

Market Potential of Alternative Fuel Technology Vehicles to Mitigate Climate Change

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The United States has committed to reduce its greenhouse gas (GHG) emissions by 26-28 percent below the 2005 level by 2025 in the 2015 Paris Climate Summit. Transportation is one of the largest contributors to U.S. GHG emissions. According to the Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2014 (EPA, 2016), transportation represented 26% of total U.S. GHG emissions in 2014. The on-road transportation sector, including light-duty (LDV), medium, and heavy-duty vehicles (HDV), accounts for 80% of total transportation emissions and 22% of total U.S. GHG emissions. Thus, reducing emissions from on-road transportation can play a significant role in overall climate change mitigation. There have been multiple policies and programs that have required increasingly stringent levels of Corporate Average Fuel Economy (CAFE standards) with the goals of increasing fuel use efficiency and reducing GHG emissions and petroleum dependence. One of the major opportunities for automakers to meet these standards is production of more vehicles relying on Alternative Fuel Technologies (AFVs) (electric vehicle (BEV), fuel cell vehicles (FCEV), hybrid (HEV), compressed natural gas vehicles (CNGV), biofuel) rather than traditional fossil fuels. Expanded use of AFVs can potentially result in substantial reductions in GHG emissions. However, consumers' acceptance of these AFVs and their net effect on GHG emissions, accounting for market interactions, remain important questions for assessment of the overall impacts of programs and policies promoting the use of AFVs. This study uses a Computable General Equilibrium Model (CGE) to examine the potential of alternative fuel technologies to mitigate climate change and the interactions between expanded use of these technologies and the U.S. economy, energy and food markets.

1. Literature Review

Recent studies on AFVS is from using MIT EPPA which used a computable general equilibrium model, to evaluate the potential for the PHEV to enter the U.S. personal vehicle market before 2100 and alter electricity output, refined oil consumption, carbon dioxide emissions, and the economic welfare losses associated with the imposition of a strict climate policy. The PHEV is defined by its ability to run on battery-stored electricity supplied from the grid as well as on refined fuel in an internal combustion engine. Sectors that produce PHEV transportation as well as other electric-drive vehicle technologies were added to the MIT Emissions Prediction and Policy Analysis (EPPA) Model as a perfect substitute for internal combustion engine (ICE)-only vehicles. Engineering cost estimates for the PHEV, as well as information about the pre-existing fleet, were used to specify PHEV sector input shares and substitution elasticities in the model.

Based on the MIT model results, several conclusions emerged from this work. First, lower vehicle cost markups may hasten PHEV market entry, especially in the absence of a climate policy. Second, in the short term, the lower cost of electricity compared with refined

fuels on a per mile basis is likely to favor adoption of vehicles with longer all-electric ranges. However, realizing the electricity advantage will depend on whether or not current battery cost and performance limitations can be overcome. Third, the availability of biofuels as a carbon neutral fuel substitute could delay PHEV market entry, especially when a climate policy is imposed. Fourth, large-scale adoption of the PHEV will increase electricity demand, reduce refined oil consumption, and could offset the economic welfare cost of pursuing a climate policy, especially if biofuels are not available. Fifth, realizing the maximum carbon emissions reduction potential of grid-charged electric-drive vehicles such as the PHEV will depend on concurrent reductions in power sector emissions.

3. Methods

The model used for this analysis is the Applied Dynamic Analysis of the Global Economy (ADAGE) model, a recursive dynamic, multi-region, and multi-sector CGE model developed by RTI International. ADAGE follows the classical Arrow-Debreu general equilibrium framework covering all aspects of the economy, including production, consumption, trade, and investment. Households can distinguish between domestic or imported consumption goods, including personal and purchased transportation services. Producer firms maximize profits subject to technology constraints in a nested CES structure. The dynamics in ADAGE are represented by: (i) growth in the available effective labor supply from population growth and changes in labor productivity, (ii) capital accumulation through savings and investment, (iii) changes in stocks of natural resources, and (iv) technological change from improvements in manufacturing, energy efficiency and land productivity. ADAGE is simulated for the period 2010-2050 with a five-year time step.

The key underlying database used in ADAGE is the Global Trade Analysis Project (GTAP) database version 7.1 (Narayanan and Walmsley, Ed., 2008), which was updated from 2004 to the baseline year 2010 using secondary data from World Energy Outlook (WEO, 2010) and International Energy Outlook (IEO 2010) and Food and Agricultural Organization. The model has rich details in energy, agriculture, biofuel, land where energy consists all fossil fuels (refined oil, natural gas, coal and electricity generation from them) and renewable fuel (nuclear, solar, wind and hydro power), agriculture has eight crop categories, one livestock and one forestry sector and by-products from biofuel production. Seven types of first generation biofuels (corn ethanol, soybean ethanol, sugarcane ethanol and so on) and five types of second generation biofuels (switchgrass, miscanthus, ag residue, forest residue, and forest wood) are included in the model, used as substitutes of refined oil in light-duty transportation. Five land types (cropland, pastureland, managed forestland, natural grassland and natural forestland) are included in the model, allowing land conversion between each other to respond increasing land competition. ADAGE has full greenhouse gases accounting (GHG) where data for GHGs (carbon dioxide, CO₂; methane, CH₄; nitrous oxide, N₂O; hydrofluorocarbons, HFCs; perfluorocarbons, PFCs; and sulphur hexafluoride, SF₆) are from U.S. EPA inventory data and projects. ADAGE has been undergoing continuous enhancement since 2009 and has been applied for various economic, energy, and environmental policies analysis, for example, renewable fuel policy

analysis (Beach et al., 2011; Cai et al, 2013), climate change evaluation (Cai and Beach, 2013) and food, energy and climate mitigation analysis (Cai, Beach, and Zhang, 2014a, 2014b; Cai and Beach, 2015a, 2015b).

As we know, greater sector disaggregation can improve the representation of energy substitution possibilities among transportation modes. In order to gain a fuller understanding of the GHG mitigation potential of the transportation sector for this study, we disaggregated the transportation sector into seven types (light-duty passenger, road freight, road passenger, rail freight, rail passenger, air, water and all other transportation). However, with only three types of transportation (air, water and the rest) included in the GTAP 7.1 database, six transportation sectors in the IEA database (road, rail, air, water, pipeline and other) and two types in the previous version of ADAGE (auto transportation and all other), one of the key challenges overcome for this paper was development of a disaggregated transportation sector that is as consistent as possible with each of these data sources. On the production side, data on the labor, capital, energy and intermediate goods that are used to produce different types of transportation service as well as the service level provided are needed to break out these sectors. Those data were obtained from the Global Change Assessment Model (GCAM), an integrated assessment model developed and maintained by Pacific Northwest National laboratory (PNNL), the U.S. Department of Commerce and the Bureau of Transportation Statistics within the U.S. Department of Transportation. The transportation module in GCAM includes output parameters such as energy usage, energy price, service production (vehicle-mile traveled (vmt)), and service price (\$/vmt) and input parameters such as the non-fuel price (\$/vmt), energy intensity (MJ/vmt), load factor (persons or tonnes per vehicle) for various modes, size class and alternative fuel technology for 14 regions world-wide. The non-fuel price is composed from capital costs, operating costs, fuel taxes and/or government subsidies. Input-output data obtained from U.S. Department of Commerce provides the shares of labor, capital and aggregated intermediate inputs used in transportation production in the United States in 2010. After combining the input cost data in 2010 from GCAM and the Department of Commerce, we were able to obtain region-specific input shares for labor, capital, intermediate goods and energy for these seven sectors, which were used to split IEA and GTAP data in production, consumption, investment and trade.

A second key challenge is to ensure the zero profit condition is met and market clearance for all goods in the base year, a requirement for all CGE models. We assumed that all goods output and energy inputs used remain unchanged while labor, capital and intermediate goods and household consumption can be adjusted to rebalance the data and ensure these conditions hold after the data disaggregation procedures. To maintain data integrity, an optimization model was developed that minimizes the sum of the square of least deviation from raw data for all goods while satisfying the constraints of zero profit and total demand being equal to total supply for all goods. The simulated data produced using this model then serves as the base year data used in ADAGE.

A third important task is to introduce the alternative fuel technology for these on-road technologies into the model. First, we added a technology allowing the use of biofuels in HDV sectors (biofuels were only used in LDV in previous versions of ADAGE), used as substitutes of

refined oil in HDVs similar to the potential substitution available for LDV in the previous version of the model. Input costs (for electric vehicle, fuel cell vehicles, hybrid, compressed natural gas vehicles), markup factor and fuel efficiency for LDV are collected from the GCAM database while the fuel efficiency in the USA is replaced by projections from AEO 2014. The markup factor relative to refined oil vehicle for USA for LDV is 1.13 for GASV, 1.68 for BEV, 1.30 for HEV, and 2.57 for FCEV in 2010. These markup factors are assumed to gradually decrease over time, indicating that although these AFVs is not as competitive as conventional LDV using refined oil and biofuels in 2010, they will tend to become more competitive over time as the technologies continue to develop and are likely to gradually penetrate the market even in the absence of policy incentives. Input cost, markup factor and fuel efficiency for Medium and Heavy-duty AFVs shows a similar pattern as these AFVs in the LDV sector. Production technologies for these disaggregated transportation sectors and AFVs are described using nested CES functions. The nesting structures and elasticities of substitution used in ADAGE remain unchanged as auto and other transportation in the previous version where elasticity of substitution is drawn from EPPA4 (Paltsev, et al, 2005).

3.2 Scenarios

In this study, four scenarios are designed to explore the market potential of Alternative Fuel Technology and tradeoffs when facing energy, food, and climate challenges: 1) A business-as-usual scenario (BAU) where regional GDP projections are based on the reference case in the International Energy Outlook 2013; 2) an emission reduction path relative to emissions in 2005 is applied to on-road transportation only (TRNO) ; 3) the same percentage emission reduction path as in 2) is applied to all GHG emissions excluding land use emissions (ALNL) ; 4) the same percentage emission reduction path as in 2) is applied to all GHG emissions including land use emissions (ALLD). The first set of these scenarios apply to the United States only and we plan to conduct a second set of analysis at the global level where the emission reduction paths will follow the corresponding regional commitment.

4. Results and Discussion

The preliminary results from the first set of runs with policies applied to the U.S. only indicate that under the BAU case, despite continued increases in energy efficiency in future decades, the effects of population and economic growth would dominate, leading to an increase of energy usage of refined oil in on-road transportation, with biofuel and AFVs only slowly entering into the market in the USA. Comparing the transportation only (TRNO) with the BAU scenario, there are substantial increases in AFVs and biofuel usage in all on-road transportation. When the emission reduction is applied to all industries excluding land use change (ALNL), we see even more AFVs and biofuels in all on-road transportation, and greater reduction in transportation sector than other industry. In the fourth case (ALLD) with the introduction of emission from land use change, the level of penetration of AFVs lies between BAU and TRNO. This study provides some implications on policy design on how to view consumers' acceptance of AFVs and their effect on overall fuel economy standards.

4.1 The impact of bioenergy target in short term during 2015~2020

4.1.1 Biofuel production

4.1.2 Ag price and production

4.1.3 Energy price and consumption

4.1.4 GHG emissions

4.2 Biofuel potential and implications in long term from 2020 to 2050

4.2.1 Biofuel production

4.2.2 Ag price and production

4.2.3 Energy price and consumption

4.2.4 GHG emissions

5. Conclusion

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