness of conversion of truck fleets to LNG, although in Europe this effect will be of secondary nature relative to the effective tax subsidy discussed above.

Current long-term LNG contracts are reportedly being negotiated at slopes of around 14% to oil, which we use as our starting point for our sensitivity analysis.⁷ Although Europe has been getting LNG at effective slopes well below 14% in recent years on its spot market, we believe this was mostly due to the temporary (and largely exhausted) LNG glut of 2009. For planning purposes the owners of European truck fleets will have to consider the sustainability of LNG costs, which implies they may look to long-term, oil-linked contracts in order to lock in the price differentials, which in turn implies LNG costs rising to 14% slopes rather than the 10%-11% slopes seen of late.

⁷ A slope of 14% means that, when oil prices are at \$100/bbl, LNG will cost 14% x \$100 = \$14.0/mmmbtu.

We will compare the landed cost of LNG with the wholesale price of ultra-low-sulfur (ULS) diesel in NW Europe which, as we show in Figure 70, has historically traded at a 20.5% slope to oil in \$/MMBtu.⁸ This 6.5 percentage point gap – a 20.5% slope for ULS diesel vs. a 14% slope for LNG – implies LNG will \$6.50/MMBtu cheaper than ULS diesel in a \$100/bbl oil environment, or c\$0.90 per diesel gallon equivalent.⁹

Citi's assumptions: We use a 13.0% slope in our optimistic scenario, and 14.0% in our pessimistic one. If instead Europe is able to keep prices around the 11% Gazprom slope, then economics will be boosted significantly.

3. Additional Cost of an LNG Truck

Reports vary, but typically indicate that the up-charge (additional cost) of an LNG-fueled, long-haul truck ranges from \$40,000¹⁰ to \$70,000 more than a comparable diesel-only truck. Over time the cost premiums for CNG (Compressed Natural Gas) trucks in the US for fleet use have been squeezed from around \$40k to below \$20k. We would expect the additional cost of an LNG truck to follow a similar path of decline as economies of scale kick in. However, it is as yet early days in this industry, and it is possible that LNG trucks will prove less susceptible to price decreases with mass production than their CNG-fuelled brethren.

Citi's assumptions: We are using \$40,000 as our optimistic scenario, and \$55,000 as our pessimistic one.

4. Truck Efficiency (mileage)

The more efficient the truck, the less compelling the economics for switching to LNG. Since the potential customer for an LNG-powered truck will be in the market for a new, premium-priced truck, our base-case assumption for truck efficiency is a near best-in-class diesel efficiency.

Mercedes recently achieved 25.9 l/100km (8.7mpg) in a 10,000km road test of its premium HD truck. With an aerodynamic trailer, Daimler thinks that fuel consumption can be driven below 25 l/100km (9mpg). However, these are idealistic levels of fuel consumption, with drivers and engineers consciously trying to maximize mileage using experimental equipment. We think real-world efficiencies will remain substantially below this level for some time to come.

Citi's assumptions: Our optimistic case (from the point of view of LNG economics) is run at 7.0mpg (32 l/100km), while our pessimistic case is for 8.0mpg (28 l/100km).

⁸ We have relatively robust data regarding the relative costs of landed LNG and ULS diesel at the wholesale level, but little data as to the relative costs of getting LNG and diesel from the port to the retail filling station and into trucks' fuel tanks. Lacking better data, we assume the cost of shipping and handling between the wholesale and retail levels is \$0.5/gal more expensive for LNG vs. diesel. However, some studies⁸ have suggested that the initial cost of the LNG would typically account for c80% of the pump price in Europe. By comparison, shipping, handling, and other costs associated with getting a liter of diesel from a barge in NW Europe to Germany accounts for an average €0.70/liter, or some 27%⁸ of the final pump cost. This implies that shipping, handling, and other costs between the wholesale point and the retail nozzle may be comparable. If that is so, we are understating the returns available for converting trucks from diesel to LNG.

⁹ To get from \$/MMBtu to \$/gal of diesel equivalent, divide by 7.24.

¹⁰ <http://www.truckinginfo.com/channel/fuel-smarts/article/story/2012/09/natural-gas-what-fleets-need-to-know-part-2-new-engines-more-options.aspx?prestitial=1>

5. Intensity of Use (miles per day)

The more miles a truck is driven on a daily basis, the more sense it makes to switch to an LNG-fuelled truck and its lower equivalent fuel price. Early on, we would expect only the most heavily used trucks to make the conversion – maybe the top 5% of the active fleet – but over time for more lightly used vehicles to make the switch as the refueling infrastructure is built up. But how many miles per day are we talking about?

In the US the very most heavily used trucks can approach 1,000 miles per day¹¹ of regular use, while 350-400 mi/day can be expected of more typical long-haul trucks, we think. In Europe, unfortunately, we have less insight into the distances heavily used trucks cover in a typical day, but think it is likely to be a noticeably smaller number than in the US. Although the quality of the European road network is comparable to that of the US, population density is higher – likely lowering average speeds – and overall distances are shorter. For example, a trip halfway across the country in the US – from Dallas to Los Angeles, say – runs about 1,440 miles. A similar trip halfway across Europe – from Frankfurt to Rome, say – is about half of that at c740 miles.

Therefore, we start our analysis with the assumption that the average heavy-use, heavy-duty truck in Europe travels 300 miles per day on average, 330 days per year, for a total of 99,000 miles per year or 165,000 km.

We have seen reports¹² that heavy-duty LNG trucks are currently being tested in Europe at utilization levels that see the equivalent of 37 to 56 gallons per day of diesel consumption. This is actually in excess of our 29 gal/day of diesel that drops out of our base-case assumptions of 7.0 mpg and 300 mi/day. If the level of usage of those trucks subject to those tests represents a significant segment of the market, say 5% of the European fleet, then the potential for LNG demand for on-road use is significant.

Citi's assumptions: We are using 300 mi/day for our optimistic assumption, and 200 mi/day in our pessimistic scenario. We suggest looking at the sensitivity to this assumption mostly as a guide to how far and how quickly LNG might penetrate into the European truck fleet.

6. Oil Prices

With LNG prices typically set via long-term contract as a fixed percentage of oil prices, the higher oil prices go, the larger the actual gap between LNG and diesel in dollars per unit of energy and the larger the stimulus to switch fuels.

Sensitivity Results

In Figure 69 we present the sensitivity of on-road LNG economics to the 6 prime drivers we discussed above: Under our optimistic scenario, an investment in an LNG truck will give the operator an IRR of 62% and a payback period of 1.8 years. However, under our pessimistic scenario (all-in), returns drop precipitously to only 3% with a 6.2 year payback.

¹¹ <http://www.lngworldnews.com/fedex-freight-testing-new-lng-tractors/>

¹² http://www.unece.org/fileadmin/DAM/energy/se/pp/wpgas/21wpg_2011/18Jan2011/Aubee_IPaceGlobal.pdf

- **Oil prices:** Due to the high level of tax subsidy, oil prices have a relatively small impact on economics, reducing the IRR we calculate from 62% to 55% and increasing the payback in an LNG truck from 1.8 years to 2.0 years.
- **LNG slopes:** For similar reasons, the sensitivity to LNG price slopes is relatively modest, with an increase in the slope from 13.0% to 14.0% only decreasing the IRR from 62% to 56%.
- **Tax advantage:** Here the sensitivities are understandably larger. If we lower our assumed tax advantage from the current \$1.75/gal to \$1.00/gal, the IRR is reduced from 62% to 33% and the payback period increased from 1.8 years to 2.7 years.
- **Intensity of usage:** This is another relatively critical assumption, as lowering it from 300mi/day to 250mi/day lowers the IRR from 62% to 46%.
- **Efficiency:** Increasing the mileage of the truck from 7.0mpg to 8.0mpg drops the IRR from 62% to 50%.
- **Upcharge:** Under our optimistic scenario, truck makers are able to drive down the additional cost of an LNG truck down to \$40k. However, if this proves stubborn and the upcharge remains at a relatively high \$55k/truck, then the IRR is reduced from 62% to 37%.

Figure 69. LNG for Diesel Substitution: Sensitivities for Truck Purchasers

	Optimistic	Oil	LNG	Tax adv	Intensity	Efficiency	Up-charge	Pessimistic
Oil, \$/bbl	\$100	\$85	\$100	\$100	\$100	\$100	\$100	\$85
Diesel, \$/gal	\$2.83	\$2.41	\$2.83	\$2.83	\$2.83	\$2.83	\$2.83	\$2.41
LNG slope	13.00%	13.00%	14.00%	13.00%	13.00%	13.00%	13.00%	14.00%
LNG, \$/MMBtu	\$13.00	\$11.10	\$14.00	\$13.00	\$13.00	\$13.00	\$13.00	\$11.90
LNG, \$/gal equivalent	\$1.80	\$1.53	\$1.93	\$1.80	\$1.80	\$1.80	\$1.80	\$1.64
LNG price advantage, \$/gal equiv	\$1.04	\$0.88	\$0.90	\$1.04	\$1.04	\$1.04	\$1.04	\$0.76
LNG tax advantage, \$/gal equiv	\$1.75	\$1.75	\$1.75	\$1.00	\$1.75	\$1.75	\$1.75	\$1.00
Total LNG cost advantage, \$/gal equiv	\$2.79	\$2.63	\$2.65	\$2.04	\$2.79	\$2.79	\$2.79	\$1.76
Miles/day	300	300	300	300	250	300	300	250
Efficiency, mi/gal	7	7	7	7	7	8	7	8
LNG truck cost (extra), \$k	\$40	\$40	\$40	\$40	\$40	\$40	\$55	\$55
NPV10	\$47.10	\$41.90	\$42.50	\$22.20	\$34.40	\$37.60	\$36.30	(\$9.10)
IRR	62%	55%	56%	33%	46%	50%	37%	3%
Payback, years	1.8	2	1.9	2.7	2.2	2.1	2.5	6.2

Source: Citi Research

Notes: 1) We are comparing wholesale diesel prices (NW Europe barge) to landed LNG prices, assuming distribution costs to be similar; 2) We assume identical tax treatment on a \$/MMBtu basis, although we expect LNG to be favored for ecological and other policy reasons; 3) We assume each truck is run 330 days of the year, with the other 30 to account for holidays and maintenance

More on Utilization vs. Up-Charges

Aside from the tax and cost advantage – which are fairly transparent to us¹³ – the key drivers we isolate from the discussion above are the upcharge on a heavy-duty, LNG-fuelled truck and the number of miles that truck can be expected to cover on a typical day.

For example, if the up-charge is \$70,000 – at the upper end of the reported range that we've seen – then assuming \$85/bbl oil, a 14% LNG slope, a \$1/gal tax advantage for LNG over diesel (vs. the current \$1.75/gal we see), and a \$0.50/gal in additional distribution and retail costs for LNG – a truck will have to be used on average around 550 miles per day on a 330 day operating year, or 181,500 miles/year in order to achieve a 25% IRR.

However, if higher production runs and incremental improvements in manufacturing bring down the additional cost of an LNG truck from \$70k to \$50k, then trucks running 400mi/day can achieve a 25% IRR on the investment, bringing the technology to a broader swath of Europe's truck fleet.

Note that the current tax subsidy of \$1.75/gal, the miles needed to justify that \$70,000 upcharge is a reasonable 345mi/day, or 114,000 miles per year. It will take some time and higher volume production to bring down up-charges, so we would expect market penetration to start with only the most heavily used trucks, perhaps those running back and forth between ports and/or distribution centers. Later, as costs come down and as the availability of LNG refueling stations becomes more widespread, we'd expect to see trucks with lower levels of utilization begin to switch from diesel to LNG, tempered by any reduction in tax advantages as European governments presumably begin to try to moderate revenues losses from the fuel-switching.

Industry Trends

Europe's industrial base and politicians are just beginning the work required to allow gas to make significant inroads into Europe's on-road fuels market. However, although it is undoubtedly early days yet, both trucks and some fuelling points are now available, allowing the process to begin.

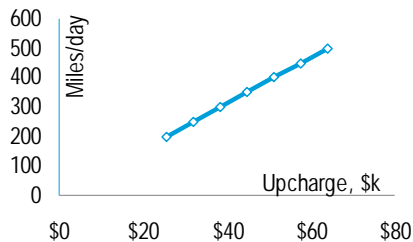
Product: Truck Makers Introducing Products

The number of available LNG-fuelled trucks in Europe is modest but expanding, and includes products from IVECO (Stralis), Mercedes (Econic), Scania (P310 LNG), and Volvo (MethaneDiesel). Engines offered generally range from 270hp to 330hp, but larger (>400hp) models are on the way.

Volvo began taking orders for the MethaneDiesel in May of 2011, with limited production to start that August. Volvo at the time expected to sell about 100 units in Sweden, Britain and the Netherlands – the 3 European markets with the best availability of LNG – ramping up to 400 trucks in 2012 with sales expanding to additional, unnamed markets in Europe. In 2011 the initial MethaneDiesel trucks were offered in the UK, Sweden and the Netherlands at a £30,000 (\$45,000) price premium (upcharge) to the comparable diesel-only version of the same truck, although we have seen other data indicating the upcharge is €45,000 (\$58,000).

The MethaneDiesel is a dual fuel truck, using a mix of 75% natural gas (LNG) and 25% diesel in mixed mode, or purely on diesel if LNG is unavailable. Note the split in the fuel is 75/25 gas/diesel only in ideal conditions, and in stop and start traffic the mix can move to more like 50/50, decreasing the cost advantage of diesel. A better estimate for the average gas to diesel fuel mix would be maybe 67/33.

Figure 70. Upcharge vs. Mileage for 25% IRR



Source: Citi Research

Note: Assumptions include \$85/bbl oil; 14% LNG slope; \$1/gal tax advantage for LNG over diesel; \$0.5/gal higher retail costs for LNG.

The availability of LNG-fuelled trucks is expanding in Europe

¹³ Barring the extra cost of distribution and retail relative to diesel

Infrastructure: European Mandate for Infrastructure

The European Commission is supporting the build-out of a network of alternative fuel stations across Europe. The LNG portion of the EC's efforts will focus first on ensuring a minimal threshold of LNG bunkering in Europe's ports to allow the conversion of local shipping from fuel oil to LNG. With the sulfur mandates on fuel oil pushing prices effectively to the level of ULS diesel, LNG is looking like a good alternative for bunkering fuel as well as for the trucking industry. The EC is proposing that LNG refueling stations be available in all 139 of Europe's major maritime ports by 2020.

At this time there are only 38 LNG filling stations in the EU, so the EC is proposing that by 2020 refueling stations be available at least every 400km (240mi) along the Trans European Core Network of roads.¹⁴

Implications of LNG for Diesel Substitution

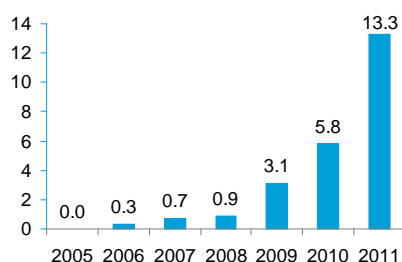
The main conclusion for us from this study is that, should LNG trucks indeed begin to take material market share from diesel-fuelled trucks in Europe, the impact on the global LNG market could be material. The advent of LNG-fuelled trucks would likely result in a strengthening of the oil link in LNG pricing.

LNG Consumption Potential

NGVA Europe¹⁵ estimates the number of Medium & Heavy Duty (MHD) natural gas fueled¹⁶ trucks in the region as being around 5,100, with MHD busses adding another 12,500 to that. Those numbers are relatively small, with natural gas fueling only c0.2% of the near 4mn MHD diesel-fueled trucks on the road in Europe.

However, if the economics are right, then China has shown that growth can be rapid. Albeit from a low base, China's LNG vehicle (LNGV) count has been growing by leaps and bounds in recent years (Figure 71), from zero in 2005 to 13,300 in 2011, the most recent data we have, and reportedly accounted for a significant 8% of HD truck sales in 2012.¹⁷

Figure 71. China's LNG Vehicle Count, k units



Source: Westport

Applying the same basic inputs we used in Figure 69 (300 miles/day for 330 days per year and 7.0mpg), we calculate a heavy-duty truck would use about 25 tons of LNG per year. As such, it would take about 29,000 such trucks to consume 1bcm of LNG per annum, or about 39,000 trucks to consume 1mtpa of LNG. This amounts to c0.9% of the existing diesel-powered fleet by numbers of trucks. However, as we would expect LNG to penetrate the market first among the heaviest users of fuel, the effect could be somewhat larger, depending upon just how heavily that top few percent of European trucks are utilized.

Assuming the economics were compelling – which our work suggests might be the case, given the quite favorable tax treatment of on-road LNG vs. diesel – then we think it plausible that LNG-fuelled truck sales could ramp up to take 20% of annual new truck sales in Europe by 2020. In that case, by 2025 LNG trucks could account for maybe 9% of Europe's current medium and heavy-duty diesel-fueled truck fleet and consume about 12bcm per year of LNG, with usage growing about 1.5bcm per annum going forward.

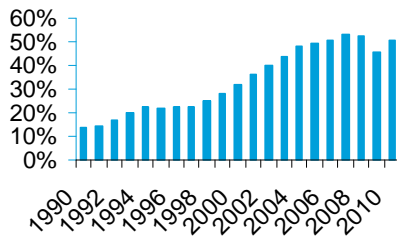
¹⁴ http://ec.europa.eu/commission_2010-2014/kallas/headlines/news/2013/01/clean-fuel-strategy_en.htm

¹⁵ http://www.unece.org/fileadmin/DAM/energy/se/pp/wpgas/21wpg_2011/18Jan2011/Au_bee_IPaceGlobal.pdf

¹⁶ No data was available as to what fraction of these vehicles use LNG as opposed to CNG, but we assume the latter fuel dominates at this time.

¹⁷ <http://www.businessspectator.com.au/article/2013/4/2/resources-and-energy/invisible-assassin-stalking-oil-demand>

Figure 72. European Passenger Car Registrations, % diesel



Source: European Automobile Manufacturers' Assoc.

Is this level of penetration possible? We think so, and we have a precedent to guide us in the form of diesel-power cars in Europe. Faced with a compelling value proposition – diesel being noticeably cheaper than gasoline in Europe due to taxation policy, an interesting parallel to the LNG-vs.-diesel situation currently – diesel penetration rose from 14% of the European car market in 1990 to 53% in 2007 (Figure 72). While we think a similar level of penetration in the HD truck market unlikely – it would likely over-stress LNG supply, driving up prices and therefore reducing the investment to convert trucks to diesel – this still shows that a sea change in on-road fuels is possible provided the correct incentives are in place.

We have seen estimates that penetration of LNG into the European HD truck fleet could hit 5% by 2015 and 15% by 2020. Although our numbers suggest that this level of penetration so soon seems a bit ambitious to us, it is not impossible.¹⁸

Blue-Sky Potential Impact on LNG Market

According to the IEA, OECD Europe currently uses about 5.7mmbpd of diesel. Of that, some 2.1mmbpd is consumed by trucks.¹⁹ If one could magically convert all of that to LNG usage, it would require about 91mt (124bcm) of LNG, almost 40% of the 323bcm of LNG traded globally in 2012. While that level of substitution is not possible, even 20% conversion of all European truck diesel consumption into LNG would absorb 25bcm of LNG, or over 50% of the LNG imported into Europe imported in 2012, or 8% of total global trade.

In other words, were a noticeable portion of Europe's truck fleet to be converted to LNG from diesel, it could result in a material increase in global LNG demand. This exercise is intended more as sensitivity tests than prediction: Although we can see the potential in this trend, it is as yet early days, and predicting growth rates and market penetration levels even 5 years out is fraught with difficulties. Rather, we are seeking here to delineate the boundaries within which the trend may develop.

On-Road LNG Re-Links Oil and Gas on Demand Side

With the effective elimination of fuel oil from the European electricity generation mix, gas and oil had lost much of the demand-side link that used to exist between the two fuels. Between that and the development of the U.S. shale revolution – which decidedly broke the relationship between oil and gas prices in that country in 2008 – global gas producers have seen pressure put on their long-term contracts that expressly link gas prices to oil prices.

This has affected not only LNG producers – which have seen the slopes they could negotiate for their product drop from 15%-17% in the previous decade to around 14% lately – but sellers of pipeline gas as well. Since 2009 both Gazprom and Statoil have had to link at least some of their long-term European contract prices to spot prices. The Norwegian company has embraced this more enthusiastically than the Russian company, but both still have significant oil-linked contract volumes at stake. Additionally, in 2012 Gazprom extended around 10% formula discounts to practically all of its European customers.

However, the development of LNG-fuelled trucking would have gas once again become a direct substitute for oil and, could support the link between oil prices and LNG prices.

¹⁸ http://www.nytimes.com/2013/04/23/business/energy-environment/natural-gas-use-in-long-haul-trucks-expected-to-rise.html?pagewanted=all&_r=0

¹⁹ Data per FACTS Global Energy

Energy 2020: Macro Analysis

5. NGVs in Other Regions

Edward L Morse

Global Head of Commodities Research

Anthony Yuen

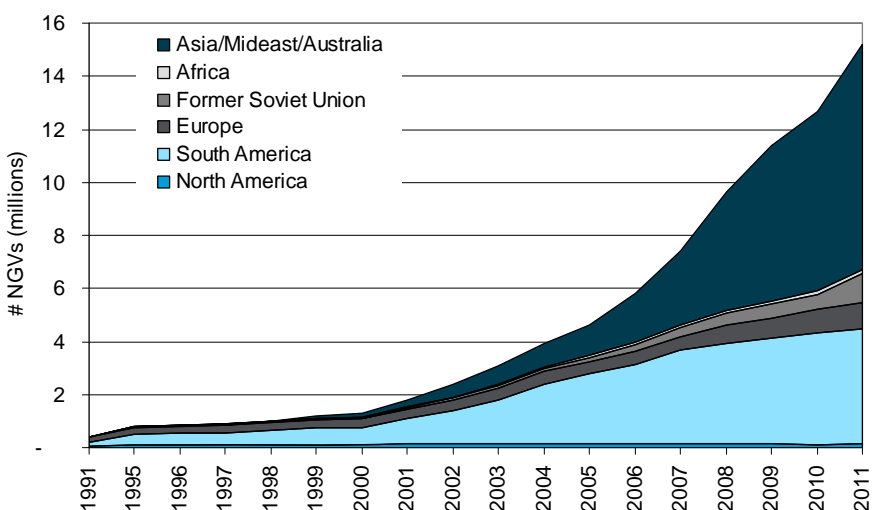
Gas & Power Commodities Research

Seth M Kleinman

Head of Energy Strategy

The growth of NGVs accelerated starting in the late 1990s, with South America first taking the lead before demand in Asia surged within the last ten years. Europe and North America only saw modest growth in the last twenty years until now. Total number of NGVs worldwide grew from about 0.4-million in 1991 to 15-million in 2011, driven mainly by two emerging market areas: total NGVs in South America rose from about 0.13-million to 4.3-million in the same period but Asia was even stronger, from near zero to 8.4-million. The growth in China is particularly remarkable, as discussed in an earlier section.

Figure 73. Number of NGVs Globally (1991-2011)



Source: NGV Global, Citi Research

A combination of factors contributed to the strong increase in emerging market areas. Fuel economics favorable to natural gas, particularly if retail prices are controlled by the government, incentivize a switch from liquid-petroleum-based fuels to natural gas. This is particularly the case for natural gas producing countries. In addition, for fuel diversity or supply/national security reasons, governments in some countries often provide further incentives to switch. The case in point is Iran and Thailand. Changes in subsidies also indirectly affect NGV use: when Malaysia gradually removed subsidies for diesel and gasoline, the conversion to NGV surged. Further, environmental concerns have been a critical demand driver of NGVs, such as what has happened in India starting about 10 years ago.

Iran

Energy security concerns have driven Iran's rapid adoption of NGVs. Government support and incentives have driven Iran's rapid adoption of NGVs. The government aims to reduce the country's dependence on gasoline imports - a source of strategic vulnerability - in addition to the general concern on the overall energy security. A detailed incentive plan was revealed in 2006 under President Ahmadinejad's administration, with a focus on conversion of existing cars to NGV and a massive build of refueling stations. Specifically, the plan called for the conversion of most

(Iran's government aims to reduce the country's dependence on gasoline imports, driving adoption of NGVs)

cars to run on natural gas by 2015, at an annual rate of 1.2 million additional cars, along with retrofitting 10,000 refueling stations to supply natural gas.

Pakistan

Government incentives and high domestic petroleum prices are drives for NGVs in Pakistan

The shortage of natural gas and safety problems has become an issue for NGV development, which began after discoveries of gas in the country, both onshore and offshore. Pakistan has seen a major shift towards CNG vehicles in both public transportation fleets and private sector in the last few decades, mostly due to government incentives and high domestic petroleum prices. According to NGV Global, there are some 3 million NGVs on the road. However, the growth of NGV is being constrained by a couple of factors: a shortage of natural gas and the rising number of accidents involving CNG vehicles. Over 2000 persons were killed in CNG cylinders' accidents in 2011. Subsequently, Pakistan's Minister of Petroleum announced policies to gradually phase-out CNG. This included a policy to stop issuing new licenses and cease renewing contracts of CNG refueling stations currently in operation. The country also appears to be banning new conversions to CNG and manufacture of new NGVs.

South America

NGVs are typically flex-fuel cars that run on natural gas, gasoline, E20-25 or E100

Natural gas vehicles are common in big cities, especially for taxicabs. NGVs in South America are typically flex-fuel cars that can run on natural gas, gasoline, E20-E25 or even E100. This helps to ease the problem of infrastructure build and affords greater flexibility on NGVs. Argentina has over 2 million NGVs on the road. The NGV industry grew with limited government intervention or support. Instead, high gasoline taxes, rich natural gas resources, price-controlled natural gas and a well-established pipeline system fostered the adoption of NGVs. The government has since encouraged the development of the NGV industry, especially CNG vehicles, due partly to the number of jobs that the industry creates. The country also exports NGV equipment and technology globally. Brazil also has nearly 2 million NGVs. To take advantage of low natural gas prices, industries have extended their world-leading bi-fuel cars that can run on gasoline and ethanol into tri-fuel cars that can also burn natural gas. The cost of converting a car to NGVs is about 25% of the prices in U.S.

Canada

The Canadian Green Corridor spearheaded by Shell involves LNG refueling stations for heavy duty trucking along key highways in Alberta that connect Edmonton and Calgary, as well as other locations for off-road and industrial uses. LNG would be produced by a Movable Modular Liquefaction System (MMLS), with a capacity of 0.25-mtpa, currently under construction.

6. Other Conversions – Rail & Marine

Rail

Railroads may be able to leverage alternative fuels

While trucking and passenger vehicles typically dominate discussions of natural gas fuel application potential, we also note that railroads may be able to leverage alternative fuels, albeit with a slightly different set of applications and challenges. Railways are another mode of transportation in which natural gas looks set to start displacing diesel in a transition similar to the shift from coal to oil decades ago.

Cost and complexity are hurdles to adoption

While railroads own their own land and could build terminal natural gas infrastructure along their lines, doing so would require a large investment. Additionally, maintaining asset utilization could be pressured given that having to refuel a locomotive could add additional layers of complexity to running an efficient railroad, particularly for manifest freight (trains hauling different types of freight cars headed to different end markets). Given that the length of haul for a train routinely exceeds 1,000 miles, which can also include stops at hump yards and switch yards, the investment in fueling facilities and inefficiencies from refueling along the track lines may be large.

In fact, the U.S., Canada, Russia and India are all starting to test LNG powered locomotives. The costs of modifying a diesel-electric locomotive to running on LNG reportedly run at \$600,000 to \$1m, but as one locomotive can burn 400,000 gallons of diesel in a year and on an energy-equivalent basis natural gas is more than \$1/gal cheaper, payback periods can be quick. Both Caterpillar and engine manufacturer Westport have announced plans to make natural gas powered locomotives, albeit no formal timetables are available as of yet. The announcement in March 2013 that BNSF, the railroad company owned by Warren Buffet's Berkshire Hathaway, is to start testing LNG as a fuel, is likely a precursor of things to come in the heavy rail transport sector.

Figure 74. Tonnage of Trailer-on-Flatcar and Container-on-Flatcar Rail Intermodal Moves – Freight Traffic Dominated by Several Key Routes (2010)



Source: US Department of Transportation

Feasibility studies are starting in rails as cost arbitrage appears compelling

While there is limited information, data and studies regarding the potential for railroads to utilize natural gas, there is clearly potential given that Burlington Northern Santa Fe has engaged feasibility studies and preliminary testing on LNG powered locomotives. With \$4/gallon diesel and 48c DGE for industrial grade natural gas, the cost arbitrage appears compelling. Additionally, the fact that rails own their own land and infrastructure, and have the scale to invest in LNG technology eliminates two important impediments to adopting the technology.

BNSF is working with GE and Caterpillar to develop and test the use of LNG-powered locomotives. A small number of locomotives should enter the testing phase in later in 2013. This development is not confined to the US. Canadian National Railway (CN) was field-testing two diesel-electric locomotives burning LNG instead. Russia has developed the GT1-001 gas-turbine-electric locomotive that can haul 16,000 tons in 170 rail cars, with 17 tons of LNG fuel-tanks onboard. It has a range of 750km.

Canadian diesel demand for powering rail is ~40-kb/d, in India it is ~50-kb/d. Canada is currently testing two LNG fuelled locomotives in northern Alberta. India is reportedly going to tender for LNG powered trains, with Russia reportedly interested in supplying them. Russia itself is planning an LNG locomotive prototype that, if tests go well starting in 2013, should be followed by 39 more for delivery by 2020.

Tender cars that store LNG can trace their history back to at least 1994 when it was introduced by Union Pacific (the rail company). One type of tender car has a net volume of 26-k gallons. Using internal pumps, low pressure gas can be transferred to the locomotive as a fuel. Challenges going forward include the standardization of tender cars, locomotives and engines, a robust emergency shut-off between the tender and locomotive, so that accidents at one end won't affect the other, as well as the optimal selection of fuel phase for transfer: liquid or gaseous.

Marine Transport

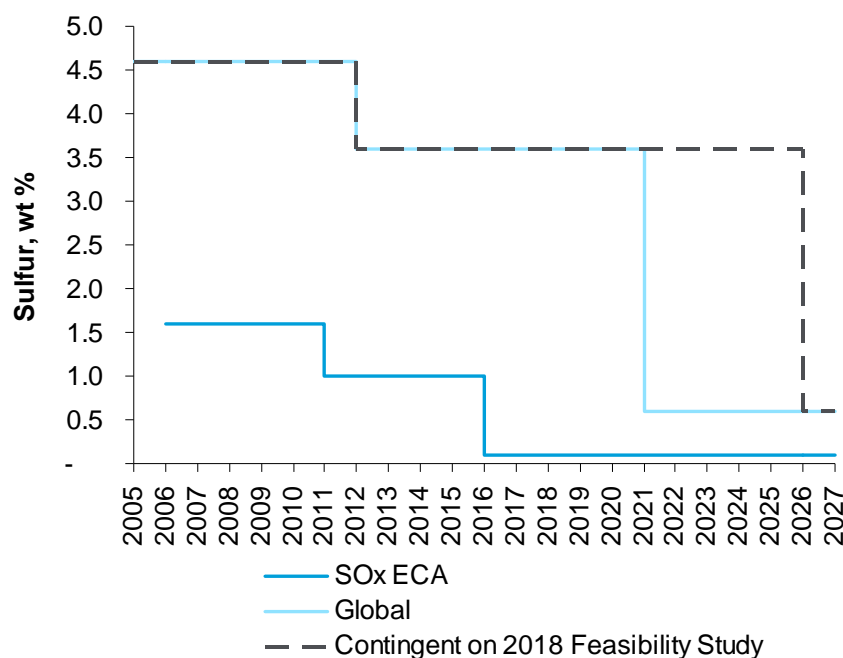
Natural gas is expected to make inroads in bunker fuel for shipping

Bunker fuel for shipping is another area in which natural gas is expected to make inroads into oil demand in the coming years. Global bunker is over 3.5 mb/d of oil demand, with around 300 kb/d of residual fuel demand in the US accounted for by bunkering.

Regulation on SOx and NOx likely to drive adoption

A major driver of gas-for-oil substitution in marine transport is the protocol by the International Maritime Organization, adopted in 1997 and implemented in 2005. Annex VI in MARPOL (ie, Marine Pollution) sets limits ship exhausts of sulfur oxide (SOx) and nitrogen oxide (NOx) emission. Special SOx Emission Control Areas (SECAs) are created with more stringent regulations, where either the sulfur content of fuel oil used must not exceed 1.5% m/m or that ships must be retrofitted with emission control technology to limit SOx emissions.

Figure 75. Sulfur limit by MARPOL Annex VI – Falling Emissions Limit a Driver of Fuel-Switching



Source: IMO, Poten and Partners, Citi Research

Several major ports in Europe, including the Netherlands, Norway and nations along the Baltic Sea are already supplying LNG for marine transport.

Natural gas has already captured 6% of the marine fuel market, consuming about 12-mtpa (12-million tonne per annum) of LNG out of a market potential of 185-mtpa currently dominated by 180-mt of intermediate fuel oil and 55-mt of marine gasoil. In comparison, the fuel consumption of a container ship is roughly equivalent to about the demand of 3,500 class 8 trucks.

Intermediate fuel oil use is hindered by the requirement of scrubbers in new regulation

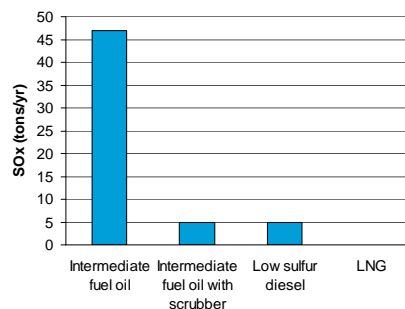
Marine diesel oil or gasoil is an option but higher fuel prices make it less competitive vs. LNG

In light of stringent emission rules in ECAs, ships consuming intermediate fuel oil (IFO) face with several choices that should move a certain segment to the LNG option. Some ships could retrofit with sulfur scrubbers, but the cost is prohibitive and NOx control remains an issue, where SCRs (Selective Catalytic Reduction) would have to be installed for some. Maintenance of emission control equipment could complicate ship operation. In addition, the design of some ships prevents them from installing scrubbers.

Using marine diesel oil (MDO) or marine gasoil (MGO) is an option that requires less ship modification. The refueling infrastructure is also widely available, but higher fuel prices vs. intermediate fuel oil and LNG make it much less competitive. NOx emissions are also not fully under control and SCR needs to be installed. Note that these sulfur scrubbers and SCRs are the same type of emission abatement equipment that has to be installed at coal-fired power plants in the U.S. due to existing emission rules. The high retrofit cost involved is expected to force at least 50-GW of coal units to retire by the middle of this decade. This capacity is equivalent to the entire nuclear fleet in Japan.

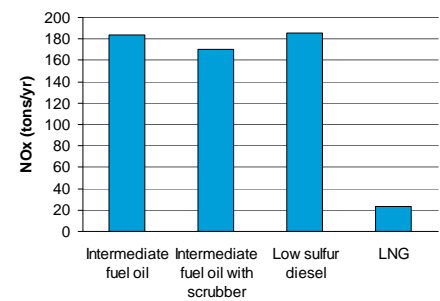
The following graphs illustrate the amount of emissions for a typical Baltic Sea cargo ship using different fuels:

Figure 76. SOx Emissions(Tons year)



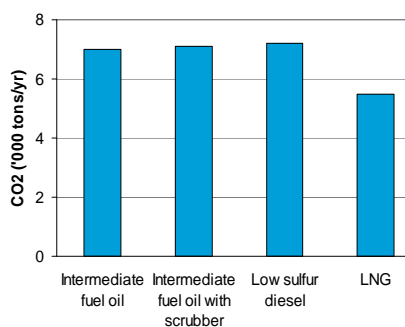
Source: DNV, Citi Research

Figure 77. NOx Emissions (Tons/year)



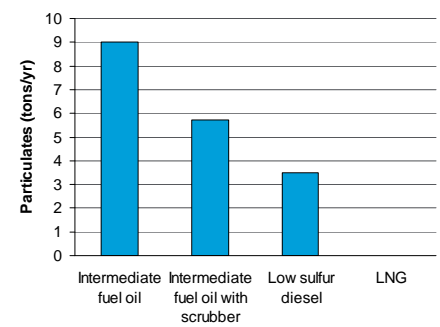
Source: DNV, Citi Research

Figure 78. CO2 Emissions (Tons/year)



Source: DNV, Citi Research

Figure 79. Particulate Emissions (Tons/year)



Source: DNV, Citi Research

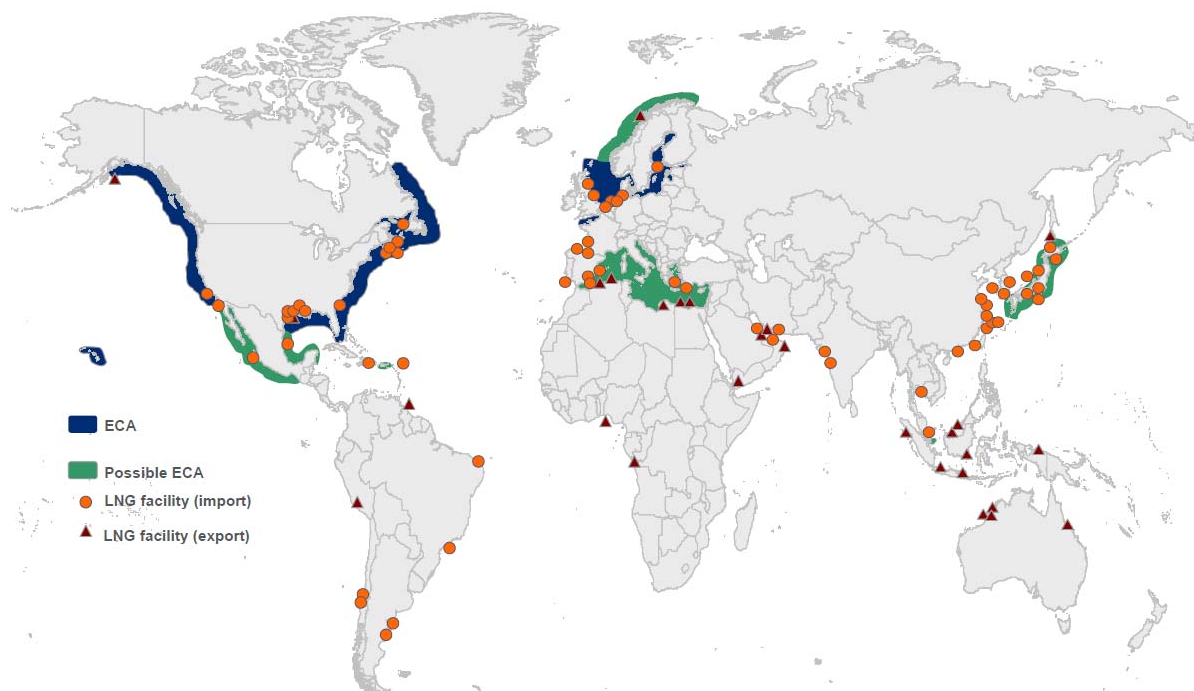
Negligible emission of SOx and NOx along with better fuel economies than MDO and MGO makes LNG a competitive choice in shipping

This leaves LNG as an option for wider adoption as a marine transport fuel. Its negligible emission of SOx and NOx, along with better fuel economies than MDO and MGO, makes LNG a competitive choice. LNG-powered ships also have significantly lower maintenance costs due to its much cleaner burning attributes, unlike IFO and MDO/MGO. However, retrofitting existing ships with LNG tanks and making other modifications limit the appeal of LNG use in existing ships, especially given low tanker day rates reducing the return on capital investment. New ships face none of these obstacles and could be designed to accommodate the use of LNG.

Infrastructure was previously thought to be a major obstacle, but natural gas liquefaction or regasification facilities are typically in close proximity to major shipping ports. Along with the development of small-scale LNG facilities that also supply LNG use by on-road vehicles, the infrastructure hurdle can be overcome.

Factors that remain to stimulate this market going forward are ship regulations and specifications, which allow for certain transfer/refueling of LNG. Regulations on shore-to-ship, truck-to-ship and ship-to-ship bunkering would need to be implemented for safe adoption of LNG as a marine transport fuel. The final draft regulation (ISO TC67WG10PT1) should be available in 2Q'13.

Figure 80. Major Bunker Ports Globally – a Number of Major Ports are Close to LNG Facilities, Easing the Need for Infrastructure Build-Out

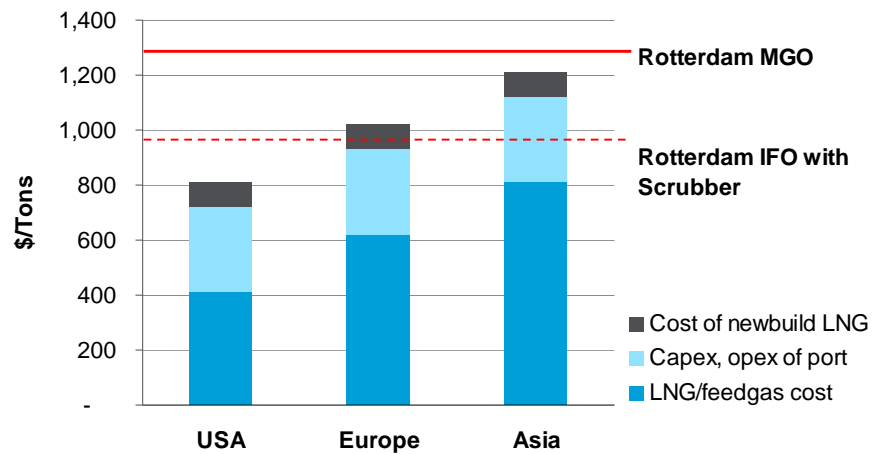


Source: Platts, IMO, Poten and Partners, Citi Research

Fuel economics are power drives, especially in North America

Fuel economics are powerful drivers globally, especially in North America. On an equivalent basis, intermediate fuel oil costs about \$16/MMBtu at a Brent oil price of ~\$100. Ships switching from IFO would have to pay about \$22/MMBtu for MDO/MGO. In comparison, long term natural gas prices should remain in the \$4 to 6/MMBtu range in North America, \$8 to 10/MMBtu in Europe and \$11 to 14/MMBtu in Asia. Citi examined the global natural gas market in the report "[Natural Gas – Bumpy Road to Global Markets](#)" (Dec 11, 2012).

Figure 81. Fuel Economics of LNG for Marine Transportation vs. Fuel Oil and Marine Gasoil (MGO)

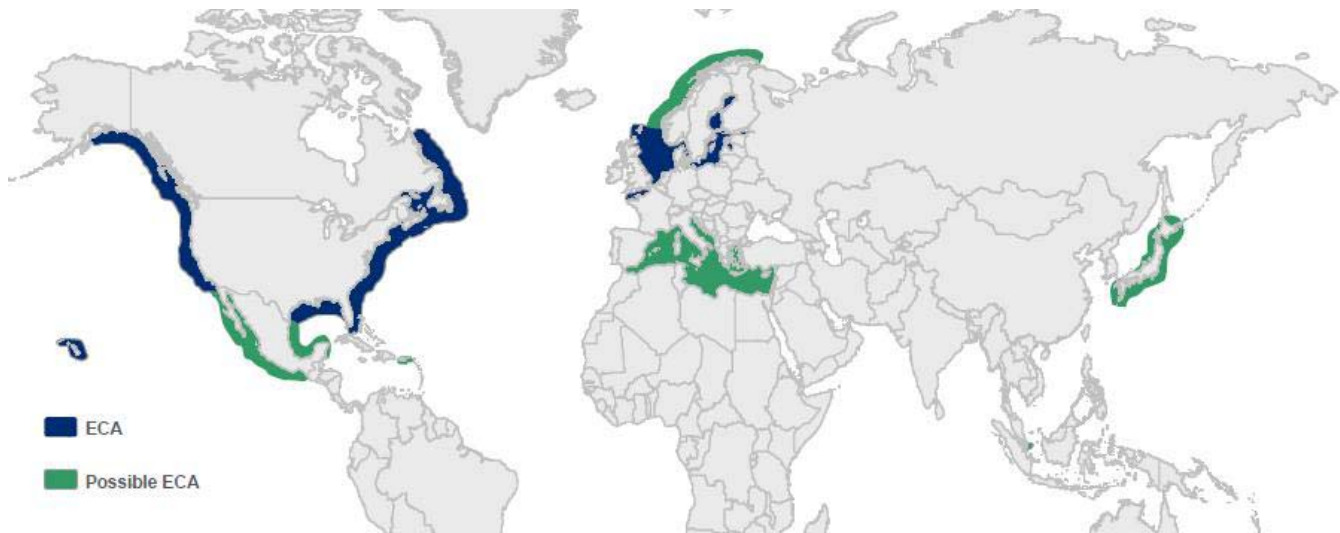


Source: Poten and Partners, Citi Research

Lack of infrastructure and ship models is an issue, as in NGVs

Marine transport's use of LNG faces similar issues as on-road NGVs, with a lack of infrastructure and ship models. However, most historical episodes of fuel-switching, as outlined in earlier sections, involved these same types of obstacles but the transition still took place. In global marine transport, comparative fuel economics and emission rules as discussed above are powerful drivers for adoption. Estimates from Poten and Partners suggest that if there is global sulfur limitation by 2020, the LNG demand for marine transport could reach ~2.5-mtpa (0.3-Bcf/d) in 2020 and ~24-mtpa (~3.2-Bcf/d) by 2025. If global sulfur limitation were implemented by 2025 instead, LNG demand could still rise to ~8-mtpa (1.1-Bcf/d) by 2025. Of course, without a global sulfur limit, the incentive to switch falls. TOTAL estimates that LNG demand for marine transport could reach 11-mtpa (~1.5-Bcf/d) in 2020 and 33-mtpa (~4.5-Bcf/d) in 2030. These could be 5% and 10% of the overall marine fuel market, respectively. The conversion to LNG could be faster than expected.

Figure 82. Current and Potential New Emission Control Areas (ECAs) – Possible Drivers of Fuel-Switching from Fuel Oil to Diesel and/or LNG



Source: IMO, DNV, Citi Research

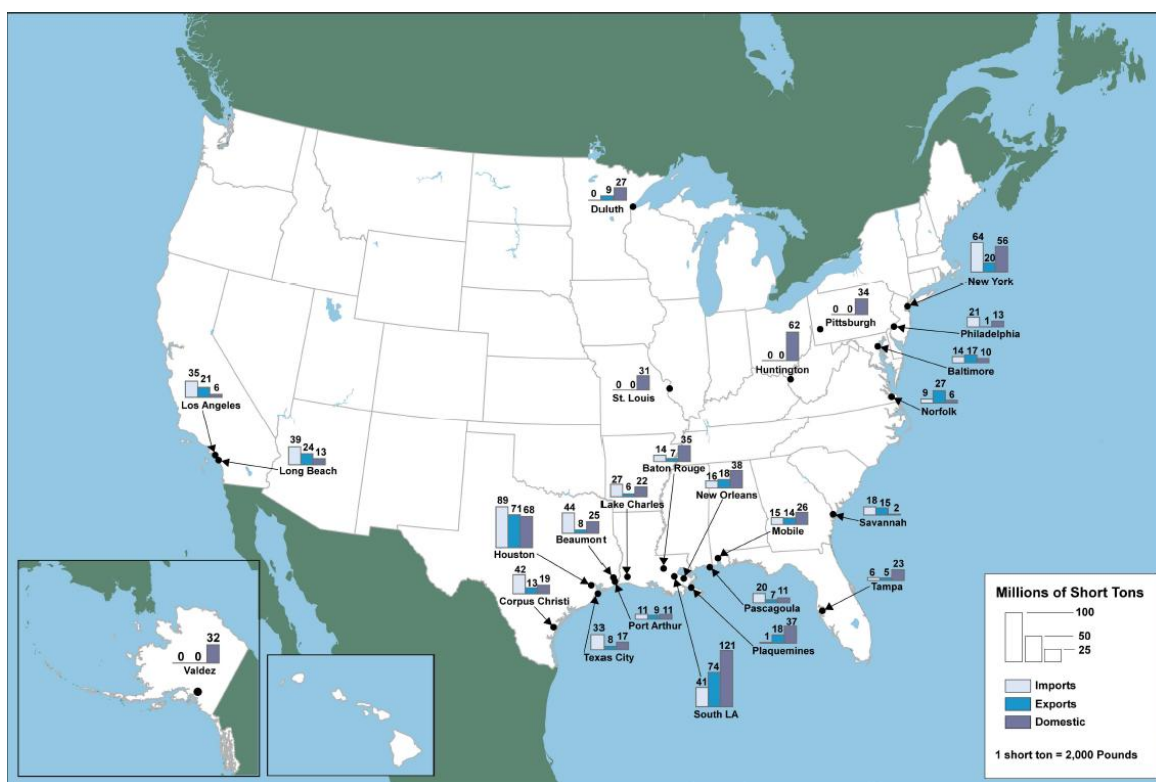
But as with NGVs, starting with high traffic ports....

Within the U.S., several ports dominate marine traffic and these could be first ones to have LNG refueling facilities constructed. Recall in the earlier section about the majority of the domestic barge traffic takes place on the Mississippi River, retrofitting barges that traverse this route should capture the majority of the market: in particular, South LA, Houston, New Orleans, Plaquemines, Baton Rouge, St. Louis, Huntington and Pittsburgh are all along the Mississippi or within close proximity of domestic barge traffic.

...and some key liquefaction facilities, will help

Shell is looking to build two small-scale liquefaction facilities located in the Gulf Coast and Great Lakes region, supplying the LNG demand from the expected growth of on-road NGVs and marine transport in those regions. In particular, the Gulf Coast facility, which has a capacity of 0.25-mtpa and should come online in three years, will be located at Shell's Geismar Chemical facility in Louisiana. The marine market will encompass the Mississippi River, Intra-Coastal Waterway and US Gulf of Mexico. The LNG produced will be barged to refueling facilities and bunkered into customer vessels.

Figure 83. Top 25 Ports by Tonnage – Traffic Dominated by Several Key Ports (2010)



Source: US Department of Transportation

Figure 84. Top 25 Water Ports by Containerized Cargo – Traffic Dominated by Several Key Ports (2010)



Source: US Department of Transportation

Container port infrastructure may be less

The infrastructure requirement may also be smaller than expected for container ports, as certain ports also dominate container traffic in the U.S. and globally as highlighted in the graph above for the U.S. and Fig. 13 for the worldwide market. This dominance by a few ports means that, once these ports are outfitted with LNG supply capability, container ships that travel only between these ports could more easily switch fuels and adopt LNG, instead of the more expensive diesel.

On a more regional level, ferries and other smaller-sized ships can also make use of natural gas as a fuel for fuel savings and environmental reasons. For example, the Staten Island Ferry in New York will convert one Austen-class ferry from low sulfur diesel to LNG in 2013 and Washington State Ferries has received Coast Guard approval to retrofit six of the ferries that travel around Puget Sound.

Aviation

Little prospects for airlines switching to CNG or LNG in the near future

There is little prospect in the immediate future of airlines switching to CNG or LNG, but earlier this year Qatar Airways did make the first commercial flight running on a blend of natural gas-to-liquids (GTL) and conventional jet fuel, and Boeing has completed a concept study for NASA looking at possible future fuel technologies including LNG.

7. Gas Availability – Production & Distribution

Gas Production

The world is very gas prone. Between 1988 and 2011, global proved gas reserves grew by 92%, climbing significantly in recent years because of the shale gas revolution and other offshore discoveries. In contrast, proved oil reserves only rose by 61% during the same period.

North America

North America has thus far seen the strongest natural gas production growth benefiting from the shale gas revolution, but shale is also present in many places globally. As the source rock of hydrocarbons in conventional reservoirs that have served as the bedrock of global oil and gas production, shale formations are being tapped, with advances in technology – mainly hydraulic fracturing and horizontal drilling – unlocking vast amounts of gas as well as oil.

U.S. gas production could rise by more than 20-Bcf/d between 2012 and 2020

Specifically, production in the U.S. could rise by more than 20-Bcf/d between 2012 and 2020 even if gas rig counts stay at a low level of around 400. Gas production may not necessarily fall despite a sharply lower gas drilling rig count. Three key areas will be supporting production growth despite low rig counts: technological improvements, associated gas production and clearing of the backlog of drilled-but-not producing wells.

Technology has led to increased efficiency and production rates...

First, technological improvements have increased the efficiency and production rates over the last few years in the modern shale drilling era, but multi-fold increase could very well be possible. Better well-bore placement, fracturing design and other advances in petroleum engineering have helped to keep gas production high despite low rig counts and the high number of drilled-but-not producing wells. Geosteering, logging-while-drilling, fracture modeling and reservoir simulation, proppant application, sliding sleeves over traditional plugs in fracturing stages, and the use of wireless technology down hole are just a short subset of technology being applied. Improvements on individual technologies and combining their uses should further boost production.

...while gas production from oil and liquids producing wells has increased

Second, gas production from oil and liquids producing wells could make up a large portion of gas production growth. Citi estimates that oil production could grow by an average of 0.5-mb/d every year until the year 2020.

Finally, the backlog in well completions means that incremental output can be brought on quickly.

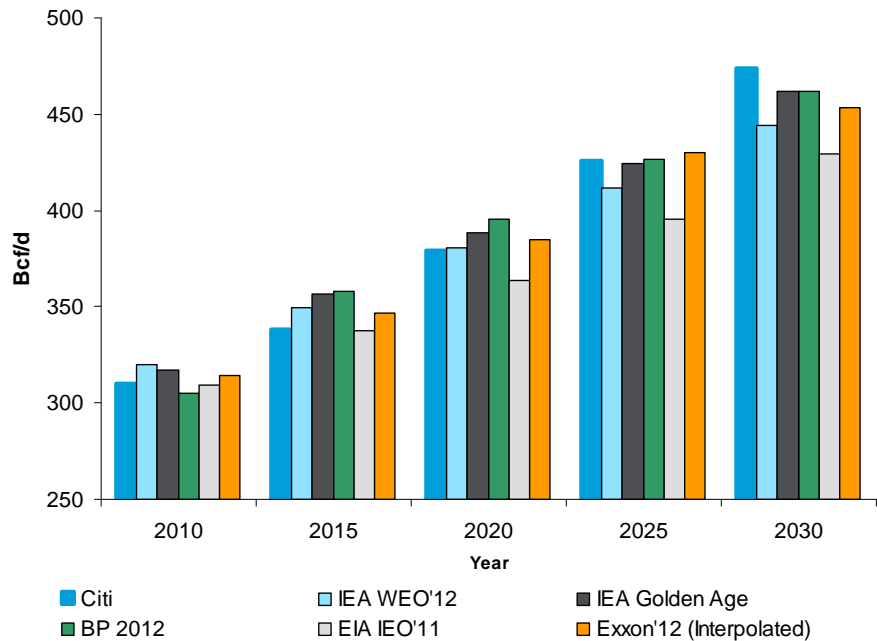
In Canada, natural gas plays in the Western part of the country, including the Duvernay in Alberta, the Montney that straddles Alberta and British Columbia, as well as Horn River, Liard Basin and Cordova Embayment in British Columbia, are significant natural gas resources where production lags because of lack of markets.

Global gas reserve discovery should lead to increased supply globally

Global Supply

A surge in the discovery of gas reserves globally is expected to increase supply in the coming decade and beyond. See below for a highlight of several locations.

Figure 85. Rising Global Natural Gas Supply to Meet Demand Needs – Estimates from Different Forecasters



Source: : BP, EIA, Exxon, IEA, Citi Research

New policies in China could increase output

Russian producers are increasing output, with Novatek and Rosneft both boosting their supply to domestic users and intensifying the domestic competition within Russia.

In China, although unconventional gas production remains low, new policies could come into place to boost output. The current gas pricing reform implemented in the two southern provinces, Guangdong and Guangxi, are meant to provide extra incentives for producers to explore and produce. This price reform links city gate prices in those two provinces with prices of fuel oil and liquefied petroleum gas (LPG) in Shanghai, but with a 10% discount to encourage gas demand. In the old system that applies to the rest of the country, prices are set based on a cost-plus system that adds transport costs on top of production costs + 10%. If shale gas is tied to market prices instead, then the incentive to explore and produce would be much stronger.

East Africa has large gas resources and is well positioned to supply Asia and Europe

East Africa – particularly Mozambique and Tanzania – is a hotspot for gas exploration and discoveries, with vast reserves (that could see further upside) able to support significant LNG supply, albeit likely beginning towards the end of this decade. Not only is the resource large, but East Africa is also well positioned to supply Asian as well as European markets. However, as a frontier region, there are drags from technical as well as commercial challenges, which could delay development.

East Africa has been home to recent major gas discoveries, with around 100 Tcf discovered to date – Mozambique's Rovuma Basin was a major contribution to global discovered reserves in 2011. While smaller, Tanzania's reserves of 33 Tcf have seen continued revisions upwards as new discoveries continue to be made, and exploration exceed expectations. Kenya could contribute further volumes.

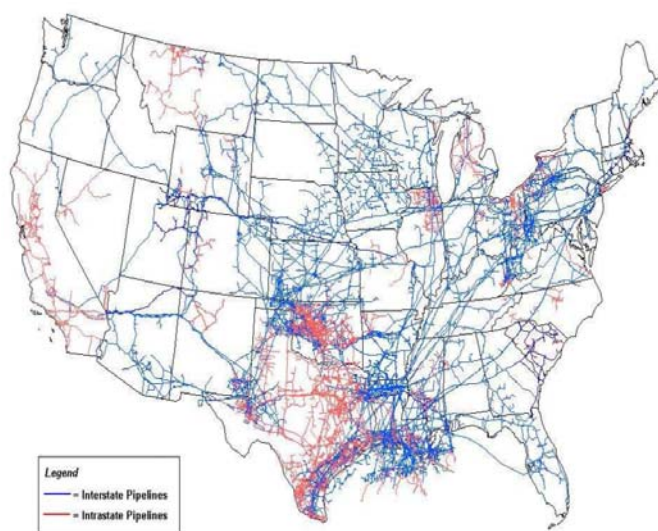
The discovered reserves have major supply potential, with Mozambique's reserves potentially able to support 16 LNG trains. So far, some six LNG train projects have been proposed for Area 1, and another two for Area 4, but the resource potential allows for further expansion. Anadarko has started work on an initial two-train 10 mtpa plant, with final investment decision for late-2013. The timeline for LNG supply remains a long one; Wood Mackenzie assumes four trains from Mozambique and one from Tanzania towards the end of this decade, which would supply some 4.2-Bcf/d at its peak, but this could well undershoot actual development. With Citi's model seeing global gas supply growth of over 40-Bcf/d worldwide in a base case, East African supply upside could boost this further.

Gas Distribution

A key part of the whole supply-chain is the availability of distribution networks to deliver the fuel to refueling stations or depots and, in the case of LNG, liquefaction facilities to produce the specialty fuel. This is typically the segment in the value chain that is typically not discussed in the market. However, it is the lack of liquefaction facilities in the U.S. that could slow fuel-switching from diesel to LNG in trucking.

In both the U.S. and Europe, gas pipeline networks are highly developed that the pipeline infrastructure can ensure deliverability to regional local distribution companies (LDCs), liquefaction (LNG) plants or compressed natural gas (CNG) facilities.

Figure 86. US Natural Gas Pipeline Map – Robust Distribution Network



Source: EIA

Figure 87. European Natural Gas Pipeline Map – Robust Distribution Network



Source: ENTSOG

Small-Scale Liquefaction

Liquefaction plants should be near places with LNG demand

One crucial linkage is the availability of liquefaction plants located close to places with LNG demand. In the U.S., although there are over 100 liquefaction plants, most are peak-shaving plants owned by utilities to serve peak demand mostly during winter or summer. Most existing facilities are on the East Coast and parts of the Midwest and Southeast. To serve the growing market of LNG in transportation, natural gas liquefaction facilities will have to be expanded, especially in locations where LNG transport corridors would be most active. The current available liquefaction capacity may not be able to meet demand starting in 2016, if demand growth for natural gas vehicles were as strong as the refuse truck segment. NGVs currently account for over 50% of new refuel truck sales.

Peak-shaving facilities could provide a supply-chain backbone for LNG transportation

Currently peak-shaving plants, which have large on-site storage facilities, store gas during the injection season from April to October by liquefying pipeline gas. The LNG is stored in large, flat-bottom, low pressure storage tanks. When gas demand spikes in winter or at times in summer, the LNG is regasified and fed into the local pipeline distribution system. Many of these facilities were built between mid-1960s and late 1970s.

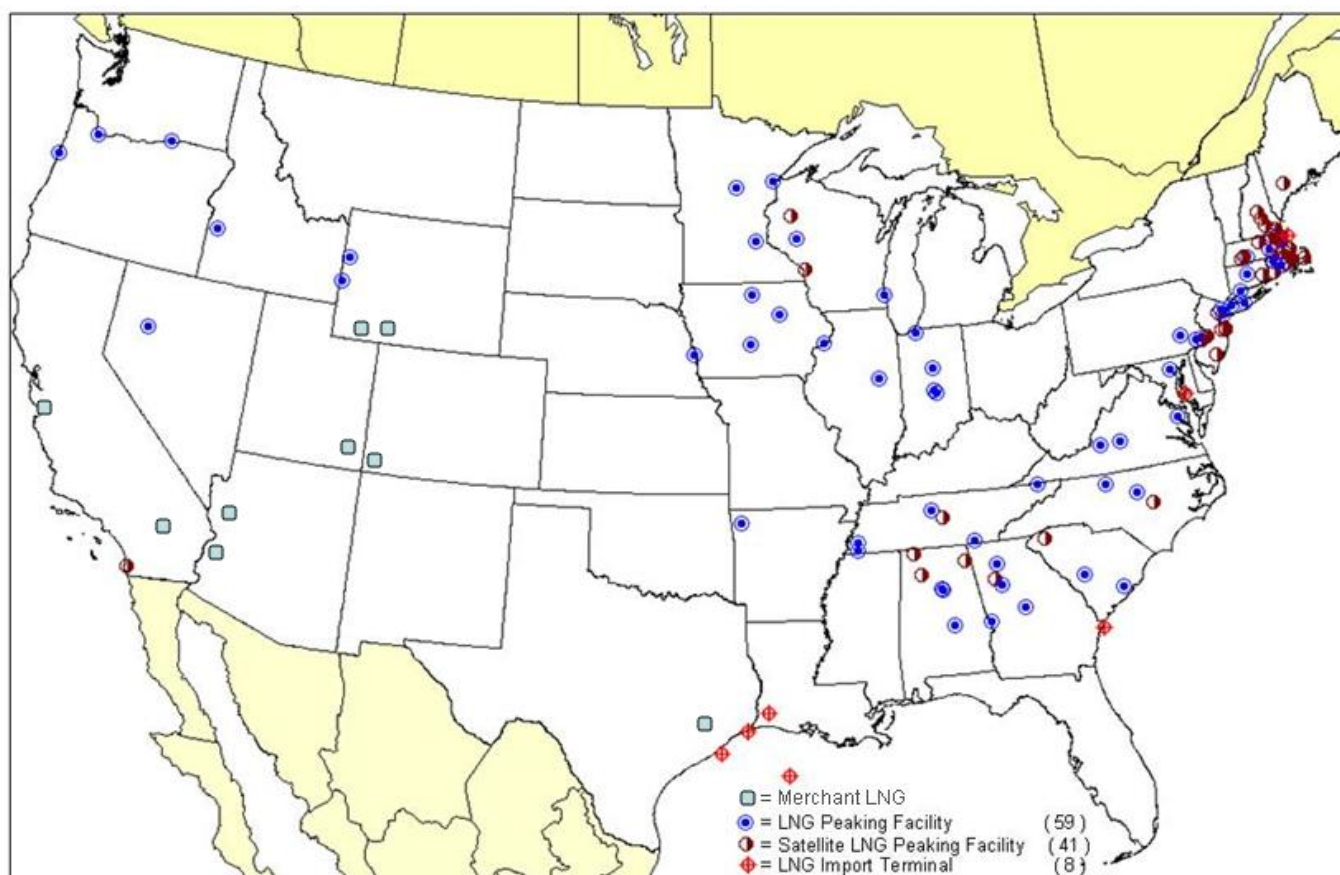
However, these under-utilized peak-shaving facilities could provide the necessary supply-chain backbone for the development of LNG in transportation. These facilities became under-utilized as inter- and intra-state natural gas pipeline networks were vastly expanded in the last few decades. Some of these LNG facilities were kept for contingency reasons or for rate-base purposes. As one of the largest expenditure of building a new LNG liquefaction facility is the cost of storage tanks, the presence of these same tanks at existing facilities could prove crucial. As of 2001, there was about 86-Bcf of LNG storage capacity excluding storage at LNG import terminals.

Liquefaction capacity needs to be expanded and updated

What is needed then is the expansion of liquefaction capacity. The current liquefaction capacity can only supply about 0.07-mb/d of LNG in diesel-equivalent terms. In addition, efficiencies are worsening at these facilities as plants age. New merchant natural gas liquefaction plants are typically over 1-million gallon/day in capacity.

Even a small-scale LNG facility requires 14 to 16 months to build if it were to use a standard design. A custom designed facility will take longer to come online, due to the need to conduct Front End Engineering Design (FEED), engineering and procurement contracting, and the construction of custom-built parts that stretches the online time into two years or more. At the moment, some of the liquefaction facility manufacturers are undergoing expansions, so that more parts can be manufactured. Resolving this bottleneck can lay the foundation for a rapid increase in liquefaction facilities to meet demand.

Figure 88. LNG Peak-Shaving and Import Facilities in the U.S.



Note: Satellite LNG facilities have no liquefaction facilities. All supplies are transported to the site via tanker truck.

Source: Energy Information Administration, Office of Oil & Gas, Natural Gas Division Gas, Gas Transportation Information System, December 2008.

Source: EIA, GTI, Citi Research

LNG liquefaction facilities are not cheap

Based on a standard design, a plant that can produce 100,000 gallon per day of LNG may require \$45 to \$60 millions of capital expenditure. The operating cost of the plant could add \$0.55/gallon to the cost of natural gas. On a diesel-equivalent basis, the operating cost amounts to about \$0.97/gallon.

Figure 89. Infrastructure Cost to Accommodate the Growth of NGVs in the U.S. (US\$ Billions)

	Fuel production	Fuel dispensing
CNG for light duty vehicles	Possibly nil	100 to 200
LNG	20 to 40	10 to 20
Hydrogen	30 to 90	300 to 500
Biogasoline	100 to 250	20 to 40
Electricity	N/A	70 to 130

Source: NPC, Citi Research

Although there are just over 100 liquefaction plants in the U.S. that theoretically can serve the NGV market, many of them belong to utilities used for peak-shaving purposes, particularly in winter when the gas is temporarily stored as LNG behind the citygate and released during different parts of the day to meet demand. As many of these plants are part of the rate-base structure, regulations could prevent these liquefaction plants from selling LNG to the broader market, including NGV.

Small-scale LNG may become more popular at places where gas is flared or where pipeline access is limited or restricted

Both in North America and elsewhere globally, small-scale LNG may become more popular at places where a large amount of gas is being flared or where pipeline access is limited or restricted. At times, the cost of building pipelines could be high to justify the capture or transportation of natural gas, particularly for associated gas that comes from oil or liquids producing wells. To reduce the environmental impact, gas is typically flared because flared gas produces carbon dioxide, a much less potent greenhouse gas than methane. But increasingly the gas can be captured and liquefied using small-scale LNG technology that has been in existence for decades. The LNG can then be transported by trucks to refueling stations or even to power drilling rigs, taking advantage of this "byproduct" of oil/liquids production.

Further, gas fields that currently have no or limited pipeline access can also be monetized by liquefying the gas and supply local consumers. Shale gas in China could potentially be developed and captured, at the initial stage, through these small-scale LNG facilities.

Regions with an abundance of natural gas could pick-up NGV adoption quicker and drive the building of refueling stations

LNG-powered vehicles could very well develop outside of the currently targeted segments, such as goods-shipping heavy-duty trucks that travel dedicated routes. With the abundance of natural gas, particularly flared gas in some of the oil and liquids producing region where the cost of natural gas could be very low, the heavy demand for liquids shipment (from the well-head to rail loading facilities or elsewhere) and other goods shipments may prompt some trucks to switch over to natural gas from diesel-powered. As more trucks, vehicles and drilling rigs are converted to use natural gas, a critical mass can possibly be developed where enough refueling stations could emerge, turning the region into a natural gas refueling hub. Pockets of these hubs could then develop organically, helping to bridge the broader infrastructure problem that has been limiting a nation-wide adoption of natural gas refueling network.

Typically a refueling station would have to be located within a 300 mile radius of the liquefaction plant, as the transport cost of LNG adds up the further a refueling station is away from the liquefaction facility. LNG would be transported by trucks that can use diesel as an engine fuel. Further, LNG boil-off also slightly decreases the amount of LNG available for sale at the pump.

Current refueling stations could add LNG storage and dispensing to their facilities

Refueling stations currently offering gasoline and diesel would need to accommodate LNG storage and dispensing facilities. However, two types of LNG may have to be offered due to different engine requirements, so that different sets of tanks and fuel dispensers might be needed, adding to cost. LNG boil-off can limit the shelf life of the fuel at a station.

Nonetheless, these are not deal-breaking requirements. A single LNG dispensing system could be part of the improvement in fuel management. Refueling stations that have dedicated traffic or are dedicated depots can best optimize fuel management, boil-off and other issues. Standardizing station design and retrofits, with most components made offsite similar to other station components, should reduce cost.

Glossary

LNG (Liquefied Natural Gas) is made up of 95% or more of methane (ie, pipeline-quality natural gas) cooled to about 162C (or 260F), so that its volume is about 1/600 that of natural gas in gaseous state. When vaporized, it burns only in concentration of 5% to 15% when mixed with air. Methane has a chemical composition of CH₄. Natural gas liquefied to such small volume makes the transport of natural gas much easier when pipeline is not an option. LNG can also be used as a transportation fuel. For other applications, LNG is generally regasified as natural gas before consumption. LNG's volumetric energy density is about 60% that of diesel.

NGL (Natural Gas Liquids) is made up of a range of hydrocarbon molecules heavier than methane but lighter than black oil. NGL typically includes ethane (C₂H₆), propane (C₃H₈), butane, iso-butane, pentane-plus. NGLs are typically produced alongside natural gas, or vice versa. Ethane is typically used as a petrochemical feedstock, propane as a feedstock and heating/transportation fuel, and butane as a fuel and blending component.

LPG (Liquefied Petroleum Gas) is made up primarily of propane and butane in a liquid state at room temperature when under moderate pressure. For some locations, LPG is used as a vehicle fuel available at petrol/gasoline stations. LPG is highly flammable.

CNG (Compressed Natural Gas) is made up of pipeline-quality natural gas (methane) compressed to less than 1% of its volume at normal temperature and pressure. CNG is typically used as a transportation fuel. CNG's volumetric energy density is about 25% that of diesel and 42% that of LNG.

GTL (Gas-to-Liquids) is a process that transforms natural gas into some form of liquid fuel, such as methanol, gasoline or diesel. It typically uses the Fischer-Tropsch process (the same process used in coal-to-liquids) to turn natural gas into syngas before undergoing chemical reactions, with cobalt or iron as a catalyst, to produce liquid fuels.

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Notes

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Key Insights into Natural Gas Adoption in Transportation



INFRASTRUCTURE

Natural gas is still in the early adoption phase for transportation companies as the infrastructure continues to ramp up. / [Under today's technology, roughly 25% of the truck market has the ability to convert to natural gas by 2020.](#) More dense freight corridors of the U.S. such as the northeast, southern California and Texas are the prime areas where diesel trucks can convert in the near-term as refueling infrastructure is key to adoption.



COMMODITIES

Transportation currently accounts for 44-mb/d of global oil demand, or 50% of world demand. Within that total, light vehicles account for over 20-mb/d of demand and North America uses about 16mb/d for transportation. / [Natural gas-for-oil substitution in transportation could have a far-reaching impact on the energy market as conversion globally could curb oil demand between 2.6-mb/d and 4.5-mb/d by 2030.](#)



GLOBAL REACH

Asia is currently the largest NGV market, led by Pakistan, Iran and India, with China surging ahead. / [Growth potential in North America is huge given low natural gas prices and the thickness of trade corridors but Europe, South America and the former Soviet Union are all growing quickly with government support and infrastructure build.](#)



