

The Feasibility of Natural Gas as an Eventual Substitute for Gasoline

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HSA10-5 The Economics of Oil and Energy

April 7, 2016

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)

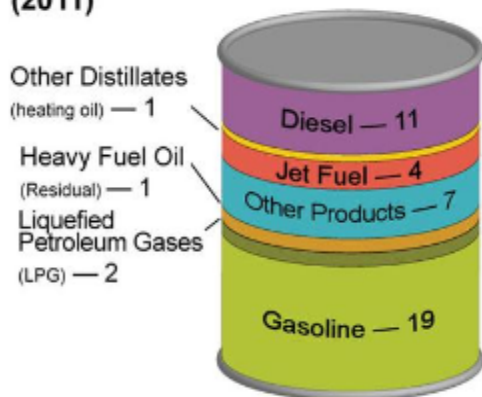


Figure 1: Distribution of products made from a barrel of petroleum. Source: http://www.eia.gov/energyexplained/index.cfm?page=oil_home

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

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>.

by aquatic plant and animal remains that settled to the bottom of ancient seas millions of years ago. This, of course, 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 to 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)) = $\sim 5.79 \cdot 10^{11}$ 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

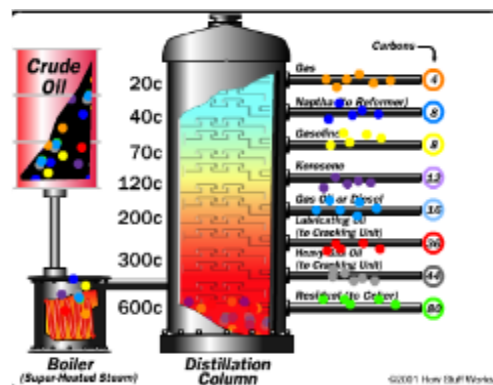


Figure 2: A Fractional Distillation column, the first step of fractional distillation. It refines the crude oil into various liquid fractions that may pass to condensers or other areas for chemical processing. Source: <http://science.howstuffworks.com/environmental/energy/oil-refining4.htm>

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 further refined or can be directly utilized in fuel blending. Additionally, petroleum hydrocarbons have varying boiling points. By distillation, oil refineries can separate these hydrocarbons. The process involves “fractional distillation,” which 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

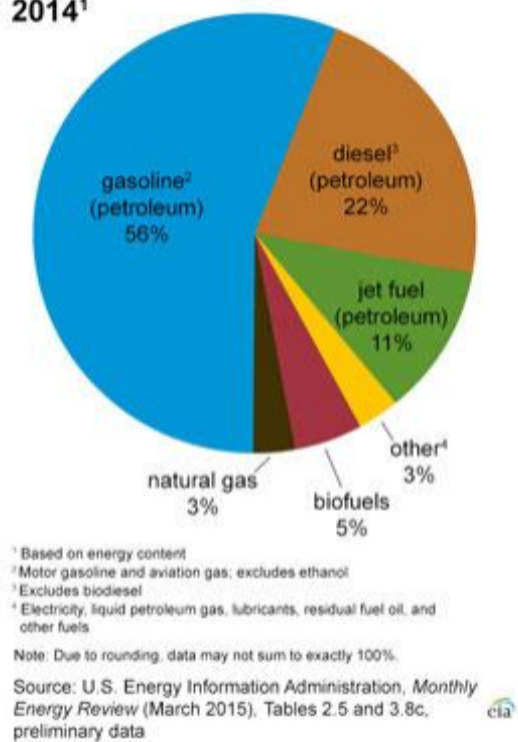


Figure 3: Fuel used for U.S. Transportation

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 only 9,433 thousand-barrels domestically in comparison.¹⁰ 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 consumption averaged 8.8 million

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. “Petroleum & Other Liquids - Crude Oil Production.” *U.S. Energy Information Administration*. 2016. https://www.eia.gov/dnav/pet/pet_crd_crpdn_adc_mbbblpd_m.htm.

barrels per day for transportation use.¹¹ America's dependence on foreign fuel and its various costs 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.

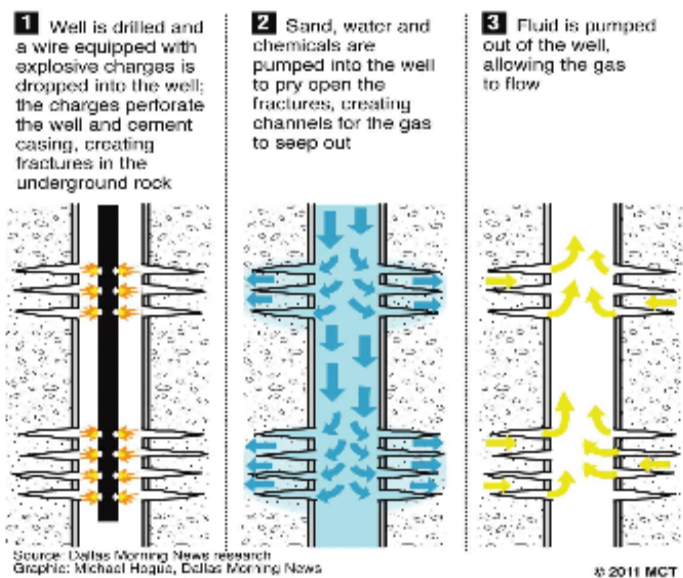


Figure 4: A diagram explaining visually how Hydraulic Fracturing - a method of retrieving Natural Gas from the ground/rocks - works. Source: <http://www.theoquitar.com/wp-content/uploads/2011/12/Fracking003.jpg>

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 like water 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 exists currently due to increases in technology.¹⁴ This massive increase in shale gas accounts for the increase in 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 2012.¹⁵

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

The U.S. Department of Energy calls natural gas the “ideal fossil fuel.”¹⁶ 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.¹⁷

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 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.¹⁸ In terms of vehicle performance, NGVs are “similar to gasoline or diesel vehicles with regard to power, acceleration, and

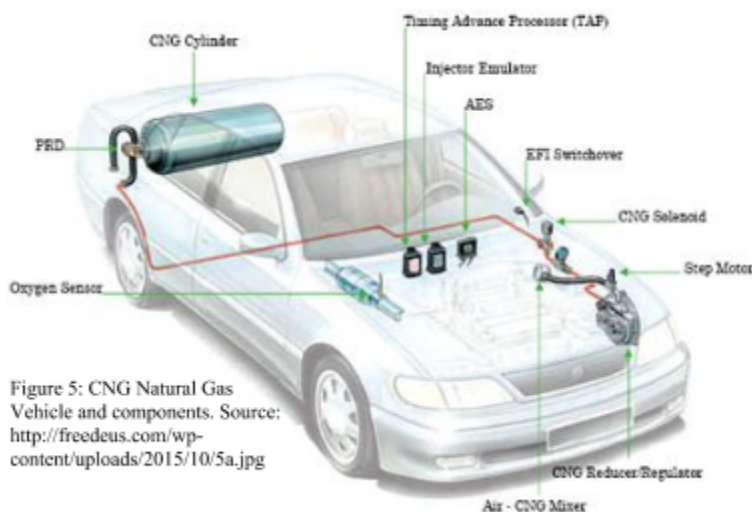


Figure 5: CNG Natural Gas Vehicle and components. Source: <http://freedeus.com/wp-content/uploads/2015/10/5a.jpg>

¹⁶ 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.

¹⁷ 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.

¹⁸ 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>.

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” 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.”¹⁹ 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.²⁰ Additionally, there is progress towards making refuelling units that cost less than \$1000. 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.

V. Natural Gas as a Feasible Substitute for Gasoline

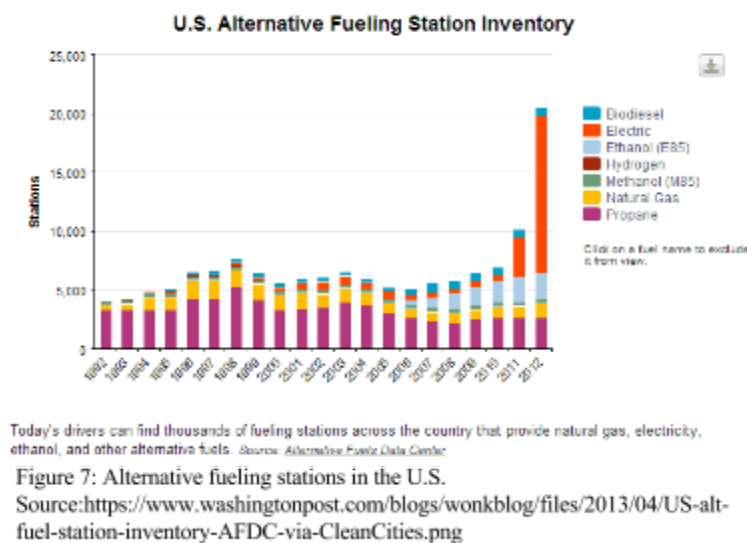
In 2013, the United States imported about 33% of the petroleum it consumed with nearly 70% of total petroleum consumption utilized for transportation. This put the U.S. in a position of dependency on foreign oil.²¹ Much of this oil is located in “politically volatile” areas, which

¹⁹ NaturalGas.org. “Natural Gas in the Transportation Sector.” *NaturalGas.org*. 2013. <http://naturalgas.org/overview/uses-transportation/>.

²⁰ CNGNow! “Refueling : Refueling at Home.” *CNGNow!*n.d. <http://www.cngnow.com/vehicles/refueling/Pages/refueling-at-home.aspx>.

²¹ 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.

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.²² From 2009 - 2013, around 35,000 jobs had been created due to oil and gas extraction alone.



i. Cost Analysis of NGVs

Comparing a Honda Civic NGV to a normal Honda Civic (both 2013 models), given that both travel about 40 miles per day (average miles traveled per person per day)²³ with 3,484 miles per year for travel outside commute, we see that the annual fuel cost is about \$1.98 per gallon for gasoline and \$2.09 per GGE (gallon of gasoline 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 \$234.89 per year and the Civic owner pays \$215.57 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 \$239.53 - greater than the gas cost of the NGV.²⁴ Over

²² 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>.

²³ Office of the Assistant Secretary for Research and Technology (OST-R). "National Household Travel Survey Daily Travel Quick Facts." *United States Department of Transportation*.d. https://www.rita.dot.gov/bts/sites/rita.dot.gov/bts/files/subject_areas/national_household_travel_survey/daily_travel.html

²⁴ Energy.gov. Office of Energy Efficiency & Renewable Energy. "FACT #915: MARCH 7, 2016 AVERAGE HISTORICAL ANNUAL GASOLINE PUMP PRICE, 1929-2015." *Energy.Gov*. 2016.

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 gallons of gasoline because of the plunging price of a barrel of oil. This is because of Saudi Arabia's rapid production of oil, oil companies' stubbornness to halt production as long as prices cover daily costs, and unexpected consumer habits.²⁵

ii. Environmental Impacts of NGVs in Terms of CO₂

We find some surprising results when analyzing GHG emissions of both vehicles. 9646 lbs of CO₂ for the normal Civic and 8243 lbs of CO₂ for the NGV are produced annually.²⁶ If everyone drove a 2013 Civic, 122.01 million cars²⁷ would be exerting 9646 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.²⁸ However, gasoline cars have mpgs that can be almost as low as 12 mpg. This means that the calculations above greatly

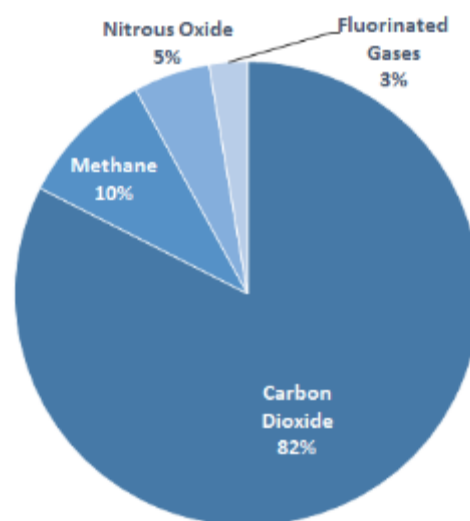


Figure 8: U.S. Greenhouse Gas Emissions in 2013.
Source: <http://www3.epa.gov/climatechange/ghgemissions/gases.html>

<http://energy.gov/eere/vehicles/fact-915-march-7-2016-average-historical-annual-gasoline-pump-price-1929-2015>.

²⁵ 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>.

²⁶ 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.

²⁷ 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>.

²⁸ 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=yym>.

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.²⁹ 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 cause several respiratory issues, decrease air quality, and can lead to cardiovascular problems.³⁰ Argonne National Laboratory's GREET model measures lifecycle petroleum use and GHG (greenhouse gas) emissions. It found that NGVs emit 6% - 11% lower levels of GHG than do gasoline in the fuel life cycle.

iii. 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. There exist hundreds of CNG and LNG (compressed and liquified) natural gas stations in the United States.³¹ This will assist with the initial transition for the American public to use NGVs. Not only is natural gas as a fuel historically cheaper than gasoline, but its use will assist with decreasing the political dependence America has on foreign oil and will reduce several pertinent detriments that petroleum and petroleum-related fuels have been causing.

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

²⁹ EPA. "Understanding Global Warming Potentials." *Environmental Protection Agency* n.d. <http://www3.epa.gov/climatechange/ghgemissions/gwps.html>.

³⁰ 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>.

³¹ U.S. Department of Energy. "Natural Gas Vehicle Emissions." *U.S. Department of Energy* n.d. <http://www.ehhi.org/reports/exhaust/exhaust06.pdf>.

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

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