



USDOT Region V Regional University Transportation Center Final Report

NEXTRANS Project No.

**Analysis of Policies Aimed at Increasing Use of Natural Gas in the Transportation System**

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## **DISCLAIMER**

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# TECHNICAL SUMMARY

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In this paper we examine the implications of leveling the vehicle fuel choice playing field between PHEV and CNG vehicles in the US. Currently, US policy provides a subsidy of \$7,500 for most PHEV vehicles but nothing for CNG vehicles. We use a modified version of the MARKAL-Macro model to evaluate the impacts on the transportation system, the general economy, and GHG emissions of maintaining only the PHEV subsidy or applying an equivalent subsidy to CNG vehicles. Some very interesting conclusions emerge from the analysis. In 2050 there are 36% more CNG internal combustion vehicles in the fleet if the CNG LDV subsidy is in effect compared with only the PHEV subsidy. On the other hand, if only the PHEV subsidy is in effect, there are 15% more of those vehicles compared to the case with the CNG LDV subsidy as well. Interestingly, the CNG subsidy also results in a reduction in GHG emissions relative to the case with only the PHEV subsidy. Oil imports also decrease with the CNG subsidy. Thus, we have documented that if a CNG subsidy were provided as is the case for PHEV; it would have important impacts on the transportation system.

**Keywords:** MARKAL; Compressed Natural Gas; US LDV policy

# Analysis of Policies Aimed at Increasing Use of Natural Gas in the Transportation System

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## Introduction

The US has gone from scarcity and high prices of natural gas just a few years ago to abundance today. Over the past decade, liquefied natural gas (LNG) import terminals were built to import natural gas because of inadequate domestic natural gas. However, since 2007, the shale oil and gas revolution has erupted [1-3] and the US is now converting many of these LNG import terminals to export. Thus, the US now has an abundance of natural gas, part of which could be used in the transportation sector.

Current US energy policy with respect to natural gas and transportation has several components. For transportation, there are three key policy components. First, there is the Corporate Average Fuel Economy (CAFE) standard. It calls for increasing US vehicle fuel economy to 54.5 miles per gallon by 2025 [4-6]. Second, the U.S. has a Renewable Fuel Standard (RFS) mandating 36 billion gallons ethanol equivalent by 2022 [7, 8]. Third, purchasers of plug-in hybrid electric vehicles (PHEV) receive a subsidy of up to \$7,500 for the vehicle purchase [9]. The exact amount of the subsidy depends on the vehicle battery size, but most PHEV vehicles receive the maximum subsidy.

Most of current energy policy relevant to transportation was put in place before the shale gas boom. Yet today the U.S. has abundant and inexpensive natural gas. The U.S. wholesale price in May 2014 was around \$4.40/MCF compared with prices ranging between \$13 and \$18 in Europe, Japan, and China [10]. Natural gas is considered a cleaner fuel than gasoline or diesel, yet it receives no subsidy such as that accorded to PHEV vehicles. Thus a natural policy question relates to the impact of providing a subsidy for compressed natural gas (CNG) that would be roughly equivalent to the PHEV subsidy. In

other words, this policy move would provide a level playing field for alternative technologies aimed at reducing greenhouse gas (GHG) emissions in the transportation sector.

In this paper, we evaluate the impacts of two kinds of CNG vehicle subsidies – cars and light duty trucks, and fleet vehicles such as buses and garbage trucks. We compare cases with and without these subsidies to estimate the impacts each would have in the market place.

## Relevant Literature

There are a limited number of studies that are related to the use of Natural Gas (NG) as an alternative fuel in the transportation sector within US. From a theoretical perspective Waller and his colleagues carried out a technical efficiency analysis, investigating the efficiency from well to wheel energy flow [11]. As they mention, main efficiency difference between CNG pathway and electric vehicle pathway rises due to combustion of natural gas Internal Combustion Engine (ICE) and Combined Cycle Natural Gas Turbine (CCGT). They find that utilizing CNG as a feedstock for vehicle propulsion is more attractive due to lower cost and increased domestic production, plus possible range advantage and already in place NG transportation infrastructure. Mallapragada and his colleagues carried out a technical analysis assessing well to wheel efficiency of different pathways of using NG including hydrogen, electric vehicle and ICE [12]. They also found a similar results stating that using NG as CNG is the most favored option due to current proven technology, expected higher efficiency compared to the electric pathway and higher driving range compared other alternative fuel forms.

Andres and his colleagues analyzed the current state of US alternative fuel technologies from both oil consumption reduction and greenhouse gas reduction perspectives and under current and expected policies such as CAFE, RFS and Clean Air Act [13]. The authors' claim that compared to other possible alternatives CNG is 33% cheaper than gasoline and 42% less costly than diesel on an energy basis. The only barrier for wide spread use of CNG is shown to be public CNG refueling stations. They also mention that overcoming this barrier would require government subsidies if wide spread use is expected, very similar to the case of electric vehicles.

Another interesting study carried out by Peterson and his colleagues investigates the competitiveness of light duty natural gas vehicles in the US with a time horizon up to 2050 [14]. With their parametric approach they point out a very similar result as Andress, Das [13]; infrastructure limits wide spread use. In addition, they highlight that CNG vehicles are economical and they mostly compete with electric

vehicles not the ICE since they compete for consumers who drive enough so that fuel cost savings offset higher purchase cost of alternative fuel vehicles. Also, greenhouse emission reduction levels are insignificant when they replace gasoline and diesel fueled ICEs.

Even though there are previous studies assessing the policy options for alternative fuel use in the transportation sector [15, 16], it is hard to find a policy assessment study for natural gas in US. This study fills the gap to analyze possible policy options for natural gas use in US transportation sector and compare them with current PHEV and electric vehicle subsidies.

## Methodology

### US MARKAL – Macro model

MARKAL, (MARKet ALlocation) model is a widely accepted and applied, perfect-foresight, dynamic, technology-rich linear programming, energy systems, and optimization model. Standard MARKAL model's formulation has an objective of minimization of discounted total system cost which is formed by summation of capital, fuel and operating costs for resource, process, infrastructure, conversion and end use technologies. The general framework enables the calibration of a model to local, national, regional or multiregional energy systems. In general, model can be used for climate policy, impact assessment of new technologies, taxes, subsidies, and various regulations, and other applications.

The MARKAL modeling framework uses a RES which represents currently available and possible future energy technologies and energy carriers and relations among them. Due to the large number of technologies and carriers, it is not possible to cover all details of the RES in this paper. A simplified version of the RES used in the US EPA MARKAL model is depicted in Figure 1. The complete description of the RES used and other technical details in US EPA Model can be found in [http://oaspub.epa.gov/eims/eimscomm.getfile?p\\_download\\_id=461323](http://oaspub.epa.gov/eims/eimscomm.getfile?p_download_id=461323) [17]. In this analysis, a time horizon of 30 years (from 2010 to 2040) with 5-year time steps has been used. The currency unit used in this paper is US dollars for the year 2010. Further details regarding the methodology can be found in [18].

In this study the US EPA MARKAL database is used as an initial database for modelling efforts. The database we have deployed is the single region US National database that has been built upon the Energy Information Agency's 2010 Annual Energy Outlook report, extrapolated to 2055 using National

Energy Modeling System (NEMS) outputs published by DOE [19]. Further details regarding US EPA MARKAL can be found in [17].

## **Model Modifications**

Significant data and model changes were introduced into US EPA MARKAL database for this analysis. First, biomass supply was introduced using land rent outputs from the Global Trade Analysis Project (GTAP) model. Essentially, we captured the land rents as increasing amounts of biofuels were demanded in that model and used those for land supply curves for MARKAL. Second, the biochemical conversion technologies in MARKAL were updated to the latest and most reliable available. Third, biomass thermochemical conversion technologies were added to the model. All these changes are detailed in the previous work [16]. Fourth, new data on natural gas supply was introduced to reflect the increased supply of shale gas based on MIT Energy Initiative Report [20]. Further details regarding the modifications that has been carried on the database can be seen in the study published by Sarica and Tyner [4].

The last set of changes that are solely carried out for this study is the restructuring of the Compressed Natural Gas (CNG) use in the transportation sector. The distribution of CNG within the sector is restructured such that it can be tracked based on type of use such as Light Duty Vehicles (LDV), transit buses, school buses, garbage trucks and Heavy Duty Vehicles (HDV). Relevant policies can be modeled and adapted accordingly. Based on the fleet sizes and energy use distribution from Federal Transit Authority's National Transit Database [21], Institute of Education Sciences' National Center for Education Statistics [22], Waste and Recycling News magazine's 2010 Hauling and Disposal Rankings [23] and 2002 Economic Census - Vehicle Inventory and Use Survey [24], the database has been updated to reflect the economies of scale in those subsectors. The cost of CNG stations is based on the study by Caley Johnson [21], The VICE model provides the economies of scale effect on CNG station design.

Our US MARKAL-Macro model is based on the national US EPA MARKAL model with the modifications described in this section and earlier references. In the first stage of the calibration process, the MARKAL model is calibrated to the base year, 2005, to match the model outputs to the electricity outputs, primary energy use, installed technology capacity and sectoral outputs. After the first phase, MARKAL and Macro modules went through an iterative calibration process, which is used to match the projected energy service demands and projected GDP growth rates under standard reference case assumptions. Annual Energy Outlook [19] is the principal data resource in all calibration processes.

## Macro Linkage

In this paper, a neoclassical growth model has been integrated to the technology rich representation of the US energy system. Despite the simplicity, MARKAL-Macro is one of the very few hard-linked top-down bottom-up hybrid modeling approaches [25]. Figure 1 graphically summarizes the integration process.

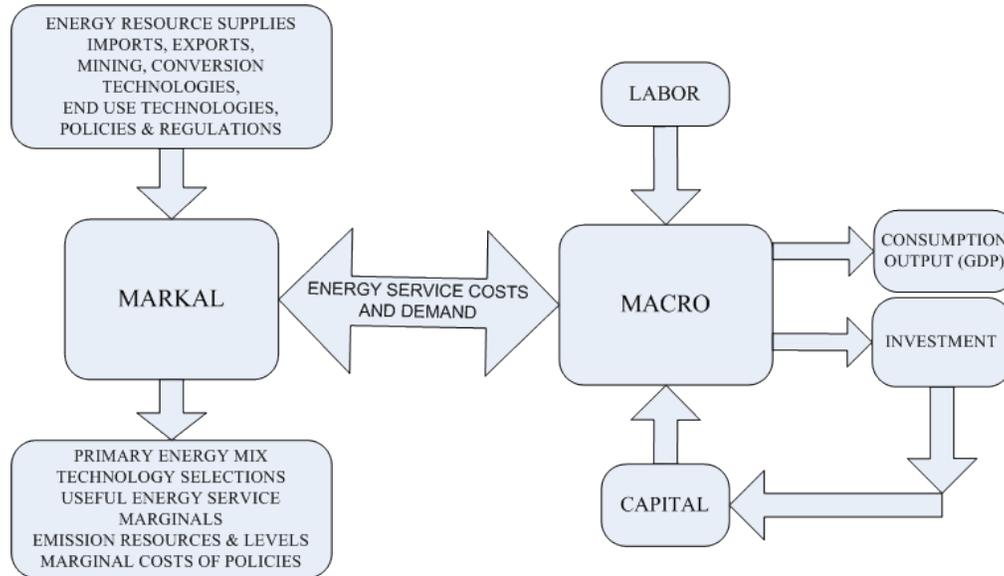


Figure 1. MARKAL-Macro Integration

Useful energy services from MARKAL are aggregated to form the energy input in the output (production) function of the Macro module. In the Macro module, there exists a competition between investment in energy and investment in the rest of the economy. Economic output is shaped based on this competition, and this information is passed back to MARKAL. With this connection between MARKAL and Macro, MARKAL-Macro determines a baseline and resultant dynamic changes for energy services demand, carbon emissions, technology choices, and GDP. Even though aggregated energy demand responds to single price elasticity (*ESUB*), sub-sectoral energy service demands will react decoupled from aggregated energy demand dependent on the economic impacts of their changes, in which demand marginal express the magnitude of those impacts.

MARKAL-Macro, with its structure, is able to incorporate aggregated energy service demand feedback due to energy price changes. Since the demand changes are autonomous, some energy service demands may be decoupled from economic growth. Through integration of the macro portion; calculation of GDP, consumption and investment in an explicit manner is possible. Overall, detailed energy systems analysis

is maintained, without loss compared to MARKAL. For a detailed mathematical overview of the MARKAL-Macro and Macro model assumptions regarding key parameters, the reader should consult Sarica and Tyner [4].

## Results

### Scenarios

The Energy Independence and Security Act of 2007 has expanded the original mandate set by Energy Policy Act of 2005 [26] to a mandate of 36 billion gallons ethanol equivalent by 2022 [8]. The mandate enforces use of predetermined levels of conventional (corn) ethanol, cellulosic biofuel, and biodiesel by 2022. A more detailed analysis and description regarding RFS policy can be found in Sarica and Tyner. The RFS is part of our reference scenario.

Starting from 31<sup>st</sup> of December 2008, purchasers of PHEVs and EVs may claim a tax credit when they file their income taxes. The tax credit is between \$2500 and \$7500, depending on the battery capacity, which is scaled between 4 and 16 kWh respectively [27, 28]. In this study, PHEV subsidy is taken as \$7500 per vehicle for all PHEV and EV vehicles since technologies included in the database had battery capacities of more than 16 kWh. This is realistic since the EV driving range limitation becomes a serious concern for lesser battery capacities.

Our first task was to define the respective CNG subsidies. Our approach was to develop a CNG subsidy that would be similar to the current PHEV subsidy. However, there is no clear way to determine what an equivalent subsidy would be (based on energy? GHG emissions, etc.), so we decided just to make the CNG subsidy the same as the PHEV subsidy - \$7,500 per vehicle. Lastly we wanted to apply a subsidy for CNG for the commercial truck and bus fleet specific to school and transit buses and garbage trucks. The approach was to make the subsidy a percentage of fleet vehicle investment cost (27%), with the resulting average subsidy being \$50,000 per vehicle. That amount was the difference in bus investment cost between a diesel and CNG bus from our previous study [29].

When we evaluated the impact of the fleet subsidy at this level, which is actually pretty high in dollar terms, we found that the fleet subsidy had almost no impact. The reason it had no impact is a bit complicated but interesting. In our reference case, as will be seen below, there is penetration of CNG vehicles in both the LDV and fleet categories. However, once the PHEV subsidy is applied, it causes the price of natural gas to increase, and that price increase more than offsets the value of the CNG fleet

subsidy. Therefore, we decided to focus this analysis on the LDV segment of the vehicle market. That makes sense since the PHEV subsidy also only applies to that segment.

We conducted our analysis for two possible future scenarios in addition to the reference scenario. In the reference case, it is assumed that no subsidy or mandate of any kind is in place as a part of federal legislation except the CAFE standard for vehicle fuel economy. In that respect, we assume that efficiency improvement is going to be enforced into the market continuously in the future. The following scenarios are evaluated in this study and compared with the reference case:

1) Reference case with RFS, and PHEV subsidy – the current policy.

2) Reference with RFS, PHEV and CNG subsidy for LDVs equivalent to the PHEV subsidy

For each case, results will be presented on GDP impacts, system cost, energy use (CNG, electricity, total), fleet composition (LDV and total), emissions (electricity, transport, and total), plus trade impacts.

## **Transportation fleet composition**

Reference case fleet composition of the LDVs on the road can be seen in Figure 2. Fleet composition changes occur mostly after 2025. Even though gasoline still dominates the market, diesel Hybrid Electric Vehicles (HEV) constitutes a significant share of the market, while gasoline PHEVs' is less than the CNG vehicles. There is no PHEV subsidy in the reference case. This figure shows us that without any government intervention, CNG vehicles are going to be in the market with a larger share than PHEVs and electric vehicles. However, market penetration of CNG vehicles are not to be expected earlier than 2020.

The PHEV subsidy and the CNG subsidy have a considerable impact on the makeup of the transportation fleet as shown in Figure 3. The PHEV subsidy (case 1), compared to reference case, delays the penetration of CNG vehicles while reducing the CNG fleet share in later periods. Diesel HEVs are negatively affected with the PHEV subsidy. Thus, PHEVs are competing with Diesel HEVs and CNG vehicles which is in line with Andress, Das [13] and Peterson, Barter [14].

Figure 4 displays the fleet composition for case 2 with both PHEV and CNG-LDV subsidies. It is clear that natural gas vehicle market penetration is much higher when natural gas vehicles have an equivalent subsidy as the PHEV subsidy compared to the reference case. The added CNG subsidy, compared to reference case, delays the penetration of gasoline PHEVs while reducing the fleet share in later periods to insignificant levels. Diesel HEV fleet share is reduced compared to reference case even though they play an important role because of their relatively high efficiency. E85 PHEVs fleet share is increased to

comply with the CAFE efficiency standard and RFS policy, since they introduce high ethanol consumption potential with high technical efficiency into the market.

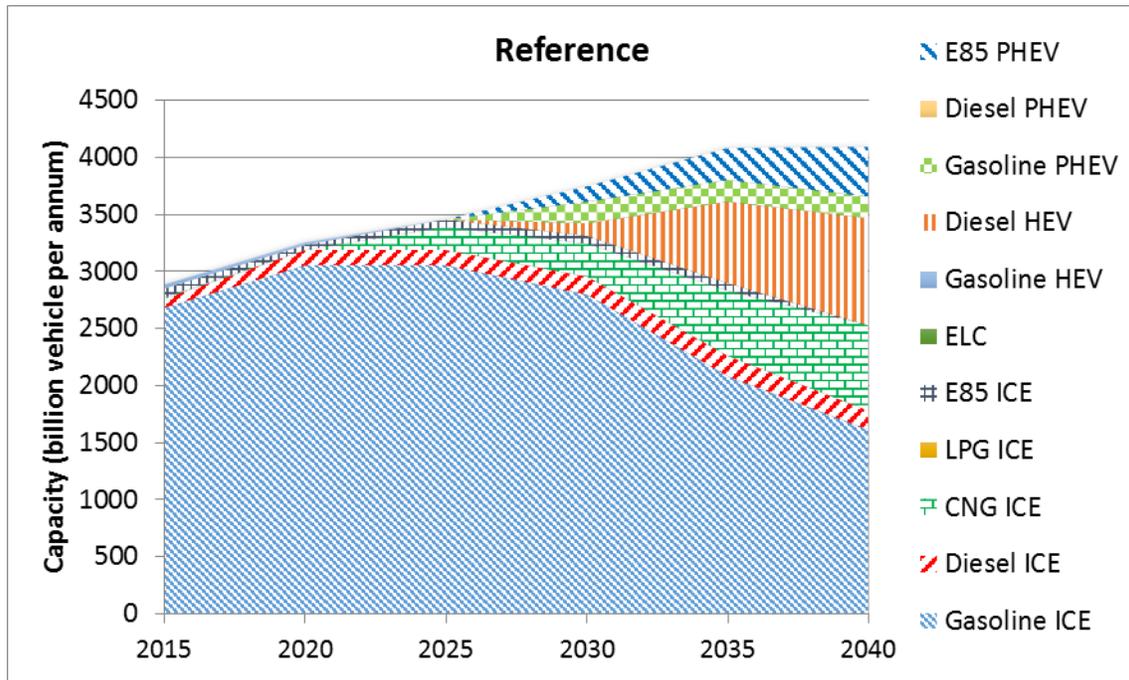


Figure 2. Fleet composition of the reference case.

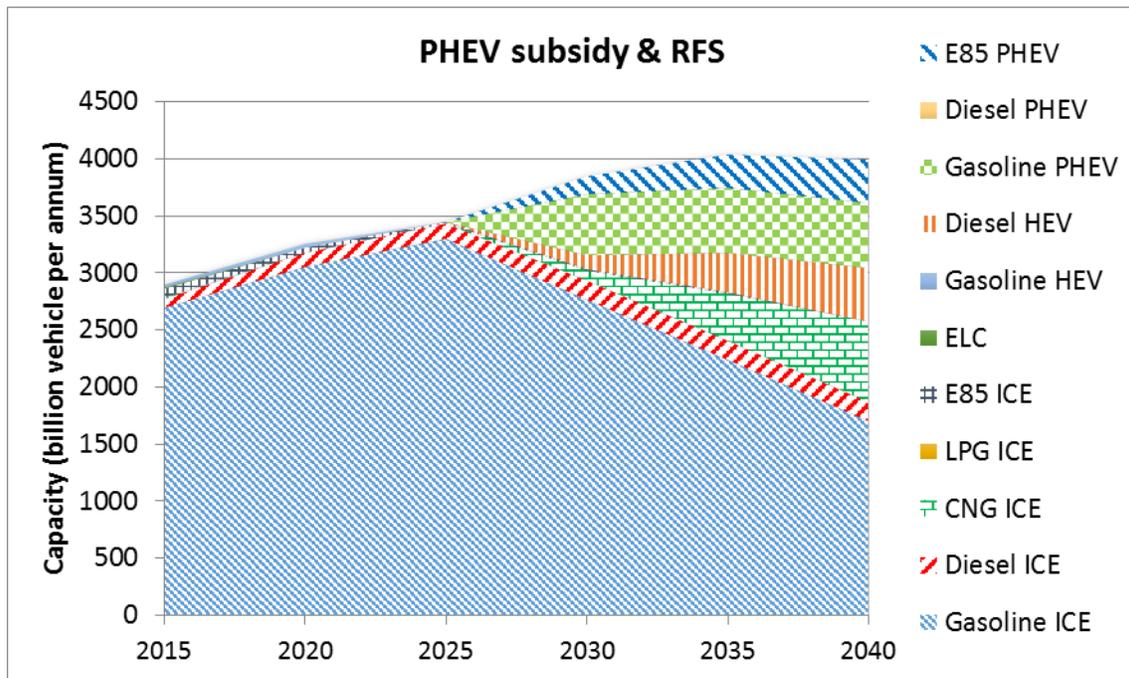


Figure 3. Fleet Composition with only the PHEV Subsidy and RFS policy (case 1)

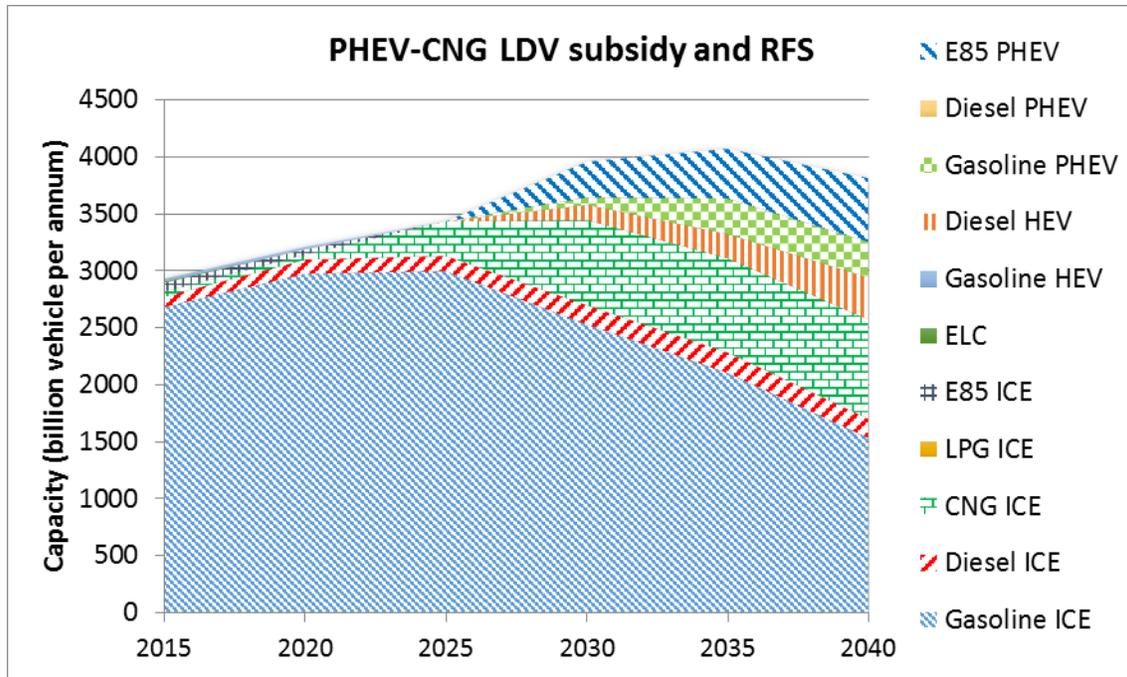


Figure 4. Fleet Composition with the PHEV and CNG-LDV Subsidy and RFS policy (case 2)

## Energy consumption

Coal and natural gas use in electricity follow opposite patterns for the PHEV and CNG subsidy cases in early years, but then become more similar in later years as shown in Figure 5. The dashed lines represent the combined subsidy case use of natural gas and coal compared to reference case, whereas the dashed dotted lines represent the PHEV only subsidy use of these resources in comparison to reference case. In the PHEV only subsidy case, coal use rises at first (2020), and then mainly falls or is relatively flat afterwards. In the combined subsidy case, coal use falls relative to reference at first, then rises to 2030 and falls afterwards. This response from the model is reasonable since the model has perfect foresight; it minimizes natural gas consumption in early periods to have more natural gas resource when the electricity consumption by the transportation sector increases due to the PHEV policies. With CNG LDV subsidy, more natural gas vehicles enter the market in early periods (Figure 4), starting by 2020, thus increasing the natural gas consumption by the transportation sector in return negatively affecting the natural gas consumption of the electricity sector compared to reference case. Thus, natural gas use in electricity follows the opposite trend, rising at first for the LDV subsidy, and then falling after 2025 only to rise again later. Due to the change in natural gas availability by the mentioned mechanism, electricity sector uses coal as a replacement.

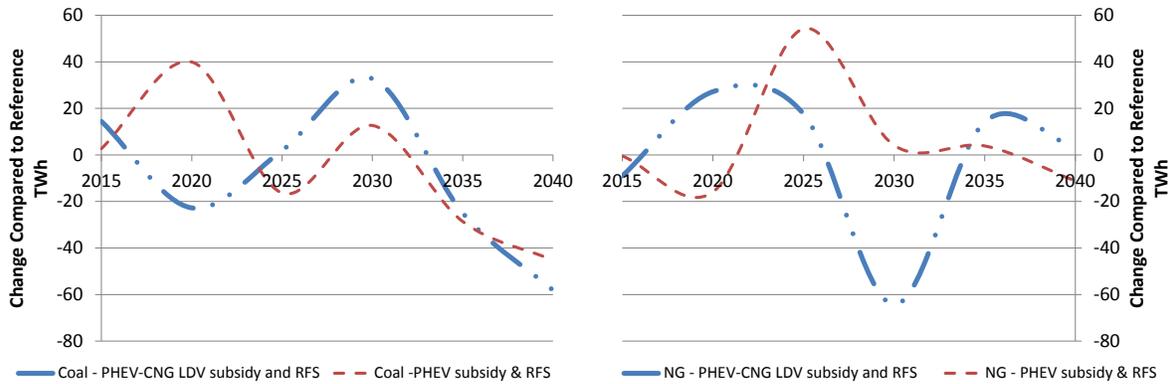


Figure 5. Change of coal and natural gas consumption in the electricity sector compared to base case

Total electricity production (Figure 6) rises with the PHEV only subsidy as would be expected. With the combined subsidy, the PHEV's share in total fleet starting from 2025 is reduced, and thus reduces total electricity consumption even though other sectors take advantage of the reduced price and increase their electricity consumption further limiting the consumption fall.

Change of electricity prices shows very interesting dynamics as shown in Figure 7, which follows nearly same behavior as natural gas prices. With only the PHEV subsidy case, electricity price does not increase with increasing total consumption. This situation is counter intuitive, but the dynamics are clear. Since these subsidies remove a lot of CNG vehicles from the fleet (Figure 3 and Figure 4) compared to reference case, more natural gas than needed for extra electricity demand is released to the market by changing the structure of the fleet. This resource allocation from transportation sector to other sectors especially to the electricity sector opens up possibility to use extra natural gas for electricity production, which reduces the cost of electricity production under reference case prices for some periods. This situation can be seen clearly in Figure 7 and Figure 8, which shows electricity prices and natural gas use by the transportation sector. When we combine CNG and PHEV subsidies, electricity prices first fall due to decrease in electricity use in transportation sector. But this opportunity is used by other sectors in the economy thus increasing electricity consumption as in Figure 6. However, increase in size of CNG fleet makes the natural gas more expensive for the economy, thus limiting the use of natural gas in electricity sector and leading to an increase in electricity prices (Figure 7), which limits electricity consumption (Figure 6).

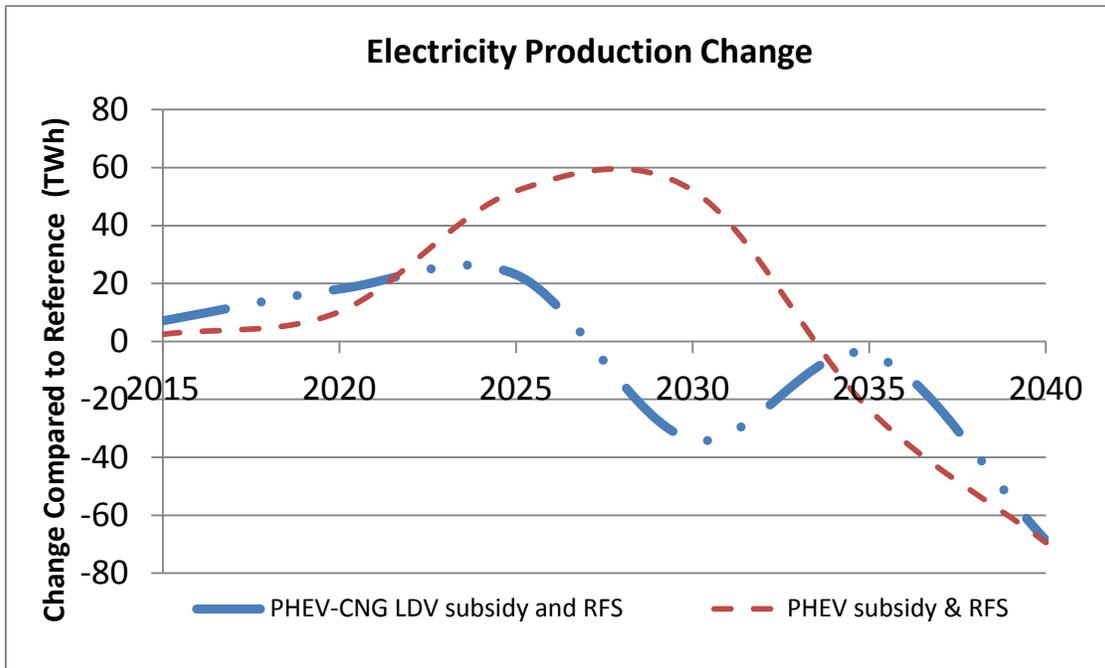


Figure 6. Change in electricity production compared to reference case under policy scenarios

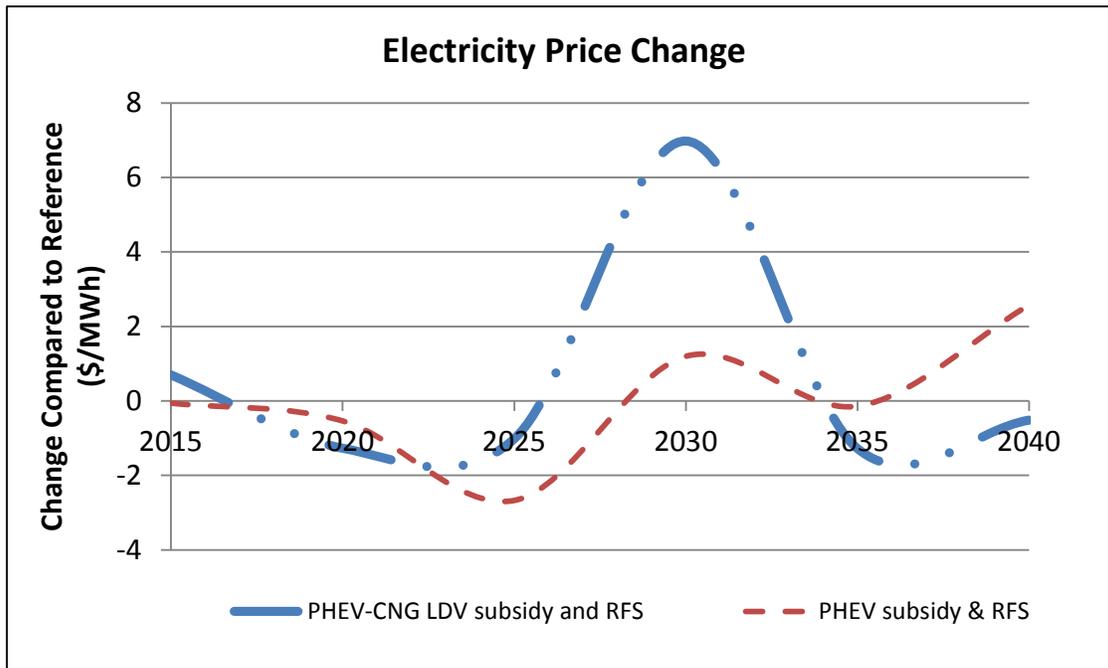


Figure 7. Change of electricity price with respect to reference case

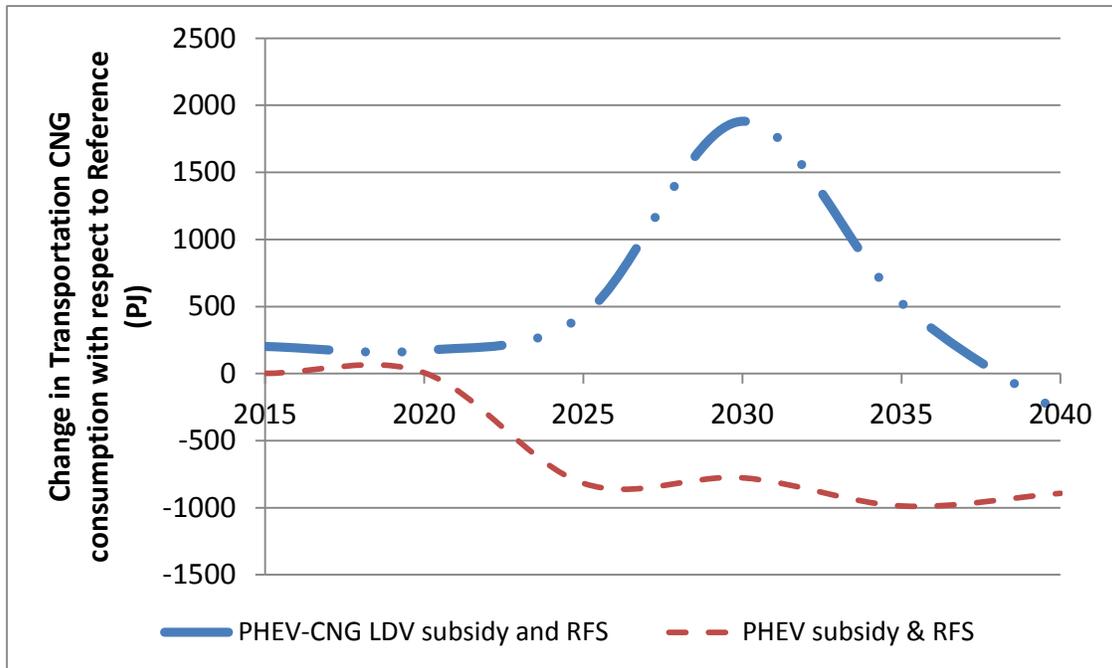


Figure 8. Natural gas consumption deviation compared to reference case for transportation sector.

Figure 9 shows total natural gas use in transportation (CNG). It is interesting that the reference case has higher CNG use than the PHEV LDV subsidy cases. There are two main driving forces for this outcome. First is the change of fleet mix, discouraging CNG vehicles from the fleet through PHEV subsidy as shown in Figure 3 and Figure 4. Besides, HDVs are the biggest natural gas users in the transportation sector in the reference case as mentioned before due to natural gas's economic feasibility against the diesel alternative. The PHEV subsidy causes more natural gas to be demanded for electricity, thereby increasing the price of natural gas especially after 2030. This natural gas price increase reduces the attractiveness of CNG for HDV uses such as trucking and fleet uses. This is the second dynamics behind the natural gas consumption decrease compared reference case for PHEV LDV subsidy cases. When the CNG LDV subsidy is included, there is again more natural gas consumption in the transportation sector as LDV consumption increases (Figure 8).

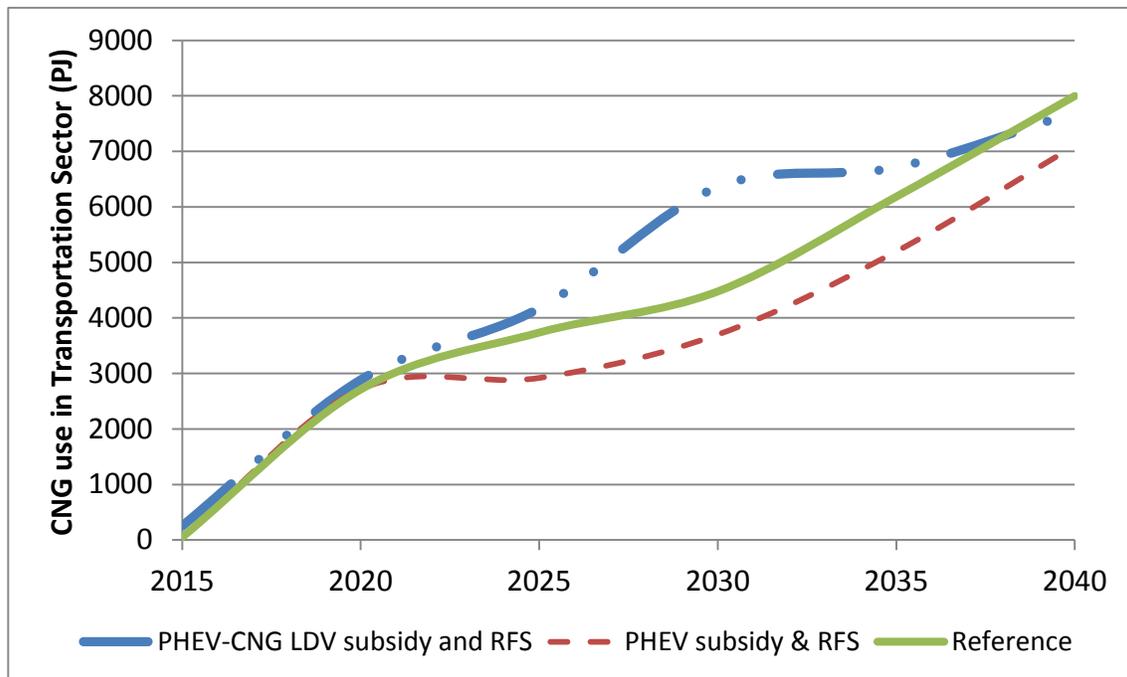


Figure 9. Total Natural gas consumption in Transportation sector

Figure 10 displays the economy wide natural gas consumption change compared to base case. PHEV LDV subsidy cases without CNG LDV subsidy show total consumption decrease in the economy. This outcome is interesting in the sense that with similar transportation demand levels economy wide natural gas demand changes significantly according to the policies that are being implemented. This result points out two dynamics that are driving this outcome. First of all with the implementation of the PHEV subsidy, a lot of CNG vehicle demand is driven away from the fleet (Figure 2 and Figure 3). PHEVs that replace those vehicles use mostly electricity and the share of natural gas in electricity mix changes between 25% and 35%. Second dynamics behind this result is the efficiency difference between two pathways; ICE and CCGT. As Waller, Williams [11] mentioned in their study, converting natural gas to useful work through CCGT to electricity is more efficient. Thus for every CNG vehicle that is removed from the fleet a more efficient form of transportation vehicle, PHEV, is added to fleet (Figure 10). This situation is also pointed out by Waller, Williams [11]. As expected CNG LDV subsidy combined with PHEV LDV subsidy increases total natural gas consumption. The dynamics behind these interacting policies can be understood by comparing Figure 2, Figure 3, and Figure 4. As PHEVs are subsidized, diesel car numbers also decrease. Thus, in this situation instead of removing mostly less efficient vehicles i.e. CNG ICE vehicles, high efficiency diesel hybrid vehicles are being substituted by PHEVs. CNG LDV subsidy on top of PHEV LDV subsidy encourages use of CNG ICE vehicles with further pushing technically high

efficient vehicles out of the system. The amount of CNG that replaces diesel fuel use is significant (Figure 4).

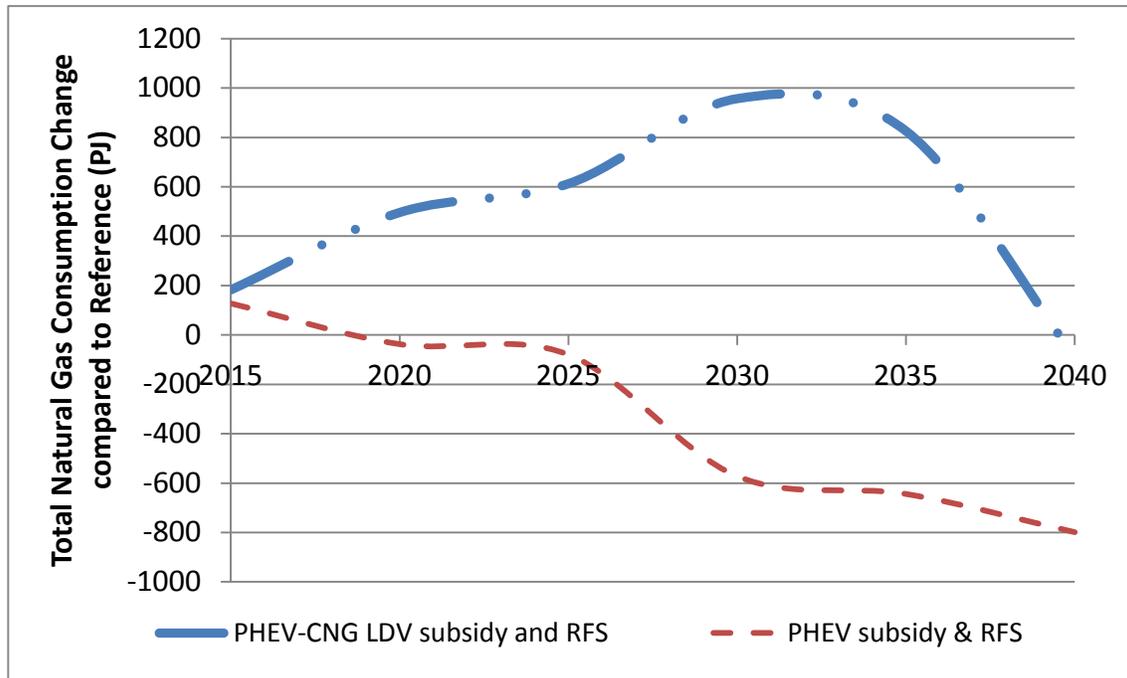


Figure 10. Economy wide natural gas consumption change compared to reference case

## Emissions

As would be expected, the change in transport sector and overall emissions follow a similar pattern. Interestingly, overall system emissions are higher with only the PHEV subsidy case without CNG LDV subsidy, as shown in Figure 11. That is driven mainly by two mechanisms; first the increased electricity emissions with increased electricity consumption, which is an expected direct outcome. The second mechanism is the increased natural gas supply that has been released from transportation use. Natural gas prices follow a very similar pattern as electricity prices as shown in Figure 7. Thus, as the natural gas prices reach bottom around 2025, every sector in the economy enjoys those prices by directly consuming natural gas. An equivalent CNG LDV subsidy combined with PHEV LDV reduces overall emissions compared to the PHEV only subsidy case. This is mainly due to higher natural gas use by transportation sector triggered by fleet composition change (Figure 4) thus increasing the price of natural gas to the overall economy thus reducing energy consumption and emissions. Each policy analyzed resulted in emission reduction in the long run, but the combined policy PHEV – CNG LDV subsidy seems to be the best option in that respect due to less carbon intensive fleet formation. But,

overall change in emission level is very small - between 5 – 6 billion tons of CO<sub>2</sub>). This outcome is in line with the finding of Peterson, Barter [14].

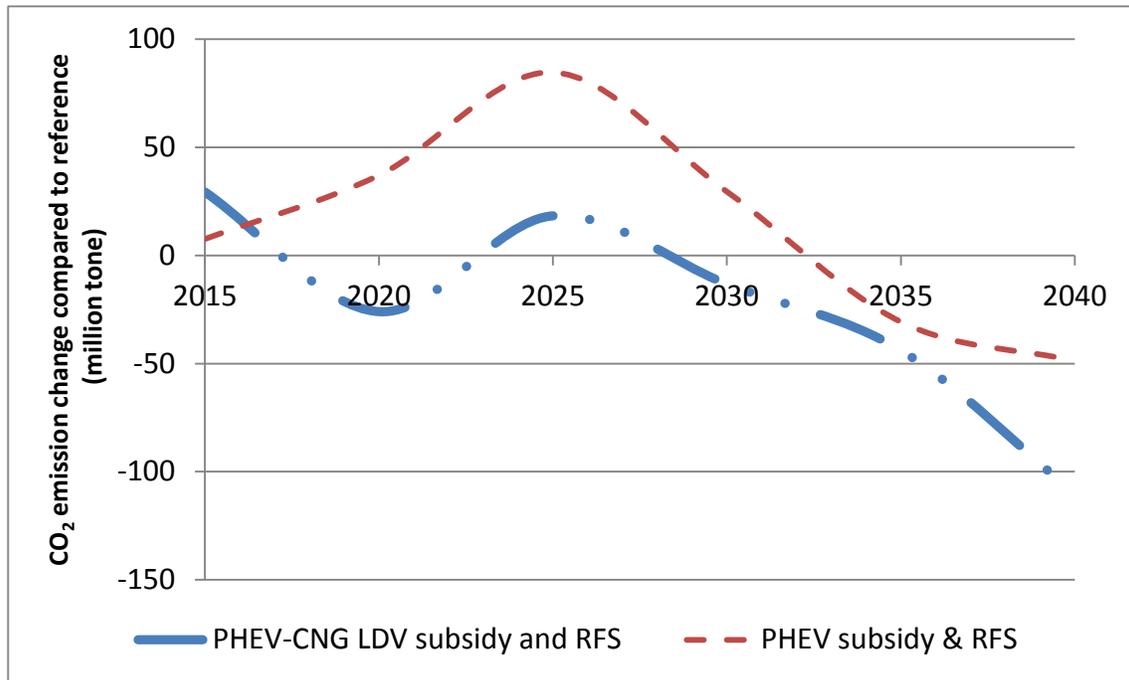


Figure 11. Relative change in economy wide emission levels compared to base case

## GDP impacts

Since transport is not a huge part of the total GDP, the GDP impacts of the different policies are relatively small. Both subsidy policies cause a very small increase in GDP in the early years and an equally small drop in later years. When both policies are in effect, the increase and decrease are in the range of 0.05%.

## Net Imports

The final dimension to consider is the impact of the different policies on oil imports. As shown in Figure 12, the CNG subsidy results in a decrease in oil imports relative to the reference case, whereas the PHEV subsidy actually causes an increase. This is mainly due to the fleet formation. In the reference case a significant share of CNG ICE vehicles is observed that use domestic natural gas as the fuel. This was limiting the gasoline ICE vehicles thus limiting oil based gasoline. But with the introduction of PHEV LDV subsidy, consumers find more space for cheaper gasoline ICE vehicles while obeying CAFE efficiency

standards due to increased number of more efficient PHEVs. CNG LDV subsidies minimize that effect by replacing diesel and gasoline vehicles by CNG counterparts thus reducing oil based fuel consumption.

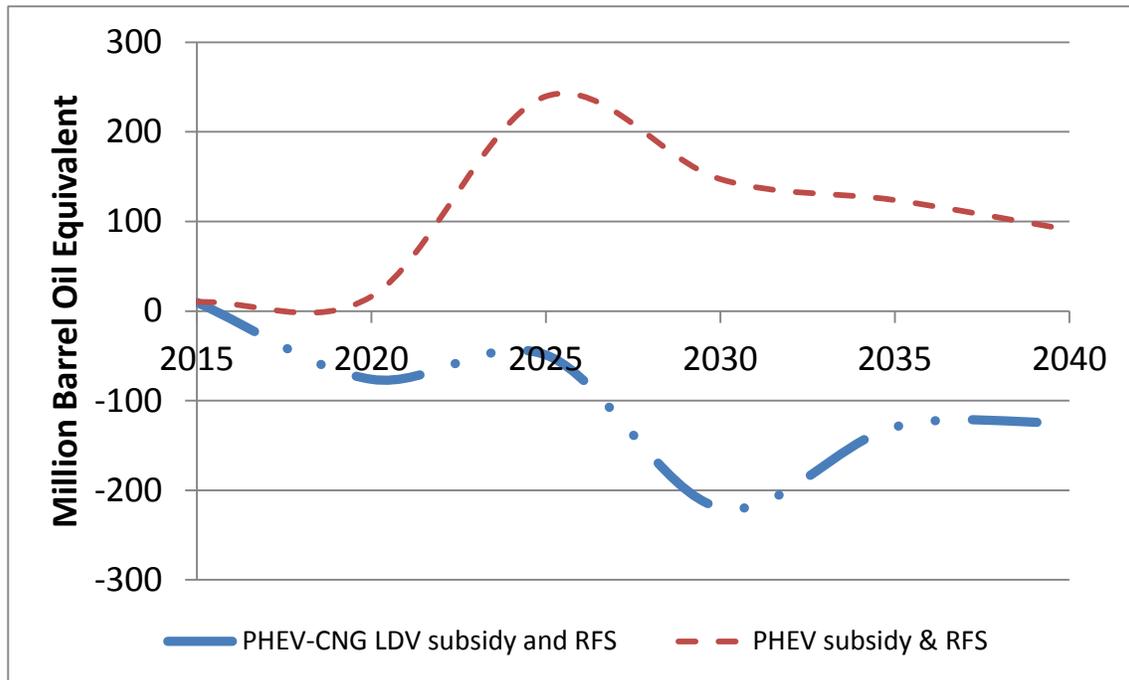


Figure 12. Net Oil Import Change due to the alternative policies compared to base case

## Conclusions

Clearly, the leveling of the playing field for CNG and PHEV subsidies has considerable impacts on fleet composition, electricity use, and transportation natural gas use as would be expected. In 2050 there are 36% more CNG internal combustion vehicles in the fleet if the CNG LDV subsidy is in effect compared with only the PHEV subsidy. On the other hand, if only the PHEV subsidy is in effect, there are 15% more of those vehicles compared to the case with the CNG LDV subsidy as well. Interestingly, the CNG subsidy also results in a reduction in GHG emissions relative to the case with only the PHEV subsidy. Oil imports also decrease with the CNG subsidy. Thus, we have documented that if a CNG subsidy were provided as is the case for PHEV; it would have important impacts on the transportation system.

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