

The Feasibility of Natural Gas as an Eventual Substitute for Gasoline

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I. Introduction

In today's world, oil dominates the mainstream media. Especially with the recent decline in the price of oil, drivers who use gasoline aren't encouraged to consider cleaner, alternative fuels. And why should they? Gasoline is cheap, effective, and has been a fuel standard for decades ever since the first gasoline cars were built. As America's dependence on oil continues, we may find ourselves face-to-face with pressing environmental and political problems. With oil as an "unclean" fossil fuel, we see that a change in our fuel is increasingly more desirable. This paper will argue that over time, natural gas is a clean, suitable alternative for gasoline in transportation that will reduce our reliance on imported oil and allow us to be more environmentally friendly.

Products Made from a Barrel of Crude Oil (Gallons) (2011)

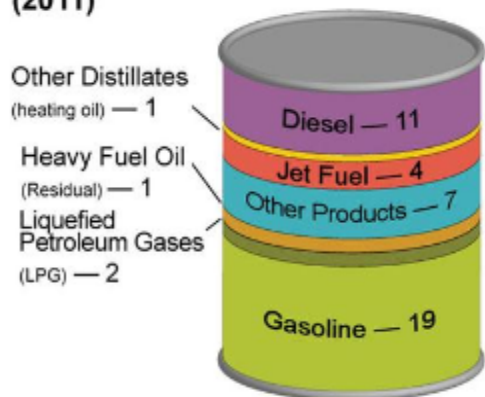


Figure 1: Distribution of products made from a barrel of petroleum. Source: http://www.eia.gov/energyexplained/index.cfm?page=oil_home

II. Petroleum - General Use and Use in Transportation

The United States consumes, as a whole, over 840 million gallons or 21 million barrels of petroleum products each day.

¹ From Figure 1, we notice that some products of petroleum include diesel fuel, heating oil, jet fuel, residual fuel oil, and gasoline.² 76% of the 6.97 billion barrels of petroleum products in the U.S. in 2014 was gasoline.³ Gasoline fuels over 200 million vehicles that travel a combination of over seven billion miles every day. Petroleum, which gasoline is made, is created by aquatic plant and animal remains that

¹State of Louisiana . "Where Does My Gasoline Come From?" *Louisiana State Department of Natural Resources*. n.d. <http://dnr.louisiana.gov/index.cfm?md=pagebuilder&tmp=home&pid=244>.

² State of Louisiana . "Where Does My Gasoline Come From?" *Louisiana State Department of Natural Resources*. n.d. <http://dnr.louisiana.gov/index.cfm?md=pagebuilder&tmp=home&pid=244>.

³ E.I.A. "What Are the Products and Uses of Petroleum?" *U.S. Energy Information Administration*. 2015. <https://www.eia.gov/tools/faqs/faq.cfm?id=41&t=6>.

settled to the bottom of ancient seas millions of years ago. This means that petroleum is a fossil fuel.

i. Environmental Impacts of Petroleum and its Derivatives

When petroleum related fuels like gasoline are burned, they release harmful emissions like carbon monoxide, nitrogen oxides, and unburned hydrocarbons.⁴ Nitrogen oxides are the main source of smog and unburned hydrocarbons are the main contributor of urban ozone. We also observe an annual 4.75 metric tons of CO₂ emitted per vehicle per year. Assuming that an average of 122.01 million cars drive daily per year, we see that (122,010,000 vehicles * 4.75 CO₂ metric tons /vehicle/year * (1000kg / 1 metric ton)) = $\sim 5.79 \times 10^{11}$ kg of CO₂ is emitted annually by gasoline vehicles.⁵ This causes climate change, pollution, intensified weather conditions, and the greenhouse gas effect.⁶ The combined costs of life-cycle climate change, health effects of greenhouses gasses, and fine particulate matter from gasoline emissions come out to be greater than \$500 million per year.⁷

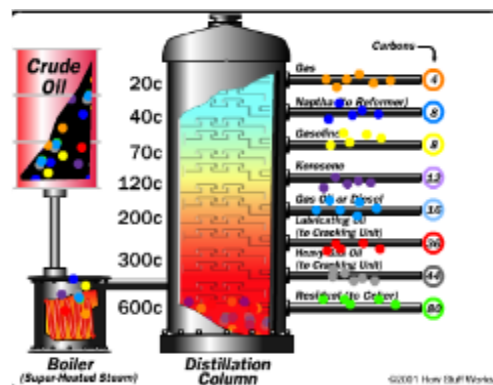


Figure 2: A Fractional Distillation column, the first step of fractional distillation. It refines the crude oil into various liquid fractions that may pass to condensers or other areas for chemical processing. Source: <http://science.howstuffworks.com/environmental/energy/oil-refining4.htm>

ii. Gasoline Derivation from Petroleum

A crucial process of obtaining petroleum is cracking. This is a petroleum refining process. It involves heavy hydrocarbon molecules being broken up into lighter molecules by heat, pressure, or

⁴ Brain, Marshall . "How Gasoline Works." *HowStuffWorks* n.d. <http://science.howstuffworks.com/gasoline5.htm>.

⁵ EPA. "GHG Equivalencies Calculator - Calculations and References." *United States Environmental Protection Agency* n.d. <https://www.epa.gov/energy/ghg-equivalencies-calculator-calculations-and-references>.

⁶ What's Your Impact? "What Are the Effects of Increased Greenhouse Gas Levels?" *Whatsyourimpact* n.d. <http://whatsyourimpact.org/effects-increased-greenhouse-gas-levels>.

⁷ Hill , Jason, Stephen Polasky, Erik Nelson, and David Tilman. "Climate Change and Health Costs of Air Emissions from Biofuels and Gasoline." *Proceedings of the National Academy of Sciences*. 2008. <http://www.pnas.org/content/106/6/2077.full>.

catalysts.⁸ This is the most important method of commercial gasoline production. The cracking of petroleum yields light oils such as gasoline and other byproducts like methane. These oils can either be refined further or can be directly utilized in fuel blending. Petroleum hydrocarbons have varying boiling points. By distillation, oil refineries can separate these hydrocarbons. Specifically for gasoline, the process is called “fractional distillation.” It involves heating crude

oil, vaporizing it, and then condensing it to retrieve gasoline. This process is shown in more detail by Figure 2. Chemical processing may also be used to retrieve gasoline from diesel fuel.

Fuel used for U.S. transportation, 2014¹

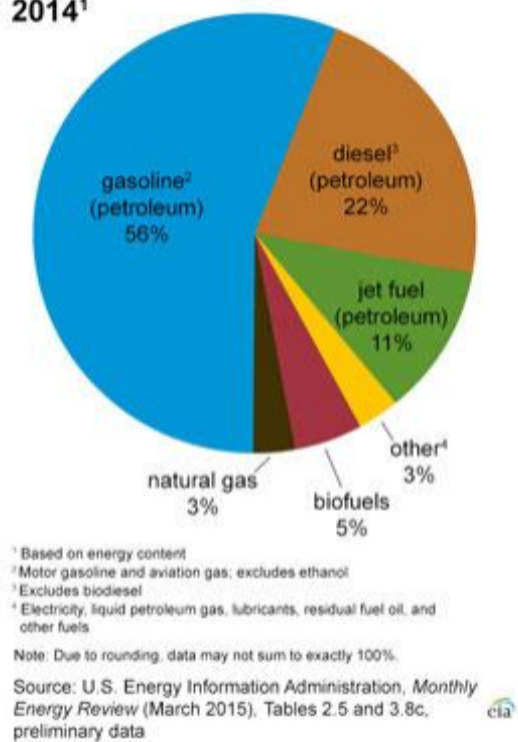


Figure 3: Fuel used for U.S. Transportation

iii. Domestic Production vs. Foreign Dependence

Although there are domestic sources producing petroleum by the methods described above, there is controversy about America's dependence on foreign fuel. In July 2015, OPEC contributed 89,785 thousand-barrels out of the total 294,833 thousand-barrels imported.⁹ In July 2015, the United States produced 292,415 thousand-barrels domestically in comparison.¹⁰ This is around 50% of oil being imported. As shown by Figure 3, gasoline, derived from crude oil, was the main transportation

fuel in the United States in 2014. It accounted for 56% of total U.S. transportation energy and its

⁸ Encyclopedia Britannica. “Cracking - Chemical Process.” *Encyclopedia Britannica* n.d. <http://www.britannica.com/technology/cracking-chemical-process>.

⁹ E.I.A. “Petroleum & Other Liquids - U.S. Imports by Country of Origin.” *U.S. Energy Information Administration*. 2016. http://www.eia.gov/dnav/pet/pet_move_impcus_a2_nus_ep00_im0_mbbbl_m.htm.

¹⁰ E.I.A. “U.S. Field Production of Crude Oil.” *U.S. Energy Information Administration*. 2016. <http://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=MCRFPUS1&f=M>.

consumption averaged 8.8 million barrels per day for transportation use.¹¹ America's dependence on foreign fuel and its various implications will be discussed later in this essay.

III. Natural Gas - Sources and Uses

Commercial use of natural gas started in Britain in 1785 to light up street lamps. Natural gas is currently utilized for a variety of reasons. Notably, it's used for generating electricity, powering the industrial sector, heating the commercial and residential sectors, and fueling natural gas vehicles. Natural gas is found deep below the earth's surface. It consists mainly of methane, non-hydrocarbon gases, and hydrocarbon liquids.

i. Natural Gas Extraction

Like gasoline, natural gas is a fossil fuel created from ancient remains that lay under sedimentary rock. These remains decay, mix with other sediments, and stack in thick layers under the Earth's surface. Extreme pressure and heat change these layers into natural gas, coal, and petroleum. Petroleum and natural gas are found in underground traps of oil and gas called reservoirs. Natural gas extraction is split into two method types: conventional and unconventional. Conventional natural gas is found in large permeable sandstone reservoirs using traditional drilling techniques. Additionally, it is important to note that conventional natural gas is a byproduct of oil production. Unconventional gas is standard natural

Hydraulic fracturing

Hydraulic fracturing, or fracking, unlocks natural gas from massive reservoir rock formations that otherwise could not be extracted economically. Some people worry hazardous chemicals used in the process pollute air and water.

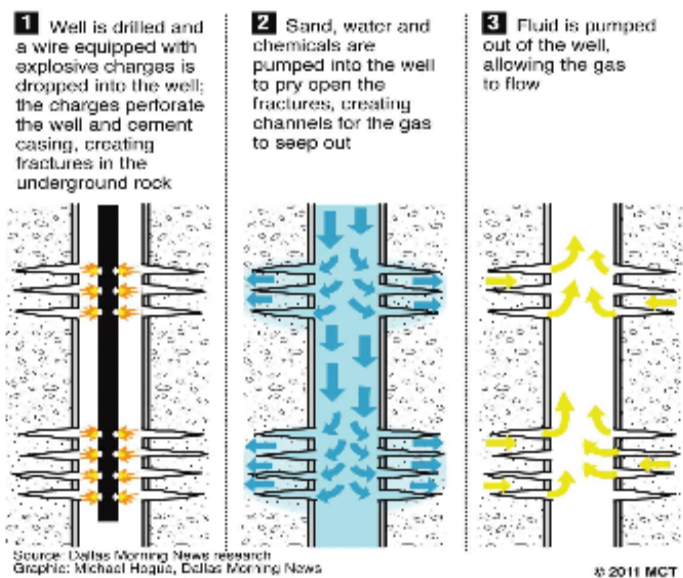


Figure 4: A diagram explaining visually how Hydraulic Fracturing - a method of retrieving Natural Gas from the ground/rocks - works. Source: <http://www.theoquitar.com/wp-content/uploads/2011/12/Fracking003.jpg>

¹¹ E.I.A. "Petroleum & Other Liquids - Crude Oil Production." *U.S. Energy Information Administration*. 2015. http://www.eia.gov/Energyexplained/?page=us_energy_transportation.

gas found in places other than sandstone reservoirs. These involve coal seam gas, found 200-1000 meters below the ground or shale gas, which is found in shale rock deposits.¹²

ii. Hydraulic Fracturing

A relatively new method of obtaining natural gas is Hydraulic fracturing. Hydraulic fracturing, called “fracking,” is used in more than nine out of ten natural gas wells. The process involves drillers forcing fluids consisting of water, sand, and other sediments with high pressure into formations. This cracks the rock. A visual representation of this process is illustrated in Figure 4. Gas flow through reservoirs is improved by creating these “fractures.” “Propping agents” are added to the fluid to open these fractures when the pressure decreases.

iii. Environmental Effects of “Fracking” and the Impact of Shale Gas

“Fracking,” however, has been directly correlated to triggering earthquakes.¹³ Additionally, shale gas produces methane - a potent greenhouse gas. There are also the serious environmental costs of water pollution and the large amounts of water (50,000 to 1000,000 gallons per well) involved in “fracking.” Despite the environmental costs, which often go unnoticed, the supply of natural gas has increased significantly by a process called shale fracturing. 750 trillion cubic feet of recoverable shale gas and 24 billion barrels of recoverable shale oil currently exists due to increases in technology.¹⁴ This massive increase in shale gas accounts for the recent increase in the supply of natural gas. This triggers a price decrease in natural gas over time. Shale gas, as mentioned above, is an unconventional gas. It is formed from hydraulic fracturing in shale and produced over 25% of America’s natural gas resources in 2012.

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¹² OriginEnergy. “Natural Gas.” *OriginEnergy*. 2015.
<https://www.originenergy.com.au/blog/about-energy/natural-gas.html>.

¹³ The National Academies of Sciences, Engineering, Medicine. “Natural Gas.” *The National Academies of Sciences, Engineering, Medicine* n.d.
<http://needtoknow.nas.edu/energy/energy-sources/fossil-fuels/natural-gas>.

¹⁴ EnergyFromShale. “What Is Shale Gas?” *EnergyFromShale* n.d.
<http://www.energyfromshale.org/articles/what-shale-gas>.

¹⁵ ShellenBerger, Michael , Ted Nordhaus, Alex Trembath, and Jesse Jenkins. “Where the Shale Gas Revolution Came From.” *Breakthrough Institute*. 2012.
http://thebreakthrough.org/images/main_image/Where_the_Shale_Gas_Revolution_Came_From2.pdf.

IV. Natural Gas in Transportation

Steven Mueller, chief executive of natural-gas company Southwestern Energy Co., states that the “abundance” of natural gas caused by fracking and shale gas wasn’t expected, yet it’s a “gift that we should take advantage of.”¹⁶ Additionally, the U.S. Department of Energy calls natural gas the “ideal fossil fuel.”¹⁷ However, its role in transportation is minimal compared to its other utilizations. Natural gas vehicles were invented in the 1930s, yet there are only 150,000 natural gas vehicles in the United States today. Most natural gas vehicles (NGV) are filled with CNG (compressed natural gas) or LNG (liquified natural gas). CNG is produced by compressing natural gas to “less than 1% of its volume at standard atmospheric pressure.” It’s stored onboard vehicles via cylinders. Liquid natural gas is formed when natural gas is cooled below its boiling point. This leaves methane and other hydrocarbons behind. However, LNG’s more expensive in production cost and must be stored in expensive cryogenic tanks. 1.5 gallons of LNG is one GGE (gallon gas equivalent) whereas 5.66 lbs of CNG is one GGE.¹⁸ The importance of the storage tanks of LNG and CNG NGVs are elaborated on later in the essay.

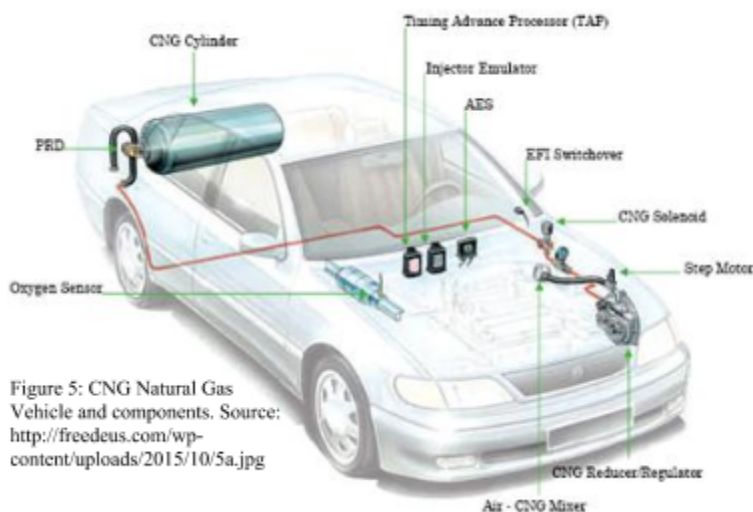


Figure 5: CNG Natural Gas Vehicle and components. Source: <http://freedeus.com/wp-content/uploads/2015/10/5a.jpg>

i. Types of Natural Gas Vehicles (NGVs)

There are three types of NGVs. First, there’s dedicated, which are NGVs running solely on natural gas. Bi-fuel NGVs are hybrids between gasoline and natural gas. Dual-fuel NGVs are diesel-natural gas hybrids for larger

¹⁶ Fowler, Tom . “America, Start Your Natural-Gas Engines.” *U.S. Energy Information Administration*. 2012.

<http://www.wsj.com/articles/SB10001424052702304192704577406431047638416>.

¹⁷ U.S. Department of Energy. “Natural Gas: Fueling the Blue Flame.” *U.S. Department of Energy* n.d. http://www.fossil.energy.gov/education/energylessons/gas/gas_production.html.

¹⁸ U.S. Department of Energy. “Alternative Fuels Data Center.” *U.S. Department of Energy* n.d. http://www.afdc.energy.gov/fuels/natural_gas_basics.html.

vehicles. It is important to note that NGVs have widely been utilized for busses, vans, and other larger transportation vehicles due to lower costs and environmental consideration.¹⁹ In terms of vehicle performance, NGVs are “similar to gasoline or diesel vehicles with regard to power, acceleration, and cruising speed.” For reference, Figure 5 refers to a CNG NGV and its inner workings - providing a visual model of its similarities and differences to gasoline vehicles.

ii. Infrastructure and Other Limitations of Natural Gas

An issue that natural gas faces today is its lack of infrastructure. As noted by Figure 7, natural gas has the third highest inventory of alternative fueling stations. Although there are many NGVs either on the market or in production and an “extensive natural gas distribution system” already exists in the United States, there is minimal infrastructure to back it up. One reason NGVs are limited in the U.S. is due to their “limited range, trunk space, higher initial costs, and lack of refueling infrastructure.”²⁰ LNG is usually delivered by tanker truck to designated stations yet custom stations can be ordered. Small fueling units can cost up to \$10,000, but such units can be placed into one’s home. These units utilize a homeowner’s existing natural gas lines - using less watts than do most small kitchen appliances.²¹ This is elaborated on later in the essay. Additionally, it is important to note that there exists a renewable natural gas source called RNG (biomethane) that produces much fewer greenhouse gasses. It is the product of organic matter decomposition and prevents methane release into the atmosphere if captured from landfills and farmlands. Importantly, it can be used in the existing natural gas distribution systems for transportation. But even so, how does natural gas compare to gasoline - a fuel standard for decades? This issue will be discussed in the next paragraph.

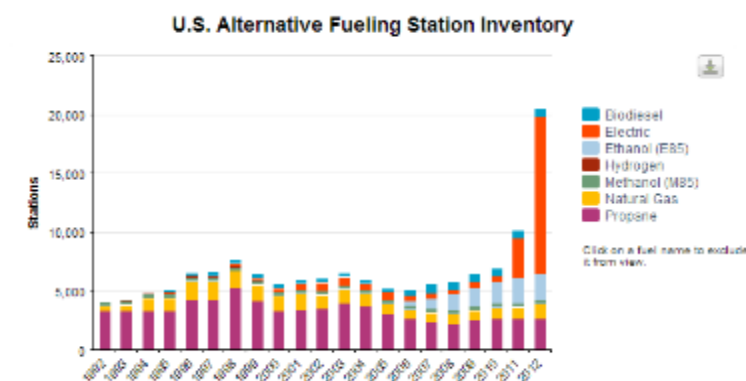
¹⁹ NGVGlobal. “NFTA Metro Adds NGV Buses and Vans to Fleet.” *Ngvglobal*. 2016. <http://www.ngvglobal.com/blog/nfta-metro-adds-ngv-buses-and-vans-to-fleet-0112>.

²⁰ NaturalGas.org. “Natural Gas in the Transportation Sector.” *NaturalGas.org*. 2013. <http://naturalgas.org/overview/uses-transportation/>.

²¹ CNGNow! “Refueling : Refueling at Home.” *CNGNow!*n.d. <http://www.cngnow.com/vehicles/refueling/Pages/refueling-at-home.aspx>.

V. Natural Gas as a Feasible Substitute for Gasoline

In 2013, the United States imported about 33% of the petroleum it consumed with nearly 70% of total petroleum consumption utilized for transportation. This put the U.S. in a position of dependency on foreign oil.²² Much of this oil is located in “politically volatile” areas, which leads to vulnerability in its supply. However, natural gas, unlike gasoline, can be domestically produced in great quantity - reducing foreign dependence. Increasing dependence on domestic production will help by lowering the trade deficit. Additionally, every “cubic foot of gas” domestically produced creates more jobs, raises national income, and increases growth.²³ From 2009 - 2013, around 35,000 jobs had been created due to oil and gas extraction alone. Additional implications of foreign dependence on oil is further elaborated on later in the essay.



Today's drivers can find thousands of fueling stations across the country that provide natural gas, electricity, ethanol, and other alternative fuels. Source: Alternative Fuels Data Center

Figure 7: Alternative fueling stations in the U.S.

Source: <https://www.washingtonpost.com/blogs/wonkblog/files/2013/04/US-alt-fuel-station-inventory-AFDC-via-CleanCities.png>

i. Cost Analysis of NGVs

To understand the monetary cost of NGVs versus gasoline vehicles, we will compare a Honda Civic NGV to a normal Honda Civic (both 2013 models). First, we assume that both owners of these vehicles travel about 40 miles per day (average miles traveled per person per day in the United States)²⁴ with 3,484 miles per year for travel outside commute. We also know that the annual fuel cost is about \$1.98 per gallon for gasoline and \$2.09 per GGE (gallon of gasoline

²² U.S. Department of Energy. “Natural Gas Benefits and Considerations.” *U.S. Department of Energy* n.d. http://www.afdc.energy.gov/fuels/natural_gas_benefits.html.

²³ WhiteHouse.gov. “Reducing America’s Dependence on Foreign Oil As a Strategy to Increase Economic Growth and Reduce Economic Vulnerability.” *WhiteHouse.gov*. 2013. <https://www.whitehouse.gov/blog/2013/08/29/reducing-america-s-dependence-foreign-oil-strategy-increase-economic-growth-and-redu>.

²⁴ Office of the Assistant Secretary for Research and Technology (OST-R). “National Household Travel Survey Daily Travel Quick Facts.” *United States Department of Transportation* n.d. https://www.rita.dot.gov/bts/sites/rita.dot.gov/bts/files/subject_areas/national_household_travel_survey/daily_travel.html

equivalent) for the NGV. Given that the regular Civic's MPG is 32 and the NGV is 31, we note that the NGV owner pays \$1,181.11 per year and the Civic owner pays \$1,155.04 per year for fuel. The Civic costs \$14,572 initially and the NGV costs \$18,000. It's important to notice, from Figure 6, that natural gas (CNG) has historically been cheaper than most forms of fuel, even if the average price for gasoline is currently cheaper than that of natural gas. The historical cost of gasoline has been \$2.20 per gallon, which would mean the Civic owner would pay around \$1,283.38 - greater than the GGE cost of the NGV.²⁵ Over a long period of time, the NGV owner will have paid the same price as the Civic owner. We should note that the current average price of natural gas is higher (per GGE) than gasoline because of the plunging price of a barrel of oil. This is due to Saudi Arabia's rapid production of oil, oil companies' stubbornness to halt production as long as prices cover daily costs, and unexpected consumer habits.²⁶

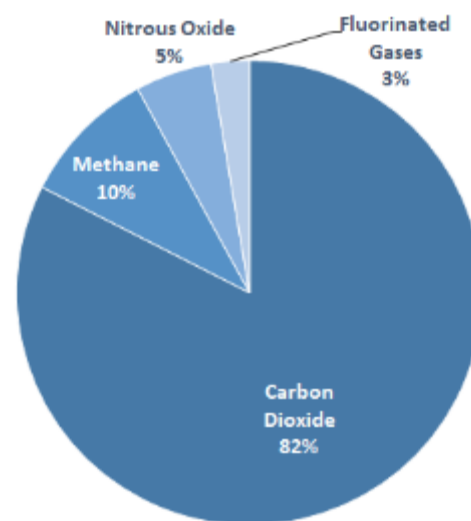


Figure 8: U.S. Greenhouse Gas Emissions in 2013.
Source: <http://www3.epa.gov/climatechange/ghgemissions/gases.html>

ii. Environmental Impacts of NGVs in Terms of CO₂

We find some surprising results when analyzing GHG (greenhouse gas) emissions of both vehicles. 9,646 lbs of CO₂ for the normal Civic and 8243 lbs of CO₂ for the NGV are produced annually.²⁷ If everyone drove a 2013 Civic, 122.01 million cars²⁸ would be exerting

²⁵ Energy.gov. Office of Energy Efficiency & Renewable Energy. "FACT #915: MARCH 7, 2016 AVERAGE HISTORICAL ANNUAL GASOLINE PUMP PRICE, 1929-2015." *Energy.Gov*. 2016. <http://energy.gov/eere/vehicles/fact-915-march-7-2016-average-historical-annual-gasoline-pump-price-1929-2015>.

²⁶ The Economist. "Who's Afraid of Cheap Oil?" *The Economist*. 2016. <http://www.economist.com/news/leaders/21688854-low-energy-prices-ought-be-shot-arm-economy-think-again-whos-afraid-cheap>.

²⁷ U.S. Department of Energy. "Alternative Fuels Data Center." *U.S. Department of Energy* n.d. http://www.afdc.energy.gov/vehicles/natural_gas.html.

²⁸ E.I.A. "Annual Energy Outlook 2015 Table: Light-Duty Vehicle Stock by Technology Type ." *U.S. Energy Information Administration*. 2016. <http://www.eia.gov/forecasts/aeo/data/browser/#/?id=49-AEO2015>.

9,646 lbs of CO₂ per year (122,010,000 cars * 9646 lbs of CO₂/year = ~1.18 trillion lbs of CO₂ annually). However, if everyone drove a 2013 Civic NGV, (122,010,000 cars * 8243 lbs of CO₂/year) = ~1.01 trillion lbs of CO₂ would be produced, a significant difference of **171.18 billion pounds of CO₂** annually. If this isn't a significant enough difference, one should note the assumptions that all cars driven are considered to be 2013 Honda Civics - a car with a 29 average mpg.²⁹ However, gasoline cars have MPGs that can be almost as low as 12 mpg. This means that the calculations above greatly underestimate exactly how much CO₂ is produced by gasoline vehicles. Thus, the difference in CO₂ produced is greatly underestimated. Increases in atmospheric concentrations of CO₂ will last thousands of years, whereas methane produced by NGVs will last about a decade.³⁰ The emissions from gasoline vehicles are known to have detrimental health and environmental effects as well. As shown in Figure 8, CO₂ is considered the largest producer to greenhouse climate change. The emissions from gasoline vehicles also cause several respiratory issues, decrease air quality, and can lead to cardiovascular problems.³¹ Argonne National Laboratory's GREET model measures lifecycle petroleum use and GHG emissions. It found that NGVs emit 6% - 11% lower levels of GHG than do gasoline in the fuel life cycle.

iii. Additional Comments on NGVs and the Environment

According to the EPA, CNG-based NGVs can reduce "carbon-monoxide emissions by 90 - 97% and nitrogen-oxide emissions by 35 - 60%" in comparison to gasoline. Also, its use can reduce "non-methane hydrocarbon emissions by 50 - 75%" while producing "fewer carcinogenic pollutants and little or no particulate matter."³² Additionally, medium and heavy duty natural gas

²⁹ U.S. Department of Energy. "Fuel Economy of 2013 Honda Civic." *U.S. Department of Energy*. 2013. <https://www.fueleconomy.gov/feg/PowerSearch.do?action=noform&path=7&year=2013&make=Honda&model=Civic&srctype=ymm>.

³⁰ EPA. "Understanding Global Warming Potentials." *Environmental Protection Agency* n.d. <http://www3.epa.gov/climatechange/ghgemissions/gwps.html>.

³¹ Environment & Human Health, Inc. "The Harmful Effects of Vehicle Exhaust: A Case for Policy Change." *Environment & Human Health, Inc.* n.d. <http://www.ehhi.org/reports/exhaust/exhaust06.pdf>.

³² ConsumerReports. "The Natural-Gas Alternative." *ConsumerReports*. 2014. <http://www.consumerreports.org/cro/2012/03/the-natural-gas-alternative/index.htm>.

engines were the first engines to satisfy EPA’s 2010 standards for nitrogen oxides. The Honda Civic NGV won the American Council for An Energy-Efficient Economy’s title of Greenest Vehicle for eight years straight. The NGV was also noted for having the “cleanest commercially available internal-combustion vehicle on Earth” by the EPA. Additionally, retrofitting an older vehicle to become an NGV can reduce cost and can greatly reduce GHG emissions. According to Figure 9, we notice that CNG NGVs reduce “20-29% fewer GHG emissions than do gasoline powered vehicles.” Also, for NGVs that run on biomethane or RNG-derived sources, the GHG reduction can approach up to 90%.³³

Light-Duty Vehicles	Carbon Intensity of Fuel (gCO ₂ e/MJ)	EER	Total	Reductions Relative to Gasoline
Gasoline (Baseline—CA RFG with EtOH mix)	95.86	1	95.9	NA
CNG	68	1	68	29%
Biomethane CNG	11.26	1	11.26	89%
CNG 20% Biomethane	56.602	1	56.6	41%

Figure 9: California Air Resource Board (CARB) analysis on carbon intensity reductions for natural gas. Source: <https://www.ngvamerica.org/natural-gas/environmental-benefits/>

iv. Infrastructure for NGVs

Although there aren’t many refueling stations when compared to that of gasoline (only 1,500 in the U.S., half of which are public), the higher initial cost to create the infrastructure will be worth the benefits politically and environmentally. Additionally, home-install units for NGVs are available and improving rapidly. Specifically, the most notable option is called the “Phill.” It is the size of an upright vacuum cleaner and can be installed on the wall of a garage with “access

³³ NGV America. “Environmental Benefits of NGVs.” [Ngvamerica.org](https://www.ngvamerica.org/natural-gas/environmental-benefits/).d. <https://www.ngvamerica.org/natural-gas/environmental-benefits/>.

to a 240-volt, 15-amp electrical circuit and natural gas line.” The refill time is about 6 hours.³⁴ There are several projects in place aimed at decreasing the high initial price of a home-refill unit down to around \$1,000. However, it’s important to note that companies like Atlanta Gas Light Co. are already offering programs to allow consumers to install “Phills for free by agreeing to a five-year lease at \$60 per month.”³⁵ Programs like these should assist with the initial transition for the American public to use NGVs.

v. Reducing Dependence on Foreign Sources of Fuel

Christopher Knittel, professor of economics and energy at MIT, states that natural gas vehicles could “increase energy security” and “decrease the U.S. economy’s susceptibility to recessions caused by oil-price shocks.”³⁶ In November 2009, it was found that “rising oil imports widened our deficit, increasing the gap between our imports and exports.”³⁷ Specifically, according to the United States Energy Security Council, oil imports constitute half of the U.S. trade deficit.³⁸ In 2008, the United States imported oil from ten countries on the State Department's Travel Warning List, “which lists countries that have ‘long-term, protracted conditions that make a country dangerous or unstable.’” Importing oil from these countries indicates sources of instability for oil. Although dependence on foreign oil has notably decreased since 2008, there are still some considerations to factor as oil continues to be imported. Asides from reducing the trade deficit, decreased dependence on foreign sources of fuel manifests itself

³⁴ Fowler, Tom . “America, Start Your Natural-Gas Engines.” *U.S. Energy Information Administration*. 2012.

<http://www.wsj.com/articles/SB10001424052702304192704577406431047638416>.

³⁵ U.S. Department of Energy. “Natural Gas Vehicle Emissions.” *U.S. Department of Energy* n.d. <http://www.ehhi.org/reports/exhaust/exhaust06.pdf>.

³⁶ Fowler, Tom . “America, Start Your Natural-Gas Engines.” *U.S. Energy Information Administration*. 2012.

<http://www.wsj.com/articles/SB10001424052702304192704577406431047638416>.

³⁷ Lefton, Rebecca, and Daniel J Weiss. “Oil Dependence Is a Dangerous Habit.” *Center for American Progress*. 2010. <https://www.americanprogress.org/issues/green/report/2010/01/13/7200/oil-dependence-is-a-dangerous-habit/>.

³⁸ Brandz, Keisha. “Why It’s Important for the US to Reduce Imported Oil Dependency.” *Market Realist*. 2014.

<http://marketrealist.com/2014/07/why-its-important-for-the-us-to-reduce-imported-oil-dependency/>.

in “higher standards of living” and “higher growth rates.”³⁹ The increase in natural gas has made itself apparent in the increase of jobs it engenders. This is a significant result of domestic fuel production. For example, the Bakken formation in North Dakota has led to such a “sudden surge in employment and population” in that area that construction companies are unable to build housing “fast enough to keep up with population growth.”⁴⁰

vi. Transitioning to NGVs and Consumer Psychology

Although natural gas has already had a huge impact in commercial-trucking or in companies that use big fleets to save on fuel, it hasn’t made much of an impact for those who use passenger cars. One reason for this is the high cost of NGVs, often costing thousands of dollars more than regular gasoline vehicles. Additionally, the lack of public refueling stations and the skepticism that consumers may have about the safety of natural gas in their vehicles are all concerns that people have had about NGVs. One of the most important considerations facing building NGVs for passenger cars is the fuel tank.⁴¹ As mentioned previously, NGV tanks are more expensive than those in gasoline-powered cars as they must be able to store high-pressure gas. Additionally, the space they take up decreases the space that can be utilized for storage. However, 3M Corporation and Chesapeake Energy corporation are working on developing natural gas tanks that use “plastic linings wrapped in carbon-composite materials.” These would be “10 - 20% lighter and have 10% - 20% more fuel capacity” than current natural gas tanks. Also, a smaller tank that allows natural gas to be stored at lower pressure has been created by the University of Missouri. It is made of out “corncobs turned into charcoal briquettes.”⁴² Perception

³⁹ WhiteHouse.gov. “Reducing America’s Dependence on Foreign Oil As a Strategy to Increase Economic Growth and Reduce Economic Vulnerability.” *WhiteHouse.gov*. 2013.

⁴⁰ Maverick, J. B. “How Has Fracking Helped the U.S. to Decrease Dependence on Foreign Oil?” *Investopedia* n.d.
<http://www.investopedia.com/ask/answers/012915/how-has-fracking-helped-us-decrease-dependence-foreign-oil.asp>.

⁴¹ Fowler, Tom . “America, Start Your Natural-Gas Engines.” *U.S. Energy Information Administration*. 2012.
<http://www.wsj.com/articles/SB10001424052702304192704577406431047638416>.

⁴² Fowler, Tom . “America, Start Your Natural-Gas Engines.” *U.S. Energy Information Administration*. 2012.
<http://www.wsj.com/articles/SB10001424052702304192704577406431047638416>.

of NGVs is a factor of consideration as to why they are not as mainstream as they could be. Many people overlook the fact that natural gas has operated at up to half of the cost of gasoline before. Another concern is the pay-off for converting to NGVs. This can be up to ten or more years. Kathryn Clay, director of the Drive Natural Gas Initiative, states that “the average person discounts any fuel savings beyond three years.”⁴³ However, if the United States were to subsidize and assist the transition to NGVs and if the research conducted on bolstering the current technology were to become a reality, consumers would be more likely to make the transition. Finally, it’s important to note that NGVs provide greater efficiency and safety than gasoline-powered vehicles. NGV vehicles owners are allowed to use the high-occupancy vehicle (HOV) lanes in some states. This will provide an impetus for the transition, as it was for hybrid vehicles. According to Okhtay Darian, an energy engineer for Associated Renewable Inc., the NGV’s oil needs to be changed less frequently due to natural gas being a cleaner-burning fuel.⁴⁴ Also, natural gas is lighter than air and will dissipate in an accident rather than spill flammable liquid fuel as would occur in a gasoline vehicle. These factors will provide an even greater impetus for NGVs to be more publicly accepted.

vii. Concerns About Excess Natural Gas from Production and its Role in Transportation

As mentioned previously, natural gas prices have decreased significantly. This is due to the increasing usage of “fracking,” specifically shale fracking. The U.S. gas futures contracts for “february delivery fell by 0.43%” and closed at “\$2.3 per MMBtu” (British thermal units in millions) on January 4, 2016. These price decreases were a result of record inventories caused by the reasons above and previously in the essay. Additionally, the United States Natural gas ETF (UNG) “fell by 1.6% and closed at \$8.5 on the same day.”⁴⁵ The variability in the price of natural gas is additionally caused by warmer winter weather, which leads to inventory not

⁴³ Fowler, Tom . “America, Start Your Natural-Gas Engines.” *U.S. Energy Information Administration*. 2012.

<http://www.wsj.com/articles/SB10001424052702304192704577406431047638416>.

⁴⁴ Duffy, Marcia P. “The Pros and Cons of Natural-Gas Vehicles.” *Fox Business*. 2012. <http://www.foxbusiness.com/features/2012/12/18/pros-and-cons-natural-gas-vehicles.html>.

⁴⁵ Christopher, Gordon . “Natural Gas Prices Volatile Due to Excess Supply.” *Market Realist*. 2016. <http://marketrealist.com/2016/01/natural-gas-prices-volatile-due-excess-supply/>.

being utilized. It's important to note a "19% decrease in natural gas prices" due to oversupply concerns. On the other hand, the increase in natural gas production puts pressure on natural gas prices. The current inventory of natural gas is "13.5% more than the five-year average." Price stability of the energy source is a strong consideration for the transition to NGVs, especially when it is one of the main factors why petroleum is looked down upon as a source of energy. However, there is a solution to the problem of excess supply. There is a possibility of converting the excess gas to transportation fuel that could be utilized in cars currently on the road. This technology to transform natural gas to low-sulfur diesel fuel originated in Germany. Royal Dutch Shell opened a "Pearl Gas-to-Liquids" project in Qatar that took "natural gas excess and converted it into diesel that fuels 160,000 cars and produces additives for jet fuel and other products." Shell is considering a similar project in Louisiana. Also, Siluria Technologies Inc. in Silicon Valley has developed a method of converting natural gas into ethylene, a "feedstock that can be used to make a wide range of fuels and other products."⁴⁶ This process can be utilized to convert excess natural gas. By converting excess natural gas to other usable products, we can not only stabilize the price variation, but we can also make the fuel more efficient for use. Using excess natural gas for transportation of non-NGV vehicles can also help assist with the transition from gasoline to NGVs.

viii. Other Benefits and Considerations of NGVs over Gasoline-Fueled Vehicles

Governments, such as those in Pakistan and Iran, have mandated a transition to NGVs to compensate for a lack in "gasoline-refining capacity."⁴⁷ Compared to the United States' approximately 150,000 NGVs, they have 2.7 and 1.9 million vehicles, respectively. Iran, although an oil power, has made a significant transition to NGVs. It has created the infrastructure to have a refueling station per 1,262 vehicles on the road. The promotion of NGVs by the government and the low cost of the fuel was a great impetus for this push. Additionally, rising

⁴⁶ Fowler, Tom . "America, Start Your Natural-Gas Engines." *U.S. Energy Information Administration*. 2012.
<http://www.wsj.com/articles/SB10001424052702304192704577406431047638416>.

⁴⁷ Fowler, Tom . "America, Start Your Natural-Gas Engines." *U.S. Energy Information Administration*. 2012.
<http://www.wsj.com/articles/SB10001424052702304192704577406431047638416>.

auto sales and smog prompted the government to find a solution. This solution was found in recognizing that the natural gas pipelines used for residential purposes could be utilized for transportation.⁴⁸ Like Iran, America has a large residential system for natural gas. Additionally, more than 131 million Americans live in areas without clean air. For example, in Los Angeles in 2014, there were 94 days where the air pollutants were “above federal regulation standards.”⁴⁹ If the United States government were to subsidize alternative fuels and to bolster the construction of refueling station, then daily commute could potentially cost “less than a penny per mile” as is the case in Iran. Additionally, if more NGVs were sold on the large-scale, it is very likely that the initial costs that skeptics denounce NGVs for would decrease. This would increase impetus for consumers to buy NGVs. Efforts to do so have already been started by companies like Honda, Chrysler Group LLC, and General Motors. Also, a study of New York City taxis that ran on natural gas “concluded that maintenance costs were also reduced”⁵⁰ by their usage.

VI. Conclusion

The dependence of America on crude oil places it in a peculiar position. We have to reevaluate if America’s relationship with oil is functional. The concerns for climate change are ever-rising. Additionally, political tensions in oil-producing nations reveal the constant economical risk that America is at every day. Thus, a gradual change from gasoline to LNG, CNG, and RNGs as fuel alternatives provide a solution to both these issues. With recent technology improvements and a change of infrastructure, the long-term benefits of using NGVs will make themselves apparent. Even if initial costs are high, the switch is economically and politically feasible. The option of NGVs for transportation isn’t a novel concept. The

⁴⁸ Erdbrink, Thomas . “In Oil-Rich Iran, Natural Gas Turns Wheels.” *New York Times*. 2012. <http://www.nytimes.com/2012/10/24/business/energy-environment/to-lower-pollution-iran-becomes-a-natural-gas-leader.html>.

⁴⁹ Sapienza, James D. “Smog Statistics: Air Quality in America’s Worst State For Smog.” *Autos Cheat Sheet*. 2015. <http://www.cheatsheet.com/automobiles/smog-studies-is-the-curb-on-emissions-working.html/?a=viewall>

⁵⁰ ConsumerReports. “The Natural-Gas Alternative.” *ConsumerReports*. 2014. <http://www.consumerreports.org/cro/2012/03/the-natural-gas-alternative/index.htm>.

infrastructure is in place. The sooner America can make the investment in NGVs and break its dependence on oil, the better for everyone.

[4,180 words]