Prospects of Alternative Fuels for Future On-road Transportation

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According to Annual Energy Outlook 2018 (AEO 2018) from U.S. Energy Information Administration (EIA), approximately 94 percent of U.S. transportation is powered by oil and the transportation sector accounts for 70 percent of total oil consumption in the United States. The potential risks to the U.S. economy associated with a lack of transportation fuel diversity, high dependence on imports, fluctuating oil prices, and environmental concern have been recognized for decades and have encouraged policymakers, industries and consumers to diversify energy resources utilized for transportation as well as increasing vehicle fuel efficiency. In recent years, the development of low-cost hydraulic fracturing (fracking) technology has contributed to a major increase in domestic crude oil (and natural gas) production. Despite expansion in domestic crude oil production that has been lowering prices, oil is a globally traded commodity with relatively volatile prices and the US could still experience an oil price shock (and AEO continues to run a variety of oil price scenarios reflecting this risk). Electricity, natural gas and biofuels are potential alternative transportation energy sources that can reduce the dependence on fossil-fuels and provide environmental benefits. Along with the falling crude oil price, prices for electricity and natural gas in the United States have also been gradually falling over time and remain relatively more stable than oil price. Biofuels as renewable transportation fuels have expanded rapidly, driven by federal and state incentives and requirements such as Renewable Fuel Standard (RFS2). However, expansion is slowing as there have been challenges in developing cost-effective means of producing advanced biofuels such as cellulosic ethanol. Alternative Fuel Vehicles (AFVs) that use fuels such as biofuels, natural gas, hydrogen, or electricity, generally with higher fuel economy than traditional fossil-fuel vehicles, have been suggested as a low-carbon alternative to further reduce the dependence on fossil-fuel-based transportation. Among these AFVs are battery electric vehicles (BEV), fuel cell vehicles (FCEV), hybrid (HEV), and compressed natural gas vehicles (GasV). While there have been considerable advances in AFV technologies, they require further advancement to lower costs sufficiently to capture a significant share of the vehicle market that currently continues to be dominated by conventional fossil fuel technologies. In this study, we use a Computable General Equilibrium Model (CGE) with a highly disaggregated transportation sector to examine the market potential of AFVs for on-road transportation of both passengers and freight under different oil price pathways and their influence on the U.S. economy, energy markets, food prices, and the environment.

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 (Cai, et al, 2018). 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), International Energy Outlook (IEO 2010), Food and Agricultural Organization, and other sources. The model has rich details in energy and electricity generation, agriculture, biofuels, and land. Energy consists of all fossil fuels (refined oil, natural gas, coal and electricity generated from them), nuclear and renewable sources (hydro, wind, solar, geothermal, and biomass). Seven types of first-generation biofuels (ethanol from corn, wheat, sugarcane and sugarbeet, and biodiesel from soybean, palm oil and rapeseed) and their byproducts, as well as five types of second-generation biofuels (switchgrass, miscanthus, ag residue, forest residue, and pulpwood) are included in the model, used as substitutes of refined oil in on-road transportation. ADAGE has full greenhouse gas (GHG) accounting where base year data for GHGs (carbon dioxide, CO_2; methane, CH_4; nitrous oxide, N_2O; hydrofluorocarbons, HFCs; perfluorocarbons, PFCs; and sulphur hexafluoride, SF_6) are from U.S. EPA historical inventory data and projections. ADAGE has been undergoing continuous enhancement since 2009 and has been applied for various economic, energy, and environmental policies analysis.

For this study, transportation sectors are disaggregated into seven types (light-duty passenger, road freight, road passenger, rail freight, rail passenger, air, water and all other transportation) using data 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. A nested CES production function is used to represent production in each of these disaggregated transportation sectors with energy, materials, labor and capital as inputs. A unique feature in ADAGE is to build up physical accounts (transportation service defined in terms of passenger-miles traveled (pmt) for passenger transportation and ton-miles traveled (tmt) for freight transportation, price of transportation service ($/pmt or $/tmt), load factor (passenger/vehicle or ton/vehicle), fuel economy (mile/gallon)) and develop linkages between the physical accounts and monetary accounts used in CGE models.

AFVs for on-road vehicles (light-duty vehicles (LDVs), heavy-duty vehicles (road freight and road passenger) are introduced as backstop technologies meaning they are not available in the base year but could enter the market when they become competitive with the conventional fossil-fuel technology. For AFVs included in the model (electric, fuel cell, hybrid, and compressed natural gas vehicles), input costs, markup factor and fuel economy are collected from the GCAM database and experts in transportation engineering. The markup factor gradually decreases over time, indicating that although these AFVs are not cost-competitive with conventional counterpart using refined oil and biofuels in 2010, they would likely become more competitive over time as the technologies continue to develop. Production technologies for AFVs are described using nested CES functions with energy (e.g., natural gas for GasV, electricity for BEV), materials, labor and capital as inputs. An innovation for this study is to allow biofuels to be used as substitutes for refined oil in all on-road transportation without any blending wall constraint. This means that both conventional and hybrid vehicles can use biofuels in light-duty as well as heavy-duty transportation at flexible ratios. Thus, we do not consider conventional internal combustion engine vehicles using biofuels as their sole energy source to be AFVs.

For this study, we explore the market potential of AFVs in on-road transportation under different oil price scenarios. These oil price scenarios are taken from AEO 2018: the reference case (REF), where crude oil price starts from $54/barrel in 2015 and rises gradually to $114/barrel by 2050; low oil price case (LOP), where crude oil price starts from $54/barrel in 2015 and drops to $31/barrel by 2020 then increases slightly to $52/barrel by 2050 as a result of lower economic growth than in the REF case; and the high oil price case (HOP), where crude oil price starts from $54/barrel in 2015 and rises significantly to $229/barrel by 2050 due to higher economic growth. Crude oil price is applied to all eight regions of the world included in the version of ADAGE applied for this study.

Our preliminary results indicate that under the reference oil price case, total on-road energy consumption grows slightly during 2010-2050, mainly coming from LDV and Road freight. In the LDV sector, with the penetration of AFVs, especially hybrid vehicles, and growing substitution of biofuels for refined oil in both conventional and AFVs, biofuels and electricity consumption rise significantly, accounting for 9% and 16% of total LDV energy consumed in 2050. Meanwhile, the share of refined oil in total LDV energy consumption declines from 94% in 2010 to 75% in 2050. For heavy-duty transportation, there is little penetration from AFVs, making biofuels used in conventional vehicles the only alternative energy source with non-negligible adoption, reaching a share of 9% by 2050.

Under the high oil price case, total on-road energy consumption decreases slightly between 2010 and 2050. In the LDV sector, AFVs expand rapidly, especially hybrid vehicles during 2020~2040 and electric vehicles during 2035~2050. As a result, share of biofuels and electricity in total LDV energy consumption rise significantly to around 52% and 48% by 2050, replacing the entire usage of fossil fuels in transportation. Meanwhile in the heavy-duty transportation, there is little expansion from AFVs. However, much greater substitution of biofuels for refined oil in the conventional technology results in biofuels reaching an 82% share of total heavy-duty vehicle energy consumption by 2050.

The low oil price scenario leads to overall more energy usage in on-road transportation than in the reference case. There is small and slow penetration of AFVs in LDV and slight biofuels expansion.

By 2050, total on-road transportation biofuels usage is around 14 billion gallons in LOP, 26 billion gallons in REF and 100 billion gallons in HOP. Correspondingly, the overall change in an agricultural price index relative to REF is around -1% in LOP and +21% in HOP by 2050. Total GHG emissions, including emissions from fossil fuel consumption, residential and other industries, and land use change are projected to change +15% in LOP, and -30% in HOP.

This study enhances our understanding of the prospects of alternative fuels in response to varying oil price. The results from this study help us to explore how AFVs compete with themselves and with conventional fuel vehicles, and how alternative energy sources compete, and overall implications on ag and other industries and GHG emissions in U.S.A. It provides implications for effective policy design regarding promotion of AFVs potential role of alternative technologies.