A MODEL AND OPTIMIZATION OF ALTERNATIVE FUEL VEHICLE FLEET COMPOSITION WITH TRIPLE BOTTOM LINE CONCERNS

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A MODEL AND OPTIMIZATION OF ALTERNATIVE FUEL VEHICLE FLEET COMPOSITION WITH TRIPLE BOTTOM LINE CONCERNS

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To Joseph G. Wilburn, Benedict Zullo, and Jeffrey J. Zullo for establishing the Ramblin' Wreck tradition

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LIST OF SYMBOLS AND ABBREVIATIONS

ICE	Internal Combustion Engine
EIA	Energy Information Administration
EPA	Environmental Protection Agency
NGO	Non-Governmental Organizations
AFV	Alternative Fuel Vehicle
CDP	Carbon Disclosure Project
CSR	Corporate Social Responsibility
SEAAR	Social and Ethical Accounting, Auditing, and Reporting
GRI	Global Reporting Initiative
ISO	International Organization for Standardization
CNG	Compressed Natural Gas
VMT	Vehicle Miles Traveled
GREET	Greenhouse gas, Regulated Emissions, and Energy use in Transportation
WTW	Well-to-Wheel
WTP	Well-to-Pump
PTW	Pump-to-Wheel
PHEV	Plug-in Hybrid Electric Vehicle
ISO	Independent System Operator
GHG	Greenhouse Gases
BEV	Battery Electric Vehicle
WTA	Withdrawals to Hydrological Availability
OEM	Original Equipment Manufacturer
HEV	Hybrid Electric Vehicle

E-450	Ford Motor Company Econoline 450
gge	gallons of gasoline equivalent
LPG	Liquefied Petroleum Gas
FFV	Flexible Fuel Vehicle
E85	Ethanol Blend (85% ethanol, 15% gasoline)
V2G	Vehicle-to-Grid
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
PADD	Petroleum Administration for Defense Districts
OPEC	Organization of Petroleum Exporting Countries
RMCP	Regulation Market Clearing Price
USDA	United States Department of Agriculture

SUMMARY

There is a growing demand to reduce dependence on the current petroleum and internal combustion engine (ICE) based transportation network. A variety of alternative technologies and fuel sources are being championed as potential solutions to this challenge of changing the status quo. However, each alternative faces its own set of drawbacks that may limit the effectiveness of its use from technology immaturity to inadequate performance. These limitations make the typical consumer wary of making the sizeable commitment to a new vehicle with so many unknowns. Corporate fleet consumers, on the other hand, are more systematic customers who are more capable of taking into account the lifecycle costs of new purchases. The choice of alternative fueled vehicles is aided by companies' additional concerns of public perception and corporate stewardship.

The idea of corporate stewardship or corporate citizenship refers to the role of a company beyond the confines of their business practice to also include the corporation's responsibility towards society. This principle has begun to be accounted for in decision-making by defining a triple bottom line of financial, environmental, and societal aspects. The triple bottom line outlines the respective decision's effects on not only the financial position of the company but also the environment and society. The difficulty in applying the triple bottom line is in the quantification of environmental and societal impact. Without understanding the implications of the decision criteria, it is impossible to accurately compute and therefore select a truly profitable triple bottom line.

This thesis takes into account the various parameters for selecting a transportation fleet through triple bottom line methodology. The financial concerns are straightforward and include the various costs and potential revenues throughout the lifecycle of the project. Due to their prominence in the public consciousness as sustainable imperatives, the two major environmental themes examined are climate change and water scarcity. These trends are quantified through the greenhouse gas emissions and water consumption of the fleet. Furthermore, the social aspect is examined through the population health impact and other social parameters. These topics are quantified through modeling to provide a numeric representation of the triple bottom line for each respective alternative. The alternatives are then optimized using utility theory under three separate scenarios of corporate preference. The scenarios capture the range of priorities of companies that include the capitalistic corporation that is purely concerned with financial performance, the corporate steward that is immensely concerned with external impacts, and finally the typical corporation that is primarily interested in financial performance but also sees benefits in the positive public perception. By utility preference elicitation of these different scenarios, it is possible to provide an optimization of the selection criteria for the respective company’s transportation fleet fuel type composition. The outcomes of these scenarios are then tested against different sensitivity analyses for effect on the outcome for different locals and different fleet operating specifications.

In all, this thesis outlines how the emerging issues of environmental and social awareness influence the traditional financial comparisons of different fuel types in fleet vehicle applications. An intuitive model will allow novice users to easily modify different parameters to provide perspective during real-life fleet composition decisions.

The greatest strength of the model is the ability to alter these parameters and to understand both the variability and the importance of examining every scenario individually. Different case studies provide an opportunity to visualize how this model could be incorporated into the decision-making process of different types of companies. This shows that both the direct impacts of a fleet and the motivating desires of a company play a role in the final fleet composition.

CHAPTER 1

INTRODUCTION

1.1 Motivation and Background

Currently, there is a growing demand for ways to reduce the national transportation network's dependence on petroleum. Global oil reserves are primarily located in the Middle East with 51% of the global oil reserves; a region that has a history of instability and is currently the origin of a number of international conflicts and political unrest (EIA 2011). This instability puts the national security at risk since a disruption in the supply of oil would have far reaching consequences in the global economy. Moreover, the rapidly growing global gross domestic product continuously increases oil consumption, while the discoveries of new oil have comparatively slowed. A significantly expanding strain on oil reserves is the economic expansion of large developing countries such as Brazil, India, and China. The industrialization of these countries has created a new strain on the global oil supply in addition to the increasing oil demand from the developed United States and European Union economies. The Energy Information Administration (EIA) projects that the world liquids consumption will increase from 85.7 million barrels per day in 2008 to 97.6 million barrels per day in 2020 and to 112.2 million barrels per day in 2035 (EIA 2011).

Meanwhile, the global transportation network's demand for liquid fuels is projected to increase more rapidly over the next 25 years than any other end-use sector, accounting for 80% of the world consumption (EIA 2011). In 2009 this consumption in the transportation sector contributed 34.1% of the U.S. energy-related carbon dioxide emissions, approximately 1.8 trillion metric tons carbon dioxide. The environmental impact on global warming and pollution by the world's gasoline based auto industry has increased the support for the advancement of an alternative fuel source. These three major issues of national policy, oil supply depletion, and environmental impact show that an alternative fuel source would help alleviate some of the most critical national and global concerns.

1.1.1 Water Scarcity

Another emerging environmental issue is the extreme water scarcity that is affecting areas all over the world. The real challenge with water scarcity, in contrast to climate change, is that it must be addressed on the local level. Therefore, mass legislation may be applicable for controlling water quality concerns but is ineffective for matters of water quantity. Water use has been growing at more than twice the rate of population growth in the last century with increasing economic progress (UN 2006). This water use increase along with climate change has caused increasing water scarcity concerns. The United Nations defines water scarcity as "the point at which the aggregate impact of all users impinges on the supply or quality of water…to the extent that the demand by all sectors, including the environmental cannot be satisfied fully" (UN 2006). Once a region has entered a state of water scarcity, it is difficult to escape since although it can be rationed, water is essential for nearly all purposes from agriculture to energy production and even everyday living. By 2025, it is projected that 1.8 billion people will be living in regions of absolute water scarcity, and two-thirds of the world population could be under stress conditions (UN 2006). When essential resources are limited, there is bound to be conflict among neighboring regions.

Water Scarcity and Transportation

There is a great deal of discussion into the ramifications of combusting petroleum fuels due to the emissions of greenhouse gases, but the link between water and transportation is often an overlooked relationship. The use of water in extraction and processing of fuel is ignored since it is often not realized in comparison to the direct tailpipe emissions. However, a shift towards lower emission fuel sources could increase the water-intensity of the transportation sector and thus significantly impact the U.S. water resources. Agriculture is the largest user of water and accounts for 70% of freshwater withdrawals from rivers, lakes, and aquifers (UN 2010). Meanwhile, thermoelectric power generation is also a large user of electricity, primarily for cooling, and is responsible for approximately 49% of total freshwater withdrawals in the United States (Scown 2011). Electric vehicles and the use of biofuels are projected to grow through legislative incentives and market demand. This new transportation composition may lead to further strains on local water resources.

1.1.2 Corporate Responsibility

A corporation's role in society has been shifting from being exclusively a financial organization and employer towards actively assisting in the wellbeing of not only their employees but also their community as a whole. This concern towards society and the environment is a stark contrast to the past, when flagrant pollution and a disregard for public safety were rampant throughout America. In 1970 a shift in the public's perception of environmental issues occurred through the formation of the Environmental Protection Agency (EPA) and the enactment of the Clean Air Act. Some believed that economic growth and environmental protection were mutually exclusive goals, as during House floor debates in 1970 a mayor was quoted as saying “If you want this town to grow, it has got to stink” (Rogers 1990). However, the overall sentiment was that the environment and business not only could, but had to, coexist as was shown in the ratification of the Clean Water Act in 1972, another landmark legislative act aimed at protecting public health through restoring the natural environment.

The awakening of the public conscious towards matters of environmental pollution put the at-fault corporations susceptible to serious ramifications. Corporations were not only liable for significant financial fines from the EPA but also faced a public relations nightmare from the media and non-governmental organizations (NGOs). Over the years, corporations have realized the opportunity present in not only risk avoidance but also the increase in brand reputation of community engagement and environmental sustainability initiatives. Today, this view has further developed in the transportation sector with the establishment of the National Clean Fleets Partnership, a collaboration of the Department of Energy and large fleets throughout the country, in an effort to explore and adopt alternative fuels and fuel economy measure to reduce petroleum use.

1.2 Consumers’ Misperceptions

The main drawback of alternative technologies is that, due to either more advanced or additional components, the upfront purchase cost is often a great deal higher than that of an equivalent traditional vehicle. Although this difference can be augmented through legislative incentives, it is most often a reduced operating cost that leads to an advantageous economic proposition for alternative fuel vehicles. This is a challenge for alternative fuels since consumers have a difficult time understanding the savings presented through reduced operating cost for transportation.

Research has shown that consumers consistently overvalue fuel economy relative to its expected present value. Greene suggests that “consumers expect fuel savings to increase linearly with miles per gallon, leading to overvaluing of fuel economy increases for high mpg vehicles relative to lower mpg vehicle” (Greene 2010). The nonlinear behavior inherent to the miles per gallon measurement of fuel economy leaves consumers valuing the transition from 5 mpg to 10 mpg the same as a transition from 25 mpg to 30 mpg. This is a hazardous misunderstanding as the former transition saves almost 15 times more fuel than the latter.

This illusion has been shown to impact not only the average consumer but even transportation professionals, who are responsible for design and implementation of transportation policy. Rowan et al. prepared two sets of surveys for groups of transportation professionals with the same following prompt: “A town maintains a fleet of vehicles for town employee use. It has two types of vehicles. Type A gets 15 miles per gallon. Type B gets 30 miles per gallon. The town has 100 Type A vehicles and 100 Type B vehicles. Each car in the fleet is driven 10,000 miles per year. The town’s goal is to reduce gas consumption and thereby reduce harmful environmental consequences. Choose the best plan for replacing the vehicles with corresponding hybrid models” (Rowan 2010). For respondents that were provided the choices in miles per gallon only 36% chose the correct option that represented the greatest fuel savings. Meanwhile within respondents given the gallons per mile options, 71% chose the correct option. Even the transportation professionals responsible for guiding future policy can be misled by the intuition of fuel economy when comparing alternatives of the same fuel type.

In an attempt to combat this phenomenon and educate the consumer, the EPA has attempted to make comparisons of different fuel economies simpler by changing the requirements for the fuel economy label on new vehicles. The new label will not only communicate the traditional fuel economy in miles per gallon but also the gallons per 100 miles, the annual fuel cost, the amount saved over 5 years compared to the average new vehicle, a fuel economy and greenhouse gas tailpipe rating, and a smog tailpipe rating. Additionally with the growth of electric vehicles, a label for alternative vehicles has been designed that presents the miles per gasoline gallon equivalent rating as well as the driving range and charging time, if appropriate. These developments may help with the consumer misperception of operating cost savings through fuel economy, but there are other factors such as unfamiliarity with the technology, inadequate refueling stations, and range anxiety that will hamper the direct comparisons of different technologies.

1.2.1 Fleet Consumer Opportunities

Fleet consumers must be much more fiscally conscious of the operating expenses, due to the need to maintain budgets and provide financial justification during the decision-making process. This understanding of the potential savings makes alternative fuels a more attractive option for fleet customers. Some fleets are also well equipped to handle alternative fuels because of their high mileage and dedicated routes. These dedicated routes are conducive to central fueling stations. A central fueling station reduces the range anxiety concerns and provides a reliable refueling location. Meanwhile, the usual high mileage of the fleet results in large quantities of fuel being consumed, which in turn translates to significant fuel cost savings. Therefore, a number of the most pervasive challenges for the adoption of alternative fuels are alleviated by the very nature of the fleet consumer.

1.3 Research Questions and Hypothesis

The previous sections outline that despite recent increased focus on environmental issues in the transportation section, there seems to be a lack of application of the available knowledge outside of policy based decisions. Currently the work on water consumption in transportation focuses on obtaining a life-cycle inventory of water consumption rather than an analysis of the impact of this water consumption. This situation leads to the central foundation of this thesis of developing a tool to analyze these topics to provide a quantification of the impact of transportation with the following central research question:

How can the impact of fleet fuel type be modeled to provide an analysis of the financial, environmental, and societal impacts of different fleet scenarios?

Developing a model provides a quantification of the impact, but the next step is the extent that the model can be constructively applied to help solve a problem. With the developments of corporate stewardship, the extraneous impacts of business decisions must be taken into account during the decision-making process. Without sufficient information, the decision-maker must make an uninformed decisions based upon common knowledge and assumptions, which may lead to deficient results. This leads to the following question:

Would developing a decision-making tool provide fleet customers with the ability to understand the triple bottom line impact of their decision?

The role of the decision-making tool is to provide an optimization of the fleet composition for not every potential customer but rather offer the optimal results for the specific firm's preferences. Some firms would be focused more on the financials, while others would be concerned with the environmental and social aspects of their fleet. Together, this provides the overriding hypothesis for the thesis:

Through the elicitation of preferences, utility theory can be utilized to provide an optimization of the fleet fuel type composition based on triple bottom line concerns of a company.

Additionally, the same fleet customer would not have the same results in different settings due to a variety of factors. In particular, the impact of water consumption is highly location dependent as the same water consumed in water scarce region would have substantially more impact than in a region that had abundant water resources. The specific fleet operating conditions would impact the results of the analysis as the distance that the fleet travels provides the majority of the environmental and social benefits for alternative fuel vehicles. Therefore, the second hypothesis is that:

The geographic location of a fleet and the distance traveled greatly influence the outputs of optimization of the fleet composition based on triple bottom line concerns.

CHAPTER 2

LITERATURE REVIEW

2.1 Alternative Technologies and Fuel Sources

The development of alternative fuels faces a variety of challenges in replacing the internal combustion engine (ICE) in the transportation network as it has become the foundation of a global economy that relies on petroleum. Alternative fuels, in general, are emerging technologies that have both high costs and low functionality compared to ICEs. Struben et al declare that "Internal combustion, the auto, and cheap oil transformed the world, economically, culturally, and environmentally. Today, motivated by environmental pressures and rising energy prices, another transition, away from fossil –power ICE vehicles, is needed" (Struben 2008). Struben et al. detailed these challenges through a dynamic behavioral model that explores the transition from ICE to alternative fuel vehicles (AFVs). This model takes into account not only the innovation adoption criteria such as word of mouth, social exposure, and the willingness of consumers to consider these alternative platforms but also the feedback influences of the various evolutions of technology. However, due to the fact that gasoline is priced below the level that reflects the environmental and other negative externalities, AFVs would have difficulty in overcoming the barriers necessary to achieve self-sustaining adoption. The main concern is the typical consumer choice that takes into account the role that transportation has as a source of personal identify and social status. This type of dynamics of market formation causes Streuben to argue "that self-sustaining adoption would be difficult even if AFV performance equaled that of ICE today" (Struben 2008).

This challenge of the individual consumer is much different to the fleet customer, who has a much different set of motivating factors. Fleet consumers make business decisions based on a more rigorous decision process. The benefits in reducing operating costs through the use of alternative technologies are better understood in financial costing of fleets. Additionally, fleets often serve a dual purpose of promoting a company's image of environmental concern to their consumers.

2.2 Triple Bottom Line Methodology

Triple bottom line refers to the idea that the success and performance of a firm should not be measured by only the traditional bottom line of financial performance but also by the social and environmental implications of the various decisions. The term "Triple Bottom Line" has most often been linked to John Elkington's *Cannibals With Forks: The Triple Bottom Line of 21st Century Business* and has grown in prominence to the point where major corporations often measure and report various metrics from the two additional bottom lines (Norman 2004). Most often companies have chosen to report their performance to their stakeholders through annual sustainability reports that usually chronicle the company's efforts to promote ethical business practices, reduce environmental impact, and present various metrics used to measure their performance in carbon and water use reduction. Furthermore, operations such as the Carbon Disclosure Project (CDP) provide firms with the ability to gain third-party validation for their strategies and performances. The CDP is a voluntary reporting system for companies concerning greenhouse gas emissions, water management, and climate change strategies for a group of 551 institutional investors with $71 trillion in managing assets (CDP 2012). This reporting mechanism provides an incentive for companies to disclose their performance in these fields in order to be a more attractive company to potential investors.

These claims of environmental and social performance are often more than just wordplay to the consumer as investors become increasingly conscious of these factors. Additionally, there are both financial and regulatory risks that can be avoided by making decisions that take into account more than just the direct profits and expenses of a project. These regulatory risks associated with environmental factors could be mitigated by including the environmental performance in the decision making process. For example, in Ford Motor Company's annual 10-K filing to the Securities and Exchange Commission, Ford states that "Governmental regulation has arisen, and proposals for additional regulation are advanced, primarily out of concern for the environment (including concerns about the possibility of global climate change and its impact), vehicle safety, and energy independence…The cost to comply with existing governmental regulations is substantial, and future, additional regulations (already enacted, adopted or proposed) could have a substantial adverse impact on our financial condition and results of operations." (Ford 2010). The main theme of triple bottom line is that financial, social, and environmental performance should be objectively measured and these metrics should be used to improve future performance. There is also a degree of transparency encouraged in the triple bottom line methodology as firms have the obligation to disclose to stakeholders the performance in these categories. Through the application of this principle, it is believed that firms will tend to be more financially profitable in the long run.

Norman et al. discuss the fact that Triple Bottom Line is not a novel approach and that the principles of triple bottom line are somewhat synonymous with corporate social responsibility (CSR). Additionally, the emphasis on measurement and reporting has been a component of SEAAR: social and ethical accounting, auditing and reporting. The SEAAR movement has been responsible for several standards including the Global Reporting Initiative (GRI), the SA 8000 from Social Accountability International, the AA 1000 from AccountAbility, and various ISO standards (Norman 2004). These types of standards provide auditing guidelines for reporting of social and environmental performance by providing metric and indicators. Norman et al. claim that it is difficult to establish a true baseline metric or compare various metrics of social performance since there so many different spectrums to consider. For instance, considering some SEAAR criteria of a firm such as percentage of female directors, percentage of senior management that are minorities, charitable donations, and annual turnover; it is difficult to conceptualize how these diverse metrics would be aggregated into a single social bottom line. Norman et al. go on to detail how the scaling or weighting of the social metrics of a firm is a daunting task and that it is impossible to say what positive aspects outweigh the negative aspects.

One of Norman's main arguments is that the triple bottom line approach is not novel since companies already take into account social and environmental impacts as "the information that goes into any report or calculation of a triple-bottom-line already figured in the deliberations of strategic plans and line managers even in the most 'single-bottom-line'-oriented corporations" (Norman 2004). However, this argument avoids the fact that although some of the information may be considered, it is often in a more qualitative sense by the management. Without an expertise in the subject matter, the management may consider qualitatively what they believe are the various impacts of a decision. In retrospect, it is very likely that the manager has some misconceptions about the specifics of the various environmental and social aspects. By providing a quantitative assessment of the environmental and social aspects, the manager is able to make a more informed decision than before even if some of the aspects are not fully examined.

The *MIT Sloan Management Review* and the Boston Consulting Group conducted a Sustainability & Innovation survey of global corporate leaders to understand the corporate commitments to sustainability-driven management. This survey revealed the finding that some companies – the embracers – believe that sustainability is already a "core" of business, while others – the cautious adopters – have the view that sustainability will eventually become a core area of business. The report states that "companies still struggle to measure financially the more intangible business benefits of sustainability strategies"(BCG 2011). However, there is a difference with the embracer companies, which "are implementing sustainability-driven strategies in their organization and have largely succeeded in making robust business cases for their investments" (BCG 2011). Figure 2.1 presents the comparison between these embracers and cautious adopters on what considerations should be included within sustainability. In the survey, a level of 1 corresponds to "not at all", while a level of 5 stands for "to a great extent".

Figure 2.1 Comparison of Sustainability Considerations (BCG 2011)

Obviously, the economic well-being of the corporation is the most important factor as this ensures the longevity of the company. Beyond the financial, there are a variety of issues of importance that may be associated with the growing external pressures. This type of analysis shows that not only do companies have varying views of the importance of sustainability, but companies have varying definitions of what sustainability entails. This may be primarily due to the extent that companies feel that sustainability has an impact on profitability and the perceived benefits of decisions. Another comparison between embracers and cautious adopters in Figure 2.2 shows the perceived benefits attained from sustainability initiatives.

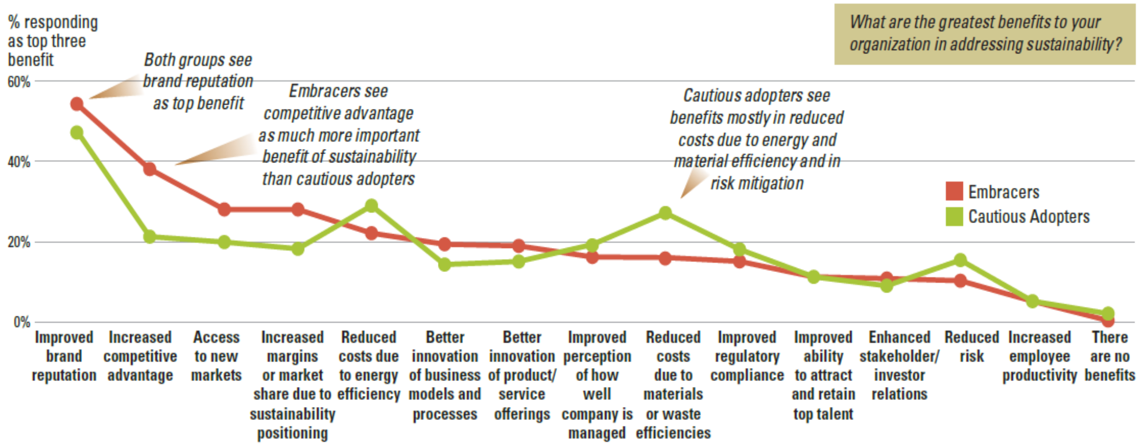


Figure 2.2 Comparison of Perceived Sustainability Benefits (BCG 2011)

2.3 Financial Implications

The use of alternative fuels for fleet operations is not a novel application, and potential benefits and drawbacks have been examined before. For example, Johnson has provided an extensive business case analysis for compressed natural gas (CNG) in Municipal fleets through analyzing project profitability depending on various fleet-operating parameters (Johnson 2010). Transit, School, and Refuse fleets were considered in constructing a model to analyze the payback period for a fleet as a function of the number of buses. Also considered in the cost of the fleet was the CNG refueling station cost, which was analyzed as a function of the throughput of monthly gas. Johnson's model, the CNG Vehicle and Infrastructure Cash-Flow Evaluation (VICE), provides a relationship between project profitability and fleet operating parameters. The VICE model emphasizes the variability of project performance depending on the specific scenarios parameters. An interesting aspect of Johnson's payback period analysis is the dependence of fuel cost on the number of miles driven and the number of vehicles in the fleet. Around 10,000 vehicle miles traveled (VMT) the project break-even point has an inflection point that before is more sensitive to VMT changes and after is more sensitive to changes in the number of vehicles as presented in Figure 2.3.

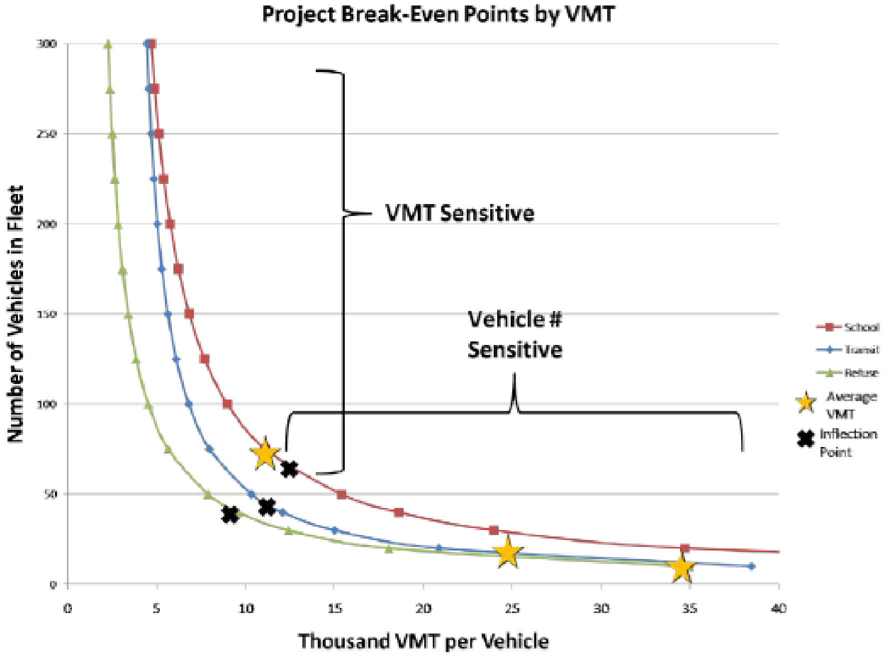


Figure 2.3 CNG Project Break-even Points by VMT (Johnson 2010)

2.4 Environmental Implications

Other works have focused on alternative fuel vehicles and their environmental mitigation potential in reducing greenhouse emissions. For example, Ogden et al. investigated the societal lifecycle costs of cars with alternative fuels that included not only the financials of the initial purchase cost and fuel cost but also the externality costs of oil supply security and damages of polluting emissions and greenhouse gases (Ogden 2004). Some research has also focused on water consumption. For example, Scown described the water requirements for different fuel productions by constructing a life-cycle inventory and also detailing a potential methodology for including impact of the particular water consumption (Scown 2011).

2.4.1 Greenhouse Gas Emissions

The most established resources for emissions in the transportation sector are the Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET) model. This model was developed by the Argonne National Laboratory as a continuously updating resource to evaluate different various vehicle technologies on a life-cycle basis. GREET evaluates the technology on a fuel-cycle, GREET 1 series, and a vehicle-cycle, GREET 2 series, to provide for a comprehensive life-cycle analysis. GREET 1 series calculate energy consumption, greenhouse gas emissions, and emissions of five criteria pollutants. The fuel-cycle also termed a well-to-wheel (WTW) analysis consists of the two primary stages. The initial stage is termed the upstream stage or well-to-pump (WTP) consists of the feedstock and fuel stage. The final stage consists of everything during vehicle operation and is termed the pump-to-wheel (PTW) or tailpipe stage. Figure 2.4 presents the stages and activities included in a GREET simulation of a fuel-cycle.

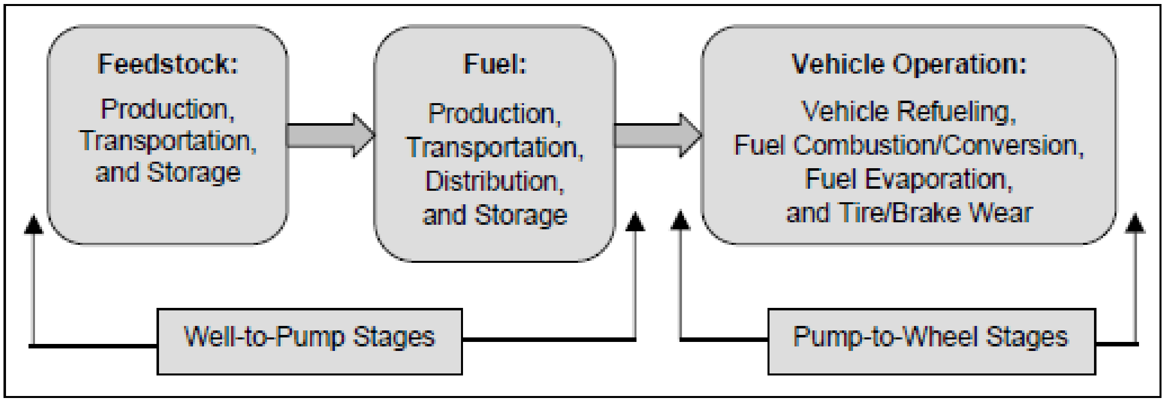


Figure 2.4 Stages Covered in GREET Fuel-Cycle Analysis (Wang 2001)

The model is appropriate for analysis of scenarios based in the United States due to being developed with assumptions reflecting U.S. fuel production. There are a number of different feedstock and fuel types included within the fuel-cycle analysis to provide for convenient comparison of the impact of different technologies. Figure 2.5 presents the more than 100 fuel pathways from various energy feedstock sources.

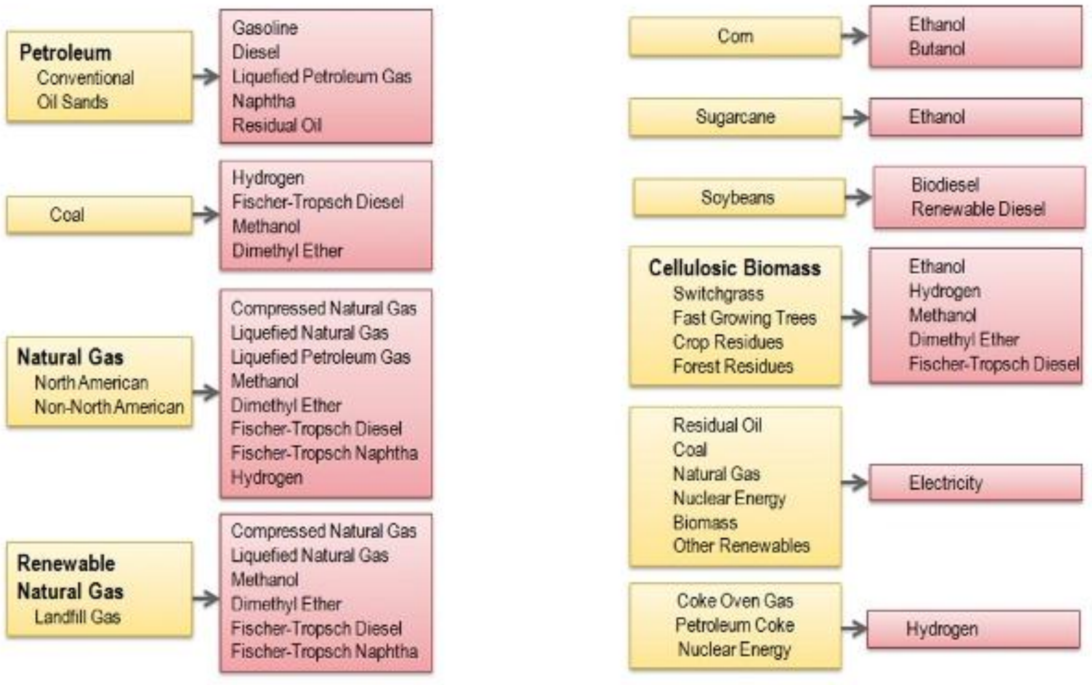


Figure 2.5 GREET Model Fuel Pathways (DOE 2011)

GREET Model Application

Elgowainy et al. used the GREET model in order to analyze the WTW energy use and greenhouse gas emissions of plug-in hybrid electric vehicles (PHEVs). Included in their analysis are the factors affecting the generation mix for electric vehicle charging including time of day, time of year, geographic region, vehicle, charger, load growth patterns, and generation expansion. For example, Figure 2.6 presents the peaks of demand for typical summer day and the additional generating unit’s source.

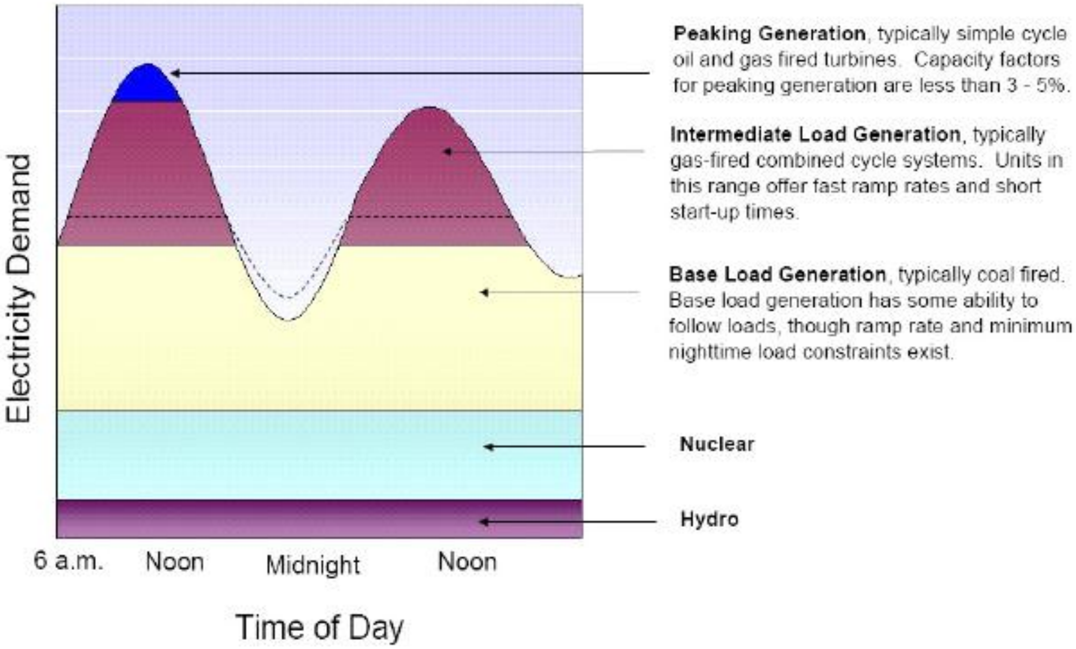


Figure 2.6 Typical Summer Load Profile and Dispatch Scheme in the U.S. Utilities (Shelby 2007)

The analysis of electric power systems was divided by the independent system operator regions of the United States including the New England Independent System Operator (NE ISO), the New York Independent System Operator (NY ISO), the state of Illinois, and the Western Electric Coordinating Council (WECC). Their electric power generation modeling encompassed simulating the electric profile of each region on hourly generation basis and projecting the future state of the grid in 2020. Also included were the transmission and distribution losses by region to determine the load that the electric system had to serve.

The GREET model was then used to calculate the WTW emissions by tracking the emissions from the primary energy source to the vehicle's wheel. For each of the WTP and PTW stages the carbon dioxide (CO_2)-equivalent GHG emissions are calculated by combining CO_2, methane (CH_4), and nitrous oxide (N_2O) with their global warming potentials of 1, 25, and 298, respectively. These global warming potentials are recommended by the Intergovernmental Panel on Climate Change for a 100-year time horizon (Elgowainy 2010). Their results found that PHEVs could realize reductions in petroleum energy use of 60-90% depending on the configuration. However, the reductions in GHG emissions vary widely based on the generation mix of the respective area. For a generation mix comparable to the U.S. average mix PHEVs produce lower GHG emissions than baseline gasoline ICEVs (-20 to -25%) but higher than gasoline HEVs (10-20%). Elgowainy et al. state that “to achieve significant reductions in GHG emissions, PHEVs and BEVs must recharge from a generation mix with a large share of nonfossil sources” (Elgowainy 2010). PHEVs recharging from renewable sources could reduce GHG emissions by 60% for power-split configuration and 90% for series configuration.

2.4.2 Water Consumption

Water Consumption

Gleick provided one of the earliest and most thorough analyses of the relationship between water and energy (Gleick 1994). Energy is required to transport and clean water in order to provide the potable water that sustains society. Meanwhile, water is required in the production of a variety of electric fuel types. Hydroelectric plants obviously need large reservoirs for generation purposes. Fossil-fuel, nuclear, and geothermal plants require water for fuel processing and cooling. While, solar photovoltaic power systems and wind turbines require little water consumption. Therefore, water is often a restrictive resource for plant location and type decisions. For example, in northeast Africa there are no reliable cooling water supplies to support large conventional fossil-fuel power plants.

All thermal-electric plants require a working fluid, often water, to be converted into steam or vapor to drive electric generating turbines. In order to recycle the vapor it must be condensed in a cooling system, during which water can be lost through evaporation. Gleick provided an estimate for the consumption of water in the production of electricity for a variety of different fuel types. However, Gleick noted that data is limited in the aspects of different fuel types and the boundaries of analysis are not always consistent. Overall, Gleick's analysis is often used as the basis of the majority of subsequent analyses of water consumption in energy production.

Fthenakis et al. reviewed the life-cycle water use for thermoelectric and renewable technology options in the United States (Fthenakis 2010). The focus on renewables such as photovoltaic and wind was that they have the ability to provide not only clean energy but could also prevent water crisis at the local level related to electricity generation. The main difference between thermoelectric and renewable technologies is that water is mostly consumed in operation of thermoelectric plants for cooling purposes. Meanwhile, in renewable cycles the majority of water consumption is upstream in the acquiring and processing of materials needed. Additionally, Fthenakis et al. show the increase in the amount of water consumed for thermoelectric power generation when carbon-capture technologies are employed.

Torcellini et al. also examined the consumptive water use for U.S. power production through a literature search of water use for thermal and hydroelectric plants (Torcellini 2004). The different types of thermoelectric power plants were aggregated for this analysis since Torcellini et al. were focused more on the water consumed in the cooling water. Values of total power plant water withdrawals were obtained from the U.S. Geological Survey, and consumption was calculated by multiplying the withdrawals by a coefficient of water loss. For their analysis, the coefficient of water loss was dependent on the cooling design of the plant: high for plants with cooling towers and low for plants with once-through cooling.

To calculate the water consumption of hydroelectric plants, Torcellini et al. compared the increased surface area of the reservoir compared to the free flowing stream to estimate the resulting additional surface water evaporation. The rate of evaporation is dependent on the size of the reservoir and other climatic factors of the region but can be estimated using isopleths, lines on maps that indicate constant yearly evaporation rates (Torcellini 2004) .

Wu et al. investigated the water consumption on the production of ethanol and petroleum gasoline. Wu focused specifically on water consumption in feed stock production and fuel processing/production for ethanol from corn, cellulosic ethanol from switchgrass, gasoline from domestic crude oil obtained from onshore wells, gasoline from Saudi Arabia conventional crude oil, and gasoline from nonconventional Canadian oil sands. For their analysis, water consumption was defined as freshwater input during feedstock and fuel production activities less output water that is recycled and reused as shown in Figure 2.7.

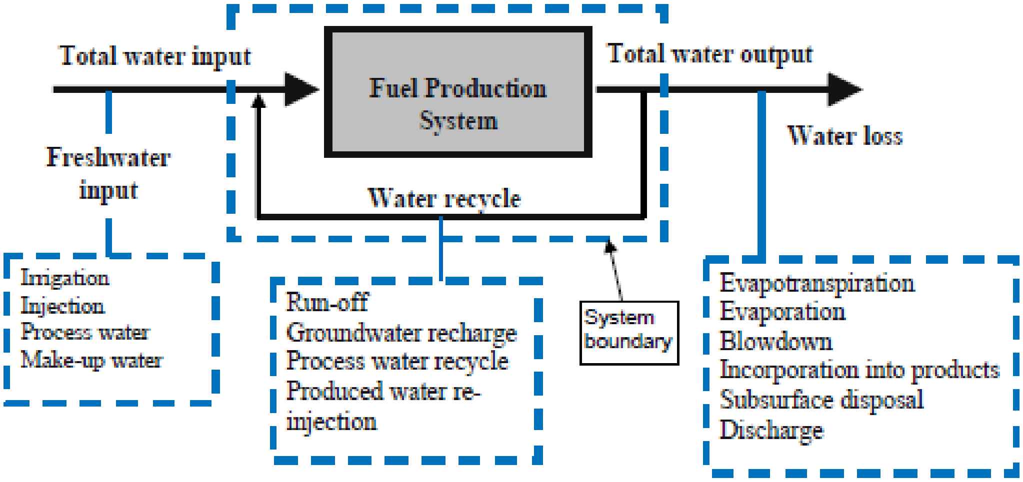


Figure 2.7 System boundary, water inputs, outputs, and losses of a conceptual feedstock and fuel production system (Wu 2009)

The production of ethanol was found to be mostly dependent on the consumptive irrigation water use for growing the feedstock if produced from corn. This leads to the ethanol water consumption being mostly dependent on the region that the feedstock is grown as irrigation demands vary greatly across the U.S. Meanwhile, ethanol produced from switchgrass varies on the production process utilized.

Oil recovery is the major water consumption step for petroleum gasoline production but varies considerably by well and over time. As wells age, different technologies must be utilized in order to maintain oil production. Primary oil recovery uses the natural pressure of the well to extract crude oil. Secondary recovery (or water flooding) requires water to be injected into the formation to increase the pressure and consequently the oil production. Finally, enhanced oil recovery (or tertiary recovery) increases well production by reducing surface tension in the well through surfactant injection or reducing viscosity contrasts via steam injection.

King et al. analyzed the water intensity of different transportation fuels on a "gallons of water per mile traveled" basis (King 2008). A wide-range of vehicle types is considered including gasoline, diesel, electric, hydrogen fuel cell, natural gas, and ethanol. The results of the investigation are presented in Figure 2.8.

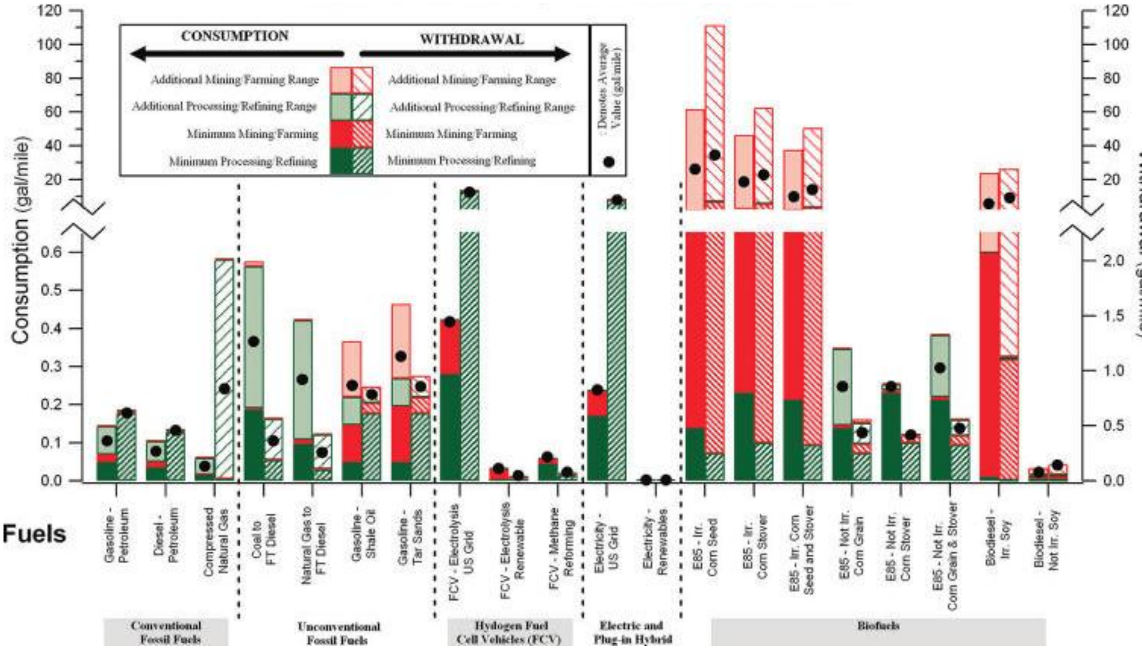


Figure 2.8 Water intensity of transportation for the United States (King 2008)

Electric vehicles were found to consume 2-5 times more water than by vehicles using fossil fuels, while vehicles operating on irrigated biofuels consumed 1-3 orders of magnitude more water than traditional petroleum. Appropriately, King et al. discuss the regional discrepancy of water consumption impact: "Making a decision while only considering aggregate water consumed and withdrawn on the basis of a region as large as the United States is too simplified. In practice regional impacts will dictate the successful implementation of any of the discussed fuels" (King 2008).

Impact Terminology

Different approaches to water analysis employ a number of terminologies in defining the source and impact of different water uses. In analyzing the potential water-use metric, Scown et al. compared the common definitions of consumption and withdrawal. Withdrawal is defined as “any freshwater that is temporarily or permanently removed from its source, whereas consumption is limited to water that is not returned to its original watershed in the short term”(Scown 2011). Consumption includes freshwater that is incorporated into a product, discharged into seawater, saline water, or a water body in a different watershed, and evaporation. For both of these metrics only freshwater is considered since saline and seawater is not considered useful or a constrained water resource. Jeswani et al. describe the differences between blue, green, and grey water . Blue water refers to the freshwater available in surface water bodies (rivers, lakes) and aquifers for abstraction. Green water includes rainwater (stored in the soil as soil moisture) used by plants and vegetation. Meanwhile, grey water is the volume of freshwater required to dilute pollutants so that the quality of water remains above water quality standards set by regulations. Water degradation is another term that incorporates pollutants and refers to the water which is discharged in the same watershed after the quality of water has been altered.

Impact Methodologies

Beyond even the inventory phase, a great deal of research has been focused on the lack of effective ways to measure the resulting impact of water consumption. Water impact methodologies, approaches, indicators, and metrics are still evolving and thus incorporate a number of different aspects and provide a wide-range of results. The main difficulty is defining both the quantity of water used as well as the resulting impact of the locational aspects. Most of the impact analysis concerning water has been done qualitatively and does not provide the necessary quantitative analysis that would facilitate decision making or provide comparison between different scenarios (Pfister 2009). As described previously, water is a location specific resource and the same consumption has varying impacts depending on the locations' available resources and demand constraints.

Water Footprint Approach

The water footprint approach (Hoekstra et al.) represents the sum of all water used in the supply chain defined in each phase of blue, green, and grey water. This type of approach is useful in defining agricultural product water footprints and directing corporate water reduction strategies. However, Jeswani et al. describes the controversy of including green water, which does not affect availability of blue water, and should rather include the "net green" water – the difference between the water evaporated from crops and the water that would have evaporated from natural vegetation (Sabmiller and WWF, 2009). Also, the estimation of dilution volumes in the grey water footprint can be subjective and may be better estimated in other impact categories such as eutrophication or toxicity.

This method provides only a quantification of the water use and does not approach the related environmental or social impacts of the potential water scarcity. Even the quantification of the water use is a simplification of the true impact of the water processes. Although water use is easily determined through total input to a system, water consumption is more appropriate in establishing impact as it incorporates only the water actually consumed rather than the remainder of the water, which is discharged back to the water bodies and is still available for future use.

The eco-scarcity method

The ecological scarcity method is based on "distance-to-target" and provides standardized generic weights. The typical weighting is based on environmental protection targets, which are legally binding targets formulated by an elected or legitimate body with orientation towards sustainability as much as possible. The "distance-to-target" approach allows for optimization of the framework based on the policy targets. The general eco-factor was introduced in 1978 and has been refined over time to provide more relevant results and allow for more extensive application. For every environmental impact, Frischknecht et al. define the eco-factor as:

$$Eco - factor = Charactertization * \frac{1 * EP}{Nomrmalization} * Weighting * Constant \quad (1)$$

The characterization is an optional component and allows for pollutants or resources that can be allocated to a specific environmental impact (ie. global warming). EP refers to the eco-point or the unit of assessed impact. Normalization adjusts the scarcity situation to the present resource extractions in a region. Meanwhile, the weighting is a dimensionless quantity determined by the ratio of the current to the critical flow. Finally, the constant adjusts for more presentable numerical quantities. The specific eco-factor for freshwater consumption is presented in Equation 2.

$$Eco - factor = \frac{1 * EP}{Fn} * (WTA)^2 * \left(\frac{1}{20\%}\right)^2 * C \quad (2)$$

The Swiss level of water consumption of 2.57 km^3/yr is used for Fn or the normalization factor. WTA is defined as the ratio of water use to available resources with the critical flow being assumed as 20% of the available resources as defined by the Organization for Economic Co-operation and Development (OECD). The constant is usually used as 10^{12}/year to obtain presentable numerical quantities in EP/m^3. Table 2.1 presents the eco-scarcity factors for 6 levels of water-scarcity from low (using less than 10% of available freshwater resources) to extreme (using more than 100% of the available freshwater resources).

Table 2.1 Eco-scarcity weighting factors and eco-factors for different levels of water scarcity (Frischknecht et al.)

Water Pressure Category	WTA range	WTA used for weighting calculation	Weighing factor	Normalization (km^3/yr)	Eco-factor (EP/m^3)
Low	<0.1	0.05	0.0625	2.57	24
Moderate	0.1 to <0.2	0.15	0.563	2.57	220
Medium	0.2 to <0.4	0.3	2.25	2.57	880
High	0.4 to <0.6	0.5	6.25	2.57	2,400
Very High	0.6 to <1.0	0.8	16.0	2.57	6,200
Extreme	≥1	1.5	56.3	2.57	22,000

Jeswani et al. discuss the limitations of this method as it does not capture the seasonal variations of water scarcity. Some regions may only experience levels of water scarcity during specific times of the year and thus the water consumption would have a greater impact during these times. Additionally, since some regions such as United Arab Emirates and Israel use seawater desalination to satisfy a majority of freshwater consumption and therefore this water consumption does not reduce the availability of freshwater in the region. The scarcity index provides the most appropriate results when used on the watershed level since a more accurate level of impact is obtained. However, if the life cycle inventory does not specify the regional or scarcity-based differentiation, then an average eco-factor of 97 is utilized.

The Pfister et al. approach

Pfister et al. attempt to assess the environmental impact of freshwater consumption by considering the damages of consumption to human health, ecosystem quality, and resources. The first step to conducting this type of analysis requires documenting the amount of consumptive water use with both quantification and geographic location. The regionalization of the data is desirable up to the watershed level, although often country-level inventory data is only available. A Water Stress Index (WSI), ranging from 0 to 1, is then developed that provides a midpoint characterization for the portion of water consumption that deprives other users of freshwater.

The initial step in Pfister's analysis is defining the ratio of total annual freshwater withdrawals to hydrological availability (WTA). This was done by using the WaterGAP2 global model, which describes the WTA ratio of more than 10,000 watersheds. Equation 3 represents the equation in the model that provides for WTA through a comparison of annual freshwater availability (WA) and withdrawals of different users (WU),

$$WTA_i = \frac{\sum_j WU_{ij}}{WA_i} \tag{3}$$

where, WTA_i is WTA in watershed i and user groups j are industry, agriculture, and households. However, Pfister takes this approach a step further by defining a modified WTA that takes into account periods of increased stress due to both monthly and annual variability of water availability. This modified WTA* is described by Equation 4,

$$WTA^* = \begin{cases} \sqrt{VF} * WTA & for\ SRF \\ VF * WTA & for\ non-SRF \end{cases} \tag{4}$$

where VF is a variation factor and SRF differentiates watersheds with strongly regulated flows that are not affected as much by variable precipitation but experience increased evaporation. This variation factor is defined by the standard deviation of monthly and annual precipitation for the watershed from 1961-1990.

$$VF = e^{\sqrt{\ln\left(s^*_{month}\right)^2 + \ln\left(s^*_{year}\right)^2}} \tag{5}$$

These combined provided a WSI in Equation 6 that quantifies the degree of water scarcity of watersheds as follows: $WSI<0.1$ low; $0.1 \leq WSI \leq 0.5$ moderate; $0.5 \leq WSI \leq 0.9$ severe and $WSI>0.9$ extreme. This water stress indicator is then used to quantify the degree of damage to the three aforementioned categories: human health, ecosystem quality, and depletion of freshwater resources.

The damage to human health due to water consumption can be attributed to lack of freshwater for hygiene and ingestion, which results in the spread of diseases, and the lack of freshwater for irrigation, which results in malnutrition. In this analysis, Pfister focus on the health damages due to malnutrition, as the damage ($\Delta HH_{\text{malnutirution},i}$) in a watershed *i* due to the water consumption ($WU_{\text{consumptive},i}$,($m^3$)), as measured in disability adjusted life years (DALY).

$$\begin{gathered}
WDF_i = WSI_i \times WU_{\%,agriculture,i} \\
EF_i = HDF_{malnutrition,i} \times {WR_{malnutrition}}^{-1} \\
CF_{malnutrition,i} = WDF_i \times EF_i \\
\Delta HH_{malnutrition,i} = CF_{malnutrition,i} \times WU_{consumptive,i}
\end{gathered} \tag{6-9}$$

The term CF is the expected specific damage per unit of water consumed for malnutrition.

The next area that is considered is the ecosystem quality, which is defined as

$$\Delta EQ = \frac{NPP_{wat-lim}}{P} \times WU_{consumptive} \tag{10}$$

Where: ΔEQ is the damage to ecosystem quality (m^2year); $NPP_{wat-lim}$ is the net primary production limited by water availaibilty representing vulnerability of an ecosystem due to water shortage; P is the mean annual rainfall (m/year).

Finally the depletion of freshwater resources is taken into account through the following equation

$$\Delta R = E_{desalination} \times F_{depletion} \times WU_{consumptive} \tag{11}$$

Where: ΔR is the damage to freshwater resources (MJ); $E_{desalination}$ is the energy required for seawater desalination (MJ/m^3); $F_{depletion}$ is the fraction of freshwater consumption that contributes to depletion. These categories are then aggregated into a single score indicator per the Eco-indicator 99 method.

Impact Implementation

A recent study conducted by Volkswagen investigated the water footprint of different vehicles through the potential impacts of water consumption throughout the automobile life cycle. Berger et al. claimed that the investigation represented the first application of impact-oriented water footprint methods on complex industrial products. The water consumption of the vehicles life cycle was inventoried and then assigned to regions on the country level. The impact metrics were then computed by the human health, ecosystems, and resources. The difficulty of water inventories on the watershed level, time of use, and water quality was discussed and reveals the relative immaturity of water analysis. As such Berger et al utilize country-specific characterization factors, which as they admit “reflect hydraulic conditions in countries with inhomogeneous water scarcity, like Spain or the United States, more realistically, it would be preferable to use watershed-specific factors” (Berger 2012). Figure 2.9 presents the comparison of results for three different Volkswagen vehicles in terms of water inventory and impact assessment methods.

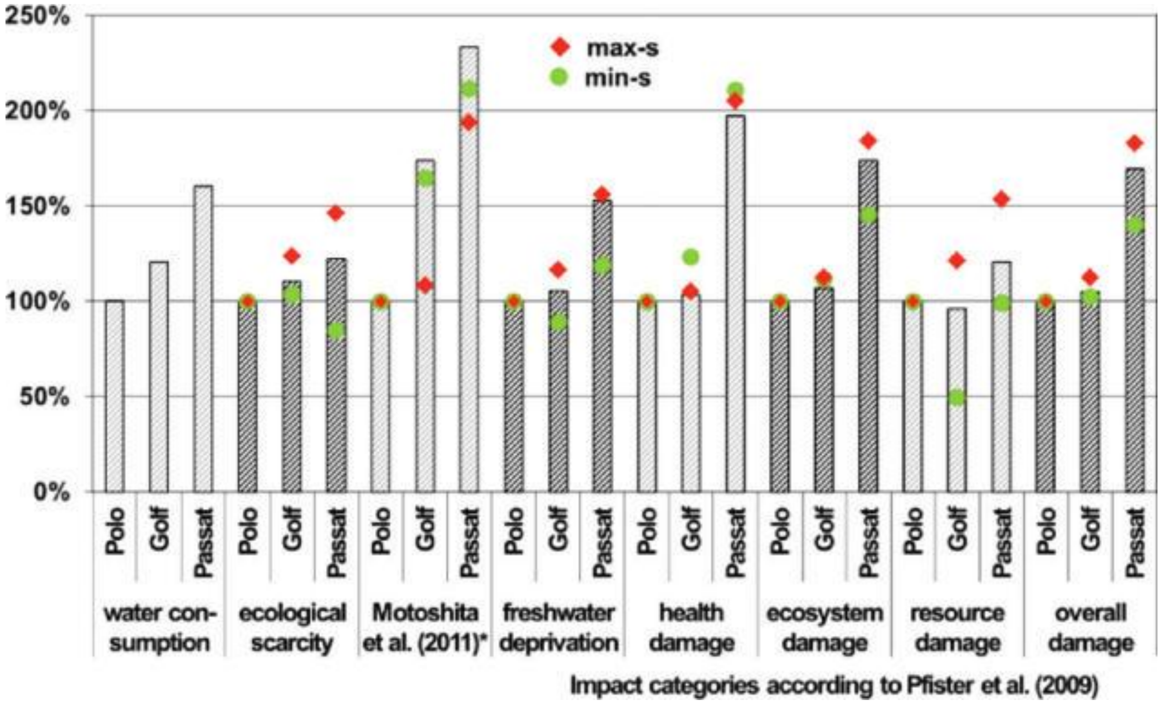


Figure 2.9 Relative comparisons of results on inventory and impact assessment levels for the Polo, Golf, Passat normalized to the results obtained for the Polo in the default scenario (bars), min (circles), and max (diamonds) (Berger 2012)

For the water inventory and the model and the model of Motoshita et al. lead to similar conclusions. However, for a number of impact categories developed by Pfister et al. the impacts of the Polo and Golf are relatively similar even though the Polo consumes less absolute water. This is mainly attributed to the manufacturing location of the Polo, Spain, which is more water stressed than the Golf's manufacturing location, Germany.

Berger et al. describe a number of challenges in implementing the entire life cycle analysis of water consumption including production, use, and end-of-life. The first challenge involves the development of water inventories that only contain water use instead of water consumption (ecoinvent) or underestimate water consumption in background processes (GaBi). These databases are often used by researchers to provide a quick analysis of lifecycle assessments but may not be the most reliable. This problem would lead to incorrect decisions being formed as results are only as accurate as their inputs; hence the saying 'garbage in equals garbage out'. Additionally, Berger et al. mention that since water flows are not geographically differentiated, which limits the effectiveness of top-down approaches. Thus the need for more detailed inventory data sets that take into account the spatial differentiation of water flows, type of watercourse used, quality data, and temporal information. This level of detail is difficult to attain presently and although there is a growing demand for water inventory would be unrealistically costly.

In all, the absolute results by Berger et al. are questionable in terms of accounting 95% of the water consumption to the production phase, which may be attributed to their use of general LCA databases such as ecoinvent and GaBi. However, the qualitative assertions around water impact modeling provide a level of perspective to the complexity of water consumption in comparison to the well-established environmental factor of greenhouse gas emissions. However, just because climate change may be better understood does not mean that water consumption should be ignored. By providing an absolute inventory and a rudimentary analysis of impact at least informs the user’s outlook.

2.5 Societal Implications

Alternative fuels require training of maintenance personnel on the necessary safety precautions when servicing the vehicles. Vehicles that incorporate an electric drive train feature high voltage components that may be a safety hazard if not handled properly, while CNG has the danger of the pressurized vessel on the vehicle. A survey of CNG transit fleet operators found that the majority (78%) of fleets reported some training of their personnel with almost half of the training being provided by the CNG engine OEM (Eudy 2002). This training is vital to the durability of the program as more than half of the fleets that reported training was important found that the CNG transit experience was a success. Additionally, this training results in a more educated workforce that can result in an increase in wage and standard of the living. Even in 1998 transit operators experienced a widening gap between the skill set of maintenance workers and the pace of technological development (Finegold, Robbins et al. 1998). With the future expanse of AFVs in the nation’s transportation mix, this training in AFV maintenance will be a distinguishing factor in the job market.

The training should not be only limited to the maintenance staff but should also be extended to the drivers of these shuttles to promote efficient driving practices. The idea is to employ persuasive interfaces to promote ideal practices by the driver and influence a change in behavior. Ford has utilized a SmartGuage with EcoGuide in some vehicles that feature variable growing leaves depending on the efficiency of the driver as a way to communicate instantaneous levels of performance. Studies have found that these types of systems are found to be accepted by the user and are useful in delivering their message of efficiency (Meschtscherjakov, Wilfinger et al. 2009). A persuasive system could be implemented in conjunction with an incentive based program to provide the drivers a positive reinforcement of economic driving practices. Such programs have had success in affecting transit driver absentee records and occurrences of accidents and could be adjusted to provide financial incentives towards drivers that improve fuel economy of the shuttle during their work shift (Beaudry, Schepman et al. 2011).

The upstream impacts of human rights are increasingly being taken into account in purchasing decisions. For instance, legislation such as the California Transparency in Supply Chain Act of 2010 (SB 657) forces companies to provide publicly available human rights codes that disclose their efforts to eradicate slavery and human trafficking from its direct supply chain if doing business in California.

Different studies have also attempted to estimate the externality cost that emissions and pollution has on public health. Litman et al. produced a comprehensive study of transportation benefit and costing (Litman 2011). Although 16 different aspects of vehicle costing are discussed, the most relevant for comparing societal impact of different fuel types is the discussion on the cost analysis of air pollutants. There are a variety of different pollutants that differ on source, harmful effects, and the scale of impact. The unit air pollution costs are an estimated cost per kilogram of a particular pollutant in a particular location. These costs are affected by the mortality (deaths) and morbidity (illnesses) causes by pollutant exposure, which is referred to as the dose-response function. Additionally, the unit costs are adjusted for the number of people exposed and the value placed on human life and health. The value of human life and health is measured based on the Value of a Statistical Life (VSL), the Value of a Life Year (VOLY), Potential Years of Life Lost (PYLL), and Disability Adjusted Life Years (DALYs).

2.6 Triple Bottom Line Analysis

Gifford et al. provides an analysis of financial and environmental concerns of different fuel types by analyzing the primary energy consumption, GHG emissions, water usage, and cost of vehicle operation. Table 2.2 and Table 2.3 present the nomenclature for the different fuel types and transportation scenarios considered in their analysis.

Table 2.2 Nomenclature used with automotive transportation scenarios

Abbreviation	**Meaning**
CNG	Compressed Natural Gas
NGCC	Natural Gas Combined Cycle
TS SCO	Tar Sands Synthetic Crude Oil
OS SCO	Oil Shale Synthetic Crude Oil
BEV	Battery Electric Vehicle
FCEV	Fuel Cell Electric Vehicle
FCHEV	Fuel Cell Hybrid Electric Vehicle
ICE	Internal Combustion Engine
HEV	Hybrid Electric Vehicle

Table 2.3 Automotive Transportation Scenario (Gifford 2011)

Primary Energy Source	**Energy Carriers**	**Primary Movers**
Conventional Crude Oil	Gasoline	ICE, HEV
Conventional Crude Oil	Diesel	ICE, HEV
Tar Sands Synthetic Crude Oil	Gasoline	ICE, HEV
Tar Sands Synthetic Crude Oil	Diesel	ICE, HEV
Oil Shale Synthetic Crude Oil	Gasoline	ICE, HEV
Oil Shale Synthetic Crude Oil	Diesel	ICE, HEV
Natural Gas	Compressed Natural Gas	ICE, HEV
Natural Gas	Electricity	BEV
Electric Grid	Electricity	BEV
Electric Grid	Hydrogen	ICE, HEV
Electric Grid	Hydrogen	FCEV, FCHEV
Coal	Hydrogen	ICE, HEV
Coal	Hydrogen	FCEV, FCHEV
Corn Grain	Ethanol	ICE, HEV
Corn Stover	Ethanol	ICE, HEV

Different fuel types were analyzed around these metrics and aggregated into a normalized composite score termed the CWEG (cost-water-energy-GHG). These scores were normalized based on the alternative that presented the most beneficial criteria being weighted as a 100 for the respective category. Figure 2.10 and Figure 2.11 present these

CWEG scores with fifteen non-hybrid transportation and hybrid transportation respectively.

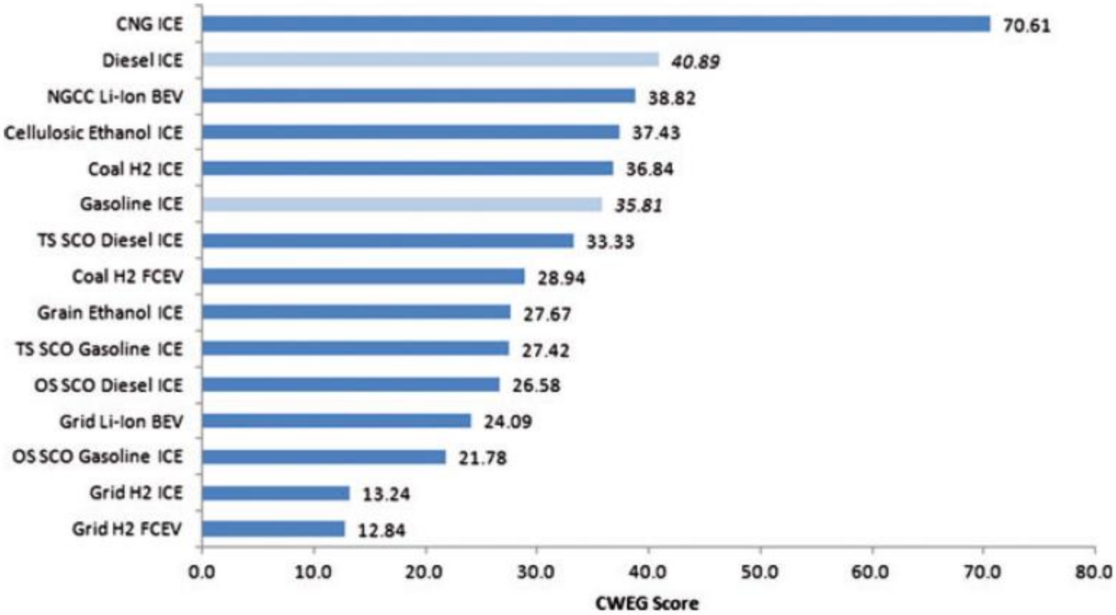


Figure 2.10 CWEG scores for non-hybrid transportation scenarios (Gifford 2011)

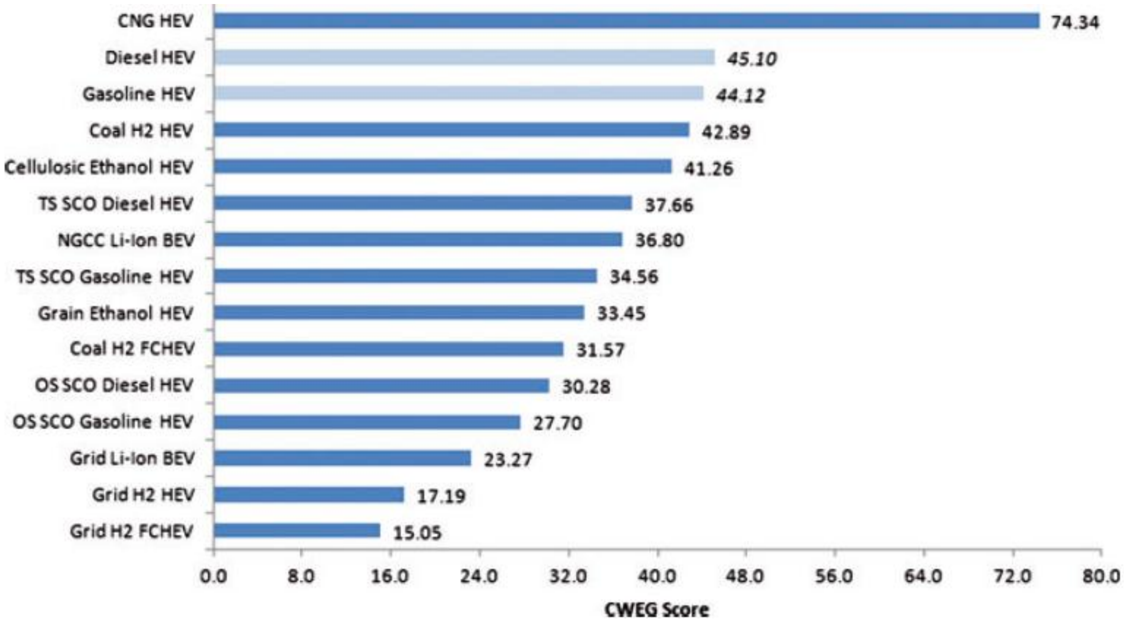


Figure 2.11 CWEG scores for hybrid transportation scenarios (Gifford 2011)

The use of primary energy consumption as a scoring metric is incongruent with the other categories, which are more of resultants rather than inputs. The primary energy consumption will be factored into the cost and the environmental factors of water usage and GHG emissions of the primary energy used in the fuel production process. Furthermore, this analysis is more of a generalization of the inventories for the different fuel sources and does not include the necessary impact aspects and ignores the variability of location. The variability of location is essential for water analysis and also impacts the results of the GHG emission calculations.

Gifford et al. compiled the GHG emissions from a variety of sources, the most concerning of which is the GHG emissions for power from the electric grid. These emissions were estimated by dividing the total emissions attributed to the electric sector by the net generation. This type of estimation does not designate between the varieties of different sources for electric generation with each subset having different emissions. Therefore, in their analysis a battery electric fleet operating in Georgia and another operating in California would have the same GHG emissions, when in reality these fleets would have very different emissions due to the electric grid in the two states having different compositions of electric power generations.

The financial analysis includes the fuel refining costs and capital costs of the different vehicle platforms. The refining cost is a highly variable factor and includes the primary energy cost and the processing costs such as labor, utilities, and chemicals. These costs are the market cost for the respective fuel cost rather than the cost that the consumer would be obligated to pay. The fuel infrastructure was not included within their analysis due to the fact that the additional cost “can distort comparisons between technologies that require infrastructure investment (fuel cell, battery electric, or CNG vehicles) and those that rely on existing but aging infrastructure (internal combustion engines that rely on existing but aging infrastructure)”. This simplification ignores a significant cost that would have to be realized by any consumer that decided to implement the respective technology. As explained by Johnson, a CNG fleet will most likely require a dedicated station that has a major influence on the profitability of marginal projects as in general a 50% increase in station cost results in a 30% increase in payback years. Additionally, Gifford made a significant simplification in the vehicle platform cost estimation and other costs based on ratios for generic costs. This analysis of the cost specifications for different fuel types is not appropriate for decision making as it does not reflect the costs that the operator would experience if the respective fuel type was selected for implementation in a real world fleet.

Gifford et al. differentiates the importance of analyzing the water impact on the transportation sector due to the scarcity of water resources. However, the metric considered is the water usage, which is defined as “withdrawal from any water source”. Within this paper the author interchangeably utilizes water usage and water consumption while referring to the same category of data. Since these phrases have very different meanings, it is difficult to precisely determine the validity of further assertions around water without analyzing the individual original sources for the water data.

The analysis employed by Gifford et al. is much more applicable to broad generalizations of fuel types. However, this is not appropriate for fleet decision analysis since each fleet scenario is unique and the inclusion of local parameters is essential for a true impact rating. This thesis will illustrate that these various concerns beyond financial metrics should be integrated to provide a more robust decision-making for a given scenario. Because of the regional dependency of electric grid mixes and water consumption impact, specific scenarios are analyzed with differing preferences to provide representative case studies.

2.7 Decision Analysis

Decision analysis is a field that has been present for hundreds of years that attempts to assist people in making more rational decisions than would be possible using intuition alone. Although this field has a storied history in philosophical arenas, the practical application of decision analysis has grown in recent years with the advent of the computational powers of computers. The process of decision analysis can be discerned into a few steps as exemplified in Figure 2.12.

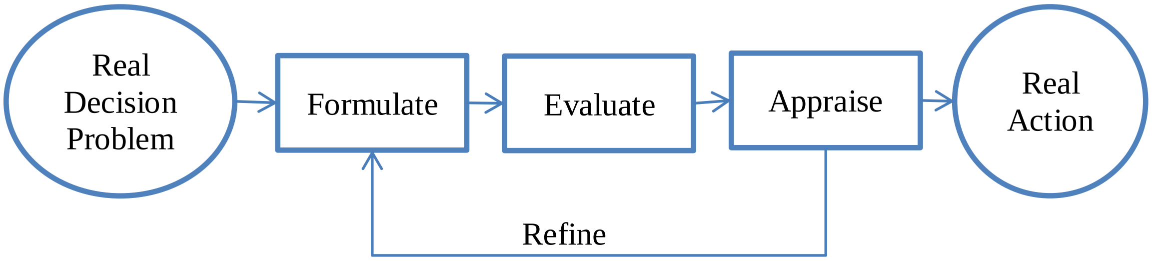


Figure 2.12 The Decision Analysis Process (Howard 1988)

The initial step is the formulation of a model that accurately details the situation. Howard calls this representation the “decision basis,” which can be broken down to three parts: the choices or alternative the decision-maker faces, the relevant information, and the preferences of the decision-maker (Howard 1988). The relevant information would be any mathematical relationships, models, or probability assignments that signify the uncertainty as well as the connection between decisions and outcomes. This quantification of the situation is important for the evaluation phase so an alternative can be recommended that is consistent with the basis. Finally, the chosen alternative is appraised so that it is understood why the particular alternative was chosen over the others. A more extensive representation of the elicitation and evaluation process is presented in Figured 2.13.

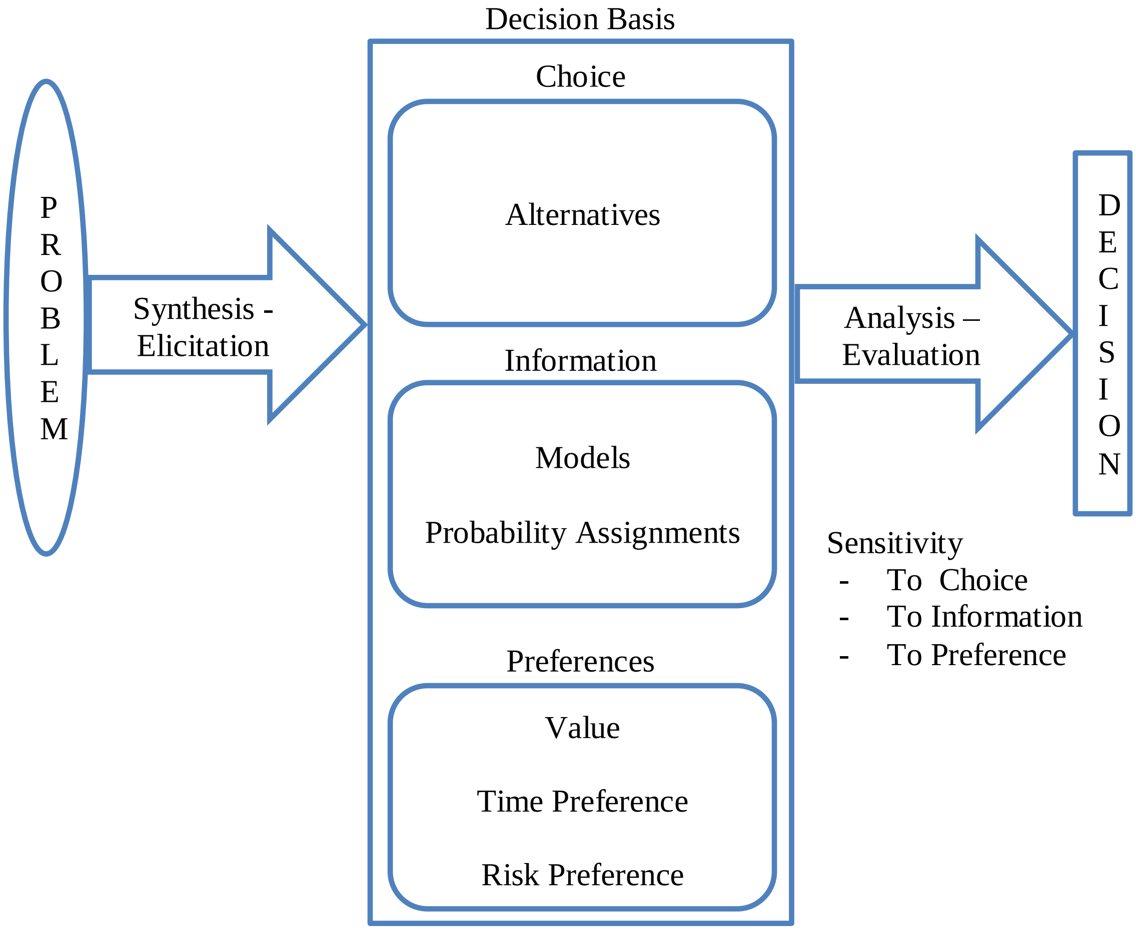


Figure 2.13 Elicitation and Evaluation of the Decision Basis (Howard 1988)

2.8 Fleet Optimization

As a specific application, the National Renewable Energy Laboratory qualitatively described the use of alternative fuel vehicle fleets within airports both theoretically and by illustrating current uses at national airports (Howards 2001). Airport fleets are excellent examples of effective uses of AFVs due to the central routes, high fuel consumption, public image, and air quality concerns. Additionally with a number of airports being located in air quality nonattainment areas, airports often use AFVs as a means of reducing pollutants and improving air quality. The infrastructure demands of AFVs can also be possibly offset by utilizing the fleet location as an “activity center” that can support the public’s regional fueling needs in addition to serving the private fleet’s needs.

A number of fuel types have been represented by Yacobucci, who provided an investigation into the current state of different potential alternative fuel sources, while discussing the potential advantages and disadvantages of each implementation.(Yacobucci 2005)

Liu et al. discuss the various methods of transit fleet optimization by defining a specific case of capacitated vehicle routing problem (CVRP). The CVRP has a fleet that must service the known customer demands at a minimum cost. A specific variation of this method is the fleet size and mix vehicle routing problem (FSMVRP), which attempts to determine how many vehicles of each type to use given a mix of vehicle types with different characteristics and costs (Liu 2009).

CHAPTER 3

APPROACH

3.1 Vehicle Specifications

Alternative fueled technologies are becoming increasingly popular among consumers as an ability to present their progressive images. However, the majority of potential alternative fueled fleet technologies are not available directly from the Original Equipment Manufacturers. Instead, fleet vehicles are converted to the correct specifications by an approved third-party company. These approved third-party conversion companies will often provide a comparable warranty service for the converted vehicle. The following section provides an overview of the different alternative technologies.

3.1.2 Alternative Technologies and Fuel Sources

Hybrid Electric Vehicles (HEV)

The simplest alternative technology to implement would be a hybrid drivetrain, which runs on gasoline while a traction motor in parallel or series can power the vehicle at low speeds and recharge through regenerative braking. A hybrid provides greater efficiency due to the reduced demands on the gasoline engine and braking losses. However, this improved fuel economy comes at a higher purchase cost to provide for the additional technological components. Additionally, the hybrid drivetrain still carries the stigma of relying on a gasoline engine instead of on an alternative fuel source. The reduced environmental impact during the use phase of the vehicle is only associated with the reduced fuel consumption due to being more efficient than traditional drivetrains.

Plug-in Hybrid Electric Vehicles (PHEV)

Plug-in Hybrid Electric Vehicles (PHEVs) share a lot of the technology and powertrain architecture with power assisted hybrid electric vehicles but also have the ability to plug in to off-board electrical power to recharge a typically larger battery. Due to the unique specifications required, PHEVs are different than both the high power energy storage systems required for HEVs and the high energy battery systems in battery electric vehicles (BEVs). The transition to a PHEV fleet is much less drastic than a BEV fleet as PHEVs can still use existing gas station infrastructure, although electric charging stations must be installed to utilize the electric benefits. Additionally, PHEVs benefit from reduced fuel consumption through both all-electric driving as well as through energy recovered during regenerative braking. However, the added complexity of two powertrains leads to a higher initial capital cost. There is also uncertainty as to the actual fuel economy for a vehicle due to the different operating modes of a PHEV. There is a charge sustaining mode, where during the entire trip there is no energy available for electric drive propulsion and thus the battery state-of-charge is sustained. In charge depleting mode there is energy available in the battery, and the state-of-charge is being depleted during the trip. Finally, there can be mixed mode where there is energy in the battery at the start of the trip but it becomes fully depleted before the end of the trip. Each of these different modes of travel will lead to very different fuel economy profiles, making it harder to estimate the average fuel economy over a long period of time.

There is another type of electric vehicle that will be grouped in with this category and that is the extended-range electric vehicle (EREVs), such as the Chevrolet Volt. EREVs are powered exclusively by an electric motor; but when the battery becomes depleted, an onboard generator powered by an internal combustion engine provides supplemental power to recharge the battery. These vehicles are sometimes grouped into the same category as BEVs since their only source of propulsion is the electric powertrain. However, an EREV is more similar in terms of environmental impact and cost structure to a PHEV because there are emissions during the driving cycle once the onboard generator begins charging the battery.

Battery Electric Vehicles (BEV)

Electric vehicle technology has been limited in the past by the available battery capacity technology both in terms of manufacturing cost and in available energy density (Tollefson 2008). Currently, major automakers are introducing a series of battery electric and plug-in hybrid electric vehicles: Ford (Focus and Transit Connect Electric), Nissan (Leaf), and GM (Volt). Along with significant government incentives, this introduction of vehicles by major auto manufacturers, as well as smaller ones such as Tesla, will spur the development of electric vehicle technology over the coming years. The battery technologies implemented in consumer cars will most likely transition into electric shuttles as the technology becomes more cost effective. Another limiting factor of electric vehicles is the recharge time of the vehicle once the battery has been depleted.

Compressed Natural Gas Vehicles

Natural gas is a fossil fuel that has been transformed by heat and pressure over millions of years from organic material. The production process of natural gas involves extracting the gas from formations in the ground through drilling. This gas is then further processed to separate the gas from petroleum liquids and to remove contaminants. In order to increase production and allow access to tight shale formations, producers are increasingly relying on a process known as hydraulic fracturing. Hydraulic fracturing involves injecting high volumes of fracturing fluids into the well in order to restore the small fractures in the reservoir rock. The fracturing fluid is a mostly a mixture of 98 to 99.5 percent water and sand, with the rest being chemical additives. It is projected that in the next ten years 60-80 percent of all wells in the US will require hydraulic fracturing to remain operating (FracFocus 2012). However, this process has been under increasing scrutiny, due to both the high water use and water contamination concerns.

Natural gas is viewed as a potential way to increase the energy security of the United States as the majority of natural gas consumed is produced domestically. In addition to natural gas being extracted from wells, it can be captured from decaying organic material from landfills, which provides a potentially environmentally friendly production source. The increasing governmental support of natural gas production and vehicles is exemplified in President Obama's 2012 State of the Union Address in which he stated:

> This country needs an all-out, all-of-the-above strategy that develops every available source of American energy. A strategy that's cleaner, cheaper, and full of new jobs. We have a supply of natural gas that can last America nearly 100 years. And my administration will take every possible action to safely develop this energy... And I'm requiring all companies that drill for gas on public lands to disclose the chemicals they use. Because America will develop this resource without putting the health and safety of our citizens at risk. The development of natural gas will create jobs and power trucks and factories that are cleaner and

> cheaper, proving that we don't have to choose between our environment and our economy. (NYTimes 2012)

With this level of bipartisan political support, it should be expected that the role of natural gas will be further embodied in the national energy strategy going forward. This is important since risks of increasing the production from unconventional sources includes rising costs and environmental regulation.

Compressed natural gas (CNG) vehicles run on natural gas that is compressed and stored within pressurized tanks, while meeting the same safety standards as gasoline vehicles. Natural gas tends to actually be safer than gasoline since the fuel is non-toxic and is more difficult to ignite as it usually dissipates faster due to its lower density (Yacobucci 2005). The onboard pressurized tank undergoes rigorous testing procedures to insure that the tank would not rupture during use; these tests include collisions, fires, and even gunfire. The increased use of natural gas in the transportation sector could lower the United States' reliance on imported fuel. However, due to the extensive use in electricity production, an increase in demand would increase prices or have to be offset by other electricity sources. CNG is sold in gallons of gasoline equivalent (gge), the amount of CNG that contains the same energy content as a gallon of gasoline. Equation 12 presents the calculation for the cubic feet in a gge.

$$1\, gge = 116{,}090 \frac{BTU}{gal.gas} \Big/ 983\, \frac{BTU}{ft^3} = 118.10\, ft^3 \qquad (12)$$

The lower heating values, net heat of combustion, for measuring energy is utilized, which is the standard heat of combustion referenced to water in combustion exhaust as water vapor (Shapouri 2002). These values are based on the energy content provided by GREETs fuel specifications. The main advantage of CNG vehicles is the reduced fuel cost, which may offset the increased vehicle purchase cost.

Propane Vehicles

Liquefied petroleum gas (LPG) is used in vehicles since the components of LPG are gases at normal temperature and pressure. Although LPG is the most commonly used alternative fuel, it is closely linked with petroleum as it is produced as a by-product of natural gas processing and petroleum refining. LPG is not as desirable of an alternative fuel to reduce reliance on foreign oil sources being a derivation of oil. However, propane is a widely used alternative transportation fuel due to it being much easier to implement with a more affordable infrastructure.

Flex Fuel Vehicles

Flexible fuel vehicles (FFVs) are vehicles that can run on any mixture of gasoline or E85 (85% ethanol, 15% gasoline). The vehicle must be equipped with components designed to be compatible with ethanol's chemical properties, as the increased ethanol composition can have detrimental effects on a typical vehicle. Although FFVs typically perform just as well when fueled with gasoline, the fuel economy with E85 is reduced due to the fact that ethanol contains lower energy content per gallon. The purchase cost is typically comparable to a gasoline vehicle; however, the fuel cost is often increased due to the reduced fuel economy.

3.1.2 Vehicle Fuel Economies

The four different shuttle options analyzed are gasoline, hybrid, propane (LPG), flexible fuel (FFV) on E85, compressed natural gas (CNG), and electric (BEV). All of the vehicles in the comparison are based on Ford’s E-450 chassis with a shuttle bus body to provide a consistent platform for comparison. Partner companies convert Ford’s E-450 vehicles to AFV drivetrains. Azure Dynamics is a conversion company that takes light to heavy-duty commercial vehicles and converts the vehicle to an electric or hybrid electric drive. Their E-450 hybrid shuttle has a number of fuel economy boosting features including electric-launch assist, engine-off at idle, and regenerative braking. BAF Technologies provides dedicated CNG Ford vehicles for a variety of applications including the certified E-450 cutaway shuttle. Finally, although there is not currently an all-electric shuttle available, it was included in the analysis to provide a comparison for the likely future developments. For example, the electric efficiency is based on the Eqo 14, and E-450 chassis BEV, recently announced by Balqon Corporation. Table 3.1 presents the fuel economy for the various vehicle types.

Table 3.1 Fuel Economy Dependence on Fuel Type

Fuel Type	Gasoline	Hybrid	Propane	FFV on E85	CNG	Electric
Fuel Economy	7.00 miles/gal (2.98 km/liter)	9.45 miles/gal (4.02 km/liter)	7.00 miles/gal (2.98 km/liter)	4.96 miles/gal (2.11 km/liter)	7.00 miles/gge (2.98 km/liter eq)	1.00 miles/kWh (1.61 km/kWh)

The fuel economy for a FFV running on E85 features performance differences in terms of the reduced energy content of the ethanol and increased vehicle power since ethanol is a high-octane fuel. Equation 3.X presents the computation of the fuel economy for a FFV based on the energy content of fuels used in the GREET analysis.

$$FE_{FFV} = FE_{gas} * \left(\frac{EC_{E85}}{EC_{gas}}\right) = 7.00 * \left(\frac{82{,}294}{116{,}090}\right) = 4.96\ mpg \quad (13)$$

where FE_{FFV} is the fuel economy of the FFV in miles per gallon of E85, FE_{gas} is the fuel economy of the gasoline vehicle in miles per gallon of gasoline, EC_{E85} is the energy content of E85 in BTU per gallon of E85, and EC_{gas} is the energy content of gasoline in BTU per gallon of gasoline. The resulting fuel economy of a FFV running on E85 is reduced by approximately 29% due to the energy content difference.

The electric fuel economy for the general analysis was derived based on the released specifications of the electric Eqo 14. This fuel efficiency will be treated as a worst case scenario and compared against other future potential vehicle efficiencies during sensitivity analysis. The vehicle efficiency of the Eqo 14 is obtained by dividing the estimated driving range on a full charge by the battery capacity as demonstrated in Equation 14.

$$FE_{BEV} = \frac{Range}{Battery\ Capacity} = \frac{80\ miles}{80\ kWh} = 1.00\ miles/kWh \quad (14)$$

where FE_{BEV} is the fuel efficiency of the BEV in miles per kWh.

3.2 Financial Inputs

Purchase cost, operating cost, and salvage cost are the three main financial components usually taken into consideration during the decision process. These expenditures must be balanced to ensure that there is sufficient initial capital for the project, while also providing for the longevity of the program. Although AFVs typically have a higher purchase cost, the large number of miles traveled can present significant fuel cost savings over conventional gasoline. The operating cost can be split between the fuel consumption cost and maintenance cost and should include conversion for the time value of money so that the future cash flows are discounted to obtain the net present costs of the various alternatives. The net present cost allows a direct comparison to determine the lower life-cycle cost of ownership.

The fuel cost can also vary from year to year depending on the impact of the market on fuel prices. The price of CNG is historically less than that of gasoline and tends to be more stable. Additionally, the national retail price of electricity has a general upward change varying by approximately 2% per year. Therefore, projections for the life-cycle of the project should include estimates for the trends of the respective fuel types. The consistency of the fuel price is important in defining the operating budget of the fleet as unexpected spikes in fuel cost could jeopardize the liquidity of the program. This variability can be managed by fleet operators through long term contracts with fuel suppliers, thus creating a more stable price (Werpy 2010).

Another potential advantage of electric vehicles is the supplementary revenue streams that could be obtained through providing ancillary services to the electric grid while the vehicle is charging. Electric vehicles are potential assets within the frequency regulation market that can provide regulation by adjusting the rate at which the vehicle charges. EVs would be able to provide a distinct advantage to traditional generators, which are slower to react, produce more emissions, and are least efficient with variable output. There are two different power interactions possible between electric vehicles and the electric grid; grid-to-vehicle charging (G2V) and vehicle-to-grid capability (V2G). The current generation of electric vehicles provides only one-way G2V charging, where the electric grid provides energy to the vehicle through a charging station. Future generations of vehicles may be able to provide V2G services as the vehicle becomes a distributed energy and power resource capable of bi-directional charging. However, there is a significant increase in the cost structure for V2G vehicles as well as uncertainties of the impact of the increased cycling on the battery life-cycle.

3.2.1 Types of Cost

Infrastructure Cost

There are a number of fuel types that would not typically have readily available refueling stations for use by the fleet. The Department of Energy provides data on the number of alternative fuel stations located in the United States. There are currently about 10,000 alternative fuel stations in the United States, while there are approximately 160,000 gasoline stations. If public or private stations were not accessible the operator would then have to install the necessary equipment to fulfill the refueling needs of the specific fuel type of the fleet. Figure 3.1 presents the distribution of public and private fueling stations for CNG, electric, E85, and propane.

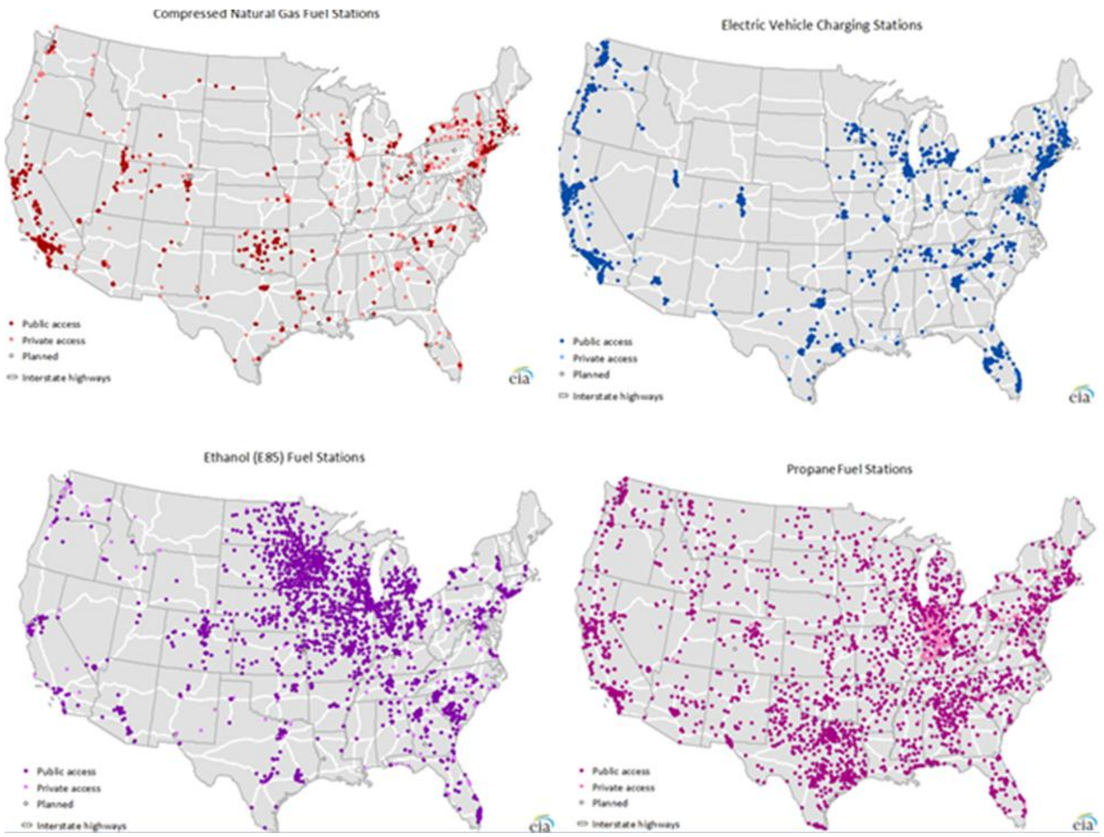


Figure 3.1 Access to alternative transportation fuel stations in the US (EIA 2012)

CNG Station

As of January 2012 the Department of Energy states that there are 975 CNG refueling stations in the United States. California currently has the most available stations with 228. However, the type of station is also important as there can be slow fill stations that provide refueling over an extended period of time or fast-fill systems that provide refueling in a matter of minutes. The type of station depends on the use patterns of the fleet as slow-fill stations would be appropriate for a fleet that only needs to refuel once and can park overnight at a central location. Conversely, fast-fill stations are necessary for fleets that require multiple refueling during their use-cycle.

Time-fill stations fill multiple vehicles simultaneously over a six- to eight-hour period as a compressor compresses the natural gas from pipeline pressure (5-100 psi) to the vehicle pressure (2400-3600 psi) (DOE 2003). These stations require an extended period of inactivity for the fleet but are the least expensive option since there are relatively small compressors and no CNG storage. There are two different fast-fill stations, cascade and buffered, that provide quicker refueling needs with storage systems so compressed CNG is already available for refueling. Cascade fast-fill stations feature a bank of storage tanks for refueling multiple vehicles during peak times. Meanwhile, buffered fast-fill stations contain a storage buffer that is suitable for fueling high-volume applications. Figure 3.2 presents these different station types.

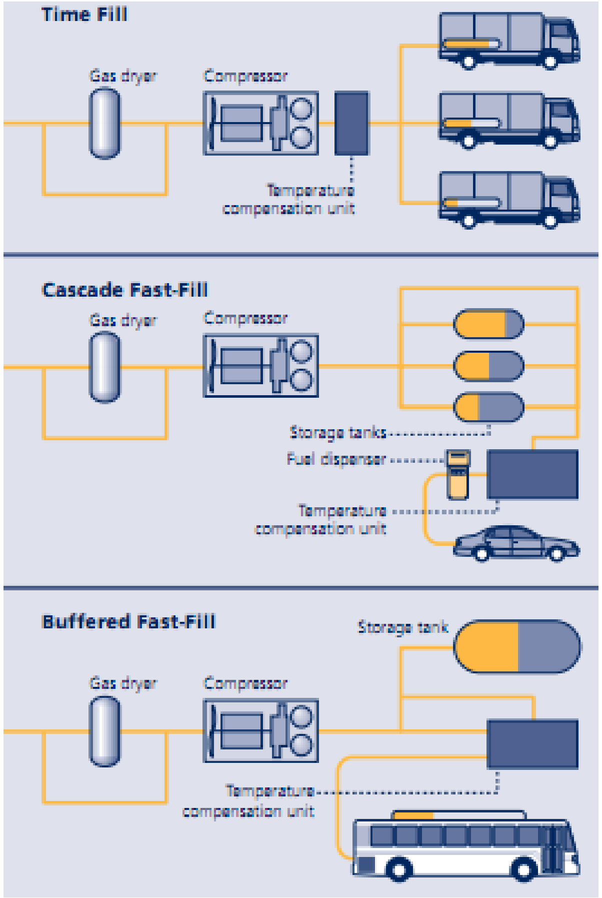


Figure 3.2 Different CNG refueling station types (DOE 2003)

CNG fuel system providers usually need a minimum of 20,000 GGE per month throughput for an economically viable station (Galligan 2010). An estimate for the infrastructure cost demands of a CNG station is provided from the Clean Cities Vehicle and Infrastructure Cash-Flow Evaluation Model. This model of station cost is derived for a buffered fast-fill station and is based on numerous real-world installations. The equation obtained from this model that is used to estimate CNG station cost is presented in Equation 15 and is dependent on the monthly throughput of CNG expressed in gallons of diesel equivalent.

$$Station\ Cost = 15.351829 \times \frac{Monthly\ DGE}{0.904} + 1{,}329{,}224 \tag{15}$$

This cost could be offset if the fleet was able to take advantage of any potential cooperatives with other CNG fleets in their local. Additionally, there is the potential for Federal incentives to reduce the cost of infrastructure. There is an Alternative Fuel Infrastructure Tax Credit, which provides for a 30% tax credit up to $30,000. This tax credit used to be for costs up to $200,000 and may depend on future legislative developments.

Propane Fueling Station

Propane is stored as liquid and thus requires substantially less pressurization than CNG. This contributes to providing simpler and more affordable refueling options for fleet applications. A portable application is an entire system – tanks, pumps, etc. – installed on a movable skid without any major permanent installation. Therefore, propane refueling infrastructure can be up to an order of magnitude less than refueling infrastructure that a CNG fleet would require.

CleanFuel USA estimated the average cost for a propane fueling station with various tank sizes including equipment, installation, and permitting fees for California. These costs are detailed in Table 3.2 and are for stations with fully integrated electronic dispenser and capability to interact with most major fuel management network cards designed for fleet motor fuel applications.

Table 3.2 Propane Fueling Stations Estimated Costs (Werpy 2010)

Tank Size	Type	Cost
500-gallon	Turnkey dispenser skid system	$37,000
1,000-gallon	Turnkey dispenser skid system	$45,000
2,000-gallon	Turnkey dispenser skid system	$60,000
15,000-gallon	Two dispensers on the fueling island	$130,000
15,000-gallon	Four dispensers on the fueling island	$155,000

E85 Fueling Station

Although gasoline sold in the United States can be blended with 10% ethanol content, there are a limited number of stations that support E85. The majority of these stations are located in the corn-producing Midwest region. Johnson et al provided an analysis of E85 retail business case. For the default cost of a new E85 installation at an existing gasoline station Johnson estimated approximately $60,000 including new underground storage tank, pump, dispenser, and installation (Johnson 2007). This figure is mostly affected by dispenser needs and installation requirements. Another estimate is available in the EPA's Renewable Fuel Standard which estimates the costs of a new E85 dispenser at $23,000 with an additional $102,000 for installation of a new tank (EPA 2010).

Electric Charging Station

Any charging station for electric vehicles is referred to as electric vehicle supply equipment (EVSE) and provides safe power flow between the electric distribution system and the vehicle. In the United States, there are three separate levels of charging distinguished as Level I through Level III. The different levels are categorized by voltage and power levels: Level I is 120V AC up to 20A (2.4kW), Level II is 240V AC up to 80A (19.2 kW), and Level III is 240V AC at power levels of 20-250kW. Level III is not fully defined yet and is often referred to synonymously with DC fast charging. Additionally, there is a Society of Automotive Engineers (SAE) standard, SAE J1772, which defines a five-pin configuration for all Level I and Level II charging. The same standard for Level III connectors and DC stations has not been established; limiting vehicles capable of fast charging.

The charging requirements of an EV fleet would be dependent on the demand and scheduling needs of the unique scenario. For a fleet with a predictable, shorter route and overnight downtime, Level II stations would most likely be appropriate. Meanwhile, fleets with longer, continuous, or unpredictable routes would need a Level III DC station. A Level II station would take 3 to 8 hours; while a Level III DC station would take 10 to 15 minutes. Schroeder et al. provides a compilation of information on EV charging station cost presented in Table 3.3. All cost data was converted from Euro to US Dollars at an exchange rate of 1.30 $/€.

Table 3.3 Compilation of information on EV charging station cost (Schroeder 2012)

	'Super-fast' DC public	**Level III DC public**	**Level III AC public**	**Level IIAC public**	**Level II AC home**
Station Lifetime	10	10-15	10-15	10-15	10-15
Load limit (Volt)	2,000	500	230	230	230
Load limit (Ampere)	125	125	96	16	16
Current	DC	DC	AC	AC	AC
Power limit (kW)	250	63	50	4	4
Duration of 20 kWh charge cycle (min)	5	19	24	333	333
Max. number of 20 kWh charging per day	288	75	60	4	1
Material Station Cost	$ 78,000	$ 52,000	$ 52,000	$ 2,600	$ 650
Grid reinforcement cost	$ 26,000	$ 19,500	$ 13,000	$ 1,300	-
Transformer Cost	$ 45,500	0-$45,500	-	-	-
Total Capital Cost	$ 149,500	$ 71,500	$ 65,000	$ 3,900	$ 650
Cost per power unit ($/kW)	598	1,144	1,300	1,083	181

As a rule of thumb, Schroeder estimates that annual maintenance and repair would be approximately 10% of the investment cost (Schroeder 2012). One clarification is the fact that these are only representative numbers for electric charging station costs. The complexity of each installation would be unique to the respective location and thus have varying installation and permitting costs. Additionally, the evolving nature of the

EV industry means that there is continuous innovation occurring leading to opportunities for potential cost reductions. As the industry grows, there will also be opportunities for EVSE producers to obtain economies of scale in the production process leading to lower marginal costs in manufacturing. Another future opportunity for charging fleets with predictable routing schedules would be inductive charging instead of the traditional conductive charging through plug-in connectors. This developmental technology would allow the vehicle to recharge wirelessly by utilizing transmitting pads that can transfer power via induction when the vehicle is parked on it. This type of technology would allow EVs within fleets to experience much less downtime for recharging as the vehicle could potentially recharge while in service. For example, if the transmitting pad was located at a stop, an electric shuttle with inductive charging would be able to recharge during the loading/unloading of passengers.

Purchase Cost

The purchase costs of the vehicles are estimated from information provided by the third-party companies that modify the original chassis provided by Ford Motor Company. The base vehicle cost is obtained from data provided by Azure Dynamics and includes the chassis and shuttle bus body. The conversion cost is then the cost of converting the vehicle to operate on the respective fuel source. FFVs are assumed to be relatively on level with gasoline version as all but the 6.8L E-450 come with flex fuel capability. Table 3.4 presents an overview of these costs.

Table 3.4 Purchase Costs per Vehicle

Cost Specifications	**Gasoline**	**Hybrid**	**E-85**	**CNG**	**Propane**	**BEV**
Source	*AD*	*AD*	*AD*	*BAF*	*Roush*	*Estimate*
Base Vehicle Cost	$ 47,500	$ 47,500	$ 47,500	$ 47,500	$ 47,500	$ 47,500
Conversion Cost	$ -	$ 45,000	$ -	$ 20,500	$ 13,900	$ 40,000
Miscellaneous	$ -	$ -	$ -	$ 2,000	$ -	$ -
Total Vehicle Cost	$ 47,500	$ 92,500	$ 47,500	$ 70,000	$ 61,400	$ 87,500
Tax	$ 4,038	$ 7,863	$ 4,038	$ 5,950	$ 5,219	$ 7,438
Net Chassis Cost	$ 51,538	$ 100,363	$ 51,538	$ 75,950	$ 66,619	$ 94,938
Federal Tax Credit	$ -	$ -	$ -	$(18,000)	$ -	$(7,500)
Net Purchase Cost	$ 51,538	$ 100,363	$ 51,538	$ 57,950	$ 66,619	$ 87,438

The estimate for the BEV is obtained by a comparison the cost differential from a Transit Connect gasoline vehicle to a Transit Connect electric vehicle. The tax is based on an 8.5% tax rate.

Fuel Cost

The fuel cost is one of the more unpredictable aspects of the financial analysis since it is always so dynamic in today's marketplace. As previously mentioned, the reduction in fuel cost is often the leading financial benefit from switching to AFVs.

Fuel Trends

The Clean Cities Alternative Fuel Price Report is a quarterly report that provides the prices of alternative fuels and conventional fuels in the U.S. These prices represent the retail, at-the-pump sales prices for each fuel, including federal and state motor fuel taxes. Figure 3.3 presents the U.S. average retail fuel price from April 2000 until July 2011in the cost per gallons of gasoline equivalent.

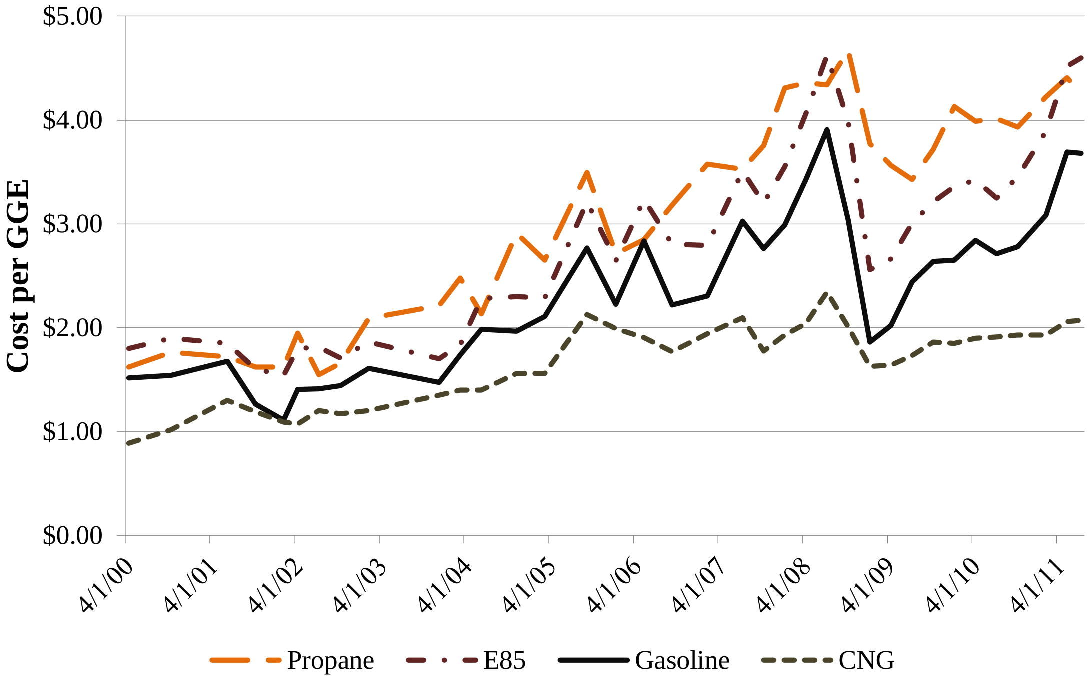


Figure 3.3 U.S. Average Retail Fuel Price Trends (Cities 2011)

Prices can also be grouped in the regions defined by the Petroleum Administration for Defense Districts (PADD) to provide a regional perspective on price variation. Figure 3.4 displays the different districts.

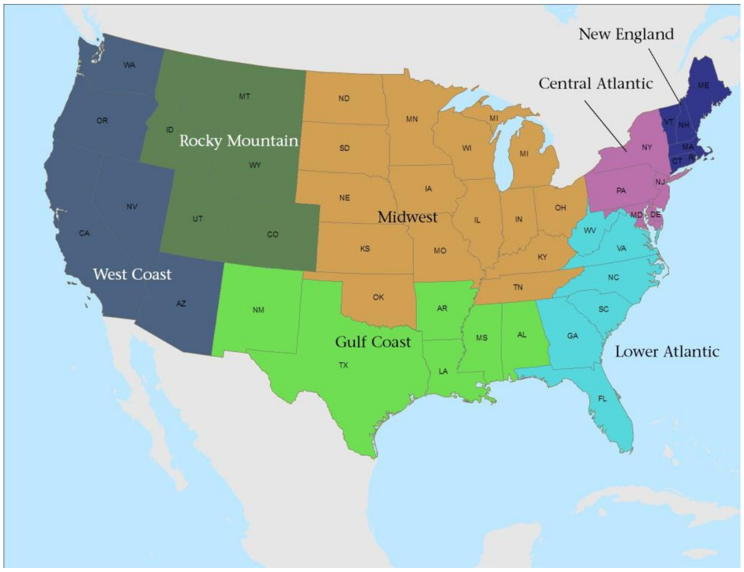


Figure 3.4 Map of U.S. areas by PADD definition

The Energy Information Administration (EIA) provides data on the cost of electricity by both U.S. averages and state averages. Figure 3.5 reports the monthly U.S. average price of electricity to commercial customers from January 2009 until November 2011. This trend shows that there is an increase in electricity price over time, while also experiencing seasonal variation.

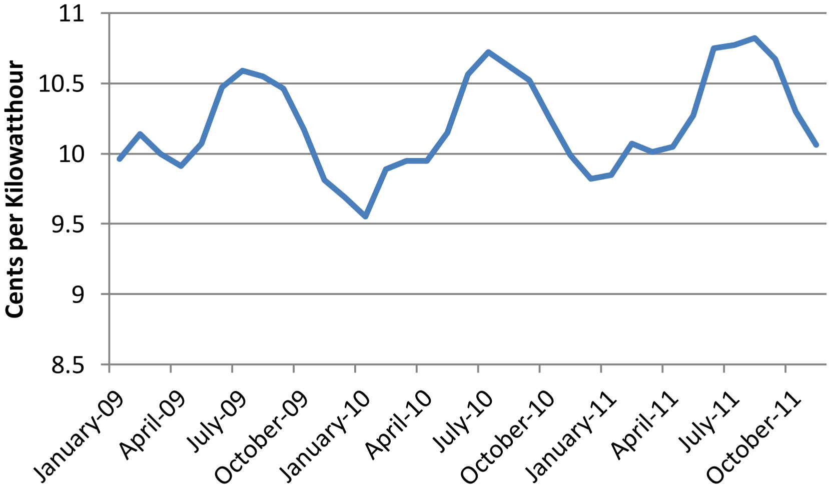


Figure 3.5 U.S. Average Price of Electricity to Commercial Customers (EIA 2011)

This data can also be broken down into regional variation as presented in Figure 3.6, which presents the price of electricity and the consumption of electricity for November and June 2011by census divisions.

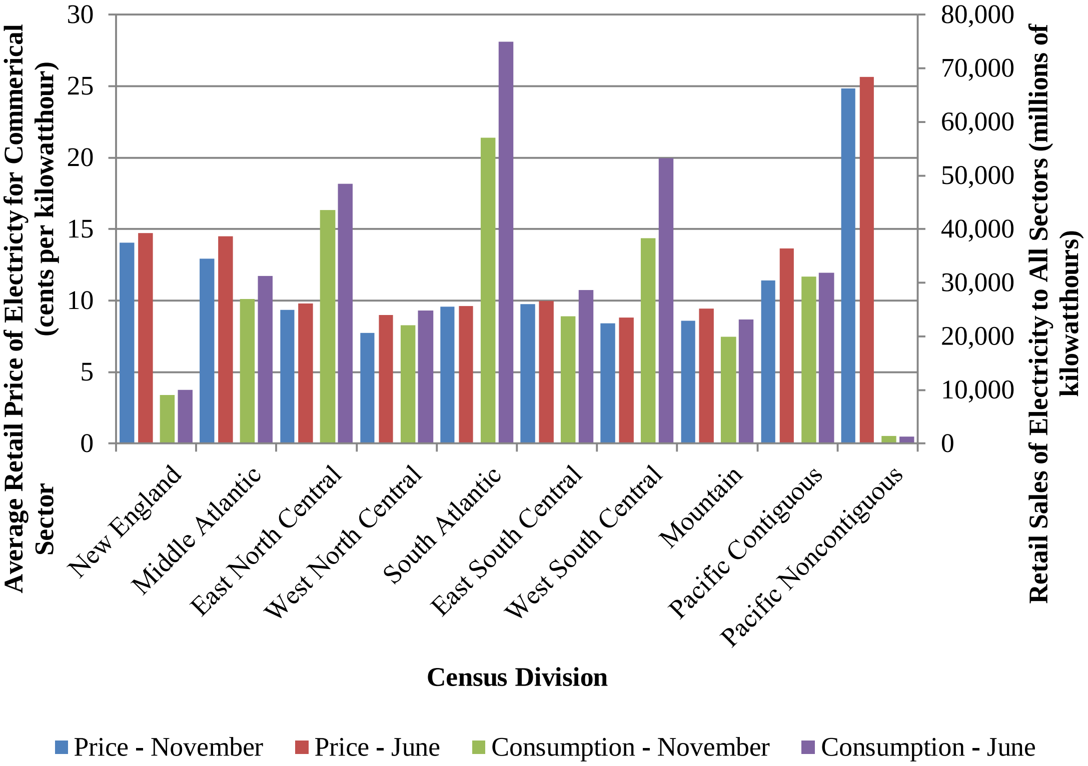
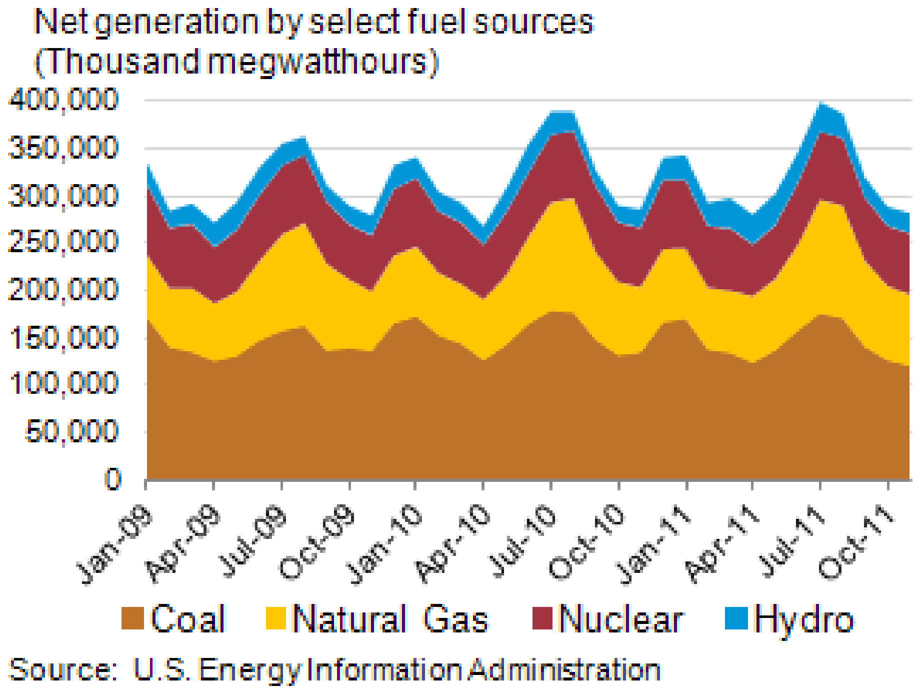


Figure 3.6 Electricity Price and Consumption Comparison for Different Census Divisions (EIA 2011; EIA 2011)

This comparison shows that the price of electricity in the Pacific Noncontiguous states (Alaska and Hawaii) is dramatically higher than in the rest of the United States. Also, the price, while not as dramatic as the Pacific Noncontiguous, is substantially higher in New England, Middle Atlantic, and Pacific Contiguous regions. There are a number of factors that contribute to this variation in the seasonal price, but the most prevalent is the increase in consumption of electricity during the hotter summer months. This causes a downturn in the fuel stockpile levels and thus an increase in the marginal price of generation. Figure 3.7 presents the net generation by fuel source in the United States over a period from January 2009 until November 2011.


Net generation by select fuel sources (Thousand megwatthours)

Source: U.S. Energy Information Administration

Figure 3.7 Net Generation by Select Fuel Source for the United States (EIA 2011)

The fuel cost for the fleet is dependent both on the price of the fuel and on the efficiency of the vehicle type. Meanwhile, an operator would also prefer a more consistent fuel price so that projected budgets can be more accurate. This would also remove uncertainty around the future fuel cost; therefore, it is important to also understand the potential future cost of the respective fuel source. To provide an assessment of the future price of gasoline, Figure 3.8 illustrates the EIA's projections for the average annual world oil price.

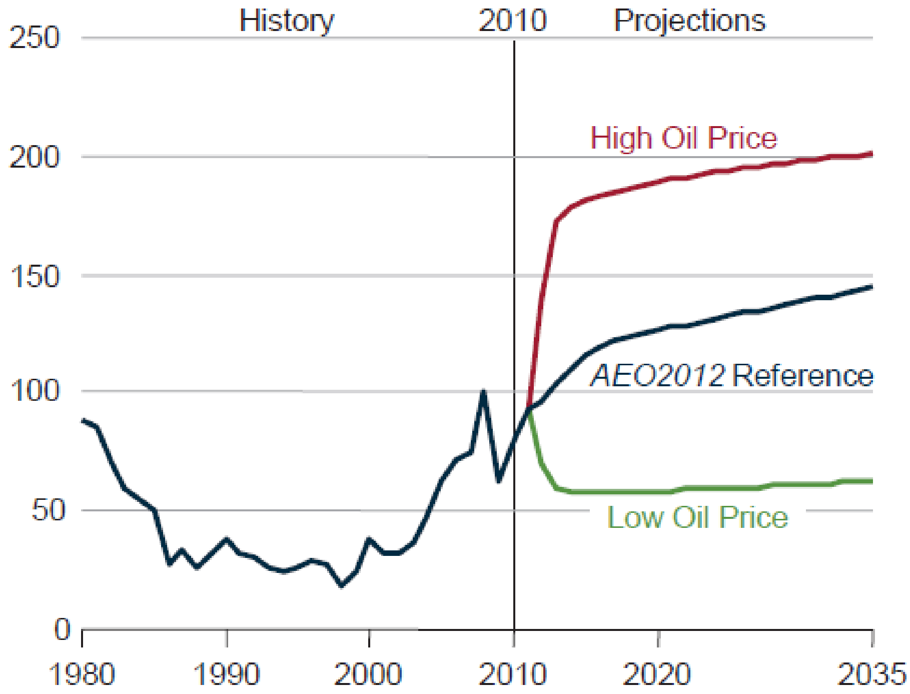


Figure 3.8 Average annual world oil prices in three cases, 1980-2035 (real 2010 dollars per barrel) (EIA 2011)

The annual energy outlook 2012 (AEO2012) projection assumes that the limitation on access to energy resources restrains the growth of producers outside the Organization of Petroleum Exporting Countries (OPEC) in conventional liquids. However, there is significant uncertainty around the future world oil price due to unknown investment and production decisions for both OPEC and non-OPEC members. These future high oil prices will both increase the policy pressure and economic advantages for alternative fuels.

Fuel Cost Modeling

An average of Clean Cities Alternative Fuel Price Reports is utilized to estimate the regional variation for the gasoline, CNG, E85, and propane fuel cost data. This average is obtained from the last six reports that cover a period from July 2010 until

October 2011. Table 3.5 presents the overall average of each fuel type for the different regions.

Table 3.5 Regional fuel cost averages [per gge]

Region	Gasoline	CNG	E85	Propane
New England	$3.32	$2.33	$3.15	$3.34
Central Atlantic	$3.28	$2.26	$2.89	$3.24
Lower Atlantic	$3.15	$1.79	$2.90	$3.04
Midwest	$3.22	$1.71	$2.82	$2.89
Gulf Coast	$3.10	$1.86	$2.81	$2.85
Rocky Mountain	$3.15	$1.48	$2.73	$2.74
West Coast	$3.47	$2.27	$3.03	$3.08
National Average	$3.23	$2.00	$2.86	$3.02

Since the model allows the user to vary the regional parameter on the state level, each state is matched with the respective region to obtain the fuel cost data. Meanwhile, the cost for electricity is determined on the state level from data provided by the EIA. The cost for electricity for each state is presented in Appendix X.

Maintenance Cost

The maintenance cost of vehicles is dependent on the type of fuel source. EVs feature the benefit of requiring no oil changes, radiators, water pumps, tune ups, or other maintenance associated with gasoline vehicles. However, the costly batteries that provide the power for these vehicles will degrade over repeated charging cycles. Currently, EVs have been able to experience revitalization due to battery technologies for vehicle traction increasing in energy density with the advancements in lithium-ion batteries. The majority of current EVs produced by major OEMs rely on lithium-ion batteries with a Manganese Spinel based cathode system. These cathode systems are relatively stable, mature technology, and with failure modes that are well understood and controlled. However, the Manganese Spinel have lower energy capacity and have known cycle-life problems due to manganese dissolution, which can be exacerbated at high temperatures (Duong 2010). Peterson et al. found that this degradation in energy capacity was less than 10% regardless of the depth of discharge, the percentage of battery capacity utilized in a given cycle (Peterson 2010). However, rapid discharge and charge events, similar to V2G modes, do lead to more rapid battery capacity fade. Figure 3.9 presents the degradation of the energy capacity over uses with varying depths of discharge (DOD).

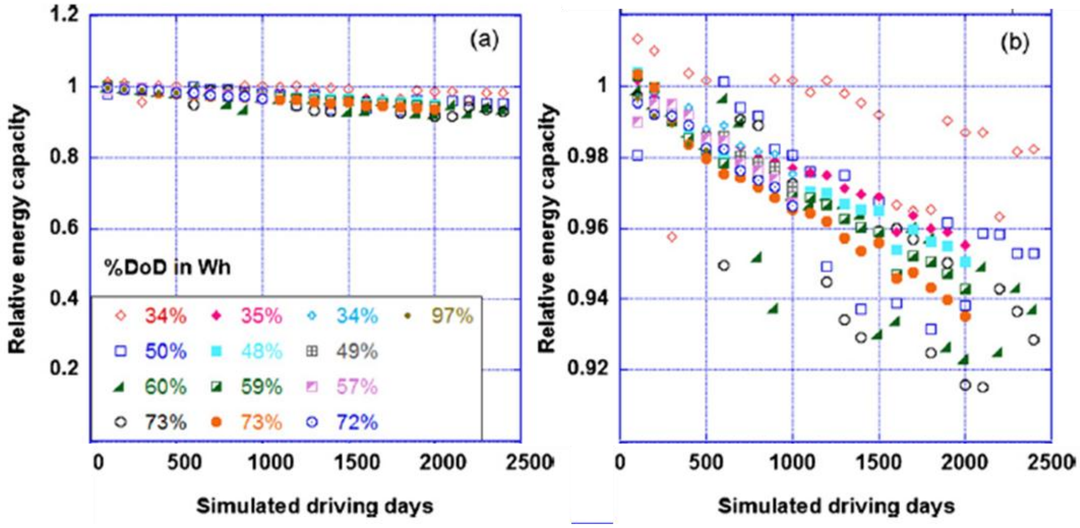


Figure 3.9 Degradation of cells vs. driving days simulated (a) full range, (b) same information zoomed (Peterson 2010)

The model will disregard maintenance variation by fuel type due to the wide range of unverifiable claims for the different fuel types. For HEV and BEV there are proposed reductions in maintenance due to savings in brake life from reduced wear and tear through regenerative braking. Similarly, in CNG applications there have been small sample sizes of reduced routine maintenance and increased unplanned maintenance (Eudy 2000).

Revenue Generation

The electricity market of the United States can be broken down into several distinct regions as presented in Figure 3.10.

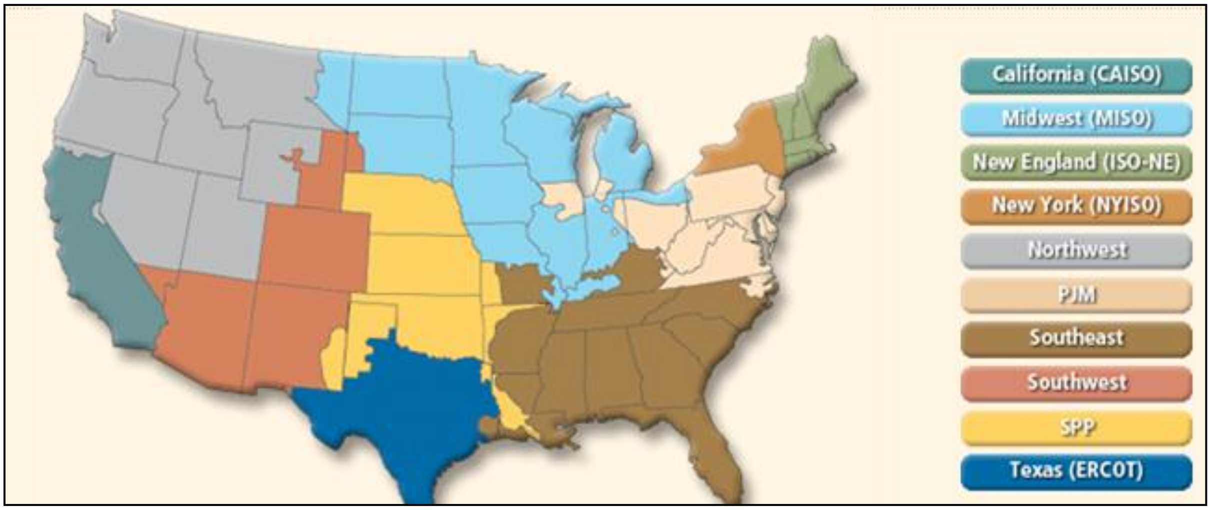


Figure 3.10. Electricity markets of the United States (FERC 2011)

The regions can further be differentiated by the presence of an Independent System Operator (ISO) or Regional Transmission Organization (RTO), which separates the generation sector from the natural monopoly functions of electricity transmission and distribution. ISOs grew out of Orders Nos. 888/889 where the Federal Energy Regulatory

Commission used Independent System Operators as a method to break up the existing power pools and provide even access to transmission (FERC 2011). Figure 3.11 displays the different regions that are controlled by ISOs/RTOs.

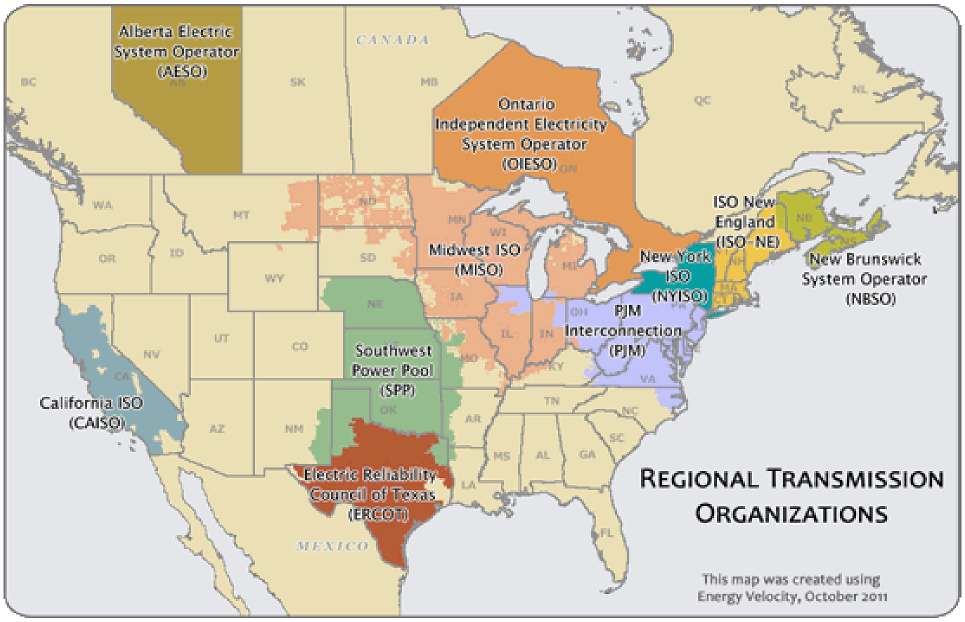


Figure 3.11 ISOs/RTOs Regions (FERC 2011)

Ancillary Services

ISOs are responsible for maintaining reliability of the grid by matching the variability of demand and supply. Ancillary services are functions performed within the electric power system necessary to support the transmission of electricity and maintain reliable operations. One of these services is frequency regulation, which maintains a frequency in the electric grid of 60 Hz by balancing supply and load. If there is greater demand than supply, the frequency decreases below 60 Hz and generator output must be increased to meet demand and vice versa as represented in Figure 3.12.

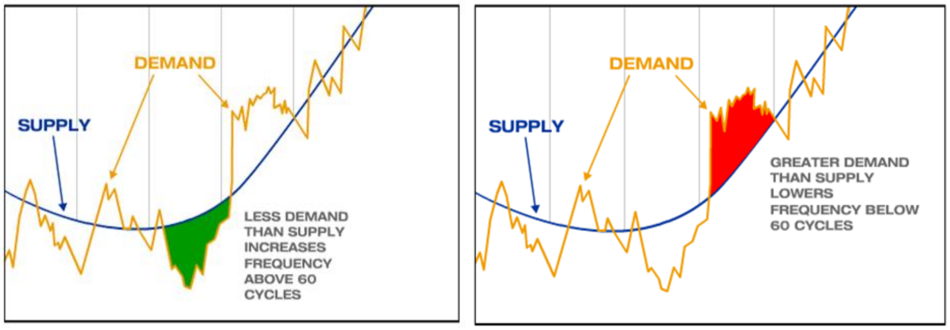


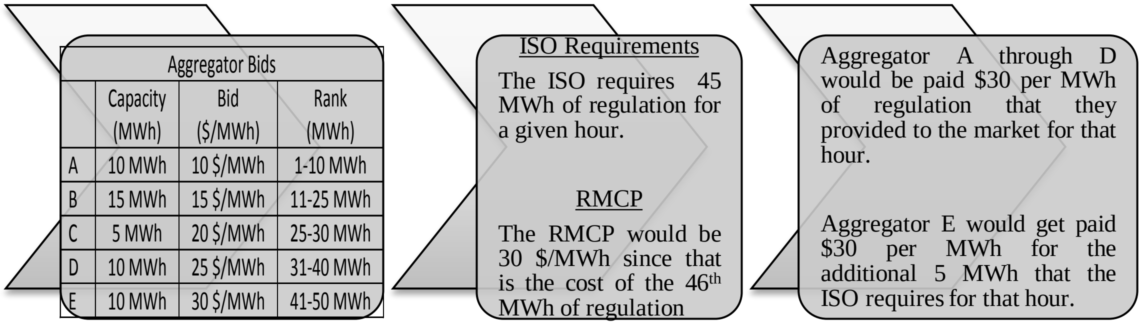
Figure 3.12 Impact of supply/demand variations on electric grid frequency (Power 2012)

This has become a very dynamic market due to the recent developments of compressed air storage, flywheels, and batteries. These technological developments allow for more rapid response to the frequency demand changes within the electric grid than conventional generators.

Frequency Regulation Market Process

An aggregator must currently have 500 kW to join the market, although this qualification will be reduced to 100 kW at the end of this year. Once an aggregator is participating in the market, they must determine 20 minutes before the hour how much capacity to bid in depending on their own algorithms. For small aggregators an encrypted signal is sent over the internet that is decrypted by a provided box based on a secure protocol. An aggregated response is required every 4 seconds, although the aggregator can decide how to allocate the signal among the resources.

The aggregator is paid for the capacity bid into the market before the hour at the Regulation Market Clearing Price (RMCP), the highest cost marginal generator. This price is determined by ranking the current bids from lowest to highest bid price for the given hour and the last bid beyond the needed capacity sets the RMCP. As an example, in a given hour, the ISO determines that 45 MW of regulation are required. The RMCP will be set at the price of the 46th MW of capacity that was bid into the market. Some aggregators bid low to ensure participation in the market. This process is illustrated in Figure 3.13.



Aggregator Bids

	Capacity (MWh)	Bid ($/MWh)	Rank (MWh)
A	10 MWh	10 $/MWh	1-10 MWh
B	15 MWh	15 $/MWh	11-25 MWh
C	5 MWh	20 $/MWh	25-30 MWh
D	10 MWh	25 $/MWh	31-40 MWh
E	10 MWh	30 $/MWh	41-50 MWh

ISO Requirements

The ISO requires 45 MWh of regulation for a given hour.

RMCP

The RMCP would be 30 $/MWh since that is the cost of the 46th MWh of regulation

Aggregator A through D would be paid $30 per MWh of regulation that they provided to the market for that hour.

Aggregator E would get paid $30 per MWh for the additional 5 MWh that the ISO requires for that hour.

Figure 3.13 Example of regulation market process to determine the RMCP

RMCP Patterns

As seen in Figure 3.14, the daily average RMCP features an elevated level during the early morning hours. This aspect can be attributed to the fact that the frequency reserve market is mostly dependent on the incremental capacity from fossil fuel and hydroelectric generation sources. During the early morning hours the plant's incremental capacities are not available or cost-effective for use in the frequency regulation market. The fossil plants are at their minimum levels, the 'run of river' hydroelectric stations are waiting for higher daytime prices, and the pumped hydroelectric stations are pumping water up to the high level lakes to be available for later generation. The reduced supply results in higher prices due to units bidding in at higher levels to cover additional maintenance costs, which raises the RMCP. As the day progresses the generation capacities begin responding to the increased energy cost and can bid into the frequency regulation market more economically, which lowers the RMCP.

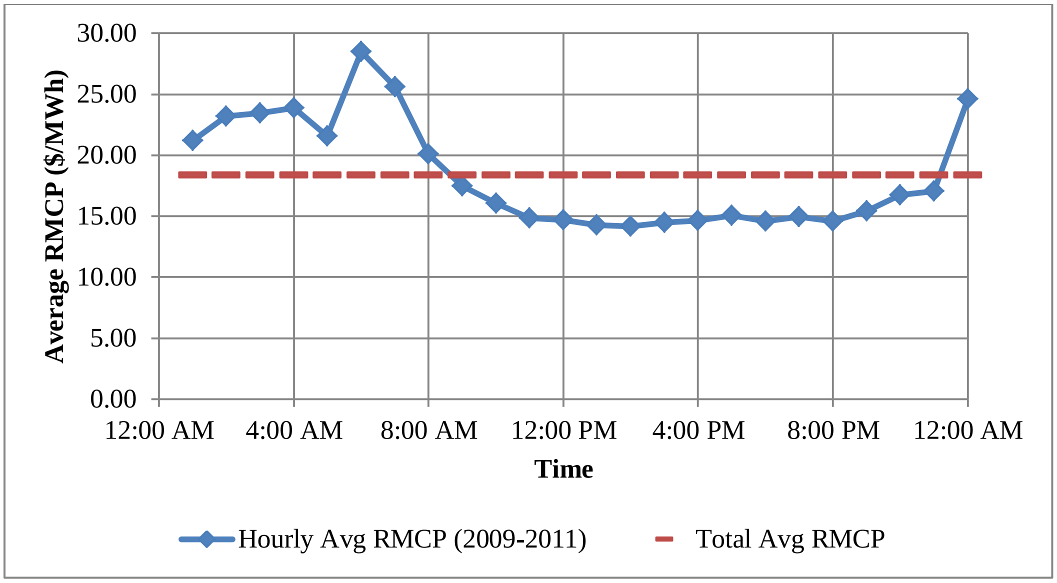


Figure 3.14 Daily Average RMCP ($/MWh) for PJM ISO from 2009-2011

Additionally, the RMCP can vary based upon the fuel input cost, which increases the marginal incremental price for the various generators. The marginal fuel types for a few of the ISOs are PJM (Coal [74%] and Natural Gas [22%]), NY (Natural Gas), and MISO (Coal).

Future regulations may also cause increases for the operating costs for these marginal fuel types. The E.P.A. estimates that a new ruling on air toxins and mercury that should be completed in November will result in a loss of 10,000 MW (1% of US generating capacity). Meanwhile, electricity experts state that combined with rules on coal ash and cooling water, up to 48,000-80,000 (3.5-7%) may have to be shutdown. These rulings will hasten the retirement of older low-cost generators and could increase the rates from 10-35% as the newer high-cost generators are installed to manage peak loads or older generators are retrofitted for compliance (Wald 2011).

Electric Vehicle's Role

Electric vehicles are potential assets within the frequency regulation market that can provide regulation by adjusting the rate at which the vehicle charges. EVs would be able to provide a distinct advantage to traditional generators, which are slower to react, produce more emissions, and are least efficient with variable output. To determine the bid per vehicle, one must determine the bias point or the level of charge that can be symmetrically fluctuated around. For example, a Ford Focus EV has the ability to provide a maximum bias point of 3.3 kW of regulation to the market due to the limits on charging power available through a dedicated level 2 charger of 6.6 kW. Therefore, an aggregator would need a fleet charging of 152 vehicles currently (31 vehicles in 2012) to participate at the minimum bid quantity of 500 MW (100 MW in 2012).

There are a number of challenges that would have to be addressed in order to utilize a collection of electric vehicles for frequency regulation in the ancillary services market. The aggregator's resources must be located within an electric distribution company's region and there may be multiple distribution companies within a metro area. Additionally, each vehicle can only provide capacity when the battery is sufficiently depleted. As a vehicle approaches a full charge, its symmetric charge rate or market capacity is reduced.

These limitations create a challenging business case for an aggregator that would have to assemble a sufficient collection of distributed individual electric vehicles. However, a fleet operator may be able to also operate as an aggregator for frequency regulation and thus create a new possible revenue stream. Many of the previously discussed limitations are managed by the fact that the fleet operator is in direct control of the electric vehicles. One is able to then manage these now dynamic resources to maximize potential benefit for both transportation services and frequency regulation revenue generation.

Future Developments

There are also a number of future developments within the frequency regulation market that would increase the possible revenue streams. Currently, the qualifications for frequency regulation require a response of 10 minutes for bias charging, 10 minutes for full charge with 75% full charge within 5 minutes, and 10 min of negative charge. However, due to a federal mandate, new qualification in seconds range would provide higher prices to an aggregator. This pay-for-performance price structure is currently implemented in the New England ISO and would be beneficial to electric vehicles, which can respond much quicker than traditional thermoelectric regulation sources.

In discussions with PJM representatives, a new accounting method for PJM ISO would take into account the lost opportunity credit; this is the amount of money paid to generators to provide capacity to the frequency regulation market instead of the energy market. The method could potentially increase RMCP by approximately 20%.

Bi-directional V2G technology would allow for twice the possible revenue due to the ability to bid 6.6 kW per vehicle. Additionally, with future frequency market saturation; EVs could be part of a real price responsive demand based on the wholesale price of electricity.

Other ancillary service markets exist to assist with other reliability concerns for the electric grid. Although an aggregator can only bid into one market, these markets create other possible revenue sources depending on the development of ancillary markets.

The Synchronous Market pays to not charge in order to reduce demand in case a large generator goes offline. This market requires that an aggregator be able to respond in 10 minutes to the grid in support of issues (i.e. major power outages). These loads are always on standby and are required by federal regulation to be available. The total standby required is established based upon the largest generator, which is operating in the system. For example, if a 1.5 GW nuclear power generator is in the system, then there must be enough spinning reserve to support that amount of power generation. There is a different pay structure for the spinning reserve, about 1/5 the amount of frequency regulation revenue stream. The average is $10.5 for spinning reserve.

3.3 Environmental Inputs

As previously stated, current environmental analyses typically focus on one aspect of the environmental implications of fuel choice. Instead it is proposed that both GHG emissions and water consumption should be examined due to the fact that these factors often have inverse relationships when comparing different fuel types. For example, electric vehicles are often seen as reducing greenhouse gas emissions, but electricity generators are also major consumers of water. Hence, it is important to identify the tradeoffs between improvements in these categories.

3.3.1 Greenhouse Gas Emissions Inputs

The CO_2 equivalent emissions were calculated using the full life-cycle model called GREET (Greenhouse gases, Regulated Emissions, and Energy use in Transportation) developed by the DOE's Argonne National Laboratory. GREET allows the evaluations of various vehicle and fuel combinations on a full fuel-cycle basis. The emissions per unit energy of the various fuels are broken up into upstream and tailpipe emissions. Upstream emissions are defined as the emissions from the production and transportation of feedstock and production and distribution of product fuels. Tailpipe emissions are the direct emissions due to the combustion of the product fuels during vehicle operation. The global warming potentials of the greenhouse gases are 1 for CO_2, 25 for CH_4, and 298 for N_2O.

Table 3.6 presents the energy content, upstream emissions, tailpipe emissions, and total emissions of the various fuel types.

Table 3.6 GREET CO_2-Equivalent Emissions by Fuel Type

Fuel Type	Energy Content	Upstream	Tailpipe	Total	Unit
Gasoline	116,090 Btu/gal	0.019	0.078	0.096	g(CO2-Eq)/Btu
Hybrid		0.019	0.078	0.096	
CNG	116,090 Btu/gge	0.017	0.061	0.078	
CNG (Landfill)		-0.053	0.061	0.008	
LPG	116,090 Btu/gge	0.019	0.069	0.088	
E85 (Corn)	82,294 Btu/gal	0.001	0.076	0.077	
E85 (Cellulosic)		-0.057	0.076	0.019	
Battery EV (Coal)	3,412 Btu/kWh	0.362	0	0.362	
Battery EV (NG)		0.188	0	0.188	
Battery EV (Nuclear)		0.005	0	0.005	
Battery EV (Hydro)		0.001	0	0.001	
Battery EV (Solar)		0.001	0	0.001	

Electric power sources do not have any tailpipe emissions since there is no combustion during vehicle operation and the entirety of the emissions is related to the upstream content. For a pure BEV, the emissions of the fuel source have been transferred upstream to the source of the electricity, the respective type of power plant, which determines the true environmental impact of the vehicle. Landfill CNG is captured from decaying organic material and is provided a negative upstream content since this methane and carbon dioxide is being prevented from escaping to the atmosphere.

3.3.2 Water Consumption Inputs

Water consumption is a much different issue from greenhouse gas emissions because it must be addressed at the local level. In regions that have a surplus of water, variations in the level of consumption may have little noticeable impact. However, in water scarce regions, the same consumption could put extreme strain on the available water resources. The water consumption that is analyzed is based only on the water that is consumed in the extraction, processing, transportation, and electricity generation of the desired fuels within a local transportation network. Table 3.7 presents the water consumption for the various fuel types in terms of liters of water per liter of fuel or kWh of electricity.

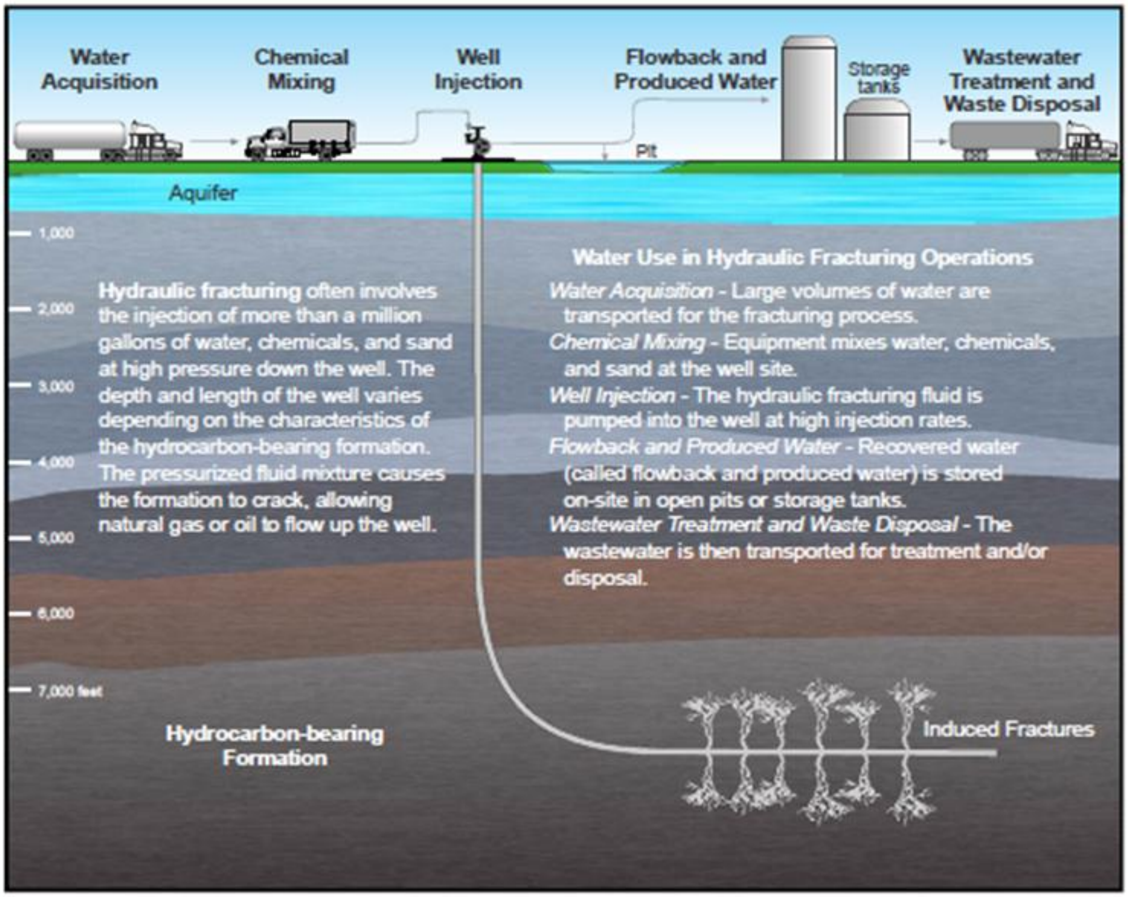
Table 3.7 Water Consumption by Fuel Type

Fuel Type	Extraction	Process	Transport	Plant or Compression	Total	Unit	Source
Gasoline	2.10	1.09	0.65	0.00	3.84	liter (H_2O)/liter (fuel)	(Gleick 1994)
Hybrid	2.10	1.09	0.65	0.00	3.84	liter (H_2O)/liter (fuel)	(Gleick 1994)
LPG	2.10	1.09	0.65	0.00	3.84	liter (H_2O)/liter (fuel)	(Combs 2008)
CNG	0.00	0.05	0.03	See Equation 3.X	0.08 >	liter (H_2O)/ liter (gasoline equivalent)	(Gleick 1994; King 2008)
E85 (Corn)	Regional			3.00	Regional	liter (H_2O)/liter (fuel)	(Wu 2009)
E85 (Cellulosic)	Process Dependent					liter (H_2O)/liter (fuel)	(Wu 2009)
Battery EV (Coal)	0.01	0.03	0.42	2.60	3.06	liter (H_2O)/kWh	(Gleick 1994)
Battery EV (NG)	0.00	0.06	0.03	1.02	1.11	liter (H_2O)/kWh	(Fthenakis 2010)
Battery EV (Nuclear)	0.00	0.13	0.00	3.20	3.33	liter (H_2O)/kWh	(Gleick 1994)
Battery EV (Hydro)	0.00	0.00	0.00	Regional	Regional	liter (H_2O)/kWh	(Torcellini 2004)
Battery EV (Solar)	0.00	0.00	0.00	0.02	0.02	liter (H_2O)/kWh	(Gleick 1994)

As discussed previously, this data represents the total water consumption in the extraction, processing, transportation, and any water consumed at the plant level or to compress the natural gas. For the electricity sources, the majority of the water consumption is at the plant level due to the water required in the cooling processes within the plant. LPG is a byproduct of oil production, so its water consumption is similar to that of oil (Combs 2008). CNG is also dependent on the source of power for the compressor as there is either electric or natural gas powered devices. To compress the natural gas to the 4,000 psi range requires 0.01-0.016 kWh/SCF for an electric compressor with 91.7% efficiency and 8.3% of the natural gas also being used to power the compressor (King 2008) . Equation 16 presents the formula used to calculate the water consumption for the compression of natural gas.

$$Water_{CNG} = \frac{121.5\ ft^3}{gallon\ of\ gasoline} * \frac{0.016\ kWh}{ft^3} * \frac{gallon}{3.785\ liter} * Water_{Regional\ Electricty} \tag{16}$$

This discrepancy creates variability in the impact of CNG vehicles depending on the technology utilized at the fuel storage location. Additionally, natural gas has come under increasing scrutiny in the extraction phase if it is extracted using hydraulic fracturing (fracking) that would both increase water consumption and present significant water quality concerns from chemical surfactant additives. The EPA has recently released new standards for the Clean Air Act that issues regulations around advances in horizontal drilling and hydraulic fracturing technologies. These advances have increased stress on water supplies due to the large volumes of water withdrawals as shown in Figure 3.15.



Hydraulic fracturing often involves the injection of more than a million gallons of water, chemicals, and sand at high pressure down the well. The depth and length of the well varies depending on the characteristics of the hydrocarbon-bearing formation. The pressurized fluid mixture causes the formation to crack, allowing natural gas or oil to flow up the well.

Water Use in Hydraulic Fracturing Operations

Water Acquisition - Large volumes of water are transported for the fracturing process.

Chemical Mixing - Equipment mixes water, chemicals, and sand at the well site.

Well Injection - The hydraulic fracturing fluid is pumped into the well at high injection rates.

Flowback and Produced Water - Recovered water (called flowback and produced water) is stored on-site in open pits or storage tanks.

Wastewater Treatment and Waste Disposal - The wastewater is then transported for treatment and/or disposal.

Figure 3.15 Illustration of a horizontal well showing the water lifecycle in hydraulic fracturing (EPA 2011)

In addition, the shale gas wastewater can contain high levels of total dissolved solids, fracturing fluid additives, metals, and naturally occurring radioactive materials. The technology standards set by the EPA will allow for quantification of the impact of fracking as the EPA is currently in the process of studying the potential impacts of hydraulic fracturing on water resources. However, the model will restrict natural gas water consumption to conventional extraction methods.

Gasoline Variation

The variability in the water consumption depending on location and technology is a ubiquitous problem throughout the fuel types. Gasoline production is highly variable and dependent on the type of well the crude oil is being extracted from as older wells often require the injection of water within the wells to increase the well pressure and thus the oil yield. These discrepancies in technologies utilized and the amount of water recycled within the operation leads to a dependence on the location the crude oil is obtained from for how much water is consumed in gasoline production. The variation is presented in Figure 3.16, which presents the minimum, median, and maximum as well as the 25th to 75th percentile range for gasoline obtained from U.S., Saudi Arabia, and Canadian Oil Sands (Wu, Mintz et al. 2009).

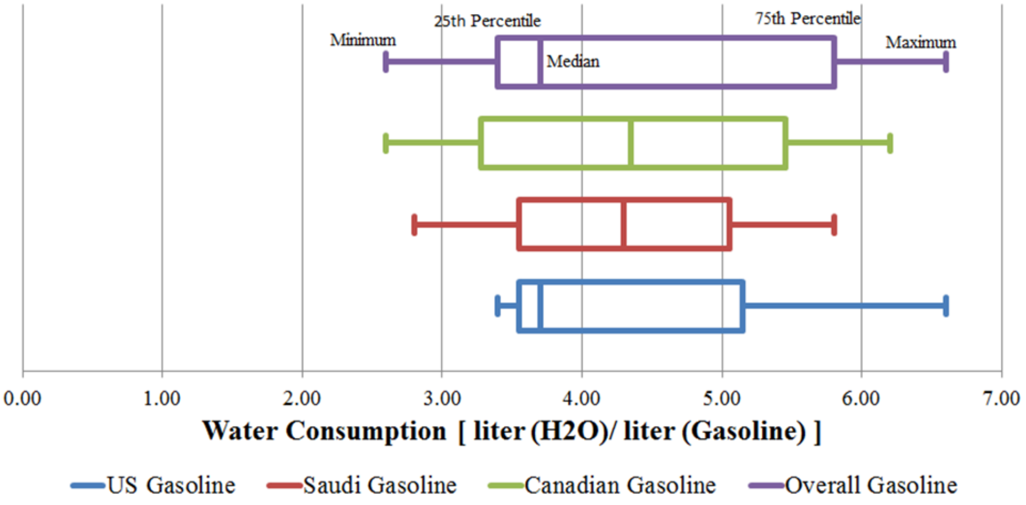


Figure 3.16 Gasoline Water Consumption Regional Variation

The impact of the water consumption is also variable as the same water consumption will have varying effects in different watershed regions. If the water consumption during the extraction of crude oil was considered for gasoline, the water consumption total would increase by 2.10 liter (H_2O)/liter of gasoline produced to a total 3.84 liter (H_2O)/liter of gasoline produced.

Electric Variation

Similarly, electric plants may vary in water consumption depending on cooling technology and potential recycling of water within the processes. These variations, as well as whether the boiler operates as subcritical or supercritical, creates a range of water consumption values at the plant level. Feeley et al. provides a national average water consumption factors for model thermoelectric power plants in 2005 with varying cooling water system type and boiler type. Additionally for coal plants, Feeley et al. included whether flue gas desulfurization occurred and if this process utilized water or not. Figure 3.17 presents the range for the respective fuel sources at the power plant level, which dominates the water consumption for electricity generation as shown in Table 3.X.

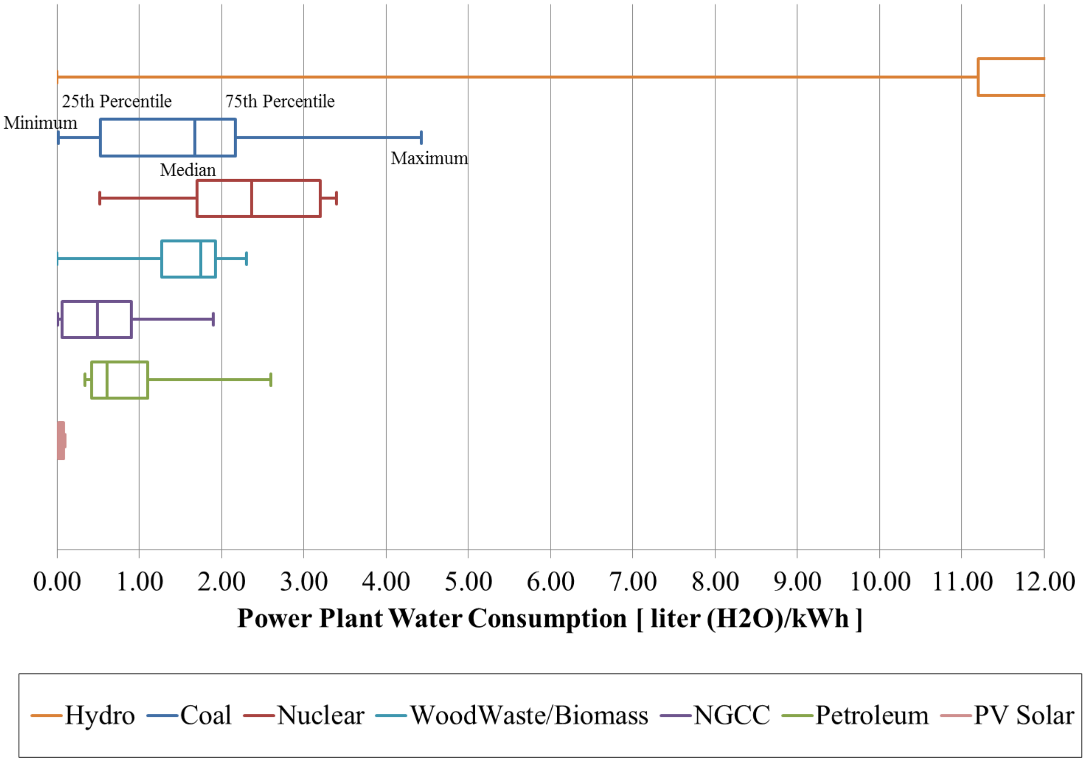


Figure 3.17 Power Plant Water Consumption Variation

Hydroelectric Variation

The power plant water consumption for hydroelectricity is not fully presented on this figure for convenience purposes as the maximum value extends to 208 liter/kWh. Hydroelectric power consumes a magnitude larger than other plant types due to the evaporative losses attributed to the large surface areas of the reservoirs. However, there is a great deal of debate on the extent that the evaporative losses can be attributed to the production of electricity as the reservoirs are often used for a multitude of other purposes. When a reservoir and dam are used for more than one purpose, i.e. electric power production as well as flood control, water storage, or recreation, it is difficult to attribute the water consumption to only one of the uses. The substantial regional differences in the water consumption for hydroelectricity further emphasis the need for an understanding of the local conditions to interpret both the representative water consumption and the resulting impact on the river basin. Additionally, there are a variety of ecological impacts that are considered detrimental in the way that dams alter the natural ecosystem but are difficult to fully quantify.

For modeling purposes, Torcellini et al.'s analysis was used to provide the geographic variation of regional hydroelectric power water consumption. In their report the hydroelectric site water was presented for a number of states as shown in Appendix X. These state-level hydroelectric water consumptions were then averaged by their geographic region to provide an estimate for the states that did not have data points. Table 3.8 presents these regional consumption averages.

Table 3.8 Regional Hydroelectric Water Consumption Averages (Torcellini 2004)

Region	**Hydroelectric Water Consumption Average [gallons/kWh]**
New England	5.57
Central Atlantic	2.46
Lower Atlantic	9.63
Midwest	33.96
Gulf Coast	17.50
Rocky Mountain	54.70
West Coast	33.33
National Average	18.27

Ethanol Variation

Ethanol production varies by both regional production and feedstock source. There are two methods of obtaining ethanol; corn based or cellulosic based feedstock. The majority of corn production occurs in USDA Regions 5, Region 6, and Region 7 as these regions accounted for 89% of corn production and 95% of ethanol production in 2006 (Wu 2009). However, these regions require varying levels of irrigation to produce ethanol as shown in Table 3.9.

Table 3.9 Regional Variation of Water Consumption for Ethanol Production (gal water/gal ethanol produced) (Wu 2009)

	Region 5	**Region 6**	**Region 7**
Share of US Ethanol Production Capacity (%)	51	17	27
Share of US Corn Production (%)	53	17	19
Corn irrigation, groundwater	6.7	10.7	281.2
Corn irrigation, surface water	0.4	3.2	39.4
Ethanol production	3.0	3.0	3.0
Total	**10.0**	**16.8**	**323.6**

In calculating water consumption for corn-based ethanol production, these totals were used for states located in the respective USDA Region. For states located in one of the other seven USDA regions, a weighted average of these regions was used to estimate the national average for water consumption as shown in Equation 17.

$$National\ Average = \frac{51\%}{95\%} * 10.0\frac{gal}{gal} + \frac{17\%}{95\%} * 16.8\frac{gal}{gal} + \frac{27\%}{95\%} * 323.6\frac{gal}{gal} = 100.4\frac{gal}{gal} \qquad (17)$$

There is additional variation for ethanol depending on the process used to ethanol produced from cellulosic feedstock. Currently there are several methods of producing cellulosic ethanol: biochemical conversion, thermochemical conversion using gasification, and thermochemical conversion using pyrolysis. Table 3.10 presents the water consumption for these processes assuming that the cellulosic ethanol is produced from switchgrass that does not require irrigation for acceptable yields.

Table 3.10 Water Consumption for Cellulosic Ethanol Production by Process Type (Wu 2009)

Process	**Water Consumption (gal water/gal ethanol)**
BioChemical, future	5.9
BioChemical, current	9.8
Thermochemical using Gasification	1.9
Thermochemical using Pyrolysis	2.2

Since corn-based ethanol currently dominates the market, the model considers that ethanol is from a corn feedstock as a default. The potential impact of transitioning to cellulosic ethanol is presented in the sensitivity analysis section.

3.4 Societal Inputs

Emissions from vehicles and related sources have a variety of negative impacts on human health from mortality to chronic illness. There has been extensive work into quantifying these impacts through monetary valuation of health damage costs of the air pollution. However, the majority of current work is being conducted in Europe so the last extensive study in the United States was in the 1990s.

3.4.1 Emission Costs

The analysis was restricted to the four criteria pollutants investigated by Mcubbin et al. for which there was sufficient air-quality data and dose-response functions: carbon monoxide (CO); nitrogen dioxide (NO_2); ozone (O_3); and particulate matter (PM), including PM less than 2.5 microns in aerodynamic diameter ($PM_{2.5}$), and PM between 2.5 microns and 10 microns (coarse PM_{10}). Criteria pollutants are pollutants regulated by the EPA through national ambient air quality standards and also include sulfur dioxide (SO_2) and lead.

Mcubbin et al provide the cost per kilogram of vehicle emissions in the US in 1990 by linking emissions, exposure, health effects, and economic value. Although this cost data may be outdated, it is considered the most comprehensive studies done for the USA. Table 3.11 presents the cost per kilogram in the United States and Urban Areas as well as a low and high estimate for both.

Table 3.11 Cost per Kilogram of Vehicle Emissions in the USA in 1990 (1991 $) (McCubbin 1999)

Emission	**Ambient Pollutant**	**United States**		**Urban Areas**	
		Low	*High*	*Low*	*High*
CO	CO	0.01	0.09	0.01	0.10
NO_x	Nitrate-PM_{10}	1.02	16.56	1.39	22.38
	NO_2	0.15	0.73	0.19	0.96
	Total	1.17	17.29	1.59	23.34
$PM_{2.5}$	$PM_{2.5}$	10.42	159.19	14.81	225.36
PM_{10}	Coarse PM_{10}	6.70	17.68	9.09	23.89
	Total for PM_{10}	9.75	133.78	13.74	187.47
SO_x	Sulphate-PM_{10}	6.90	65.52	9.62	90.94
VOC	Organic-PM_{10}	0.10	1.15	0.13	1.45
VOC + NO_x	ozone	0.01	0.11	0.02	0.14

However, this data points must be adjusted for inflation and to current population levels. The data was adjusted by a factor 1.68 to convert from 1991 dollars to 2012 dollars according to the Consumer Price Index inflation. Additionally, the $/kg factors are proportional to the exposed population. The 2010 Census reported that the US population was 308,745,538 people with 249,253,271 located in urban areas. In 1990 the US population was 248,709,873 people with 187,053,487 people located in urban areas. Therefore, there was a 24.14% increase in the US population and a 33.25% increase in the number of people located in urban areas. Table 3.12 presents the adjusted totals for the cost of vehicle emissions to 2012 dollars and 2010 population totals.

Table 3.12 Cost per Kilogram of Vehicle Emissions in the USA in 2010 (2012 $)

(McCubbin 1999)

Emission	**Ambient Pollutant**	**United States**		**Urban Areas**	
		Low	*High*	*Low*	*High*
CO	CO	0.02	0.19	0.02	0.22
NO_x	Nitrate-PM_{10}	2.13	34.54	3.11	50.10
	NO_2	0.31	1.52	0.43	2.15
	Total	2.44	36.06	3.56	52.25
$PM_{2.5}$	$PM_{2.5}$	21.73	332.00	33.15	504.50
PM_{10}	Coarse PM_{10}	13.97	36.87	20.35	53.48
	Total for PM_{10}	20.33	279.00	30.76	419.68
SO_x	Sulphate-PM_{10}	14.39	136.64	21.54	203.58
VOC	Organic-PM_{10}	0.21	2.40	0.29	3.25
VOC + NO_x	ozone	0.02	0.23	0.04	0.31

3.4.1 GREET Emissions

In order to calculate the impact of air pollution on populations the emissions for each fuel type were obtained from the GREET model developed by Argonne National Laboratory. These scenarios were run using GREET's default settings for the various fuel pathways. Each scenario was used to determine criteria air pollutants for the specific fuel type. Table 3.13 displays the overall results for the emissions for each fuel type on an energy content basis.

Table 3.13 Total Emissions on an energy content basis by fuel type (DOE 2011)

Emissions (grams/mmBTU)	**Gasoline**	**CNG**	**LPG**	**E85 (Corn)**	**E85 (Cellulosic)**
VOC: Total	64.223	33.645	40.454	82.917	75.952
CO: Total	776.009	736.214	775.633	791.509	823.147
NOx: Total	81.487	71.895	80.013	117.828	131.947
PM10: Total	10.614	6.545	12.964	35.094	7.886
PM2.5: Total	6.343	3.727	7.062	13.103	6.287
SOx: Total	41.949	67.509	26.446	55.336	-16.459

The GREET model was also run for each electricity type to determine the emissions for each electricity type on an energy content basis as shown in Table 3.14.

Table 3.14 Total Emissions on an energy content basis by electricity type (DOE 2011)

Emissions (grams/mmBTU)	**Petroleum**	**Natural Gas**	**Coal**	**Nuclear**	**Renewable**
VOC: Total	218.358	28.335	32.354	218.358	0.000
CO: Total	2,638.431	102.590	82.012	2,638.431	0.000
NOx: Total	277.055	172.762	427.746	277.055	0.000
PM10: Total	36.088	21.435	695.162	36.088	14.548
PM2.5: Total	21.565	12.173	181.768	21.565	4.849
SOx: Total	142.627	34.662	1,085.774	142.627	0.000

The emissions by electricity were then multiplied by the respective energy mix of the region of interest to determine the criteria air pollutants on an energy content basis for electric vehicles.

CHAPTER 4

IMPLEMENTATION

4.1 Model Overview

The goal of the model is to provide an easily modifiable platform for novice users to create their own fleet scenarios that estimate the financial, environmental, and social impact. However, more advanced users may modify data within the model to tailor results to their specifications. This was accomplished by creating a macro-enabled Microsoft Excel file that featured both a macro based user input form and a basic cell based input form. The responses from the input forms populate throughout the model in order in order to calculate the results for the impact categories. Figure 4.1 presents the flow diagram for the input form for the scenario generator.

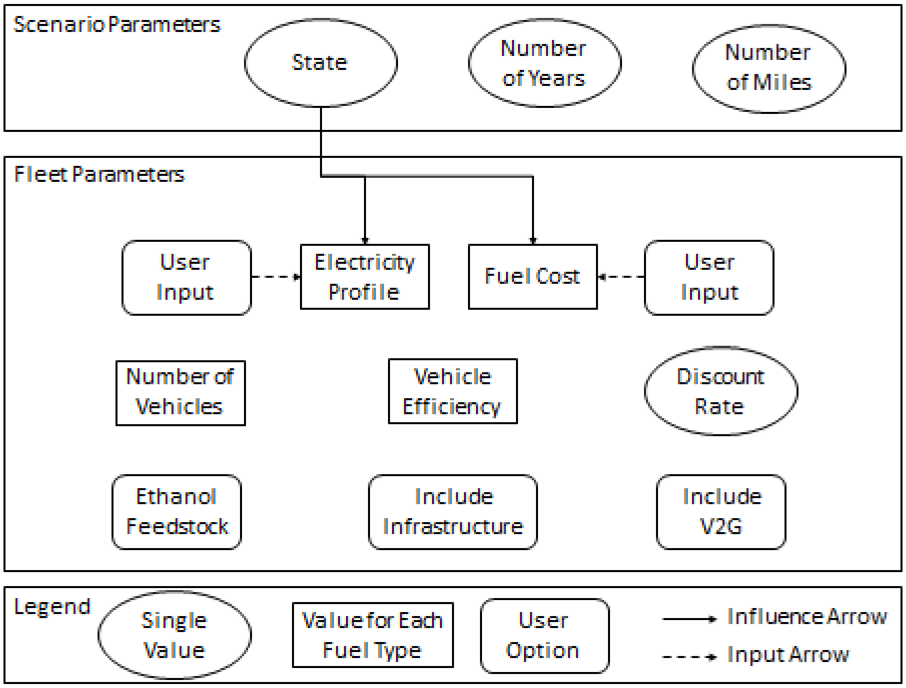


Figure 4.1 Scenario Generator Flow Diagram

These parameters are then inputted into the various impact categories to calculate the financial cost, water consumption, GHG emissions, and societal cost. The flow diagrams are presented in Figure 4.2 through 4.5. Section 4.2 explains the specifics behind the various calculations for each impact category.

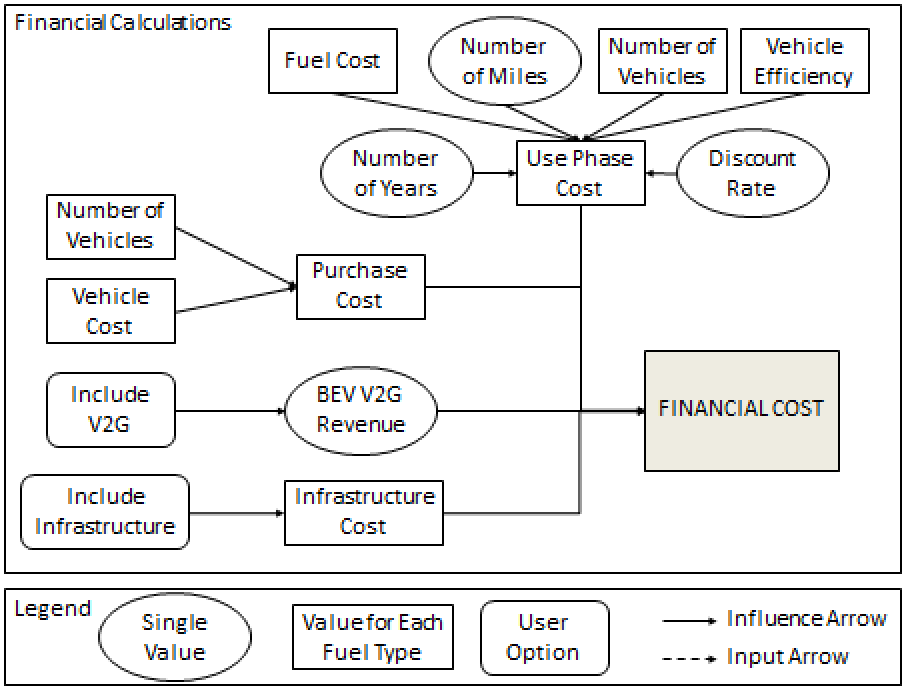


Figure 4.2 Financial Calculations Flow Diagram

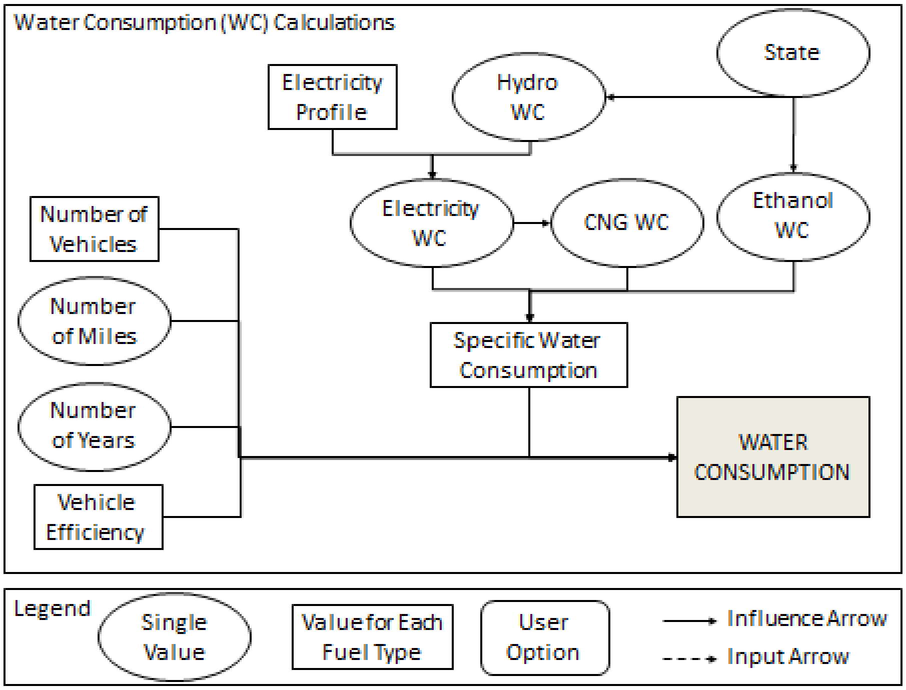


Figure 4.3 Water Consumption Calculations Flow Diagram

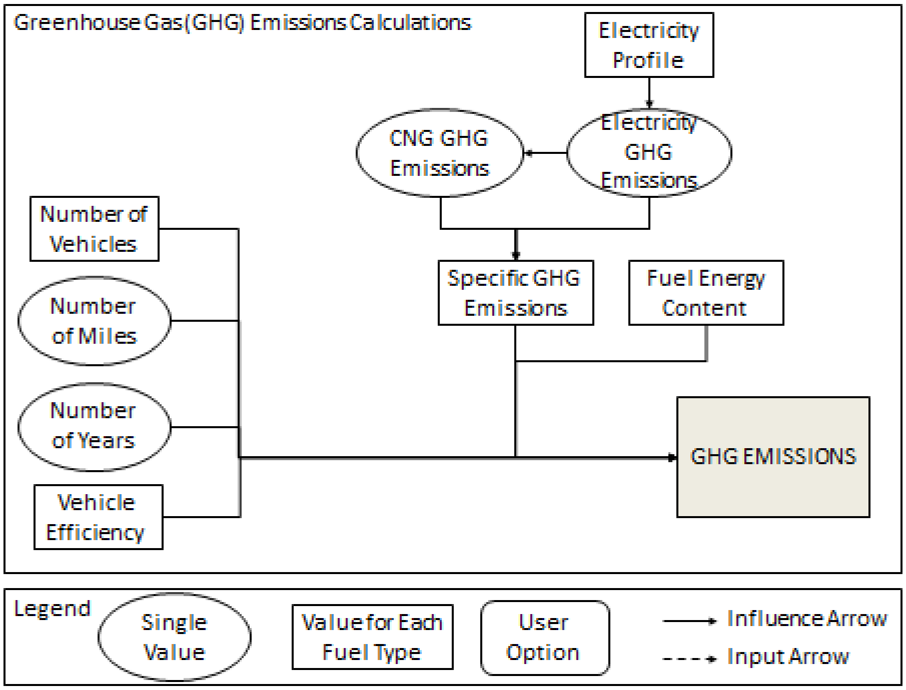


Figure 4.4 GHG Emissions Calculations Flow Diagram

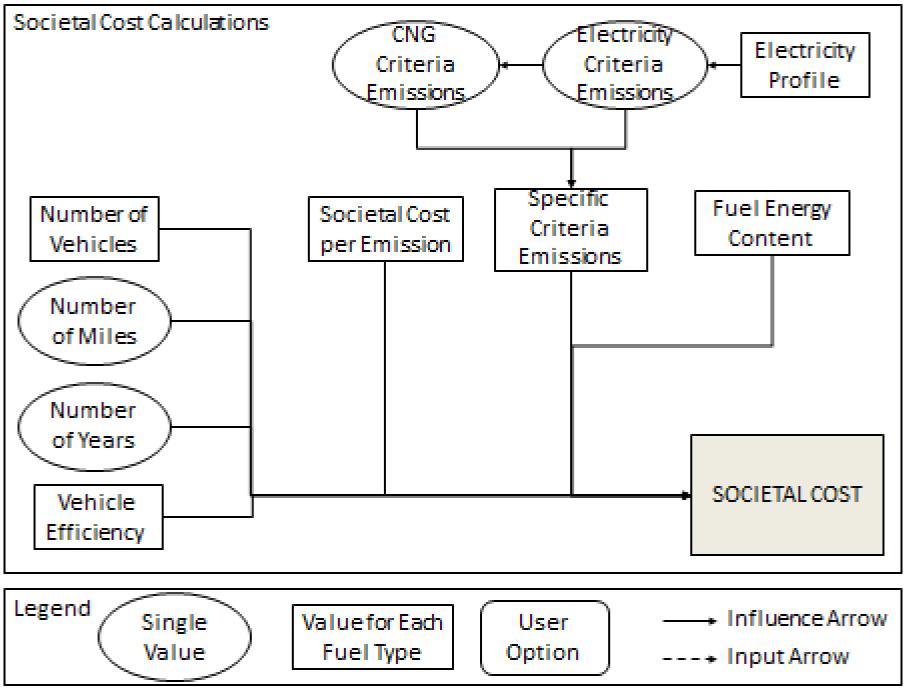


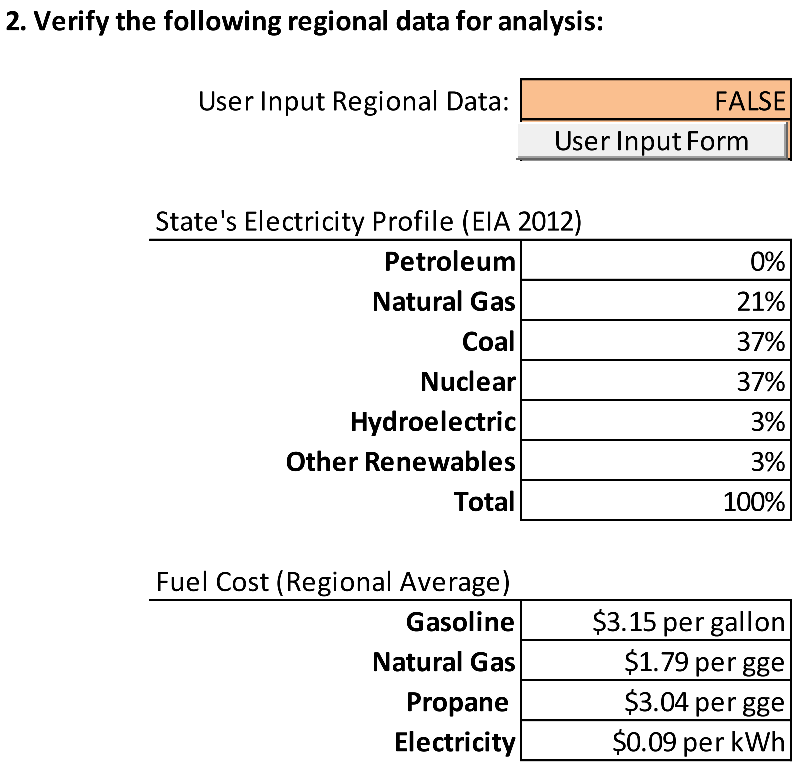
Figure 4.5 Societal Cost Calculations Flow Diagram

4.1.1 Cell Based Input Form

The first section of the cell based input form provides the different scenario aspects to consider for the analysis of the fleet. The user is first presented a color legend that explains that there are two different modifiable cell types. Some cells are modified through dropdown lists to prevent unsupported options from being entered. Meanwhile, other numeric cells must be entered directly by the user. The first scenario parameter considered is the state that is being considered for this fleet to provide a more local analysis. The dropdown list provides the different US states as well as a national average. This selection then adjusts the region cell to reflect the respective PADD divisions. The user must then input the number of years and the miles per vehicle per month for their respective fleet. To account for the time-value of the money and calculate the present value of the annual revenues and costs of the fleet, the discount rate utilized for the firm's financial analyses must be entered.

The next section provides different fuel type parameters decisions to determine the aspects the firm wishes to include in analysis. The first would be whether or not the necessary refueling infrastructure should be considered. For instance, if there are readily available refueling stations available then perhaps it would not be necessary for the firm to personally invest in the construction of refueling infrastructure. The next three true/false selections concern the use of electric vehicles for vehicle-to-grid frequency regulation. The first option is whether or not to consider using the vehicles for V2G frequency regulation at all. The second and third affect the financial performance of a fleet performing frequency regulation and determine whether or not to consider new accounting methods being utilized by PJM ISO and future bi-directional V2G capability respectively. The user can choose to use either corn or cellulosic feedstock for ethanol production in analysis of FFVs running on E85. Finally, the vehicle efficiency parameters provide an opportunity to be varied if different vehicles are being analyzed.

The regional data is populated based upon the state selected in the first section of the model. The state electricity profile presents the mix of electricity sources on a percentage basis for the respective state. The fuel cost is from the regional level and is dependent on the PADD region that the state is located within; except for electricity cost, which is obtained from the state level. The layout of the regional data is displayed in Figure 4.6.



2. Verify the following regional data for analysis:

User Input Regional Data: FALSE

State's Electricity Profile (EIA 2012)

Petroleum	0%
Natural Gas	21%
Coal	37%
Nuclear	37%
Hydroelectric	3%
Other Renewables	3%
Total	100%

Fuel Cost (Regional Average)

Gasoline	$3.15 per gallon
Natural Gas	$1.79 per gge
Propane	$3.04 per gge
Electricity	$0.09 per kWh

Figure 4.6 Regional Data Section of Model

The user can choose to either use regional averages for the state and PADD chosen in the previous section or enter their own data. The user can enter specific regional data by selecting the ‘User Input Form’ command box. This initializes a form using Excel VBA Macro as presented in Figure 4.7.

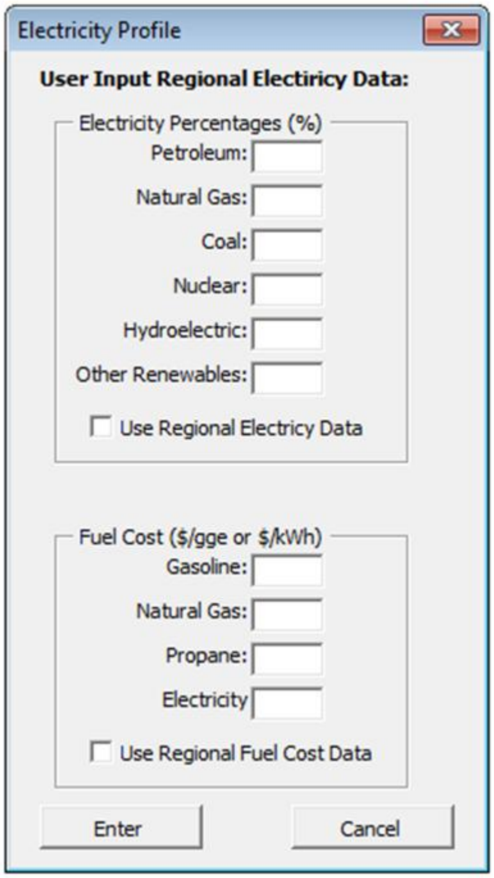
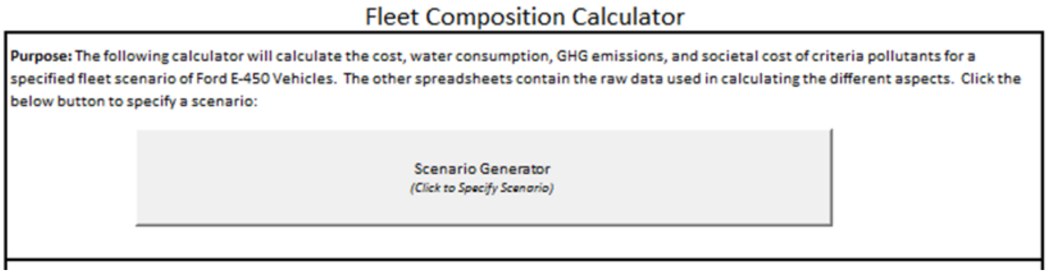


Figure 4.7 User Input Dialog Box

This dialog box provides the choice of entering the electricity percentages and fuel costs. Additionally, if the checkboxes in each category are selected the regional data will automatically populate the respective category. The last parameter that can be varied is the number of vehicles for each fuel type. Throughout the parameter adjustment process, the resulting outputs for the given fleet scenario are automatically displayed for total present cost ($), yearly water consumption (liters/year), GHG emissions (short tons CO2-eq), and societal cost ($).

4.1.2 User Interface Prompt

In order to facilitate use of the model for application by a fleet manager another Excel VBA Macro prompt was designed. This user input form provides a more intuitive interface for the user to modify the various parameters discussed in the previous section. Upon first opening the model the user is presented with the following description and a button for form control in Figure 4.8.

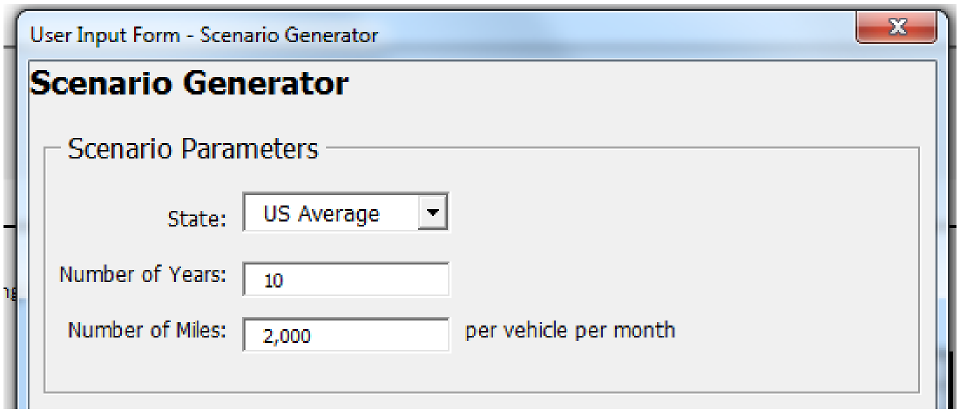


Fleet Composition Calculator

Purpose: The following calculator will calculate the cost, water consumption, GHG emissions, and societal cost of criteria pollutants for a specified fleet scenario of Ford E-450 Vehicles. The other spreadsheets contain the raw data used in calculating the different aspects. Click the below button to specify a scenario:

Figure 4.8 Model User Introduction

Once the "Scenario Generator" button is selected, a user input form is displayed that is pre-populated with the default options. The top portion of the user input form contains the scenario parameters including the state, number of years, and number of miles per vehicle per month. This portion of the form is presented in Figure 4.9.



Scenario Generator

Scenario Parameters

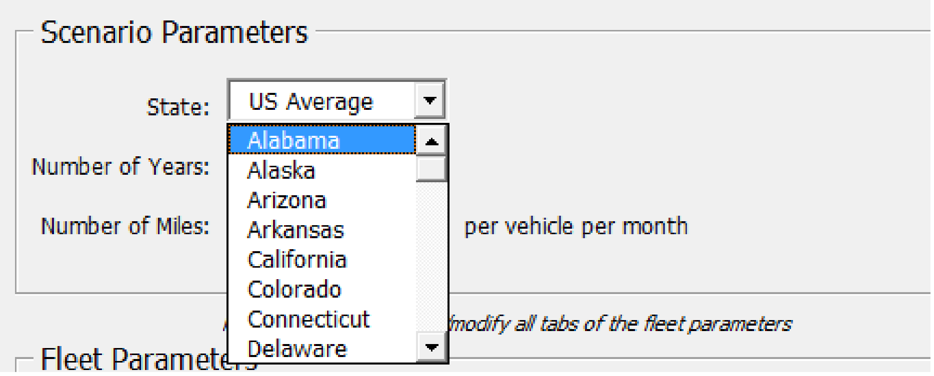
State: US Average

Number of Years: 10

Number of Miles: 2,000 per vehicle per month

Figure 4.9 User Input Form - Scenario Parameters

The state parameter is defaulted to the US Average but can be modified to a different American state through a dropdown menu to provide for a more regional analysis as illustrated in Figure 4.10.

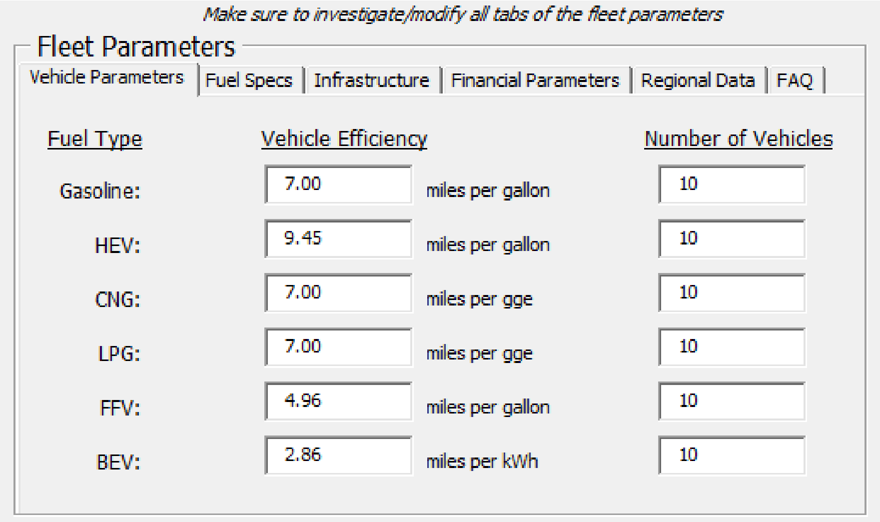


State: US Average

Figure 4.10 User Input Form – State Dropdown Menu

The state parameter impacts the regional data of electricity percentage and fuel cost. The other two scenario parameters, number of years and number of miles, are related to the specific fleet implementation.

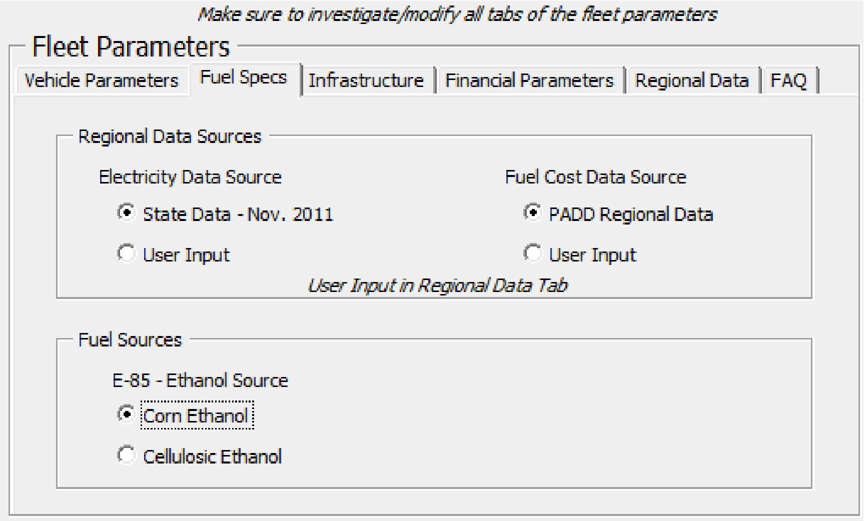
The next section of the user input form is the Fleet Parameters, which is presented in a series of tabbed views. The first tabbed view is the Vehicle Parameters that provide the user an opportunity to vary the efficiency or number of vehicles in the fleet for each of the fuel types. The Vehicle Parameters tab is presented in Figure 4.11 with the default values for a fleet of E-450 vehicles with 10 vehicles of each fuel type.



Fuel Type	Vehicle Efficiency		Number of Vehicles
Gasoline:	7.00	miles per gallon	10
HEV:	9.45	miles per gallon	10
CNG:	7.00	miles per gge	10
LPG:	7.00	miles per gge	10
FFV:	4.96	miles per gallon	10
BEV:	2.86	miles per kWh	10

Figure 4.11 User Input Form – Vehicle Parameters

The second tabbed view is the fuel specifications portion that allows the user to provide user input data for the regional data, similar to the user input dialog box, and modify the fuel feedstock source for E-85 and CNG. This view is displayed in Figure 4.12.



Regional Data Sources

Electricity Data Source
● State Data - Nov. 2011
○ User Input

Fuel Cost Data Source
● PADD Regional Data
○ User Input

User Input in Regional Data Tab

Fuel Sources

E-85 - Ethanol Source
● Corn Ethanol
○ Cellulosic Ethanol

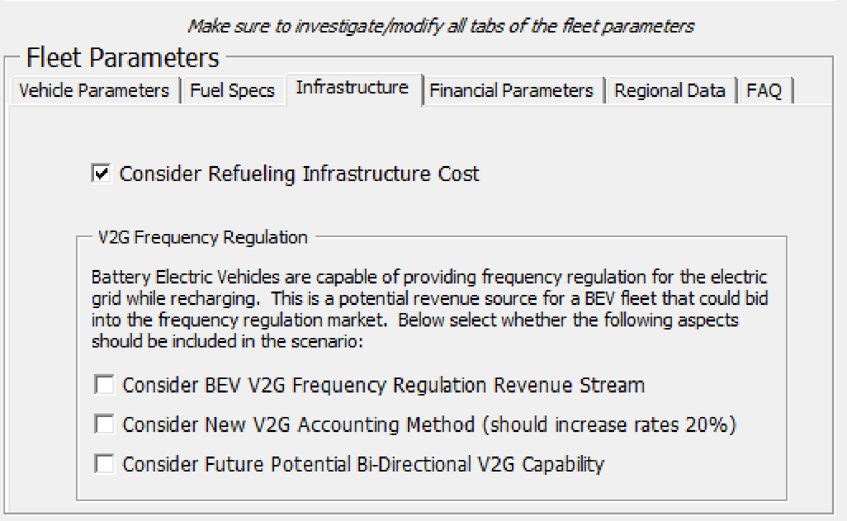
.

Figure 4.12 User Input Form – Fuel Specifications

The electricity data source and fuel cost data source can be varied from the state data for the previously selected state or switched to user input to be inputted in a later tab.

Meanwhile, the fuel sources can be varied between corn and cellulosic feedstock for E-85 and between regular natural gas and natural gas that has been captured from decaying organic matter in landfills. These distinctions are very important for the ultimate results because although the different feedstock result in the same fuel type; the environmental impact is quite drastically different. The different settings in this section are varied by an option button that only allows for one of the options for each category to be selected at a time. Therefore, if user input is selected under electricity data source the state data option button's value is transferred from true to false.

The next tab relies on check box selection that allows for different properties to be considered independent of each other. This tab is considered the infrastructure tab and provides the fleet an opportunity to include the cost of refueling infrastructure in the analysis as well as the future potential of V2G frequency regulation for battery electricity vehicles as seen in Figure 4.13.



Make sure to investigate/modify all tabs of the fleet parameters

☑ Consider Refueling Infrastructure Cost

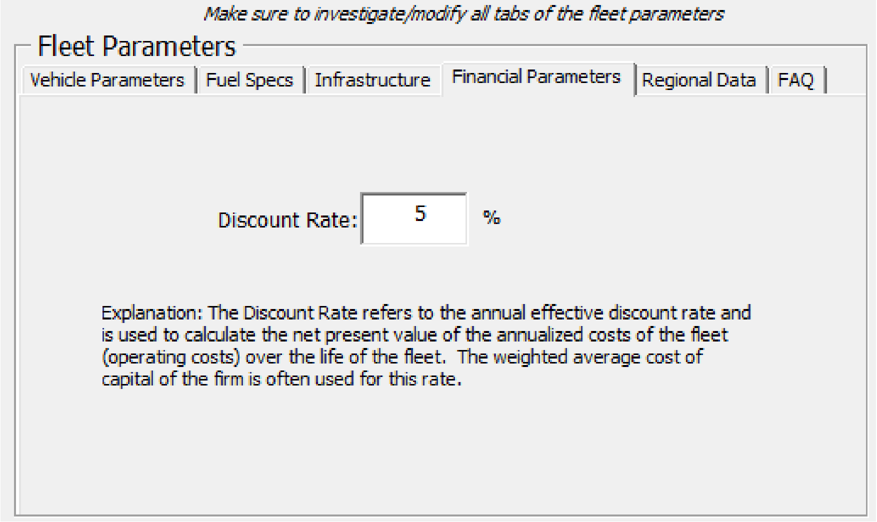
Battery Electric Vehicles are capable of providing frequency regulation for the electric grid while recharging. This is a potential revenue source for a BEV fleet that could bid into the frequency regulation market. Below select whether the following aspects should be included in the scenario:

☐ Consider BEV V2G Frequency Regulation Revenue Stream
☐ Consider New V2G Accounting Method (should increase rates 20%)
☐ Consider Future Potential Bi-Directional V2G Capability

Figure 4.13 User Input Form - Infrastructure

The V2G frequency regulation portion also includes a brief description of what frequency regulation is and why this is important. This illustrates the value of presenting the option interface to the user using the user input form as it provides an opportunity to describe the different alternatives to the user and the familiarity of interacting with a checkbox instead of a true or false selection within the regular Excel spreadsheet.

This capability is also useful in the following section that includes the financial parameter of discount rate, which impacts the time value of the finances of the fleet. The discount rate presented without any description may be confusing, thus it is valuable to provide an explanation of the discount rate as shown in Figure 4.14.

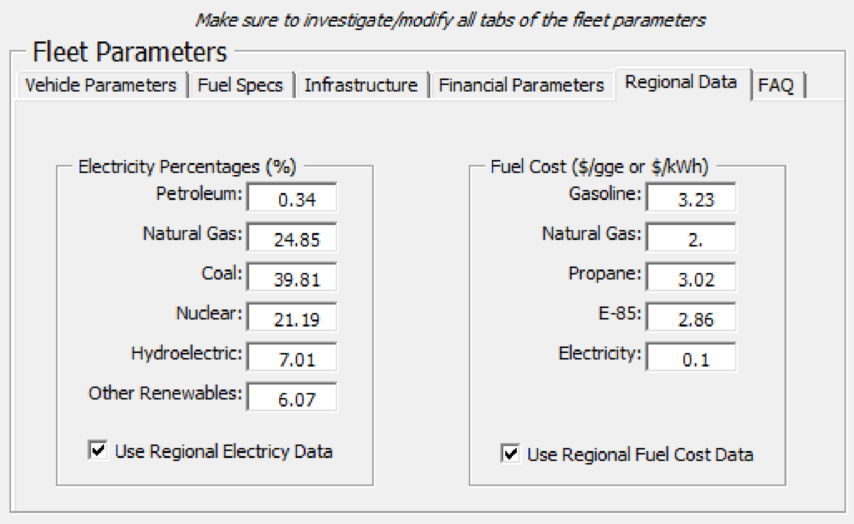


Discount Rate: 5 %

Explanation: The Discount Rate refers to the annual effective discount rate and is used to calculate the net present value of the annualized costs of the fleet (operating costs) over the life of the fleet. The weighted average cost of capital of the firm is often used for this rate.

Figure 4.14 User Input Form – Financial Parameters

The interactive tab of the Fleet Parameters is the regional data that provides the opportunity for the user to input specific data for the electricity percentages and fuel cost. The data is pre-populated with the regional data for the selected state if the option buttons from the fuel specifications tab are not changed to user input. Similarly, the checkboxes at the bottom of the respective frames provide another opportunity to select the use of regional data. If these checkboxes are altered then the corresponding option box in the fuel specifications tab is automatically modified to reflect the choice. Figure 4.15 presents the tab with the default values for the US average.

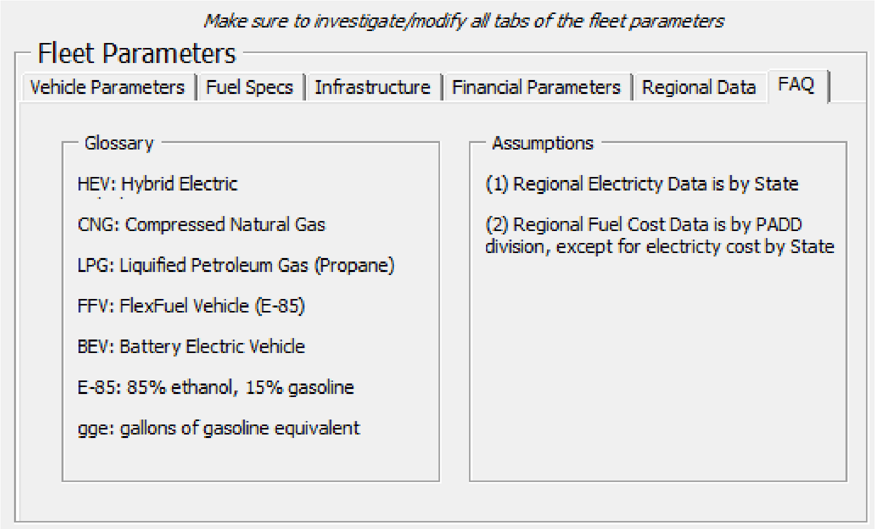


Electricity Percentages (%)
Petroleum: 0.34
Natural Gas: 24.85
Coal: 39.81
Nuclear: 21.19
Hydroelectric: 7.01
Other Renewables: 6.07
☑ Use Regional Electricy Data

Fuel Cost ($/gge or $/kWh)
Gasoline: 3.23
Natural Gas: 2.
Propane: 3.02
E-85: 2.86
Electricity: 0.1
☑ Use Regional Fuel Cost Data

Figure 4.15 User Input Form – Regional Data

Finally, the last tab of the Fleet Parameters section is termed Frequently Asked Questions (FAQ) and provides a glossary for the various acronyms utilized in the different areas of the input form around vehicle type and different fuels. Additionally, some of the common assumptions within the model are also described. Figure 4.16 presents these descriptions in case the user is unfamiliar with the terminology of alternative fuel vehicles.



Glossary
HEV: Hybrid Electric
CNG: Compressed Natural Gas
LPG: Liquified Petroleum Gas (Propane)
FFV: FlexFuel Vehicle (E-85)
BEV: Battery Electric Vehicle
E-85: 85% ethanol, 15% gasoline
gge: gallons of gasoline equivalent

Assumptions
(1) Regional Electricty Data is by State
(2) Regional Fuel Cost Data is by PADD division, except for electricty cost by State

Figure 4.16 User Input Form – Frequently Asked Questions

Once all of the various tabs have been investigated and modified to provide the desired scenario for the user, the user is presented with three different self-explanatory command buttons. Figure 4.17 shows the presentation of these command buttons.

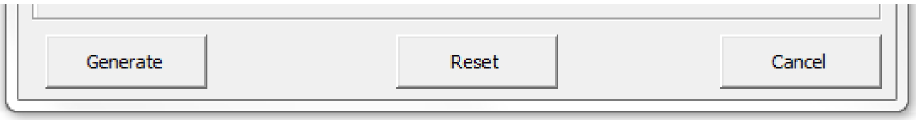
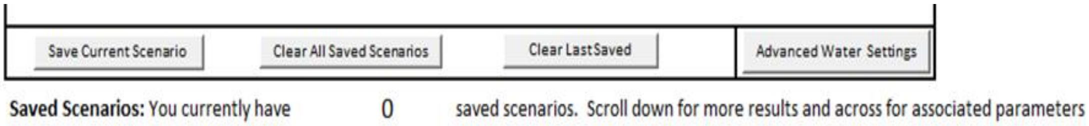


Figure 4.17 User Input Form – Command Buttons

The generate button outputs the scenario options of the input form to the previously described overview form in order to obtain the resulting impacts. The reset button changes all of the various options back to the default settings. Finally, the cancel button closes the form without making any changes to the scenario settings.

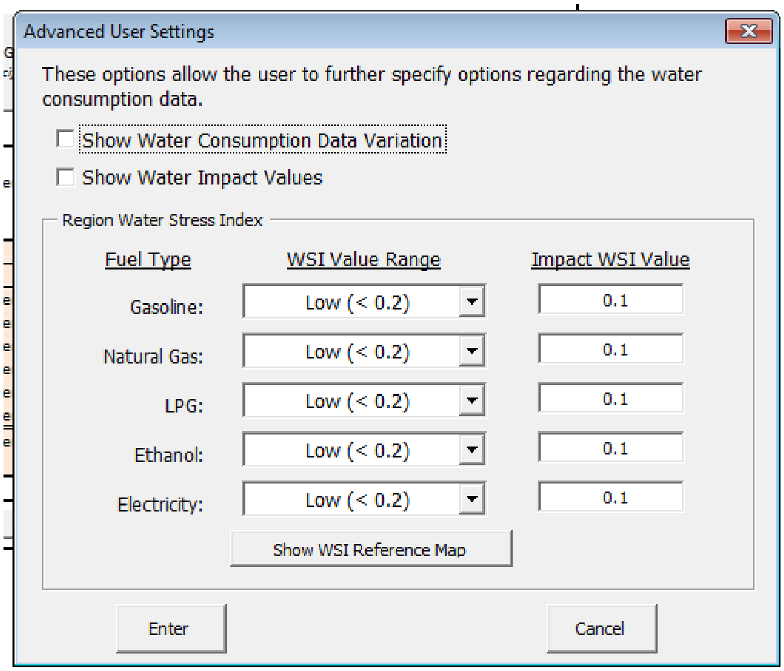
In order to facilitate comparisons between different model scenarios an option was included that allowed the user to save the results and associated parameters from a run scenario. There are three macro buttons that allow the user to save the current scenario, clear all of the saved scenarios, and lastly clear the last scenario that was saved. Figure 4.18 presents the scenario save options layout.



Saved Scenarios: You currently have 0 saved scenarios. Scroll down for more results and across for associated parameters

Figure 4.18 Scenario Save Options

There are additional advanced options available that facilitate more in-depth analysis of water consumption. These are accessed by a macro-button labeled "Advanced Water Settings", which displays the user input form presented in Figure 4.19.


Advanced User Settings

These options allow the user to further specify options regarding the water consumption data.

☐ Show Water Consumption Data Variation

☐ Show Water Impact Values

Region Water Stress Index

Fuel Type	WSI Value Range	Impact WSI Value
Gasoline:	Low (< 0.2)	0.1
Natural Gas:	Low (< 0.2)	0.1
LPG:	Low (< 0.2)	0.1
Ethanol:	Low (< 0.2)	0.1
Electricity:	Low (< 0.2)	0.1

Figure 4.19 Advanced User Settings for Water Input Form

This form allows the user to enable a chart that displays the variation of water consumption data. The second option switches from water inventory to water impact analysis, using the eco-scarcity method. For this method the user must enter the regional water stress index value for each fuel type. A dropdown menu of the value ranges is presented to facilitate the selection of the WSI value. Additionally, a pop-up map of the WSI values for the United States, presented in Figure 4.20, is initialized by selecting "Show WSI Reference Map".

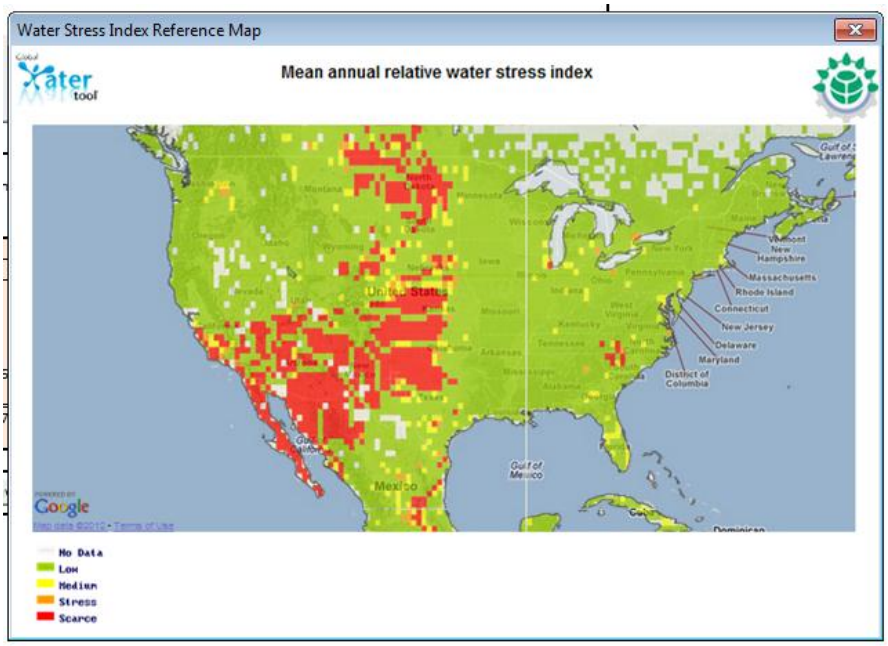


Figure 4.20 Mean Annual Relative Water Stress Index Map Pop-up

4.2 Model Calculations

Once the different settings have been inputted by the user, the model calculates the different impact categories for the desired scenario. The inputted settings are compiled in the *Overview* spreadsheet, which is then referenced by the rest of the Excel file.

Financial Calculations

The *Cost* spreadsheet refers to the *Overview* spreadsheet in order to determine the number of vehicles, number of miles, discount rate, and if infrastructure cost will be included in the analysis. Additionally, the regional data for the different fuel cost is obtained for the respective fuel types in the desired region. The costs are separated into the fleet purchase cost, fuel cost, revenue, and infrastructure cost. The fleet purchase cost is relatively straightforward and is obtained from Equation 18.

$$Fleet\ Purchase\ Cost = (Number\ of\ Vehicles) * (Base\ Vehicle\ Cost + Conversion\ Cost + Miscallanious\ Cost + Tax - Credits) \tag{18}$$

The purchase cost already represents a present value as it is assumed that the organization has enough present liquidity to purchase the fleet outright. If it is necessary for the organization to acquire capital to purchase the fleet of vehicles then the cost for this capital would also have to be included in the analysis.

The next cost category is the fuel cost for the fleet of vehicles. In the analysis the yearly fuel consumption is first calculated to facilitate the calculation of the infrastructure cost. The yearly fuel cost is calculated by Equation 19.

$$Fuel\ Cost_A = \frac{Number\ of\ Vehicles * Yearly\ Miles * Fuel\ Cost_{per\ unit}}{Fuel\ Economy} \tag{19}$$

Since this is a value that would be considered an annuity over the life of the fleet, the total fuel cost must be converted into a present value. Equation 20 presents the calculation used for calculating the annual fuel cost and converting to a present value:

$$Fuel\ Cost_{PV} = \frac{Fuel\ Cost_A}{i} * \left[1 - \frac{1}{(1+i)^n}\right] \tag{20}$$

Where $Fuel\ Cost_{PV}$ is the present value of the annual fuel cost, i is the discount rate or the interest rate that would be compounded for each year, n is the number of years for the scenario, and $Fuel\ Cost_A$ is the annual fuel cost.

Revenue generation through frequency regulation by BEVs is an option provided to the user. There are four different implementations of V2G revenue generation considered in the model by combinations of current versus new accounting practices and one-way versus two-way capability. The calculations are based on the charger power limit (63 kW) for a Level III DC charger and the number of vehicles. Equations 21 through 25 are used to determine the maximum possible revenue that could be generated by the fleet given evenly distributed charging times.

$$Energy\ Required = \frac{Miles\ per\ Day}{Fuel\ Efficiency} * Number\ of\ Vehicle \tag{21}$$

$$Vehicle\ Recharges\ per\ Day = \frac{Miles\ per\ Day}{Vehicle\ Range} \tag{22}$$

$$Time\ per\ Charge = \frac{Battery\ Capacity}{\left(\frac{Charger\ Power\ Limit}{2}\right)} \tag{23}$$

$$Time\ Spent\ Recharging = Time\ per\ Charge * Vehicle\ Recharges\ per\ Day \tag{24}$$

$$Revenue\ per\ Day = Average\ RMCP * Time\ Spent\ Recharging * Bid\ per\ Hour \tag{25}$$

Although the market for utilizing EVs for frequency regulation is only just emerging, this analysis allows the opportunity to investigate possible revenue generation for future electric fleets. That is why the future accounting practices is provided as an option, which would increase the average RMCP by approximately 20%. Additionally, the future benefit of bi-directional V2G charging is included, which would double the revenue potential.

Finally, the infrastructure costs are determined as previously discussed in Chapter 3. These costs are then combined for each fuel type to determine the total financial cost of the fuel type fleet as a present value.

Water Consumption Calculations

The water consumption for the majority of the fuel types is straightforward as presented in Equation 26

$$Water\ Consumption = Number\ of\ Years * Number\ of\ Vehicles * Miles\ per\ Vehicle * \frac{Specific\ Water\ Consumption}{Vehicle\ Efficiency} \tag{26}$$

The specific water consumption is the amount of water needed to produce each specific amount of fuel and is a combination of the water consumption needed throughout the fuel lifecycle. This lifecycle includes extraction, processing, transport, and plant or compressor. For gasoline and LPG the lifecycle involves only summing these stages to obtain a total value.

However, to determine the regional specific water consumption for CNG, E-85, and BEV further calculations are required. The state specific water consumption is obtained by Equation 27.

$$Region\ Water\ Consumption_{Electricity} = WC_{Petroleum} * \%_{Petroleum} + WC_{Natural\ Gas} * \%_{Natural\ Gas} + WC_{Coal} * \%_{Coal} + WC_{Nuclear} * \%_{Nuclear} + Region\ WC_{Hydro} * \%_{Hydro} + WC_{Renew} * \%_{Renew} \tag{27}$$

Where WC_X is the specific water consumption for the respective generation source in liters H2O/kWh, $\%_X$ is the percentage of that generation source for the state, and $Region\ WC_{Hydro}$ is the specific water consumption for the hydroelectricity in that region. The water consumption during the compression of natural gas is linked to this regional electricity water consumption as described in Chapter 3. The compression water consumption is then combined with the extraction, processing, and transportation water consumption to obtain the total regional water consumption for CNG. The regional variation for E-85 is combined with the processing requirements for ethanol to calculate the water consumption for E-85.

Greenhouse Gas Emissions Calculations

The GHG emissions are also straightforward as show in Equation 28.

$$GHG\ Emissions = Number\ of\ Years * Number\ of\ Vehicles * Miles\ per\ Vehicle * \frac{Fuel\ Energy\ Content}{Vehicle\ Efficiency} * (Upstream\ Emissions + Taiplipe\ Emissions) \tag{28}$$

The regional specific emissions for electricity are calculated in a similar fashion as water consumption for BEV by multiplying the respective emission categories and the percentage of that generation source for the state. The GHG emissions for CNG were obtained by multiplying the emission categories and the percentage of that generation source for the state. This value was then added to the tailpipe emissions for CNG to get a total fuel lifecycle emission for each specific state.

Societal Cost Calculations

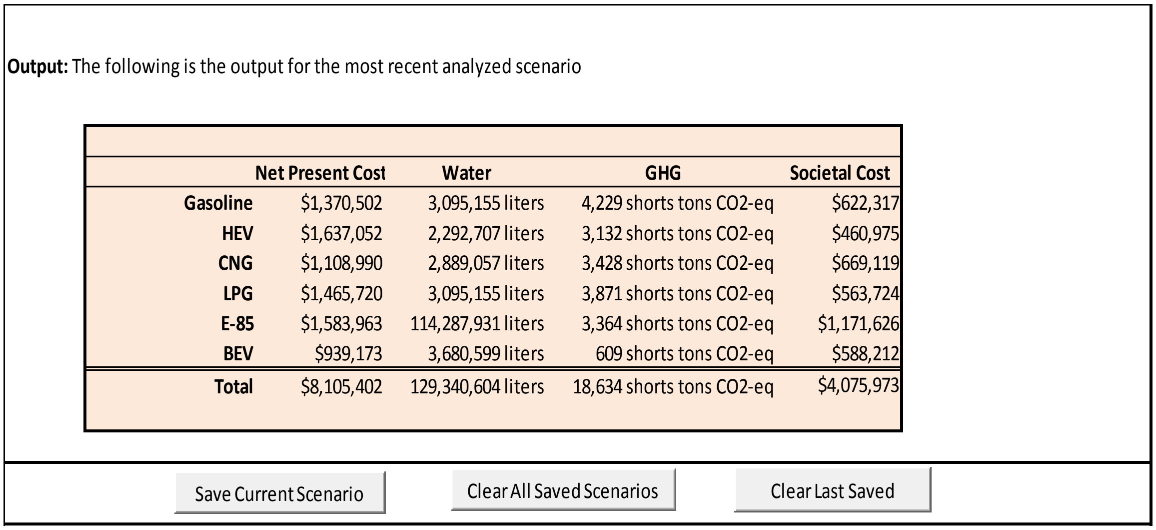
The societal cost of criteria pollutants was obtained by summing the cost of each individual pollutant. Each of these pollutants has specific emissions for each fuel type that were obtained from analyses using GREET. The amount of pollutant was then multiplied by the specific pollutant cost as demonstrated in Equation 29.

$$Societal\ Cost = Number\ of\ Years * Number\ of\ Vehicles * Number\ of\ Miles * \frac{Fuel\ Energy\ Content}{Vehicle\ Efficiency} * \sum_{x=i}^{6} \left(Societal\ Cost * (Feedstock\ Emissions_x + Fuel\ Emissions_x + Vehicle\ Operation\ Emissions_x)\right) \tag{29}$$

Where *x* from *i* to *6* represents the summation of the respective criteria pollutants, which are VOC, CO, NOx, PM_{10}, $PM_{2.5}$, and SOx.

Overview

All of these results are then presented to the user in a simple summary table that provides the opportunity to save the particular scenario's results and corresponding parameters for later reference. Figure 4.21 displays how this interface is viewed by the user.



Output: The following is the output for the most recent analyzed scenario

	Net Present Cost	Water	GHG	Societal Cost
Gasoline	$1,370,502	3,095,155 liters	4,229 shorts tons CO2-eq	$622,317
HEV	$1,637,052	2,292,707 liters	3,132 shorts tons CO2-eq	$460,975
CNG	$1,108,990	2,889,057 liters	3,428 shorts tons CO2-eq	$669,119
LPG	$1,465,720	3,095,155 liters	3,871 shorts tons CO2-eq	$563,724
E-85	$1,583,963	114,287,931 liters	3,364 shorts tons CO2-eq	$1,171,626
BEV	$939,173	3,680,599 liters	609 shorts tons CO2-eq	$588,212
Total	$8,105,402	129,340,604 liters	18,634 shorts tons CO2-eq	$4,075,973

Figure 4.21 User Result Interface

4.3 Utility Preference

4.3.1 Influence Diagram

The design variable in this model is the vehicle fuel type chosen for the fleet of vehicles. There are three separate utilities that are of concern for the decision of the fleet fuel type; the financial utility, the environmental utility, and the societal utility. The financial utility of the project has three costs considered infrastructure, purchase, and operating cost. Once the vehicle fuel type is decided upon, the decision-maker must then decide whether or not there is a need for refueling infrastructure to support the fleet. Figure 4.22 presents the influence diagram for the financial utility of the fleet

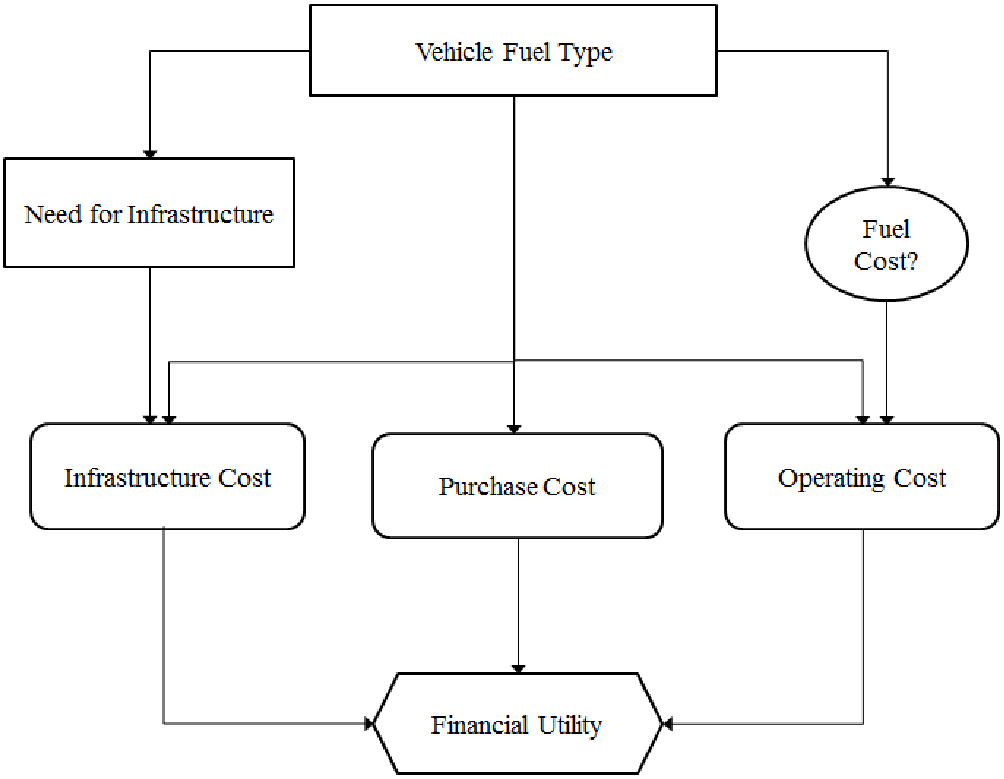


Figure 4.22 Influence Diagram for Financial Utility

The influence diagram for environmental and societal utility is presented in Figure 4.23. The environmental utility is dependent on both the GHG emissions and the water consumption of the fleet, which has uncertainty in the water consumption data. Meanwhile, the societal utility is dependent on the human cost of emissions, which also has uncertainty in the cost calculations. These two utilities are then combined to provide an externality utility. The financial utility and externality utility are then combined to provide a total utility for the decision of the vehicle fuel type.

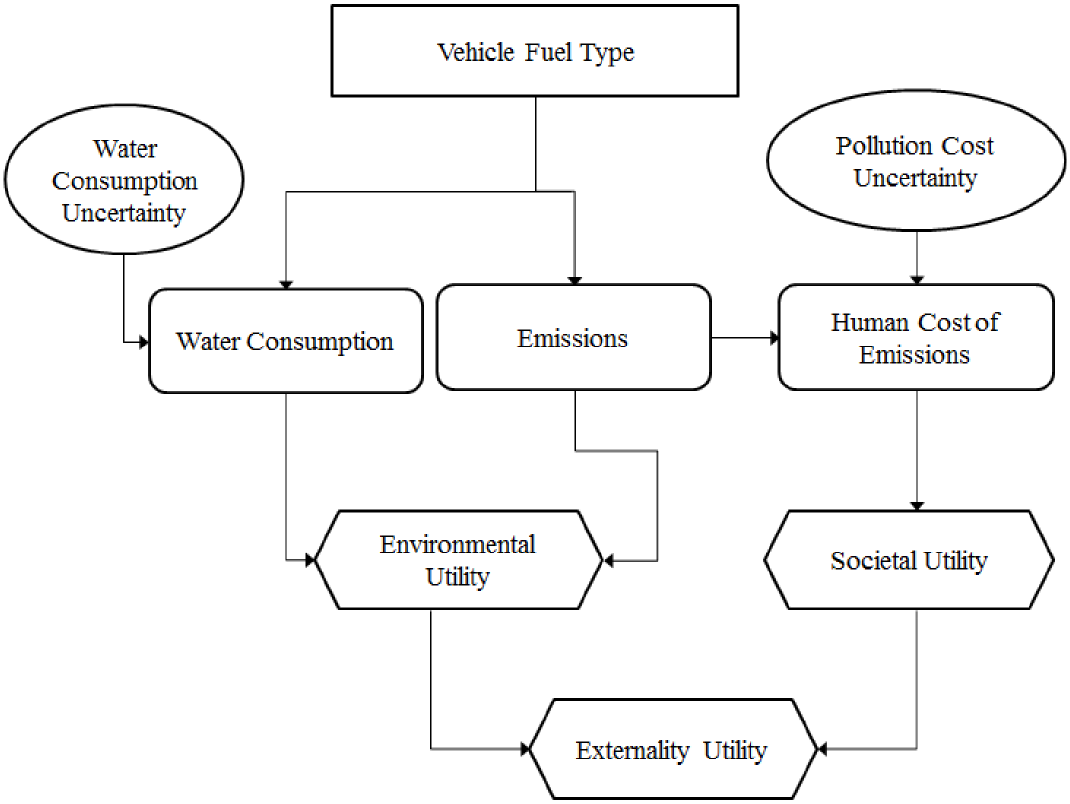


Figure 4.23 Influence Diagram for Externality Utility

4.3.2 Utility Function Elicitation

To elicit a single attribute utility function, utilities of 0 and 1 are assigned to the minimum and maximum values. Next, elicitation questions are used to find the “50/50” point on the utility curve. The question posed is “For what guaranteed value of the attribute are you indifferent to a 50/50 gamble between the minimum and maximum attribute?” Equation 30 presents the question in preference notation.

$$[0.5, Attribute_0; 0.5, Attribute_1] \sim Attribute_{0.5} \qquad (30)$$

After finding the point for utility of 0.5 the elicitation question is again used between that point and the extreme values as shown in Equation 31 and 32.

$$[0.5, Attribute_0; 0.5, Attribute_{0.5}] \sim Attribute_{0.25} \quad (31)$$
$$[0.5, \mathrm{Attribute}_{0.5}; 0.5, \mathrm{Attribute}_1] \sim \mathrm{Attribute}_{0.75} \quad (32)$$

This process is repeated until sufficient points along the utility curve are generated to give a reasonable profile for spline interpolation. Table 4.1 presents the numeric results for the elicitations of the respective attributes of the fleets for the default scenario. Only the default scenario values are considered due to the maximum and minimum values varying so widely depending on the parameters chosen.

Table 4.1 Attribute Utility Elicitations

Utility	**Financial Cost [$]**	**Water Consumption [liters]**	**GHG Emissions [short tons CO2-EQ]**	**Societal Cost [$]**
0	1,750,000	200,000,000	4,500	1,600,000
0.05	1,600,000	135,000,000	4,000	1,400,000
0.15	1,500,000	100,000,000	3,600	1,000,000
0.375	1,400,000	55,000,000	3,250	775,000
0.5	1,350,000	35,000,000	3,000	725,000
0.625	1,300,000	20,000,000	2,750	675,000
0.9	1,200,000	4,000,000	2,000	550,000
1	1,000,000	3,000,000	1,000	400,000

These utility elicitations points provide the following utility curves for the respective attributes. The Financial Cost, GHG Emissions, and Societal Cost utility curves have similar shapes that begin risk averse for low values and transitions to risk seeking at higher values. Meanwhile, the Water Consumption is difficult to visualize as it varies dramatic difference between the maximum and minimum values but the overall trend is risk seeking. Figures 4.24 through 4.27 show the graphical representations of spline interpolation for the respective utility curves of a theoretical fleet decision maker.

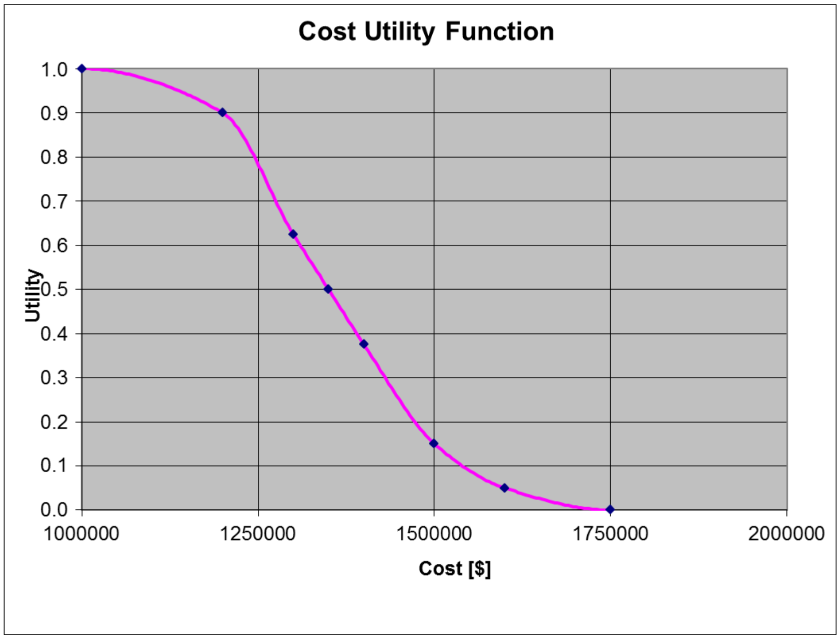


Figure 4.24 Single attribute utility function for Financial Cost

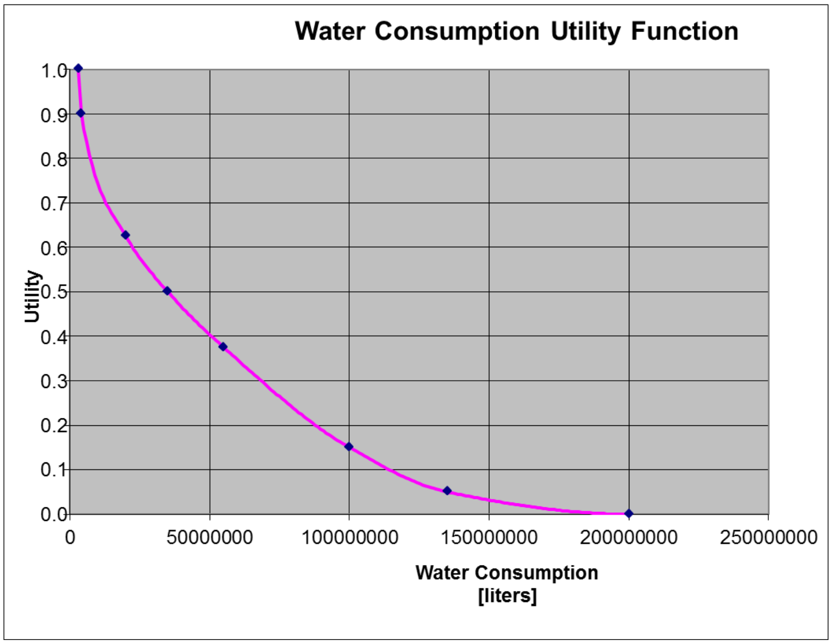


Figure 4.25 Single attribute utility function for Water Consumption

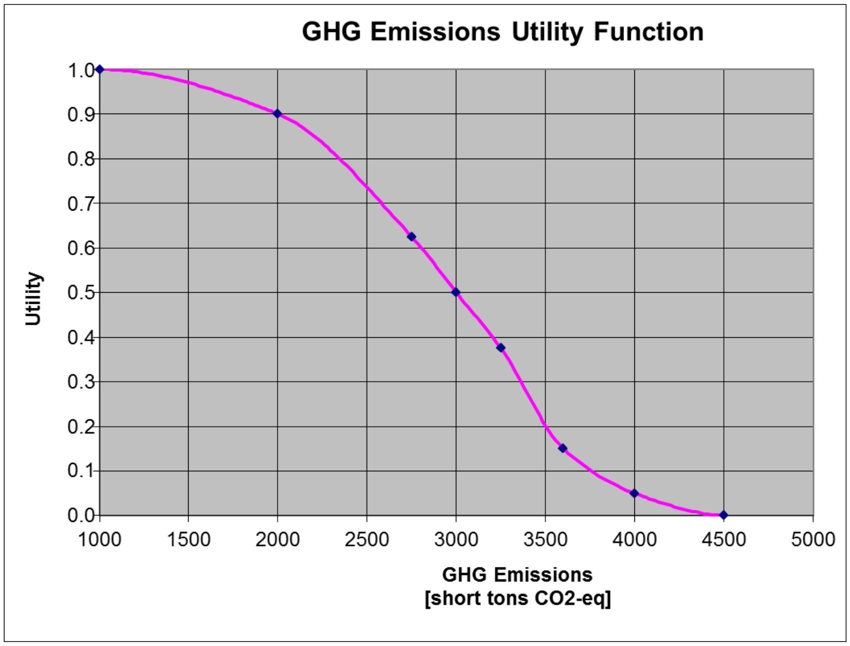


Figure 4.26 Single attribute utility function for GHG Emissions

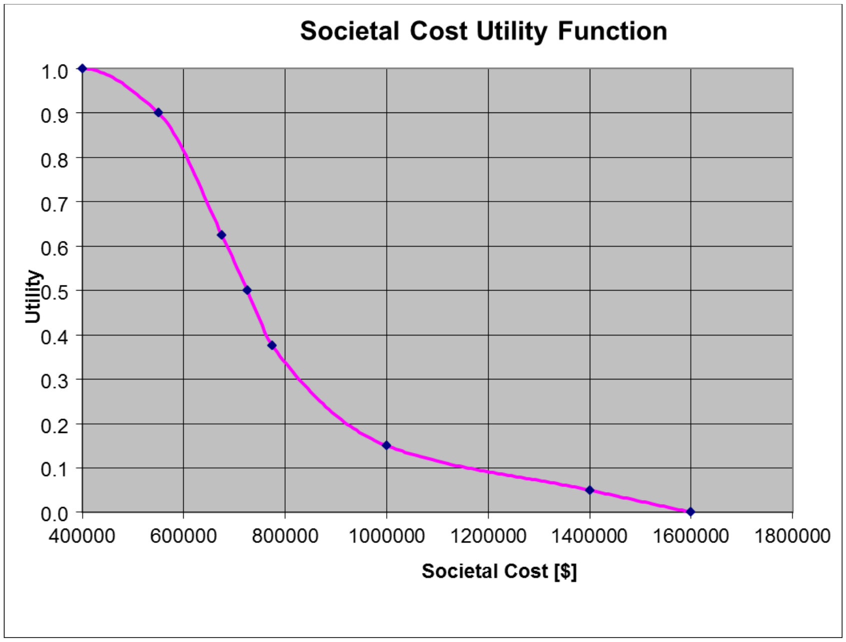


Figure 4.27 Single attribute utility function for Societal Cost

Once the single attribute utility functions have been elicited, the multi-attribute utility curves can be elicited by determining equivalent combinations of multiple utilities for each multi-attribute. These inputs are then inputted into a least squares regression relating the single attribute utilities to obtain Equation 33.

$$U(Attribute_1, Attribute_2) =$$

$$k_1U(Attribute_1) + k_2U(Attribute_2) + k_{12}U(Attribute_1)U(Attribute_2) \tag{33}$$

$$k_1, k_2 > 0$$

$$k_1 + k_2 + k_{12} = 1$$

Table 4.2 presents a theoretical multiple utility elicitation results for multiple utility elicitations of: (1) water consumption utility and GHG emissions utility for environmental utility, (2) environmental utility and societal cost utility for externality utility, and (3) financial utility and externality utility for total utility.

Table 4.2 Multiple Attribute Utility Elicitation Results

Multi-Attribute	**Attribute 1**	**Attribute 2**	**k_1**	**k_2**	**k_{12}**
Environmental Utility	Water Consumption Utility	GHG Emissions Utility	0.27	0.26	0.46
Externality Utility	Environmental Utility	Societal Cost Utility	0.37	0.15	0.48
Total Utility	Financial Cost Utility	Externality Utility	0.55	0.22	0.23

For Environmental Utility the utility of water consumption is assumed to be slightly more impactful since it is more a measure of local impact than GHG emissions. Similarly, Environmental Utility is more important than Societal Cost since environmental performance is a more publicized impact category and since environmental utility already takes into consideration some emissions. Finally, financial cost is considered the most impactful for Total Utility calculations since without a strong financial basis the typical company would have difficulty justifying the increased expenditure.

CHAPTER 5

SCENARIO RESULTS

5.1 Description

In order to facilitate comparison between different scenarios a representative default scenario was defined. This scenario uses the US average for all regional values for a fleet scenario that last 10 years with 10 vehicles of each fuel type that travel 2,000 miles per month. These default parameters are based on the fact that approximately 50% of new fleet purchases are for fleets of 5-14 vehicles (Fleet 2011). Additionally, in 2010 the average number of miles per month was 2,000-2,400 miles for commercial fleets.

All of the vehicle fuel types have the default efficiency discussed in Chapter 3. Additionally, this scenario uses a discount rate of 5% for present value conversion, does not consider refueling infrastructure needs, and uses corn based ethanol feedstock. Table 5.1 presents the results from this default scenario for the impact categories.

Table 5.1 Default Scenario Results

	Net Present Cost	**Water Consumption**	**GHG Emissions**	**Societal Cost**
Gasoline	$1,370,502	4,981,169 liters	4,229 short tons CO2-eq	$559,372
HEV	$1,637,052	3,689,755 liters	3,132 short tons CO2-eq	$414,349
CNG	$1,108,990	4,843,863 liters	3,837 short tons CO2-eq	$356,836
LPG	$1,465,720	4,981,169 liters	3,871 short tons CO2-eq	$506,043
E-85	$1,583,963	157,393,787 liters	3,364 short tons CO2-eq	$1,048,058
BEV	$1,059,697	17,063,353 liters	1,755 short tons CO2-eq	$1,507,427

The rest of this chapter will refer to this default scenario when making comparisons to other scenarios.

5.2 Scenario Comparisons

There are a number of different parameters that can be adjusted that affect the outcome of the scenarios. The scenario comparisons are broken down into three distinct categories: regional comparisons, fleet parameters, and fuel type parameters.

5.2.1 Regional Comparisons

The regional comparison presents the results of the default scenario for each state. Figure 5.1 through 5.4 displays the results for Financial Cost, Water Consumption, GHG Emissions, and Societal Cost by fuel type for the lifecycle of default scenario fleet. Each impact category has specific regional variations based upon the assumptions previously made in developing the model. BEVs and CNGs are the least expensive fuel types

The Financial Cost has variation based on the regional fuel cost for each fuel type. BEV has cost variations for each state based on the electricity cost of that respective state. The other fuel types have variation based upon the PADD district of the respective state as collected by the Clean Cities Alternative Fuel Price Report. The degree of variation for each fuel type is presented in Table 5.2.

Table 5.2 Variation of Financial Cost by Fuel Type

Fuel Type	**Financial Cost ($)**			**Percentage Variation from Min to Max**
	Minimum	**Average**	**Maximum**	
Gasoline	$1,335,644	$1,373,167	$1,433,600	7%
HEV	$1,611,232	$1,639,026	$1,683,791	4%
CNG	$969,999	$1,088,347	$1,196,356	19%
LPG	$1,390,709	$1,461,645	$1,550,880	10%
E-85	$1,536,014	$1,596,308	$1,692,317	9%
BEV	$989,274	$1,060,431	$1,339,903	26%

Water consumption only varies by region for three of the fuel types; BEV, E85, and CNG. FFVs running on E85 have the widest variation due to the wide range of irrigation requirements for corn based ethanol. States within USDA Region 7 (North Dakota, South Dakota, Nebraska, and Kansas) have the highest water consumption for ethanol production. The majority of this water consumption is driven by the irrigation requirements for corn in Region 7 at 320.7 liters water per liter denatured ethanol. Region 5 (Iowa, Indiana, Illinois, Ohio, and Missouri) and Region 6 (Minnesota, Wisconsin, and Michigan) have similar magnitude water consumption with 7.1 and 13.8 liters water per liter denatured ethanol respectively. Meanwhile, the other states' ethanol water consumption is based upon the market share percentage, which is dominated by Region 7's high consumption. Fleets running on E85 that obtained ethanol feedstock from Region 5 and Region 6 would have 89% and 83% less water consumption than the national average. Conversely, Region 7 represents a 221% increase in water consumption compared to the default scenario.

The electricity mix is broken down by state so each state has different water consumption. Additionally, there are regional differences in the evaporative losses during the generation of hydroelectric power. The most obvious outlier for electric water consumption is South Dakota with a consumption level 3,680% higher than US average. This high consumption level can be attributed to hydroelectricity being the major source of electricity generation for South Dakota, while also having high consumption per kWh of electricity produced. Table 5.3 shows a comparison between the breakdown of hydroelectric water consumption and hydroelectricity generation between different states and the resulting impact on a BEV fleet.

Table 5.3 Regional BEV Fleet Water Consumption Comparison

State	**Hydroelectric Water Consumption (liter/kWh)**	**Hydroelectricity Generation Percentage**	**Fleet Water Consumption (liters)**	**Percentage Change from Default Scenario**
Idaho	32.21	64%	49,680,689	193%
Maine	21.08	24%	13,448,706	-21%
Nevada	277.58	6%	43,299,427	156%
Oregon	16.69	55%	23,444,160	38%
South Dakota	434.72	62%	644,762,967	3,707%
US Average (Default Scenario)	69.16	7%	17,059,164	-

This comparison shows the relationship between both hydroelectric water consumption and hydroelectric generation percentage. Some states such as Maine and Oregon have higher than average hydroelectric generation but this increase is countered by the lower than average consumption per kWh. This results in Maine actually having reduced fleet water consumption of 21% in comparison to the default scenario. Conversely, states such as Nevada have lower generation percentage but increased water consumption due to climate factors and thus an increase of 156% in water consumption.

CNG is the last fuel type that has variations in water consumption due to the electricity required in compressing the natural gas. Since this electricity water consumption in based on the state’s generation mix, the CNG water consumption variation mimics the water consumption variations of the BEV fleet. South Dakota is again the highest consumer of water with an increase of 3,600% over the default scenario.

BEVs are the most environmentally favorable fuel source in terms of GHG emissions for all regions. The variation in each state’s GHG emissions is also based upon the electricity generation mix of the respective state. One interesting aspect in comparing water consumption and GHG emissions is that the states that have high water consumption often have low GHG emissions for BEVs. For example, South Dakota has 85% less GHG emissions than the default scenario due to the high hydroelectric generation. A BEV fleet in Texas has a 71% reduction in water consumption versus a 9% increase in GHG emissions for the default fleet. Similar to water consumption, the electricity used to compress the NG causes a slight variation in GHG emissions for CNG vehicles.

Society costs have variation in CNG and BEV due to the electricity generation mix. The BEV fleet has an extreme variation from $67,293 up to $3,262,048 depending on how much percentage of generation is based on renewable resources or dirtier electricity sources such as coal. Again, the CNG fleet emits varying levels of pollutants depending on the electricity generation used during compression of the natural gas.

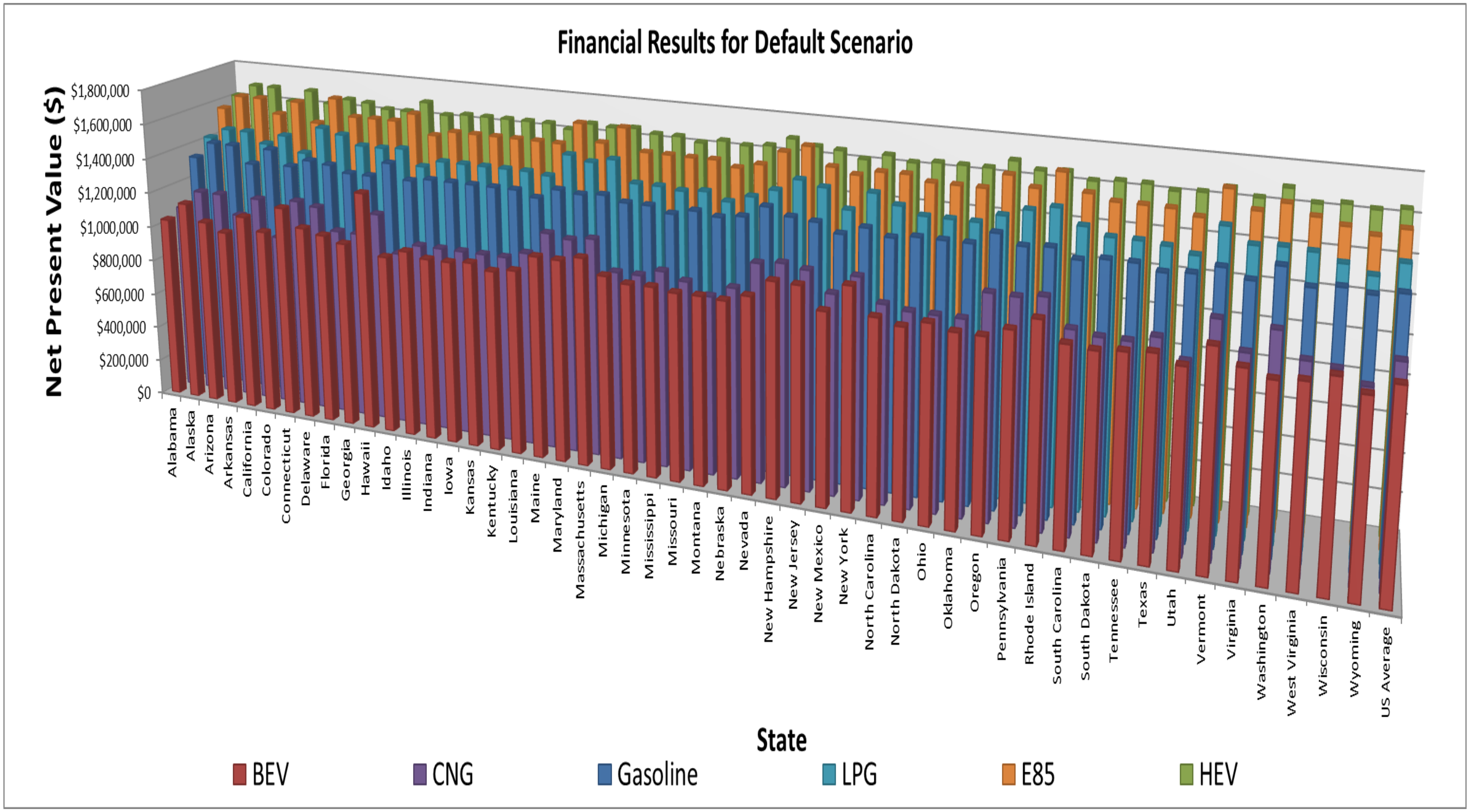


Figure 5.1 Financial Costs for Default Scenario by State

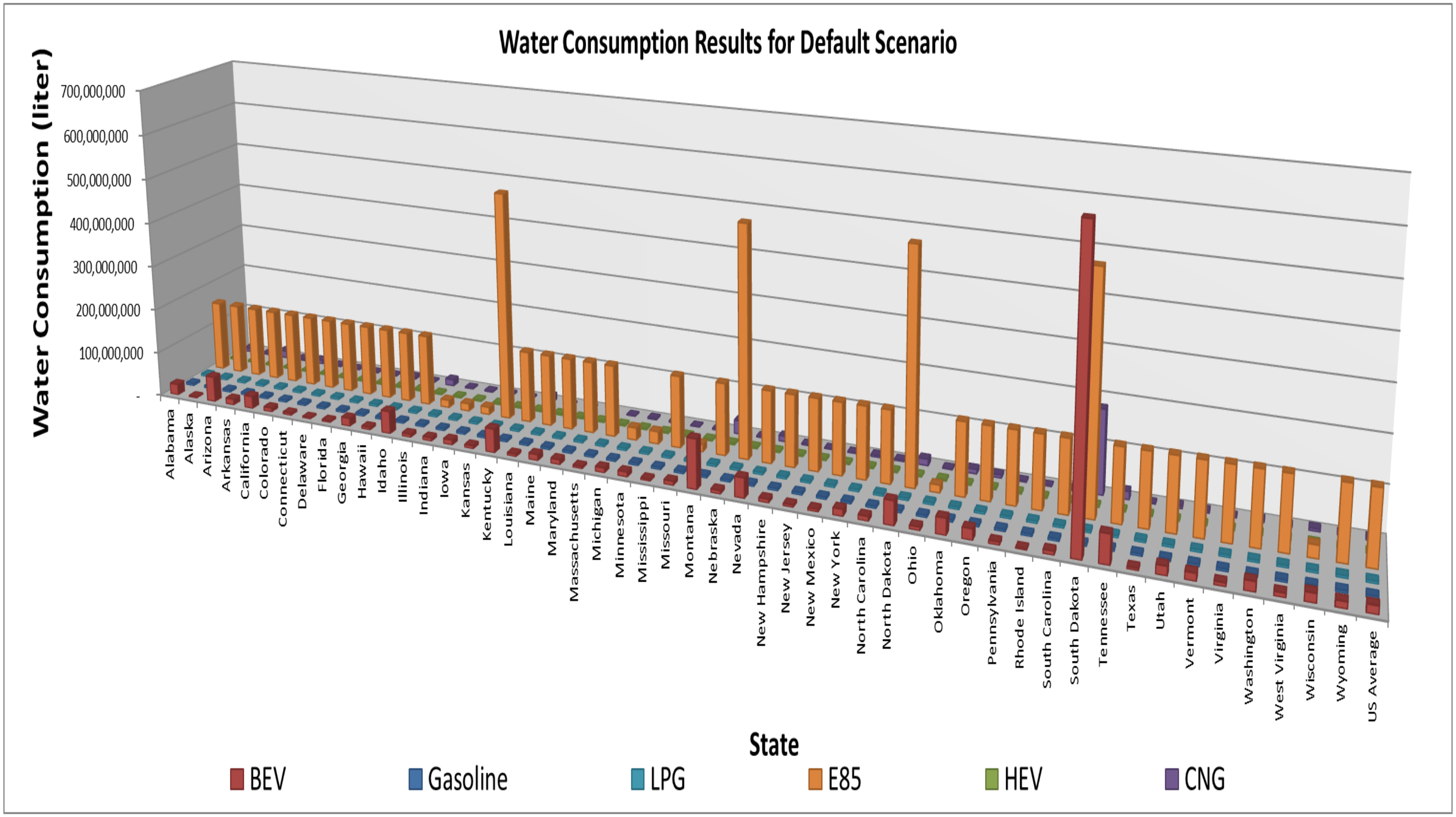


Figure 5.2 Water Consumption for Default Scenario by State

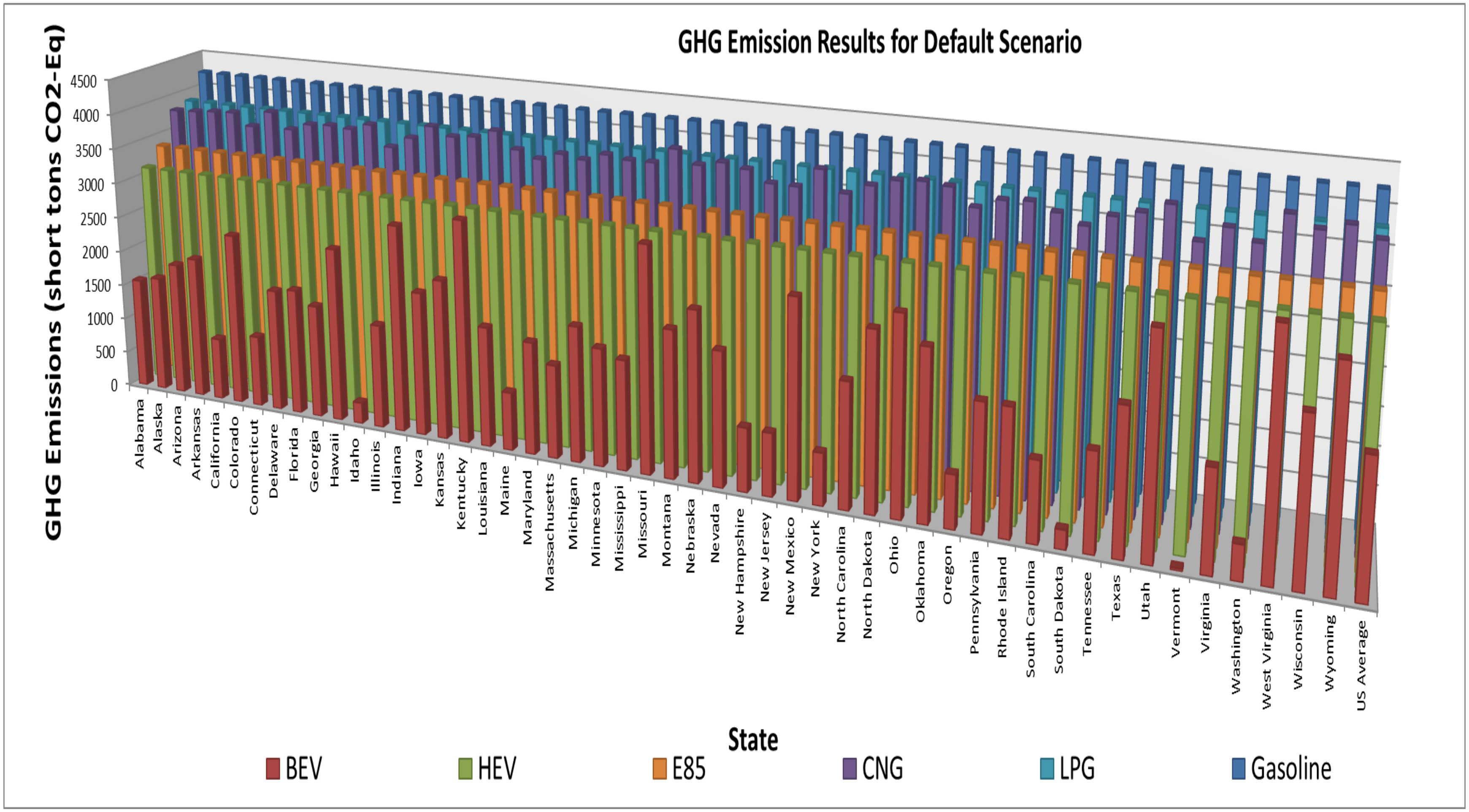


Figure 5.3 GHG Emissions for Default Scenario by State

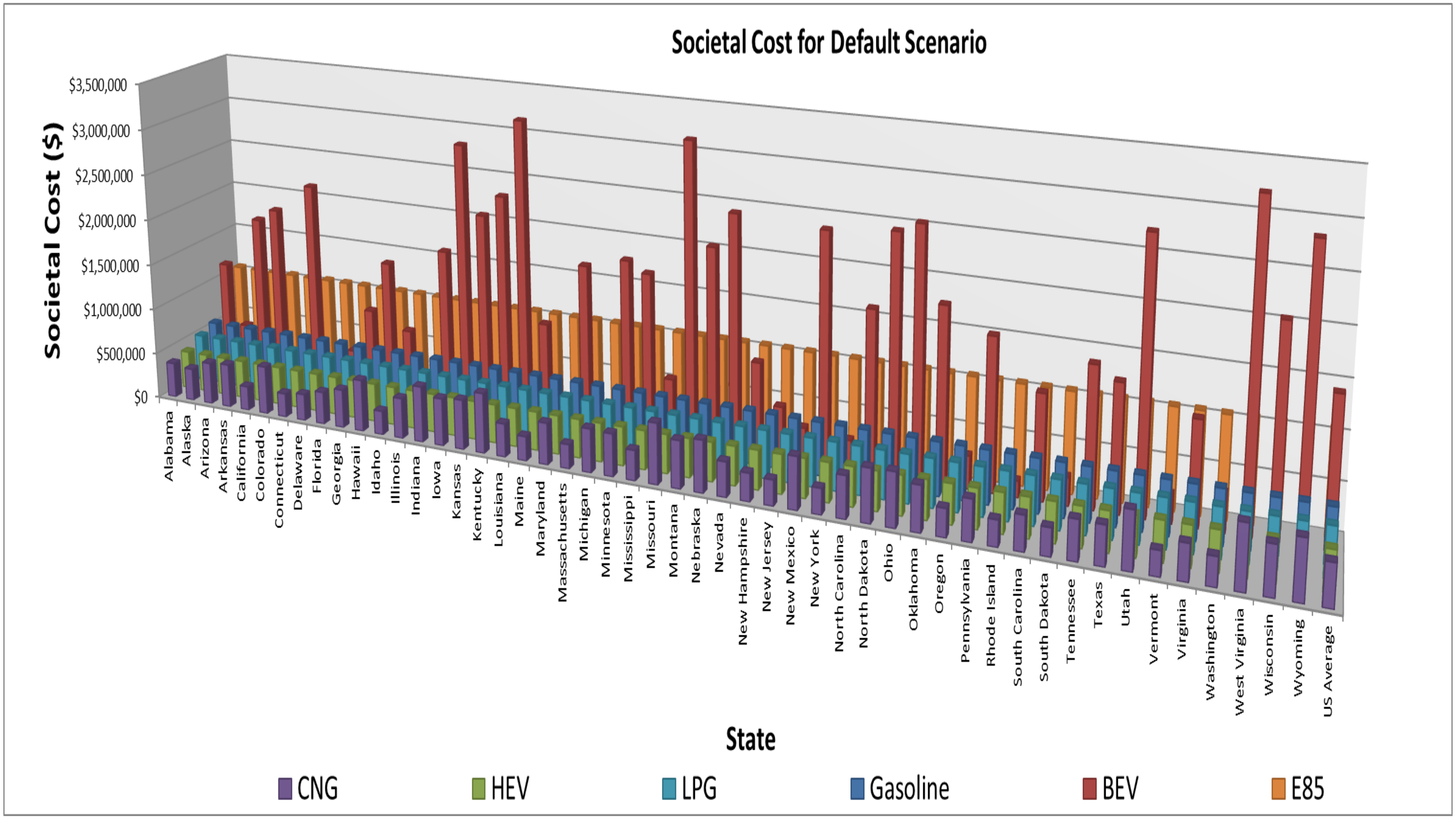


Figure 5.4 Societal Costs for Default Scenario by State

5.2.2 Fleet Parameters

Number of Year Analysis

The number of years only has a non-linear impact on the financial results for the scenarios. The rest of the impact categories all have a linear relationship with the number of years the scenario is run for. The non-linear relationship for financial cost of the fleet is a result of the conversion of the fuel cost from an annuity to a present cost. Equation 34 presents this relationship.

$$Cost = Fleet\ Cost + \frac{Fuel\ Cost_A}{i} * \left[1 - \frac{1}{(1+i)^n}\right] \tag{34}$$

Figure 5.5 displays how the number of years that the scenario is run for impacts the different fuel types for the default scenario parameters.

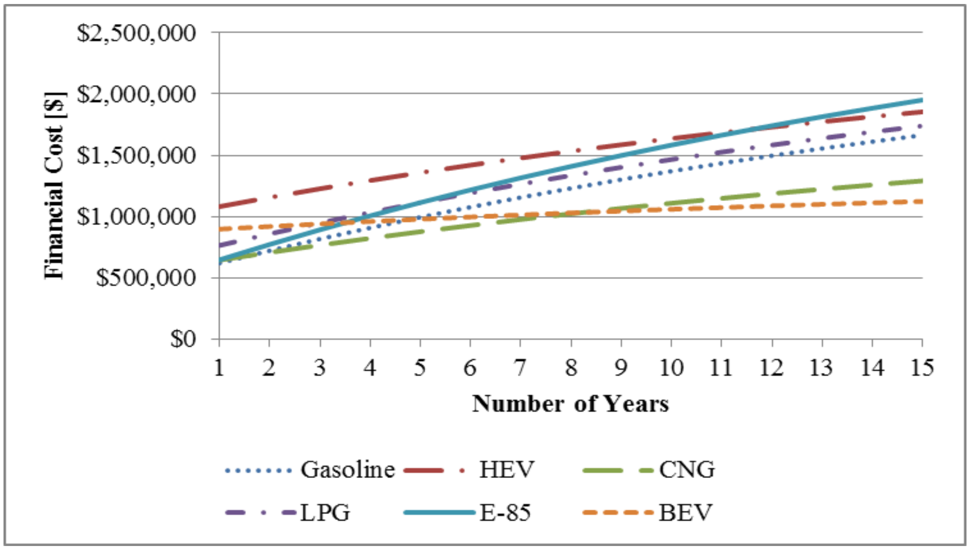


Figure 5.5 Impact of Number of Years on the Financial Results for Each Fuel Type

For fuels that have reduced fuel costs the increasing number of years counters the increased purchase cost of the vehicles. For example, BEV have a much higher purchase cost than the rest of the vehicle types but end up as the least expensive vehicle for the lifetime costs due to the comparative low costs for electricity.

Discount Rate Analysis

The discount rate of the analysis also has a non-linear impact on the financial cost of the fleet. The discount rate does not factor into the results for the other impact categories. This discount is to compensate for the fact that money is worth more at the present time than it is in the future. An increasing discount rate indicates the less that future money is worth in comparison to the present cost. This relationship is also explained by Equation 34. Figure 5.6 shows that discount rate impacts the magnitude of cost but not the order of fuel types, expect for E-85 becoming less expensive than HEVs at higher discount rates.

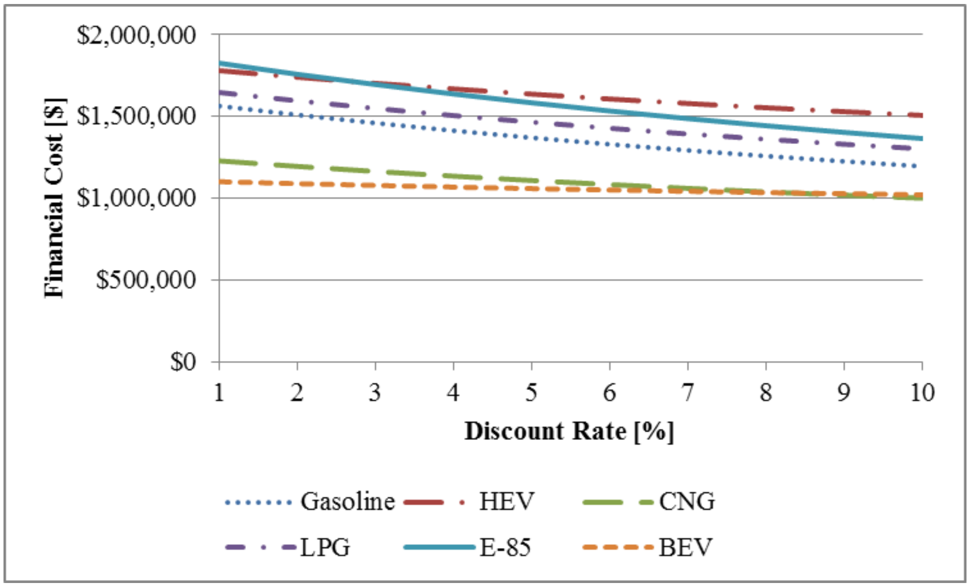


Figure 5.6 Impact of Discount Rate on the Financial Results for Each Fuel Type

Number of Miles Analysis

The number of miles per month impacts the fuel cost of each fuel type in a linear relationship. Figure 5.7 shows the variations on the financial performance for each fuel type with increasing number of miles per month.

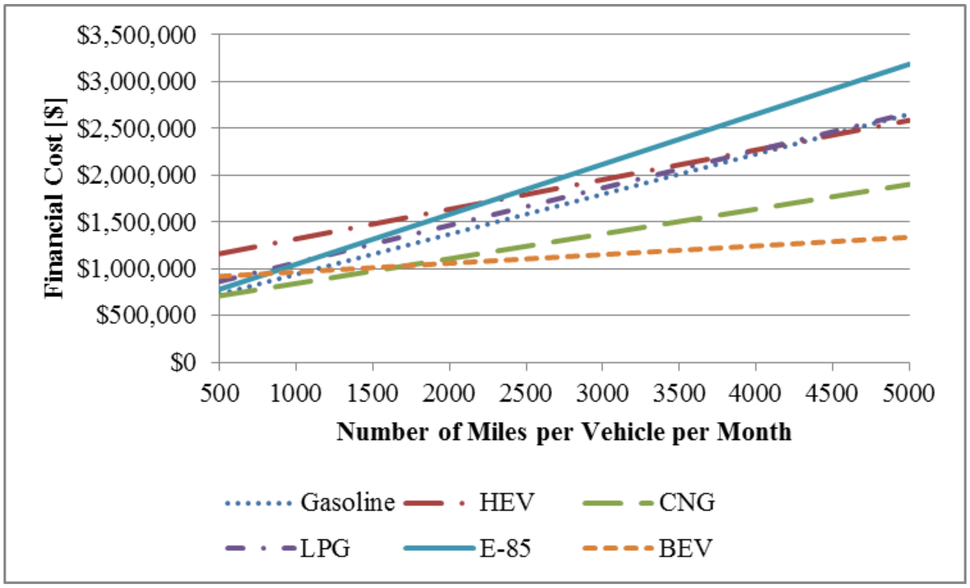


Figure 5.7 Impact of Number of Miles on the Financial Results for Each Fuel Type

Fuel Types, such as BEV, becomes more financially favorable with the higher number of miles per month as the reduced fuel cost counters the high purchase cost of the BEVs. E-85 goes from being one of the cheaper fuel types at low mileage to the most expensive by a wide margin due to FFVs being less efficient and E-85 being a comparatively expensive fuel source. The other impact categories have similar linear relationships with the number of miles per month. The magnitude of the separation between the fuel types increases with high number of miles per month with E-85 having the largest separation due to the high irrigation requirements of corn based ethanol. Similarly, GHG emissions and societal cost have no changes in the order of fuel type performance with increasing number of miles.

Number of Vehicles Analysis

The number of vehicles does not have an impact on the order of fuel type results for each category but instead serves to scale the magnitude of the respective impact. Figure 5.8 presents this for the Financial Cost. This type of relationship is replicated in the other impact categories.

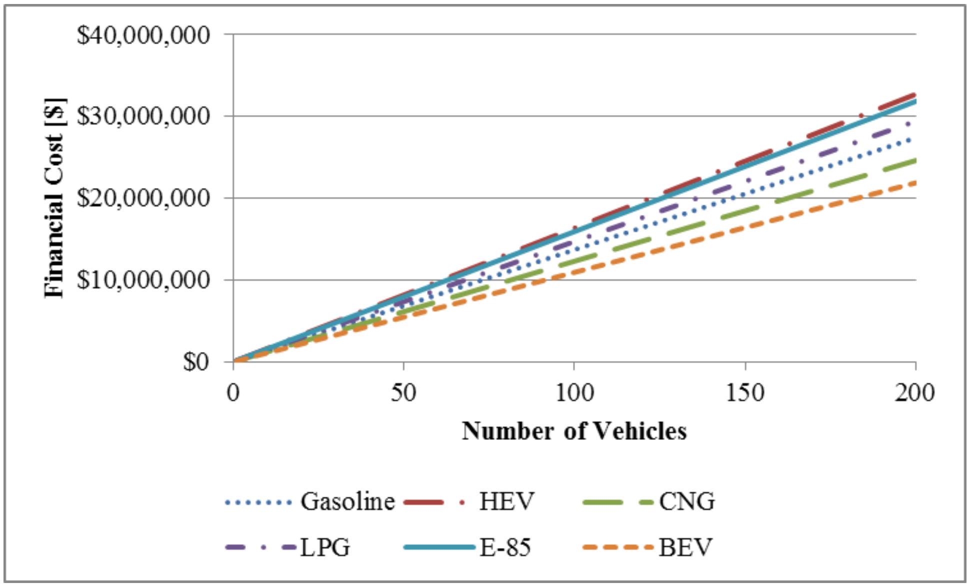


Figure 5.8 Impact of Number of Vehicles on the Financial Results for Each Fuel Type

5.2.3 Fuel Type Parameters

Refueling Infrastructure

A number of fuel types would most likely require additional infrastructure to support refueling of the fleet. Although most fleets install some type of central refueling, it was assumed for gasoline and HEV fleets there would be sufficient refueling opportunities at retail gasoline stations. Figure 5.9 presents the changes of the various fuel types' financial cost due to refueling infrastructure for three different fleet sizes of 10 vehicles, 25 vehicles, and 50 vehicles.

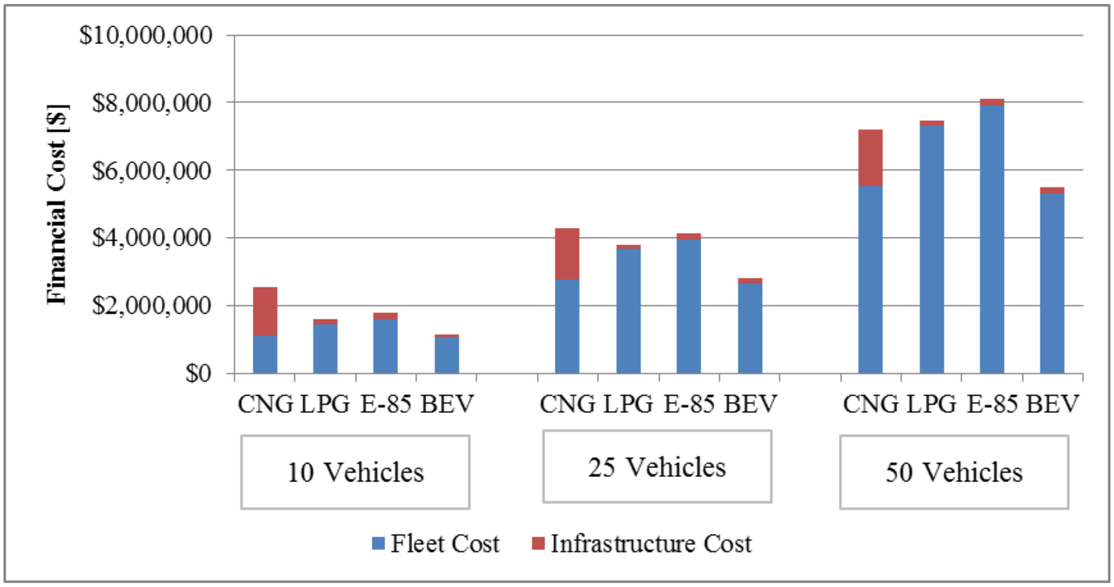


Figure 5.9 Fleet and Refueling Infrastructure Cost for Different Fleet Sizes

The CNG refueling infrastructure is most expensive as it accounts for 56%, 35%, and 23% of the total costs for the respective three fleet sizes. The other fuel types range from 2% to 11% of the total cost. This comparison shows the importance of fleet size in determining refueling infrastructure needs. Larger fleets require greater refueling needs but take advantage of economies of scale in reducing the marginal cost of installation per vehicle. However, improved logistics are required to schedule refueling windows for all the vehicles. BEVs have an especially difficult logistics due to the frequency of recharging and the longer charge time, which could require more charging stations and increased costs.

V2G Revenue Generation

As discussed previously, there are five different scenarios considered for revenue generation for electric vehicles through future developments in vehicle-to-grid frequency regulation. These scenarios are: (1) Not included in analysis, (2) Considering V2G, (3) Consider V2G with new accounting practices, (4) Consider V2G with bi-directional capabilities, and (5) Consider V2G with new accounting practices and bi-directional capabilities. Table 5.4 presents the results from these different scenarios.

Table 5.4 Financial Costs for Different V2G Revenue Generation Scenarios

Scenario	**Financial Cost**
Not included in analysis	$1,059,697
V2G	$1,012,003
V2G with new accounting practices	$1,002,464
V2G with bi-directional capabilities	$964,309
V2G with new accounting practices and bi-directional capabilities	$945,231

As seen in the results, a significant financial advantage of approximately $115,000 could be realized in the future V2G scenario. However, in the near term a fleet operator may not be convinced that the financial benefits of approximately $48,000-$57,000 would outweigh the downsides. These downsides could range from the cost and hassle of implementation to the potential risk of degradation of the costly lithium-ion battery through the increased battery cycling.

Ethanol Feedstock

The feedstock used for ethanol production has a significant impact on its environmental viability as an alternative fuel source. Cellulosic ethanol produced from switchgrass can reduce water consumption and emissions considerably as seen in Table 5.5.

Table 5.5 Variation in Results from Ethanol Feedstock

	Switchgrass Based Ethanol	Corn Based Ethanol			
		Region 5	Region 6	Region 7	US. Average
Water Consumption (liters)	4,012,598	16,779,204	27,366,146	504,868,367	157,393,787
GHG Emissions (short tons CO_2-Eq)	836	3,364	3,364	3,364	3,364
Societal Cost	$284,821	$1,048,058	$1,048,058	$1,048,058	$1,048,058

The financial cost is not considered in this comparison because there is not a reliable source for how retail ethanol cost varies due to feedstock. The water consumption reduction is due to switchgrass being a deep-rooted and relatively drought tolerant plant that does not need to be irrigated in native habitats to produce acceptable yields. However, there are some variations in water consumption in the production of cellulosic ethanol. Figure 5.10 presents how the process used impacts the water consumption results for a fleet of vehicles running on E-85.

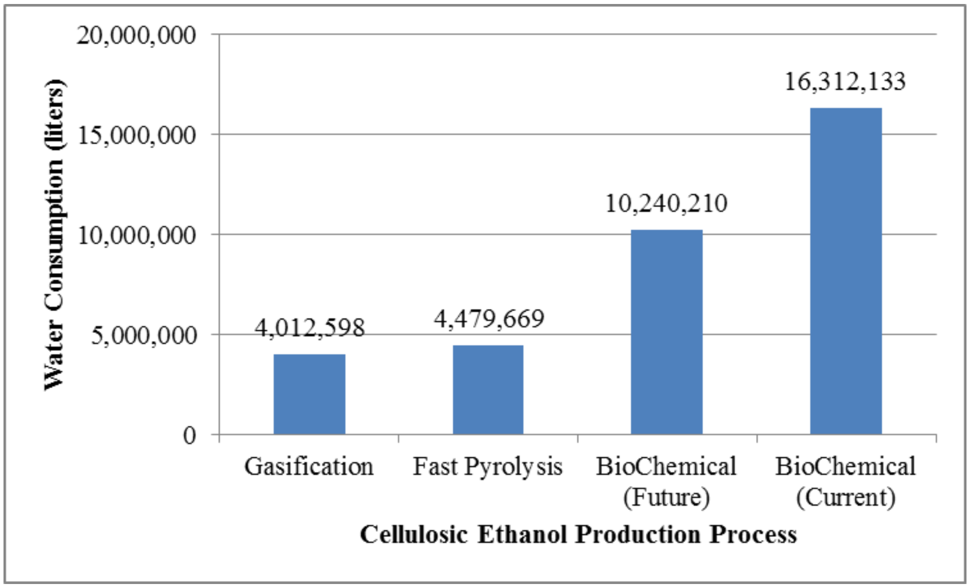


Figure 5.10 Water Consumption Variations for Cellulosic Ethanol Production Process

Cellulosic ethanol produced through the current BioChemical process consumes almost as much water as corn based ethanol produced in Region 5. The reduction of freshwater use has been a priority in the development and optimization of cellulosic ethanol production processes (Wu 2009).

Electricity Generation Source

As mentioned previously, the electricity generation source plays a drastic role in determining the water consumption and emissions occurred during electricity production. The regional comparisons exemplified these variations between state electricity profiles. However, it is also important to examine each electricity generation source individually to understand how marginal increases in each electricity source would impact the results. This could help influence policy decisions around increases in certain electricity sources. Additionally, firms may be influenced to provide their own electricity through alternative means such as solar power generation. Figure 5.11 through 5.13 present the water consumption, GHG emissions, and societal cost respectively for the default scenario.

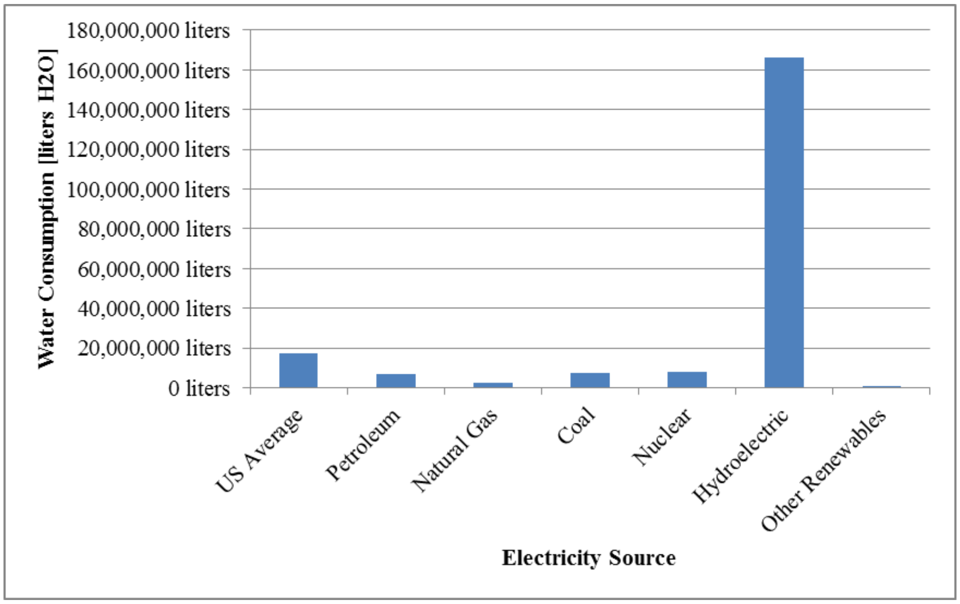


Figure 5.11 Water Consumption of BEV Default Fleet for Each Electricity Source

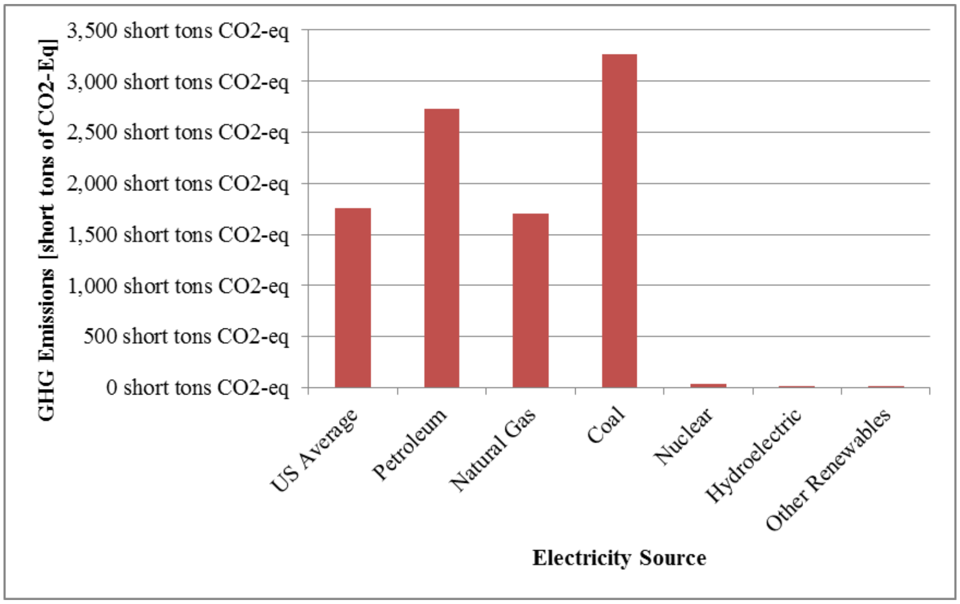


Figure 5.12 GHG Emissions of BEV Default Fleet for Each Electricity Source

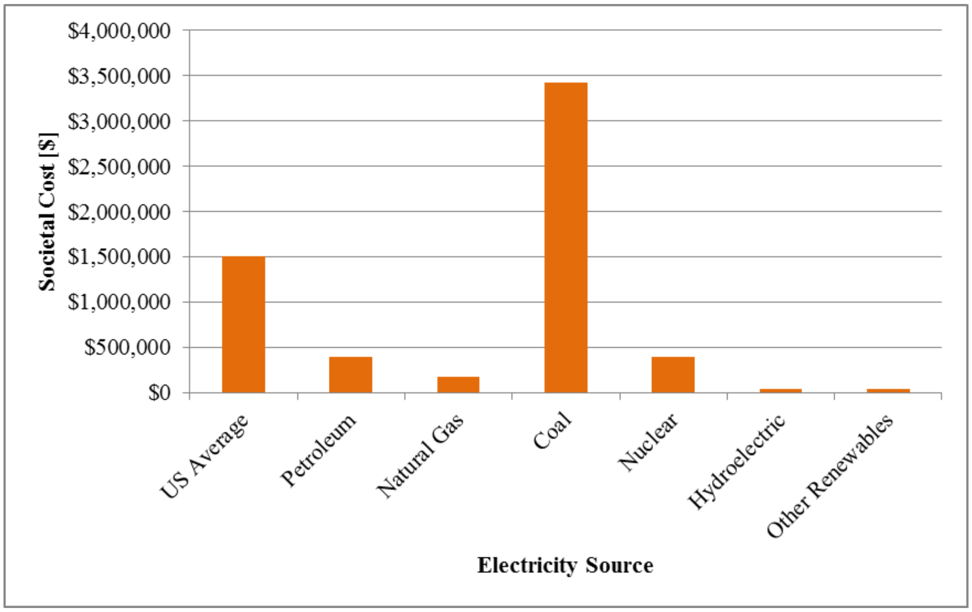


Figure 5.13 Societal Cost of BEV Default Fleet for Each Electricity Source

As would be expected, the fossil fuel electricity sources (petroleum, natural gas, and coal) emit the majority of greenhouse gases and criteria pollutants. Meanwhile, hydroelectricity is the most dominant source of water consumption. This type of analysis provides an important perspective into the importance of understanding the electricity source. Although all electricity is the same when consumed, the source of generation will decide a BEV fleet's impact. Additionally, if a fleet operator was able to obtain electricity from renewable resources, such as solar energy, the environmental and societal impact would be almost negligible.

Fuel Efficiency

Since there are no production electric E-450s, the BEV efficiency was assumed from specifications released by Balqon Corp. concerning their upcoming Eqo 14. This efficiency is considered a worst case scenario, as future vehicles would be able to build upon the lessons learned in the first generation of EVs to produce comparable efficiencies for larger vehicles such as the E-450. Therefore the results of the model were compared for varying BEV efficiencies. One such method was comparing the curb weight of various electric vehicles and the respective efficiencies of these vehicles to establish a relationship. Table 5.6 presents the different vehicle specifications.

Table 5.6 Electric Vehicle Curb Weight and Efficiency

Vehicle	**Curb Weight**	**Unit**	**Efficiency**	**Unit**
Ford Focus	3421	lbs	4.35	miles/kWh
Transit Connect	3948	lbs	2.86	miles/kWh
Nissan Leaf	3500	lbs (est)	4.17	miles/kWh
Smith Newton	16535	lbs	1.19	miles/kWh
Modec Van	12100	lbs	1.18	miles/kWh

A linear fit was then applied to establish the relationship between curb weight and efficiency as presented in Figure 5.14.

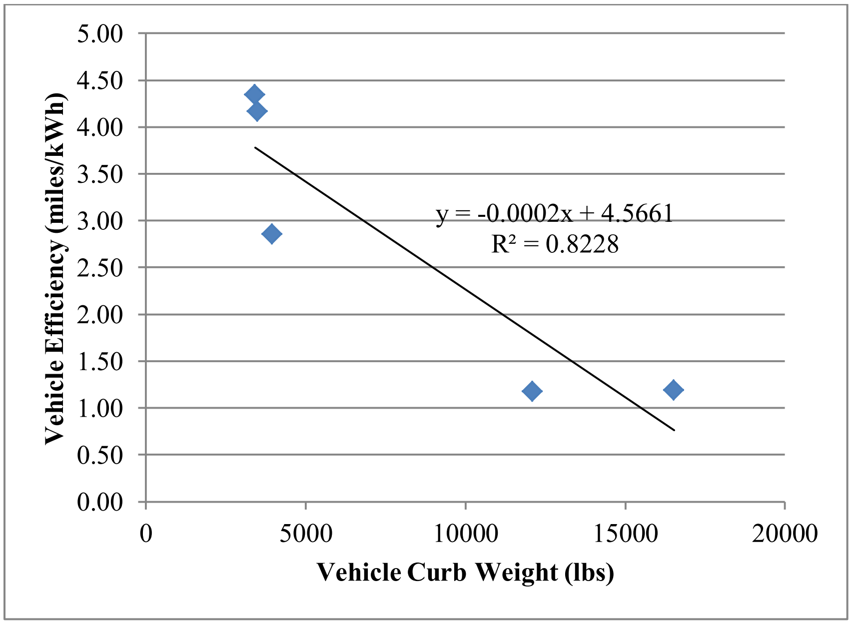


Figure 5.14 Vehicle Curb Weight and Efficiency Relationship

Equation 35 presents the linear relationship between curb weight and electric vehicle efficiency with a R^2 value of 0.8228.

$$Vehicle\ Efficiency = 4.5661 - 0.0002 * (Vehicle\ Curb\ Weight) \qquad (35)$$

Therefore with a curb weight of approximately 5,400 lbs for an E-450 cutaway, this model would predict that the efficiency for an electric vehicle of this size to be 2.94 miles/kWh. This efficiency is actually greater than that of the smaller Transit Connect Electric so another method was employed to estimate the efficiency by comparing the gasoline efficiency to the electric efficiency of the same vehicle type to establish a relationship between vehicles miles per gallon and miles per kWh. Table 5.7 presents the relationship for a Ford Focus and Transit Connect.

Table 5.7 Efficiency Relationship between Fuel Types

Vehicle	**Fuel Type**	**Fuel Efficiency**	**Relationship**
Ford Focus	Gasoline	25 miles/gallon	0.17 gallons/kWh
	Electric	4.36 miles/kWh	
Transit Connect	Gasoline	21 miles/gallon	0.14 gallons/kWh
	Electric	2.86 miles/kWh	
Average			0.15 gallons/kWh

For an E-450, which has a gasoline fuel economy of 7 miles/gallon, this would translate to an electric efficiency of 1.08 miles/kWh.

These different efficiencies were then compared with the model to determine the sensitivity of the results for BEVs. The results of these comparisons are presented in Table 5.8.

Table 5.8 BEV Efficiency Impact on Results

	Transit Connect Electric	**Curb Weight**	**Gasoline and EV Relationship**	**Model (Balqon Eqo 14)**
Efficiency (miles/kWh)	2.86	2.94	1.08	1.00
Financial Cost ($)	$939,173	$937,410	$1,045,969	$1,059,697
Water Consumption (liters)	1,868,871 liters	1,818,018 liters	4,949,048 liters	5,344,972 liters
GHG Emissions (short tons CO2-Eq)	613 short tons CO2-eq	597 short tons CO2-eq	1,625 short tons CO2-eq	1,755 short tons CO2-eq
Societal Cost ($)	$527,072	$512,730	$1,395,766	$1,507,427

Each impact categories increase with the decrease in the efficiency of the vehicle as would be expected. The financial cost and GHG emissions still remain lower than the other fuel types even for the worst case scenario. The water consumption is much higher than all the other categories except for the corn-based E-85 fleet. However, the societal cost is extremely higher than the other categories due to the 186% increase in cost in comparison to Transit Connect Electric, which had a societal cost that was in the middle of the other fuel types.

5.3 Utility Theory Optimization

As discussed in Chapter 4, the utility preferences for the different impact categories were elicited for the default scenario. These utility preferences provide the ability to optimize the results for the default scenario. Three separate scenarios of corporate preference were analyzed. The first corporate preference is a firm purely motivated by financial performance. This optimization only takes into account the utility of financial cost. The second firm takes into consideration both financial and environmental issues, termed the "sustainable" firm. An example of this type of firm would be one that views reporting on environmental issues as a possible competitive advantage. Finally, the third firm is the corporate steward that takes into account financial, environmental, and social performance; the triple bottom line. Figure 5.15 presents the utility results for these three preferences.

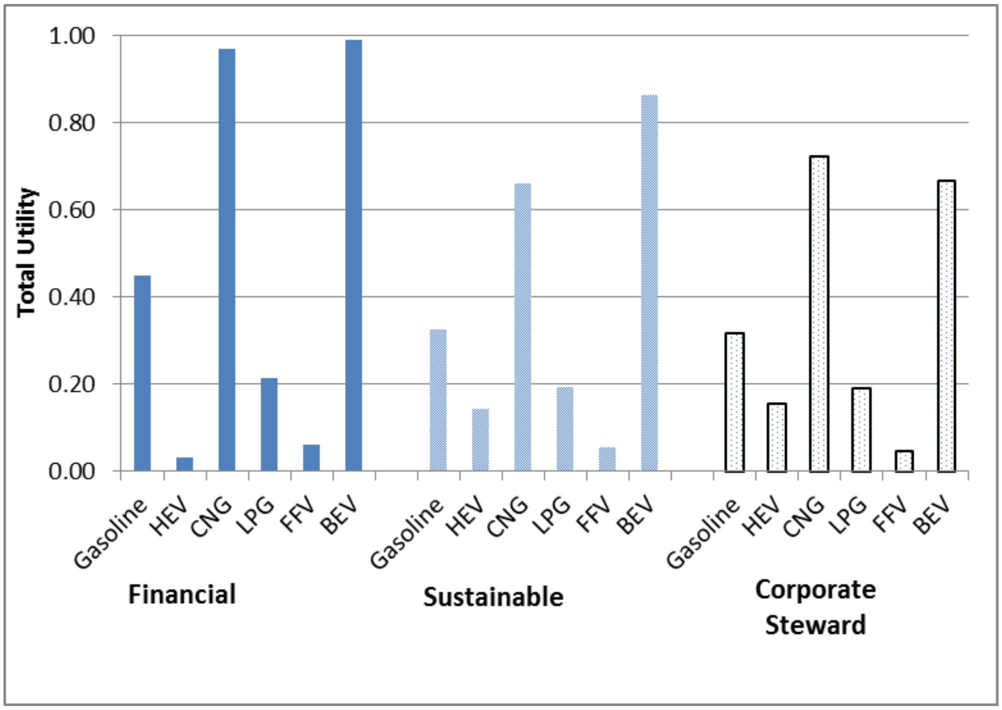


Figure 5.15 Utility Results for Different Corporate Preferences

For both financial and sustainable firms the BEV fleet would be the correct choice to maximize utility. However, to maximize utility for a corporate steward firm CNG fleet would provide the most utility. One interesting note, two of the currently most proliferate alternative fuels, HEV and FFV, provide the least utility due to their high costs and limited external benefits. Therefore, the third most beneficial fleet would actually be a gasoline fleet. In order to apply utility theory to other fleet scenarios the utility preferences would have to be elicited again. The limited applicability of utility preferences is due to the wide variations in results between different scenarios.

5.4 Case Studies

Airports are ideal areas to focus on for AFVs due to air quality concerns and the tendency to be located in air quality nonattainment zones (Howards 2001). Airport fleets travel routes that provide for integrated central refueling stations and the associated high mileage increases the potential fuel savings of AFVs. Another aspect is the potential public goodwill and airport image improvement that may be gained by passengers being transported to their respective flights through sustainable methods. These reasons have led airports to operate successful AFV fleets over the past decade with the number growing with the maturation of the technology.

In order to provide perspective on potential applications of the fleet impact calculator model a number of case studies were developed to provide realistic inputs into the fleet model. These inputs were then used to calculate the financial cost, water consumption, greenhouse gas emissions, and societal cost associated with criteria pollutant emissions.

5.3.2 SuperShuttle Case Study

Description

The Denver SuperShuttle is a shuttle service that operates both in-town service around Boulder, Colorado and inter-city service between Boulder and Denver International Airport (DIA). In 1999 a fleet study was conducted to analyze and compare SuperShuttle's recently acquired CNG and gasoline 15-passenger Ford E-350s. This case study provides an opportunity to relate the model with actual real-world results, while also examining the motivations and difficulties of fleet implementation.

SuperShuttle chose to include CNG vehicles in their fleet to improve relations with Boulder's environmentally conscious community (Eudy 2000). Additionally, the CNG vehicles were comparable in cost to gasoline vehicles because of a range of financial incentives from the OEM (Ford), private partnerships, and state government. The refueling requirements for the fleet were satisfied by public stations in the Boulder area and at DIA so no investment in refueling infrastructure was required.

Input Parameters

On average the SuperShuttle vehicles traveled 55,054 miles (4,588 miles/month) over the course of the study (Eudy 2000). The CNG vehicles averaged only 3,692 miles/month with most travel being limited to in-town service, which was attributed to driver's range anxiety. This discrepancy also resulted in CNG vehicles having an average fuel economy of 10.6 miles/gge compared to 11.7 mpg for the gasoline vehicles. Therefore, the fuel economy will be normalized to 11 miles/gge to account for these variations in drive cycles. The other fuel type fuel economies were determined by the formulas discussed in Chapter 3 with conversion factors of $1.35\frac{mpg_{HEV}}{mpg_{Gas}}$, $0.71\frac{mpg_{E-85}}{mpg_{Gas}}$, and $0.15\ \frac{miles/kWh}{mpg_{Gas}}$ for HEV, E-85, and BEV respectively. Table 5.9 shows the model input parameters used for this case study.

Table 5.9 SuperShuttle Case Study Input Parameters

Scenario Parameters		*Fuel Type Parameters*	
State:	Colorado	Consider Refueling Infrastructure	FALSE
Number of Years:	5 years	Consider BEV V2G Freq. Regulation	FALSE
Region:	Rocky Mountain	Consider New V2G Accounting Method	FALSE
		Consider Bi-directional V2G	FALSE
		Corn Ethanol	TRUE
Fleet Parameters		Cellulosic Ethanol	FALSE
Miles Traveled	4,588 /vehicle/month		
Financial Parameters			
Discount Rate:	5%		
Vehicle Parameters		State's Electricity Profile (EIA 2012)	
Fuel Type	Efficiency	**Petroleum**	0.02%
Gasoline	11.00 miles per gallon	**Natural Gas**	21.05%
HEV	14.85 miles per gallon	**Coal**	63.11%
CNG	11.00 miles per gge	**Nuclear**	0.00%
LPG	11.00 miles per gge	**Hydroelectric**	2.36%
E-85	7.80 miles per gallon	**Other Renewables**	13.45%
BEV	1.70 miles per kWh	**Total**	100%
Fuel Cost (Regional Average)		*Fleet Composition*	
		Number of Vehicles of Each Fuel Type	
Gasoline	$3.15 per gallon	**Gasoline**	5
Natural Gas	$1.48 per gge	**HEV**	5
Propane	$2.74 per gge	**CNG**	5
E-85	$2.73 per gallon E-85	**LPG**	5
Electricity	$0.09 per kWh	**E-85**	5
		BEV	5

Results

Those parameters are inputted to the model to obtain the net present cost, water consumption, GHG emissions, and societal cost. These results are presented in Table 5.10.

Table 5.10 Results from Model for SuperShuttle Case

Fuel Type	Net Present Cost	Water	GHG	Societal Cost
Gasoline	$598,981	1,817,900 liters	1,543 short tons CO2-eq	$204,145
HEV	$754,622	1,346,593 liters	1,143 shorts tons CO2-eq	$151,219
CNG	$450,104	955,006 liters	1,435 shorts tons CO2-eq	$169,058
LPG	$629,966	1,817,900 liters	1,413 shorts tons CO2-eq	$184,683
E-85	$674,824	57,399,496 liters	1,227 shorts tons CO2-eq	$382,213
BEV	$500,284	3,051,027 liters	817 shorts tons CO2-eq	$743,831

Although the fuel efficiencies have been modified to reflect the change from E-350s to E-450, the purchase costs were not changed because of a lack of available data. The magnitude of the purchase cost is skewed by this simplification but most likely better represents the current cost structure than the zero incremental purchase cost experienced by SuperShuttle. The financial cost has been converted to net present value, including purchase and fuel costs, but does not include refueling infrastructure costs as specified in the Table 5.9. Including refueling infrastructure would dramatically alter the total costs and impact the financial performance ranking of the fuels. Figure 5.16 presents the financial and societal costs of the model for each fuel type.

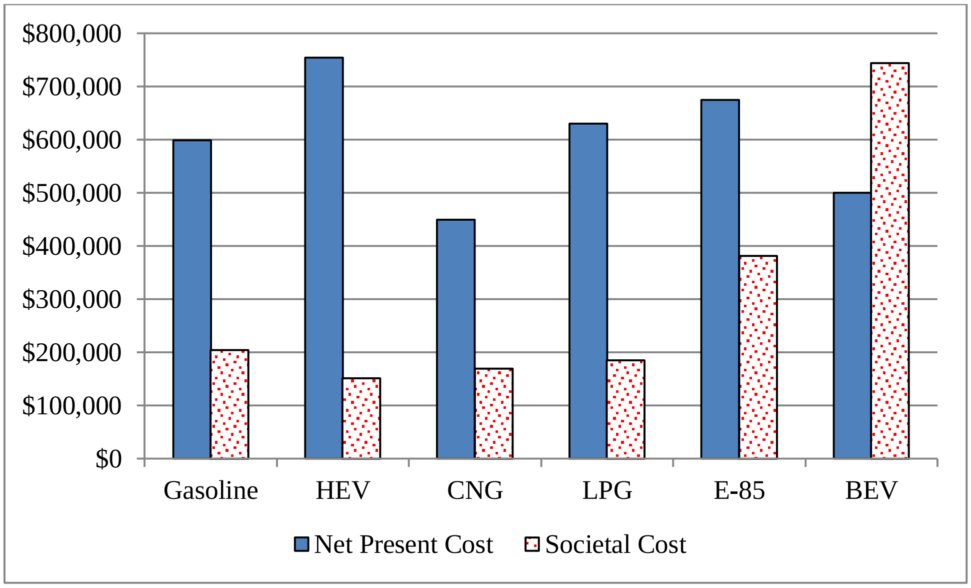


Figure 5.16 Financial and Societal Costs for SuperShuttle Case Study

CNG has the lowest financial cost at 25% less than the gasoline fleet. This is quite similar to the results obtained during the SuperShuttle study, which found dedicated CNG vehicles to be 22.6% less than gasoline vehicles (Eudy 2000). Maintenance costs were included in their analysis but were not found to be significantly different for the fuel types (0.04 cents/mile difference). The fuel cost differential between CNG and gasoline has actually increased from the price levels of 1999 as shown in Figure 5.17.

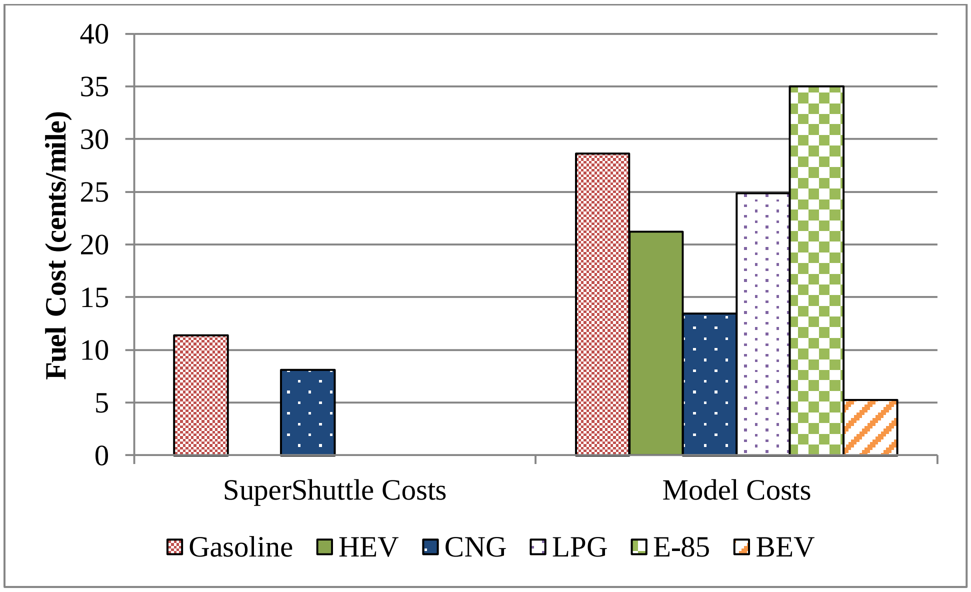


Figure 5.17 Fuel Cost Comparison between SuperShuttle and Model (Eudy 2000)

The trends of fuel cost follow the overall cost as the main cost driver with the exception of HEV. The fuel cost for HEV does not compensate for the additional high purchase cost. Meanwhile, E-85 is the only alternative fuel to have higher fuel costs than gasoline. E-85 in the Rocky Mountain region retailed for approximately $2.73 per gallon of E-85 in 2011 compared to $3.15 gallon of gasoline. However, the lower fuel economy associated with the lower energy content of ethanol leads to the higher per mile cost of fuel. The model scenario was only ran for 5 years

The societal cost due to criteria pollutants represents a fraction of the financial cost for most of the fuel types. However, BEV has a societal cost that is 49% higher than the financial cost. The societal cost is driven by the high percentage of coal generated electricity. Particularly the emissions of sulfur dioxide gases and particulate matter (PM-10) cause the vast majority of the societal costs. This shows that although a fuel type may have less climate change potential and zero tailpipe emissions, there may be unrealized negative externality further upstream. Figure 5.18 presents other environmental impacts of water consumption and greenhouse gas emissions.

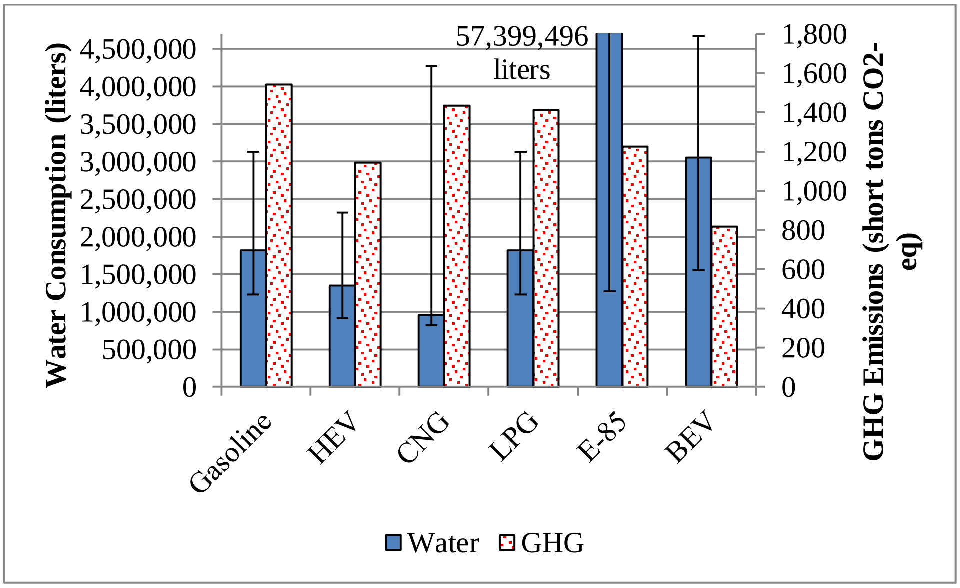


Figure 5.15 Environmental Results for SuperShuttle Case Study

For clarity of comparing the results of the other fuel types, the E-85 water consumption result was truncated but extends to a value of 57,399,496 liters of water. The irrigation requirements for corn-based ethanol lead to this high consumption. This consumption can be reduced to levels comparable with other fuel types by switching to switchgrass feedstock. CNG has the lowest water consumption but has potential data variation that extends beyond the other fuel types. This high range of consumption for CNG can be attributed to more water intensive extraction processes, such as hydraulic fracturing, and the high water consumption of the electricity used during compression. Although Colorado has a large share of other renewable electricity sources, the small percentage of hydroelectric water consumption dominates the BEV water consumption. If one was to not consider hydroelectric water consumption, the BEV water consumption would be slightly less than that of gasoline at 1,755,590 liters of water consumption.

Recommendations

For this scenario it is recommended to purchase a fleet of CNG vehicles. Although there are some environmental benefits from a HEV fleet, the high purchase cost per vehicle makes this option prohibitively expensive. Ethanol vehicles are the least attractive option because of the high cost, extremely high water consumption, and limited GHG reductions. Meanwhile, BEVs have the lowest GHG emissions but would be the most difficult fleet type to implement due to the reduced range and recharging limitations.

The reduced range of CNG vehicles was also a concern highlighted by the SuperShuttle management and drivers. However, newer vehicles often offer extended range packages that provide larger capacity fuel tanks. The abundant refueling infrastructure in the operational area of SuperShuttle alleviates some of these concerns as well as avoids the substantial cost of installing refueling infrastructure. As demonstrated in Figure 5.3 there is a wide variation in the water consumption for CNG and only a small reduction in GHG emissions. However if the fleet was able to obtain the natural gas from more sustainable resources such as landfill gas, the GHG emissions could be reduced further.

5.3.1 Aerotropolis Case Study

Description

One potential fleet scenario is the shuttle program of the planned Aerotropolis Atlanta development at Hartsfield Jackson International Airport. An aerotropolis refers to the concept of an urban economic development around an airport. This proximity to a high density travel portal allows for increased connectivity between the air travelers and surrounding mixed-use development. The Aerotropolis Atlanta plans to feature a 30-acre parking area that will include two separate shuttle services: one to the existing western terminal and another to the new international terminal. Table 5.11 outlines the specifications of the desired shuttle service.

Table 5.11 Aerotropolis Atlanta Shuttle Route Specifications

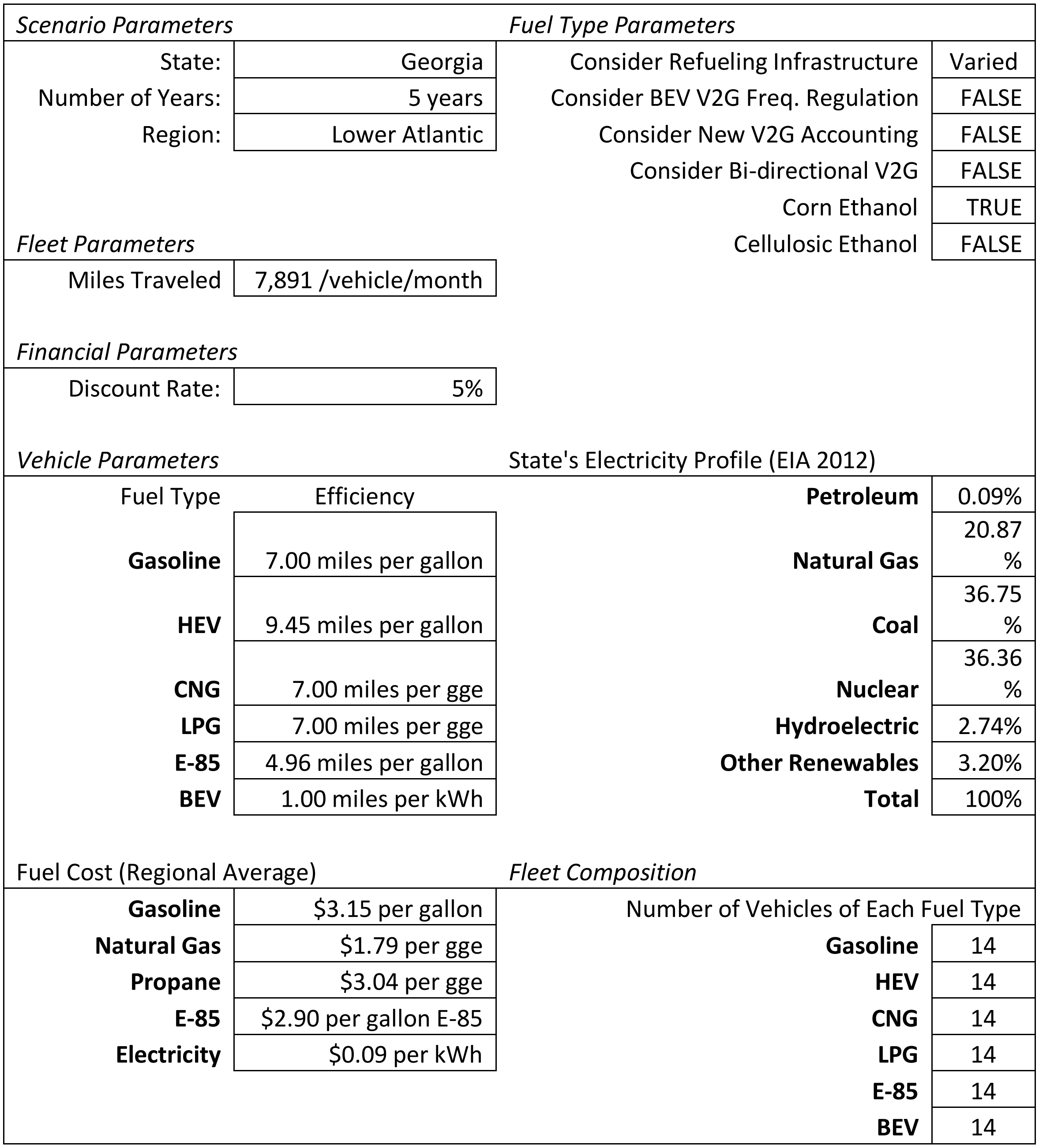
Given Variables:	
Number of Shuttle Vans	
International Terminal	6 vans
Western Terminals	6 vans
Frequency (minutes) - 5 minute hold for pickups	
International Terminal	18 min/trip
8 min travel (4 min each way) and two 5 min stops	
Western Terminals	30 min/trip
20 min travel (10 min each way) and two 5 min stops	
Distance (miles round trip)	
International Terminal	2.8 miles/trip
Western Terminals	10.0 miles/trip
International Terminal served 24/7 but at half capacity from 1:00 am to 5:00 am	
Western Terminals not served from 1:00 am to 5:00 am	
Duration of Operation (hours)	
International Terminal	24 hrs/day
Western Terminals	20 hrs/day
Calculations:	
Number of Trips per Day (trips/day)	
24/7 International Terminal (3 vans)	80 trips/day
20/7 International Terminal (3 vans)	67 trips/day
Western Terminals	40 trips/day
Number of Miles per Day (miles/day)	
24/7 International Terminal (3 vans)	224 miles/day
20/7 International Terminal (3 vans)	187 miles/day
Western Terminals	400 miles/day
Number of Miles per Month (miles/month)	
International Terminal	37,473 miles/month
Western Terminal	73,000 miles/month
Total	110,473 miles/month
Total per Van	9,206 miles/month/van

Input Parameters

These specifications are set by the potential operator of the shuttle service and result in a total of 9,206 miles/month for each van. This type of high mileage fleet application is especially well suited for alternative fuel vehicles. To compensate for the downtime spent refueling and potential maintenance issues, the fleet size is increased to

14 vehicles, which decreases the number of miles per month to 7,891 miles/month for each van. Two scenarios were run: one that takes into account the additional refueling infrastructure and the other that assumes the fleet would utilize refueling options located at the airport. Table 5.12 shows the model input parameters used for this case study and

Table 5.12 Aerotropolis Case Study Input Parameters



Scenario Parameters		*Fuel Type Parameters*	
State:	Georgia	Consider Refueling Infrastructure	Varied
Number of Years:	5 years	Consider BEV V2G Freq. Regulation	FALSE
Region:	Lower Atlantic	Consider New V2G Accounting	FALSE
		Consider Bi-directional V2G	FALSE
		Corn Ethanol	TRUE
Fleet Parameters		Cellulosic Ethanol	FALSE
Miles Traveled	7,891 /vehicle/month		
Financial Parameters			
Discount Rate:	5%		
Vehicle Parameters		State's Electricity Profile (EIA 2012)	
Fuel Type	Efficiency	**Petroleum**	0.09%
Gasoline	7.00 miles per gallon	**Natural Gas**	20.87 %
HEV	9.45 miles per gallon	**Coal**	36.75 %
CNG	7.00 miles per gge	**Nuclear**	36.36 %
LPG	7.00 miles per gge	**Hydroelectric**	2.74%
E-85	4.96 miles per gallon	**Other Renewables**	3.20%
BEV	1.00 miles per kWh	**Total**	100%
Fuel Cost (Regional Average)		*Fleet Composition*	
Gasoline	$3.15 per gallon	Number of Vehicles of Each Fuel Type	
Natural Gas	$1.79 per gge	**Gasoline**	14
Propane	$3.04 per gge	**HEV**	14
E-85	$2.90 per gallon E-85	**CNG**	14
Electricity	$0.09 per kWh	**LPG**	14
		E-85	14
		BEV	14

Results

Table 5.13 presents the associated results without considering infrastructure cost.

Table 5.13 Results from Model for Aerotropolis Case Study

Fuel Type	Net Present Cost	Water	GHG	Societal Cost
Gasoline	$3,304,316	13,757,242 liters	11,679 short tons CO2-eq	$1,544,901
HEV	$3,318,253	10,190,550 liters	8,651 short tons CO2-eq	$1,144,371
CNG	$2,278,981	14,076,378 liters	10,518 short tons CO2-eq	$978,373
LPG	$3,425,264	13,757,242 liters	10,692 short tons CO2-eq	$1,397,615
E-85	$4,077,302	434,698,032 liters	9,292 short tons CO2-eq	$2,894,578
BEV	$1,740,683	49,641,073 liters	4,343 short tons CO2-eq	$3,976,736

The financial and societal costs are shown in Figure 5.19. The additional cost for refueling infrastructure is presented as well.

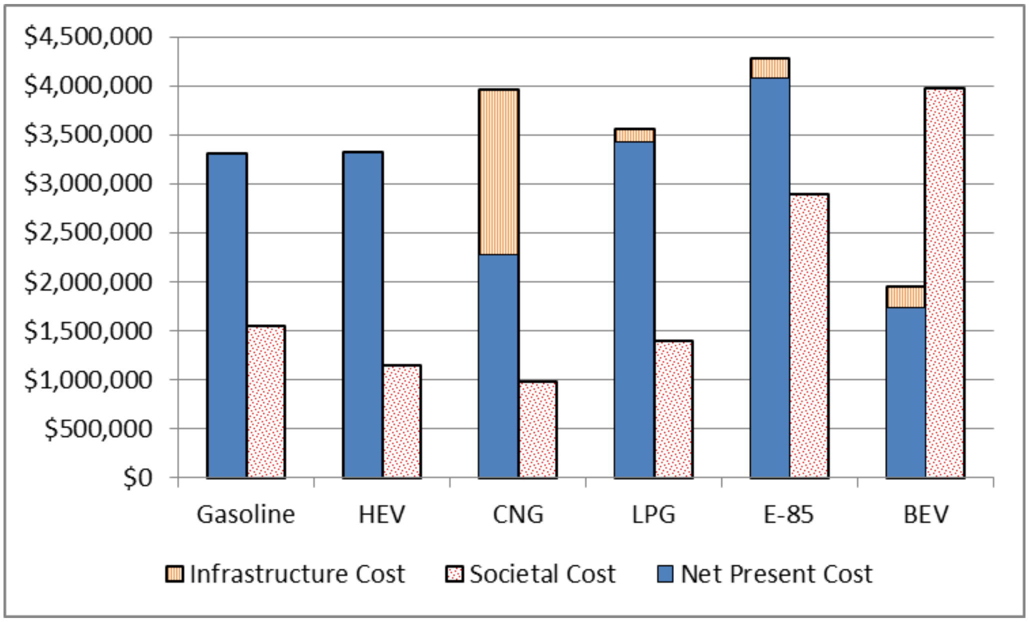


Figure 5.19 Financial and Societal Costs for Aerotropolis Case Study

The additional financial cost for infrastructure dramatically alters the results for CNG, going from the second least expensive option to the second most expensive option.

A BEV fleet is very financially attractive in Georgia as a result of the low electricity cost of the region. However, Georgia obtains a large share of their electricity generation from coal. This drives the high societal cost associated with the criteria pollutants emitted. There has been significant legislation from the Environmental Protection Agency in attempting to promote standards and reduce the hazardous emission under the Clean Air Act. Figure 5.20 presents the water consumption and greenhouse gas emission results.

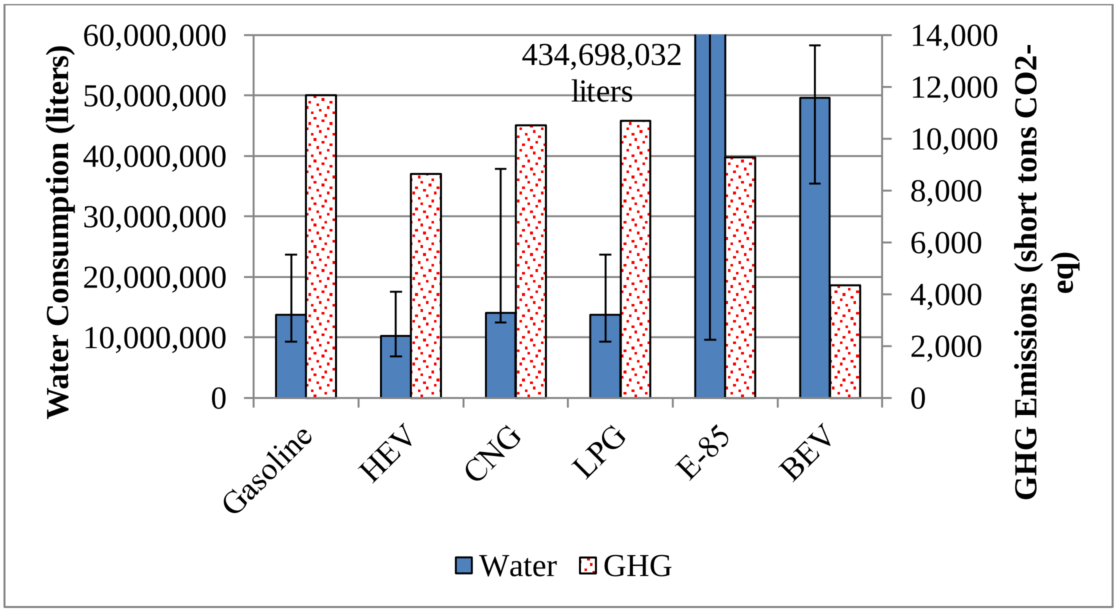


Figure 5.20 Environmental Results for Aerotropolis Case Study

The environmental results from the Aerotropolis case study mimic the findings from the SuperShuttle Case Study. Similarly, not considering the hydroelectric water consumption would reduce the overall BEV water consumption to 17,039,649 liters.

Recommendations

There are a number of differences between the SuperShuttle scenario and the Aerotropolis case beside just a change in location, which include: the increase in mileage, lower fuel economies, and the possible inclusion of infrastructure cost. However, there are trends that remain constant. E-85 vehicles are an expensive option and consume a magnitude more water. If the fleet operator was most concerned about financial performance and was able incorporate the recharging/refueling needs of a BEV or CNG fleet into the current infrastructure then either of those options would be advisable. For this scenario if the fleet had to develop their own infrastructure for alternative fuels, HEVs would be the recommended vehicle type. The high mileage of the fleet provides fuel savings for HEV that offsets the increased purchase cost. The reduction in fuel consumption also leads to corresponding reductions in water consumption and GHG emissions. This shows that the outcome of each scenario is highly dependent on the assumptions made for the fleet and fuels.

CHAPTER 6

DISCUSSION

6.1 Impact of Results

As demonstrated in Chapter 5, the results of each scenario are highly dependent on the assumptions and parameters chosen for the particular analysis. The Ford E-450 was chosen as the fleet vehicle due to the ability to outfit for a number of body types typically utilized in corporate fleets. A range of third-party companies have converted E-450s into alternative fuel platforms for shuttle buses and other fleet situations. The relative inefficiency of the E-450 leads to high fuel consumption when operating in these high mileage fleets. Since most alternative fuels have reduced use phase costs, AFVs become more attractive options for these fleet scenarios. However, when taking into consideration both environmental and social issues alternative fuels have varying performance.

The order of results would also have to fit the specific needs of the company. For example, this analysis does not take into account the challenges of refueling. A BEV fleet would have a much more difficult implementing the long and frequent recharging requirements. This complexity would be a disadvantage for two of the more advantageous alternative fuels: CNG and BEV. CNGs have expensive refueling infrastructure requirements. BEVs have limited range and require long recharging time windows. These challenges might cause some fleets to gravitate towards other fuel types regardless of the other benefits.

However, the model provides an opportunity for the decision maker to run a variety of different fleet scenarios and see the potential impact of changes to the parameters. Previously the fleet operator may have made assumptions of fuel type performance based on generalizations. As shown in Chapter 5, the results for each fuel type are highly dependent on the particular scenario and should be analyzed individually.

6.2 Drawbacks

6.2.1 Data Variability

Collecting water consumption data for energy production is an extremely difficult endeavor because the water must be measured on site and often varies significantly depending on the technology used for each process. Additionally, it has not been until relatively recently that water has become an important material issue so it was often not measured accurately. Many of the popular life-cycle inventory databases do not contain the necessary data as remarked by Berger et al.: "data sets either only contain water use figures (ecoinvent) or tend to underestimate water consumption due to the partly ignorance of water consumed in background processes (GaBi)" (Berger 2012). Therefore, the same potentially outdated studies are often repeatedly cited, such as Gleick's review of water intensity of energy in 1994. The data that does exist has variation in water consumption attributable to the technologies and assumption made. Figure 6.1 presents the variation in results of the different fuel types for the default scenario. The E-85 results have been truncated to facilitate comparisons of the other fuel types but extend to 15,739,379 liters. The data for these variations in water consumption is presented in Appendix B.

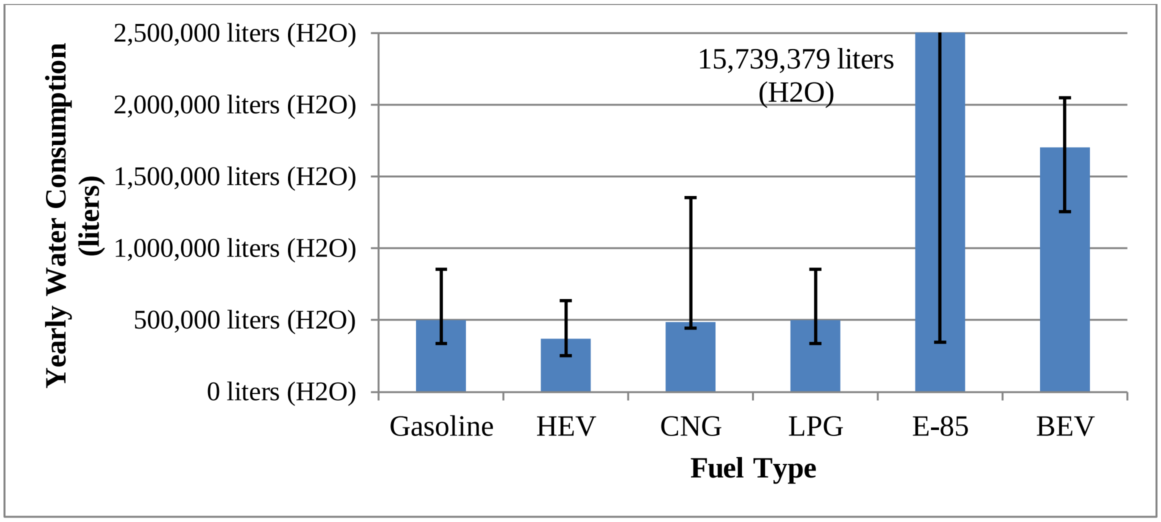


Figure 6.1 Water Consumption Data Variation

The fuel type with the largest variation is CNG, which has variation in extraction and the electricity used in compressing the natural gas. The low end of natural gas water consumption is associated with natural gas obtained through conventional methods. However, the high end of consumption is caused by natural gas obtained through hydraulic fracturing. Both vertical and horizontal wells consume significantly more water than conventional methods. This assumes that all flowback and produced water is lost through evaporation or is no longer available as deep well injection (Goodwin 2012).

6.2.2 Locality

The importance of distinguishing between absolute water consumption and water impact has been previously discussed. However, due to the limitations of current data sources this impact analysis is not possible for all fuel types. Most fuel productions pathways do not have geographic differentiation of water flows. This lack of data can be attributed to the complex nature of water consumption, the cost of data collection, and the fact that databases developed from emissions that do not have the same spatial requirements. If one was able to determine the source of water consumption for extraction, refining, and other fuel lifecycle stages then a complete water impact analysis could be conducted. Berger et al. mention the additional effort that should be put into developing "both more detailed inventory data sets and robust and applicable impact assessment methods, in order to promote the important assessment of water consumption and its consequences in LCA and other disciplines" (Berger 2012).

The World Business Council for Sustainable Development has developed the Global Water Tool to map water use and assess water-scarce regions. The Global Water Tool utilizes the World Resources Institutes data to provide a local perspective of water resources. Figure 6.2 shows the map for the annual renewable water supply per person by river basin in 1995.

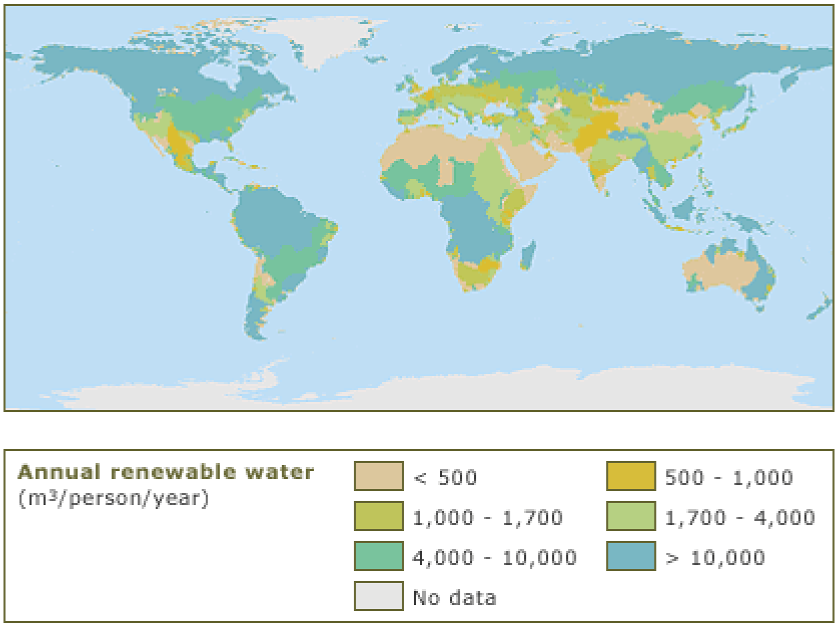


Figure 6.2 Map of Annual Renewable Water Supply per Person by River Basin, 1995 (WRI 2000)

Figure 6.3 shows the map for the projected annual renewable water supply per person by river basin in 2025 with the more stressed river basins highlighted. A number of the regions exhibit an increase in stress level from 1995 data to the 2025 projection. The Colorado River Basin went from having sufficient renewable water supply (1,700-4,000 m^3/person/year) to stressed renewable water supply (1,000-1,700 m^3/person/year). Similarly, the Rio Grande River Basin is projected to have extreme scarcity in 2025 with less than 500 m^3/person/year of renewable water supply.

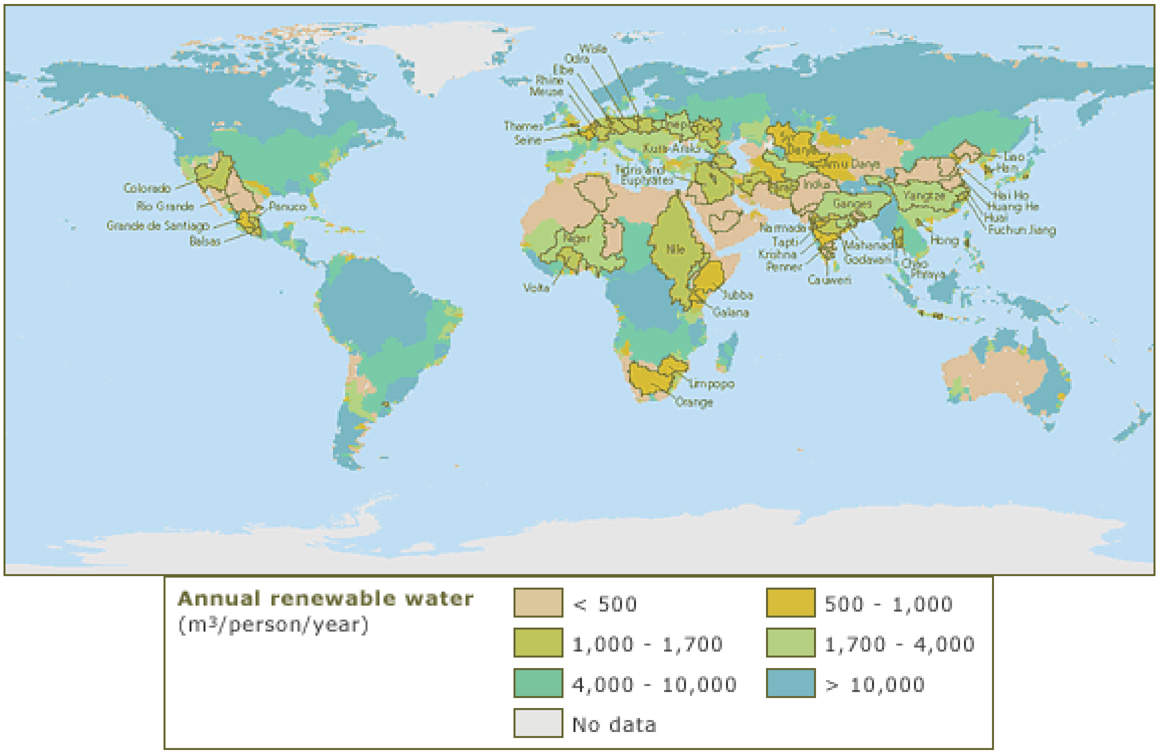


Figure 6.3 Map of Projected Annual Renewable Water Supply per Person by River Basin, 2025 (WRI 2000)

This annual renewable water supply per person can then be combined with water use statistics to obtain a water stress index. These water uses include domestic water demand distributed geographically on a per capita basis, industrial usage in proportion to urban population, and country-level irrigation withdrawals distrusted over irrigated lands based on estimated irrigation need. Figure 6.4 presents the mean annual water stress index as a ratio of human water use to renewable water resources for 1995.

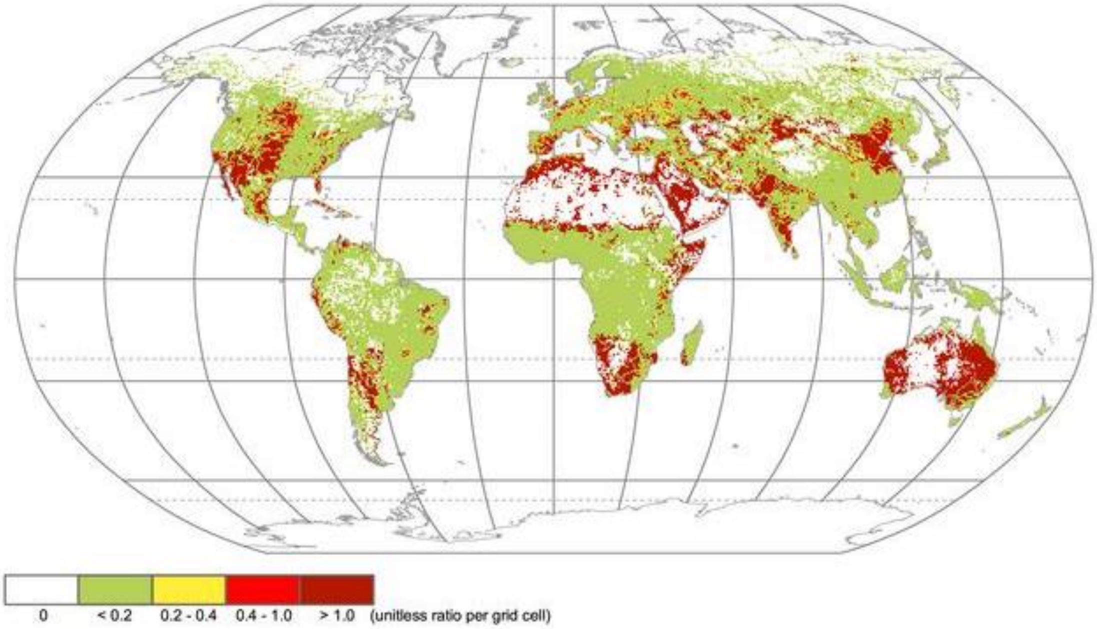


Figure 6.4 Map of Mean Annual Relative Water Stress Index (UNH ; Vorosmarty 2000)

A ratio of 0.4 or greater indicates conditions of water stress. These ratios are expected to increase even more when taking into account the changes in demand due to climate change and population growth. Vorosmarty et al. state that the increased demand due to population growth will drive water scarcity concerns than climate change (Vorosmarty 2000).

Water Impact Analysis

This water impact analysis investigates the water impact of a BEV fleet that operates in a number of representative states. Table 6.1 presents the electricity profile for each state that will be used in the analysis.

Table 6.1 State Electricity Generation Mix

Source	**Percentage**				
	Nevada	**Georgia**	**South Dakota**	**Oregon**	**Texas**
Petroleum	0%	0%	0%	0%	0%
Natural Gas	59%	21%	0%	26%	26%
Coal	25%	37%	7%	8%	8%
Nuclear	0%	37%	0%	0%	0%
Hydroelectric	6%	3%	62%	55%	55%
Other Renewables	10%	3%	31%	10%	10%

A major city in each of these states was chosen to analyze the local watershed impact of the water consumption for a BEV fleet. Table 6.2 presents the associated watershed metrics for the Las Vegas region. These metrics obtained from the Global Water Tool show a city that has limited water resources, which are expected to become exacerbated in the future. The comparison between annual renewable water supply and mean annual relative water stress index shows that, although there are sufficient supplies of water in 1995, the resources are scarce due to the overuse of the supplies.

Table 6.2 Watershed Metrics for Las Vegas

Metric	**Level**	**Value**
Annual Renewable Water Supply per Person (1995)	Sufficient	1,700 – 4,000 m^3/person/year
Annual Renewable Water Supply per Person (Projections for 2025)	Stress	1,000 – 1,700 m^3/person/year
Mean Annual Relative Water Stress Index	Scarce	>1

For the application of impact analysis only the water stress index is required. Table 6.3 presents the mean annual relative water stress index for the different cities respective watersheds.

Table 6.3 Mean Annual Relative Water Stress Index by City's Watershed

City, State	**Watershed**	**Level**	**Value**
Las Vegas, Nevada	Colorado (Ari)	Scarce	> 1
Atlanta, Georgia	Appalachicola	Stress	0.4 - 1.0
Sioux Falls, South Dakota	Mississippi	Low	< 0.2
Portland, Oregon	Columbia	Low	< 0.2
Houston, Texas	Trinity	Medium	0.2 - 0.4

The eco-scarcity method

The eco-scarcity method, defined in Chapter 2, provides a distance-to-target principle using Equation 36.

$$Eco-factor = \frac{1\,EP}{2.57\frac{km^3}{yr}} * WTA^2 * \left(\frac{1}{20\%}\right)^2 * 10^{12}\,\frac{EP}{m^3} \qquad (36)$$

Table 6.4 presents the WTA, ratio of water use to available resources, and the intermediate results to calculating the eco-points of the yearly water consumption. The weighting factor refers to the term: $WTA^2 * \left(\frac{1}{20\%}\right)^2$.

Table 6.4 Water Impact Calculations using Eco-Scarcity Method

City	WTA Used	Weighting Factor	Eco-factor (EP/m3)	Yearly Water Consumption (m^3/yr)	Eco-Points
Las Vegas	1.1	30.25	11,770	4,331	50,982,654
Atlanta	0.6	9	3,502	1,797	6,294,344
Sioux Falls	0.1	0.25	97	64,544	6,278,618
Portland	0.1	0.25	97	2,345	228,148
Houston	0.3	2.25	875	497	435,229

A graphical representation of this data is presented in Figure 6.5. By taking into account the impact of the water consumption for the electricity generation, the results for the different cities change dramatically.

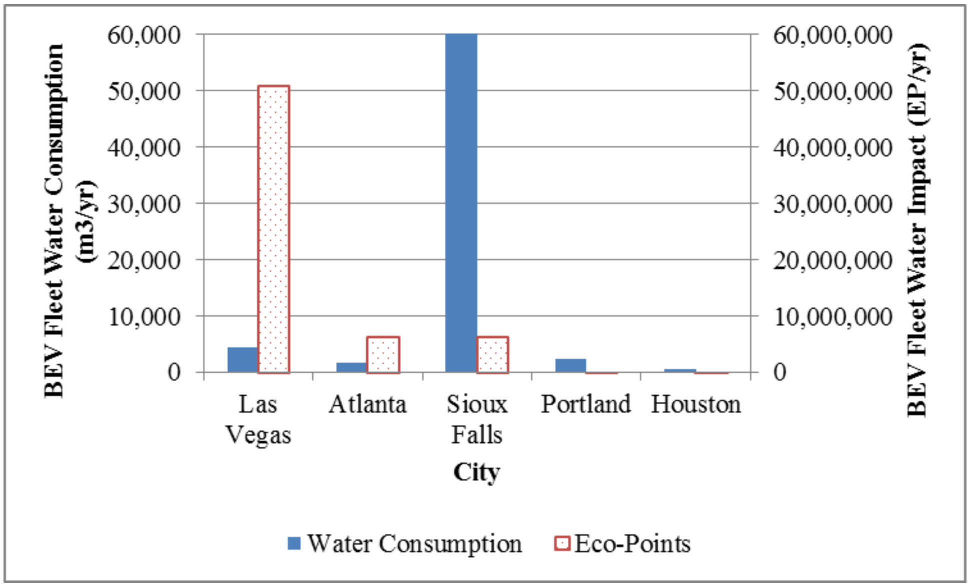


Figure 6.4 Water Consumption and Eco-Point Comparison for Different Cities

The water consumption in Las Vegas is much more impactful than the other water consumptions due to the resource scarcity. Conversely, Sioux Falls goes from having water consumption 1,390% higher than Las Vegas to an eco-point water impact of 88% less. Although eco-points are not a prefect representation of the life-cycle water consumption, the eco-scarcity method does provide perspective to the relative importance of resource consumption in varying scarcity regions.

The rest of fuel types are more difficult to establish the geographic location of water consumption. That is why the model features an option for the more advanced user to specify the regional water scarcity for the various fuel types if this knowledge is available. The same challenge was encountered by Berger et al. in quantifying the impact of water consumption in Volkswagen vehicles' lifecycles. The majority of data available are presented in top-down approaches, which limit the ability to calculate local water impact.

6.2.3 Vehicle Variation

Other vehicle types could be considered to provide a more robust analysis and ensure that truly the most beneficial option is selected. Diesel vehicles are one option that could reduce various impacts as many different European diesel vehicles actually have remarkably high fuel economies. Other more alternative technologies include fuel cell vehicles that haven't experienced the same growth as the AFVs consider in this analysis as shown in Figure 6.6.

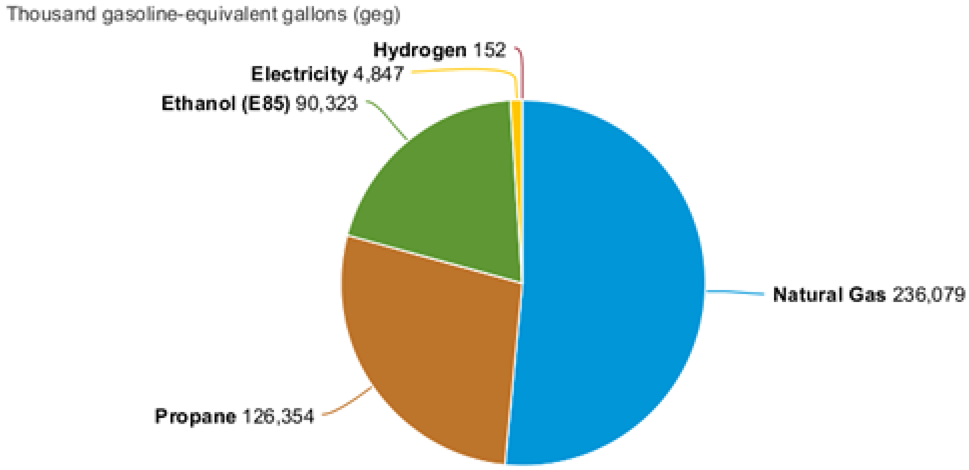


Figure 6.6 Consumption of alternative fuels in fleet vehicles by fuel type, 2010 (EIA 2010)

Fuel cell vehicles have potential for high efficiency but are difficult to implement due to challenges of hydrogen storage and infrastructure development. However, further advancements in technological capability could result in hydrogen becoming the alternative fuel of the future.

Additional fuel pathways could be considered that may change the order of the results. Natural gas can also be obtained from extracting the gas generated by decaying organic materials in landfills. The gas from landfills must be purified in order to remove CO_2 and other impurities. Depending on the efficiency of purification and the profile of the electricity consumed, CNG derived from landfill gas produces far less emissions due to GHGs being captured and stored in the fuel during fuel production. Figure 6.7 shows this reduction in emissions for landfill NG compared to feedstock from North American and Non North American sources.

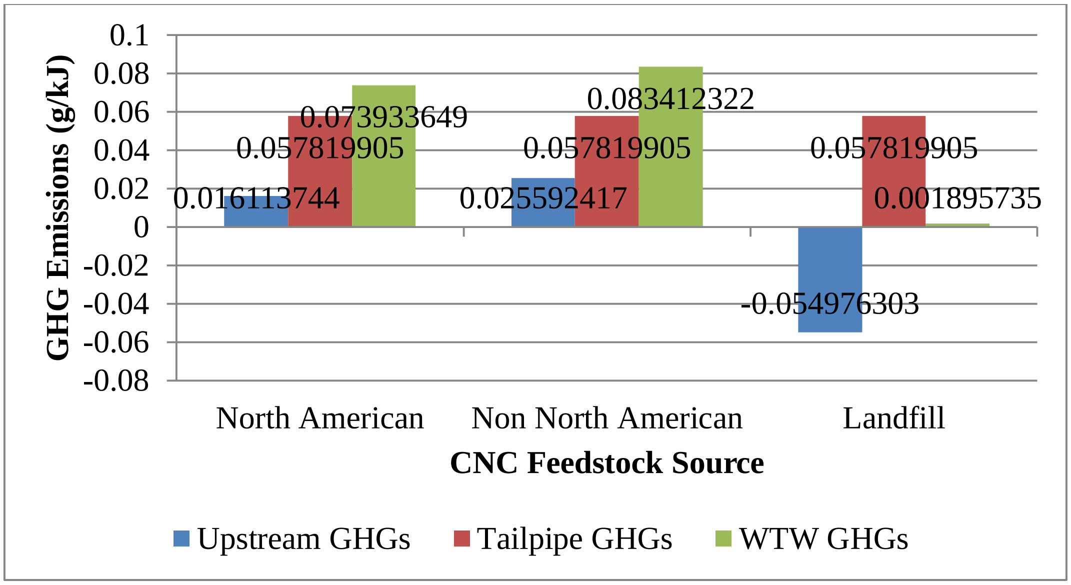


Figure 6.7 GHG Emissions by CNG Feedstock Source

However, this feedstock source was not considered in the analysis due to a lack of data concerning water consumption for landfill natural gas. This challenge underscores a problem that is ubiquitous across fuel types. Since so many different fuel types and impact categories were examined in this analysis, there were often incomplete data sources that prevented incorporating certain aspects into the model.

CHAPTER 7

CONCLUSIONS

7.1 Summary

The results obtained from this research show the importance of analyzing each fleet scenario individually before making claims of fuel type superiority. Through modeling of the financial, environmental, and social impact of different fuel types a decision maker would now be able to make an educated decision on which fuel type best fits the respective fleet scenario. Additionally for the more advanced users, the model allows the ability to inspect the regional impact of the calculated water inventory. These types of analyses become increasingly vital to making accurate decisions with the proliferation of alternative fuel vehicles.

Many of these alternative fuel types have significant future potential for reducing the triple bottom line impact and dependency on foreign oil supplies. BEVs are one of the most publicized fuel types due to both advancements in technical capabilities and an increase in political support. The technical capabilities mostly revolve around the improvements in battery technology, especially in terms of energy density. However, these batteries continue to be expensive and have limited driving ranges. Similarly, FFVs that operate on E-85 are hampered by the use of corn-based feedstock for ethanol production. A transition to cellulosic-based feedstock, such as switchgrass, would have a drastic impact on the appeal of E-85 as an alternative fuel. These types of advancements are typical for the other fuel types as well. The performance and results for each fuel type is a dynamically evolving attribute, and this should be represented by modifying the model as more current data becomes available.

7.2 Future Work

7.2.1 Data Availability

The majority of the potential future work revolves around the availability of additional reliable data sources. GHG emissions have been a central issue for a long time and thus have a great deal of reliable data sources. Specifically, the GREET model from Argonne National Laboratory utilized in this analysis has become a standard for evaluating and comparing the impacts of transportation fuels and vehicles. However, the financial aspects may be specific to the vehicle and purchase agreements of the respective fleet size. Meanwhile, water consumption and societal cost are areas that the majority of cited data presents concerns around the age and reliability of data. The work of Gleick in the 1990s remains the standard on water consumption in energy production. Similarly, the most comprehensive study on the social costs of vehicle related air pollution for the USA was conducted in 1990-1991 by McCubbin and Delucchi. The age of these studies produces concerns around the validity with the multitude of changes in the environmental climate and technological capabilities. As mentioned previously, the data around the impact of water consumption is another evolving field of study. Further data collection and standard definitions are necessary for a thorough analysis of the true impact of regional water consumption.

7.2.2 Life-Cycle Analysis

The current model only includes the fuel life-cycle impact when calculating the environmental impact of the various fuel types. A more complete analysis would be to include the life-cycle of the entire vehicle to take into account the variation in impact of the different vehicle types during raw material production, vehicle production, and end-of-life. The use phase has been shown to dominate the environmental impact for water consumption in previous studies of gasoline vehicles as shown in Figure 7.1.

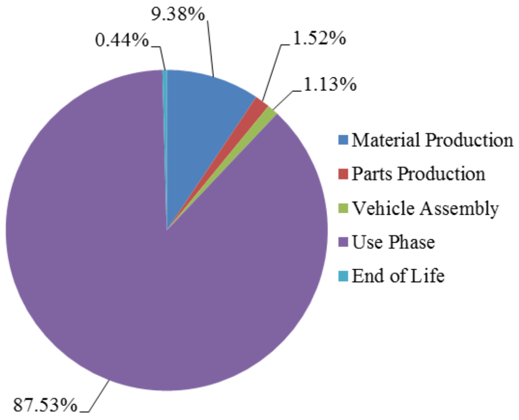


Figure 7.1 Vehicle Life Cycle Water Consumption (Tejada 2012)

However, the additional materials needed to produce the different vehicle types may have unforeseen effects on the environmental impact. This is especially true for the lithium-ion batteries of BEVs, whose impacts in water consumption in water scarce regions have not been fully investigated.

7.2.3 Vehicle Type

The only vehicle type investigated were Ford E-450 vehicles, due to their frequent use in shuttle fleet applications. However given the necessary data around the purchase cost, conversion cost, and fuel efficiency of the different fuel types, the model could easily be modified to include various vehicle types for different fleet scenarios. Additionally due to lack of valid data on maintenance of vehicles, the maintenance cost of vehicles were not included in analysis but could be added for fleets that were aware of their cost differentiations.

7.2.3 Complexity

As with all models, this study was an abstraction of the real world with a number of assumptions made to facilitate the analysis. However, there are a number of factors that given sufficient data could be incorporated to create a more robust model. The fuel cost for each fuel type is a dynamic value that depends on the current market conditions and variations in this value were not considered within the context of the model. Further work could incorporate this dynamic nature by including projections of future cost to calculate the cost of the use phase.

There were assumptions made for electricity that are often made in energy analysis but do not reflect reality. The most drastic assumption is that each state is treated as a separate electric entity. In fact, electricity is often imported and exported between states. Additionally, many electric utilities offer discounted rates for off-peak charging, which would especially advantageous for BEV fleets.

The social accounting of alternative fuels is another area of potential expansion. This model only took into account the health costs of criteria pollutants. Some other types of social benefits from alternative fuels could be job creation and noise pollution. BEVs are especially quiet and have even had to add noise creation devices for safety concerns. These and other social issues would create a more complete analysis for the societal aspect of the triple bottom line analysis.

7.3 Research Questions

7.3.1 Triple Bottom Line Analysis

The initial research question revolved around the ability to model the financial, environmental, and societal impacts of different fleet scenarios. This was accomplished through calculating the results of the impact categories obtained from various data sources. A macro-enabled Microsoft Excel file was then created that allowed for users to easily modify various parameters and obtain results for their specific fleet scenarios. This user input allows for an answer to the second research question of developing a decision-making tool to provide fleet customers with the ability to understand the triple bottom line impact. Although the model does not conglomerate the different impact categories, an inventory result of the different categories is presented for the desired scenario.

This ability to obtain the results for different scenarios allows the user the ability to compare different scenario and actively view the impact these changes. Previously, a user would either not be able to obtain these results, specifically water consumption and societal cost, or would have to go to different sources, financial cost and GHG emissions. Providing the different categories in one platform increases the capability of the user to understand and respond to modifications of their fleet. This model could also be used to influence policy decisions around regional incentives for alternative fuel vehicles to promote specific fuel types that actively benefit the region.

7.3.2 Utility Theory Impact

The utility theory was shown to provide the ability to provide optimization of fuel type depending on the preferences of the firm. The preferences of the firm would alter the order of results. However, the preferences would have to be elicited for each scenario in order due to the wide variation in the scale of results depending on parameters. Two case studies concerning shuttle fleets in airport applications also show the ability of the model to provide information to the decision maker around the benefits and drawbacks of the different fuel types.

7.3.3 Geographic Variation

The geographic location and the distance traveled were shown to greatly influence the outputs of optimization of the fleet composition. The geographic location determined the electricity profile, fuel costs, and other aspects of the water intensity of fuels. Most alternative fuel types benefitted from increasing the distance traveled as the use phase becomes more significant. However, each scenario was found to generate unique outputs for the triple bottom line analysis. Each scenario is a collection of parameters that describe the individual fleet application. These parameters include not just geographic location and distance traveled but also number of years, fuel efficiency, number of vehicles, fuel feedstock, infrastructure requirements, frequency regulation, discount rate, and water impact.

The complexity of the issue explains the importance of these types of analyses during fleet composition decisions. If consumers are unreliable in comparing the benefits of different gasoline fuel economies, this challenge will become even more daunting when comparing these extremely disparate fuel types. Additionally, the emergence of environmental and social issues in decision-making increases the difficulty in comparing different fuel types. This model provides the ability to produce results for specific fleet scenarios. Through utility theory these result could then be optimized to maximize the utility of the firm's preferences. In all there is no perfect fuel type for every scenario. Different fleets must be analyzed individually to provide the truly most beneficial fuel type for the specific parameters.

APPENDIX A

REGIONAL DATA

This Appendix provides the regional data for each state that is utilized in the model. Table A.1 presents the percentage generation by state by source from EIA.

Table A.1 Percentage Generation by State by Source (EIA 2011)

State	Petroleum	Natural Gas	Coal	Nuclear	Hydroelectric	Other Renewables
Alabama	0%	36%	29%	28%	6%	2%
Alaska	15%	55%	9%	0%	21%	0%
Arizona	0%	19%	47%	24%	9%	1%
Arkansas	0%	18%	52%	22%	5%	4%
California	0%	50%	1%	22%	13%	14%
Colorado	0%	21%	63%	0%	2%	13%
Connecticut	0%	59%	0%	37%	1%	3%
Delaware	0%	91%	7%	0%	0%	2%
Florida	0%	63%	21%	12%	0%	2%
Georgia	0%	21%	37%	36%	3%	3%
Hawaii	77%	0%	12%	0%	0%	11%
Idaho	0%	17%	0%	0%	64%	19%
Illinois	0%	1%	43%	50%	0%	6%
Indiana	0%	9%	85%	0%	0%	5%
Iowa	0%	0%	61%	10%	2%	28%
Kansas	0%	2%	66%	22%	0%	10%
Kentucky	0%	1%	95%	0%	3%	1%
Louisiana	0%	50%	27%	20%	1%	3%
Maine	0%	46%	0%	0%	25%	28%
Maryland	0%	2%	46%	42%	7%	3%
Massachusetts	0%	78%	0%	14%	4%	4%
Michigan	0%	13%	49%	33%	1%	3%
Minnesota	0%	3%	48%	25%	2%	23%
Mississippi	0%	63%	13%	21%	0%	4%
Missouri	0%	2%	93%	2%	1%	2%
Montana	0%	0%	63%	0%	32%	5%
Nebraska	0%	0%	70%	21%	4%	4%
Nevada	0%	59%	25%	0%	6%	10%
New Hampshire	0%	33%	8%	48%	5%	5%
New Jersey	0%	45%	2%	51%	0%	2%
New Mexico	0%	22%	70%	0%	0%	7%

Table A.1 continued

State	Petroleum	Natural Gas	Coal	Nuclear	Hydroelectric	Other Renewables
New York	0%	35%	3%	35%	22%	5%
North Carolina	0%	12%	44%	38%	4%	2%
North Dakota	0%	0%	73%	0%	9%	18%
Ohio	0%	11%	76%	11%	0%	1%
Oklahoma	0%	34%	52%	0%	2%	12%
Oregon	0%	26%	8%	0%	55%	10%
Pennsylvania	0%	18%	42%	36%	1%	2%
Rhode Island	0%	99%	0%	0%	0%	1%
South Carolina	0%	14%	24%	58%	2%	2%
South Dakota	0%	0%	7%	0%	62%	31%
Tennessee	0%	4%	37%	44%	14%	2%
Texas	0%	45%	35%	10%	0%	10%
Utah	0%	14%	81%	0%	2%	3%
Vermont	0%	0%	0%	72%	20%	8%
Virginia	1%	28%	24%	42%	2%	4%
Washington	0%	9%	9%	8%	66%	8%
West Virginia	0%	0%	95%	0%	2%	2%
Wisconsin	0%	11%	60%	19%	4%	6%
Wyoming	0%	1%	85%	0%	1%	13%
US Average	**0%**	**25%**	**40%**	**21%**	**7%**	**6%**

Table A.2 presents the other regional data used in the model analysis. The regional water consumption for hydroelectric power assumes that states did not import or export power as adapted as is typically used when reporting other power generation numbers. These values were taken from Torcellini et al. and adapted to provide a regional perspective of the impact of hydroelectric power on water consumption.

Table A.2 Regional Data

State	**Region**	**Electricity Cost ($/kWh)**	**Hydroelectric Water Consumption**	**USDA Region**
Alabama	Gulf Coast	$0.09/kWh	37.00 gal/kWh	3
Alaska	West Coast	$0.15/kWh		10
Arizona	West Coast	$0.10/kWh	64.85 gal/kWh	9
Arkansas	Gulf Coast	$0.07/kWh	17.50 gal/kWh	4

Table A.2 continued

State	Region	Electricity Cost ($/kWh)	Hydroelectric Water Consumption	USDA Region
California	West Coast	$0.13/kWh	20.87 gal/kWh	10
Colorado	Rocky Mountain	$0.09/kWh	17.91 gal/kWh	9
Connecticut	New England	$0.17/kWh	5.57 gal/kWh	1
Delaware	Central Atlantic	$0.12/kWh	2.46 gal/kWh	1
Florida	Lower Atlantic	$0.11/kWh	9.63 gal/kWh	3
Georgia	Lower Atlantic	$0.09/kWh	47.42 gal/kWh	3
Hawaii	West Coast	$0.25/kWh		10
Idaho	Rocky Mountain	$0.07/kWh	8.51 gal/kWh	9
Illinois	Midwest	$0.09/kWh	33.96 gal/kWh	5
Indiana	Midwest	$0.08/kWh	33.96 gal/kWh	5
Iowa	Midwest	$0.08/kWh	33.96 gal/kWh	5
Kansas	Midwest	$0.08/kWh	33.96 gal/kWh	7
Kentucky	Midwest	$0.07/kWh	154.34 gal/kWh	2
Louisiana	Gulf Coast	$0.08/kWh	17.50 gal/kWh	4
Maine	New England	$0.13/kWh	5.57 gal/kWh	1
Maryland	Central Atlantic	$0.13/kWh	6.72 gal/kWh	1
Massachusetts	New England	$0.14/kWh	5.57 gal/kWh	1
Michigan	Midwest	$0.10/kWh	33.96 gal/kWh	6
Minnesota	Midwest	$0.08/kWh	33.96 gal/kWh	6
Mississippi	Gulf Coast	$0.09/kWh	17.50 gal/kWh	4
Missouri	Midwest	$0.08/kWh	33.96 gal/kWh	5
Montana	Rocky Mountain	$0.08/kWh	36.77 gal/kWh	9
Nebraska	Midwest	$0.08/kWh	2.18 gal/kWh	7
Nevada	West Coast	$0.10/kWh	73.33 gal/kWh	9
New Hampshire	New England	$0.15/kWh	5.57 gal/kWh	1
New Jersey	Central Atlantic	$0.15/kWh	2.46 gal/kWh	1
New Mexico	Gulf Coast	$0.08/kWh	68.00 gal/kWh	9
New York	Central Atlantic	$0.16/kWh	5.57 gal/kWh	1
North Carolina	Lower Atlantic	$0.09/kWh	10.37 gal/kWh	2

Table A.2 continued

State	**Region**	**Electricity Cost ($/kWh)**	**Hydroelectric Water Consumption**	**USDA Region**
North Dakota	Midwest	$0.07/kWh	57.80 gal/kWh	7
Ohio	Midwest	$0.09/kWh	33.96 gal/kWh	5
Oklahoma	Midwest	$0.08/kWh	136.96 gal/kWh	8
Oregon	West Coast	$0.08/kWh	4.41 gal/kWh	10
Pennsylvania	Central Atlantic	$0.10/kWh	2.46 gal/kWh	1
Rhode Island	New England	$0.14/kWh	5.57 gal/kWh	1
South Carolina	Lower Atlantic	$0.08/kWh	9.63 gal/kWh	3
South Dakota	Midwest	$0.08/kWh	114.84 gal/kWh	7
Tennessee	Midwest	$0.09/kWh	43.35 gal/kWh	2
Texas	Gulf Coast	$0.09/kWh	17.50 gal/kWh	8
Utah	Rocky Mountain	$0.07/kWh	73.34 gal/kWh	9
Vermont	New England	$0.13/kWh	5.57 gal/kWh	1
Virginia	Lower Atlantic	$0.09/kWh	9.63 gal/kWh	2
Washington	West Coast	$0.07/kWh	3.19 gal/kWh	10
West Virginia	Lower Atlantic	$0.07/kWh	9.63 gal/kWh	2
Wisconsin	Midwest	$0.10/kWh	33.96 gal/kWh	6
Wyoming	Rocky Mountain	$0.06/kWh	136.96 gal/kWh	9
US Average	National Average	$0.10/kWh	18.27 gal/kWh	Avg

Table A.3 presents the regional variation of fuel costs.

Table A.3 Regional Fuel Cost Variation

Gasoline Cost Data	Jul-10	Oct-10	Jan-11	Apr-11	Jul-11	Oct-11	Averages
New England	$2.81	$2.86	$3.26	$3.43	$3.95	$3.62	$3.32
Central Atlantic	$2.82	$2.72	$3.19	$3.65	$3.78	$3.51	$3.28
Lower Atlantic	$2.56	$2.73	$3.00	$3.61	$3.62	$3.35	$3.15
Midwest	$2.65	$2.78	$3.08	$3.74	$3.66	$3.38	$3.22
Gulf Coast	$2.59	$2.61	$2.95	$3.64	$3.57	$3.23	$3.10
Rocky Mountain	$2.72	$2.76	$2.89	$3.55	$3.50	$3.45	$3.15
West Coast	$3.01	$2.98	$3.28	$4.00	$3.77	$3.77	$3.47
National Average	$2.71	$2.78	$3.08	$3.69	$3.68	$3.46	$3.23

Table A.3 continued

CNG Cost Data	Jul-10	Oct-10	Jan-11	Apr-11	Jul-11	Oct-11	Averages
New England	$2.33	$2.28	$2.36	$2.38	$2.17	$2.46	$2.33
Central Atlantic	$2.15	$2.11	$2.27	$2.41	$2.33	$2.28	$2.26
Lower Atlantic	$1.85	$1.76	$1.82	$1.87	$1.81	$1.61	$1.79
Midwest	$1.70	$1.76	$1.70	$1.66	$1.70	$1.74	$1.71
Gulf Coast	$1.83	$1.98	$1.79	$1.84	$1.94	$1.75	$1.86
Rocky Mountain	$1.57	$1.59	$1.37	$1.39	$1.45	$1.48	$1.48
West Coast	$2.12	$2.17	$2.21	$2.32	$2.37	$2.42	$2.27
National Average	$1.91	$1.93	$1.93	$2.06	$2.07	$2.09	$2.00

E85 Cost Data	Jul-10	Oct-10	Jan-11	Apr-11	Jul-11	Oct-11	Averages
New England	$2.39	$2.62	$2.90	$3.29	$3.85	$3.85	$3.15
Central Atlantic	$2.34	$2.43	$2.82	$3.24	$3.25	$3.25	$2.89
Lower Atlantic	$2.39	$2.43	$2.80	$3.26	$3.36	$3.13	$2.90
Midwest	$2.23	$2.42	$2.72	$3.16	$3.24	$3.12	$2.82
Gulf Coast	$2.23	$2.34	$2.69	$3.26	$3.30	$3.04	$2.81
Rocky Mountain	$2.18	$2.35	$2.61	$2.99	$3.11	$3.15	$2.73
West Coast	$2.55	$2.64	$2.92	$3.35	$3.36	$3.38	$3.03
National Average	$2.30	$2.44	$2.75	$3.20	$3.26	$3.19	$2.86

Propane Cost Data	Jul-10	Oct-10	Jan-11	Apr-11	Jul-11	Oct-11	Averages
New England	$3.17	$3.31	$3.35	$3.40	$3.34	$3.48	$3.34
Central Atlantic	$3.49	$3.10	$3.54	$3.47	$3.15	$2.68	$3.24
Lower Atlantic	$2.69	$2.84	$3.06	$3.35	$3.17	$3.15	$3.04
Midwest	$2.89	$2.95	$2.79	$2.90	$2.82	$3.01	$2.89
Gulf Coast	$2.60	$2.61	$2.98	$2.96	$2.89	$3.05	$2.85
Rocky Mountain	$2.67	$2.52	$2.72	$2.80	$2.80	$2.91	$2.74
West Coast	$2.84	$2.80	$3.01	$3.33	$3.32	$3.16	$3.08
National Average	$2.90	$2.85	$3.05	$3.19	$3.09	$3.06	$3.02

APPENDIX B

WATER CONSUMPTION VARIATION

This Appendix provides the variation in water consumption data for a number of literature sources. Table B.1 presents these water consumption values for each fuel type.

Table B.1 Water Consumption Data Variation

Gasoline (gal/gal)	Min	Max	Source
Gasoline (US conventional crude)	3.40	6.60	(Wu 2009), (Gleick 1994)
Gasoline (Saudi conventional crude)	2.80	5.80	(Wu 2009), (Gleick 1994)
Gasoline (Canadian oil sands)	2.60	6.20	(Wu 2009), (Gleick 1994)
Gasoline (overall)	2.60	6.60	(Wu 2009), (Gleick 1994)

Electricity Power Plant (gal/kWh)	Min	Max	Source
Coal	0.02	4.43	(Feely 2003), (Fthenakis 2010), (Gleick 1994)
Nuclear	0.52	3.40	(Feely 2003), (Fthenakis 2010), (Gleick 1994)
Petroleum	0.34	2.60	(Feely 2003), (Fthenakis 2010), (Gleick 1994)
NGCC	0.01	1.90	(Feely 2003), (Fthenakis 2010), (Gleick 1994)
WoodWaste/Biomass	0.00	2.30	(Fthenakis 2010), (Gleick 1994)
Hydro	0.00	584.00	(Gleick 1994), (Torcellini 2003)
Wind	0.00	0.00	(Fthenakis 2010), (Gleick 1994)
PV Solar	0.02	0.10	(Fthenakis 2010), (Gleick 1994), (Harto 2010)

Electricity Feedstock (gal/kWh)	**Min**	**Max**	Source
Coal	0.47	0.97	(Fthenakis 2010), (Gleick 1994)
Nuclear	0.14	0.38	(Fthenakis 2010), (Gleick 1994)

Table B.1 continued

Electricity Total (gal/kWh)	Min	Max	Source
Coal	0.49	5.40	(Feely 2003), (Fthenakis 2010), (Gleick 1994)
Nuclear	0.66	3.78	(Feely 2003), (Fthenakis 2010), (Gleick 1994)
Petroleum	0.34	2.60	(Feely 2003), (Fthenakis 2010), (Gleick 1994)
NGCC	0.01	1.99	(Feely 2003), (Fthenakis 2010), (Gleick 1994)
WoodWaste/Biomass	0.00	2.30	(Fthenakis 2010), (Gleick 1994)
Hydro	0.00	584.00	(Gleick 1994), (Torcellini 2003)
Wind	0.00	0.00	(Fthenakis 2010), (Gleick 1994)
PV Solar	0.02	0.10	(Fthenakis 2010), (Gleick 1994), (Harto 2010)

Ethanol (gal/gal)	Min	Max	Source
Corn Feedstock	10.10	323.60	(Wu 2009)
Cellulosic Feedstock	1.90	9.80	(Wu 2009)
Total	1.90	323.60	(Wu 2009)

Ethanol (gal/gal)	Min	Max	Source
Corn Feedstock	10.10	323.60	(Wu 2009)

Natural Gas (gal/gge)	Min	Max	Source
Extraction	0.00	5.98	(Gleick 1994), (Goodwin 2012)

REFERENCES

BCG (2011). "Sustainability: The 'Embracers' Seize Advantage." MIT Sloan Management Review(Winter).

Beaudry, A., S. Schepman, et al. (2011). The Effects Of An Incentive Program Intervention On Driver Performance In A Private Nonprofit Agency.

Berger, M., Warsen, Jens, Krinke, Stephan, Bach, Vanessa, and Finkbeiner, Matthias (2012). "Water Footprint of European Cars: Potential Impacts of Water Consumption along Automobile Life Cycles." Environmental Science & Technology **46**(7): 4091-4099.

CDP. (2012). "Carbon Disclosure Project - What We Do." Retrieved 1/12/2012, from https://www.cdproject.net/en-US/WhatWeDo/Pages/overview.aspx.

Cities, C. (2011). Average Retail Fuel Prices in the U.S. retail_fuel_prices.xls. Alernative Fuel & Advanced Vehicles Data Center.

Combs, S. (2008). "The Energy Report - Liquefied Petroleum Gas (LPG)." from http://www.window.state.tx.us/specialrpt/energy/exec/lpg.html.

DOE (2003). "Buidling Successful AFV Fueling Stations - Tips, Best Practices, and Lessons Learned." Alternative Fuel News **7**(1).

DOE. (2011). "Argonne GREET Model." Retrieved 1/31, 2012, from http://greet.es.anl.gov/main.

Duong, T. Q. (2010). Directions for Energy Storage R&D in the Vehicle Technologies Program. Scalable Energy Storage Beyond Li-Ion: Materials Perspectives ORNL Symposium.

EIA. (2010). "Alternative to Traditional Transportation Fuels." from http://www.eia.gov/renewable/afv/.

EIA (2011). Annual Energy Outlook 2012 - Early Release Overview, EIA.

EIA (2011). Electricity Monthly Update. EIA, U.S. Energy Information Administration.

EIA (2011). International Energy Outlook. D. o. E.-U. S. E. I. Administration.

EIA (2011). Table 5.3. Average Retail Price of Electricity to Ultimate Customers: Total by End-Use Sector, 1997 through November 2011. epmxlfile5_3. EIA.

EIA (2011). Table 5.4.A. Retail Sales of Electricity to Ultimate Customers by End-Use Sector, by State. epmxlfile5_4_a.xlsx. EIA, EIA.

EIA (2011). Table 5.6.A. Average Retail Price of Electricity to Ultimate Customers by End-Use Sector, by State. epmxlfile5_6_a.exls. EIA.

EIA (2012) "Access to alternative transportation fuel stations varies across the lower 48 states." Today in Energy.

Elgowainy, A., J. Han, L. Poch, M. Wang, A. Vyas, M. Mahalik, and A. Rousseau (2010). Well-to-Wheels Analysis of Energy Use and Greenhouse Gas Emissions of Plug-In Hybrid Electric Vehicles. A. N. L. Energy System Division.

EPA (2010). Renewable Fuel Standard Program (RFS2) Regulatory Impact Analysis. A. a. S. Division**:** 781.

EPA (2011). Plan to Stud the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources. O. o. R. a. Development.

Eudy, L. (2000). SuperShuttle CNG Fleet Evaluation. N. R. E. Laboratory.

Eudy, L. (2002). Natural Gas in Transit Fleets: A Review of the Transit Experience. Other Information: PBD: 1 Feb 2002**:** Medium: ED; Size: 33 pages.

FERC. (2011). "Regional Transmission Organizations (RTO)/Independent System Operators (ISO)." from http://www.ferc.gov/industries/electric/indus-act/rto.asp.

Finegold, D., M. L. Robbins, et al. (1998). Closing the knowledge gap for transit maintenance employees: a systems approach, National Academy Press.

Fleet, A. (2011). Fleet Operating Cost. Automotive Fleet.

Ford (2010). Form 10-K. F. M. Company. SEC.

FracFocus. (2012). "Hydraulic Fracturing: The Process." Retrieved Feb. 27, 2012, from http://fracfocus.org/hydraulic-fracturing-how-it-works/hydraulic-fracturing-process.

Fthenakis, V. (2010). "Life-cycle uses of water in U.S. electricity generation." Renewable and Sustainable Energy Reviews **14**(7): 2039-2048.

Galligan, J. (2010). "CNG fueling options for fleets." Light & Medium Truck **23**(10): 17.

Gifford, J., Brown, Robert (2011). "Four economies of sustainable automotive transportation." Biofuels, bioproducts & biorefining **5**(3): 293.

Gleick, P. H. (1994). "Water and Energy." Annual Review of Energy and the Environment **19**(1): 267-299.

Goodwin, S., Douglas, C., Carlson, K. (2012). Lifecycle Analysis of Water Use and Intensity of Noble Energy Oil and Gas Recovery in the Wattenberg Field of Northern Colorado, Noble Energy Inc. and Colorado State University.

Greene, D. L. (2010). How Consumers Value Fuel Economy: A Literature Review, Assessment and Standards Division Office of Transportation and Air Quality US. Environmental Protection Agency. **EPA-420-R-10-008**.

Howard, R. A. (1988). "Decision Analysis Practice and Promise." Management Science **34**(6): 679-695.

Howards, S. (2001). Airport-Based Alternative Fuel Vehicle Fleets.

Johnson, C. (2010). Business Case for Compressed Natural Gas in Municipal Fleets, National Renewable Energy Laboratory**:** Medium: ED; Size: 40 pp.

Johnson, C. a. M., M. (2007). E85 Retail Business Case: When and Why to Sell E85, National Renewable Energy Laboratory.

King, C. W. (2008). "Water Intensity of the Plugged-In Automotive Economy." Environmental Science & Technology **42**(12): 4305-4311.

Litman, T. a. E. D. (2011). "Transporation Cost and Benefit Analysis - Techniques, Estimates and Implications." Victoria Transport Policy Institute.

Liu, S. (2009). "effective genetic algorithm for the fleet size and mix vehicle routing problems." Transportation Research: Part E **45**(3): 434-445.

McCubbin, D. a. D., Mark (1999). "The Health Costs of Motor-Vehicle-Related Air Pollution." Journal of Transport Economics and Policy **33**(3): 253-286.

Meschtscherjakov, A., D. Wilfinger, et al. (2009). Acceptance of future persuasive in-car interfaces towards a more economic driving behaviour. Proceedings of the 1st International Conference on Automotive User Interfaces and Interactive Vehicular Applications. Essen, Germany, ACM**:** 81-88.

Norman, W. (2004). "Getting to the Bottom of "Triple Bottom Line"." Business Ethics Quarterly **14**(2): 243-262.

NYTimes (2012). President Obama's State of the Union Address. The New York Times.

Ogden, J. M. (2004). "Societal lifecycle costs of cars with alternative fuels/engines." Energy Policy **32**(1): 7-27.

Peterson, S. B., Apt, J., and Whitacre, J.F. (2010). "Lithium-ion battery cell degradation resulting from realistic vehcile and vehicle-to-grid utilization." Journal of Power Sources **195**: 2385-2392.

Pfister, S. (2009). "Assessing the Environmental Impacts of Freshwater Consumption in LCA." Environmental Science & Technology **43**(11): 4098-4104.

Power, B. (2012). "Frequency Regulation." from http://www.beaconpower.com/solutions/frequency-regulation.asp.

Rogers, P. G. (1990). "The Clean Air Act of 1970." EPA Journal(January/February).

Rowan, D. (2010). "Miles per gallon illusions and corporate average fuel economy distortions." When even transport experts have trouble **ISSU**(2191): 8-15.

Schroeder, A. a. T., Traber (2012). "The economics of fast charging infrastructure for electric vehicles." Energy Policy.

Scown, C. D. (2011). "Water Footprint of U.S. Transportation Fuels." Environmental Science & Technology **45**(7): 2541-2553.

Shapouri, H., J., Duffield, and M. Wang (2002). The Energy Balance of Corn Ethanol: An Update. U. D. o. Agriculture.

Shelby, M., and S. Mui (2007). Plug-in Hybrids: A Scenario Analysis. 86th Annual Meeting of the Transportation Research Board, Washington, D.C.

Struben, J. (2008). "Transition challenges for alternative fuel vehicle and transportation systems." Environment & Planning B: Planning & Design **35**(6): 1070-1097.

Tejada, F., Bras, B., Guldberg, T. (2012). Direct and Indirect Water Consumption in Vehicle Manufacturing. ASME 2012 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference. Chicago.

Tollefson, J. (2008). "Car industry." Charging up the future **456**(7221): 436-440.

Torcellini, P. A. (2004). "Consumptive Water Use for U.S. Power Production." ASHRAE Transactions **110**(1): 96-100.

UN (2006). Coping with Water Scarcity - A strategic issue and priority for system-wide action.

UN. (2010). "World Water Assessment Programme - Food and Agriculture." Retrieved 1/18/2012, from http://www.unesco.org/new/en/natural-sciences/environment/water/wwap/facts-and-figures/food-and-agriculture/.

UNH. "World Water Development Report II: Indicators for World Water Assessment Programme." from http://wwdrii.sr.unh.edu/.

Vorosmarty, C. J., Green, P., Salisbury, J., Lammers, R.B. (2000). "Global water resources: vulnerability from climate change and population growth." Science(289): 284-288.

Wald, M. (2011). New Rules and Old Plants May Strain Summer Energy Supplies. New York Times.

Wang, M. Q. (2001). Development and Use of GREET 1.6 Fuel-Cycle Model for Transporation Fuels and Vehicle Technologies. E. S. D. Center for Transportation Research, Argonne National Laboratory.

Werpy, M. R., Burnham, A., Bertram, K. (2010). Propane Vehicles: Status, Challenges, and Opportunities. A Discussion Paper for Clean Cities Coalitions and Stakeholders to Develop Strategies for the Future.

Werpy, M. R., Santini, D., Burnham, A., Mintz, M. (2010). Natural Gas Vehicles: Status, Barriers, and Opportunities, Center for Transportation Research Energy Systems Division, Argonne National Laboratory.

WRI, W. R. I. (2000). "Water Resources and Freshwater Ecosystems: Maps." from http://earthtrends.wri.org/text/water-resources/map-265.html.

Wu, M., M. Mintz, M. Wany, and S. Arora (2009). "Water Consumption in the Production of Ethanol and Petroleum Gasoline." Environmental Management(44): 981-977.

Wu, M., M. Mintz, et al. (2009). "Water Consumption in the Production of Ethanol and Petroleum Gasoline." Environmental Management **44**(5): 981-997.

Yacobucci, B. D. (2005). Alternative Transportation Fuels and Vehicles: Energy, Environment, and Development Issues. Congressional Research Service, The Library of Congress.