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Natural Gas: The Bridge Fuel

RUTGERS School of Engineering

AIChE

WISE Washington Internships for Students of Engineering

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Prologue

About the Program

Founded in 1980 through the collaborative efforts of several professional engineering societies, the Washington Internships for Students of Engineering (WISE) program has become one of the premier D.C. internship programs. The WISE goal is to prepare future leaders of the engineering profession in the United States who are aware of, and who can contribute to, the increasingly important issues at the intersection of science, technology, and public policy. The student interns work in Washington, D.C. over the summer to learn how government officials make decisions on complex technological issues, and how engineers can contribute to legislative and regulatory public policy decisions. In addition, each student is responsible for independently researching, writing, and presenting a paper on a topical engineering-related public policy issue that is important to the sponsoring society. For more information about the WISE program, visit www.wise-intern.org

About the Author

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Executive Summary

Heavy-duty, class 8 trucks produce almost 20 percent of all carbon emissions from transportation. Alternative energy sources need to be used on a larger scale to reduce these emissions, as well as to reduce dependence on foreign oil. Natural gas is the future of fuel in long-haul vehicles. This paper tackles different issues surrounding the usage of natural gas as the main fuel for natural such as public awareness, public policy, existing infrastructure and consumer choice. States have established local programs in which public city buses are using natural gas as the fuel of their choice, and these can be used as models to implement natural gas programs in other areas of the United States as well.

The Obama Administration strives for a diversified energy portfolio to take advantage of domestic resources. In November 2013, for the first time in over twenty years, the US produced more oil domestically than it imported from foreign sources, and the US is now the main natural gas producer in the world. Natural gas prices are more stable in the long run compared to diesel or gasoline prices because it is not obtained from foreign sources, which makes it easier to plan for long-term costs. The abundance of shale plays in the US, which are locations where companies are actively seeking out natural gas, shows the possibility of the nation becoming self-sustaining. From 2005 to 2010, US dependence on oil imports fell from 60.3% to 49.3%, even by the conservative estimates. By 2012, this figure had dropped to 40% of US consumption, according to the EIA[1]. It is possible to continue this trend if trucks choose to undergo widespread measures to transition their fleets to natural gas engines, which will make way for a future in which the US is primarily self-dependent for its energy sources.

The lack of natural gas refueling infrastructure in the US also makes it difficult for fleet companies to adopt natural gas engines, even if they are ready to make the change. In mid-2013, diesel cost $1.75 more per gallon[2] than natural gas. It makes economic sense for large truck fleets for support this kind of transition because it profits them in the long run. The IEA estimates that building a compressed natural gas (CNG) pump into an existing gasoline and diesel station will cost a minimum of $400,000; building a new CNG station will cost approximately $1.5 million; building a new liquefied natural gas (LNG) station will cost

[1] "How Dependent Are We on Foreign Oil?" *EIA's Energy in Brief: How Dependent Are We on Foreign Oil?* U.S. Energy Information Administration - EIA - Independent Statistics and Analysis, 10 May 2013. Web. 1 July 2014. <http://www.eia.gov/energy_in_brief/article/foreign_oil_dependence.cfm>.

[2] Gaston, Greg. "The “Shale Gale”: What It Is and How It Will Reduce the U.S. Trade Deficit and Make Some American Companies More Competitive In World Markets." *International Journal of Business and Social Science* 5.3 (2014): 59-65. Mar. 2014. Web. 1 July 2014.

approximately $1-4 million. Both forms can be used to operate long-haul trucks; the main differences are that while significant CNG refueling infrastructure already exists, only LNG can offer the range required by these trucks to travel cross-country. By comparison, a gasoline and diesel station will cost around $100,000[3]. The steep investment cost is a key obstacle to natural gas adoption but with the current price of natural gas at approximately half of that of diesel (natural gas at $2.15 per gasoline gallon equivalent and diesel at $3.97 per gallon[4]), fleets can accomplish a full return on investment in two to three years.

Existing framework for alternative fuels such as natural gas include incentives both on the supply side, such as loan programs to construct infrastructure, and the demand side, such as tax credits for fuel-efficient vehicles. There are also public-private partnerships between state and federal agencies and private fleet companies researching on improving the efficiency of trucks and increasing the availability of refueling stations. The recommendation is the implementation of a pilot program along the interstate highway I-95 in the US Northeast that runs from Maine to Florida with regularly-dispersed natural gas refueling stations. It is a distance of about 3000 miles that contains the passages for many freight fleets transporting goods through the region. Presuming a mileage of approximately 3 miles per gallon, these stations would have to be about 150 miles apart from each other, which means there would need to be about 20 to 25 stations through this corridor. Such a program, with the aid of the policy framework already in place, can greatly speed up the adoption of natural gas into the trucking industry as a mainstream fuel.

[3] LeVine, Steve. "An Electric Car Hasn't Reached Your Garage, but a Natural Gas-fueled Vehicle Might." *Quartz*. 21 June 2013. Web. 1 July 2014. <http://qz.com/96694/an-electric-car-hasnt-reached-your-garage-but-a-natural-gas-fueled-vehicle-might/>.

[4] "Fuel Prices." *Alternative Fuels Data Center:*. U.S. Department of Energy, n.d. Web. 17 Aug. 2014. <http://www.afdc.energy.gov/fuels/prices.html>.

Issue Definition

Future global markets are geared towards an increasing consumption of energy, especially with developing countries like India and China catching up to the United States' standard of living and an increasing global population. However, the detrimental effects of climate change and global temperature increase associated with this increased energy use make the supply of this amount of energy difficult to sustain. While an ideal situation would call for a global, collaborative solution to reduce carbon emissions and satisfy the energy demand, it can be very difficult given the diverse portfolio of political, cultural and military issues around the world. It is more useful to take incremental steps in a localized, efficient way to implement solutions to this problem. The recent volatility in energy prices and policy initiatives to reduce greenhouse gas emissions have resulted in widespread uncertainty in the US about energy security. In addition, with unstable political powers like Russia and the Middle East controlling much of the world's energy supply such as crude oil and petroleum products, it is necessary to tap into domestic sources of energy production.

There is a necessity to reduce the rate at which carbon emissions are being produced. The Earth's biosphere is reaching a tipping point that will make conditions unsuitable for human life. The human population is geared towards a critical threshold after which global warming initiates a feedback mechanism that will spiral out of human control[5]. An expanding population is adding to this problem as well. Greenhouse gas (GHG) emissions production has increased the most due to the growing use of transportation. Forecasts[6] show that the Earth's surface temperature will increase by more than 2 degrees Celsius by 2040, which launches the planet into this critical threshold. If the warming increases by more than 3 degrees Celsius, 21-52% of the Earth's human population will become extinct. While it is very difficult to obtain exact figures on the amount of GHG emissions currently existing or the overall temperature increase, there is general consensus that the US's carbon habits must be changed to sustain this Earth for posterity, as well as to correct the damage done so far.

With the increasing growth of carbon emissions on this planet, there is an urgent need for reform in the transportation sector to decrease these emissions. Fossil fuel combustion, which is used for electricity, transportation and industry, is the leading cause of the total US carbon

[5] Ferguson, Spencer, and Matthew T. Gilbert. *Hydraulic Fracturing and Shale Gas Production: Issues, Proposals and Recommendations*. New York, NY: Nova Science Pub., 2013. Print.

[6] Ibid.

emissions being produced. While homes are being incentivized with tax cuts and subsidies to implement alternative energy sources for their electricity, the truck fleet industry is moving relatively slowly in switching to a more carbon-friendly method for its fuel. 45.2[7]% of fossil fuel usage in the US accounts for transportation, 22%[8] of which is used by medium- and heavy-duty trucks. There is recognition among legislators, scientists and the public that the global economy should be manufacturing low-carbon energy, but there is disagreement as to the correct method to make this transition. When determining the necessary steps to reduce GHG production, it is necessary to highlight some important figures. 39% of the United States' electricity production comes from coal and 27%[9] of it comes from natural gas (NG). The transportation industry uses 26.63%[10] of all energy production, of which 96.9% uses petroleum as its primary source of fuel[11]. Natural gas accounts for only 2.2%[12] of total transportation fuel in the US. Medium- and heavy-duty truck fleets produce 19.7%[13] of the total GHG emissions from the transportation industry, which can be significantly decreased by switching the main fuel source to natural gas. Converting truck fleets to natural gas can buy the Earth more time for renewable energy sources to become more economically practical. The following graphs relay information about the energy market in the US: Figure 1 shows the energy supply of each source in the US, and Figure 2 shows that natural gas produces about half the amount of carbon emissions as coal.

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[7] "Table 4-2: U.S. Consumption of Energy from Primary Sources by Sector (Quadrillion Btu) | Bureau of Transportation Statistics." *Table 4-2: U.S. Consumption of Energy from Primary Sources by Sector (Quadrillion Btu) | Bureau of Transportation Statistics*. United States Department of Transportation. Web. 17 Aug. 2014. <http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/html/table_04_02.html>.

[8] "Transportation Overview." *Center for Climate and Energy Solutions*. Center for Climate and Energy Solutions. Web. 17 Aug. 2014. <http://www.c2es.org/energy/use/transportation>.

[9] "Frequently Asked Questions." *What Is U.S. Electricity Generation by Energy Source?* U.S. Energy Information Administration - EIA - Independent Statistics and Analysis. Web. 17 Aug. 2014. <http://www.eia.gov/tools/faqs/faq.cfm?id=427&t=3>.

[10] "Table 4-2: U.S. Consumption of Energy from Primary Sources by Sector (Quadrillion Btu) | Bureau of Transportation Statistics." *Bureau of Transportation Statistics*. United States Department of Transportation, 18 July 2013. Web. 1 July 2014. <http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/html/table_04_02.html>.

[11] Ibid.

[12] "Chapter 26: Transportation." *Energy Report - Transportation*. Window on State Government. Web. 1 July 2014. <http://www.window.state.tx.us/specialrpt/energy/uses/transportation.php>.

[13] United States. Environmental Protection Agency. Transportation and Air Quality.*Fast Facts: U.S. Transportation Sector Greenhouse Gas Emissions (1990-2011)*. US EPA, Sept. 2013. Web. 20 June 2014. <http://www.epa.gov/otaq/climate/documents/420f13033a.pdf>. EPA-420-F-13-033a

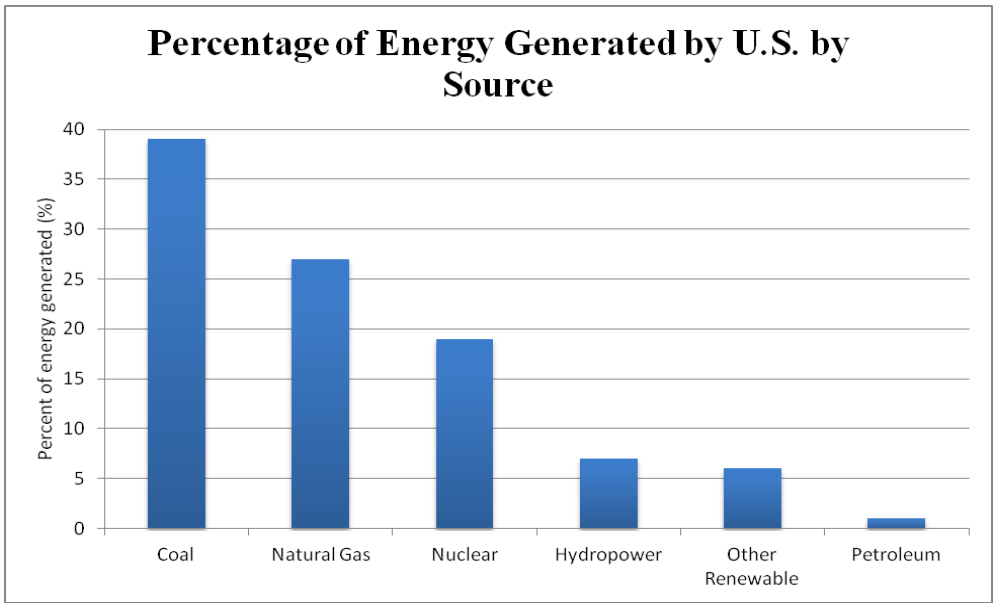

Figure 1: US Energy Production per source [14]

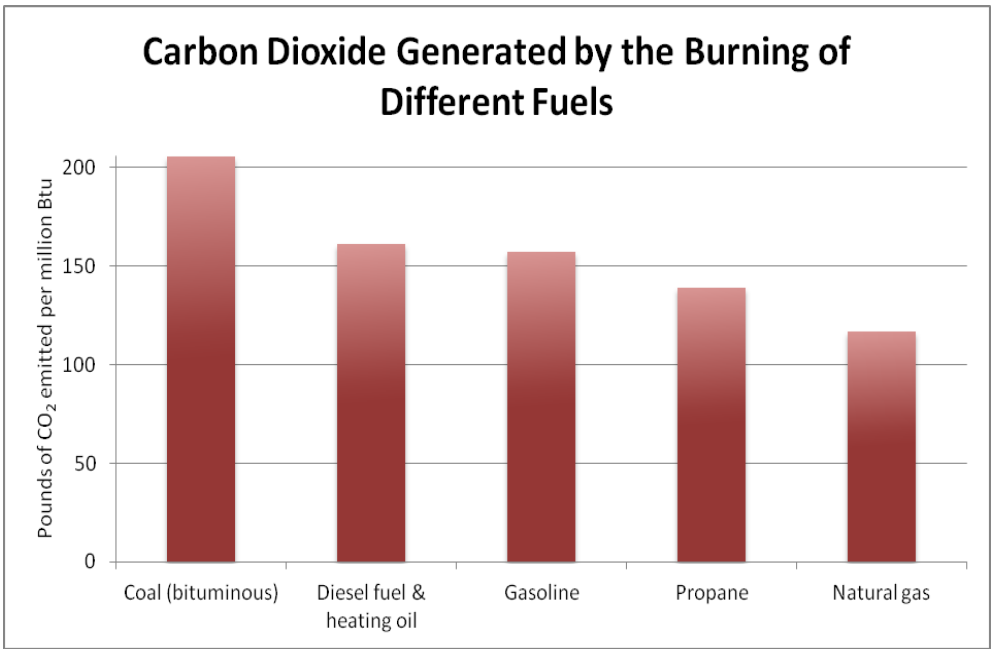

Figure 2: Carbon dioxide production per energy source [14]

[14] "How Much Carbon Dioxide Is Produced When Different Fuels Are Burned?"*FREQUENTLY ASKED QUESTIONS*. U.S. Energy Information Administration - EIA - Independent Statistics and Analysis, 4 June 2014. Web. 2014. <http://www.eia.gov/tools/faqs/faq.cfm?id=73&t=11>.

Lack of Infrastructure

Renewable energy is an idealistic solution to this problem because it is still not economically viable yet to implement on a large scale. There are many proponents of switching to a fully renewable future, but the infrastructure and knowledge to make renewable energy cheap for the public does not exist yet. Nevertheless, alternatives such as photovoltaic cells and wind farms show promise, and the future seems to be heading towards these types of clean energy methods. In the meantime, natural gas should act as the bridge fuel which will connect the coal industry to a future in which renewable energy dominates the energy production sector in the US. This particular interest in natural gas as a transportation fuel arises not only because of its reduced GHG emissions and improvement of air quality, but also due to its cost savings. While natural gas is much cheaper than diesel, using natural gas in fleets also entails more capital costs because of the lack of infrastructure both in the trucks themselves and in refueling stations. In a study conducted by the Boston Consulting Group (BCG), estimates conclude that Class 8 (heavy-duty) trucks such as tractor trailers would be $50,000 more expensive if fitted with a natural gas engine rather than a diesel engine. Many states have tax incentives to promote their transportation industry to use natural gas in their vehicles. Conversely, even with 1,300 natural gas refueling stations through the US, less that half of these are accessible to the public. About half of these are private stations of fleet owners, around 425 stand alone as a natural gas refueling station, and around 75 are part of already-existing retail gasoline and diesel stations[15]. As a result of these cost limitations, the infiltration of natural gas fleets into the market can only be done so where there is an urgent market: low-fuel-economy medium- and heavy-duty trucks. In these scenarios, companies can make a profit from their investment by switching over their vehicles that travel long distances[16] to CNG. BCG predicts that in the year 2020, more than 90%[17] of the CNG demand will come from medium- and heavy-duty trucks.

The lack of natural gas refueling infrastructure in the US also makes it difficult for fleet companies to adopt natural gas engines, even if they are ready to make the change. The lack of supply to satisfy the demand has formed a feedback mechanism: if there were more refueling stations, adoption of natural gas engines would rise but only if adoption rises will there will be

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[15] Nath, Rohan, Guillaume Aubert, and Alex Dewar. "A Realistic View of CNG Vehicles in the U.S." The Boston Consulting Group, 16 June 2014. Web. June 2014. <https://www.bcgperspectives.com/content/articles/energy_environment_automotive_realistic_view_cng_vehicles_us/?utm_source=2014Jul&utm_medium=Email&utm_campaign=Ealert>.

[16] Ibid.

[17] Ibid.

more refueling stations. These refueling capabilities exist mostly at private and municipal fleet bases. There are also a few of these refueling stations standing alone as natural gas refueling stations (without diesel or gasoline pumps) and have been developed by utilities and alternative-fuel companies, though this is a significantly more expensive option. The cheapest option, adding natural gas capabilities to current gasoline and diesel stations, is also the least prevalent. Constructing these facilities at truck fleet bases and adding them to current gasoline stations is almost 3 to 4 times cheaper than constructing a refueling station from scratch. Fleet owners have much to gain from making the switch because CNG is much cheaper than diesel and will drive down their operating costs. Fleet owners have been strongly supportive of making this switch. In mid-2013, the price discrepancy between diesel and natural gas was $1.75 per gallon[18]. It makes economic sense for large truck fleets for support this kind of transition because it profits them in the long run. In addition, existing gasoline and diesel stations have not been quick to add natural gas capacity to their pumps because of various issues: space constraints, lack of parking space to accommodate natural gas vehicles, and initial up-front cost of pumps. Despite these hurdles, a few local stores have upgraded their stations to be natural gas-accessible.

Fuel Specifications

LNG is the liquefied form of natural gas and is made by subcooling natural gas. While LNG and CNG are composed of the same substance (i.e., they have the same energy content), LNG packs more energy than CNG (i.e., LNG is more energy-dense than CNG). There is a lot of potential in the LNG market for heavy-duty truck fleets which are traveling long distances. LNG must be stored at subcooled temperatures as a liquid and it needs 70%[19] more volume for the same amount of energy storage as diesel tanks, so it is not a viable fuel option for smaller, commercial vehicles which are too small to accommodate the extra space required for LNG tanks. LNG offers a comparable energy density to diesel. Compared to CNG, it has a much larger range, which reduces its refueling frequency. The disadvantage is the high costs of maintaining sub-cooled storage for LNG on vehicles and the extensive infrastructure development required in dispensing stations, manufacturing plants and pipeline facilities. CNG needs to be stored in high-pressure tanks as a gas. From an economic standpoint, the pressurization tanks required for CNG are costly and they take up more space than LNG tanks,

[18] Gaston, Greg. "The “Shale Gale”: What It Is and How It Will Reduce the U.S. Trade Deficit and Make Some American Companies More Competitive In World Markets." *International Journal of Business and Social Science*5.3 (2014): 59-65. Mar. 2014. Web. 1 July 2014.

[19] http://anga.us/media/content/F7D3861D-9ADE-7964-0C27B6F29D0A662B/files/LNG%20Infrastructure.pdf

but CNG infrastructure is currently much farther along in development than its counterpart's. There are four rudimentary steps in the natural gas supply chain: feedgas extraction (from natural gas wells, pipelines, landfills etc), liquefaction, distribution (via tanker trucks to the refueling station from the liquefaction facility), and dispensing (into vehicles for use). The process of implementing LNG infrastructure and its adoption as a mainstream fuel for transportation requires significant investment at every step of the supply chain. While the process has flexibility and offers many choices, the whole chain needs to be established before vehicles will be willing to transition their diesel engines to natural gas ones. Effective placement and basic availability of refueling stations are necessary for natural gas vehicle purchases and for LNG to break into the fuel market. For example, one such decision involves analyzing whether it is more efficient to continue distribution of LNG for long distances or to build new liquefaction facilities nearer to a higher-use area to accommodate for an increase in demand, which would cut down on distribution and trucking.

Infrastructure Specifications

There are also other issues associated with these two fueling methods. CNG fleets can simply be connected to an existing gas-grid for refueling, but they take significantly longer time to fill than LNG fleets and need to dock at stations overnight to fill their tanks. LNG can be hauled from the liquefier over long distances while remaining cost-effective. LNG fleets have fast-fill methods that compete with refueling times for diesel tanks. This is not an issue for trucks which travel locally – such as refuse trucks or public transit buses – that return to a local base every night to be fueled concurrently. For trucks traveling long distances across the country, this is a major hurdle as they have to stay at the station until the tank is filled, which can take 4-6 hours. CNG tanks also cannot accomplish complete fills due to pressure limitations, so the final pressure of the gas in the tank is always 20% or more below the desired fill pressure, reducing the efficiency of the fuel. Given a full tank of 135 diesel gallons, a full CNG tank is about 2000 pounds heavier and a full LNG tank is about 400 pounds heavier[20]. In addition, CNG requires 4 times the space as an equivalent diesel gallon to store the same amount of energy, while LNG requires 2 times the space. This is extra expenditure on the fleet owner's part, and the vehicle must also have the space to accommodate for these extra tanks. The following is a visual

[20] Roberts, Jack. "Natural Gas 101: The Two Types of LNG, Preparing Your Shop for LNG Trucks." *Fleet Management News & Business Info*. Commercial Carrier Journal, 7 June 2013. Web. 19 Aug. 2014. <http://www.ccjdigital.com/natural-gas-101-the-two-types-of-lng-preparing-your-shop-for-lng-trucks/>.

representation of the different sizes of tanks that would be required for each type of fuel to store the same amount of energy.

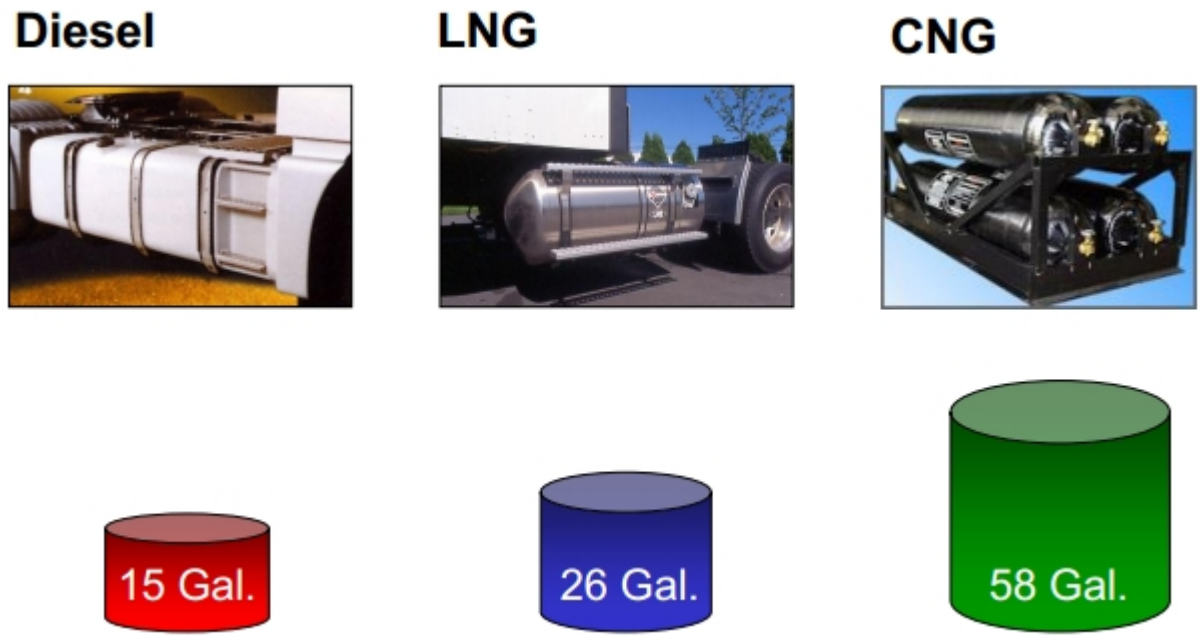

Figure 3: Space required to store the same amount of energy for each fuel[21]

CNG fuel tanks are more expensive than both diesel or LNG tanks, and can cost up to $20,000[22] to replace in the event of an accident. Most fleet owners will choose one or the either when deciding to make the switch from diesel because the specifications and investments for both are different. LNG fueling procedures require protective gear and special training for technicians because of the low temperatures. LNG also does not contain the odorant that is added to pipeline natural gas – CNG – so garages should have methane detectors when they are storing trucks indoors. Since natural gas is less dense than air, it will accumulate near the ceiling if there is a leak, so garages should have proficient ventilation systems and lighting that does not ignite easily. There is simply a lack of standards for establishing or maintaining natural gas refueling stations of repair shops, and setting up a federal framework can help speed up the process for natural gas adoption into mainstream fuel sources. It is important to understand the differences

[21] Westport, and Clean Energy. "CNG & LNG: What's Best for Your Fleet?" Audio blog post. *Westport*. 20 June 2013. Web. June 2014. <http://www.westport.com/company/news-events/webinars/>.

[22] Roberts, Jack. "Natural Gas 101: The Two Types of LNG, Preparing Your Shop for LNG Trucks." *Fleet Management News & Business Info*. Commercial Carrier Journal, 7 June 2013. Web. 19 Aug. 2014. <http://www.ccjdigital.com/natural-gas-101-the-two-types-of-lng-preparing-your-shop-for-lng-trucks/>.

between CNG and LNG but for the purpose of this project, LNG will be the focus because of its range and fast-fill options.

Energy Security

There has been general concern about the state of US energy security and the nation's energy dependence on the rest of the world for oil. In a speech by President Obama on US energy security, he detailed that the Administration aims to reduce oil imports by one-third by 2020[23] by increasing domestic oil production and increasing the use of alternative fuels and fuel efficiency. Additionally, the Administration has been expediting new drilling permits for drilling companies that can maintain high standards of environmental care. Gasoline and diesel are the major components of transportation fuel, but natural gas still does not play a large role. This landscape is changing as the lower current and projected costs of natural gas are giving fleet owners an incentive to incorporate natural gas into their fuel. This transition has the potential to help the US become energy-independent from foreign oil, significantly increase domestic employment, reduce the trade deficit, and increase the US global market power. The unexpected OPEC oil embargo in 1973 caused domestic oil prices to triple in price and keep increasing, and is a prime example of the necessity for the US to wean off foreign imports. The high prices stimulated discussion about new production infrastructure, specifically oil extraction from shale plays. This entrepreneurial response to global political problems brought about major growth in domestic petroleum production. The transportation industry, which has been reliant primarily dependent on petroleum products, imports most of its petroleum because domestic production is comparatively more expensive. The abundance of shale plays in the US shows the possibility of the nation becoming self-sustaining. Since 2005 to 2010, US dependence on oil imports fell from 60.3% to 49.3%, even by the conservative estimates. By 2012, this figure had dropped to 40% of US consumption, according to the EIA[24]. The Obama Administration strives for a diversified energy portfolio to take advantage of domestic resources. In November 2013, for the first time in over twenty years, the US produced more oil domestically than it imported from foreign sources, and the US is now the main natural gas producer in the world. Natural gas prices are

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[23] "Remarks by the President on America's Energy Security." *Office of the Press Secretary*. The White House, 30 Mar. 2011. Web. 19 Aug. 2014. <http://www.whitehouse.gov/the-press-office/2011/03/30/remarks-president-americas-energy-security>.

[24] "How Dependent Are We on Foreign Oil?" *EIA's Energy in Brief: How Dependent Are We on Foreign Oil?* U.S. Energy Information Administration, 10 May 2013. Web. 18 Aug. 2014. <http://www.eia.gov/energy_in_brief/article/foreign_oil_dependence.cfm>.

more stable in the long run compared to diesel or gasoline prices because it is not obtained from foreign sources, which makes it easier to plan for long-term costs.

The Potential Gas Committee's biennial assessment[25] the natural gas potential in April, 2013 indicated that the total supply would be enough to sustain the current population at the current rate of production for 100 years. By some conservative calculations, it can also be shown that completely cutting off imports for total self-dependence can cut the US trade deficit by more than half[26]. While it is improbable that the US will completely cut off its supply of foreign oil in favor of natural gas, it shows the potential of increasing consumption of natural gas and reducing use of foreign resources. Eventually, natural gas resources would peak and deplete as well, but this new discovery has pushed this decline a few more decades into the future, buying some time for renewable sources of energy to become economically viable for widespread use. Projections for a higher employment rate due to a developing natural gas industry exist beyond the boundaries of that industry into other areas as well, such as transportation and industry. These projections predict the creation of an additional one million American jobs. To route back to the original intention of these points, the advent of the widespread use of natural gas over diesel and gasoline can cause a host of ripple effects that benefit the US environmentally and economically.

Economics

Truck fleets will see a larger return on investment than smaller commercial vehicles. Representatives from Westport[27], a natural gas engine manufacturer, say that a range of 80,000 miles a year are necessary for a fleet to realize a full return on investment. The IEA estimates that building a CNG pump into an existing gasoline and diesel station will cost a minimum of $400,000; building a new CNG station will cost approximately $1.5 million; building a new LNG station will cost approximately $1-4 million, based on different sources. By comparison, a gasoline and diesel station will cost around $100,000[28]. The steep investment cost is a key obstacle to natural gas adoption but with the current price of natural gas at approximately half of

[25] Curtis, John B. "Potential Gas Committee - Press Release." *Potential Gas Committee*. 9 Apr. 2013. Web. July 2014. <http://potentialgas.org/press-release>.

[26] Gaston, Greg. "The "Shale Gale": What It Is and How It Will Reduce the U.S. Trade Deficit and Make Some American Companies More Competitive In World Markets." *International Journal of Business and Social Science*5.3 (2014): 59-65. Mar. 2014. Web. 1 July 2014.

[27] Westport, and Clean Energy. "CNG & LNG: What's Best for Your Fleet?" Audio blog post. *Westport*. 20 June 2013. Web. June 2014. <http://www.westport.com/company/news-events/webinars/>.

[28] LeVine, Steve. "An Electric Car Hasn't Reached Your Garage, but a Natural Gas-fueled Vehicle Might." *Quartz*. Quartz, 21 June 2013. Web. 19 Aug. 2014. <http://qz.com/96694/an-electric-car-hasnt-reached-your-garage-but-a-natural-gas-fueled-vehicle-might/>.

that of diesel (natural gas at $2.15 per gasoline gallon equivalent and diesel at $3.97 per gallon[29]), fleets can accomplish a full return on investment in two to three years. The following chart is a sample business case by Westport detailing the total fleet savings for a fleet of ten trucks, accounting for the incremental cost of the tank. The numbers might seem optimistic but this can be used as a liberal measure of how much fleet owners can save if they are willing to invest in the technology.

Sample Business Case: LNG

- 10 truck order (Westport 15L and Paccar Class 8 truck)

Average life of the truck	5 years
Mileage per truck (annual)	120,000
Fuel economy	6 mpg
Incremental cost with 53 DGE's (single tank)	$65,000*
Diesel price	$3.95/gallon
LNG price	$2.45/DGE
Fuel cost savings per truck per year	$30,000
Payback	2.2 – 2.5 years**
Total lifecycle fleet savings	**$850,000**

* All pricing to be confirmed with Paccar dealer
** Subject to duty cycle and displacement

Figure 4: Sample business case to transition from diesel engines to natural gas engines for a fleet of 10 trucks[30]

In terms of the economic analyses of investment dynamics, there are a few shifts that should be anticipated in the near future. As demand for LNG grows in fleets, new competitors for refueling station equipment will enter the market that will drive down the costs of implementing infrastructure. There will also be many more LNG fuel systems that will aim for

[29] "Fuel Prices." *Alternative Fuels Data Center:*. U.S. Department of Energy. Web. 17 Aug. 2014. <http://www.afdc.energy.gov/fuels/prices.html>.

[30] Westport, and Clean Energy. "CNG & LNG: What's Best for Your Fleet?" Audio blog post. *Westport*. 20 June 2013. Web. June 2014. <http://www.westport.com/company/news-events/webinars/>.

fuel-efficiency and process optimization. LNG storage tanks are also a possibility even though the supply and choice is currently limited. As the natural gas movement gains traction, increased competition will drive down the costs of investment. The core of the LNG transportation demand rests on the economic and public policy benefits that are yet to be gained by switching over from diesel. North America's dependence on coal and diesel has several costs such as a high energy security price and carbon emissions, which are mainly are due to reason such as fluctuating oil prices, import costs in the US, and public health issues. There are many options when deciding on the best LNG production framework and infrastructure strategies, and a successful business model necessitates an understanding of all these options, as well as their technical and economic tradeoffs and previous implementation analyses.

Example Cases

Although initial costs are high, cheap fuel provides a cost incentive for private sector companies to transition their fleets to natural gas, and there are a few companies which have started the adoption process. Waste Management has "3,000 heavy-duty natural gas trucks in North American cities today and plans to ultimately convert its entire fleet of 18,000 collection vehicles to natural gas operation"[31]. 90% of the trucks it is purchasing every year run on LNG. It has 58 refueling station across North America, of which 19 are accessible by the public. Companies such as Royal Dutch Shell, Clean Energy Fuels and ENN Group are all investing in natural gas refueling stations along highways in the US. Cummins-Westport Inc began selling 12-liter engines that run on natural gas for heavy-haul trucks. Other transportation modes are also making the switch. Caterpillar's mining carts run on natural gas. Burlington North Santa Fe Railroad is currently testing its locomotives using LNG for quality and reliability. One in every five transit buses in public transportation run on natural gas as well. Major cities such as San Francisco, San Diego, Los Angeles, New York City and Washington, D.C. have switched part of their public bus fleets to natural gas. These numbers will only increase as more American companies realize the economic advantage that can be gained from converting.

Vehicle Safety

Another item of interest is the safety of natural gas vehicles. All kinds of fuels can be dangerous if they are not handled correctly. Chemically, NG is mostly methane, but contains trace amount of ethane, propane, butane and carbon dioxide. Methane is energy-dense, which

[31] "National Clean Fleets Partner: Waste Management." *Clean Cities:*. U.S. Department of Energy. Web. 19 Aug. 2014. <http://www1.eere.energy.gov/cleancities/waste_management.html>.

makes NG energy-dense as well. Methane also contains relatively low levels of carbon, which produces fewer GHG emissions. NG is non-toxic and the risk of ground or water contamination is negligible if the fuel escapes for any reason. It is also less dense than air, so it will disperse quickly if it is exposed to the environment. Gasoline and diesel are denser than NG and tend to pool in the area of the leak, increasing chances of ignition. An odorant is usually added to the NG that can be recognized easily in the event of a leak. In addition, NG burns in a very narrow window of concentration: between 5% and 15% when mixed with air. This significantly reduces the risk of an explosion during a car crash when compared with gasoline or diesel engines, which burn at much lower concentrations and ignite at lower temperatures. Since CNG fuel systems operate at very high pressures (around 3000 PSI), the storage tank and its piping are made to be strong and robust enough to control that pressure and must also meet strict government regulations and safety standards. Most storage tanks are also installed with a release valve that automatically opens to release the internal pressure in a high-temperature or high-pressure situation.

Hydraulic Fracturing

Despite the economic gain, the Energy Information Administration's (EIA) projected outlook for 2040 only accredits 9% of the transportation fuel to natural gas[32]. A significant hindrance to the implementation of natural gas has been the hydraulic fracturing methods which have been used to obtain shale-oil. Hydraulic fracturing is the practice of pumping a high-pressure fracturing fluid into low-porosity shale reserves and inducing cracks in the formations to extract oil and natural gas, and is the method used to develop natural gas from shale deposits. This method has been detrimental to public and environmental health for various reasons, and drilling companies should take extra care to improve them and make it safer for families in well areas. The practice has been in use for many decades, but has now come into mainstream attention because of the US's abundant natural gas reserves. This development is changing the structure of the US energy economy and is stimulating interest and investments in the transportation industry. However, there are a lot of factors to consider when discussing the widespread impacts of the practice.

[32] "AEO2014 Early Release Overview." *EIA*. U.S. Energy Information Administration. Web. 19 Aug. 2014. <http://www.eia.gov/forecasts/aeo/er/early_consumption.cfm>.

One issue with hydraulic fracturing is the composition of the fracturing liquid. While this solution is composed mostly of sand to be used as proppant to keep the fissures open, it also contains some chemical additives that are highly carcinogenic. These additives help with moving the proppant through the fissures and reduce the friction between the fluid and the pipeline. Currently, no federal legislation exists which addresses this concern. The Safe Drinking Water Act (SDWA) of 1974 ensured the quality of US potable drinking water by regulating the water quality. The bill required the EPA to enforce regulations ensuring safe drinking water and applied to every US public water system, but fracking was excluded from it. This omission is called the "Halliburton loophole" and came about as a result of a provision in the Energy Policy Act of 2005. As a result of this exclusion, companies are not required to disclose the chemical content of their fracking liquids.

The Shale Gas Production Subcommittee of the Secretary of Energy Advisory Board (SEAB) has proposed several methods to address the public health concerns associated with these additives when they seep into the surrounding town's water supply. One proposed solution is mandated transparency by oil and gas service companies of the chemicals they were using in their products, allowing some flexibility for the protection of trade secrets. Full disclosure would allow health professionals to assess medical emergencies, conduct research on impacts of shale gas production and give regulators enough information to conduct water quality testing to check for groundwater contamination. Strong opponents of this disclosure, such as manufacturers of these additives and industry professionals, argue that these chemical ingredients are trade secrets and would be detrimental to the companies if competitors had access to them. Currently, the contents of the fracturing fluid are not being regulated at the federal level. President Obama stated in his State of the Union Address in 2012 that he will mandate all gas companies drilling on public land to disclose the chemicals they are using to protect public health. The Bureau of Land Management (BLM) also proposed in May, 2012 that companies drilling on land managed by the agency should disclose their chemicals. It establishes a set of rules that would require drilling companies to disclose logistical information such as the design of the drilling equipment, the total volume and amount of fluid to be used and the total anticipated pressure that will be used to inject the fluid, but it does not ask for information about the chemical composition of the fluid. Only after the drilling is over should the company provide the Fracturing Responsibility and Awareness of Chemicals Act (FRAC Act) of the 112th Congress established a framework for the disclosure requirements for drilling companies. Conversely, the Interstate Oil and Gas Compact Commission advocates for state control of the drilling requirements. Many states

already have a framework in place that detail provisions such as what information should be disclosed, to whom it should be disclosed, the amount of protection given to trade secrets and at what stage in the process these requirements must be met. This right should remain that of the state government, and standards should be raised to prevent such problems from arising. Another concern that can be easily mitigated is groundwater contamination due to methane migration from poorly cemented wells. These wells were not sealed properly or were over-pressurized. By raising the quality standards of these wells, such problems can be avoided in the future. There also seems to be a correlation between oil and gas development areas and seismic activity. There is no concrete evidence to prove this, but typically calm states such as Kansas, Oklahoma and Ohio have experienced a rise in earthquakes. The following chart shows the chemical disclosure requirements for every state as of July 2012:

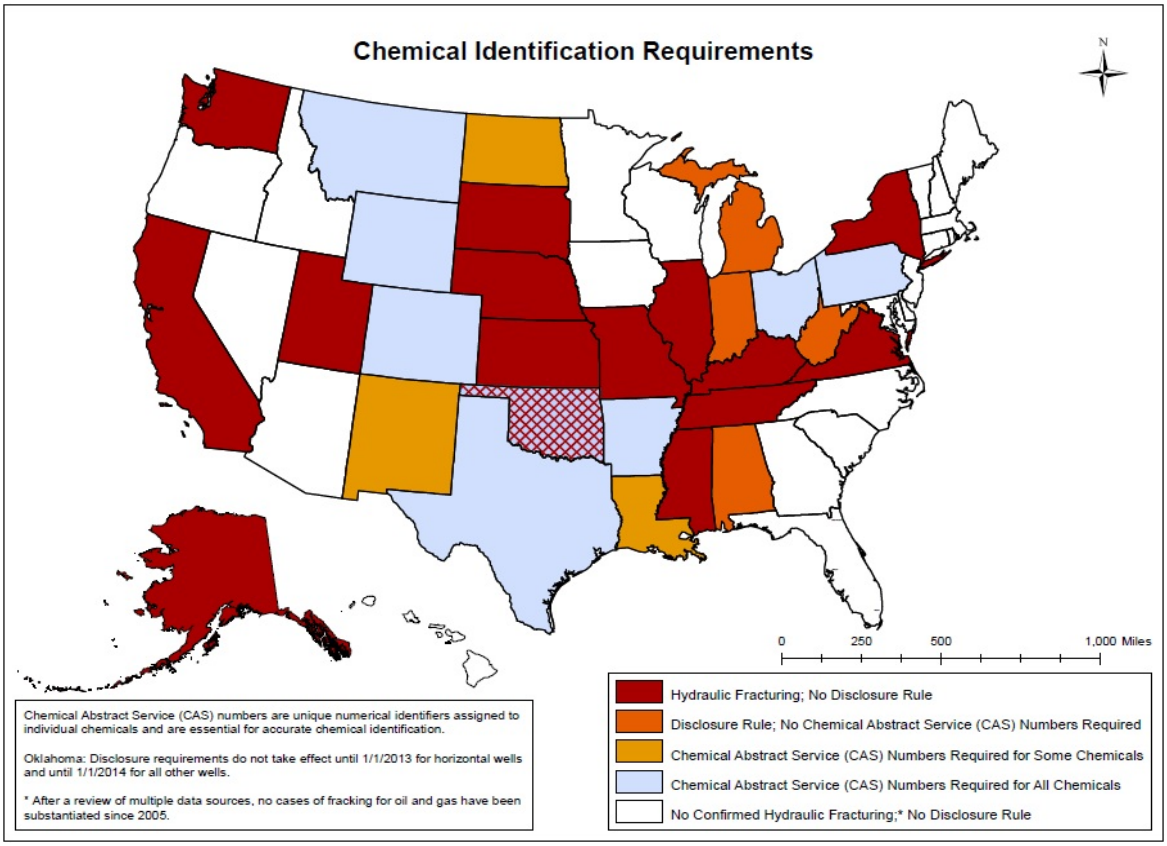

Figure 5: Chemical identification requirements per state[33]

[33] McFeeley, Matthew. *State Hydraulic Fracturing Disclosure Rules and Enforcement: A Comparison*. New York, NY?: Natural Resources Defense Council, 2012. *NRDC Issue Brief*. NRDC, July 2012. Web. July 2014. <http://www.nrdc.org/energy/files/Fracking-Disclosure-IB.pdf>.

It is imperative to realize that every new technology runs into initial problems upon implementation, but with troubleshooting and process optimization, it is possible to reach a solution. Being able to access shale deposits has taken the energy production sector by storm in the past five years, and a rush to harvest this new type of energy has led to collateral issues which are not difficult to solve. By remaining patient and optimistic about the potential of natural gas until legislators and regulators create a suitable framework, and by realizing the value of an alternative energy source, the stigma of natural gas can be overcome to allow it to become part of mainstream energy production.

Policy Framework

State regulations can assist with the increase of alternative fuel vehicles on the road. Bills can also be introduced on the federal level in the Senate or the House to promote the use of cleaner fuels and incentivize the transition from gasoline to alternatives. The following list describes various government incentives that can help speed up the process:

- Loan programs: Via the Department of Energy, this program sets up a fund derived from part of the federal revenue generated from leases such as the Outer Continental Shelf Lands Act and the Mineral Leasing Act. These loans must be repaid in four years, charge no interest, and when repaid, the money is made available to other states for more loans. The loans are given to states for programs in commercial and transportation energy efficiency and renewable generation projects.

- Tax Credits: Tax credits can be given to anyone who owns a fuel-efficient motor vehicle. Depending on the fuel economy of the vehicle, the returns can range from $900 to $2500, which are substantial savings for a fleet owner of multiple trucks. The credits are only applicable to vehicles that fall under the provisions of the Clean Air Act- vehicles manufactured primarily for use on public roads and highways and have at least 4 wheels, and excludes any vehicle that operates mainly on rails. It also increases taxes for gas guzzlers which do not meet the Corporate Average Fuel Economy (CAFE) standards. It also contains a clause for an investment tax credit for trucks which add new equipment, such as anti-idling mechanisms or aerodynamic installations, that can save fuel.

- Low-carbon fuel programs: An amendment can be added to the Clean Air Act to change the renewable fuel standard to a low-carbon fuel standard. A certain percentage of fuel

sold in the US every year must be low-carbon fuel. This percentage increases in increments of 1.5% every year after its introduction from 10% low-carbon fuel.

- Natural gas corridors: Natural gas corridors along interstate highways can reduce greenhouse gas emissions and other environmental pollutants. It allows governmental agencies such as the Environmental Protection Agency and the Department of Transportation to collaborate on projects to increase the availability of alternative fuels and to plan for new infrastructure along these highways. The Secretary of Transportation can allot grants to Interstate systems, such as the I-5 along the West Coast, to help design, develop and maintain these corridors. This proposal will also standardize truck anti-idling equipment, which produces a significant amount of carbon emissions and environmental pollutants.

The above policies can institute a framework which has a variety of incentives both from the supply side and the demand side for natural gas to establish itself as a viable fuel.

The Committee on Appropriations of the House of Representatives also recently submitted a bill (H.R. 4923[34]) for allocations towards energy and water development projects. Energy Efficiency and Renewable Energy (EERE) programs address research, development, demonstration and deployment advancing these technologies. It promotes the replacement of oil with clean domestic transportation fuels and research in public-private partnerships:

- SuperTruck Program[35]: This program is a collaborative effort between the Department of Energy and various private companies such as Cummins, Peterbilt and Navistar to focus on methods to improve overall efficiency of long-haul, heavy-duty trucks. The project requires that the private sector contributes more than 50 percent of the cost of the project. The scope of these projects includes developing technologies such as optimized combustion, waste heat recovery, idle reduction and improved aerodynamics. The goal of the project is to demonstrate a 50 percent increase in freight efficiency while adhering to the 2010 EPA standards. These trucks must also be commercially viable. One prominent issue with this program is the choice of duty cycle and whether this represents “real-

[34] Energy and Water Development and Related Agencies Appropriations Act, 2015, H.R. 4923, 113rd Cong. (2014). Web.

[35] United States. Department of Energy. Energy Efficiency and Renewable Energy.*SuperTruck Making Leaps in Fuel Efficiency*. By Shannon B. Shea. US DOE, 19 Feb. 2014. Web. June 2014. <http://energy.gov/eere/articles/supertruck-making-leaps-fuel-efficiency>.

world" specifications. With trucks undergoing vastly different conditions from carrying light loads to other carrying the maximum legal limit (or more), from driving in areas with little traffic where constant speed is possible to other areas where congestion is prevalent and speeds fluctuate, there is no way to fit a homogenized solution. One recommendation is to find a way to chart all of these details to show the efficiency of these trucks in a variety of conditions; it is important to know these details because only after such a framework is established can these proposals be adopted in the real world. The following long-haul tractor trailer is part of the SuperTruck program and is manufactured by Cumming and Peterbilt. It provides more than 10 miles per gallon, which is almost 2-3 times the usual mileage of an average diesel truck on the road today.

Figure 6: SuperTruck program technology - Class 8 truck that accomplishes 10 mpg

- Clean Cities coalition[36]: This coalition is a number of states around the US striving to improve domestic environmental, economic and energy security by investing in local operations to reduce consumption of petroleum in the transportation industry. It works with fleet owners, fuel providers, community leaders and other private stakeholders to promote alternative fuels and efficient vehicles.

The above two programs should be continued even though their funding has been downsized from the 2014 fiscal budget. This is an area with much potential and the funding should be back to the same level or increased.

[36] United States. Department of Energy. Energy Efficiency and Renewable Energy.*Clean Cities:*. US DOE. Web. July 2014. <http://www1.eere.energy.gov/cleancities/coalitions.html>.

- Federal regulation for hydraulic fracturing: There needs to be a regulated system of safety standards for fracking throughout the country. The rules of the practice vary greatly in every state and until it can be relatively safely, regulators needs to work towards setting up a framework to encourage public discussion and consumer awareness.

Recommendations

Figure 7: I-95 route

A recommendation is the implementation of a pilot program along the interstate highway I-95 in the US Northeast that runs from Maine to Florida which contains regularly-dispersed natural gas refueling stations. It is a distance of about 3000 miles that freight fleets regularly traverse when transporting goods through the region. Presuming a mileage of approximately 3 miles per gallon, these stations would have to be about 150 miles apart from each other, which

means there would need to be about 20 stations through this corridor. There would also need to be servicing stations set up at regular intervals that are equipped with the machinery needed to repair natural gas vehicles. States such as Utah and Texas have local natural gas corridors and can be used as models to implement this pilot program, which is on a much larger scale and needs major inter-state collaboration. Such a program, with the aid of the policy framework already in place, can greatly speed up the adoption of natural gas into the trucking industry as a mainstream fuel.

Overview

With global carbon emissions reaching a significant high, there is a necessity to optimize processes in various industries in the US towards more environmentally-friendly methods. Natural gas as a transportation fuel produces half the carbon emissions produced by diesel and does not produce pollutants such as sulfur dioxide or mercury. It can help the transportation industry reduce its emissions significantly. Although LNG itself is cheap, the high cost of investment for widespread refueling infrastructure is preventing it from breaking into the mainstream market. The transition also has the potential to help the US become energy-independent from foreign oil and increase the US global market power. Government incentives are needed to initiate this process and promote truck fleet owners to use LNG engines. The aim is to set up a network of LNG refueling stations around the country that will support these long-haul trucks, majorly reducing the production of carbon emissions in the US.

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