Institut für Verbrennungskraftmaschinen und Thermodynamik, Technische Universität Graz

13. Tagung "DER ARBEITSPROZESS DES VERBRENNUNGSMOTORS" **22./23. September 2011**

Alternative fuels and propulsion systems - a U.S. perspective

Alternative Kraftstoffe und Fahrzeugantriebe in den USA

Thomas Wallner, Mike Duoba
Center for Transportation Research
Argonne National Laboratory

Abstract

For more than a century almost exclusively crude oil based fuels have been used in the transportation sector worldwide. Only recently, mainly driven by environmental concerns, issues of dependence on foreign oil as well as related national security questions and in light of steadily increasing fuel prices, governments around the globe have started introducing alternative fuel road maps. Aside from a general push towards more efficient vehicles these roadmaps almost uniformly consist of increased production and utilization of alternative, domestically produced fuels such as ethanol and biodiesel as well as extended electrification of the vehicle fleet.

This study focuses on alternative fuels and propulsion systems from a U.S. perspective and attempts to shed light on current and anticipated trends. The first part identifies major drivers for wider utilization of alternative fuels, such as the Renewable Fuels Standard and E15 waiver for light-duty vehicles MY2001 and newer, and analyzes actual trends in the U.S. vehicle fleet. Further, information on market penetration and trends of alternatives such as CNG, LPG, and E85 are provided. The second part focuses on the vehicle electrification, provides details on technology penetration of hybrid vehicles, as well as perspective of large-scale introduction of plug-in hybrid and electric vehicles in the U.S.. Related challenges, such as determination of fuel economy, are also highlighted.

Kurzfassung

Weltweit werden seit mehr als einem Jahrhundert im Transportsektor beinahe ausschliesslich aus Erdoel hergstellte Krafstoffe eingesetzt. Erst in juengster Zeit, hauptsaechlich getrieben bei gesteigertem Umweltsschutzbewusstsein, durch die Abhaengigkeit von auslaendischem Erdoel verursachte Unsicherheit verbunden mit Fragen der nationalen Sicherheit und aufgrund stetig steigender Krafstoffpreise, haben Regierungen weltweit mit der Entwicklung von Roadmaps im Bereich alternativer Kraftstoffe begonnen. Diese Roadmaps fordern, abgesehen von einem allgemeinen Trend in Richtung Wirkungsgradsteigerung von Fahrzeugantrieben, eine Anhebung der Produktion und Nutzung alternativer, lokal hergestellter Kraftstoffe wie Ethanol und Biodiesel sowie eine erweiterte Elektrifizierung der Fahrzeugflotte.

Diese Studie konzentriert sich auf alternative Kraftstoffe und Antriebssysteme aus Sicht der USA und versucht gegenwaertige und zukuenftige Trends zu erlaeutern. Im ersten Teil werden die wichtigsten Einflussfaktoren fuer eine verstaerkte Nutzung alternativer Krafstoffe, wie der 'Renewable Fuels Standard' und die Genehmigung von E15 in Automobilen Baujahr 2001 und neuer, behandelt und gegenwaertige Trends in der U.S. Fahrzeugflotte analysiert. Weiters werden Informationen zur Marktdurchdringung und Trends von Alternativen wie Erdgas, Fluessiggas und E85 beleuchtet. Der zweite Teil konzentriert sich auf Fahrzeug-Elektrifizierung und beinhaltet Details zum Marktanteil von Hybridfahrzeugen sowie Perspektiven zur Einfuehrung von Plug-In Hybrids und Elektrofahrzeugen in den USA. Dazu werden auch einhergehende Herausforderungen, wie die Bestimmung des Kraftstoffverbrauches, besprochen.

1. INTRODUCTION

A recent survey under the direction of the Princeton Survey Research Associates International covering 22 nations around the globe concluded that the world's two greatest emitters of carbon dioxide, the U.S. and China, are less troubled by global warming than most other nations. Only 37% of Americans and 41% of Chinese were agreeing that climate change is a very serious challenge ranking them 20 and 18 out of the 22 nations included in the study. For comparison, 85% of Brazilians, 62% of Indians, 58% of Japanese and 52% of Germans surveyed in the study perceived climate change as a very serious challenge [1].

However, the United States as the single largest energy consumer faces challenges since the domestic petroleum consumption by far outweighs the crude oil production. Figure 1 shows the historical development of U.S. crude oil production and petroleum consumption over the last 60 years with the U.S. currently importing approx. 50% of its petroleum demand. Thus alternative energy policies are rather a matter of energy and national security than a matter of environmental concerns. This might also be reflected in the fact that the U.S. regulates it's average fleet fuel consumption whereas many other developed nations are committed to reducing greenhouse gas emissions.

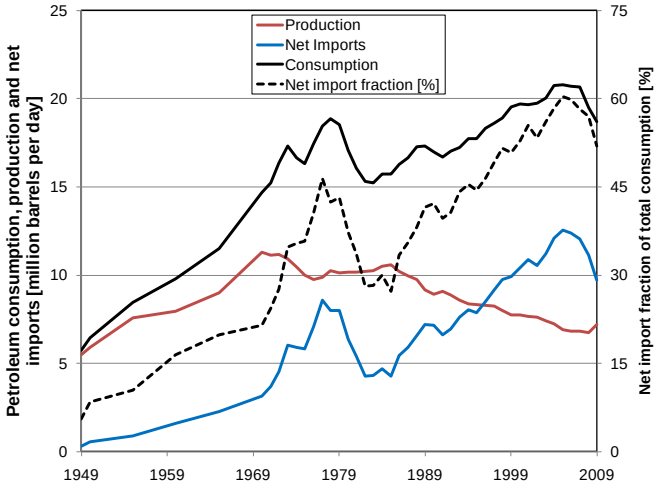

Figure 1: Comparison of historical crude oil production and petroleum consumption in the U.S. (based on data by [2])

A large-scale introduction of alternative fuels in general and in the transportation sector as one of the major consumers of crude oil based products in particular is mainly driven by uncertainties in terms of energy security. Despite recent government commitments worldwide towards greener and

more sustainable energy portfolios, fuels used for transportation are still predominantly crude oil based. Actual goals for the introduction of alternatives vary in the way they are defined, the extend and whether those goals are target values or actually mandated. An overview of biofuel blending targets and mandates worldwide can be found in [3].

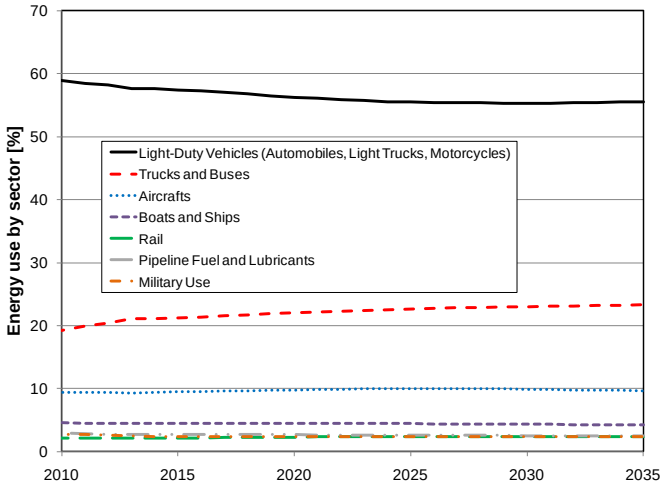

Figure 2: Current and predicted energy use by sector in the United States (based on data by [4])

The focus of this study is alternative fuels and powertrain options for passenger vehicles for the United States. This selection is based on the energy used in the light-duty vehicle sector, which currently accounts for almost 60% of the entire energy used in transportation. According to the U.S. Energy Information Administration Annual Energy Outlook 2010 the light-duty sector will remain the dominant energy user despite a predicted slight decline over the next decades (Figure 2). In the sector of light-duty vehicles automobiles and light trucks account for approx. 99.9% of the energy consumption with motorcycles only adding marginal consumption.

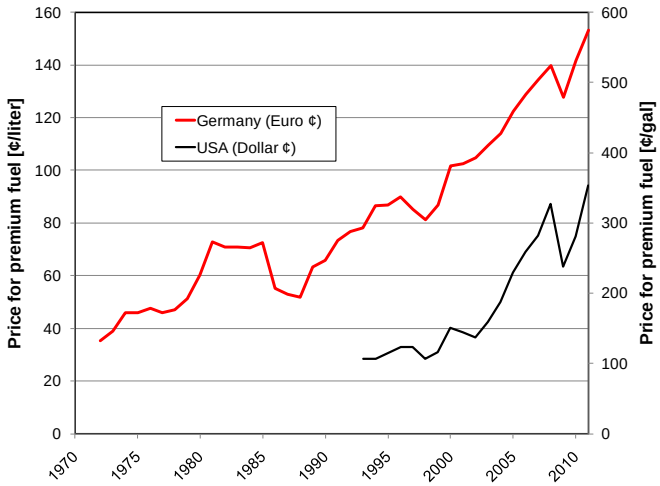

Figure 3: Historic prices for premium fuel in the U.S. and Germany (based on data by [5,6])

Historically fuel has always been significantly cheaper in the United States compared to Europe also reflected in significant differences in vehicle size and fuel economy as well as average mileage driven per year. Figure 3 compares historic prices for premium fuel in the United States and Germany showing that prices in Germany in the early 1970s already exceeded those in the U.S. from the early 1990s. In order to eliminate the influence of exchange rates the comparison is based on fuel prices in Dollar ¢ for U.S. values and Euro ¢ for German fuel prices. Values shown for 2011 only include January and February for German values and January through May for U.S.

values. Despite a well documented volatility of fuel prices mainly affected by geopolitical factors a consistent upward trend of average fuel prices over the last decades can be observed. It is interesting to note that in addition to the general upward trend the ratio of fuel cost in Germany versus the United States declined from a factor of 3 in 1993 to approx. 2 in 2010.

2. IDENTIFICATION OF MAJOR DRIVERS

As mentioned earlier, governments worldwide are adopting policies to reduce petroleum fuel consumption and increase production and use of alternative fuels. Policies come in the form of mandates or incentives, both for fuel economy and use of alternative fuels.

2.1. Bio-Fuels Production Targets and Mandates

While some countries started mandating the fraction of alternative content in petroleum based fuels (e.g. India with a mandate for E20 and B20 by 2017) the European Union targets an overall fraction of renewable fuel use in the transportation sector of 10% [3]. U.S. legislation through the Renewable Fuel Standard (RFS) mandates a four-fold increase in renewable fuel to be blended into transportation fuel from approximately 9 billion gallons in 2008 to 36 billion gallons in 2022. The RFS also limits the amount of conventional biofuels to 15 billion gallons [7]. Figure 4 shows the mandated biofuels production in the U.S. which regulates contribution by conventional biofuels, advanced cellulosic and non-cellulosic biofuels and biomass-based diesel. Despite the rapid growth, U.S. biofuels consumption remains a small contributor to U.S. motor fuels, comprising about 4.3 % of total transportation fuel consumption (on an energy-equivalent basis) in 2009 which is expected to grow to about 7 % with the mandated 36 billion gallons by 2022 [8].

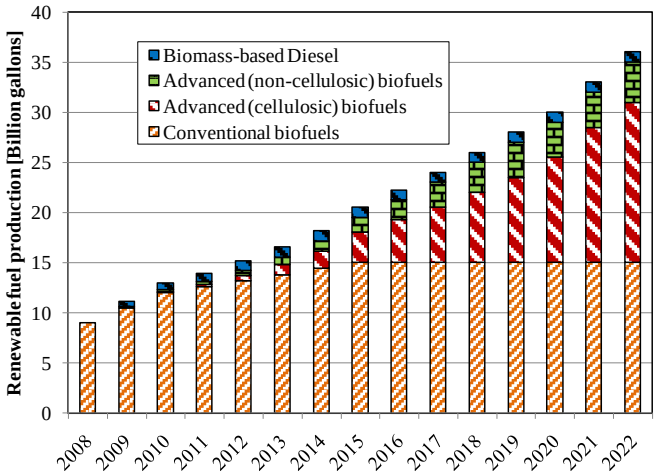

Figure 4: Renewable fuel production per U.S. Renewable Fuel Standard

Ethanol is currently the most widely used alternative fuel and is typically used in blends with gasoline. Although attempts are made to get higher blends approved, the most commonly used blend throughout the world is E10, a blend of 90 Vol-% gasoline with 10 Vol-% anhydrous ethanol. U.S. legislation limits the amount of oxygen content in blends of gasoline with alcohol fuels. In 1991 the maximum oxygen content was increased from 2 wt% to 2.7 wt% for blends of aliphatic alcohols and/or ethers excluding methanol [9]. To ensure sufficient gasoline base was available for ethanol blending, the EPA also ruled that gasoline containing up to 2 Vol-% of MTBE could subsequently be blended with 10 Vol-% of ethanol [10]. Only recently EPA granted a partial waiver to allow gasoline that contains greater than 10 volume percent ethanol and up to 15 Vol-% ethanol (E15) for use in model year 2001 and newer light-duty motor vehicles, which includes passenger cars, light-duty trucks and sport utility vehicles (SUV) [11].

2.2. Vehicle Fuel Economy Mandates

Starting in 1975, the United States Corporate Average Fuel Economy (CAFE) legislation has set standards for passenger cars and light-duty trucks. CAFE was initially established as a reaction to the Arab oil embargo in 1973-74 and its initial near-term goal was to double new car fuel economy by model year 1985. Corporate Average Fuel Economy is the sales weighted harmonic mean fuel economy, expressed in miles per gallon (MPG), of a manufacturer's fleet of passenger cars or light trucks with a gross vehicle weight rating (GVWR) of 8,500 lbs. or less, manufactured for sale in the United States, for any given model year. A particular model's CAFE fuel economy is a composite of the unadjusted Federal Test Procedure (urban driving) and the highway cycle test (harmonic weighting of 55% / 45% respectively) in accordance with the testing and evaluation protocol set forth by the Environmental Protection Agency (EPA) [12].

Within the CAFE regulations are built-in incentives for alternative fuels. For vehicle fueled solely by E85, the fuel economy is divided by 0.15, or the amount of petroleum-derived fuel in E85. So for example a vehicle with a volumetric CAFE E85 MPG of 27.5 would be calculated to be 183.3 MPG. Dual-fuel or so-called "flex-fuel" vehicles are given a generous assumption of 50% use of the alternative fuel. In the U.S., there are more than 8 million flex fuel E85 vehicles on the road, but only a small fraction of these vehicles routinely refuel with the alternative fuel. However, in 2015, this 50% assumption may not be carried into future years by EPA unless it is demonstrated that the alternative fuel is actually being used in vehicles.

A Petroleum Equivalency Factor (PEF) is used to establish a gasoline equivalent MPG for electricity. Electric and plug-in hybrids are given a PEF equating 82,049 Wh of electricity for a gallon of gasoline. Using this calculation, a typical small sedan electric vehicle consuming 244 Wh/mi would achieve a CAFE fuel economy of 335.24 MPG [13].

CAFE standards were stagnant from 1990 to 2010 (increases in light duty trucks started to increase slowly in 2005). CAFE MPG for model years 2012-2016 were changed to a method that determines the standard based on a particular vehicle's footprint. The targets are shown in Figure 5 using both, vehicle footprint in m^2 and square feet (SF) and fuel economy numbers in miles per gallon (MPG). The vehicle footprint is one measure to determine vehicle size and is calculated based on vehicle wheelbase and average track width. The vehicle footprint and resulting target fuel economy for various size vehicles are also shown in the plot.

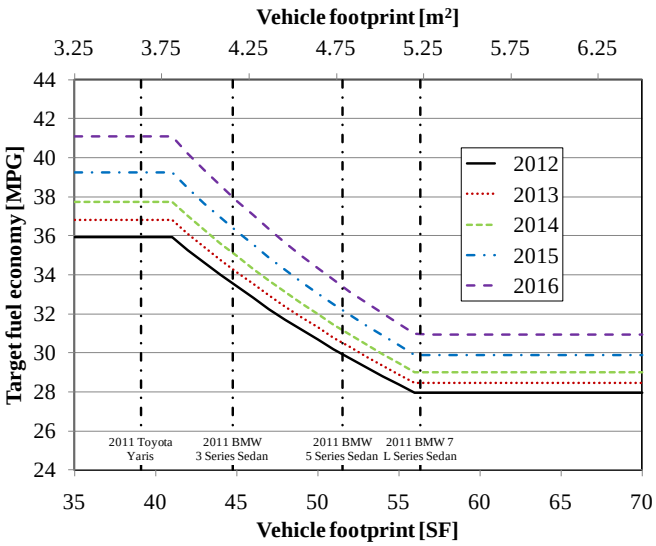

Figure 5: Corporate Average Fuel Economy (CAFE) standards 2012 - 2016 (based on [14])

Work has already started to define CAFE standards beyond 2016 until 2025. Several scenarios for regulations with varying levels of annual reductions in greenhouse gas (GHG) emissions ranging from 3, 4, 5, to 6% per year were estimated. Starting form 250 gram/mile (g/mi) of GHG for model year 2016 fleet-wide average the model year 2025 scenarios analyzed would result in 190 g/mi (calculated to be equivalent to 47 miles per gallon, MPG) under the 3% per year reduction scenario to 143 g/mi (calculated to be equivalent to 62 MPG) under the 6% per year scenario. These levels correspond to on-road values of 37 to 50 MPG, respectively [15].

Another driver for differences in vehicle fleet composition are the applicable emissions regulations. Figure 6 compares particulate matter (PM) and NOx emissions standards for the European Union and California. California regulations are listed since they are more stringent than U.S. federal regulations and California presents the single largest car market in the U.S. [16]. Further, 13 U.S. states have already adopted California regulations and 6 more states are considering their adoption. Overall, PM and NOx emissions regulations have become significantly more stringent over the last decade starting from LEV1 and Euro 4. Current Tier 2 Bin5 emissions regulations are more stringent for NOx emissions with higher limits for PM compared to Euro 5 regulations. Proposed regulations for California as well as Europe foresee another significant reduction in NOx emissions limits while PM emissions regulations remain constant. LEV3 emissions regulations are supposed to be phased in from 2014 to 2022. It is worth noting that Euro 6 regulations include particle number limits ($6x10^{11}$ Nb/km).

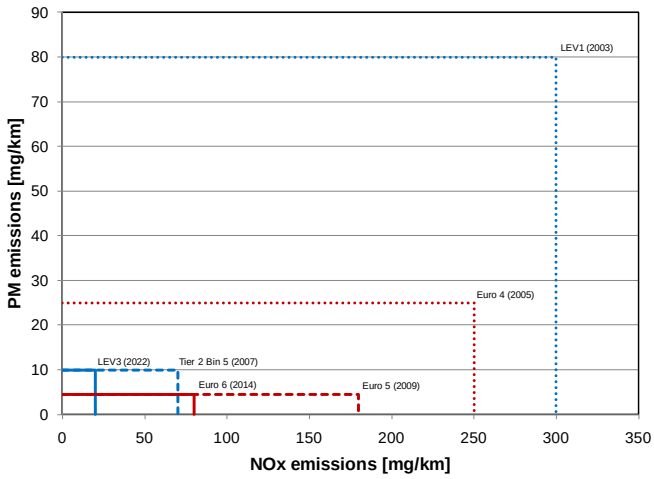

Figure 6: Comparison of U.S. and European Emissions Regulations (based on data by [17])

2.3. California ZEV Mandate

A significant driver for accelerated electric and plug-in hybrid vehicle development and deployment in the U.S. and world-wide is the California Zero Emissions Vehicle mandate. The basic principle is that a mandate was legislated that forces a certain percentage of the major vehicle OEMs' sales in California to be electric vehicles. The original plan was a simple percentage mandate structure starting in model year 1998 with 2% ZEV, and extending up to 10% by 2003. The technology to cost-effectively support such a mandate was deemed lacking as the 1998 mandate arrived so flexibility was built into the system to satisfy the mandates with low-emissions vehicles and hybrid-electric vehicles. Even though the mandates for strictly electric vehicles were not carried out in the past decade, vehicles like the EV1, Toyota RAV4, the Ford Ranger EV, and many others were developed by OEMs and provided a kick start to the industry that has accelerated in recent years.

The flexibility to achieve ZEV credits with advanced vehicles other than ZEVs comes to an end in 2012. The timing of a large number of electric vehicles being introduced into the market in MY 2011 and 2012 coincides with California mandating a total of 7500 ZEVs for each high-volume OEM. This requirement rises to 25,000 for MY 2015-2017. There are still partial credits in place and the structure to achieve the mandate was and remains quite complicated (a full description is beyond the scope of this paper). Seven other states have passed legislation to join California in extending the mandate to their state. The original objective of the ZEV mandate was air quality improvements in California (which has cities with the lowest air quality in the U.S.). However, in recent years the focus has switched from smog to reducing greenhouse gas emissions. This has led to California pursuing goals in CO2 emissions in conjunction with mandating ZEVs. In recent years, the U.S. EPA and California have harmonized CAFE with GHG emissions goals so that vehicle efficiency and GHG targets are not in over-burdensome conflict.

2.4. Incentive Programs

Currently there are federal tax incentives available to the consumer for electric and plug-in hybrid electric vehicles. At the federal level a tax credit from $2,500 to $7,500 is established based on each vehicle's traction battery capacity and the gross vehicle weight rating. Individual states have their unique legislation providing incentives for advanced and alternative fuel vehicles. For example, in Illinois, up to 80% of the incremental cost or the conversion cost of an alternative fuel vehicle (up to $4,000) is given in a state rebate program.

At the time of this draft, there is pending legislation for providing incentives similar to that given for electric drive vehicles for natural gas vehicles. The “New Alternative Transportation to Give Americans Solutions Act,” or NAT GAS Act will have tax credits for natural gas vehicles and refueling providers. With the cost differential between gasoline and commercially available natural gas at about a 2 to 1 ratio, with tax incentives to bring the incremental costs down, this program may result in a rapid adoption of natural gas vehicles in the U.S..

3. ALTERNATIVE FUEL TRENDS IN THE U.S. FLEET

As mentioned earlier, ethanol is currently the most prominent alternative fuel in the United States with a production of approximately 900,000 barrels/day (b/d) [18] compared to a gasoline demand of approximately 9,000,000 barrels/day (b/d). The majority of ethanol is dispensed as a E10 (10 Vol-% blend of ethanol with gasoline). In addition there are approximately 2,400 E85 stations nationwide [19] compared to a total number of refueling stations in the United States of 167,800 [20]. In order to utilize higher level ethanol blends up to E85, manufacturers started introducing FlexFuel vehicles in the 1980s. In 2009 the FlexFuel fleet in the U.S. accounted for approximately 8.35 million vehicles [21]. However, the number of vehicles actually operated on E85 is only 450,000 [22]. Figure 7 shows the development of alternative fuel vehicles in use in the United States since 1995. While LPG was the dominant alternative fuel in 1995 with more than 170,000 units, this number dropped to approximately 150,000 units in 2008. In the same timeframe the number of CNG vehicles increased from approximately 50,000 units in 1995 to more than 110,000 units in 2008. As mentioned earlier, the number of E85 vehicles that are actually fueled with gasoline/ethanol blends was around 450,000 units in 2008, still making it the dominant alternative fuel in the U.S.. Methanol as an alternative fuel was fairly popular in the 1990s with a peak of more than 21,000 units in 1997. Although the number of hydrogen powered vehicles has been steadily increasing since 2003, their market share with slightly over 300 vehicles in 2008 was less than 0.05 % of all alternative fuel vehicles.

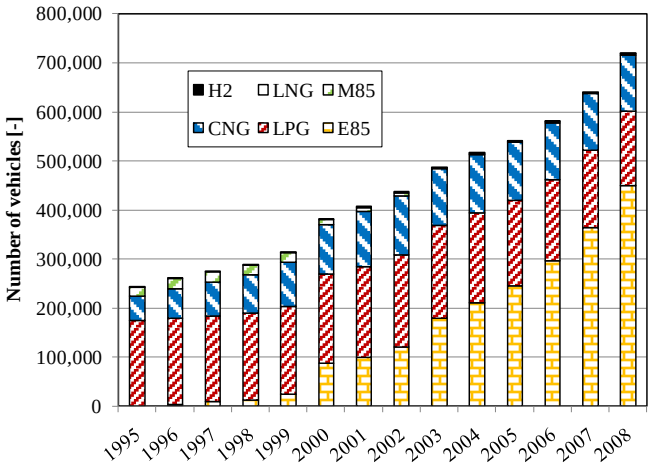

Figure 7: Alternative fuel vehicles in use in the U.S. (based on data by [22])

In 2009, the United States produced 17.7% of the world's biodiesel, making it the 2nd largest producer behind Europe. The biodiesel market is expected to grow in the U.S. over the next several years and is predicted to reach ~6,500 million liters (1,717 million gallons) by 2020. Biodiesel is considered a biomass-based diesel source and a minimum of 3.79 billion liters (1 billion gallons) must be produced by 2012. This is a 50% increase over 2010 production.

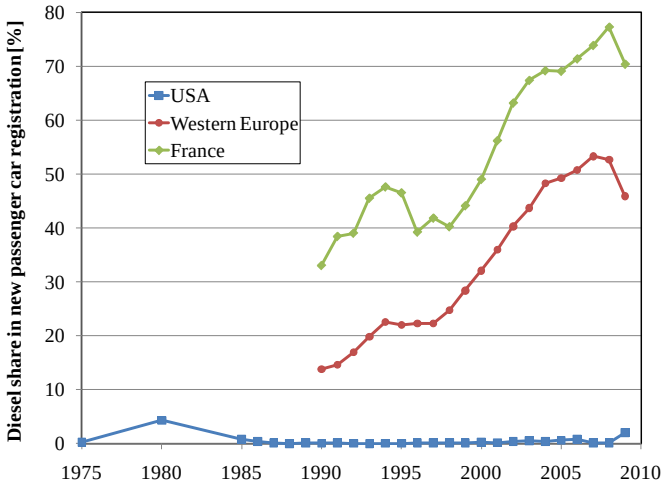

Figure 8: Share of diesel in new passenger car registration in Europe and the U.S.

However, the market share of diesel vehicles in the automotive sector is insignificant. Figure 8 compares the market share of new passenger vehicle registrations in the United States versus Western Europe and France in particular. The only significant numbers of diesel passenger cars sold in the U.S. were in the 1980s. At that time 80% of the cars Mercedes-Benz sold in the U.S. were diesel powered and General Motors sold diesel Oldsmobiles and Cadillacs. Despite the increased combustion noise, lack of performance and increased smoke emissions, customer acceptance was mainly based on economic advantages. With gas prices decreasing the interest in diesel vehicles disappeared and the only thing that remained was a bad public image. Despite some optimistic forecasts predicting increasing diesel share in the passenger car sector in the U.S., the numbers have only recently increased to slightly above 2% with a majority of the diesel vehicles sold by European manufacturers. At the same time the market share of diesel vehicles in Western Europe increased from approx. 15% in the early 1990s and reached a peak at over 50% in 2006. The market share in France is even further skewed towards diesel vehicles with a maximum of almost 80% in 2008.

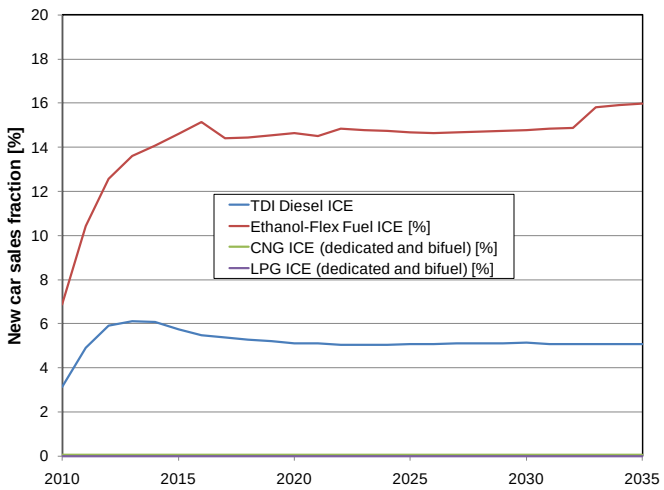

Figure 9: Predicted market share of alternative fuel cars (based on data by [23])

A prediction of market shares of alternative fuels by the U.S. Energy Information Administration is shown in Figure 9. The numbers shown are calculated based on the reference case prediction for passenger cars only (light-duty trucks are not included) until 2035. According to this forecast the fraction of FlexFuel vehicles will level out at approximately 15% market share in 2015. The prediction also suggests an increase in diesel vehicles in the passenger car segment that will level out at approximately 5% market share. It is further interesting to note that despite newly discovered natural gas reserves resulting in an 25% increase in natural gas production in the lower 48 states, compared to the 2010 forecast, the fraction of CNG and LPG vehicles will remain insignificant over the predicted timeframe. This is attributed mainly due to their high incremental cost and limited fuel infrastructure.

4. VEHICLE ELECTRIFICATION

Although advanced fuel-saving technology such as diesels have been slow to penetrate the U.S. market, hybrid-electric vehicles have been embraced as the principal “green” choice in automobile technology. Hybrids sold quickly to the market segment termed “early adopters,” starting in 2000, however in recent years it could be argued that sales have moved more into the mainstream market.

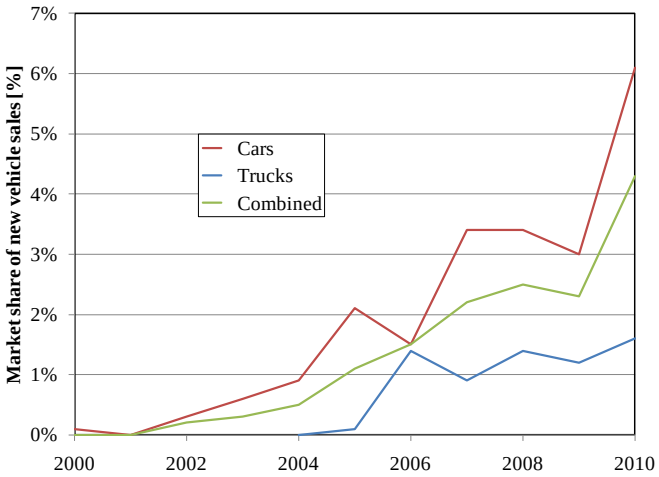

Figure 10: Market share of hybrid vehicles in the United States

From Figure 10, the percentage of vehicle sales in cars is 6%. Hybrid sales are constrained by the fact that not every manufacturer and not all vehicle market segments have a hybrid option. Although volatility in the economy and in the price of oil causes rises and falls in sales percentages, the trends are accelerating upward. It will be interesting to see the maturation point of the sales percentages of hybrid vehicles. Also, interesting will be as more PHEVs and BEVs become available, will these sales be additive, or cannibalize the hybrid sales as the early adopter segment moves on to the newest and most fuel-saving vehicle technologies.

A major goal of the current administration's energy policy is to have one million plug-in electric vehicles (PEVs) on the road by 2015. PEVs include both battery electric vehicles (BEVs) and PHEVs. Given the limited number of high-volume PEVs vehicles announced, meeting this goal would require very healthy sales of those vehicles that have been announced. A recent report from U.S. DOE has concluded that the goal is achievable and is not constrained by manufacturing capacity [24]. It is estimated that manufacturing capacity is over 1.2 million through 2015. Table 1 shows the supply of PEVs and may be optimistic. For example, if sales of a particular vehicle do not hit the targets in 2013, then they will not ramp up capacity to full, but to the level of demand.

Table 1: Estimated Supply of PEVs Through 2015 [24]

Estimated U.S. supply of PEVs from 2011-2015						
Manufacturer and model	**2011**	**2012**	**2013**	**2014**	**2015**	**Total**
Fisker Karma PHEV	1,000	5,000	10,000	10,000	10,000	36,000
Fisker Nina PHEV		5,000	40,000	75,000	75,000	195,000
Ford Focus EV		10,000	20,000	20,000	20,000	70,000
Ford Transit Connect EV	400	800	1,000	1,000	1,000	4,200
GM Chevrolet Volt	15,000	120,000	120,000	120,000	120,000	505,000
Navistar eStar EV (truck)	200	800	1,000	1,000	1,000	4,000
Nissan LEAF EV	25,000	25,000	50,000	100,000	100,000	300,000
Smith Electric Vehicles						
Newton EV (truck)	1,000	1,000	1,000	1,000	1,000	5,000
Tesla Motors Model S EV		5,000	10,000	20,000	20,000	55,000
Tesla Motors Roadster EV	1,000					1,000
Think City EV	2,000	5,000	10,000	20,000	20,000	57,000
Cumulative Total						**1,222,200**

Note: The above numbers have been taken from announced produciton figures and media reports. In some cases more conservate estimates have been used due to: delays that have occurred since

The Energy Information Agency has provided estimates of different technologies contingent upon future fuel economy regulations. Proposals for Corporate Average Fuel Economy (CAFE) requirements from 2017 to 2025 will range between two scenarios, "CAFE3" is a 3% annual rise in fuel economy and "CAFE6" is a 6% rise. The EIA projections estimate radical departures in vehicle technology mix from the reference case. The CAFE6 case would force the sales of hybrids, diesels and PHEVs in order to meet the high fuel economy requirements. Hybrids sales are shown rising from 5% to around 20%. Recalling earlier how electricity is treated in CAFE regulations, it is not a surprise that PHEVs are shown with the most profound changes in sales estimates with pressure due to the CAFE scenarios. CAFE6 case shows around 17% of sales from a very small 2% in the reference case. However, note that even with strong pressure exerted by CAFE6 for high MPG vehicles, sales of BEVs are shown not to exceed 7%. This reflects many the major barriers that BEVs have in displacing mainstream, fully-capable vehicles. Limited range, charging requirements and high cost will still be major obstacles in 2025.

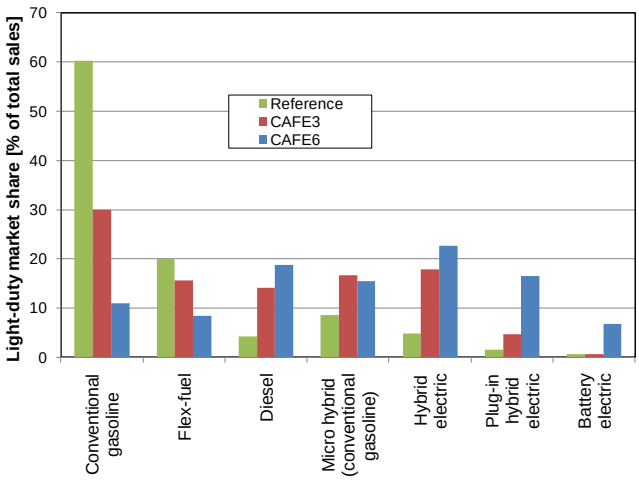

Figure 11: Projected market share of advanced vehicles in 2025 (based on [23])

5. BARRIERS AND CHALLENGES

5.1. Alternative Fuels

One major critical barrier for the large scale introduction of alternative fuels is the infrastructure. In order for consumers to be willing to switch to an alternative fuel, the supply infrastructure has to be sufficiently developed. The level of development can be gauged as a fraction compared to the number of conventional refueling stations. As mentioned earlier, there are almost 170,000 refueling stations in the United States. A study analyzing refueling infrastructure for the case of natural gas concluded that the critical fraction for consumer acceptance is between 10 and 30% [25]. In other words, for a nationwide introduction of an alternative fuel the number of stations has to exceed at least 17,000. The current nationwide count for stations dispensing alternative fuels is 2,589 for LPG, 2386 for E85, 1,296 electric charging stations, 889 CNG stations, 619 for biodiesel (B20), 58 for hydrogen and 44 for LNG [26]. The 10% target number is by far not met for any alternative fuel nationwide but regional station density varies significantly. Figure 12 shows the density of alternative fuel stations for E85, Propane, Hydrogen, CNG, Biodiesel and Electricity by state. Since corn for ethanol is produced mainly in the Midwest of the United States and transportation of ethanol is an issue by itself, the station density in Midwestern states such as Minnesota, Illinois, Missouri, Iowa, South Dakota and Wisconsin is significantly above the nationwide average.

With more than 500 stations Texas has the largest public LPG distribution infrastructure. Propane is a by-product of crude oil refining and natural gas refining with Texas being home to approx. 36% of the nations propane refining capacity [27]. Further, a $45M project partially funded by the U.S. Department of Energy that started in 2010 aims at deploying approx. 800 propane vehicles and installing or upgrading 35 propane fueling stations [28].

The only state with a significant number of hydrogen stations is California. Initial interest in hydrogen was sparked due to the ZEV mandate and the opportunity to meet those with hydrogen fuel cell vehicles which is promoted by the California Fuel Cell Partnership and the California Hydrogen Highway Network, an initiative in place to meet the demand of fuel cell and other hydrogen vehicle technologies that are being placed on California's roads. Currently stations are located in clusters in greater Los Angeles County, Orange County, Sacramento and the San Francisco Bay Area with plans to connect those areas with connector stations in the next phase.

California is also the state with the largest number of CNG stations. Development of a CNG refueling infrastructure has been closely linked to use of natural gas by transit authorities. The

California Natural Gas Vehicle Partnership (CNGVP), an alliance of air quality, transportation and energy agencies, vehicle and engine manufacturers, fuel providers, transit and refuse hauler associations, and other stakeholders, has been promoting increased deployment of natural gas vehicles in California. Further, the only OEM natural gas passenger vehicle currently available in the U.S., the Honda Civic GX has until now only been available for private sale in four states including California.

North Carolina is the state with the highest number of biodiesel (B20 or higher) stations in the nation. This might be partially attributable to Biodiesel Provider Credit, a law providing for a biodiesel provider credit equal to the per gallon excise tax the producer paid on the biodiesel. However, although North Carolina almost has 1/4 of the total number of B20 stations in the nation, the absolute number (139 stations) is far away from covering a significant fraction of the conventional fuel supply infrastructure.

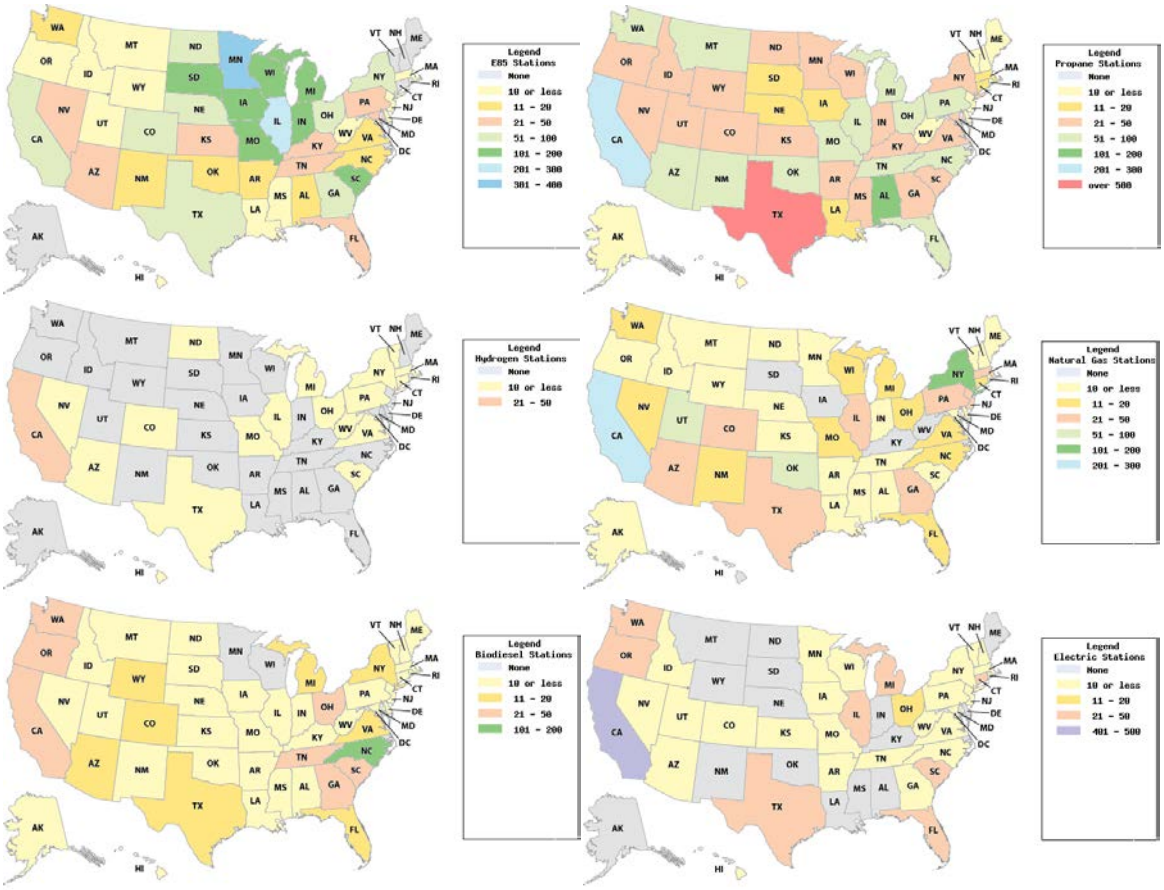

Figure 12: Overview of refueling stations for E85, Propane, Hydrogen, Natural Gas, Biodiesel and Electricity [26]

5.2. Plug-In Electric Vehicles

Lack of a suitable infrastructure is seen as a major barrier to wide scale and immediate deployment of electric vehicles. In Figure 12, existing electric vehicle charge stations are shown geographically in the U.S.. By far, California has invested the most in electric drive vehicles starting in the early 1990s. However, as discussed earlier, the generation of electric vehicles in the 1990s never saw significant sales. New vehicles and new charging standards are now being developed and deployed. With the new generation of PHEVs, electric infrastructure has expanded its scope. Industry and policy-makers did not want to see the same 1990s market failure reoccur, so major attention was given to deployment and demonstration activities for the current generation of PEVs.

Table 2: Major Plug-In Vehicle Deployment and Infrastructure Activities from ARRA Funding

Company	Award	Details
Electric Transportation Engineering Corporation	$ 114.8 M	*- Collect data from 7,500 Nissan Leaf BEVs and Chevy Volt PHEVs* *- Deploy 15,000 Level 2 charging stations, 250 Level 3* *- Full instrumentation of vehicles and infrastructure for analysis*
Chrysler, LLC$	48 M	*- Develop 140 PHEV Ram Pickups* *- Deploy in partner fleets across a wide range of climates, environments*
South Coast Air Quality Management District	$ 45.4 M	*- Development of a production PHEV system for Class 2-5 vehicles* *- Demonstration of 378 trucks through partner fleets*
Coulomb Technologies	$ 15 M	*- Deployment of ~4000 public and private charging stations in up to 9 cities*
Navistar	$ 39.2 M	*- Develop and deploy 950 battery electric trucks with 100 miles range*
Cascade Sierra Solution	$ 22.2 M	*- Deploy truck stop electrification at 50 sites along major US interstates*
General Motors	$ 30.5 M	*- Develop demonstrate 125 Chevy Volts for electric utilities,500 Volts to consumers*
Smith Electric Vehicle	$ 32 M	*- Develop and deploy up to 500 medium-duty electric trucks* *- Deploy in partner fleets across a wide range of climates, environments*

The American Recovery and Reinvestment Act dramatically increased funding for vehicle electrification in the United States and established numerous electric drive and infrastructure projects. Grants totaling $2 billion were awarded to establish advanced battery, power electronics, and motor manufacturing. Transportation electrification demonstration, infrastructure and education were awarded $400 million. There were 8 awards for grid-connected vehicle and infrastructure demonstrations; they are outlined in Table 2. The locations of the infrastructure projects are shown on a map of the U.S. in Figure 13. Data will be collected to do analysis. There are many questions about how plug-in vehicles will be used and how they will perform. Hot and cold conditions deteriorate expected range of all PEVs and in the case of PHEVs, how often they will be plugged in will have a direct impact on the amounts of petroleum usage that can be expected from this new technology. These programs leverage other research in communication standards and how they will integrate into tomorrow's "smart grid."

Figure 13: Deployment of Charging Infrastructure Projects in ARRA

An additional challenge unique to plug-in vehicles is developing appropriate test procedures and the difficulty in evaluating electricity as an alternative fuel compared to other fuels. Vehicle testing procedures have been developed for gasoline and diesel vehicles which are, without much adaptation, suitable for other alternative (combustion) fuels. Reporting efficiency for conventional alternative fuels can either be in terms of actual volumetric MPG, mass fuel per mile fuel, or with a heat-content-normalized MPG, called "MPGe." Whereas comparing one alternative fuel requires one to be mindful of the variations in fuel properties, consuming grid electricity in a PEV adds a host of new questions that must be addressed for PEVs to gain familiarity and acceptance. MPG was the sole efficiency metric that helped people compare different vehicles, but for PHEVs, normal use requires the use of both sources. Should they be combined or treated separately? Can we take the energy content of electricity and use it to calculate MPGe and compare it to gasoline MPG?

Because most electricity in the U.S. comes from burning fossil fuels, it would be misleading to suggest that PEVs achieve "0 g/mi CO2" when they consume grid electricity. And, unavoidable thermodynamic losses in the conversion process from fossil fuels to electricity result in a

misleading choice of providing PEV electric consumption in terms of MPGe. The test procedures must be modified and calculated to match the on-road experience as much as technically possible, and the metrics that are conveyed to the public will unavoidably be more complex. Consumer labels must address a vast array of concerns. A single MPG metric fails us in describing a PEV. Greenhouse gas emissions (tailpipe and upstream power plant), expected fuel costs, net petroleum usage, tailpipe smog emissions all must be addressed by an informative consumer label. However, information from the driver is also necessary to properly describe a PEV. Driver aggressiveness, average daily driving distances (before recharge), where they live (local grid CO2 intensity) all affect the final impact of a particular PEV. Comparing one advanced technology to another effectively may have to include an interactive website to address all the concerns and find a best match in technology to a particular user.

6. SUMMARY AND CONCLUSIONS

As for many other nations around the globe, fossil fuel consumption and related greenhouse gas emissions also present a major concern for the United States. While questions of national security and dependence on foreign sources are the major driver in the U.S., environmental concerns are also being considered. Significantly lower fuel prices compared to Europe present a hurdle for alternatives to enter the market place. The dominant drivers that will increase the U.S. production and consumption of alternative fuels are the Renewable Fuels Standards, which mandate an almost fourfold increase in production of alternative fuels by 2022 compared to the 2008 level. Corporate Average Fuel Economy (CAFE) mandates require significant improvements in fleet fuel economy until 2016 with extended CAFE standards until 2025 currently in discussion. The current CAFE regulations also consider the vehicle size based on a footprint calculation. Ethanol, mainly in form of blends of 10 Vol-% ethanol in gasoline, presents the most widely used alternative fuel in the U.S.. Other significantly less prominent alternative fuels include E85, propane, CNG, biodiesel and hydrogen with their refueling infrastructure as the dominant barrier for large scale utilization. Vehicle electrification is one of the major trends in the U.S. automotive with hybrids at a market share above 4% in the combined passenger car and truck market. Based on announced production numbers the Presidential Initiative to have over 1 million plug-in electric vehicles on the road by 2015 appears feasible. This initiative is further supported by major investments in vehicle deployment and infrastructure upgrades partially funded through the American Recovery and Reinvestment Act. A 2025 projection of light-duty market shares by the U.S. Energy Information Administration still predicts a 60% market share of vehicle sales for conventional gasoline vehicles in the reference case. Under a CAFE6 scenario requiring a 6% annual fuel economy improvement the market share of conventional gasoline vehicles is expected to drop to approx. 10% with significant increase in hybrid and plug-in hybrid vehicles while battery-electric vehicle market shares are still expected to be below 7%.

7. ACKNOWLEDGMENTS

The submitted manuscript has been created by UChicago Argonne, LLC, Operator of Argonne National Laboratory (“Argonne”). Argonne, a U.S. Department of Energy Office of Science laboratory, is operated under Contract No. DE-AC02-06CH11357. The U.S. Government retains for itself, and others acting on its behalf, a paid-up nonexclusive, irrevocable worldwide license in said article to reproduce, prepare derivative works, distribute copies to the public, and perform publicly and display publicly, by or on behalf of the Government.

8. REFERENCES

[1] Pew Research Center's Global Attitudes Project. 2010. http://pewglobal.org/

[2] U.S. Energy Information Administration (EIA), 'Annual Energy Review 2009', DOE/EIA-0384(2009).

[3] International Energy Agency, 'Technology Roadmap - Biofuels for Transportation', 2011.

[4] U.S. EIA, 'Annual Energy Outlook 2010', DOE/EIA-0383(2010).

[5] www.eia.gov 'Retail Gasoline Historical Prices'

[6] www.statistika.de 'Durchschnittlicher Preis für Superbenzin von 1972 bis 2011 in Cent/Liter'

[7] Section 201-202 Renewable Fuel Standard (RFS) Energy Independence and Security Act of 2007 (Pub.L. 110-140, originally named the CLEAN Energy Act of 2007).

[8] Schnepf R, Yacobucci B. Renewable Fuel Standard (RFS): Overview and Issues. CRS Report for Congress. Order Code R40155. 2010.

[9] U.S. Environmental Protection Agency (EPA). Regulation of Fuels and Fuel Additives; Definition of Substantially Similar. [FRL-3856-9]

[10] www.faqs.org/faqs/autos/gasoline-faq/part1/section-4.html

[11] www.epa.gov/otaq/regs/fuels/additive/e15/420f10054.htm

[12] National Highway Traffic Safety Administration (NHTSA) website

[13] U.S. Code of Federal Regulations 10 CFR 474.5 - Electric and hybrid vehicle research, development, and demonstration program; petroleum - equivalent fuel economy calculation.

[14] Federal Register / Vol. 75, No. 88. Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards; Final Rule. 2010.

[15] Federal Register /Vol. 75, No. 235. 2017 and Later Model Year Light-Duty Vehicle GHG Emissions and CAFE Standards: upplemental Notice of Intent. 2010.

[16] U.S. Census Bureau, Statistical Abstract of the United States: 2011

[17] Delphi. Worldwide Emissions Standards, Passenger cars and light-duty vehicles, 2011-12

[18] U.S. EIA. Weekly Ethanol Plant Production. http://www.eia.gov/dnav/pet/PET_PNP_WPRODE_S1_W.htm

[19] U.S. Department of Energy. Alternative Fueling Station Total Counts by State and Fuel Type. Updated 5/31/2011. http://www.afdc.energy.gov/afdc/fuels/stations_counts.html

[20] United States Department of Agriculture, News Release No. 0158.11, April 8, 2011

[21] U.S. EIA. Annual Survey of Alternative Fuel Vehicle Suppliers and Users," as reported in "Alternatives to Traditional Transportation Fuels" 1998-2008 reports (Tables 14 or S1 depending on year of report).

[22] U.S. EIA Alternatives to Traditional Transportation Fuels, Table V1. Available at www.eia.doe.gov/cneaf/alternate/page/atftables/afv-atf2008.pdf

[23] U.S. EIA, 'Annual Energy Outlook 2011', DOE/EIA-0383(2011).

[24] U.S. Department of Energy (DOE). Feb. 2011 Status Report One Million Electric Vehicles By 2015

[25] Yeh, S. 'An empirical analysis on the adoption of alternative fuel vehicles: The case of natural gas vehicles'. Energy Policy 35 (2007) 5865–587

[26] U.S. DOE Website. http://www.afdc.energy.gov/afdc/fuels/stations_maps.html

[27] Energy Environmental Analysis, Inc. 'Study of the Propane Industry's Impact on U.S. and State Economics'. 2004.

[28] Ball, H. 'Texas Propane Vehicle Pilot ProjectProject.' Presentation at the 2011 U.S. Department of Energy (DOE) Hydrogen and Fuel Cells Program and Vehicle Technologies Program Annual Merit Review and Peer Evaluation Meeting (AMR)