Global Policy Research Institute (GPRI) Policy Briefs

Volume 1 | Issue 1 Article 2

6-18-2013

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Dharik Mallapragada
Purdue University, dharik@purdue.edu

Rakesh Agrawal
Purdue University, agrawalr@purdue.edu

Recommended Citation
Mallapragada, Dharik and Agrawal, Rakesh (2013) "Role of Natural Gas in America's Energy Future: Focus on Transportation," *Global Policy Research Institute (GPRI) Policy Briefs*: Vol. 1: Iss. 1, Article 2.
Available at: http://docs.lib.purdue.edu/gpripb/vol1/iss1/2

Global Policy
Research Institute

Policy Brief

No. 2

Role of Natural Gas in America's Energy Future: Focus on Transportation

DHARIK S. MALLAPRAGADA
RAKESH AGRAWAL
School of Chemical Engineering
Purdue University

PURDUE
UNIVERSITY

Global Policy Research Institute
1341 Northwestern Avenue
West Lafayette, IN 47906
Phone: (765) 496-6788
Fax: (765) 463-1837
www.purdue.edu/globalpolicy

The energy landscape of the United States for the past century has been dominated by the use of fossil fuels namely coal, petroleum, and natural gas (NG). While coal usage was dominant during the early 1900's, petroleum has been dominant ever since the second half of the 20th century owing to increasing use of liquid fuels, gasoline and diesel, for transportation. In contrast, NG consumption in the U.S., currently at ~25% of total primary energy use, has only been steadily increasing since the early 1990's (BP, 2012). However, the last decade has seen rapid growth in U.S. NG consumption as a result of falling prices stemming from the surge in domestic gas reserves. According to the U.S. Energy Information Administration (EIA), currently the total recoverable U.S. natural gas reserves are estimated at 2214 trillion standard cubic feet (tcf). For an annual NG consumption of 24.1 tcf (in 2010), U.S. NG reserves are estimated to last close to 92 years. Not surprisingly, there has been a growing interest in expanding NG use in the U.S. energy supply. Here, we analyze the potential for using NG to meet the energy requirements of U.S. light duty vehicle (LDV) fleet and the associated energy policy implications. Compared to coal and petroleum, natural gas by virtue of its higher hydrogen to carbon ratio, could contribute to reducing greenhouse gas (GHG) emissions with little sequestration efforts (Burnham et al., 2011).

Currently, U.S. NG consumption is essentially used for power generation, industrial, commercial and residential consumption. Of these, the power generation sector offers immediate potential for expansion through natural gas-fired plants possibly adding to existing electricity generation capacity and also displacing the use of coal power. Due to recent heightened safety concerns of nuclear power, some of the contemplated future nuclear electric capacity will likely shift to natural gas as well. The low cost of natural gas is also promoting the resurgence of the U.S. petrochemical industry based on new plant construction announcements. Beyond these traditional sectors, NG use for transportation is a possible option that could have large societal and economic benefits by reducing imports and protecting U.S. energy security interests. Currently, less than 3% of the NG consumed in the United States is for transportation and most of that is used for powering the transportation pipeline and distribution systems.

Policy intervention is often critical in the development of alternative energy technologies and NG use for transportation is no exception. Several recent U.S. energy policy initiatives are likely to impact the potential of using NG for LDV transportation. For example, consider the recent mandate increasing the corporate average fuel economy (CAFÉ) standards of the LDV fleet to 54.5 miles per gallon of gasoline-equivalent (mpgge) by 2025 (EPA/NHTSA, 2012). Under these CAFÉ standards, alternative fuels (derived from NG or other primary energy sources) and vehicle technologies would have to compete with advanced gasoline/diesel-ICEVs using much less fuel than current LDVs. This could potentially decrease the economic motivation of consumer's to shift to alternative fuels and vehicle technologies. Other policies impacting the use of NG in transportation include: 1) The biofuel mandate under the Renewable Fuel Standard (RFS2), 2) Rebates promoting the sale of electric vehicles such as the Chevrolet Volt and Nissan Leaf, 3) The announced budget reductions for research on the use of hydrogen fuel for transportation (Wachsman et al., 2012), and 4) The proposed ruling of < 1000 lb-CO_2 emissions/MWh for new electricity generation sources (EPA, 2012).

In the following sections, we will present a comparison of the different possible pathways of using NG for LDV transportation along with the discussion of the relevant implications of the above-mentioned policies.

Methodology

NG can be used for transportation via several pathways, combining different end-use fuels and vehicle technologies. This study considered the following pathways:

- Current and improved (CAFÉ standard compliant) internal combustion engine vehicles (ICEVs) using either one of gasoline, diesel, hydrogen, and compressed natural gas (CNG).
- Fuel-cell vehicles (FCVs) using either one of gasoline, methanol, hydrogen, and compressed natural gas (CNG).
- Battery electric vehicles (BEVs) using electricity.
- Plug-in hybrid electric vehicles (PHEVs) using electricity combined with either one of gasoline, diesel, hydrogen, and compressed natural gas (CNG).

We compare between these pathways using the metric of **well-to-wheel (WTW) efficiency,** defined as *kilometers (km) driven per 100 MJ of NG at well*. This energy efficiency metric considers all the energy transformations going from primary energy (NG at well) to end-use (wheels), while having similar GHG emissions in each case. The major transformations of each pathway consist of NG extraction, recovery, processing and transportation to fuel production site, followed by fuel production, distribution and use in the specified vehicle technology. In this analysis, gasoline, diesel and hydrogen are derived from NG. From the viewpoint of finite NG reserves, pathways with higher WTW efficiency are favorable since they will require lower overall NG requirements to drive the entire LDV fleet. To facilitate consistent comparison, wherever possible we have chosen to use the data derived from the GREET (Greenhouse Gas, Regulated Emissions, and Energy use in Transportation) database for our analysis (Wang et al., 2012).

Findings

Current Technology

In Figure 1, we compare the WTW efficiency of different NG pathways for current and potential future scenarios of electrical power generation efficiency and ICEV fuel economy. Among current and future ICEV pathways, the CNG pathway is the most energy efficient due to the fewer number of energy transformations involved in its production compared to producing liquid fuels and H_2. One should note that CNG production from NG is a proven technology and has been deployed in several nations worldwide (Yeh, 2007). CNG as a fuel is also an attractive economic option in the U.S., because of its currently lower energy-equivalent price compared to petroleum-based gasoline (DOE, 2012), as well as the existing NG pipeline network for fuel distribution.

For the same reason of fewer energy transformation steps, Figure 1a shows that the direct use of CNG in a FCV is estimated to have a higher WTW efficiency than using H_2, despite the ~55% higher fuel economy of an FCV using H_2 directly. The lower fuel economy when using CNG (and other carbon fuels) in FCV compared to H_2-FCV is due to the use of a steam reformer for on-board H_2 production.

The BEV pathway using electricity derived from Natural Gas Combined-Cycle (NGCC) plant has the highest WTW efficiency in Figure 1a. Yet, current BEVs are limited to niche end-uses because of their short travel range of 90-100 miles using existing battery technologies and costs (Elgowainy et al., 2010). On the other hand, PHEVs allow for extending beyond the battery range via use of secondary fuel stored on-board the vehicle. For this analysis, the PHEV using gasoline, diesel, or CNG as secondary fuel utilize ICEV technology. In case of H_2-PHEV, we consider the use of FCV technology, which in addition to its higher fuel economy relative to H_2-ICEV has the added benefit of an all-electric powertrain. For a typical rated all-electric range (AER) of 40 miles similar to the Chevrolet Volt, our analysis estimates current PHEVs to offer 8-30% increased WTW efficiency compared to the corresponding fuel-only (ICEV or FCV) pathway.

CAFÉ Standard Impact

In case the mandated CAFÉ standards are achieved, we estimate that the CNG-ICEV pathway is not only more energy efficient than current BEV and FCV pathways but is also comparable with the future BEV pathway. CAFÉ standards also project the use of gasoline via ICEV to be more energy efficient than their alternative use in FCV. Here we have intentionally not assumed any future improvements in FCV technology, due to the relatively nascent stage of its current commercial deployment. Based on current FCV technology and the significant infrastructural challenges of delivering and storing H_2, we estimate a diminished role of H_2 as a direct fuel for NG-based transportation. This finding has been acknowledged in the recent budget cuts in U.S. H_2 research & development. At the same time, our analysis can be used to derive fuel economy targets for FCV development that will make FCV pathways competitive with the other more efficient transport pathways.

In contrast to H_2, we find CNG offers unique WTW efficiency advantages along with its relatively dense onboard storage capabilities (unlike H_2) and existing pipeline infrastructure. CNG-specific policy measures to overcome its presently existing fueling infrastructure and vehicle technology related economic challenges (EIA, 2012a), can potentially make it a viable transportation fuel option in the U.S. A recently announced U.S. Department of Energy initiative to promote research and development in the area of methane storage and refueling technologies is an encouraging step in this direction (DOE, 2012a).

Given the existing refueling infrastructure for liquid fuels as well as the mandated use of liquid biofuels such as ethanol under RFS2, NG-transport pathways using liquid fuels could be favored. Between diesel and gasoline ICEVs, traditionally diesel is the more energy efficient fuel option. In addition, our study points to the higher WTW efficiency of partial electrification pathways using liquid fuel via PHEV rather than using ICEV. As shown in Figure 1b, the WTW efficiency of PHEVs is projected to further improve when more efficient electrical power generation systems such as Solid Oxide Fuel cells (SOFCs) as well as CAFÉ standard ICEVs are used. This potential benefit of using PHEVs relative to liquid fuel-ICEVs aligns with the current US policy offering rebates to promote partial or complete vehicle electrification.

Figure 1b also shows that the anticipated future improvements resulting from CAFÉ standards and SOFC power generation are estimated to make the CNG-PHEV pathway as energy efficient as CNG-ICEV. For either of the above CNG pathways, our analysis makes a case for developing CNG fueling and pipeline infrastructure. Given the infrastructural challenges for the widespread deployment of SOFC systems and battery charging, the use of CNG-ICEV appears to be the preferred CNG-pathway. However, CNG-PHEV, if introduced, could offer an additional feature of flexibility in utilizing different primary energy sources for electricity supply.

Among the more efficient NG-transport pathways, the success of the CNG-ICEV pathway requires policy intervention for reducing the economic burden on: 1) individuals or entities establishing refueling stations and 2) consumers modifying their own vehicles for CNG use. In contrast, the liquid-fuel PHEV pathway requires policies promoting the construction of NG-to-liquid fuel conversion facilities, vehicle charging infrastructure as well as PHEV adoption by individual consumers.

NG Resource Impact

The possible expanded use of natural gas for LDV transportation via any of the above pathways as well as its increased use in other sectors such as electricity generation could potentially decrease the lifetime of U.S. NG reserves. To quantify the impact on NG reserves, we derive estimates for the lifetimes of NG reserves for two alternative future NG demand scenarios:

- **Scenario I:** Annual NG demand = 2010 NG consumption + future growth in NG LDV consumption.
- **Scenario II:** Annual NG demand = 2010 NG consumption + future growth in NG LDV consumption + future growth in NG consumption for electricity generation.

The projected annual NG LDV consumption is obtained via dividing the share of annual vehicle miles travelled (VMT) using the specified pathway with its WTW efficiency. Our calculations also account for the slow penetration of the specified pathway into the existing LDV fleet, as reflected in the increase in the VMT share (%) of the pathway for each progressive year. For the chosen rate of vehicle penetration, ~100% of the total LDV fleet is assumed to operate using the selected NG-transport pathway within a 35 year time period (NRC, 2004). Here, we also assume the annual total VMT by the entire LDV fleet to remain unchanged from the 2010 value. This is a conservative estimate, as the annual VMT is projected to increase in the U.S., nearly doubling by 2050 if historical growth rates are to prevail (Sperling and Gordon, 2009). Thus, any increase in the annual VMT in the future will lead to lower NG lifetimes than estimated here.

For projecting future growth in NG use for electricity generation, we assume that all the projected growth in electricity consumption is sourced from NG via either SOFC or NGCC power plants. This is a worst-case scenario estimate, which assumes that the currently low levels of renewable electricity penetration still hold true for the next two decades. For the calculation, we use the annual electricity consumption growth rate of ~0.8% percent as forecasted by the EIA Annual Energy Outlook (EIA, 2012a).

With the above assumptions, demand scenario I using the current CNG-ICEV pathway (Figure 1a) results in an estimated ~70 years worth of NG reserves. The use of 2025 CAFÉ standard ICEV increases the lifetime of US NG reserves by ~7 years relative to the current-ICEV case. It is also worth noting that there is also potential for expanded use of NG in the heavy duty vehicle sector (EIA, 2012a), which has been shown to be feasible in other nations (Yeh, 2007). While NG use in the U.S. HDV sector is out of the scope of this analysis, it is a likely possibility, which could further reduce the lifetime of U.S. NG reserves.

As against demand scenario I, a more realistic future demand scenario should also include future growth in US NG use for electricity generation (EIA, 2012a; ExxonMobil, 2012). As seen in the last few years, the low economic cost of NG relative to coal has led to its increasing share in electricity generation (EIA, 2012a). Moreover, the recent policy proposal by the Environmental Protection Agency (EPA) on limiting new power plants to emit less than 1000 lb-CO_2/MWh (EPA, 2012) is likely to further promote the use of NGCC power plants over the use of traditional coal power plants without CO_2 sequestration.

For scenario II using CAFÉ standard CNG-ICEV for LDVs, the total recoverable NG reserves are estimated to last 60-64 years, depending on use of either NGCC or SOFC power plants. The corresponding lifetime of NG reserves for scenario II when using the less efficient gasoline-PHEV pathway for LDVs is estimated to be 59-62 years. Thus, compared to the current consumption rate, our analysis points to the potentially drastic reduction (~30 years) in lifetime of NG reserves in case of its dominant use in future LDV transportation and electricity generation. Moreover, the expanded use of NG could also potentially increase its price from the currently low levels, which could adversely affect other sectors relying on NG. As against using NG as the dominant primary energy source for the US, our findings support its use as a transitional energy source, along with the simultaneous development of alternative renewable energy technologies.

Towards this end, existing policy initiatives such as the RFS2 mandate for promoting the use of biofuels for transportation are valuable and should be continued. The use of biofuels, partial electrification via PHEV can be combined with currently economical option of using CNG as a transportation fuel, to displace petroleum and to reduce GHGs from the LDV fleet.

Similarly, in the power generation sector, policy action is necessary to ensure the recent rapid growth of renewable solar and wind power is not abruptly curtailed in favor of the use of cheap-NG derived power in the short-term. As is evident from our resource analysis, NG offers at best, a transition solution for U.S. energy security and alternative renewable energy sources must be developed for the long-term future.

Acknowledgements

The authors would like to acknowledge the contribution of Gang Duan to this project.

References

BP, 2012. Statistical Review of World Energy. British Petroleum, London.

Burnham, A., Han, J., Clark, C.E., Wang, M., Dunn, J.B., and Palou-Rivera, I., 2012. Life-Cycle Greenhouse Gas Emissions of Shale Gas, Natural Gas, Coal, and Petroleum. *Environmental Science & Technology* 46 (2):619-627.

DOE, 2012, Clean Cities: Alternative Fuel Price Report. April 2012. U.S. Department of Energy, Washington, DC.

DOE, 2012a. ARPA-E announces new projects to advance innovative natural gas vehicle technologies. Availabile at http://arpa-e.energy.gov/media/news/tabid/83/vw/1/itemid/58/Default.aspx. Accessed on September 8, 2012.

EIA 2012, Energy Information Administration, Available at http://www.eia.gov/. Accessed on September 8, 2012.

EIA 2012a. Annual Energy Outlook 2012 Early Release. US Department of Energy, Washington, DC.

Elgowainy, A., Han, J., Poch, L., Wang, M., Vyas, A., Mahalik, M., Rousseau, A., 2010. Well-to-Wheels Analysis of Energy Use and Greenhouse Gas Emissions of Plug-in Hybrid Electric Vehicles. Argonne National Laboratory, Argonne, IL.

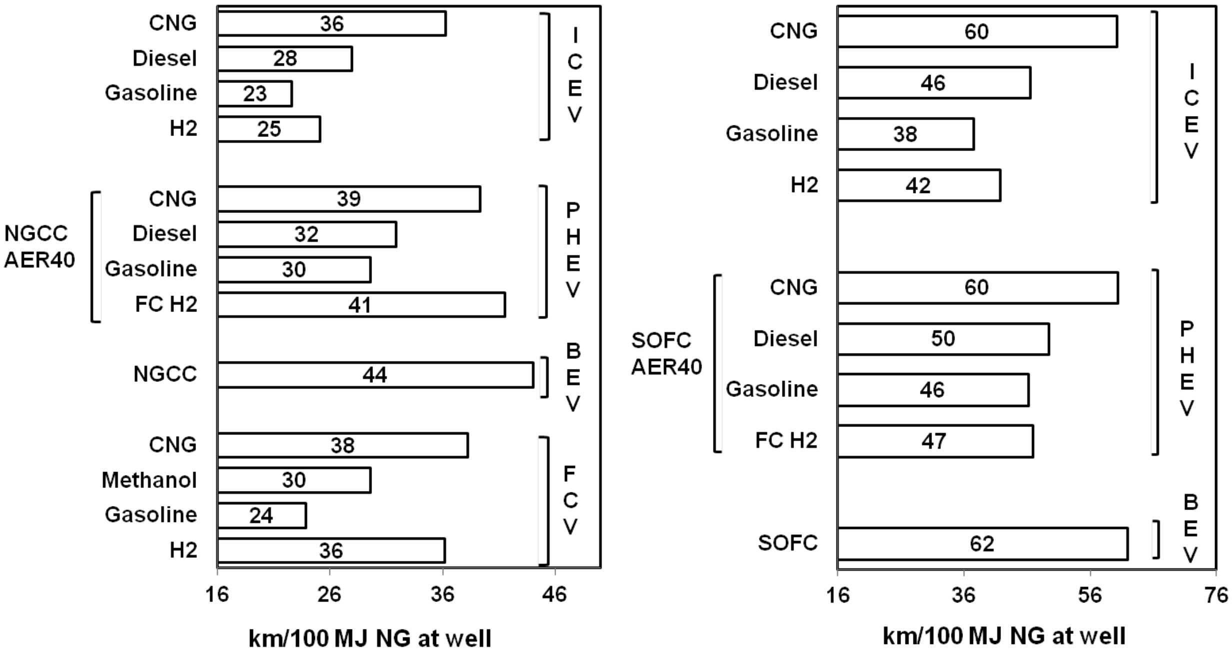

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Figure 1. WTW efficiency of NG transport pathways based on (a) current and (b) potential future technologies. **Current**: 32.8 mpgge for gasoline-ICEV, NG at plant-to-electricity efficiency via natural gas-combined cycle (NGCC) is 49.8%. **Future**: 54.5 mpgge for gasoline-ICEV, NG at plant-to-electricity efficiency via Solid Oxide Fuel Cell (SOFC) is 70%. AER40: PHEV designed to travel about 40 miles primarily on battery power before switching to using on-board fuel in charge-sustaining operation. FC H2: Fuel cell Hydrogen. Data for WTW efficiency estimates taken from GREET database (Wang et al., 2012).