U.S. TRANSPORTATION SECTOR: THE POTENTIAL OF THE RENEWABLE FUELS STANDARD AND CORPORATE AVERAGE FUEL ECONOMY STANDARD TO REDUCE GREENHOUSE GAS EMISSIONS AND GASOLINE CONSUMPTION

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ABSTRACT

This thesis utilizes a system dynamics approach to model total greenhouse gas emissions and gasoline consumption in the U.S. transportation sector, years 2000 to 2050, and how the Corporate Average Fuel Economy (CAFE) standard and Renewable Fuels Standard (RFS) policy, as enacted in the Energy Independence and Security Act of 2007, alters total greenhouse gases emitted and gasoline consumed. Climate change and oil dependency are two of the greatest national security threats of our time and so further research into the potential of the CAFE, RFS, and biofuels to reduce greenhouse gas emissions and gasoline consumption deserves our attention. The RFS is examined in light of a 50 percent leakage or market effect caused by biofuel use in the domestic fuel market while the CAFE standard is examined in light of a ~20 percent loss in gasoline savings attributed to the Jevons paradox or rebound effect seen from consumers driving more miles as a result of improved fuel efficiency.

Congress increased CAFE standards by requiring automakers to attain fleetwide gas mileage of 35 miles per gallon by the year 2020, and amended the RFS by increasing the required volume of biofuels used in our fuel supply to 36 billion gallons of renewable fuel by 2022. Due to the rate of auto fleet turnover in the U.S., the full benefits from the CAFE standard will not be fully seen until around 2050, which is 43 years after the legislation was passed. Both policies combined have the potential to reduce greenhouse gas emissions and gasoline consumption in the U.S. transportation sector by 2050 to levels near what were emitted and consumed respectively in the year 2000. The CAFE standard is more adept at reaching the policy goals of reducing greenhouse gas emissions and gasoline consumption as compared to the RFS, while the RFS is more adept at reducing gasoline consumption than greenhouse gas emissions. While neither is a long-term solution to the United States' dependence on oil, both policies combined can serve to mitigate climate change and extend our finite supplies of oil in the meantime.

BIOGRAPHICAL SKETCH

Fahran K.J. Robb grew up in our nation's heartland on the outskirts of Pinckneyville, Illinois, on the North Branch Paint Farm with her parents, Sam and Myrna, and two sisters, Makahla and Jodee, where they raised and showed Registered American Paint Horses. Fahran actively participated in 4-H, FFA, Perry County Agricultural Society, Oak Grove Baptist Church Youth Group, and various service projects in her hometown community.

In May 2007, she graduated with Summa Cum Laude honors with the distinction of Valedictorian from Southern Illinois University Carbondale with dual degrees; specifically, a Bachelor of Science in Agricultural Systems and a Bachelor of Arts in Political Science with three minors in Environmental Studies, Agribusiness Economics, and Speech Communication. In 2006, she became the first student in the history of SIUC to be recognized by *USA Today* as a member of the All-USA College Academic Team. In 2007, she was again named to the team which makes her one of only fifteen students since 2001 to be named to the team a second year. Her senior year, the Lincoln Academy of Illinois honored her as a student laureate which is considered the highest honor that the State of Illinois can bestow upon an undergraduate student, and SIUC Inter-Greek Council awarded her the Service to Southern Award which is the highest honor awarded to an outstanding graduating senior student leader at the University for his or her participation and service contributions. While at SIUC, she logged over 600 service hours with Saluki Volunteer Corps.

Other distinctions include Presidential Volunteer Service Award, 2005 and 2006 Morris K. Udall Honorable Mention Scholar, 25 Most Distinguished Seniors Award, Phi Kappa Phi Award of Excellence, Environmental Ambassador Award, Outstanding Agbassador Award, FFA Costa Rica Seminar, National FFA American FFA Degree, College of Agricultural Sciences Outstanding Junior and Senior Awards, Illinois State Society of Washington, D.C. Congressional Intern Award, and the Senator Penny Severns Women's Public Service Endowed Scholarship and Internship Award. Her research experiences include authoring white papers on biofuels production and policy; surveying Conservation Stewardship Program participants in the Lower Kaskaskia Watershed under the guidance of Dr. Steven Kraft (Ph.D., Cornell University, 1980); traveling to Spain and Morocco as a member of U.S. Grains Council's International Collegiate Agricultural Leadership Team; and interning in Washington, D.C. as an economic assistant with the USDA Foreign Agricultural Service Agency, a congressional intern in the Office of U.S. Senator Richard J. Durbin, and as the agriculture, sustainable biomass, and energy policy intern at the Environmental and Energy Study Institute.

Following SIUC, she moved to Ithaca, New York, where she began her graduate studies as a Masters of Science student in Applied Economics and Management with a focus on Public Policy Analysis at Cornell University. While at Cornell University, she concurrently served on the National Board for the Fraternity of Alpha Zeta and Sigma Alpha Sorority. Despite a three-year hiatus resulting from a bad motor vehicle accident in Washington, D.C., she is currently a second-year law student at the Pennsylvania State University Dickinson School of Law. Her career goal is to work in Washington, D.C. on agricultural, energy, and environmental policy issues. She would like to work towards being a Director or Vice President of Government Relations for a non-governmental organization. In her free time, she enjoys hiking, cooking, yoga, cycling, reading, traveling, theatre, and volunteering for various service projects.

DEDICATION

This thesis is completed in memory of my grandfather, James F. Robb, and in honor of my grandmother, Nelda Robb; my parents, Sam and Myrna; and my cherished friends and family who supported me and provided encouraging words while I battled health issues and tackled this thesis. Many thanks!

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Lastly, I would like to express my love and gratitude to my beloved family for their understanding, encouragement, and endless love throughout the duration of my graduate studies. Thank you for your support in my pursuit of this degree.

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I. INTRODUCTION

Motivation

Public policy is created through laws, regulations, and ordinances by city, state, and federal governments in an attempt to address issues pertaining to presumably widely-shared societal, economic, and moral values and norms. Policy may be designed for many reasons including to reinforce existing beliefs, to prompt behavioral change seen as a moral obligation or beneficial to society overall, or to correct market failures such as externalities. Statutes must be crafted in a precise and clear manner which is specific yet flexible enough to achieve targeted objectives. Public policy is an essential avenue to use when addressing social concerns and can serve as a first step in guiding the way toward innovative technological solutions.

One of the most significant battles the world will face in the years ahead will be fighting the rapidly escalating pace of global climate change (Environmental and Energy Study Institute). Concurrently, one of the greatest prospects nations will face is that of seizing the opportunity to emerge as a leader in the creation of an environmentally sustainable low-carbon global economy. Former chief economist of the World Bank, Sir Nicholas Stern, calls global climate change "a result of the greatest market failure the world has seen" (Becker 2008, 31). While public misconceptions pertaining to the existence of climate change linger yet today, skepticism amongst the scientific community has waned in light of overwhelming evidence (i.e. rising sea levels, quickening glacial melt, extreme weather events, and changes in global average temperature). A 2010 study in Proceedings of the National Academy of Sciences found that 97 to 98 percent of climate scientists believe human-caused climate change is occurring (Anderegg et al. 2010, 1). In June 2005, the U.S. National Academy of Sciences with ten other national academies from around the world issued the following joint statement: "The scientific understanding of climate change is now sufficiently clear to justify nations taking prompt action. It is vital that all nations identify cost-effective steps that they can take now, to contribute to substantial and long-term reductions in net global greenhouse gas emissions" (Sandalow 2008, 20).

According to an April 2008 report published by the Center for International Climate and Environmental Research, scientific evidence regarding climate change has asserted that global emissions of greenhouse gases into the atmosphere must be reduced by at least 80 percent below 2000 levels by 2050 in order to have a 50 percent chance to stabilize the climate against global warming (Environmental News Network 2007). An increase of a mere two degrees Celsius in global average temperature compared to pre-industrial levels has the ability to severely impact human health and ecosystems, including the extinction of 20 to 30 percent of known plant and animal species, rapid spread of infectious diseases, a global sea level rise between 12 and 40 feet that will lead to coastal flooding, and severe water stress. Thus far, global average temperatures have increased approximately 0.8 degrees Celsius (Becker 2008, 68-9; Union of Concerned Scientists 2008). Additionally, between 1970 and 2004, there has been a 70 percent increase in greenhouse gas emissions overall, including an 80 percent increase in emissions of carbon dioxide (Pachauri 2009, 2).

A February 2007 report by the Intergovernmental Panel on Climate Change attributed human-induced activities, especially the extraction and combustion of fossil fuels, to the increase in the concentration of heat-trapping greenhouse gases since the pre-industrial era and concluded that the global "net effect of human activities since 1750 has been one of warming" (Intergovernmental Panel on Climate Change 2007). The Central Intelligence Agency maintains that the United States is the "largest single emitter of carbon dioxide from the burning of fossil fuels" in the world (Central Intelligence Agency). According to the Energy Information Administration, if the

United States continues business as usual, emissions are expected to increase by 35 percent by 2030 and atmospheric concentrations are expected to double pre-industrial levels by 2050 (Becker 2008, 8). Moreover, atmospheric concentrations are expected to triple to 800 parts per million by 2075 (Friedman 2008, 212). Until recently, the United States had only taken negligible steps to address climate change, and under the Obama Administration, the United States has made a more serious, concerted effort to address this vitally important issue that affects not only the United States but also life as we know it. Dr. James Hansen, chief climate scientist at NASA's Goddard Institute for Space Studies, has stated "the concentrations of carbon dioxide in the atmosphere are rapidly approaching the point at which they are too high to maintain the climate to which humanity, wildlife, and the rest of the biosphere are adapted" (Becker 2008, 6-7). The notion of climate change can no longer be swept under the rug and met with inaction or mediocrity.

According to a June 2008 study by the McKinsey Global Institute, "the world needs a shift as radical as the Industrial Revolution to cut greenhouse gas emissions by 2050." While the Industrial Revolution occurred over a 125-year period, the study indicated that the "Carbon Revolution" needs to occur in a period of 42 years – that's in one-third the time of the Industrial Revolution (Environmental News Network 2008). The need to tackle the accelerating pace of global climate change is critical so that irreversible catastrophic consequences in our global environment can be avoided. Time is of the essence if the United States is to lay groundwork for a sustainable future that will mitigate climate change, reduce dependency on carbon-intensive energy, lower energy costs, stimulate economic development, and create jobs ("To Review Renewable Fuels Standard Implementation" 2008). Currently, Congress, the business community, environmental advocates, and United States citizens alike are searching for policy options that not only address threats posed by rising levels of greenhouse gas emissions, but also address skyrocketing energy prices, and increased reliance on energy imports (Environmental and Energy Study Institute 2008).

In a time when urgency in regards to circumventing the impacts of climate change is high and competition among developing and developed countries is increasing over uncertain and dwindling supplies of finite energy resources, it is only logical for a country, such as the United States, who has the capability and resources to lead in the "Carbon Revolution" to do so promptly especially in light of the economic times we are in. Former President Bill Clinton has stated, "Creating the low-carbon economy will lead to the greatest economic boom in the United States since we mobilized for World War II" (Becker 2008, 11). The United States is in a position to choose whether to be an innovative leader in the transformation to a sustainable low-carbon global economy all while gaining a competitive advantage in the clean tech market, or to be a follower in the successful pursuit of other countries' entrepreneurial ability all while forgoing the creation of millions of jobs and a secure energy future. Regardless, initiative must occur across the globe. Currently, the Pew Charitable Trusts calls China, with $54.4 billion in private clean energy investments and a 106 percent five-year growth rate in energy capacity, the "world's clean energy powerhouse." Germany was second with $41.2 billion of investments and a 67 percent five-year growth rate in energy capacity, and the United States was third with $34 billion and a 30 percent growth rate (The Pew Charitable Trusts 2011).

Reaching the objective of an 80 percent reduction of greenhouse gas emissions below 2000 levels by 2050 should involve replacing conventional uses of carbon-intensive, finite fossil fuels with a strategy to sustainably diversify our nation's energy supplies with domestic, renewable sources of low-carbon energy combined with a strategy to improve energy efficiency, conservation, performance standards, clean technologies, and smart growth development. Sustainable energy technologies that produce fuel, electricity, and heat from renewable sources have the potential to play a large role in the transition to a low-carbon economy, to reduce local air pollution, and to stimulate growth in rural economies.

Currently, about 40 percent of energy consumption in the United States is dependant on petroleum (Yergin 2009, 772). The U.S. transportation sector, which is 96 percent dependent on petroleum, is second to electricity in the emission of greenhouse gas emissions. "Over 80 percent of world [oil] reserves are controlled by governments and their national oil companies," and sixteen of the world's twenty largest oil companies are state-owned (770). The volatile Middle East contains over two-thirds of proven world oil reserves (Cooper 2007, 2). Some analysts claim that a direct link from the transition of an off-shore balancing over-the-horizon military posture towards protecting oil supplies in the Persian Gulf, which was initiated by the Carter Doctrine in 1980, to maintaining troops on the ground after the Gulf War can be drawn to the rise of Al Qaida and the terrorist attacks of September 11, 2001 (Leverett 2011). All of this raises a second concern and motivation for this thesis – national energy security. Some report that worldwide oil demand will grow by 40 percent over the next quarter century and that two billion cars are expected to be on the road worldwide by 2030. Yergin states that, "for several decades to come…oil will be a central factor in world politics and the global economy, in the global calculus of power, and in how people live their lives" (Yergin 2009, 773).

The final motivation for this thesis is that I worked on what became the Energy Independence and Security Act of 2007 while interning in U.S. Senator Richard Durbin's office prior to my matriculation at Cornell University. I was charged with tracking amendments to the bill and researching legislative history pertaining to the CAFE standard so that a strategically crafted floor statement negating Senator Levin's previous objections to CAFE standard increases could be written for the Senator.

Objective

David Sandalow, an Energy and Environmental Scholar at the Brookings Institution, asserts that “oil is the leading cause of global warming worldwide” and “is the single largest source of heat-trapping gases in the United States” (Sandalow 2008, 30). Today, the U.S. transportation sector, of which oil meets 96 percent of its energy needs, accounts for approximately 30 percent of all U.S. greenhouse gas emissions and oil accounts for 43 percent of all U.S. greenhouse gas emissions from fossil fuel combustion (Friedman 2008, 325). This high reliance on oil is particularly alarming because the United States contains less than 3 percent of proven oil reserves and the volatile Middle East contains over two-thirds of oil reserves (“Oil Market Basics: Supply”; Cooper 2007, 2). There are essentially four avenues to reduce greenhouse gas emissions in the U.S. transportation sector: 1.) use lower-carbon fuels, 2) improve vehicle fuel efficiency, 3) reduce total vehicle miles travel, 4) change vehicle fueling structure (i.e. electric, hydrogen). This thesis will focus on the first two means of reducing greenhouse gas emissions.

The production and use of biofuels have been touted as one approach to help mitigate climate change and reduce our dependency on oil. The emphasis will be on biofuels because presently in the transportation sector, biofuels are the only viable substitute for petroleum, although ultimately, hydrogen, electricity, or other forms of alternative transportation will likely come to fruition (“Clearing the Air, Feeding the Fuel Tank” 2008). Biofuels policy has many objectives, some of which include environmental benefits; however, it is not yet known to what extent biofuels can meet societal and environmental goals by lowering atmospheric greenhouse gas concentrations to help curb global warming, and how various policies can alter the potential ability of biofuels to mitigate climate change. This thesis will utilize a system dynamics approach to examine total greenhouse gas emissions in the U.S.

transportation sector and how Corporate Average Fuel Economy (CAFE) standard and Renewable Fuels Standard (RFS) policy, as enacted in the Energy Independence and Security Act of 2007, alters total greenhouse gases emitted and gasoline consumed. Climate change and oil supply are two of the greatest national security threats of our time and so further research into the potential of biofuels and use of CAFE standards deserves our attention.

System dynamics was founded in the 1950's by Jay Forester, an engineer assigned to the MIT business school. It is a "method to enhance learning in complex systems and is fundamentally interdisciplinary and grounded in the theory of nonlinear dynamics and feedback control developed in mathematics, physics and engineering applied to solve real-world problems" (Nicholson 2008). It uses computer simulation for policy analysis and aids to help people "build progressively richer understandings of some dynamic problem, and anticipate weaknesses in policy initiatives" (Nicholson 2008). Mental models of reality are constructed through a series of causal loop diagrams and stock and flow structures that form systems of ordinary differential equations that are solved through numerical integration. Model structures can be created with various modes of dynamic behavior, and research results and policy scenarios can be inputted into the model. Model boundaries are established based on the specific problem behavior the model was designed to examine. The model is by no means a perfect, exhaustive portrayal of reality, rather it is a simplified version of reality, modeled with the problem in mind in an iterative process that may result in more accurate findings congruent with reality than other forms of evaluation may provide. A benefit of the use of system dynamics modeling is discovering areas of dynamic complexity in the system, potential unintended consequences that may arise, as well as areas where policy resistance may occur (Nicholson 2008).

II. REVIEW OF LITERATURE

Oil's Pervasive Significance: Supply, Demand, and Greenhouse Gas Emissions

According to the Energy Information Administration, in 2007, the United States consumed 101.605 quadrillion Btu's of energy of which 6.830 quadrillion Btu's were from renewable sources of energy. The percentage of energy provided by source is as follows: 39.8 percent was provided by petroleum, 23.6 percent from natural gas, 22.8 percent from coal, 6.8 percent from renewable energy, and 8.4 percent from nuclear electric power (Annual Energy Review 2008) (*See Table 1*). Of total U.S. renewable energy consumed, biomass-based energy accounted for 53 percent of which 17.3 percent was consumed in the transportation sector ("Renewable Energy Consumption and Electricity Preliminary 2007 Statistics" 2008).

Table 1. Percentage of U.S. Energy Provided by Source

Percentage of U.S. Energy Provided by Source (2007)

Energy Source	*Percentage (%)*	*Energy Source*	*Percentage (%)*
1. Petroleum	39.8	4. Nuclear Electric power	8.4
2. Natural Gas	23.6	5. Renewable Energy	6.8
3. Coal	22.8		

Source: U.S. Energy Information Administration. Annual Energy Review. 2008.

The percentage of energy consumed by sector is as follows: 29 percent was consumed by the transportation sector, 21.4 percent by industrial, 10.6 percent by residential and commercial, and 40.6 percent by electric power (*See Table 2*). The United State's transportation sector is an alarming 96 percent dependent on petroleum and consumed 70 percent of total U.S. petroleum demand. Around two percent of transportation sector demand was fulfilled by natural gas which equates three percent of total U.S. natural gas demand, and another two percent was fulfilled by renewable energy which equates nine percent of total U.S. renewable energy demand (Annual

Energy Review 2008). Between 2006 and 2007, the use of renewable energy in the transportation sector grew by 30 percent ("Energy in Brief" 2008). The United State's industrial sector was 44 percent dependent on petroleum and consumed 24 percent of total U.S. petroleum demand. The United State's residential and commercial sector was 18 percent dependent on petroleum which equates five percent of total U.S. petroleum demand (Annual Energy Review 2008).

Table 2. Percentage of U.S. Energy Consumed by Sector

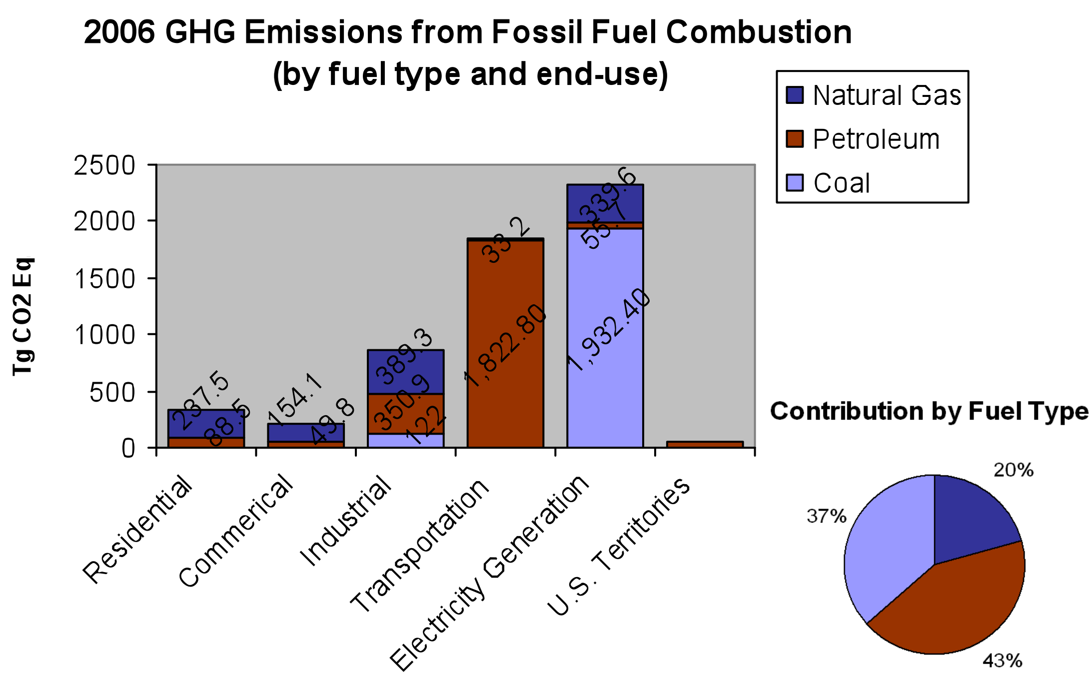
Percentage of U.S. Energy Consumed by Sector (2007)

Sector	*Percentage (%)*	*Sector*	*Percentage (%)*
1. Electric Power	40.6	3. Industrial	21.4
2. Transportation	29	4. Residential and Commercial	10.6

Source: U.S. Energy Information Administration. Annual Energy Review. 2008.

In 2006, according to the U.S. Environmental Protection Agency's "U.S. Greenhouse Gas Inventory Report," total U.S. greenhouse gas emissions amounted to 7,054.6 teragrams (Tg) of carbon dioxide equivalent which was a 14.7 percent increase over 1990 levels. Energy-related activities accounted for 86 percent, or 6,076.9 Tg of carbon dioxide equivalent, of total U.S. anthropogenic greenhouse gas emissions, which included 97 percent of total U.S. carbon dioxide emissions, 37 percent of total U.S. methane emissions, and 13 percent of total U.S. nitrous oxide emissions. This was a 17 percent increase over 1990 levels of energy-related greenhouse gas emissions. Total fossil fuel combustion-related greenhouse gas emissions in the United States was 5,637.9 Tg of carbon dioxide equivalent which was a 19 percent increase compared to 1990 levels and about 20 percent of total global greenhouse gas emissions due to the combustion of fossil fuels (28,193 Tg of carbon dioxide). Approximately 82 percent of total energy consumed in the U.S. is through the combustion of fossil fuels such as coal, natural gas, and petroleum. Coal accounted for 2,065.3 Tg of carbon dioxide equivalent of total fossil fuel combustion-related greenhouse gas emissions, natural gas accounted for 1,155.1 Tg of carbon dioxide equivalent of those emissions, and petroleum accounted for 2,417.1 Tg of carbon dioxide equivalent of those emissions (*See Figure 1*). Of total U.S. greenhouse gas emissions in 2006, petroleum-based fuels accounted for 25.8 percent, or 1,822.8 Tg of carbon dioxide equivalent, of the total. Petroleum-based fuel's carbon dioxide per physical unit ranges from 227 to 615 kg of carbon dioxide per petroleum barrel (U.S. Environmental Protection Agency 2008, 3-1 – 3-5).

Figure 1. 2006 GHG Emissions from Fossil Fuel Combustion



There are roughly 800 million cars and trucks on the road in the world today that are almost entirely dependent on oil and that figure is expected to increase to 2 billion vehicles by 2030 (Sandalow 2008, 30). Roughly 240 million of those vehicles are located in the United States. Approximately 16 million new vehicles are sold each year in the United States which comprises less than 7 percent of the total U.S. auto fleet; hence, it would take roughly 15 years to replace the current auto fleet (18). The average driver in the United States consumes 2.8 gallons of gasoline per day or 570 gallons per year (16, 19). Other average gasoline consumption rates per day include: industrialized world, 1.4 gallons per day; Japan, 1.8 gallons per day; China, 0.2 gallons per day; and world, 0.5 gallons per day (16, 43) (*See Table 3*). On average, 5 pounds of carbon dioxide are emitted when producing and refining gasoline and 20 pounds of carbon dioxide are emitted when gasoline is burned, so roughly 25 pounds of carbon dioxide are emitted with each consumed gallon of gasoline. This means the average car in the United States emits around 6 tons of carbon dioxide each year. Annual U.S. vehicle-related carbon dioxide emissions increased from 1.2 billion tons in 1980 to 1.8 billion tons in 2003. It is expected that this figure will increase to 2.5 billion tons by 2020 (30).

Table 3. Average Gasoline Consumption Rate per Driver per Day by Country

Average Gasoline Consumption rate per Driver per Day by Country

Country	*Gallons*	*Country*	*Gallons*
1. United States	2.8	4. China	0.2
2. Japan	1.8	5. World	0.5
3. Industrialized World	1.4		

Source: David Sandalow. Freedom From Oil: How the next President can end the United States' Oil Addiction. 2008.

Petroleum is not only the energy source the United States is most dependent on in the transportation sector and the fossil fuel responsible for the highest annual amount of energy-related greenhouse gas emissions, but also it is the fossil fuel the United States has the least reserves of and it is considered the most politically contentious of fossil fuels used. In 2006, Saudi Arabia was the world's largest oil producer at 10,665 thousand barrels per day, Russia was second at 9,677 thousand barrels per day, the United States was third at 8,330 thousand barrels per day (8 percent of global production), Iran was fourth at 4,148 thousand barrels per day, and

China was fifth at 3,845 thousand barrels per day ("Country Energy Profiles" 2008) (*See Table 4*). In 2007, OPEC produced 38.5 percent of worldwide petroleum supply (Organization of Petroleum Exporting Countries 2008, 28, 33). The production cost for oil is $2 per barrel in Saudi Arabia, $15-20 per barrel in the United States, and $30 per barrel in Canada (Sandalow 2008, 17).

Table 4. Oil Production by Country

Oil Production by Country (2006)

Country	*Production (thousand b/d)*	*Country*	*Production (thousand b/d)*
1. Saudi Arabia	10,665	4. Iran	4,148
2. Russia	9,677	5. China	3,845
3. United States	8,330		

Source: Energy Information Administration. "Country Energy Profiles." 2008.

Around 75 percent of world annual oil production is traded annually. The United States imported 34 percent of its petroleum needs in 1973, 40 percent in 1990, and roughly 65 percent, or 4.9 billion barrels, in 2007 (Sandalow 2008, 51; and Monthly Energy Review 2008, 43). In 2006, the United States sent $280 billion directly in payments to foreign oil producers; combined with other oil-related expenses, the U.S. spent $450 billion on oil or 3 percent of its Gross Domestic Product (Sandalow 2008, 39, 42). U.S. oil production peaked in 1970 at 9.6 million barrels per day and production in 2005 peaked at 2.5 million barrels per day (42). In Alan Greenspan's words, in the early 1970s, "rising world demand finally exceeded the excess crude oil capacity of the United States" (50). Power shifted to foreign producers during this time as countries like Saudi Arabia boosted oil production from 2 million barrels per day in 1965 to 8 million barrels per day by 1974 (50). During the time period 1968 to 2000, the U.S. subsidized its oil industry by over $130 billion (U.S. Government Accountability Office 2000, 2). Today, about 50 percent of U.S. domestic supply comes from the Gulf of Mexico and Texas, 17 percent from Alaska, and 13 percent from California (Sandalow 2008, 42). Around 11 percent of U.S. oil supply is from the Persian Gulf; in comparison, Japan imports 78 percent and Europe imports 17 percent of its oil needs from the Persian Gulf (17).

Two-thirds of the world's known oil reserves lie in the volatile Middle East (Oil Market Basics: Supply"). As of 2007, Saudi Arabia contained 20 percent of proven oil reserves at 262.3 billion barrels, followed by Canada at 179.2 billion barrels, Iran at 136.3 billion barrels, Iraq at 115 billion barrels, Kuwait at 101.5 billion barrels, United Arab Emirates at 97.8 billion barrels, Venezuela at 80 billion barrels, and Russia at 60 billion barrels ("Country Energy Profiles" 2008). The United States contains less than 3 percent of the world's proven oil reserves, or 20.9 billion barrels, and consumes one-quarter of the world's oil (Cooper 2007, 2; "World Proved Reserves of Oil and Natural Gas, Most Recent Estimates" 2008). Following the United States in oil consumption is China at 9 percent of the world's annual supply; Japan at 6 percent; and Germany, Russia, and India each at 3 percent (Sandalow 2008, 16). Daniel Yergin wrote in his book, The Prize, "Today, we are so dependent on oil, and oil is so embedded in our daily doings, that we hardly stop to comprehend its pervasive significance." The United States simply has no comparative advantage whatsoever when it comes to oil, yet the freedom of mobility cherished by the American people remains enslaved to oil with a heavy dependence of 96 percent.

Table 5. Proven Oil Reserves by Country

Proven Oil Reserves by Country (2008)

Country	*Reserves (billion barrels)*	*Country*	*Reserves (billion barrels)*
1. Saudi Arabia	262.3	6. United Arab Emirates	97.8
2. Canada	179.2	7. Venezuela	80
3. Iran	136.3	8. Russia	60
4. Iraq	115	--	--
5. Kuwait	101.5	United States	20.9

Source: Energy Information Administration. "Country Energy Profiles." 2008.

Climate Change and Its Impacts

The global climate depends on a balancing act which can be likened to the human body. The earth 'breathes' by inhaling carbon in warm growing seasons and through its lungs – vegetation, soils, and oceans that store carbon. It exhales in cold seasons when plant life is dormant and when once living organisms decompose. Carbon is either stored by plants, soils, and oceans or is emitted into the atmosphere. Carbon in the atmosphere can bond with oxygen to form carbon dioxide, a heat-trapping gas. Carbon dioxide, one of six major greenhouse gases, is most often referred to in relation to climate change because it is the most common and most persistent in that once emitted into the atmosphere, it can remain for thousands of years. The carbon that enters the atmosphere behaves analogous to an insulating blanket in that some of the sun's heat is trapped which maintains the global average temperature humans and species are adapted to. When an excessive amount of carbon enters the atmosphere, the global average temperature raises; when too little carbon enters, the temperature decreases (Becker 2008, 5).

Climate change skeptics will argue that other factors attribute to changes in global average temperature. One reason average temperatures vary is due to the fact that the earth's orbit around the sun is elliptical and not circular. This slight change in the amount of radiation the earth is exposed to occurs in cycles of roughly 100,000 years. Another reason for changes in average temperature is due to the fact that the earth's axis is tilted – thus the reason there is seasons. In cycles of about 40,000 years, the tilt of the earth's axis changes by one or two degrees which, in turn, results in an increase or decrease in the amount of radiation that reaches various locations on earth. Lastly, there are subtle changes that occur in cycles of 21,000 years in which the plane of the earth's orbit in relation to the sun alters. This too results in either an increase or decrease in the amount of radiation that reaches earth. These processes, which result in different solar radiation impacts, are called the Milankovitch cycles. However, these cycles are known and can be measured in regards to how much more or less radiation the earth is subject to when the earth's orbit changes and they are not solely responsible for the temperature changes we are now seeing (Friedman 2008, 117-8).

Due to ice core data going back 670,000 years, both the yearly global average temperature and average atmospheric concentrations of carbon dioxide are known. It is known that the difference of global average temperature in glacial and interglacial periods is only 6 degrees Celsius and during that time the total change in atmospheric concentrations of carbon dioxide was 120 parts per million, going from 180 parts per million to 300 parts per million and back to 180 parts per million depending on the period. In other words, for the past 670,000 years, when atmospheric concentrations of carbon dioxide have increased, temperature has increased; when it has decreased, temperature has decreased. For 10,000 years prior to the onset of the Industrial Revolution in 1750, the earth has had an approximate atmospheric concentration of 280 parts per million of carbon dioxide. Today, due to deforestation and human emissions of greenhouse gases (i.e. burning fossil fuels) particularly in the last 50 years combined with the natural limitations of carbon sinks (i.e. forests), the atmospheric concentration has been pushed up to roughly 384 parts per million of carbon dioxide with an annual increase of approximately 2 parts per million (Friedman 2008, 117; Adam 2008). Scientists claim that this level of concentration has probably not existed on earth in the past twenty million years. Since scientists know that the earth's relationship to the sun has not changed significantly in the past one hundred years, but that the atmospheric concentration of carbon dioxide has risen dramatically, it can only be assumed that some other stimulus is amplifying the release of carbon dioxide and causing the increase in global average temperatures in the present time period. Scientists have definitively measured that the increase in carbon dioxide in the atmosphere in the past fifty years has come from carbon released in fossil fuel combustion and not from the carbon dioxide in the oceans due to the fact that carbon can be dated and its source identified. They claim that the impact of human-induced greenhouse gas emissions on recent warming is five to ten times greater than the effect from the sun (Friedman 2008, 118-9).

While a slightly warmer planet may not seem like a big deal to some skeptics, think again of the human body. A temperature increase of 2 degree centigrade is a fever and an increase of 5 or 6 degree centigrade of the human body, the difference between glacial and interglacial periods, is fatal (Becker 2008, 7). The aforementioned February 2007 IPCC report claimed that a temperature anomaly above 2^oC compared to pre-industrial levels is considered the level at which 'dangerous' effects from climate change will occur. The International Energy Agency's 2008 World Energy Outlook claimed that energy demand could theoretically jump by 50 percent by 2030 which could raise global temperature by as much as six degrees Celsius; whereas the IPCC report found that continuing business as usual will result in an increase of atmospheric concentrations of carbon dioxide to a level of 550 parts per million by mid-century, approximately double preindustrial levels, which would result in a temperature increase of 3^oC (Essick 2009, 7; Union of Concerned Scientists 2008). Concentration levels would be expected to triple by 2075 to above 800 parts per million. The report called for stabilizing atmospheric concentrations of greenhouse gas emissions at levels of no more than 450 parts per million of carbon dioxide equivalent which would provide a 50 percent chance of preventing 'dangerous' climate change from occurring. This means that during the period 2000-2050, only 160 to 265 gigatons of carbon dioxide equivalent can be emitted, of which 45 gigatons of carbon dioxide equivalent has already been emitted. If emissions peaked in 2010, reductions of an average of four percent per year must occur through

2050; this figure doubles to reductions of eight percent per year through 2050 if United States emissions do not peak until 2020 (Union of Concerned Scientists 2008). However, Dr. James Hansen urges that carbon dioxide growth needs to be halted and reversed to atmospheric levels of no more than 300-350 parts per million of carbon dioxide equivalent and that “the solution of the climate problem requires that we move to carbon-free energy promptly” because time is running out while also cautioning that “the consequences of continued increase of greenhouse gases extend far beyond extermination of species and future sea level rise” (“The Connection between Climate Change and Extreme Weather” 2008).

“The impacts of climate change on natural systems and their services affect not only our species but all species; not only this generation but also those that will follow” (Presidential Climate Action Project 2008). In the 1860’s, physicist John Tyndall first identified a connection between climate change and the greenhouse effect. In 1896, a Swedish geochemist, Svante Arrhenius, predicted burning fossil fuels would result in global warming. During the 1900’s, American scientists’ David Keeling and Roger Revelle measured increases in carbon dioxide emissions and subsequently expressed concern regarding global warming to the U.S. Presidents of the 1960’s (Presidential Climate Action Project 2008).

Twenty years ago on June 23, 1988, Dr. James Hansen, regarded by many as the Paul Revere of climate change, told a U.S. Senate Committee that he was 99 percent certain that the year’s record temperatures were not the result of natural variation. An unprecedented heat wave, crop damage due to droughts, wildfires, and an unnavigable Mississippi River led to nearly half of the nation being declared a disaster area that summer (“The Connection between Climate Change and Extreme Weather” 2008). He noted that “global warming enhanced both extremes of the water cycle, meaning stronger droughts and forest fires, on the one hand, but also heavier rains and floods" ("The Connection between Climate Change and Extreme Weather" 2008). His testimony marked the first time a lead scientist depicted a connection between human activities, a growing concentration of atmospheric pollutants, and a warming climate ("The Connection between Climate Change and Extreme Weather" 2008). Exactly 20 years later to the day, before the House Select Committee on Energy Independence and Global Warming, Dr. Hansen stated, "We have used up all slack in the schedule for actions needed to defuse the global warming time bomb" and that "climate is nearing dangerous tipping points" ("The Connection between Climate Change and Extreme Weather" 2008).

The summer of 2008 has been marked by floods that have ravaged crops across the Midwest, wildfires on the west coast, and according to the National Oceanic and Atmospheric Administration (NOAA), moderate to exceptional drought conditions that have been causing crop damage and water supply shortages in much of the southern Atlantic, southern, west, and Pacific southwest states. The last several years have seen a shrinking snowpack and warmer springs with earlier runoff in the western United States according to a January 2008 study published in *Science* magazine ("The Connection between Climate Change and Extreme Weather" 2008). Eleven of the twelve warmest years on record have occurred since 1995 and average temperatures in the Northern Hemisphere between 1950 and 2000 are thought to be the highest average temperatures experienced in at least the past 1,300 years (Sandalow 2008, 29). The IPCC said that "the last time the polar regions were significantly warmer than present for an extended period (about 125,000 years ago), reductions in polar ice volume led to 4 to 6 meters of sea level rise" (29). The IPCC also concluded that in the 21st century "the resilience of many ecosystems is likely to be exceeded…by an unprecedented combination of climate change, associated disturbances (i.e. flooding, drought, wildfire, insects, ocean acidification) and other global change drivers (i.e. land use change, pollution, over-exploitation of resources)" (29-30).

In June 2008, the U.S. Climate Change Science Program and the Subcommittee on Global Change Research released a scientific assessment that presented the first comprehensive analysis of observed and projected changes in weather and climate extremes in North America and U.S. territories ("The Connection between Climate Change and Extreme Weather" 2008). Major findings include that "droughts, heavy downpours, excessive heat, and intense hurricanes are likely to become more commonplace as humans continue to increase the atmospheric concentrations of heat-trapping greenhouse gases" ("The Connection between Climate Change and Extreme Weather" 2008). The report acknowledged scientific evidence that a warming world is accompanied by changes in the intensity, duration, frequency, and geographic extent of weather and climate extremes ("The Connection between Climate Change and Extreme Weather" 2008). Dr. Tom Karl, director of NOAA's National Climatic Data Center, stated, "We are now witnessing and will increasingly experience more extreme weather and climate events" ("The Connection between Climate Change and Extreme Weather" 2008).

In May 2008, the U.S. Climate Change Science Program and U.S. Department of Agriculture released a scientific assessment that examined the impact of climate change on U.S. ecosystems. The report found that climate change such as temperature increases, increasing carbon dioxide levels, and altered patterns of precipitation are already affecting U.S. water resources, agriculture, land resources, and biodiversity, and will continue to do so in the future. Findings of the report include that the growing season has increased by 10 to 14 days across temperate latitudes over the past 19 years; and that the interior West, Southwest, and Alaskan forests are being affected by increased size and frequency of forest fires, insect outbreaks, and tree mortality.

Livestock mortality will increase due to hotter summers. Increased invasion of exotic grass species in arid lands will cause increased fire frequency; and weeds will grow more rapidly, migrate northward, and be less sensitive to herbicide applications. Much of the United States has experienced higher precipitation and streamflow while the West and Southwest are expected to experience increased drought severity and duration; and increased temperatures combined with decreased or variable precipitation will lead to increased grain and oilseed crop failure, among other findings ("The Connection between Climate Change and Extreme Weather" 2008).

Energy Independence and National Security

A 2011 report by the U.S. Department of Energy stated that U.S. oil dependency is a long-term threat to the climate and that it is the "greatest immediate threat to U.S. economic and national security" (Report on the First Quadrennial Technology Review 2011, ix). Even the skeptic of climate change cannot disagree that the world's supply of nonrenewable fossil fuels is finite. American consumers are bearing the weight of skyrocketing prices at the pump while demand for an ever-tightening supply of oil continues to soar worldwide ("To Review Renewable Fuels Standard Implementation" 2008). Today, the United States consumes over 21 million barrels of crude oil each day, over half of which is imported, with over 14 million barrels of that oil being consumed by the transportation sector (Friedman 2008, 290). Currently, about 40 percent of total energy consumption in the United States is dependent on petroleum (Yergin 2009, 772). This dependence on oil poses a significant economic, energy, and national security challenge to our nation ("To Review Renewable Fuels Standard Implementation" 2008). Energy hegemonic influence has long been a central pillar of American primacy. Since, World War II, the U.S. has seen its ability to control disposition and marketing of a significant share of oil and gas production decrease which adds even more depth to the problem oil dependence poses to the United States. This type of hegemonic influence is important because of the interdependence of a Nation's economic well-being and access to energy resources, irrepressible population growth, tightening energy resource supplies, and an economy's reliability on oil to function, and consequently, its pervasiveness, in our daily lives (Leverett 2011).

On June 2, 2005, The Financial Times published a story, "Kissinger Warns of Energy Conflict," in which Henry Kissinger, former U.S. Secretary of State, commented along the lines that "the global battle for control of energy resources could become the modern equivalent of the 19th century "great game," the conflict between the UK and Tsarist Russia for supremacy in central Asia" (Daniel 2005). He cautioned that competition for access to a finite amount of energy can become the life and death for many societies, and that a widespread nuclear weapon option in countries of varying diplomatic statures and dispositions would put the world in a state of "permanent imminent catastrophe." In essence, he said, "The great game is developing again" (Daniel 2005). The unfolding of this 'great game' can be observed in the context of three energy battlegrounds, Iran, Iraq, and Central Asia, where resource mercantilism and resource nationalism, particularly in terms of oil, bump up against each other and have strategic implications on U.S. energy security and preeminence (Leverett 2011).

Our dependence on oil is becoming more perilous due to a more competitive, global marketplace for an increasingly scarce, non-renewable resource, crude oil (Copulos 2006, 1, 3). Former Senator Gary Hart has stated, "Oil is now the centerpiece of America's foreign policy, economic policy, defense policy, environmental policy, and energy policy. So long as the economy of the United States is held hostage by foreign oil producers, America will remain vulnerable to volatile prices, supply interruptions, the overthrow of producing governments, and regional unrest, instability, and conflict" (Becker 2008, 83). The Unocal affair, where the United States forced China to make CNOOC withdraw its offer to buyout Unocal in 2005, "offered the first window into the global fear of resource scarcity and the new geopolitics of energy that will likely accompany it" (Klare 2008, 6-8).

Mercantilism is an old economic term originating as early as the 16th century in which society is described as being comprised of rent-seekers in a zero-sum game, meaning an increase by one requires a loss for the other in a world of limited wealth (Wikipedia 2011). Add in a finite supply of uncertain and dwindling oil and gas as the resources applied to that concept. The fluctuation of prices of oil and gas has brought a continuing struggle over money and power between producers and consumers. When oil prices have been low, power increases and economic growth is spurred in oil-importing countries. When prices have been high, such as in recent times, power and wealth has redistributed itself to oil-exporting countries in a way never before seen in history (Yergin 2009, 767). The account deficit of the United States has mushroomed as an immense amount of wealth has been transferred to oil-exporting countries. The United States' "current reliance on imported oil contributes to the nation's economic enfeeblement" (Klare 2008, 261). As supplies remain tight while demand continues to grow (especially in Asia) and the production share from non-OPEC countries shrink, market power will remain with oil-exporting countries (Yergin 2009, 767). Saudi Arabia, OPEC's "swing producer," has long considered its relationship with the U.S. as a highly strategic one until 2003, and for quite some time it had the policy of wanting to be the largest oil exporter to the U.S. In light of U.S. account deficits and China's account surpluses, Saudi Arabia has been creating a strategic partnership with China as a hedge due to concern rising over the long-term viability of a strategic American partnership. In the words of Chas Freeman, 'the

Saudi's aren't divorcing the United States, but are taking on a Chinese wife to join its American wife.' In other words, Saudi Arabia wants to keep the U.S. on board as its main security partner while maintaining its autonomy (Leverett 2011). This is one example of the decline of U.S. energy hegemonic primacy in the world.

Some will say that when a 'certain' price is reached in the respective oil and gas markets, advancements will always be triggered to produce unconventional oil and gas or technological innovations will be discovered to allow extraction of more oil and gas in fields, so that the market will always correct itself. While extraction of the world's increasingly scarce, nonrenewable energy resource supplies, such as oil and gas, may be extended by technology, technology itself is limited and can only go so far; thus, continued dependence on uncertain and dwindling finite supplies of petroleum into the foreseeable future is a risky undertaking and cannot be indefinite. It is only a matter of time, however long that may be, before the world's reserves are depleted. Some experts think that evidence exists that peak oil is approaching ("To Review Renewable Fuels Standard Implementation" 2008; Klare 2008, 32-43). Simply replacing oil with gas poses problems too due to LNG transport issues and reliability of supply as 56 percent of the world's proven natural gas reserves lie in Russia, Iran, and Qatar (43-49). Replacing oil with coal or nuclear power poses greenhouse gas emission and security issues respectively (49-55).

In the meantime, few substitutions to oil makes demand have an inelastic characteristic (although it does have elastic characteristics too) to the many Americans addicted to daily oil consumption. As demand is increasing in a more competitive global marketplace, especially due to the rise of powers such as China and India, supply has not kept up, thus tightening the margins (Leverett 2011). Some report that worldwide oil demand will grow by 40 percent over the next quarter century and that two billion cars are expected to be on the road worldwide by 2030. Yergin states that, "for several decades to come…oil will be a central factor in world politics and the global economy, in the global calculus of power, and in how people live their lives" (Yergin 2009, 773). As supply declines, prices rise, and demand grows for oil, in part due to industrializing nations such as China and India, many of our nation's military experts foresee resource conflicts in the years ahead (Becker 2008, 82). According to the U.S. Energy Information Administration's 2008 International Energy Outlook, global energy consumption of liquids and other petroleum is expected to grow from 83.6 million barrels of oil per day in 2005 to 112.5 million barrels of oil per day by 2030. The transportation sector is expected to account for 74 percent of that increased demand and the majority of that demand is expected to come from non-OECD nations. Furthermore, world oil prices are expected to be in the range of $113 to $186 per barrel in nominal terms in 2030 (International Energy Outlook 2008 2008, 2, 5). Experts predict these rising energy costs will impede the United States' international development efforts (Sandalow 2008, xii). The need for continued oil dependence poses a significant economic, energy, and national security challenge to the United States, thus giving rise to the notion of forthcoming energy conflicts.

The change in the global energy architecture does not stop on the demand side with consumers; a new set of seven sister producers have emerged from countries other than those home to the original seven sisters. In the beginning, there were the original seven sisters who "controlled the vast majority of the world's oil production and refining at the birth of the modern oil age" during a time in which the oil companies had contractual arrangements in the form of concessions with sovereign governments that favored foreign investors by placing hardly any obligations or restrictions on them (Hoyos 2007). Robin West, chairman of PFC Energy, says, "the reason the original seven sisters were so important was that they were the rule makers; they controlled the industry and the markets. Now, these new seven sisters are the rule makers and the international oil companies are the rule takers" (Hoyos 2007). Enrico Mattei, former president and founder of ENI of Italy, is credited with coining the term "Sette Sorrelle" or "Seven Sisters" around the late 1940's or early 1950's. The term was used to collectively refer to these major Anglo-Saxon oil companies, Exxon, Mobil, Chevron, Texaco, Gulf Oil, Shell, Anglo-Persian Oil Company and honorably, Total, who often pursued multiple joint ventures together, especially in the Middle East, including Aramco, Iranium consortium, Iraq Petroleum Company, and in Kuwait (Yergin 2009, 485).

The shift in power that occurred as time progressed follows along what Harvard economist Raymond Vernon dubbed the obsolescing bargain, which is particularly dramatic in the case of the oil industry. Initially, the foreign investors, or oil companies, had a large amount of bargaining power because they had the high capital, technology, and expertise requirements necessary to undertake the risky oil exploration and development projects that had no guarantee of success. Without a foreign investor, oil and gas development would not occur, so the foreign investor was able to obtain advantageous terms in the beginning, as the seven sisters did in their original concessions. This allowed the original seven sisters to be the original rule makers. Over time, the technology initially required is not so unique and the host sovereign government develops its own expertise and capabilities in that sector. As the oil companies' investment of fixed assets increased, the bargaining power shifts to the sovereign government and so the terms that a sovereign government can bargain for improve with time. The seven sisters were the only companies in the beginning who possessed the skill sets required to obtain the original concessions. Over time, other companies, such as Mattei's ENI and Dr. Armand Hammer's Occidental Petroleum, emerged in the 1950's and 1960's who also had the necessary skill sets to enter the international oil industry and began to compete with the seven sisters by undercutting their fifty-fifty deals and unraveling the then present structure of the international oil industry. The evolution to the present day international oil industry began when the seven sisters' skill sets, which included their capital, technology, and expertise, were no longer unique allowing the entrance of other major players who unraveled the then present structure by becoming the new rule makers; consequently, the sisters' collective bargaining power and leverage declined (Leverett 2011).

Following the fifty-fifty deal, in which the sovereign government's take and the foreign investor's net profits are equal, between Aramco and Saudi Arabia in 1950, a memo within Standard Oil of Jersey warned, "If we ever admit to any country that an equal division is less than 'fair,' the ground will be cut out from under our feet in every country…50/50 is a good position which needs no defense and is hard to attack; 55/45 or 60/40 would have no such appeal, and could be only rear-guard defense positions in an unlimited retreat" (Yergin 2009, 430). Enrico Mattei sensed that weakness, and when the seven sisters refused to let ENI join their Iranian consortium, he cut the feet out from under the seven sisters. In 1957, Mattei upset the stability security the seven sisters had placed in the fifty-fifty deals by striking a 75/25 deal with the Shah of Iran. In the evolution that followed, sovereign governments became aware of the true monetary, political, and strategic value of their energy reserves; reasserted their ownership rights over their own hydrocarbons; began asking for increased rents; and fought over prices between OPEC and non-OPEC producers which led to price fluctuations and a struggle over money and power between producers and consumers over the subsequent decades (Leverett 2011).

In response to the OPEC revolution that started in the 1960's in part also due to the original seven sisters unilaterally lowering the posted price of oil, occurrences of outright nationalization, and oil price hikes in the 1970's from the use of the 'oil weapon' by OPEC, the United States and its western partners attempted to undermine

OPEC's assertion of market power by trying to out-produce it and flood the market with non-OPEC oil. The price collapse of 1986 that came about as a result of weaker demand, increasing supplies, and the United States and its western partners' strategy to promote upstream liberalization in oil and gas through the use of production-sharing agreements in newly developed hydrocarbon basins such as the North Sea and African countries, along with continued low prices through the 1990's eventually led to a restructuring of the seven sisters into merged "supermajors" by the end of the 1990's. This was just the beginning of the restructuring that occurred as national oil companies became increasingly prominent and eventually emerged as the new seven sisters (Leverett 2011). "Only now is the world seeing the full extent of the "OPEC revolution" of the early 1970s: Beyond an explicit cartel of oil producers, there is today an implicit cartel of resource-owning governments that control a large share of the world's known reserves of oil and natural gas" (Leverett and Noël 2006, 65).

The new seven sisters have emerged from countries other than those of the original seven sisters: Saudi Arabia, Russia, China, Iran Venezuela, Brazil, Malaysia, and honorably Iraq as compared to United States, UK, Netherlands, and honorably France. They are for the most part state-owned and are from developing countries, and increasingly exercise control over the world's oil and gas reserves both in their parent governments and abroad (Hoyos 2007). Today, "over 80 percent of world [oil] reserves are controlled by governments and their national oil companies," and sixteen of the world's twenty largest oil companies are state-owned (Yergin 2009, 770). Specifically, the new seven sisters "control almost one-third of the world's oil and gas production and more than one-third of its total oil and gas reserves. In contrast, the old seven sisters – which shrank to four supermajors in the industry consolidation of the 1990's – produce about 10 percent of the world's oil and gas and hold just 3 percent of reserves" (Hoyos 2007). "This means that national oil companies and their parent governments, not international oil companies and their shareholders, (not only control supply but also) ultimately control the pace of development of upstream oil and gas resources" (Leverett and Noël 2006, 65). Additionally, "a high proportion of the remaining areas suitable for comparatively low-cost removal of reserves, mostly in the Middle East and former Soviet Union, are off limits to the international oil industry" but not to the to the respective countries' national oil company (64).

Trends of both increased demand and tightening supplies, and control of the world's oil reserves by foreign governments through their national oil companies, have given rise to the concepts of resource mercantilism and resource nationalism. Resource mercantilism (demand side) deals with the reliance of countries, who are hydrocarbon-importers (such as China and India), on their national oil companies to gain access to oil and gas reserves abroad and to supply them on a privileged basis in exchange for various incentives (new seven sister NOCs). Resource nationalism (supply side) is a government's assertion of ownership rights in hydrocarbon reserves over international oil companies (i.e. Mexico 1938; Iran, Iraq, Saudi Arabia, and Kuwait concessions nationalized) and, consequently, their increased control over supply, pace of upstream development, and marketing of production as compared to the early 20th century global oil marketplace (Russia/former USSR, Saudi Arabia/China). Resource Mercantilists and Resource Nationalists can make various strategic and political decisions with these advantages; they have, in essence, changed the rules of the game in that no longer do countries rely on the market for access to increasingly scarce hydrocarbon volumes needed. These energy-surplus countries heighten the problem of energy security for energy deficit countries such as the United States (Klare 2008, 14).

In 2007, the U.S. transportation sector was 96 percent dependent on petroleum and consumed approximately 70 percent of total U.S. petroleum demand, of which around 60 percent was imported ("To Review Renewable Fuels Standard Implementation" 2008). The U.S. imported over 4.9 billion barrels of oil of which 16.1 percent originated from the Persian Gulf and 44.5 percent originated from the Organization of Petroleum Exporting Countries (OPEC), a group of producers that collude on world oil prices and supplies who provided 38.5 percent of worldwide petroleum supply in 2007 (Monthly Energy Review 2008, 43; Organization of Petroleum Exporting Countries 2008, 28, 33). According to the U.S. Energy Information Administration, the U.S. will import 70 percent of oil demand by 2030 (Becker 2008, 82).

Future petroleum supplies are uncertain. Concern of a potential shortfall of supplies and high prices is worsened by the possibility of supply disruptions due to four of the top six sources of U.S. oil imports coming from the unstable countries of Saudi Arabia, Venezuela, Nigeria, and Iraq (*See Table 6)* (Copulos 2006, 2-3). Furthermore, since the price of oil is set on a global market, any supply disruption can affect the prices of oil everywhere so the United States is subject to price increases due to supply disruptions coming from countries it does not import from such as Iran (Sandalow 2008, 17). To illustrate, in the summer of 2000, the UK was energy

Table 6. Top Six U.S. Crude Oil Imports by Country of Origin

Top Six U.S. Crude Oil Imports by Country of Origin

Country	*Thousand Barrels per Day (2007 Average)*	*Country*	*Thousand Barrels per Day (2007 Average)*
1. Canada	1888	4. Venezuela	1148
2. Saudi Arabia	1447	5. Nigeria	1084
3. Mexico	1409	6. Iraq	484

Source: U.S. Energy Information Administration. "U.S. Crude Oil Imports by Country of Origin." July 23, 2008

independent in that it was a net oil exporter. British truck drivers went on strike because of rising gasoline prices. Although the UK's oil came from a domestic source, British truckers were still subject to impacts from rising world oil prices (53). Saudi Arabia has long maintained excess production capacity in order to stabilize world oil prices. In order to promote long-term demand for their oil, they have attempted to prevent oil prices from rising too high so that other countries would not be encouraged seek substitutes to oil. As world oil demand has climbed in recent years, their excess production capacity has declined which has resulted in steep price increases and volatility (41). Saudi Arabia holds around twenty percent of the world's proven oil reserves; a total of two-thirds of the world's proven oil reserves lie in the Middle East ("Oil Market Basics: Supply"). The Asia-Pacific region currently relies on the Middle East for approximately 90 percent of its imports or 50 percent of its consumption. Because the Middle East holds the majority of the world's oil reserves, increased U.S. and world dependence on this unstable region is deemed to be inevitable. The United States will remain vulnerable to supply disruptions in the Middle East due to the world's ever-increasing dependence on Middle East oil ("Oil Market Basics: Trade"). According to David Sandalow, "With half of the world's proven oil reserves, the world's cheapest oil and the world's only spare production capacity, the Persian Gulf will remain an indispensible region for the global economy so long as modern vehicles run only on oil…To minimize problems posed by financial flows to oil-exporting nations, we need to reduce global demand for oil" (Sandalow 2008, 22, 53).

U.S. dependence on oil not only transfers wealth to oil-exporting countries, but it also transfers wealth to other nations that oppose U.S. interests which in turn threatens our national security (Sandalow 2008, 23). "Every $10 increase in the price of oil adds roughly $50 billion annually in foreign payments" (44). Some of the payments to state-owned oil companies in the Persian Gulf end up in the hands of terrorist organizations such as Al Qaeda or other radical jihadists. Other funds go to empower leaders such as Hugo Chavez, president of Venezuela, who wishes the

United States ill (53). Some countries including Venezuela, Iran, and Russia, which have adversarial regimes, have used their energy supplies as leverage by threatening or actually cutting off energy supplies. This undermines foreign policy efforts such as when Iran plays the oil card in negotiations concerning their nuclear program. Many oil-producing countries have authoritarian regimes whose leaders are prone to corruption and whose citizens' rights are suppressed, thus undermining democratic institutions (Sandalow 2008, xii-3). Given the precarious political situation in many of these countries, the availability of this resource in the future is not assured.

Our reliance on foreign oil increases the vulnerability of the United States to higher oil prices and oil price shocks due to events such as natural disasters, terrorist attacks, and wars; undermines our ability to conduct foreign policy; and places us at the will of a small group of oil producing states that can use their market power to influence world oil prices (Greene and Ahmad 2005, xi). There exist several "hidden costs" or externalities associated with the consumption of imported oil such as direct and indirect costs, oil supply disruption impacts, and military expenditures (Copulos 2006, 3-4). According to the National Defense Council Foundation, the energy crises of the early and mid-1970's cost the U.S. economy between $2.3 trillion and $2.5 trillion. Today, a similar disruption could cost our economy $8 trillion (Copulos 2006, 1, 3). Other "hidden costs" include that the United States spends $137.8 billion a year on oil-related defense expenditures to protect and secure access to oil in the Persian Gulf. The direct loss of economic activity due to U.S. dependency on foreign oil is estimated at $117.4 billion annually. The loss of domestic direct and indirect investment is estimated at $394.2 billion. The loss of domestic tax revenues is estimated at $42.9 billion per year. The loss from oil supply disruptions is estimated at $132.8 billion annually. The total "hidden cost" of imported oil was $304.9 billion in 2003 and $825.1 billion in 2006. This cost is equal to adding $8.35 to the price of a gallon of gasoline refined from Persian Gulf oil (Copulos 2007, 2-4). In the past five years, approximately $1 trillion in U.S. wealth has been transferred abroad to oil-producing nations (Becker 2008, 5). The United State's reliance on crude oil imposes an immense financial burden on our nation's economy and threatens our nation's economic, energy, and national security (Copulos 2007, 5).

The more resources become scarce, the more likely the 'great game,' or race for securing access to hydrocarbon resources, is likely to lead to conflict. "Make no mistake: rising powers / shrinking planet is a dangerous formula. Addressing the interlocking challenges of resource competition, energy shortages, and climate change will be among the most difficult problems facing the human community. If we continue to extract and consume the planet's vital resources in the same improvident fashion as in the past, we will, sooner rather than later, transform the earth into a barely habitable scene of desolation. And if the leaders of today's Great Powers behave like those of previous epochs—relying on military instruments to achieve their primary objectives—we will witness unending crisis and conflict over what remains of value on our barren wasteland. This can only be avoided by redirecting the competitive impulses now channeled into the hunt for vital resources into a cooperative effort to develop new sources of energy and climate-friendly industrial processes. If successful, a transition of this sort would allow the major energy-consuming nations—both new and old—to face the future with confidence that their basic needs will be met without recourse to war or unleashing environmental catastrophe. We must choose this course for the sake of all humanity's children" (Klare 2008, 261). While energy independence is a laudable policy objective, the pace at which such a change could occur, being as there are currently no alternatives to hydrocarbons to suit our gross needs, may not be rapid enough to prevent Kissinger's warning of forthcoming energy conflicts from occurring. It is important that energy remains as a key pillar in America's hegemonic pursuits, while at the same time focusing on energy efficiency and developing alternatives to hydrocarbons at home. To date, energy security policy of securing free flow of oil from the Persian Gulf, the Carter Doctrine, has not been consistent with action (Leverett 2011).

Biofuels are already playing a substantial role in extending our finite supply of petroleum. The use of domestically produced renewable fuels extends fuel supplies by displacing the quantity of foreign oil the United States imports. A June 2008 report released by Merrill Lynch accredited biofuels as the single largest contributor to global oil supply growth, especially due to the inability of non-OPEC crude oil supply to expand (Merrill Lynch 2008, 2). "According to the International Energy Agency, 'biofuels have become a substantial part of faltering non–OPEC supply growth, contributing around 50 percent of incremental supply in the 2008–2013 period" (Renewable Fuels Association, Canadian Renewable Fuels Association, European Bioethanol Fuel Association, and UNICA 2008). On average, retail gasoline prices would be at least $21 per barrel higher without incremental biofuel supplies. Corn-based ethanol is adding over 400 thousand barrels per day or 2 percent to domestic supplies which is up from 0.2 percent at the start of the decade. Ethanol production has reduced oil prices by an estimated $32 per barrel in the Midwest and $24 per barrel on the east coast (Merrill Lynch 2008, 2). The Department of Energy estimates that without biofuels the United States would have to use an additional 7.2 billion gallons of gasoline or 472 thousand barrels of gasoline per day to maintain current levels of travel (U.S. Department of Energy 2008, 1).

Currently, seventy percent of all gasoline sold in the United States is blended with ethanol. This large increase in the use of ethanol has been driven by both clean air requirement blending and discretionary or economic blending (Cooper 2008, 7-9). If ethanol were removed from the marketplace, petroleum prices would likely increase sharply as demand that is currently satisfied by biofuels is fulfilled. Studies have illustrated that today's costs at the pump would be higher if renewable fuels were not blended into gasoline. On June 12, 2008, Alexander Karsner, DOE Assistant Secretary for Energy Efficiency and Renewable Energy, testified before the U.S. Senate Committee on Energy and Natural Resources that gasoline prices today would be between 20 to 35 cents per gallon higher without ethanol (Karsner 2008). Francisco Blanch, a commodity strategist for Merrill Lynch, estimated that oil and gasoline prices would be 15 percent higher without increased biofuel production (Barta 2008). John Urbanchuk, Director of LECG, reported that if ethanol were removed from the market, national average gasoline prices would increase by 14.6 percent in the short term (Urbanchuk 2004, 2). Mark Cooper, Director of Research of Consumer Federation of America, estimated that consumers may save as much as 8 cents per gallon of gasoline if oil companies blend gasoline supplies with 10 percent ethanol (Cooper 2005, 2). An Iowa State study found that ethanol reduced gas prices by 89 cents per gallon in 2010 (Renewable Fuels Association). Essentially, the use of renewable fuels eases the burden of transportation costs on American consumers ("To Review Renewable Fuels Standard Implementation" 2008).

U.S. Biofuel Development and Policies

In 1900, during the World Fair in Paris, France, Rudolf Diesel, inventor of the compression ignition engine, ran a diesel engine built by the French Otto Company on peanut oil for which he received the Grand Prix or highest prize offered. He believed that the use of biomass-based fuel was the future for the engine he designed. In a speech in 1912, Rudolf said, "the use of vegetable oils for engine fuels may seem insignificant today but such oils may become, in the course of time, as important as petroleum and the coal-tar products of the present time." Because petrodiesel was much cheaper to produce than biomass-based diesel fuel, by the 1920's, most diesel engine manufacturers had altered their engines to run on petroleum-based diesel fuel (Wikipedia 2008).

In 1925, Henry Ford, who designed the Model T Ford to run on ethanol, claimed ethyl alcohol as the "fuel of the future" (Kovarik 1998). Oil companies among other individuals thought otherwise until the oil embargoes of 1973 and 1979 which not only resulted in record high oil prices and gasoline shortages, but also wreaked havoc on the U.S. economy. Simultaneously, grain prices nose-dived and the U.S. lost a valuable export market after it imposed a grain embargo on the former Soviet Union following its invasion of Afghanistan. These events stimulated a drive to develop alternative, renewable supplies of energy, and also Congress to pass The Energy Security Act of 1979. The act created a federal ethanol tax incentive which aimed to reduce our nation's alarming reliance on foreign oil and to create a crucial value-added market for U.S. grain through the production of a domestic, renewable fuel (Renewable Fuels Association).

Following the energy crises of the 1970's, President Jimmy Carter also established the Solar Energy Research Institute, what is today referred to as the National Renewable Energy Laboratory (NREL). It was at this time that NREL began algae-to-biofuel research through the Aquatic Species Program. Funded from 1978-1996, NREL collected over 3,000 strains of freshwater and marine algae throughout the United States and researched the feasibility of producing renewable transportation fuels from algae by examining algae's ability to produce natural oils and grow under extreme conditions. Researchers made significant molecular biology and genetic engineering breakthroughs and were able to utilize 90% of injected carbon dioxide while mass producing microalgae in an open pond system (Sheehan 1998, i-iii).

Another major catalyst for the ethanol industry was the introduction of the Clean Air Act Amendments of 1990. This act required emission reductions of carbon monoxide (CO) and volatile organic compounds (VOCs) through the use of oxygenated or reformulated gasoline (RFG) in the nine areas that contained excessive carbon monoxide and ozone pollution as of January 1, 1995 (Yacobucci and Womach 2003, i). Oxygenates such as methyl tertiary butyl ether (MTBE) or ethanol could be blended into the fuel (6). While RFG was a year-round program, the Oxygenated Fuels program which began in 1992 is only active during winter months in 16 areas that are marked as carbon monoxide nonattainment areas (10). Decreasing petroleum fuel levels and replacing it with cleaner-burning ethanol lessens air pollution and related health costs (Governors' Ethanol Coalition 2004, 2). Studies from the first year showed successes of the RFG program, including a 38% median reduction of benzene (a human carcinogen) from the previous year. From later studies, the EPA also noted significant improvements in air quality, such as a 17% reduction of VOCs and a 30% reduction of toxic emissions (10). The Energy Policy Act of 2005 removed the RFG oxygenate requirement 270 days after its enactment in place of the Renewable Fuels Standard (Renewable Fuels Association).

In August 2005, the Energy Policy Act of 2005 which contained the Renewable Fuels Standard (RFS) was passed. The RFS required that 7.5 billion gallons of ethanol be used in our fuel supply by the year 2012. Experts estimated that approximately 2.7 billion bushels of corn would be utilized to meet the demand. It also mandated that beginning in 2013, 250 million gallons of cellulose-based ethanol must be used to meet RFS requirements (Renewable Fuels Association). The RFS is expected to reduce crude oil imports by 2 billion barrels, reduce outflow to foreign oil producers by $64 billion, create 234,840 new jobs within the United States, increase U.S. income in households by $43 billion, add $200 billion to GDP through 2012, create $6 billion in new investment of renewable production facilities, and would require the purchase of $70 billion of goods and services to produce ethanol and biodiesel through 2012 of which feedstock will comprise $43 billion (Renewable Fuels Association 2006, 5, 19). Furthermore, Americans benefit as domestic, renewable fuels supersede imported crude oil which ultimately reduces America's dependence on oil imports from the unstable Middle East (Urbanchuk 2003, 15). The RFS provided a positive roadmap to reduce consumer fuel prices, increase energy security, and stimulate rural economies by taking advantage of America's renewable energy potential (Renewable Fuels Association).

On December 19, 2007, the Energy Independence and Security Act of 2007 was signed into law which increased the Renewable Fuels Standard passed in 2005 to 36 billion gallons of renewable fuels by 2022. Conventional ethanol, or ethanol derived from corn starch, may meet up to 15 billion gallons required by the mandate and any new conventional ethanol facilities going under construction after the enactment of the law must achieve at least a 20 percent reduction in greenhouse gas emissions compared to baseline lifecycle greenhouse gas emissions. The remaining 21 billion gallons must come from advanced biofuels such as cellulosic biofuels. Advanced biofuels are defined as renewable fuel derived from renewable biomass other than corn starch that achieve at least a 50 percent reduction in greenhouse gas emissions. This definition contains two subcategories, one for cellulosic biofuels, which must achieve a 60 percent reduction in greenhouse gas emissions, and one for biomass-based diesel which must achieve a 50 percent reduction in greenhouse gas emissions (Renewable Fuels Association).

In addition to a plethora of biofuel-related research and development loan and grant programs, there are several tax credits that support the biofuel industry. The American Jobs Creation Act of 2004 extended the Volumetric Ethanol Excise Tax

(VEETC) through 2010 (51 cent blender's credit), created a tax credit for biodiesel, and enhanced the Small Ethanol Producer Tax Credit that had been relatively ineffective due to poor language when originally enacted as part of the Omnibus Budget Reconciliation Act of 1990. Under the provisions of the law, small ethanol producers (including cooperatives) who own a production facility with a capacity of less than 60 million gallons can receive a tax credit of $0.10 per gallon for the first 15 million gallons produced or a maximum of $1.5 million through December 31, 2010. The law also created an excise tax credit for biodiesel in the amount of $1.00 per gallon for agri-biodiesel made from virgin oils derived from agricultural products and animal fats, $0.50 per gallon for biodiesel made from agricultural products and animal fats, and $1.00 per gallon for renewable diesel made from biomass using a thermal depolymerization process. The Energy Policy Act of 2005 created a Small Agri-Biodiesel Producer Tax Credit that provides agri-biodiesel producers $0.10 per gallon for the first 15 million gallons produced from virgin oils or a maximum of $1.5 million through December 31, 2008. The Food, Conservation, and Energy Act of 2008 contained a $1.01 per gallon Cellulosic Biofuel Tax Credit through December 31, 2012. The VEETC was reduced from $0.51 cents to $0.45 cents. The secondary tariff on ethanol was extended though 2010 and was not reduced (Renewable Fuels Association).

The United States places a 2.5% ad valorem tax on imported ethanol. A secondary tariff of 54 cents a gallon was placed on ethanol imports to offset the ethanol tax credit value foreign producers can receive; it was not meant to serve as a barrier to market entry but rather to prevent U.S. tax dollars from further subsidizing imported ethanol. The Energy Tax Act of 1978 offered a partial exemption from the federal excise tax on gasoline to motor fuels blended with ethanol. The Crude Oil Windfall Profit Tax Act of 1980 offered an income tax credit for ethanol. All imported and domestic ethanol in the United States received a 51 cent per gallon tax credit which was reduced to 45 cents in the Food, Conservation, and Energy Act of 2008. Imported ethanol received this tax credit because of an Internal Revenue Service ruling that this incentive applied to all ethanol. Essentially, the IRS ruling eliminated the support Congress had designed to aid the expansion of our domestic ethanol industry. Therefore, Congress amended the U.S. tariff schedule in 1980 to include a secondary tariff on ethanol to counterbalance the effect of the IRS ruling. It was not created as a barrier to market entry; it was created to reestablish support for domestic ethanol production and to strengthen national security (Renewable Fuels Association 2005). This had been a very contentious issue over the past few years and removal of the secondary tariff was strongly opposed by U.S. agriculture lobbying groups and farm state members of Congress. David Sandalow has suggested restructuring the ethanol excise tax credit so that it is variable depending on the world price of oil and that it is paid to ethanol producers rather than blenders which would thus eliminate the justification for the tariff (Sandalow 2008, 94-9). In June 2011, U.S. Congress voted to end VEETC and the accompanying tariff on ethanol imports in December 2011 (Mercer 2011). Chris Throne, spokesman for Growth Energy, said, “The (subsidy) did a great thing in building up demand and encouraging production of ethanol…We don’t have a production problem anymore” (Mercer 2011). Economists noted that the tax credit has not been the primary driver of ethanol demand, the RFS mandate has been (Mercer 2011).

Historical U.S. Corn and Ethanol Production

Agriculture represents the third largest use of land in the United States which has a land base of approximately 2.263 billion acres. Forestland covers 33 percent of the land, grassland and range cover 26 percent, cropland covers 20 percent, special uses (i.e. public facilities) comprise 8 percent, and miscellaneous uses (i.e. urban areas, swamps, and deserts) comprise 13 percent. Agricultural land comprises 455 million acres of land in the United States of which 349 million acres are actively farmed, 39 million acres are idle farmland, and 67 million acres are pasture. In the past 30 years, active farmland has ranged from 330 to 380 million acres of land. Since 1997, at least seven million acres of farmland have been lost to other uses. Of total cropland use, roughly 60 percent is accounted for by corn, soybean, and small grain (particularly wheat) production (Perlack et al. 2005, 2, 18). In 2007, corn was planted on 93.6 million acres and was harvested with an average yield of 155.8 bushels per acre on 86.5 million acres (USDA Feed Grains Database).

In the United States, corn represents approximately 90 percent of the feedstock used in ethanol production. The other 10 percent is comprised largely of grain sorghum and some barley, wheat, cheese whey, and potatoes (Yacobucci and Womach 2003, 2). The U.S. ethanol industry gradually grew over a period of twenty years and grew at a quicker rate in the past ten years (*See Figure 2*). During the period 1980-1995, ethanol production increased by 700 percent from 175 million gallons to 1.4

<u>Figure 2. Historical U.S. Fuel Ethanol Production: 1990-2010</u>

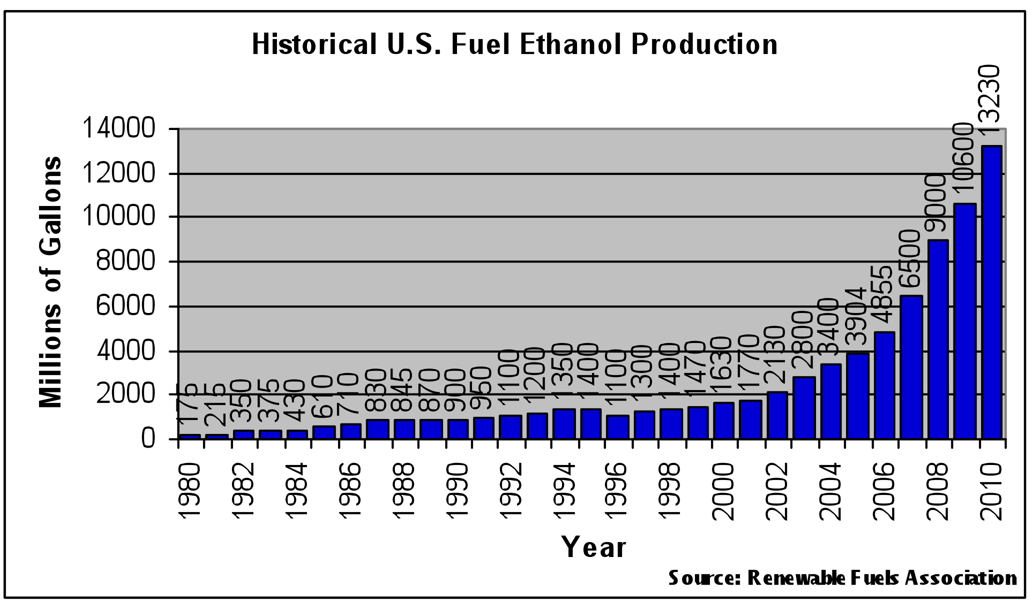


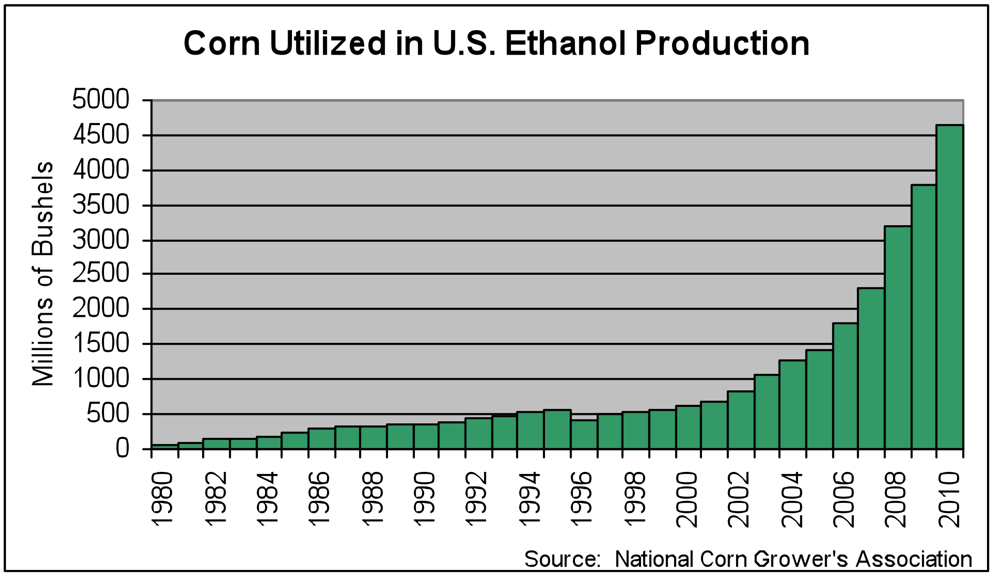
Table 7. Historical U.S. Ethanol Production

Year	Ethanol Production (Million Gallons)	Production Capacity (mgy)	Imports (Million Gallons)	Ethanol Plants	% of Utilized Corn Crop	Bushels Utilized in Corn Ethanol (Million Bushels)
1980	175				1.05%	70
1981	215				1.06%	86
1982	350				1.70%	140
1983	375				3.59%	150
1984	430				2.24%	172
1985	610				2.75%	244
1986	710				3.45%	284
1987	830				4.66%	332
1988	845				6.86%	338
1989	870				4.62%	348
1990	900				4.54%	360
1991	950				5.08%	380
1992	1100				4.64%	440
1993	1200				7.57%	480
1994	1350				5.37%	540
1995	1400				7.57%	560
1996	1100				4.58%	423
1997	1300				5.43%	500
1998	1400	1701.7		50	5.51%	538
1999	1470	1748.7		54	5.99%	565
2000	1630	1921.9		56	6.32%	627
2001	1770	2347.3		61	7.17%	681
2002	2130	2706.8	45.5	68	9.13%	819
2003	2810	3100.8	60.9	72	10.68%	1077
2004	3410	3643.7	159.9	81	10.67%	1260
2005	3904	4336.4	135.5	95	12.87%	1430
2006	4855	5493.4	653.3	110	17.09%	1800
2007	6500	7888.4	435.2	139	17.64%	2300
2008	9000	10569.4	600	170	26.46%	3200
2009	10600	11877.4	193.7	189	29.03%	3800
2010	13230	13507.9	9.7	204	37.36%	4650
Under Construction		522.0		10		
Total Capacity		14029.9				

(Sources: Renewable Fuels Association, USDA/ERS Feed Grains Database) billion gallons (Renewable Fuels Association). The percentage of U.S. corn crop utilized increased over 620 percent, while the increase in the amount of bushels utilized was 700 percent or 490 million bushels (*See Table 2*). From 1980-1995, corn production increased 11.5 percent (USDA Feed Grains Database). In 1996, a corn price run-up resulted in a decrease in ethanol production for one year (Hart 2004).

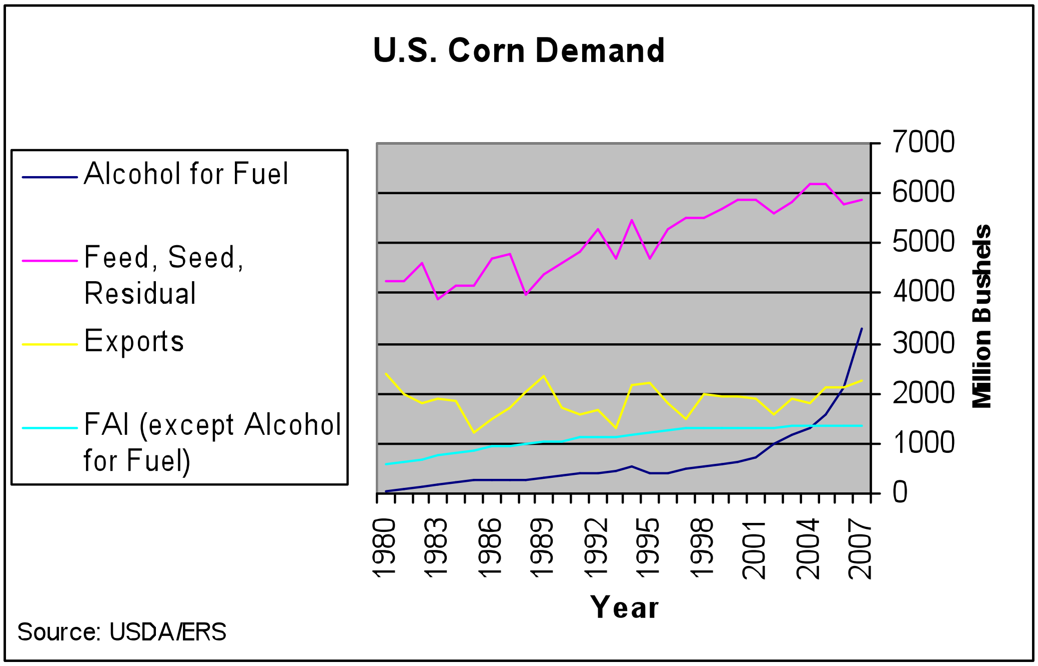
During the period 1997-2005, ethanol production increased by 200 percent from 1.3 billion gallons to 3.9 billion gallons. The percentage of U.S. corn crop utilized in ethanol production increased 137 percent, while the increase in the amount of bushels utilized was 186 percent or 930 million bushels. From 1997-2005, corn production increased by 20.7 percent or 1.9 billion bushels. Corn production increased by 17 percent from 2003-2004 and by 5.4 percent from 2004-present. In 2005, approximately 3.904 billion gallons was produced, an increase of 14 percent from the previous year, which utilized close to 13 percent of U.S. corn crop or 1.4 billion bushels, a 13.5 percent increase from the previous year. In 2006, production increased by 24.36 percent to 4.855 billion gallons of ethanol which utilized 17 percent of U.S. corn crop or 1.8 billion bushels. In 2007, production increased by 34 percent to 6.5 billion gallons of ethanol which utilized almost 18 percent of U.S. corn crop or 2.3 billion bushels (*See Figure 3*) (Renewable Fuels Association). According to the Renewable Fuels Association, the production and use of 6.5 billion gallons of ethanol is 2007 reduced greenhouse gas emissions by 10.1 million tons of carbon dioxide equivalent and displaced the need for 228 million barrels of oil ("Changing the Climate" 2008, 8, 17).

Figure 3. Corn Utilized in U.S. Ethanol Production: 1990-2010



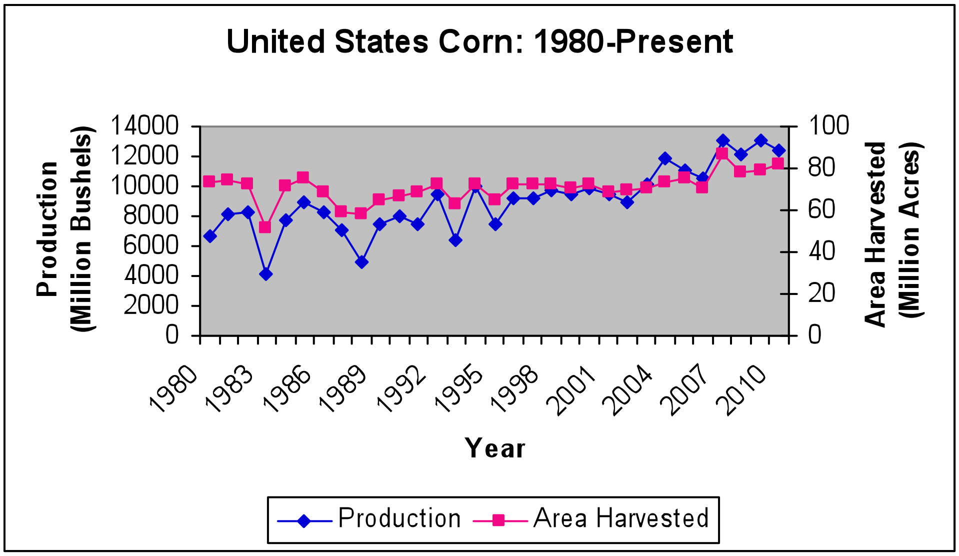
Grain industry analysts have raised the question of how increased ethanol production will affect feed, food, and export markets (*See Figure 4*). Specifically, if there will be enough corn to satisfy these needs and how much more corn can go towards ethanol production without significantly disturbing other markets (Noel 2006). Many foresee the beginning of a "corn crunch" occurring within the next couple of years as a transition occurs from having surplus production capacity to a period of chronically tight corn supplies followed by high corn prices in the grain and livestock sectors. Corn supplies could become even tighter if China steps down as the world's second or third largest corn exporter and becomes a net corn importer. This will cause foreign grain users to turn to the United States to fulfill their corn supply needs which could increase U.S. corn export demand by 300 to 600 million bushels (Wisner 2004).

Figure 4. U.S. Corn Demand: 1990-2008



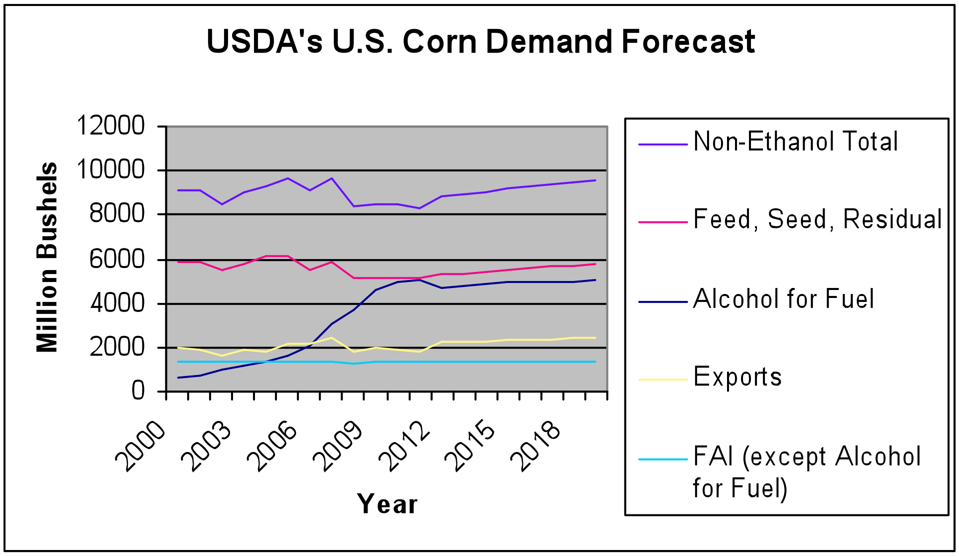
To meet the Renewable Fuels Standard requirements by 2012, it is estimated that there needs to be a 5-9 percent increase in acreage (*See Figure 5*). The need for increased acreage could come from acreage shifts in soybeans and to a lesser degree cotton and wheat or Conservation Reserve Program land. Demand signals from the marketplace, high corn demand, a profitable revenue-per-acre projection, stagnant soybean yields, rapid growth of corn yields, and extra costs to treat soybean pests and diseases, may encourage a gradual shift from soybeans to corn to meet needs (Wisner 2004; Noel 2006). The speed may slow depending on development of the biodiesel industry and agronomic and economic advantages of a corn/soybean rotation (Wisner 2004). In a personal interview with John Caupert, current Director of the National Corn-to-Ethanol Research Center and former Director for the National Corn Growers Association, I was informed that acres of corn planted is expected to remain between 88.7 million acres and 93.7 million acres for many years to come (Caupert 2011).

Figure 5. United States Corn Production and Area Harvested: 1980-2010



A new yield record for corn was reached in 2004 at 160.4 bushels/acre. The National Corn Growers Association expects that average yields will hit 162 bushels/acre by 2010 and 173 bushels/acre by 2015 (National Corn Growers Association). The USDA estimates that average yields will reach 184.7 bushels per acre by 2020, 224.4 bushels per acre by 2030, 246.8 bushels per acre by 2035, 272.7 bushels per acre by 2040, 300 bushels per acre by 2045, and 330 bushels per acre by 2050 (Glauber 2009). With every two bushels per acre increase, an extra 150 million bushels of corn are grown. Each additional 1 million harvested acres adds approximately 150 million bushels to U.S. corn supply (National Corn Growers Association). In 2019, USDA projects that feed, seed, and residual will reach 5.8 billion bushels and export use will reach 2.4 billion bushels. Total non-ethanol corn use is expected to flat-line around 9.6 billion bushels (USDA ERS) (*See Figure 6*).

Figure 6. USDA's U.S. Corn Demand Forecast: 2000-2018



In 2005, 9 million metric tons of distillers dried grains, a high protein co-product of ethanol production, were produced. By 2007, the production of this feed co-product increased to 14.6 million metric tons. In 2009, 30.5 million metric tons of distillers dried grains displaced more than 1 billion bushels of corn used for feed. Today, approximately 18 pounds of distillers grains are produced with the use of each bushel of corn (National Corn Growers Association). Each bushel of corn also produces approximately 2.8 gallons of ethanol. The average ethanol conversion rate is expected to increase above 3 gallons/bushel. This increased ethanol conversion rate and corn yields will result in a much higher ethanol per acre figure. It is likely that corn growers will harvest 14 to 15 billion bushels by 2015-2016. This would mean that 5.5 billion bushels of corn at a 2.9 gallons/bushel conversion rate could produce 16 billion gallons of ethanol which would be equivalent to 10 percent of our nation's expected gasoline demand and would meet the 15 billion gallon RFS requirement (Noel 2006). While it appears farmers have responded to market signals and have been able to meet demand, concern of the sustainability of producing corn-based ethanol and its affect on indirect land use changes and food prices worldwide have raised concern.

Advanced Biofuels

The cost of ethanol and the geographic concentration of ethanol, or lack of ethanol on the east and west coasts, is a major impediment to the growth of the industry. One of the main motivations behind research on cellulosic ethanol is the potential to expand production geographically. Cellulose is found in all plant matter and thus is the most abundant organic material on earth; this abundance could potentially allow every region to produce fuel with locally available feedstock. The costs of using ethanol would be reduced if production facilities could be located closer to the points of consumption. Also, an increase in regional agricultural income would occur if regions could produce fuel ethanol from local crops (Yacobucci 2006, 4).

The presumed key to reducing wholesale ethanol is low cost feedstock which cellulosic materials provide; technology to produce cellulosic ethanol in a commercially viable manner has come a long way in the past few years and the first commercial-scale biorefinery is currently under construction and plans to be in operation by the end of 2012 (Yacobucci 2006, 9; Mattingly, Robb, and Wong 2008). A combination of six pilot-scale and demonstration-scale cellulosic biorefineries are already in operation, and an additional forty-nine biorefineries that plan to use a wide variety of feedstocks are either under construction or on the drawing board in 31 states across the country, most of which are scheduled to come online between 2009 and 2011. The expected nameplate capacity is an estimated 629.5 million gallons per year with a potential expansion of 995 million gallons per year (Mattingly, Robb, and Wong 2008). Cellulosic biomass is high in cellulose which cannot be directly fermented due to its fibrous nature, so production costs can be high; however, the

Natural Resources Defense Council estimates that cellulose-based ethanol could be produced for \$0.59 to \$0.91/gallon with advances in production technology (Yacobucci 2006, 9).

While the main drive behind research on cellulosic conversion to ethanol is primarily due to its lower feedstock cost compared to corn, one could also look at it in an environmental perspective because materials such as municipal solid waste (MSW), forest thinnings, and rice straw are typically disposed or burned. Cellulosic feedstocks can be comprised into four main categories: agricultural waste, forest residue, MSW, and energy crops. Agricultural wastes include crop residues consisting of corn stover (leaves, stalks, and cobs), wheat straw, rice straw, citrus waste, and sugar cane. Forestry wastes consist of underutilized wood; logging and mill residues; hazardous fuels (thinning and slash); excess saplings; small trees; and rough, rotten, and/or salvable dead wood. MSW contains cellulosic materials such as paper. Energy or dedicated crops consist of crops which are grown specifically for fuel production such as fast-growing trees, shrubs, and grasses that include hybrid poplars, willows, pine trees, switchgrass, and miscanthus (DiPardo 2002).

Another key advantage of cellulose-based fuels is that it has a higher energy balance and can reduce greenhouse gas and air pollutant emissions more than corn-based ethanol (Yacobucci, 2006, 10). Cellulose-based E10 fuel can reduce fossil energy use/mile by 8 percent and cellulose-based E85 fuel can reduce fossil energy use/mile by 70 percent. On the other hand, corn-based E10 fuel can reduce fossil energy use/mile by 3 percent, and corn-based E85 fuel can reduce fossil energy use/mile by 40 percent (14-15). Greenhouse gas emissions on a per gallon of ethanol to displace an energy-equivalent amount of gasoline basis results in an 85 to 86 percent reduction of greenhouse gas emissions for cellulose-based ethanol. Early studies showed corn-based ethanol results in an 18 to 29 percent reduction of greenhouse gas emissions compared to gasoline; however, more recent studies have shown that technological advances have improved reductions by as much as 40 to 59 percent compared to gasoline (Wang 2005; Liska et al. 2008, 1; Mueller and Copenhaver 2008, 2).

Feedstock cost is also an important factor in biodiesel production as it accounts for 80 percent of production costs. Although somewhere in between 75 to 90 percent of U.S. biodiesel production is made from soybean oil, many other feedstock options exist including virgin oil feedstock such as canola, mustard, flax, sunflower, palm oil, jatropha, and camelina; animal fat such as tallow, chicken fat, lard, and waste fish oil; waste greases such as yellow or trap grease, and waste vegetable oil; and perhaps most promising, algae (Carriquiry 2007). Of the virgin oil feedstock, camelina is worthwhile because it is tolerant of low rainfall and can be grown in areas unsuitable for food crops. Great Plain, a company based in Montana where most camelina is currently grown, asserts that camelina can be intercropped with wheat which will result in a 15 percent increase in yield and 100 gallons of camelina oil per acre (McDermott 2008). Utilizing waste greases and animal fat is also a hopeful low-cost feedstock. Yellow grease or recycled cooking has the potential to produce 100 million gallons of biodiesel per year from an estimated leftover 2.5 billion pounds (Radich).

In particular, algae-to-biofuel shows high promise. No land, water, climate, or carbon dioxide resource limitations exist; however, there are a few research and development hurdles to overcome. In high-oil varieties of microalgae, approximately 50-60 percent of the algal biomass is oil which can be used to produce a variety of biofuels, namely biodiesel, jet fuel, ethanol, or methanol. There are many benefits to using algae as a feedstock including that microalgae are capable of producing 30 times the amount of oil per acre of crop compared to terrestrial plants with production estimates ranging from 1,000 to 10,000 gallons of biodiesel per acre of algae per year.

Algae can also grow rapidly on non-arable land thus eliminating competition with food, feed, and fiber crops; and it can grow in saltwater and wastewater thus minimizing competition for freshwater resources. Additionally, it does not have the same indirect land use effects on lifecycle greenhouse gas emissions like traditional biofuel feedstock, and it can utilize waste carbon dioxide from flue gas emitted by coal-fired power plants to grow which means the carbon is used twice for energy production before being released into the atmosphere thus increasing the Btu-to-greenhouse gas emission ratio (Sheehan 1998, i-iii). The United States consumes around 60 billion gallons of petroleum diesel and 120 billion gallons of gasoline annually. If all spark ignition engines were gradually replaced with diesel engines, petroleum diesel demand would rise to approximately 138 billion gallons of petroleum diesel or roughly 140.8 billion gallons of biodiesel annually. While it would take all of the arable land in the United States to meet this demand with soy-based biodiesel, only 15,000 square miles or 9.5 million acres, roughly the size of Maryland or 12.5 percent of the Sonora desert in the Southwestern United States, would be needed to fulfill fuel demand from algae-based biodiesel (Briggs 2004; Hartman 2008).

Sustainable Biomass Supply and Distribution Potential

Biomass resources are regionally distributed across the United States which will allow for the use of local feedstock when cultivating appropriate regionally-based solutions. A significant untapped potential remains despite that biomass has been used as a source of energy ever since humans first discovered fire (Environmental and Energy Study Institute 2008). Additionally, David Williams, chairman of the United Kingdom government’s Renewables Advisory Board, claims that biomass is the best economic choice and has the best carbon dioxide abatement performance in comparison to all forms of renewable energy. Biomass-based energy is the only renewable source of energy that has the potential to be carbon-negative. Biomass-based energy is essentially carbon-neutral because any carbon dioxide that is emitted when the biomass-based energy is used was essentially offset by the amount of carbon dioxide the biomass absorbed during its life through a process called photosynthesis (Biopact). Utilizing sustainable, renewable biomass resources from America's farms, forests, and open spaces can enable the United States to lower its greenhouse gas emissions, improve energy security, reduce energy price volatility, and stimulate economic development in rural communities across the nation (Environmental and Energy Study Institute 2008).

Some critics argue that biomass should not be used for biofuel production because of the impact of biofuels on world food prices. "Because biofuels development has created a global market and brought a laser beam of attention to the relationship between energy, land use, and climate change, much of the media has jumped to point fingers at biofuels without doing due diligence on the issue" (Wong 2008). The United Nations Food and Agriculture Organization and the Organization for Economic Cooperation and Development have found that a number of factors influence the price of food including energy costs, changing consumption patterns, production shortfalls due to weather-related events, speculation in commodity markets, decreased commodity stock levels, export restrictions, and the production of biofuels from agricultural commodities (Wong 2008). Ed Lazear, Chairman of the White House Council of Economic Advisors, has estimated that increased production of ethanol accounts for only 3 percent of the 43 percent global increase in food prices and only 0.25 percent of the 4.5 percent increase in U.S. food prices ("Update on 'Food vs. Fuel' Debate" 2008).

An underlying important notion that should be inferred from the 'food versus fuel' debate is that biomass used for biofuel production should be sustainable in nature in all aspects from the planting, growing, harvesting, and transporting, to the conversion of biomass to energy. A March 27, 2008, article in Times, "The Clean Energy Scam," rightly highlighted the possibility of indirect land use changes and emissions resulting from biofuel production that utilized food crops, but wrongly assumed that all biofuel production was harmfully unsustainable. Indirect land use emissions are the emissions due to agricultural expansion elsewhere because of an increased demand for an agricultural product resulting from a shift of farmland from food to fuel production ("Clearing the Air, Feeding the Fuel Tank" 2008). Although these are valid concerns, increased agricultural productivity has been the primary source to meet growing agricultural demand. For example, in 2007, it would have taken 330 million hectares instead of 158 million hectares to produce the world corn crop grown that year if yields had not increased from that of 40 years ago in 1967. In the 2007-2008 crop year, only 0.9 percent of total world major cropland was needed to meet feedstock requirements for the U.S. ethanol industry. When feed co-products such as distillers grains were factored in, only 0.6 percent of total world major cropland, or an area the size of West Virginia, was needed. Informa Economics estimates that the amount of land needed to produce 15 billion gallons of grain-based ethanol in the U.S. in 2015 is less than one percent of total world cropland. Furthermore, the land area of global coarse grains production (corn, sorghum, barley, oats, rye, and millet) has decreased by 8 percent since 1980 while annual global coarse grain production has increased by 50 percent since 1980. It appears as though increased corn production for use in ethanol production has not significantly driven land use changes. In order to address climate change and energy production issues, it is important to more fully understand land use changes such as deforestation, urbanization, and agriculture expansion before jumping to conclusions ("Understanding Land Use Change" 2008, i-ii).

While agricultural land used for coarse grains production will likely increase to a certain extent in the years ahead to meet growing demands for food, fiber, and fuel, agriculture expansion can occur without jeopardizing rainforests or other environmentally-sensitive lands. While the March 2008 Times article blamed biofuel production for the rapid increase in deforestation, the Oak Ridge National Laboratory asserts that "land is available for agricultural expansion without clearing new forest" ("Understanding Land Use Change 2008, ii). A 2002 study completed by the United Nations Food and Agriculture Organization stated, "there is still potential agricultural land that is as yet unused and that an amount of land twice as large as that which is currently farmed is to some degree suitable for rainfed (agricultural) production" (ii). Researchers at Stanford University recently claimed that abandoned agricultural land in the amount of 385-472 million hectares, roughly half of the land area of the continental United States, could potentially be brought back into production (ii). It seems clear that land is available to meet growing demands for food, fiber, and fuel in the years ahead.

A diverse portfolio of feedstocks would be wise so as to create a biofuel industry that is not reliant on one specific crop or source for biofuel production. There are many sustainable feedstocks available that would not weaken society's ability to maintain healthy ecosystems or meet food demand of both present and future generations. Limiting the use of agricultural commodities in lieu of using agricultural byproducts in biofuel production, not diverting prime agricultural or undisturbed land to biofuel production, and growing dedicated energy crops or perennial grasses on degraded farmland will result in limited environmental impact. Some of the agricultural residue left on soil can be a good source for biofuel production assuming enough residue is left on the field to improve soil quality and reduce erosion. Several types of woody biomass including logging residues, industrial wood residues, hazardous fuels residues, construction debris, yard debris, and demolition debris offer another potential feedstock source for biofuel production. Algae and wastes such as tallow, yellow grease, and municipal solid waste offer even more alternative choices to conventional biofuel feedstocks. All of these biomass resources are regionally distributed across the United States which will allow for the use of local feedstock when cultivating appropriate regionally-based solutions (“Clearing the Air, Feeding the Fuel Tank” 2008).

The production of renewable energy feedstocks should be done in a manner that does not compete with the goals of sustainable agriculture and forestry by using the best management practices available to protect and improve soils and habitat, conserve water, sequester carbon, and minimize greenhouse gas emissions. This may include growing winter cover crops on land for the dual purpose of attaining a cellulosic feedstock and using a conservation practice to reduce soil erosion, improve soil and water quality, and sequester carbon. It may also mean growing perennial grasses on degraded agricultural land or other deserted land in order to take advantage of perennial grasses’ deep root systems to improve soil and water quality, reduce soil erosion, or create a habitat for wildlife. There are many forms of biomass, specifically waste and residue materials, both on and off of agricultural land that can be used to produce energy in a sustainable manner. Land is the most finite of resources and is ultimately the foundation from which civilization garners all wealth, and so it is important that land is not degraded or used unsustainably, but rather the appropriate use at the appropriate scale so as to prevent adverse impacts to the environment and economy. Through good stewardship and wise allocation of our resources, the United States can supply ample biomass for energy and food production, in addition to healthy and diverse ecosystems (“Clearing the Air, Feeding the Fuel Tank” 2008).

A 2005 study jointly completed by the United States Departments of Agriculture (USDA) and Energy (DOE) found that U.S. land resources are capable of sustainably supplying 1.3 billion tons of biomass per year and that a supply of biomass at that level could displace at least 30 percent of U.S. petroleum consumption. The report found that approximately 368 million dry tons of sustainable biomass could be available annually from forested lands and 998 million dry tons could be available from agricultural lands. Of the biomass from forested lands, 52 million dry tons could come from harvested fuelwood; 145 million dry tons could come from wood processing, pulp, and paper mill residues; 47 million dry tons could come from urban wood residues such as construction and demolition debris; 64 million dry tons could come from logging and site clearing operations; and 60 million dry tons could come from fuel treatment operations to reduce fire hazards. Of the biomass from agricultural lands, close to 1 billion dry tons could be produced and food, feed, and export demands could still be met. Approximately 428 million dry tons could come from crop residues; 377 million dry tons could come from perennial crops; 87 million dry tons could come from grains; and 106 million dry tons could come from animal manures, process residues, and other miscellaneous feedstocks (Perlack et al. 2005, i). Today, the current availability of cropland biomass is around 194 million dry tons annually, which includes 5 million dry tons from grain, 6 million dry tons from corn fiber, and 75 million dry tons from corn stover (21). Both this report and a 2007 report by American Solar Energy Society (ASES), "Tackling Climate Change," claimed that biofuels could supply 20 percent of transportation sector demand by 2030. The ASES report claimed that 28 to 35 billion gallons of biofuels per year could be produced by 2030, but that corn-based ethanol would only represent roughly 10 billion of those gallons (Kutscher 2007, 163). According to John Ashworth, a biomass expert at the National Renewable Energy Laboratory, corn-based ethanol production could amount to a maximum of 18 billion gallons per year, or close to 13 percent of U.S. annual consumption of 140 billion gallons of gasoline. He has also commented that approximately one billion tons of cellulosic feedstock could be available to produce 100 billion gallons of ethanol annually. He added that while that is not technically feasible, cellulosic ethanol production at a level of 45 billion gallons annually should be attainable (Hargreaves 2006). A recent report by Sandia National Laboratories claims that 90 billion gallons of biofuels is feasible by 2030 of which 15 billion gallons would be corn-based ethanol and 75 billion gallons would be cellulosic ethanol (West et al. 2009, 1).

III. RESEARCH

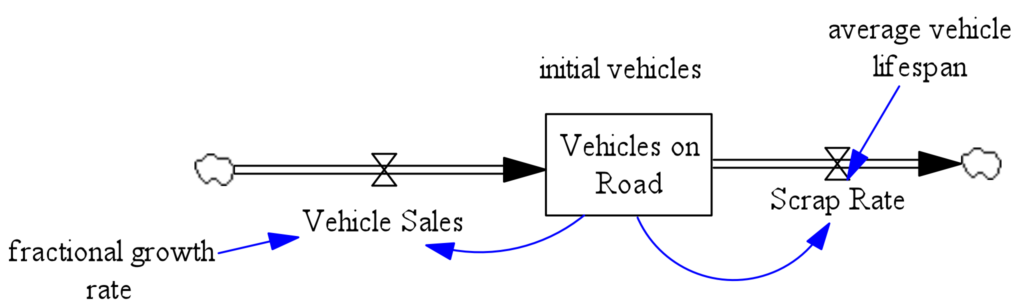
Model Structure and Evaluation

There are essentially four avenues to reduce greenhouse gas emissions in the U.S. transportation sector: 1.) use lower-carbon fuels, 2) improve vehicle fuel efficiency, 3) reduce total vehicle miles travel, 4) change vehicle fueling structure (i.e. electric, hydrogen). This model is designed to examine the first two means of potentially reducing greenhouse gas emissions and gasoline consumption. The model can be divided into three sectors. One sector will consist of modeling gasoline consumption from vehicles on road and will use a co-flow structure to examine the impact of altered Corporate Average Fuel Economy (CAFE) standards on greenhouse gas emissions. The last two sectors will consist of modeling biofuel consumption. One sector will model any greenhouse gas emission reductions that will occur with the use of renewable biofuel, advanced biofuel, and cellulosic biofuel as mandated by the RFS. The last sector consists of any greenhouse gas emission reductions that can occur with the use of those three fuels at reasonable levels above what is mandated by the RFS. The time frame that is modeled is from the year 2000 to 2050.

CAFE Standard Sector:

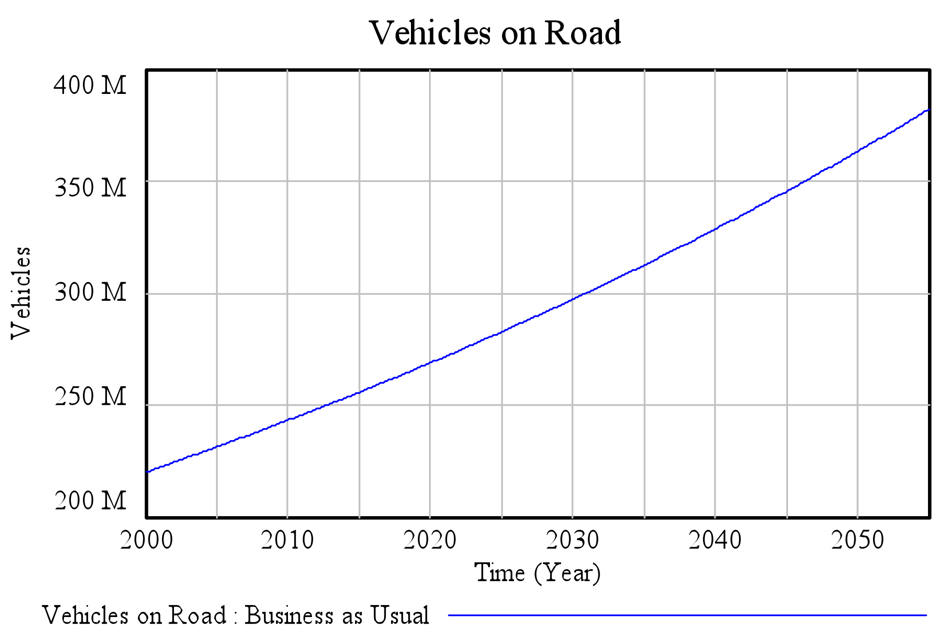
The initial component of the first sector to be modeled is the total number of vehicles on the road (*see Figure 7*). The initial number of vehicles estimated to be on

Figure 7. Vehicles on Road Model Structure



the road in 2000 is 220 million vehicles (United Nations Environment Programme 2000). The stock 'Vehicles on Road' equals the flow 'Vehicle Sales' less the flow 'Scrap Rate.' The average vehicle lifespan is 15 years (U.S. Government Accountability Office 2001, 17). The 'Scrap Rate' follows protocol for a first-order material delay, outflow = stock / average lifespan. Thus, it equals 'Vehicles on Road' divided by the constant variable 'average vehicle lifespan.' This creates a 6.6 percent scrap rate in 2000. This is close to the 6.8 percent scrap rate L. Polk and Company reported for the year 2000 (Business Wire 2000). Sandalow reports that the average sales rate comprises around 7 percent of the U.S. auto fleet and that there are 240 million vehicles in the U.S. in 2008 (Sandalow 2008, 18). The book, Two Billion Cars, claims that the average vehicle growth rate is expected to stay at around one percent (Sperling and Gordon 2009, 4). Due to this information, the fractional growth rate was set at 7.67 percent (6.6%+1%). When running the simulation, total vehicle population equals 240 million in 2008 and reaches 363 million in the year 2050 (*see Figure 8*). This is consistent to current estimates ranging from 346 million vehicles in

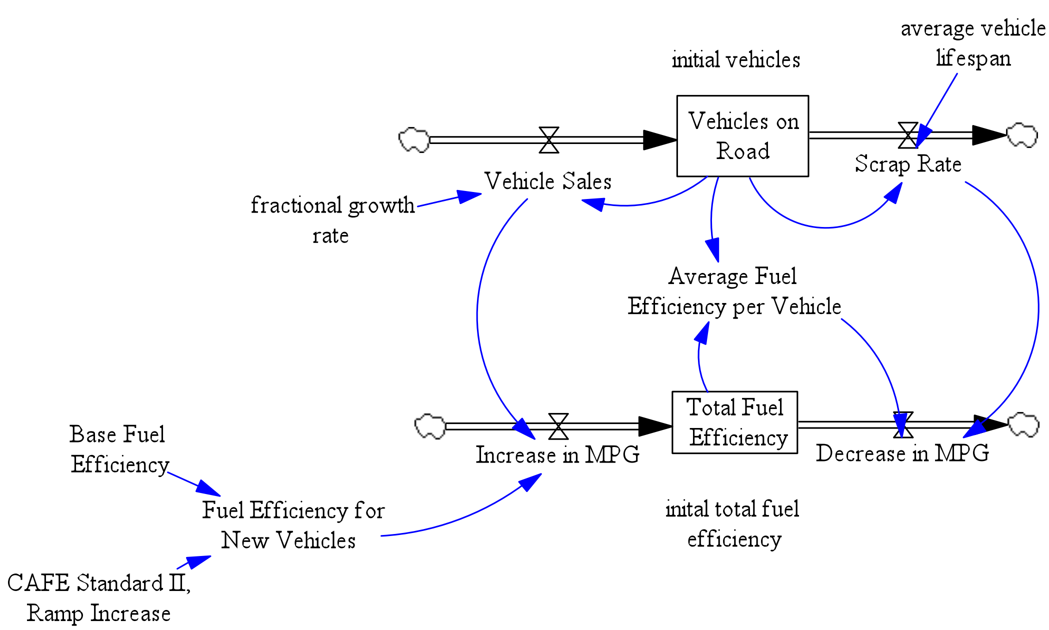
Figure 8. Vehicles on Road: 2000-2050



the year 2050 to close to 400 million vehicles in the year 2055 (Camarota 2008; American Association of State Highway and Transportation Officials 2007, 3).

The next step in building the model is to create a coflow structure designed to examine the attribute of total fuel efficiency also known as total miles per gallon. Generic stock-flow structures are designed to examine the quantity of a material or stock such as total vehicles on road. A coflow structure allows one to examine the quality or an attribute of a stock over time such as total fuel efficiency. Through the use of a coflow structure, one can examine the impacts of changing Corporate Average Fuel Economy standards. Below is the design of the coflow strucuture (Nicholson 2008) (*See Figure 9)*.

Figure 9. Vehicle Fuel Efficiency Coflow Model Structure

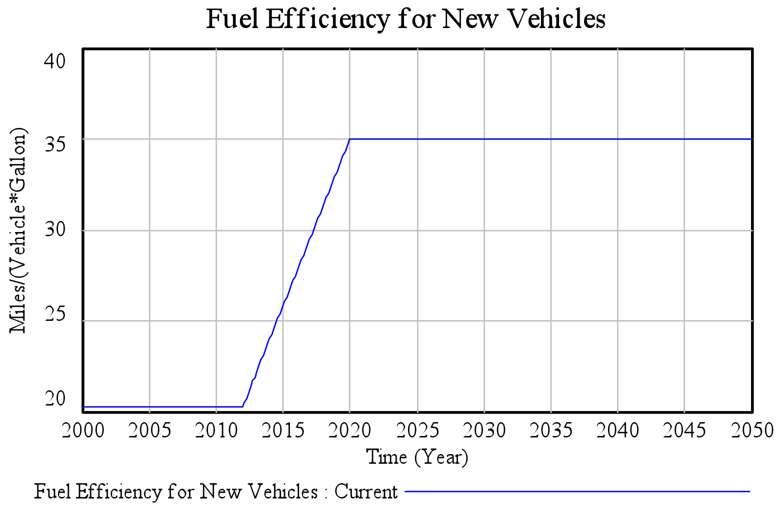


‘Average Fuel Efficiency per Vehicle’ is equal to ‘Total Fuel Efficiency’ divided by ‘Vehicles on Road.’ ‘Increase in Miles per Gallon’ is equal to ‘Fuel Efficiency for New Vehicles’ multiplied by ‘Vehicle Sales’ and ‘Decrease in Miles per Gallon’ is equal to ‘Average Fuel Efficiency per Car’ multiplied by ‘Scrap Rate.’

‘Total Fuel Efficiency’ increases or decreases depending on ‘Increase in MPG’ less ‘Decrease in MPG.’ The initial value for the attribute is calculated by initial total fuel efficiency multiplied by initial vehicles. Initial total fuel efficiency and base fuel efficiency were set at 20.3 miles per gallon per vehicle based on information provided by the Environmental Protection Agency (EPA) (U.S. Environmental Protection Agency 2005). ‘Fuel Efficiency for New Vehicles’ is calculated by ‘Base Fuel Efficiency’ plus ‘CAFE Standard II, Ramp Increase.’

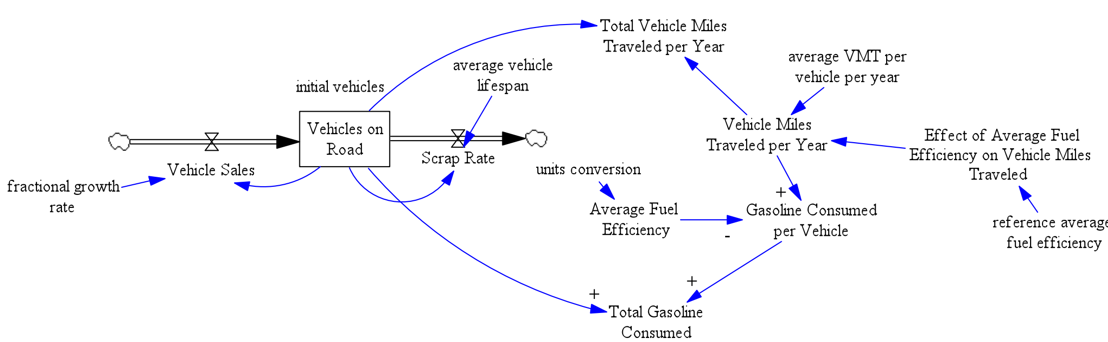
‘CAFE Standard II, Ramp Increase’ is a variable that is a test input calculated by a ramp increase. In the Energy Independence and Security Act (EISA) of 2007, Congress increased CAFE standards for the first time since its enactment by requiring automakers to attain fleetwide gas mileage of 35 miles per gallon by 2020. CAFE standards were first introduced in Congress in the Energy Policy Conservation Act of 1975 with the intent to improve the average fuel economy of cars and light trucks. The National Highway Traffic Safety Administration, who has executive responsibility for CAFE Standards, is currently requesting information from vehicle manufactures to assist the agency is setting new CAFE standards for the years 2012 through 2016 due to the requirements of the 2007 EISA; thus the start time for the test input is 2012 (National Highway Traffic Safety Administration). The end time of the test input is set at 2020 and the slope is set at 1.8375 to account for the increase from 20.3 to 35 miles per gallon (*see Figure 10*).

Figure 10. Fuel Efficiency for New Vehicles: 2000-2050



The next part to be modeled deals with 'Total Gasoline Consumed' which is a function of 'Vehicles on Road' multiplied by 'Gasoline Consumed per Vehicle.' 'Gasoline Consumed per Vehicle' is a function of 'Vehicle Miles Traveled per Year' divided by 'Average Fuel Efficiency.' 'Total Vehicle Miles Traveled per Year' is calculated by multiplying 'Vehicles on Road' by 'Vehicle Miles Traveled per Year' (*See Figure 11*). This auxiliary variable represents all vehicle miles traveled for the U.S. transportation sector.

Figure 11. Total Gasoline Consumed Model Structure



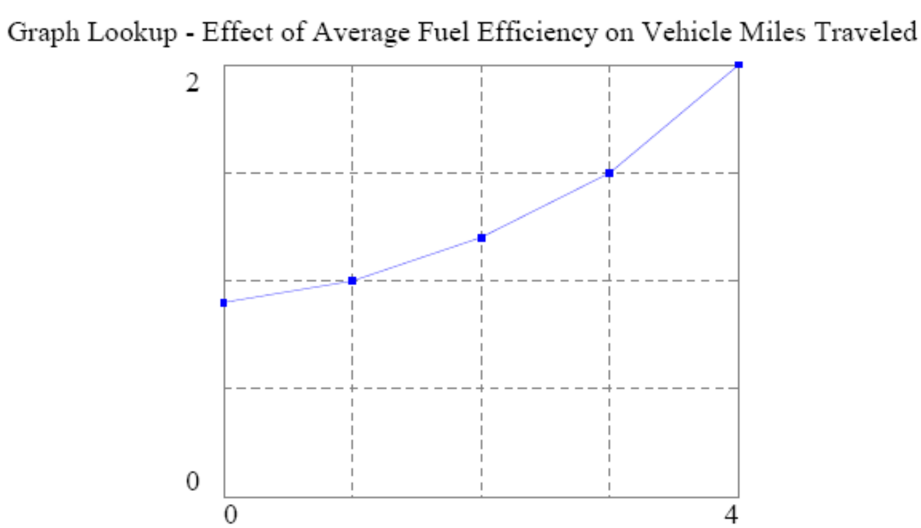
The initial value for vehicle miles traveled per vehicle per year is 12,000 miles per vehicle per year based on the average number of miles driven per year for all passenger vehicles provided by the EPA (U.S. Environmental Protection Agency 2005). Because increased fuel efficiency will reduce the fuel cost per mile driven for consumers, it is argued that growth in vehicle travel is encouraged (National Academy of Sciences 2002, 19). This notion is known as Jevons paradox or rebound effect.

In 1865, William Stanley Jevons, an English economist, coined this term when he observed that technological improvements that led to increased efficiency in the use of coal in coal-fired steam engines caused the rate of consumption of coal in a wide range of industries to increase. Jevons argued that "contrary to common intuition, technological improvements could not be relied upon to reduce fuel consumption" (Wikipedia 2011). Efficiency gains are inevitably lost to increased consumption (Owen 2010, 78). This is because as consumption of a resource becomes more energy efficient, it would be inefficient to not use more (Komanoff 2010). In other words, technological advances that improve energy efficiency in the use of a resource results in an increase, not decrease, in the rate of consumption of that resource. This rebound effect, or tendency to consume more when efficiency cuts costs, can easily be illustrated in the case of refrigeration. While refrigerators have tripled in thermodynamic efficiency and decreased in cost, since the 1970s, the quantity and locations of refrigerators have increased (i.e. multiple and larger refrigeration appliances in households, hotels, and gas stations), the availability to purchase chilled food has increased in terms of location and quantity, and the per-capita food waste in the United States has increased by half. Currently, more than a quarter of total U.S. freshwater consumption is used toward producing food that is later discarded, a quantity equivalent to approximately 40 percent of total edible food produced. The increase in energy-consuming activities that has occurred due to the increased efficiency of refrigeration technology is a manifestation of the Jevons paradox (Komanoff 2010, Owen 2010, 78). Owen's stated that, "Teasing out the precise contribution of a particular efficiency improvement isn't just difficult, however; it may be impossible, because the endlessly ramifying network of interconnections is too complex to yield readily to empirical, mathematics-based analysis" (Owen 2010, 78).

It is argued that improvements in vehicle fuel efficiency via increased CAFE standard policy will result in an increased use of fuel per vehicle, or more miles driven. Ken Small, an economics professor from UC-Irvine, found in a study that less than 20 percent of total gasoline savings seen from improved fuel efficiency is lost as a result of consumers driving more miles. Len Brookes, an English economist, stated, "When we talk about increasing energy efficiency, what we're really talking about is increasing the productivity of energy. And, if you increase the productivity of anything, you have the effect of reducing its implicit price, because you get more return for the same money — which means the demand goes up" (Komanoff 2010). This increase in demand is the rebound effect from improved fuel efficiency in vehicles. Increased fuel efficiency obviously means an individual needs less fuel to drive the same miles, but it also lowers the relative cost of fuel thereby increasing fuel demand and offsetting gasoline savings seen from increased fuel efficiency. Improved fuel efficiency could also accelerate economic growth causing even more of an increase in overall fuel use (Wikipedia 2011). Some economists advocate that improved fuel efficiency should be coupled with a carbon tax, or green tax, to keep the costs of fuel the same or higher in order to counteract manifestations of the Jevons paradox (Komanoff 2010). Parry 2007 found that increasing CAFE standards are not as cost-effective as taxes in reducing gasoline consumption because lower fuel costs per mile driven increases vehicle miles driven. Parry and Small 2005 found that carbon taxes more strongly "improve welfare by deterring vehicle use and reducing traffic congestion, accidents, and local air pollution, in addition to reducing carbon emissions and oil dependence" (Fischer, Harrington, and Parry 2007, 2). Fischer et al. 2007 advocate that benefits of a higher fuel economy resulting from a gradual tightening of CAFE standards may outweigh downside efficiency costs resulting from the Jevons paradox asserting that the social return on fuel efficiency technologies "may have a multiplier effect on addressing the threat of climate change and the geopolitical dimensions of western dependence on oil from unstable regions" (19-20).

A multiplicative effect is used to model the nonlinear Jevons paradox relationship in order to show the rebound effect of average fuel efficiency on vehicle miles traveled. Variable Y, Vehicle Miles Traveled, was set to its normal at the year 2000 and multiplied by the product of the effect, a function of Variable X, Average Fuel Efficiency ($Y=Y^{*}$ * Effect of X on Y). The nonlinear function of input X was normalized by a reference value which was the value of variable X at the year 2000, 20.3 miles/gallon/vehicle (Effect of X on Y = $f(X/X^{*})$. Normalization ensures that when input X is equal to its reference value, output Y will be equal to its reference value too (Sterman 2000, 525). The output variable y is changed by input variable x through a Lookup function illustrated below with a reference point of (1,1) (*See Figure 12*).

Figure 12. Graph Lookup of Effect of Average Fuel Efficiency on Vehicle Miles Traveled



Forecasts for total vehicle miles traveled per year range from over 4 trillion miles to slightly under 7 trillion miles by the year 2050 (American Association of State Highway and Transportation Officials 2007, 3). The multiplicative effect raises vehicle miles traveled per year per vehicle from 12,000 miles in 2000 to over 13,600 miles in 2050 (*See Figure 13*) and raises total vehicle miles traveled per year from 2.64 trillion in 2000 to 4.94 trillion miles by 2050. Without the increase, vehicle miles traveled reach 4.36 trillion miles in 2050 (*See Figure 14*).

Figure 13. Vehicle Miles Traveled per Year: 2000-2050

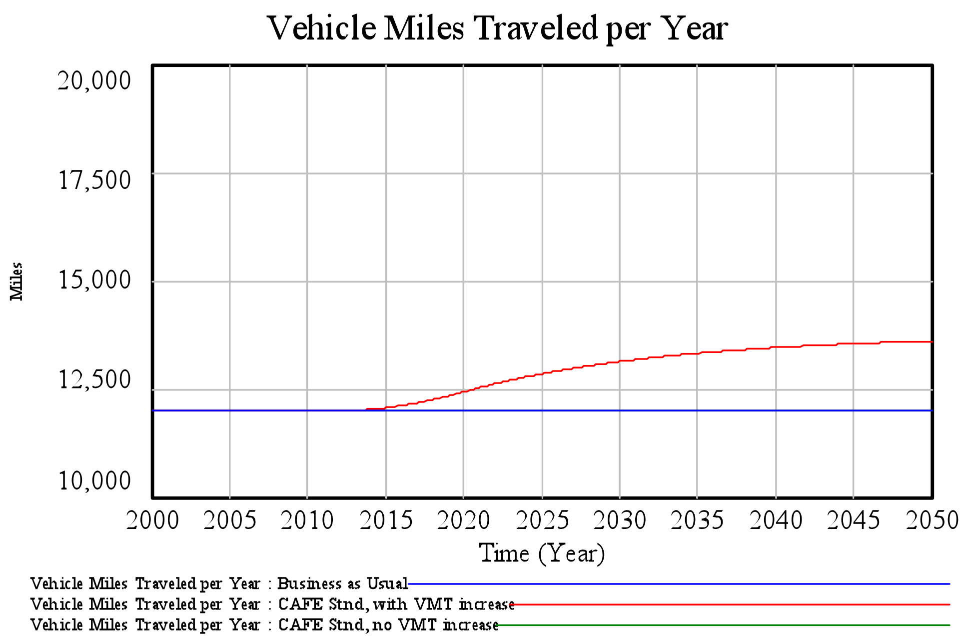
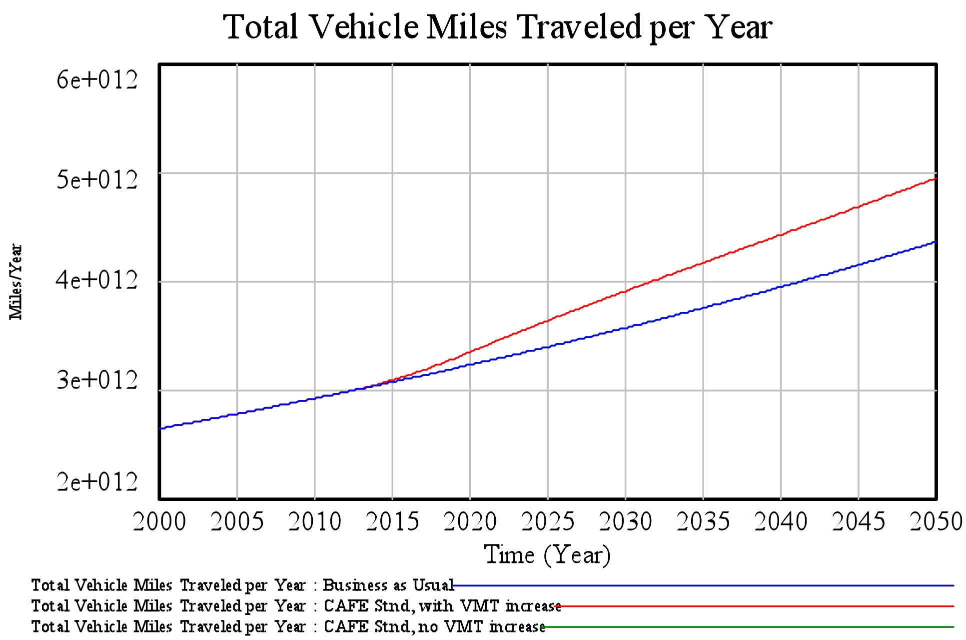
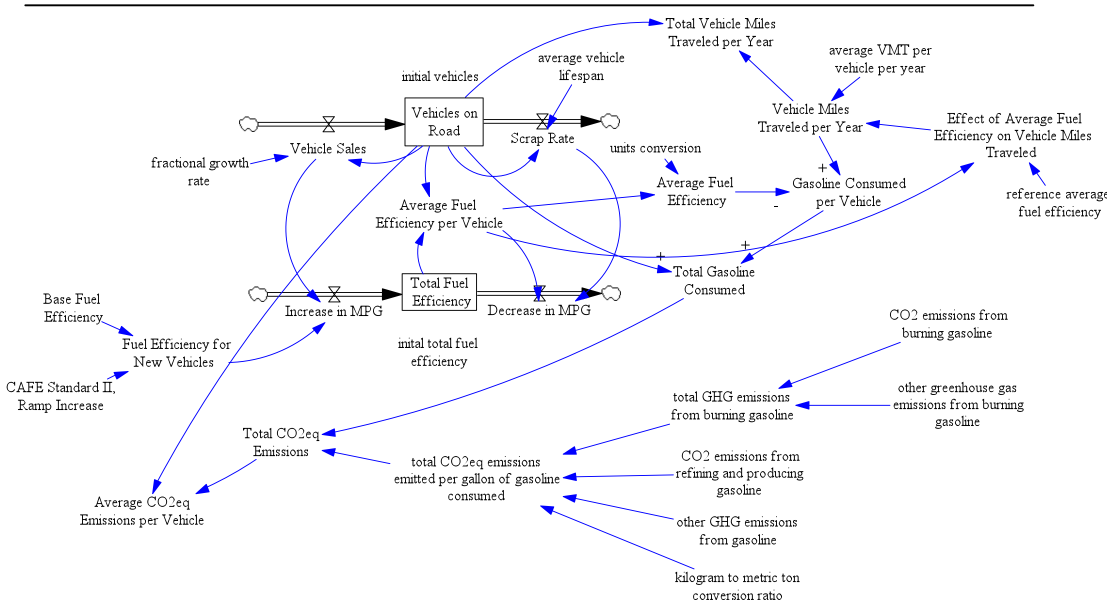


Figure 14. Total Vehicle Miles Traveled per Year per Vehicle: 2000-2050



The last section of this part of the model to be constructed is that relating to total carbon dioxide equivalent emissions related to total gasoline consumed (*See Figure 15*). The EPA states that 8.87 kilograms of carbon dioxide equivalent emissions are emitted per each gallon of gasoline consumed. Other greenhouse gas

Figure 15. Carbon Dioxide Emissions Model Structure



emissions emitted include nitrous oxide, methane, and hydrofluorocarbons. The amount of these emissions are not easily estimated, but it is assumed that these greenhouse gases represent five to six percent of total greenhouse gas emissions from passenger vehicles. To estimate these emissions, the EPA multiplies 100/95 by the number of carbon dioxide emissions from burning gasoline (U.S. Environmental Protection Agency 2005). Sandalow reports that five pounds of carbon dioxide on average are emitted when producing and refining gasoline (Sandalow 2008, 18). This is equal to 2.27 kilograms per gallon. This means that total carbon dioxide equivalent emissions emitted per gallon of gasoline consumed is equal to 11.6068 kilograms per gallon or 0.0116068 metric tons per gallon. The final rule promulgated by the EPA for the RFS program set the 2005 baseline for gasoline greenhouse gas emissions at 98 kilograms of carbon dioxide equivalent emissions emitted per million metric Btu's (kg CO_2e/mmBTU) ("Regulation of Fuels and Fuel Additives: Changes to Renewable Fuel Standard Program, Final Rule" 2010, 14788). To convert this to kilograms of carbon dioxide equivalent emissions emitted per gallon of gasoline consumed, the set baseline emissions per heat content of gasoline (98 kg CO_2e/mmBtu) is multiplied by the average heat content per gallon of gasoline (0.125 mmBtu/gallon) ("Calculations and References" 2011). 98 kg CO_2e/mmBtu * 0.125 mmBtu/gallon = 12.25 kilograms per gallon or 0.01225 metric tons per gallon. 12.25 minus 11.6068 results in a difference of .6432 kilograms per gallon. Because this model will be testing greenhouse gas emission reductions resulting from the RFS program, a variable, titled 'Other Greenhouse Gas emissions from Gasoline,' was added to make up for this .6432 kilograms per gallon difference. This results in 'total carbon dioxide equivalent emissions emitted per gallon consumed' being equal to 0.01225 metric tons per gallon. 'Total Carbon Dioxide Equivalent Emissions' is calculated by multiplying 'total carbon dioxide equivalent emissions emitted per gallon consumed' by 'Total Gasoline

Consumed.' Finally, 'Average Carbon Dioxide Equivalent Emissions per Vehicle' is calculated by dividing 'Total Carbon Dioxide Equivalent Emissions' by 'Vehicles on Road.'

RFS Sector:

The last two sectors consist of modeling biofuel consumption. One sector will model any greenhouse gas emission reductions that will occur with the use of renewable biofuel, advanced biofuel, and cellulosic biofuel as mandated by the RFS. The last sector consists of any greenhouse gas emission reductions that can occur with the use of those three fuels at reasonable levels above what is mandated by the RFS. Due consideration is given to USDA corn production forecasts, Sandia National Laboratories 90-billion gallon biofuel deployment study, and the 2005 USDA-DOE billion ton annual supply joint study.

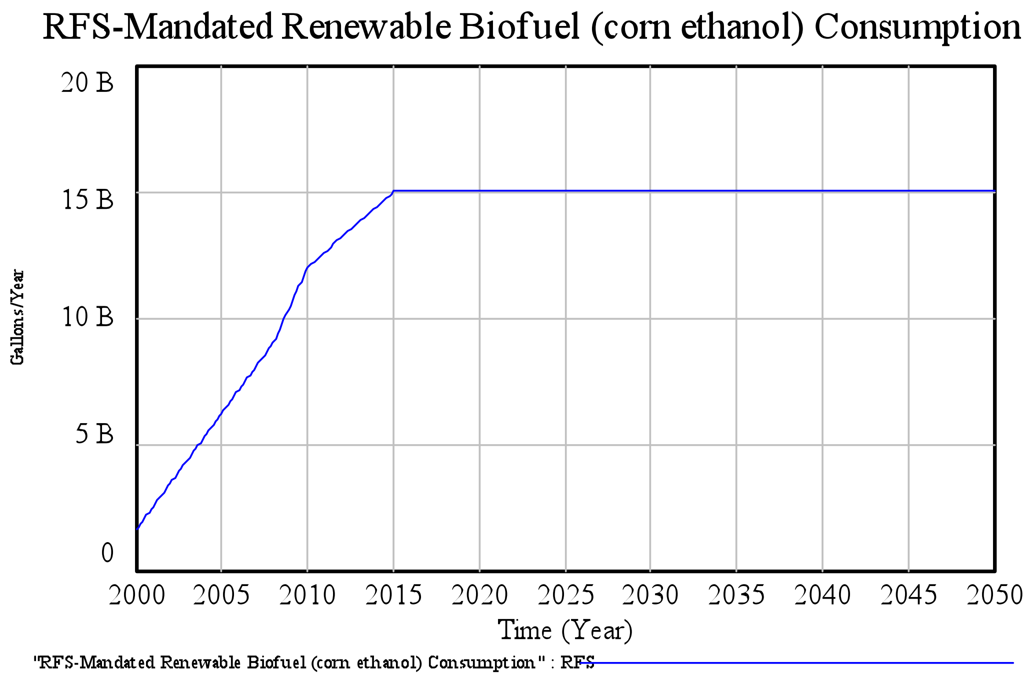
Modeling of the RFS biofuel sector starts with the creation of three variables: 'RFS Renewable Biofuel (corn ethanol) Targets,' 'RFS Advanced Biofuel Targets,' and 'RFS Cellulosic Biofuel Targets.' The variable targets were created as mandated by the RFS (*See Table 8*). The 'RFS Renewable Biofuel (corn ethanol) Targets' variable was created using eight ramp functions set at the mandated level each year a different target level was specified for the years 2008 to 2015. The target level is maintained steady at 15 billion gallons from the year 2015 to 2022. Actual corn ethanol production was 1.63 billion gallons in the year 2000 (Renewable Fuels Association). The 'RFS-Mandated Renewable Biofuel (corn ethanol) Consumption' variable was created using an initial corn ethanol production value set at 1.6 billion gallons for the year 2000 and adding the specified target levels to that amount. This results in 15 billion gallons being consumed in 2022 as shown in the graph below (*See Figure 16*). The RFS mandates that corn ethanol production must attain at least a 20

Table 8. EISA of 2007 Renewable Fuels Standard Targets

EISA of 2007 Renewable Fuels Standard Targets				
Year	**Renewable Biofuel**	**Advanced Biofuel (total non-corn starch biofuel)**	**Cellulosic Biofuel (specific carve-out)**	**Total RFS**
2008	9.0			9.0
2009	10.5	0.6		11.1
2010	12.0	0.95	0.1	12.95
2011	12.6	1.35	0.25	13.95
2012	13.2	2.0	0.5	15.2
2013	13.8	2.75	1.0	16.55
2014	14.4	3.75	1.75	18.15
2015	15	5.5	3.0	20.5
2016	15	7.25	4.25	22.25
2017	15	9.0	5.5	24
2018	15	11.0	7.0	26
2019	15	13.0	8.5	28
2020	15	15.0	10.5	30
2021	15	18.0	13.5	33
2022	15	21.0	16.0	36

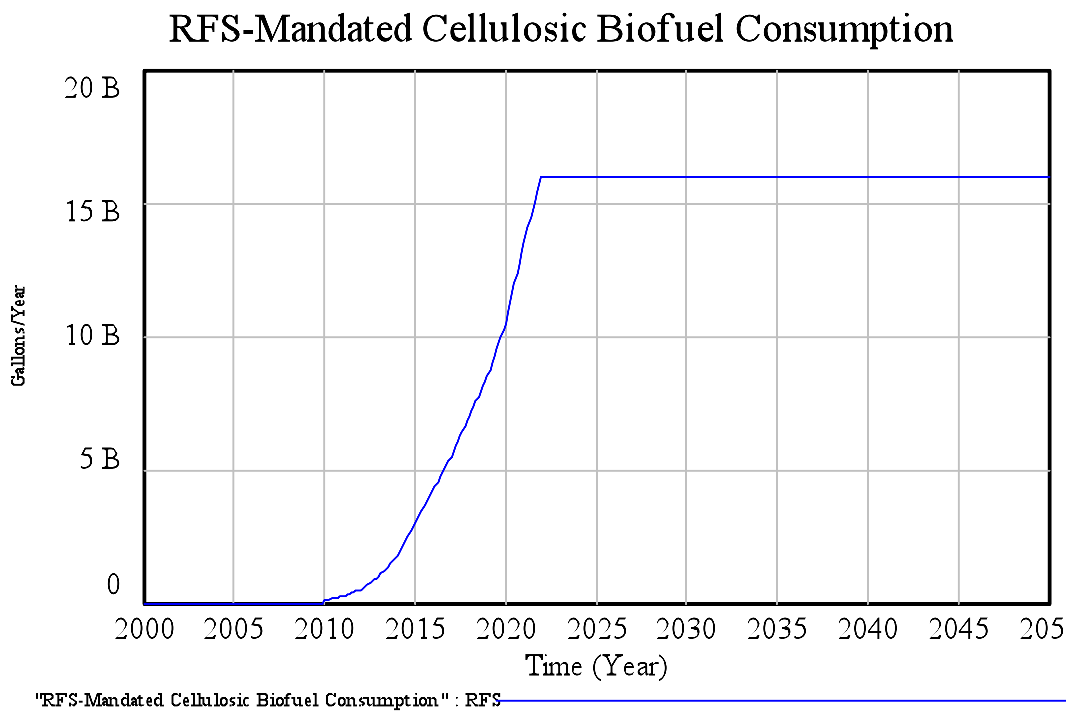
percent reduction in greenhouse gas emissions from the 2005 baseline for gasoline greenhouse gas emissions (Renewable Fuels Association). The variable, 'total CO_2eq emissions emitted per gallon of corn ethanol consumed,' was set at 0.0098 metric tons per gallon which is twenty percent of 0.01225. 'Total Renewable Biofuel CO_2eq emissions' is calculated by multiplying 'RFS-Mandated Renewable Biofuel (corn ethanol) Consumption' by emissions created per gallon consumed. 'Gallons of gasoline displaced 1' is calculated by multiplying 'RFS-Mandated Renewable Biofuel (corn ethanol) Consumption' by 'BTU conversion factor.' This results in the number of gasoline equivalent gallons of ethanol produced. 'BTU conversion factor,' which is 1.493506494, is the quotient of the heat content of gasoline, 115,000 Btu's, and the heat content of ethanol, 77,000 Btu's, as established in the RFS final rule ("Regulation of Fuels and Fuel Additives: Changes to Renewable Fuel Standard Program, Final Rule" 2010, 14710, 14762). So, roughly 1.49 gallons of ethanol is the energy equivalent of 1 gallon of gasoline.

Figure 16. RFS-Mandated Renewable Biofuel (corn ethanol) Consumption: 2000-2050



The 'RFS Cellulosic Biofuel Targets' variable was created using an initial step function of 100 million gallons in 2010 and twelve ramp functions set at the mandated level for each successive year a carve-out level was specified from years 2011 to 2022. This results in 16 billion gallons being consumed in 2022 as shown in the graph below (*See Figure 17*). The RFS mandates that cellulosic biofuel production must attain at least a 60 percent reduction in greenhouse gas emissions from the 2005 baseline for gasoline greenhouse gas emissions (Renewable Fuels Association). The variable, 'total CO_2eq emissions emitted per gallon of cellulosic biofuel consumed,' was set at 0.0049 metric tons per gallon which is sixty percent of 0.01225. 'Total Cellulosic Biofuel CO_2eq emissions' is calculated by multiplying 'RFS-Mandated Cellulosic Biofuel Consumption' by emissions created per gallon consumed. 'Gallons of gasoline displaced 3' is calculated by multiplying 'RFS-Mandated Cellulosic Biofuel Consumption' by 'BTU conversion factor.'

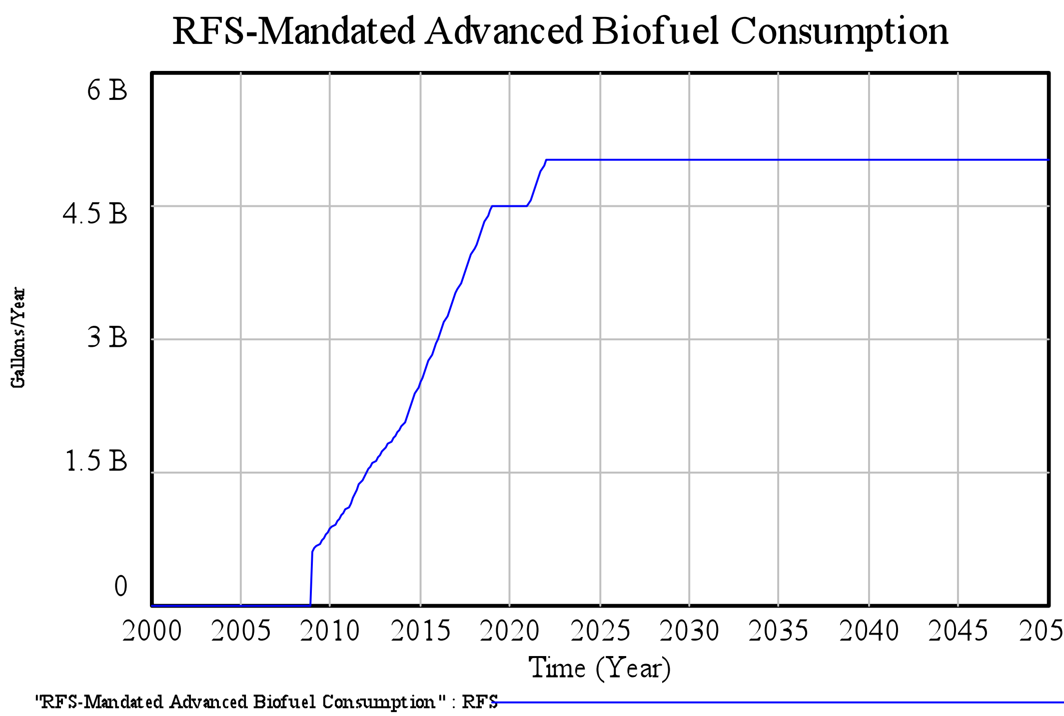
Figure 17. RFS-Mandated Cellulosic Biofuel Consumption: 2000-2050



The 'RFS Advanced Biofuel Targets' variable was created using an initial step function of 600 million gallons in 2009 and eleven ramp functions set at the mandated level minus the cellulosic carve-out level for each year from 2010 to 2022 that a different target level is specified. This results in five billion gallons being consumed by 2022 as shown in the graph below (*See Figure 18*). The 'RFS Advanced Biofuel Targets' variable includes the RFS carve-out for biomass-based diesel which reaches a final level of 1 billion gallons in 2012. This is because the RFS mandates that both advanced biofuel production and biomass-based diesel production must attain at least a 50 percent reduction in greenhouse gas emissions from the 2005 baseline for gasoline greenhouse gas emissions (Renewable Fuels Association). The variable, 'total CO_2eq emissions emitted per gallon of advanced biofuel consumed,' was set at

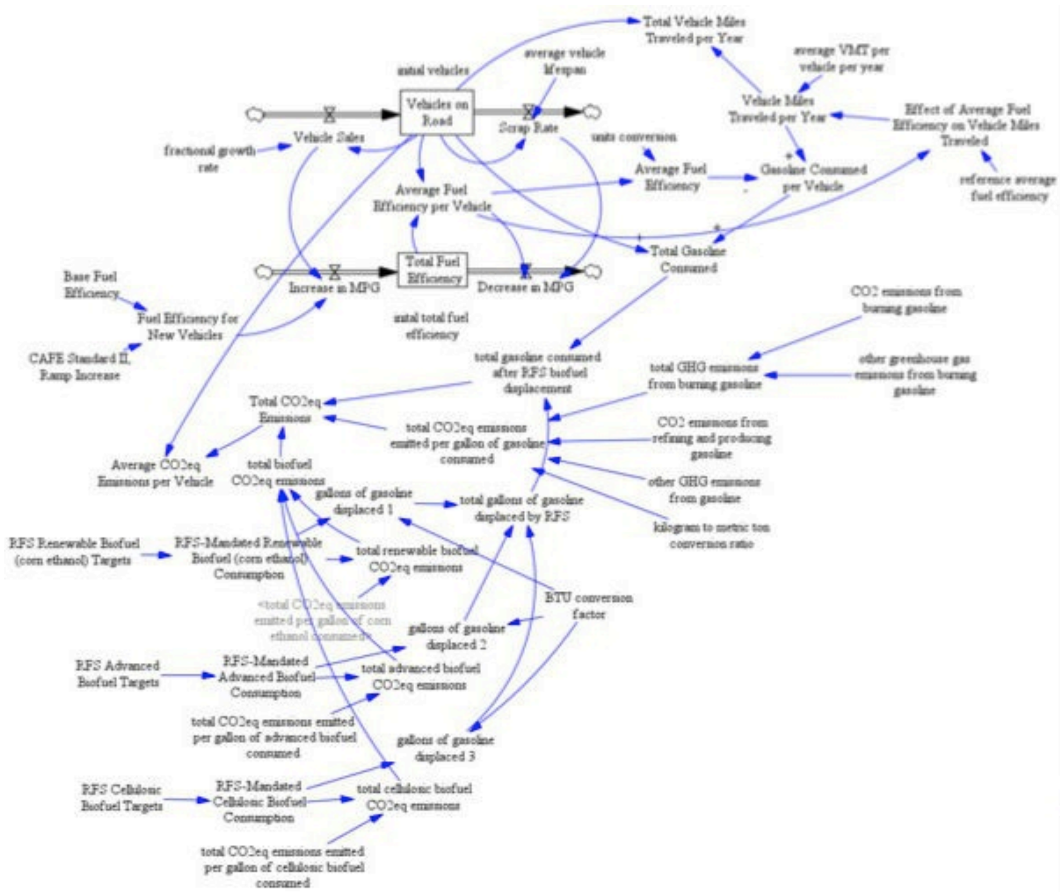
0.006125 metric tons per gallon which is fifty percent of 0.01225. 'Total Advanced Biofuel CO_2eq emissions' is calculated by multiplying 'RFS-Mandated Advanced Biofuel Consumption' by emissions created per gallon consumed. 'Gallons of gasoline displaced 2' is calculated by multiplying 'RFS-Mandated Advanced Biofuel Consumption' by 'BTU conversion factor.'

Figure 18. RFS-Mandated Advanced Biofuel Consumption: 2000-2050



Gallons of gasoline from each biofuel category are added together to create the variable 'total gallons of gasoline displaced by RFS.' This figure is subtracted from the variable 'total gasoline consumed' in the variable 'total gasoline consumed after RFS biofuel displacement.' The model assumes 1:1 replacement versus displacement, meaning that the ethanol mandated merely replaces a portion of projected fuel consumption and that total fuel consumption remains constant. That figure is then multiplied by the variable 'total CO2eq emissions emitted per gallon of gasoline consumed.' This product is added to the variable 'total biofuel CO2eq emissions,' which is the sum of all carbon dioxide equivalent emissions from each biofuel category, to arrive at 'Total CO2eq Emissions' (*See Figure 19*).

Figure 19. Complete Model Structure



CAFE Standard and RFS Sectors, Market Leakage:

Life-cycle accounting is most commonly used in assessing the 'cradle-to-grave' direct greenhouse gas emissions and indirect land use change emissions associated with biofuel production. This method arbitrarily assumes that total fuel consumption remains constant while the entire amount of biofuel produced merely replaces gasoline. In other words, each energy equivalent gallon of ethanol is assumed to completely replace one gallon of gasoline. This method makes little economic sense because it fails to consider the leakage or market effects caused by biofuel production in markets such as commodity or fuel markets (de Gorter 2010, 671-2). Carbon leakage, which is when "emissions reductions by an environmental policy are partially or more than offset because of market effects," is often said to undermine environmental policies (Drabik et. al 2010, 3).

A 2010 study by Rajagopal, Hochman, and Zilberman referenced this flaw and showed that biofuels do not replace fossil fuels one-to-one because the use of biofuels affects fuel price and consequently total fuel consumption, which may either increase or decrease depending on a variety of other factors such as the policy regime in place and market conditions. The study argued that life-cycle assessment studies should incorporate indirect fuel use change in addition to indirect land use change into their research highlighting that the "environmental impact of new technologies depend on policy regime and market technology" (Rajagopal 2010, 228-233). Their study showed that a biofuel mandate causes change in the amount of global fuel consumption and that this net effect can have a significant impact on total greenhouse gas emissions. It also showed that "market-mediated indirect effects of biofuels may be large and even negate indirect land use change" (228-233).

A 2010 study by Thompson, Whistance, and Meyer highlighted that U.S. biofuel policymakers do not thoroughly address the impacts biofuel policy creates in petroleum product markets such as its indirect effect on total greenhouse gas emissions. The researchers examined U.S. agricultural, biofuel, petroleum, petroleum product, and world petroleum and petroleum product markets to examine the sensitivity of U.S. biofuel greenhouse gas emissions to policy, price responsiveness of global petroleum supplies and uses, and biofuel trade. In particular, the study looked at biofuel tax credits and ethanol tariffs (Thompson et. Al 2010, 5509-18).

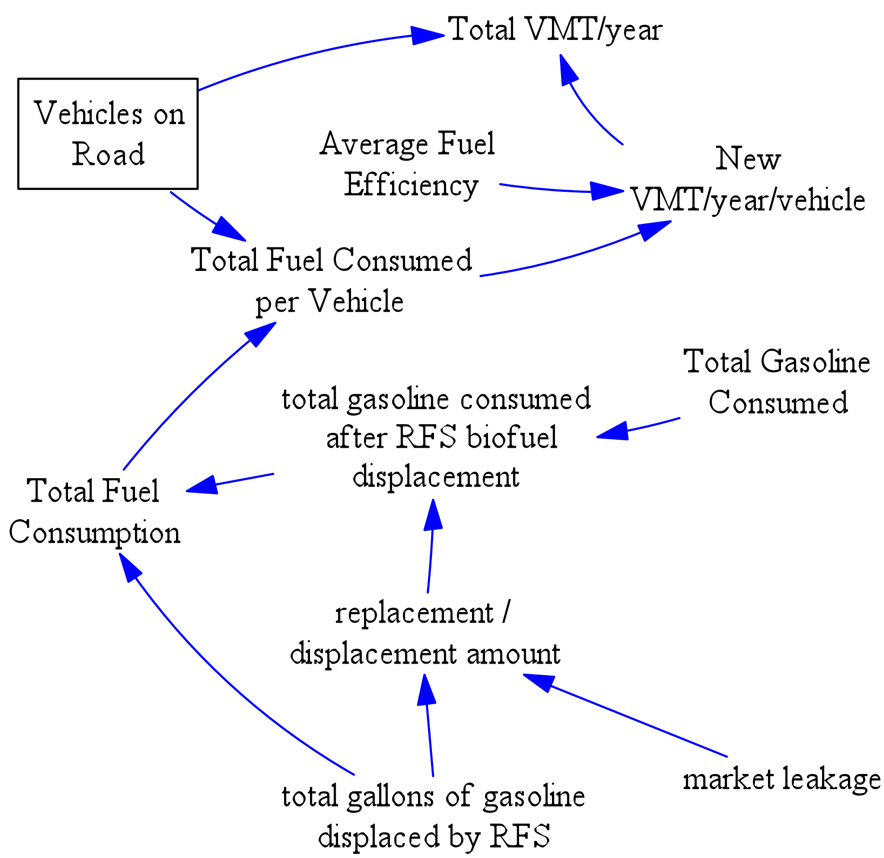
A 2011 study by Bento, Klotz, and Landry examined four sources of carbon leakage, domestic fuel markets, domestic land markets, world land markets and world crude oil markets; and quantified the impact of biofuel policies, specifically the VEETC and Renewable Fuels Standard, on greenhouse gas emissions (Bento et. al 2011, 1). Leakage was greater than 100 percent, which means that greenhouse gas emissions increased, in four out of the five policy scenarios studied. The study found that U.S. biofuel policies are "unlikely to reduce greenhouse gases" when considering both land and fuel market leakage (37).

A 2010 study by Drabik, de Gorter, and Just examined how the carbon leakage or effect of biofuel production differs depending on the biofuel policy regime and market conditions (Drabik et. al 2010, 2). It identified two components of carbon leakage: a market leakage effect, "the resulting market effect of biofuels in displacing gasoline and other oil consumption," and an emissions savings effect, "the relative carbon emissions of biofuels versus gasoline" (3-4). The magnitude of the leakage or market effect varies depending on the "domestic and foreign gasoline supply and fuel demand elasticities, and on consumption and production shares of world oil markets for the country introducing the biofuel policy." The study showed that the market effect or leakage from a biofuel tax credit is always greater than a biofuel mandate, while a combination of the two policies create a greater leakage or market effect than the biofuel mandate by itself (2). The study also distinguished between domestic leakage, which can be negative, and international leakage, which is always positive because world gasoline prices decline with either the tax credit or mandate (2, 4). "Domestic leakage with a mandate can be negative under some market conditions, making it possible that total (domestic plus international) leakage can be negative" (4). The study found that one energy equivalent gallon of ethanol replaces only 0.35 to 0.40 gallons of gasoline while the rest, 0.60 to 0.65 gallons, is displaced, yet another study dispelling the common assumption in life-cycle accounting research that biofuels replace fossil fuels one-to-one. The market leakage was found to be between

60 to 65 percent in all three policy scenarios (tax credit, mandate, and combination of both). This means that one energy equivalent gallon of ethanol emits 1.13 times more carbon than a gallon of gasoline; when indirect land use change emissions are included, one gallon of ethanol was found to emit 1.43 times more carbon than a gallon of gasoline (5).

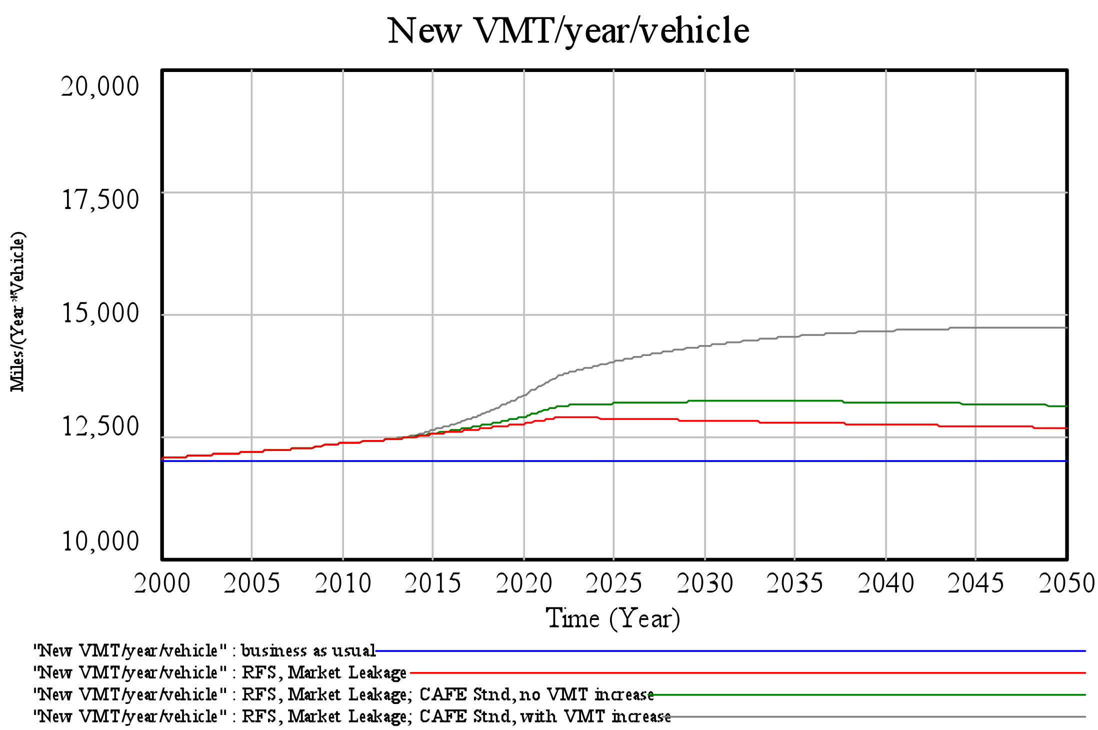
In light of this research, it is important to simulate this concept in the model. Rather than using a market leakage of 60 to 65 percent, a more conservative 50 percent market leakage will be modeled. This means that one energy equivalent gallon of ethanol replaces only 0.50 gallons of gasoline while the rest, 0.50 gallons, is displaced. This will allow incorporation of research on the leakage or market effects of biofuels in the domestic fuel market which shows that biofuels do not replace fossil fuels one-to-one because the use of biofuels affects fuel price and consequently total fuel consumption. This means that total fuel consumption will not remain constant and that the presence of biofuels in the domestic fuel market will not merely replace gasoline. To accomplish this task, a few variables need to be added to the model (*See Figure 20*). The variable 'total gallons of gasoline displaced by RFS' represents the total amount of energy equivalent gallons of ethanol produced. In order to calculate the replacement and displacement amounts, which would be the same since the model is calculating market leakage at 50 percent, one multiplies the variable 'total gallons of gasoline displaced by RFS' by the amount of market leakage, 0.50, which yields the 'replacement / displacement amount.' 'Total Gasoline Consumed' is the amount of conventional gasoline consumed without biofuels and market leakage factored in. To calculate 'total (conventional) gasoline consumed after RFS biofuel displacement,' one subtracts the 'replacement / displacement amount' from 'Total Gasoline Consumed.' 'Total Fuel Consumption' is the total amount of conventional gasoline and energy equivalent gallons of biofuel consumed. This variable is calculated by adding ‘total gasoline consumed after RFS biofuel displacement’ and ‘total gallons of gasoline displaced by RFS.’

Figure 20. RFS Market Leakage Addition to Model Structure



Because the use of biofuels affects fuel price and consequently total fuel consumption, total fuel consumed per vehicle and vehicle miles traveled will need to be calculated from the resulting increase in total fuel consumption. ‘Total Fuel Consumed per Vehicle’ is calculated by dividing ‘Total Fuel Consumption’ by ‘Vehicles on Road.’ ‘New VMT/year/vehicle,’ which is the average amount of vehicle miles traveled per year per vehicle, is calculated by multiplying ‘Total Fuel Consumed per Vehicle’ by ‘Average Fuel Efficiency’ (*See Figure 21*). In the

Figure 21. Vehicle Miles Traveled per Year per Vehicle, RFS Market Leakage: 2000-2050



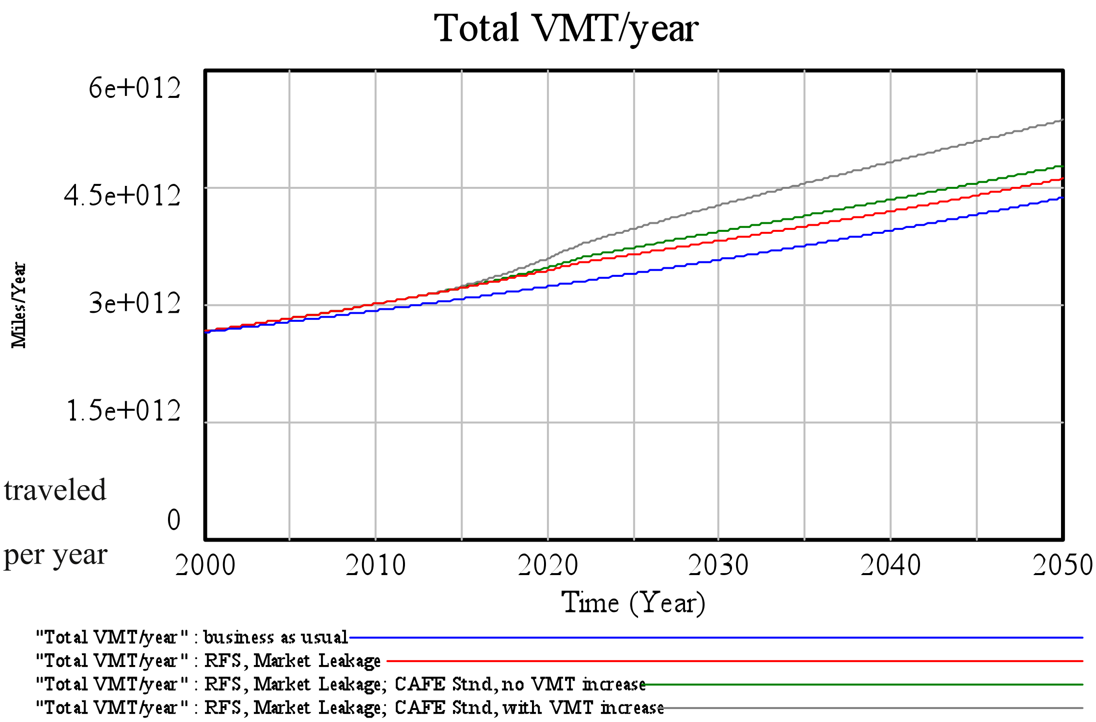
"Business as Usual" scenario, vehicle miles traveled per year per vehicle remains constant at 12,000 miles. In the "RFS, Market Leakage" scenario, vehicle miles traveled per year per vehicle are 12,892 miles in 2022 and 12,674 miles in 2050. In the "RFS, Market Leakage; CAFE Stnd, no VMT increase" scenario, vehicle miles traveled per year per vehicle are 13,122 miles in 2022 and 13,125 miles in 2050. In the "RFS, Market Leakage; CAFE Stnd, with VMT increase" scenario, vehicle miles traveled per year per vehicle are 13,743 miles in 2022 and 14,733 miles in 2050 (*See Table 9*).

Table 9. Summary Table of Results for all Simulation Runs, Vehicle Miles Traveled

Summary Table of Results for all Simulation Runs						
	Vehicle Miles Traveled/Year/Vehicle (Miles per Year per Vehicle)			Total Vehicle Miles Traveled/Year (Trillion Miles per Year)		
SCENARIO	**2000**	**2022**	**2050**	**2000**	**2022**	**2050**
Business as Usual	12000	12000	12000	2.64	3.29	4.36
CAFE Standard Sector						
no VMT increase	12000	12000	12000	2.64	3.29	4.36
with VMT increase (Jevons Paradox, ~20% gasoline savings loss)	12000	12620	13608	2.64	3.46	4.94
RFS Sector						
RFS	12000	12000	12000	2.64	3.29	4.36
RFS, Market Leakage (50%)	12049	12892	12674	2.65	3.54	4.60
CAFE Standard and RFS Sectors						
RFS, CAFE Stnd, no VMT increase	12000	12000	12000	2.64	3.29	4.36
RFS, Market Leakage; CAFE Stnd, no VMT increase	12049	13122	13125	2.65	3.60	4.77
RFS, CAFE Stnd, with VMT increase	12000	12620	13608	2.64	3.46	4.94
RFS, Market Leakage; CAFE Stnd, with VMT increase	12049	13743	14733	2.65	3.77	5.35

'Total VMT/year,' which is the estimated total amount of vehicle miles driven in a year in the United States, is calculated by multiplying 'Vehicles on Road' by 'New VMT/year/vehicle.' In the "Business as Usual" scenario, total vehicle miles traveled per year is 2.64 trillion miles in 2000, 3.29 trillion miles in 2022, and 4.36 trillion miles in 2050. In the "RFS, Market Leakage" scenario, total vehicle miles

Figure 22. Total Vehicle Miles Traveled per Year, RFS Market Leakage: 2000-2050



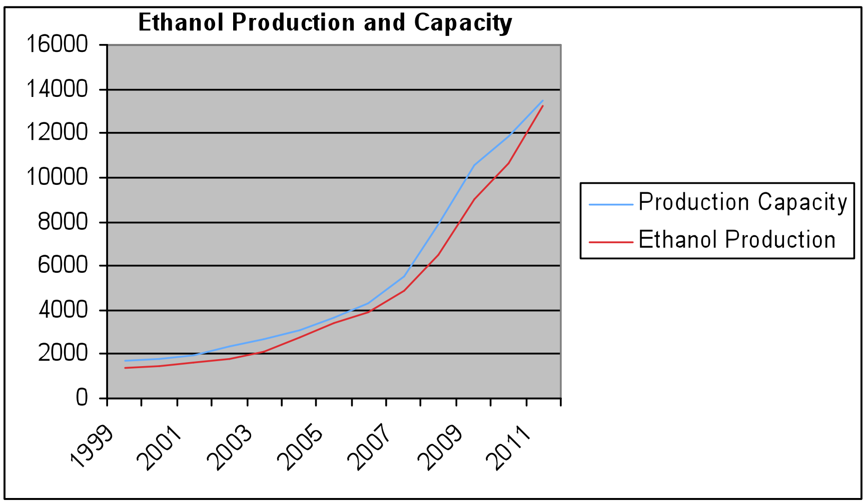
traveled per year

per is 3.54 trillion miles in 2022, and 4.60 trillion miles in 2050. In the "RFS, Market Leakage; CAFE Stnd, no VMT increase" scenario, total vehicle miles traveled per year is 3.60 trillion miles in 2022, and 4.77 trillion miles in 2050. In the "RFS, Market Leakage; CAFE Stnd, with VMT increase" scenario, vehicle miles traveled per year is 3.77 trillion miles in 2022, and 5.35 trillion miles in 2050 (*See Figure 22*).

Biofuel Sector:

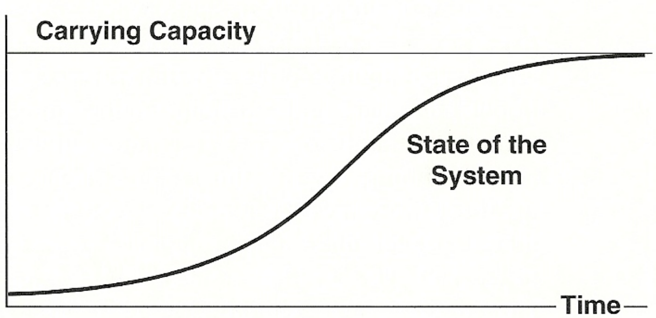
The last sector to be modeled consists of greenhouse gas emission reductions that can occur with the use of renewable biofuel, advanced biofuel, and cellulosic biofuel at high, yet reasonable levels above what is mandated by the RFS. In the 110 billion gallons scenario only, the model structure for corn ethanol production was changed to reflect an s-shaped growth mode of dynamic behavior. This is because historical data shows dynamic behavior most consistent with s-shaped growth (*See Figure 23*). The logic behind s-shaped growth is that no real quantity can grow forever due to constraints that halt growth. As shown in the illustration below, growth

Figure 23. Ethanol Production and Capacity: 1999-2011



is at first exponential and then slows gradually as the state of the system reaches its equilibrium level (Sterman 2000, 118) (*See Figure 24*).

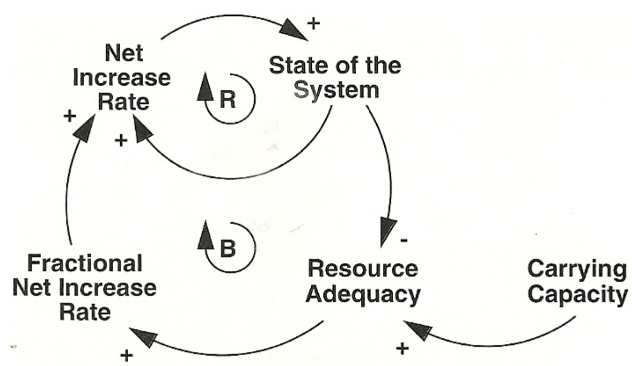
Figure 24. S-Shaped Growth Mode of Dynamic Behavior



The structure of an s-shaped growth model requires a goal (carrying capacity), or, in this case, a desired level of ethanol production, which needs to be determined

(Sterman 2000, 118) (*See Figure 25*). This requires an examination of past corn production and usage data and trend forecasts. In a personal interview with John Caupert, current Director of the National Corn-to-Ethanol Research Center and former Director for the National Corn Growers Association, I was informed that acres of corn planted is expected to remain between 88.7 million acres and 93.7 million acres for many years to come (Caupert 2011). From 2000 to 2011, the average percent of loss

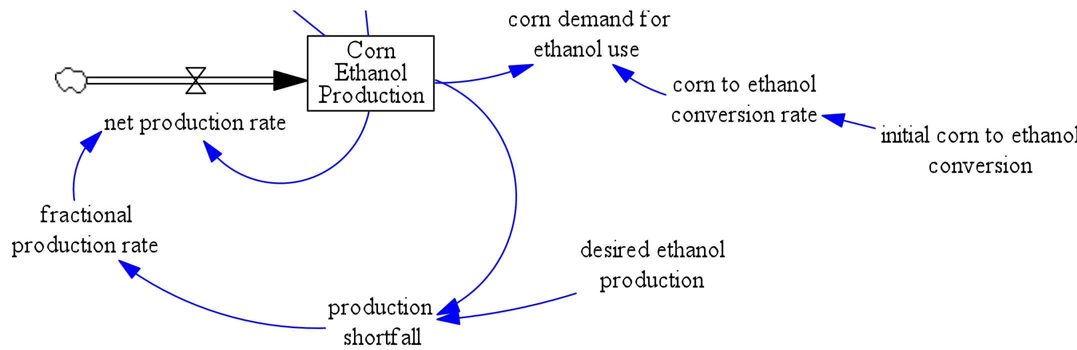
Figure 25. S-Shaped Growth Model Structure



from acres planted to acres harvested is 0.0897 percent (USDA Feed Grains Database). Using this same loss rate, acres of corn harvested can be expected to be between 80.742 million acres and 85.298 million acres. The USDA estimates that corn yield will reach 246.8 bushels per acre by 2035 and 330 bushels per acre by 2050 (Glauber 2009). This would lead to production levels of 19.9 to 21.1 billion bushels of corn in 2035 and 26.6 to 28.1 billion bushels of corn in 2050. Total non-ethanol corn demand is expected to be around 8.3 billion bushels in 2011 (USDA Feed Grains Database). The current corn-to-ethanol conversion rate is 2.87 gallons per bushel and is expected to reach 2.9 gallons per bushel (Caupert 2011). With a corn-to-ethanol conversion rate of 2.9 gallons per bushel, if total non-ethanol corn demand is between 9 and 15 billion bushels of corn, a goal of, or desired level of ethanol production, of 35 billion gallons of corn ethanol by 2050 is feasible. A little over 12 billion bushels of corn would be needed to meet this goal of 35 billion gallons of corn ethanol by 2050.

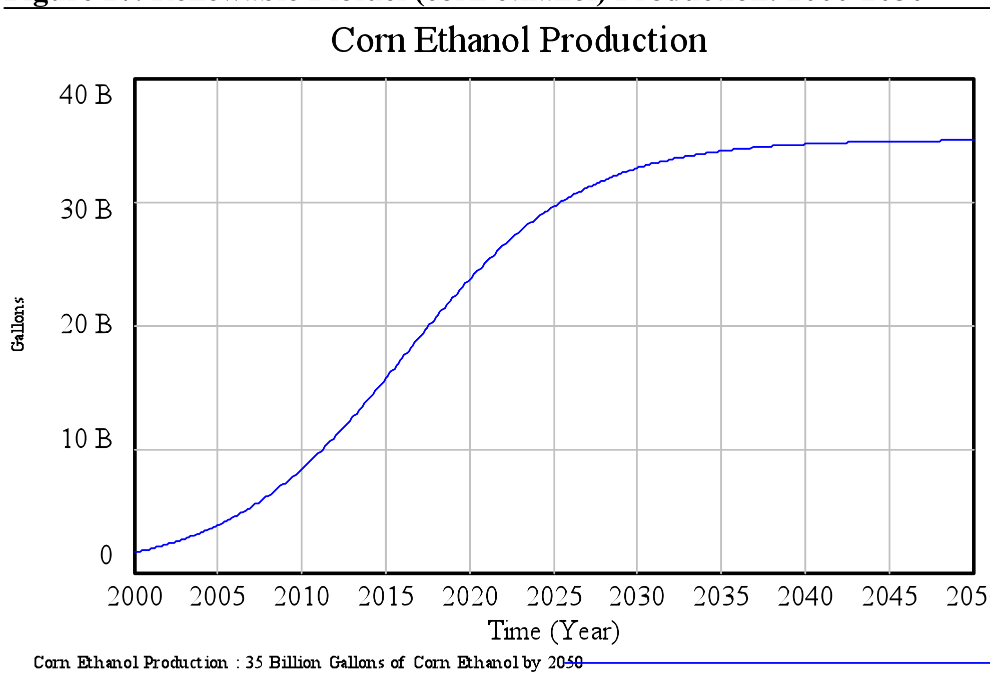
The model structure for corn ethanol production is analogous to the structure of the s-shaped growth model as shown in Figure 20 (*See Figure 26*).

Figure 26. Renewable Biofeul (corn ethanol) S-Shaped Growth Model Structure



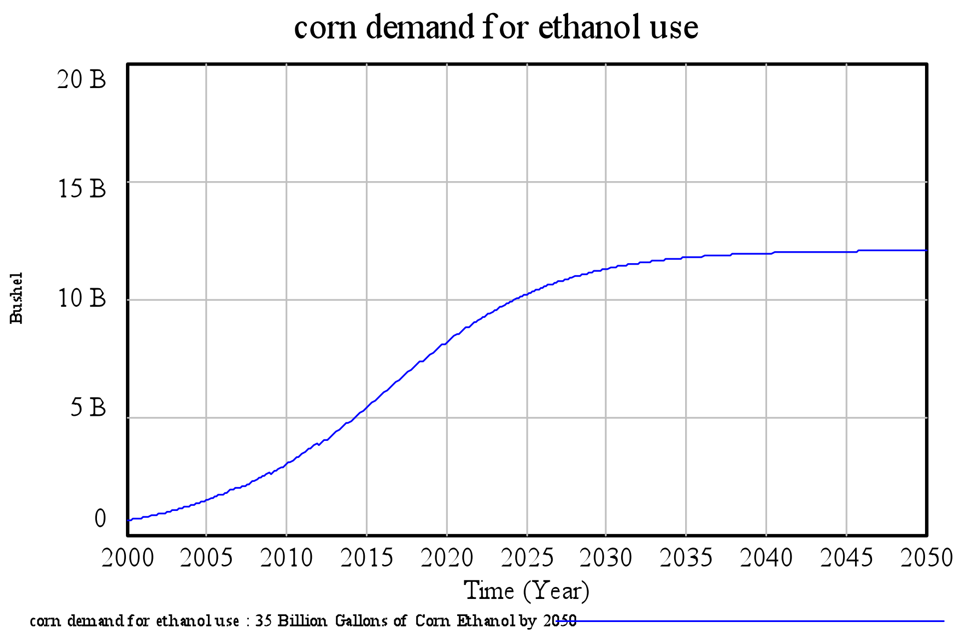
The last variable that needs to be defined is the 'fractional production rate' variable. 'Fractional production rate' is equal to g * (1-production shortfall) where g is the maximum fractional growth when corn ethanol production is at its lowest (Sterman 2000, 296). With g at 0.19, the behavior of the s-shaped model for corn ethanol production will start slowing exponentially by 2022 and will be approaching its equilibrium level by 2035 (*See Figure 27*). By 2044, corn demand for ethanol

Figure 27. Renewable Biofuel (corn ethanol) Production: 2000-2050



production will be slightly over 12 billion bushels (*See Figure 28*). A step up function is used for the 'corn to ethanol conversion rate' variable. The value is initially at 2.6 gallons per bushel and rises to 2.9 gallons per bushel by 2012. The 'net production rate' is equal to the 'fractional production rate' multiplied by 'Corn Ethanol Production.'

Figure 28. Corn Demand for Ethanol Use: 2000-2050



Initial advanced and cellulosic biofuel production has the same model structure as the RFS sector because initial production of advanced and cellulosic biofuels were prompted by the RFS mandates. A report by Sandia National Laboratories found that 90 billion gallons of biofuel could be produced by the year 2030 with 15 billion gallons coming from corn ethanol and the other 75 billion gallons coming from cellulosic ethanol (West et al. 2009, 1, 4). The model structure for advanced biofuel and cellulosic biofuel is kept the same. An additional ramp function is used to extend advanced biofuel production to 35 billion gallons by 2050 (*See Figure 29*) and cellulosic biofuel production to 40 billion gallons by 2040 (*See Figure 30*). This yields a total of 75 billion gallons worth of advanced biofuels by the year 2050.

Figure 29. Advanced Biofuel Consumption: 2000-2050

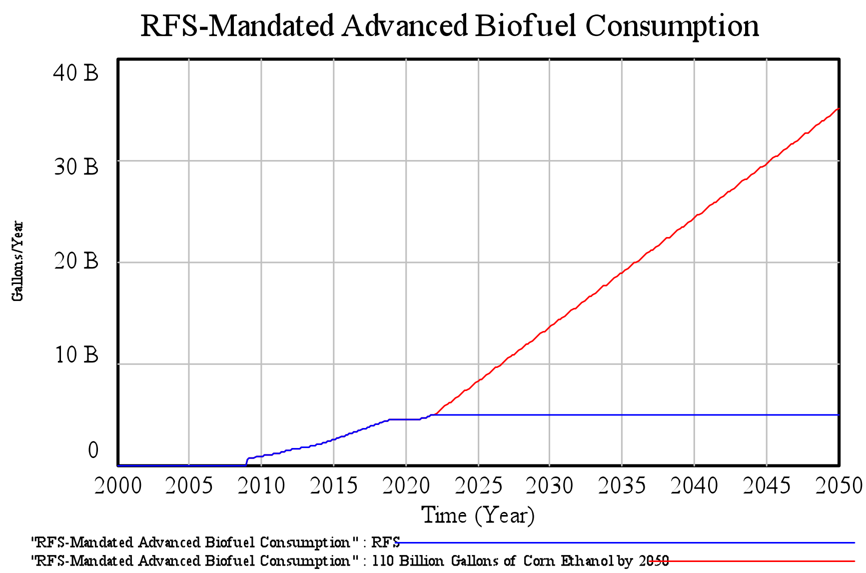
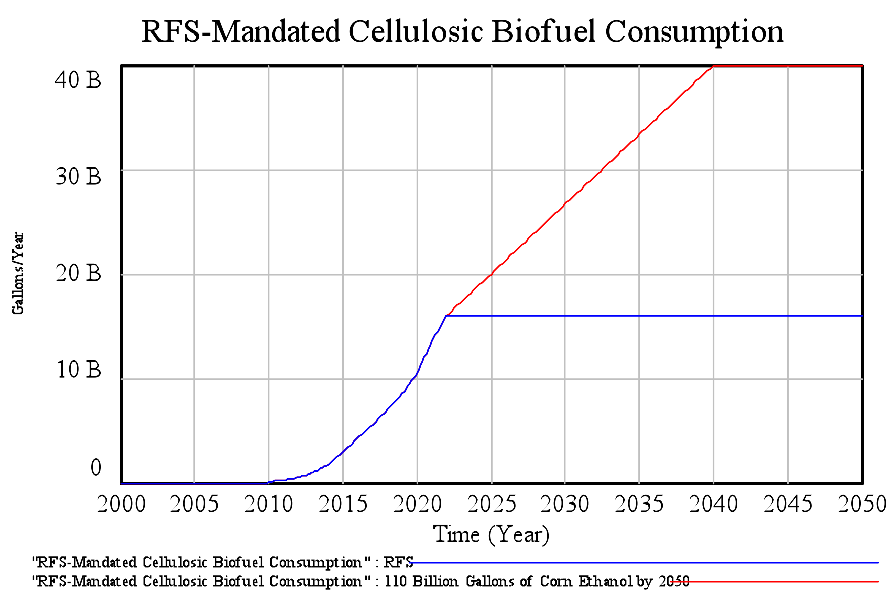


Figure 30. Cellulosic Biofuel Consumption: 2000-2050

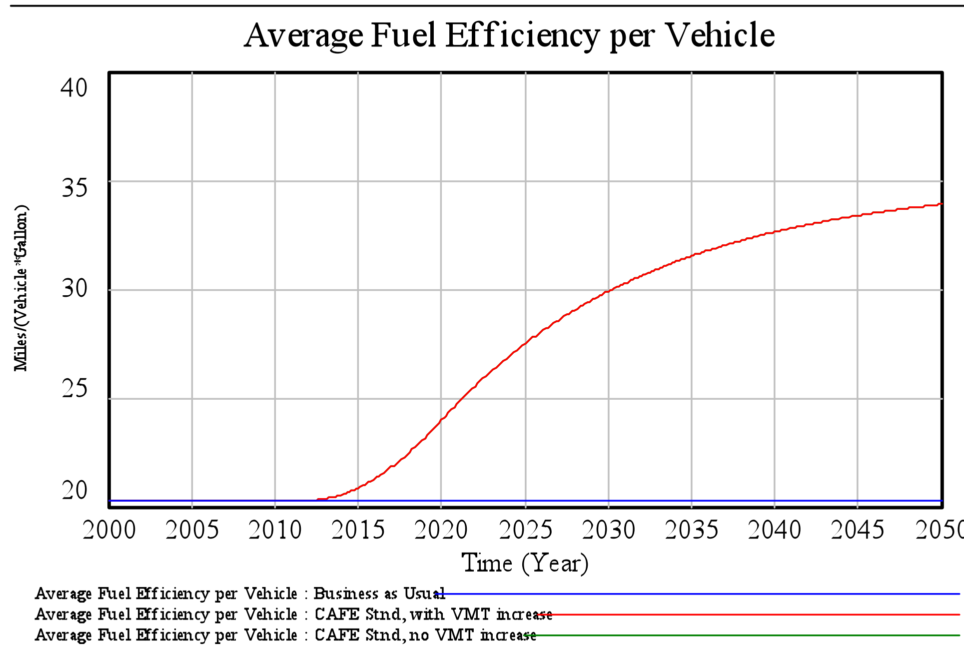


Model Results

CAFE Standard Sector:

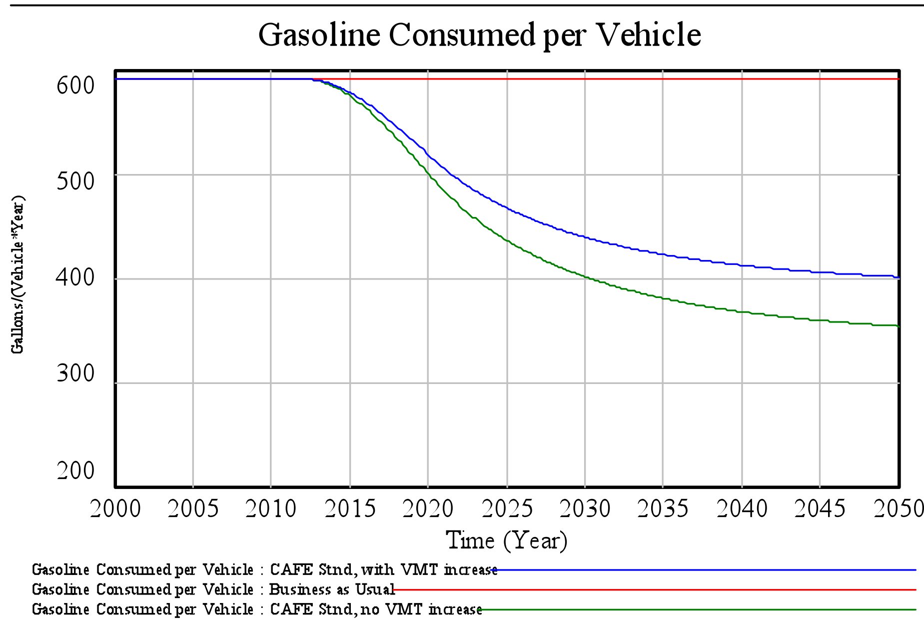
In the Energy Independence and Security Act (EISA) of 2007, Congress increased CAFE standards for the first time since its enactment in 1975 by requiring automakers to attain fleetwide gas mileage of 35 miles per gallon by the year 2020. Implementation is scheduled to start in the year 2012 (National Highway Traffic Safety Administration). In the model, the start time for the test input was 2012 and the end time of the test input was set at 2020 with a slope of 1.8375 to account for the increase from 20.3 to 35 miles per gallon. Average fuel efficiency in the vehicle population of the U.S. transportation sector is 20.3 miles per gallon in the year 2000, begins increasing in an s-shaped growth mode of behavior in the year 2012 due to the implementation of the CAFE standard, and reaches 33.9 miles per gallon in the year 2050 (*See Figure 31*). This illustrates the time delay between enacting a policy in a dynamic system and seeing the consequences or, in this case, benefits resulting from enacting the policy. The full benefits from the CAFE standard will not quite be fully seen 43 years after the legislation was passed or 38 years after policy implementation.

Figure 31. Average Fuel Efficiency per Vehicle: 2000-2050 (CAFE)



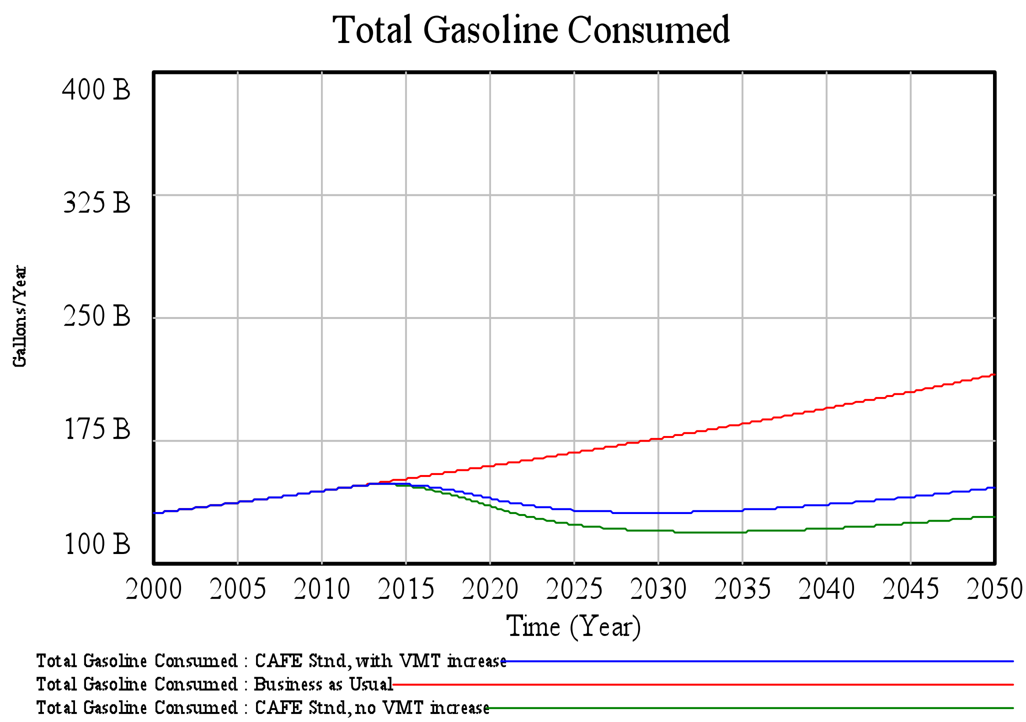
Gasoline consumed per year in a vehicle that has an average fuel efficiency of 20.3 miles per gallon that traveled 12,000 miles is approximately 591 gallons (*See Figure 32*). Because the dynamic relationship between average fuel efficiency and gasoline consumption has a negative polarity, the graph below shows that the enactment of the CAFE standard causes gasoline consumed per vehicle to decrease in an s-shaped mode of behavior as average fuel efficiency increases. The graph also shows that gasoline consumed per vehicle is close to reaching an equilibrium level at the year 2050 just as average fuel efficiency per vehicle was close to reaching an equilibrium level at the year 2050. Some critics of the CAFE standard argue that an unintended consequence of this policy is that as fuel efficiency increases and the fuel cost per mile driven is reduced for consumers, growth in vehicle travel will occur. The dynamic relationship between average fuel efficiency and vehicle miles traveled has a positive polarity, so as vehicle miles traveled increases, more gasoline is consumed. Gasoline consumption is roughly 401 gallons per year due to growth in vehicle miles traveled and is close to 354 gallons per year without the growth.

Figure 32. Gasoline Consumed per Vehicle: 2000-2050



Total gasoline consumed is calculated by two variables, vehicles on road and gasoline consumed per vehicle. Due to the linear shape of vehicles on road and the s-shaped mode of behavior for gasoline consumed per vehicle, the mode of behavior for total gasoline consumed is a combination of the modes of behavior for the two variables that influence it. Total gasoline consumed in the "Business as Usual" scenario which has only an increase in the vehicle population with no technology improvements is 130 billion gallons in the year 2000 and reaches almost 215 billion gallons by the year 2050 (*See Figure 33*). Total gasoline consumed in the "CAFE

Figure 33. Total Gasoline Consumed: 2000-2050 (CAFE)



Stnd, with VMT increase" scenario is 130.05 billion gallons in the year 2000, reaches a maximum level in the year 2014 at 148 billion gallons, approaches near its minimum level in the year 2029 at 130.58 billion gallons, and reaches a level of 146 billion gallons by the year 2050. Total gasoline consumed in the "CAFE Stnd, no VMT increase" scenario is 130 billion gallons in the year 2000, reaches a maximum level in

2013 at 148 billion gallons, reaches a minimum level in 2033 at 119 billion gallons, and reaches a level of 129 billion gallons by 2050. By the years 2029 and 2033, respectively, the vehicle population positive loop influence becomes strongest, so total gasoline consumed begins increasing as the benefits seen earlier from the CAFE standard are negated. Total gasoline savings seen from the "CAFE Stnd, no VMT increase" scenario in 2050 is 86 billion gallons. Total gasoline savings seen from the "CAFE Stnd, with VMT increase" scenario, which models the Jevons effect resulting from increased fuel efficiency, in 2050 is 69 billion gallons. This results in a loss of savings of 17 billion gallons, or approximately 19.77 percent of total gasoline savings seen from improved fuel efficiency, as a result of the rebound effect of consumers driving more miles. This is consistent with the research of Ken Small of UC-Irvine who found that not more than 20 percent of total gasoline savings seen from improved fuel efficiency is lost as a result of consumers driving more miles (Komanoff 2010).

With the average vehicle emitting 7.24 metric tons of CO_2eq emissions in the year 2000, total CO_2eq emissions in the U.S. transportation sector is roughly 1.59 billion metric tons of CO_2eq emissions (*See Figure 34*). In the "Business as Usual" scenario, total CO_2eq emissions increase to 1.8 billion metric tons of CO_2eq emissions by the year 2012 and reach 2.6 billion metric tons of CO_2eq emissions by the year 2050. Average CO_2eq emissions per vehicle remain flat at 7.24 metric tons of CO_2eq emissions per year just as vehicle fuel efficiency remains flat in that scenario which is analogous to the roughly constant level of vehicle fuel efficiency for the past 20 years (Sandalow 2008, 31) (*See Figure 35*). In the year 2012 when the CAFE standard is implemented, total CO_2eq emissions and average CO_2eq emissions per vehicle begin to decrease in the two CAFE standard simulations. Total CO_2eq emissions in the U.S. transportation sector reach a minimum of 1.59 billion metric tons of CO_2eq emissions in 2029 in the "CAFE Stnd, with VMT increase" scenario and reach a minimum of

1.45 billion metric tons of CO_2eq emissions in 2033 in the “CAFE Stnd, no VMT increase” scenario. By the year 2050, total CO_2eq emissions increase to 1.79 billion metric tons of CO_2eq emissions in the “CAFE Stnd, with VMT increase” scenario and increase to 1.57 billion metric tons in the “CAFE Stnd, no VMT increase” scenario. By 2025, average CO_2eq emissions per vehicle decrease to 5.7 metric tons of CO_2eq emissions in the “CAFE Stnd, with VMT increase” scenario and decrease to 5.3 metric tons in the “CAFE Stnd, no VMT increase” scenario. In 2050, average CO_2eq emissions per vehicle reach a minimum of 4.9 metric tons of CO_2eq emissions in the “CAFE Stnd, with VMT increase” scenario and reach a minimum of 4.3 metric tons in the “CAFE Stnd, no VMT increase” scenario.

Figure 34. Total CO_2eq Emissions: 2000-2050 (CAFE)

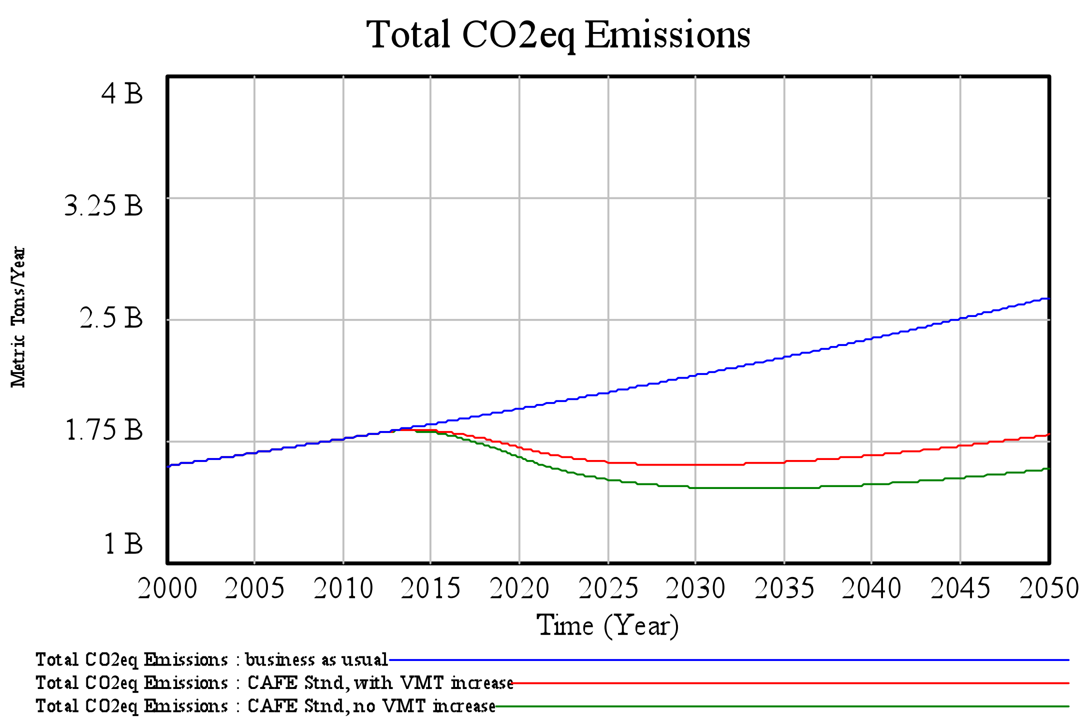
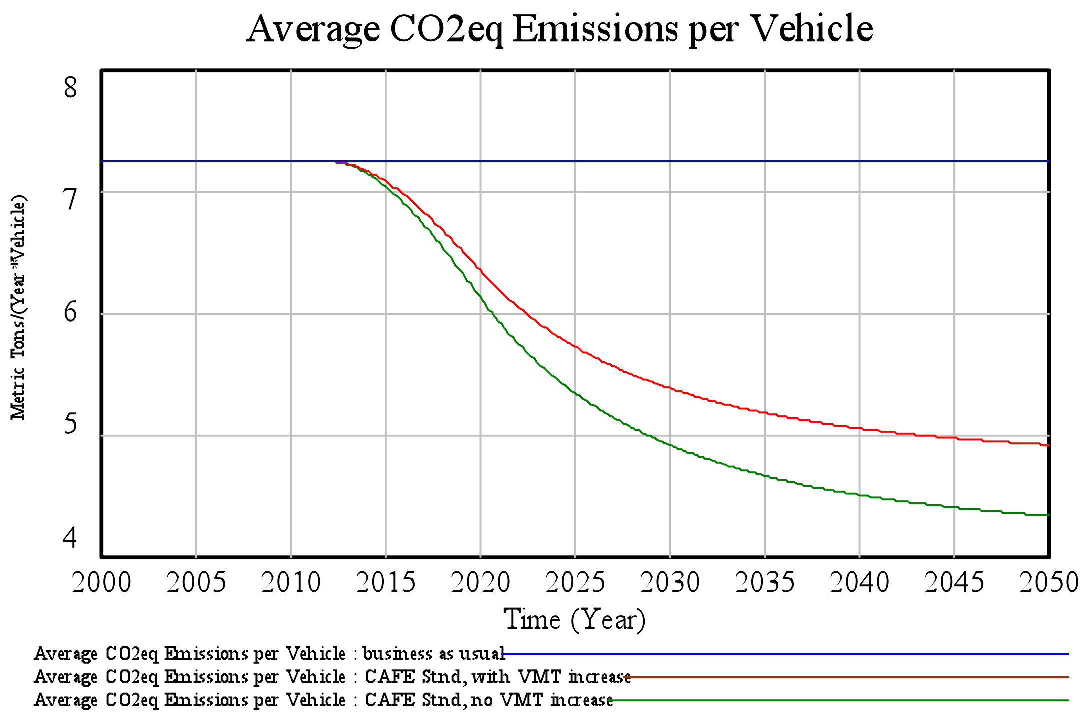


Figure 35. Average CO_2eq Emissions per Vehicle: 2000-2050 (CAFE)

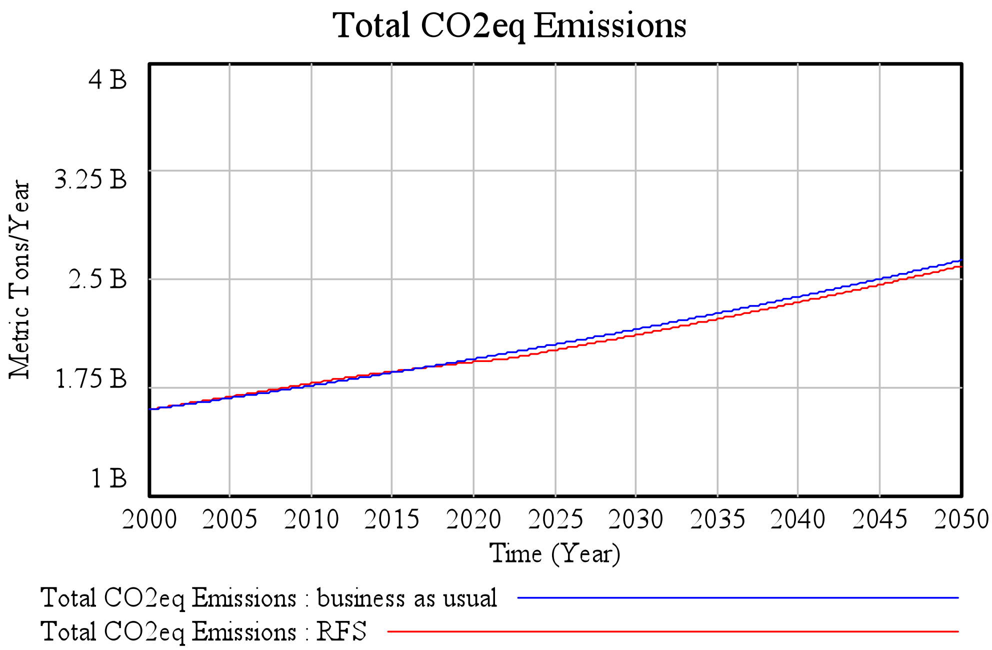


RFS Sector:

In the Energy Independence and Security Act (EISA) of 2007, Congress also amended the Renewable Fuel Standard enacted in 2005 by increasing the required volume of biofuels in our fuel supply from 7.5 billion gallons of renewable fuel in 2012 to 36 billion gallons of renewable fuel in 2022 (Renewable Fuels Association). The model was first run with only the RFS being implemented, and not the CAFE standard, so as to only view the impact that the RFS has on the U.S. transportation sector.

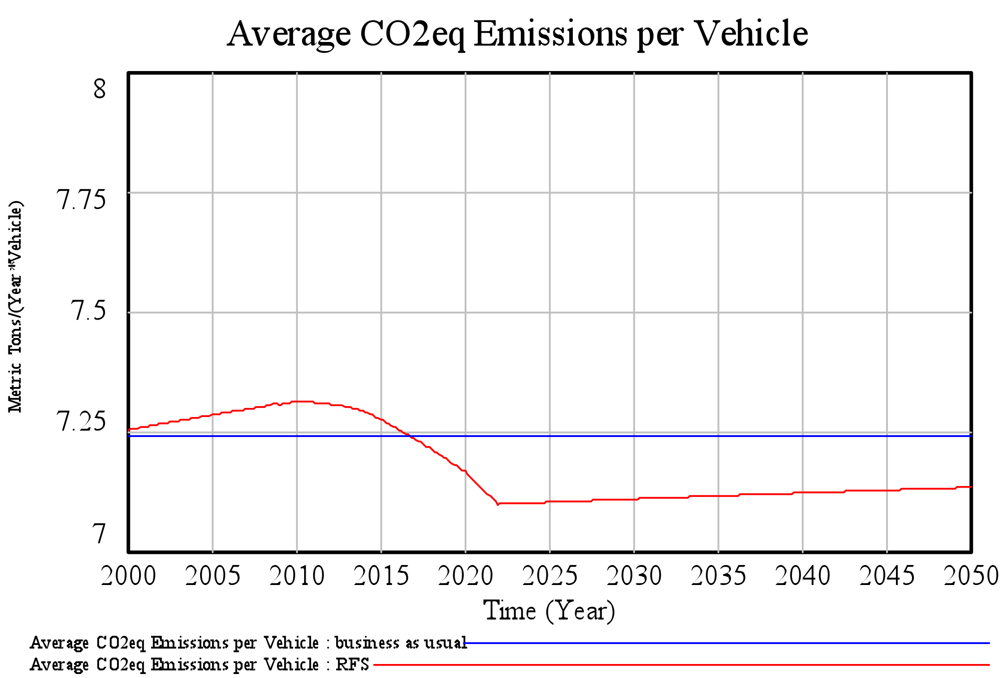
With the average vehicle emitting 7.24 metric tons of CO_2eq emissions in the year 2000, total CO_2eq emissions in the U.S. transportation sector is roughly 1.59 billion metric tons of CO_2eq emissions (*See Figure 36*). In the "Business as Usual" scenario, total CO_2eq emissions reach 2 billion metric tons of CO_2eq emissions by the year 2022 and reach 2.6 billion metric tons of CO_2eq emissions by the year 2050.

Figure 36. Total CO_2eq Emissions: 2000-2050 (RFS)



Average CO_2eq emissions per vehicle remain flat at 7.24 metric tons of CO_2eq emissions per year just as vehicle fuel efficiency remains flat in that scenario which is analogous to the roughly constant level of vehicle fuel efficiency for the past 20 years (Sandalow 2008, 31) (*See Figure 37*).

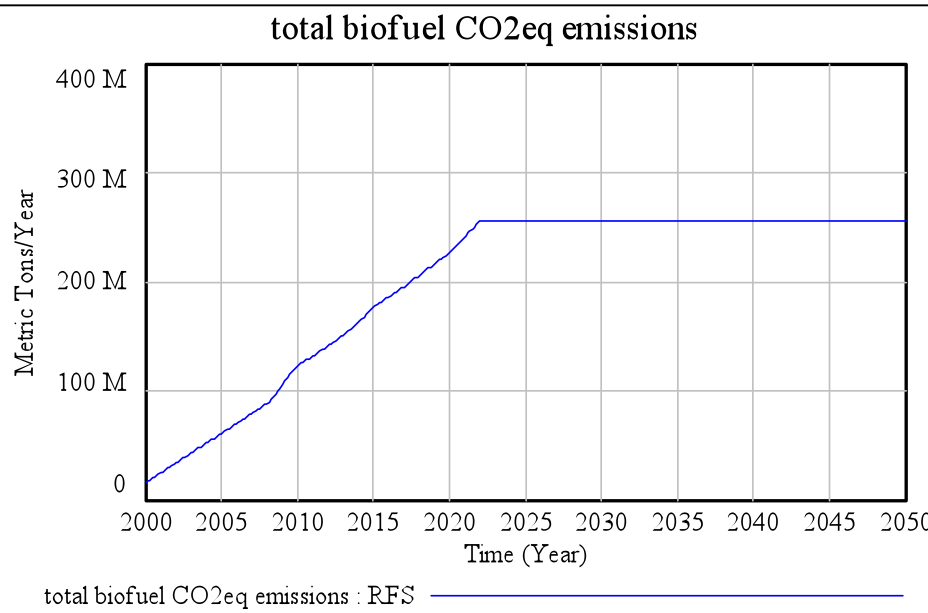
Figure 37. Average CO_2eq Emissions per Vehicle: 2000-2050 (RFS)



Total CO_2eq emissions and average CO_2eq emissions per vehicle from the implemented RFS, "RFS" run, do not become less than emissions in the "Business as Usual" run until the year 2016 when the mandated volume of renewable biofuel is 15 billion gallons, advanced biofuel is 3 billion gallons, and cellulosic biofuel is 4.25 billion gallons for a total of 22.25 billion gallons. Initially, there is an increase in greenhouse gas emissions because of the ratio of the lower energy content of ethanol and greenhouse gas emission reduction of renewable biofuel or corn ethanol. Earlier, I established that roughly 1.49 gallons of ethanol is the energy equivalent of 1 gallon of gasoline due to the heat content of gasoline being 115,000 Btu's and the heat content of ethanol being 77,000 Btu's as defined in the RFS final rule. If one takes 1.493506494 times 0.0098, 'total CO_2eq emissions emitted per gallon of corn ethanol consumed,' a 20 percent reduction in greenhouse gas emissions from the 2005 baseline for gasoline greenhouse gas emissions, one finds that an energy equivalent of 0.014636363 metric tons of CO_2eq emissions are emitted per gallon of ethanol consumed as compared to 0.01225 metric tons of CO_2eq emissions emitted per gallon of gasoline consumed, a difference of 0.002386 metric tons. To figure out what value of CO_2eq emissions emitted per gallon of corn ethanol consumed would be equivalent to CO_2eq emissions emitted per gallon of gasoline consumed, one solves the equation (115,000 Btu's / 77,000 Btu's) x = .01225. Solving for x yields an answer of 0.0082021739 metric tons. This is compared to 0.0098, greenhouse gas emissions at a 20 percent reduction level. This means that in order for renewable fuel, or corn ethanol, to reduce greenhouse gas emissions as compared to gasoline, greenhouse gas emissions from corn ethanol needs to be above a 33 percent reduction level. Due to corn ethanol being only a 20 percent reduction, this is why one at first sees an increase in both total CO_2eq emissions and Average CO_2eq emissions per vehicle. Both advanced biofuel and cellulosic biofuel are above the 33 percent break-even level, 50 percent and 60 percent respectively, so as production of these fuels increase, one notices that greenhouse gas emissions resulting from the implemented RFS begin to become lower than the 'Business as Usual' scenario.

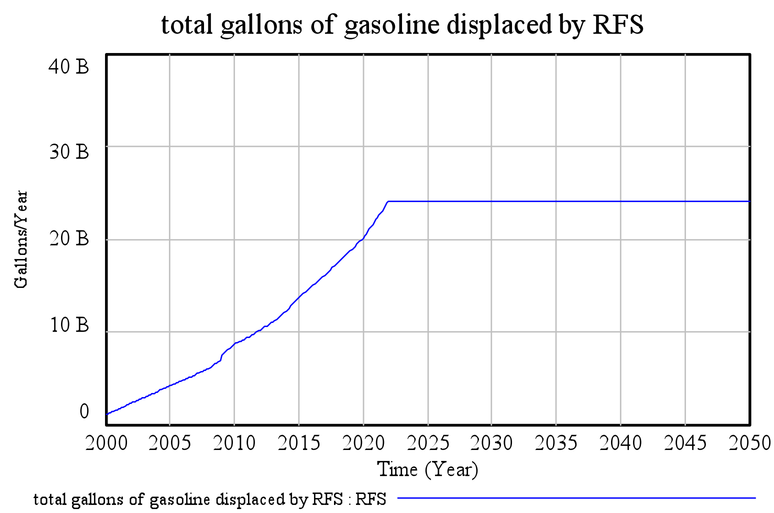
Average CO_2eq emissions per vehicle in the U.S. transportation sector reach a minimum of 7.0983 metric tons of CO_2eq emissions in 2022. By the year 2050, avereage CO_2eq emissions increase slightly to 7.133 metric tons of CO_2eq emissions. Total CO_2eq emissions in the U.S. transportation sector is 1.947 billion metric tons of CO_2eq emissions in 2022. CO_2eq emissions increase steadily to 2.59 billion metric tons in 2050. Of that amount, total biofuel emissions reach a level of 2.56 million metric tons once the RFS is fully implemented in 2022 (*See Figure 38*).

Figure 38. Total Biofuel CO_2eq Emissions per Vehicle: 2000-2050 (RFS)



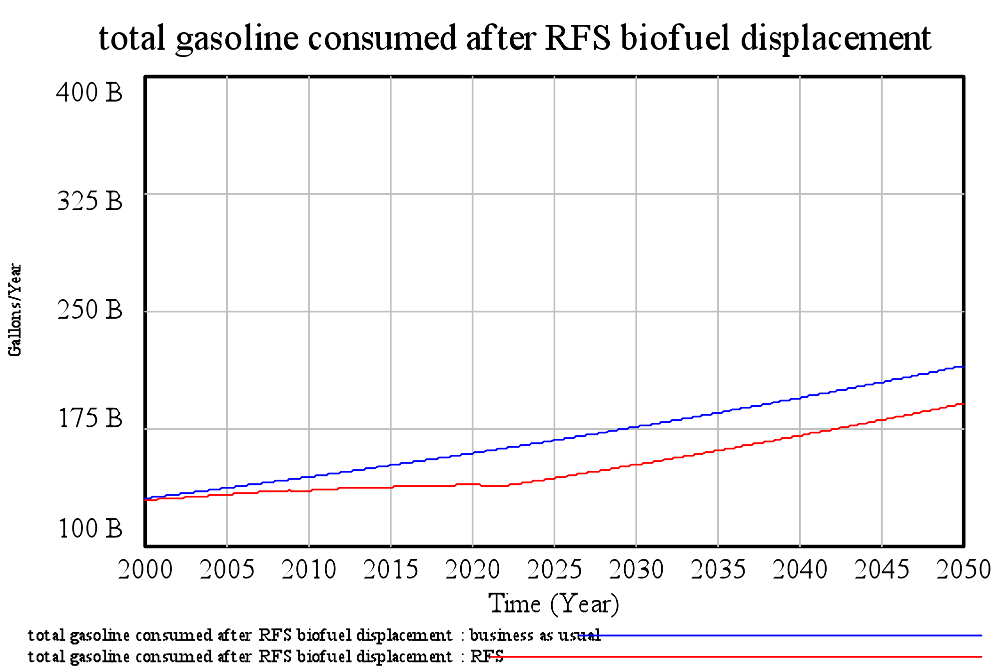
While renewable biofuels may not do anything at the mandated 20 percent reduction level to reduce greenhouse gas emissions, renewable biofuels, and biofuels in general, do reduce gasoline consumption. The maximum volume of gasoline displaced by the 36 billion gallon RFS is 24.1 billion gallons per year (*See Figure 39*).

Figure 39. Total Gallons of Gasoline Displaced by RFS: 2000-2050 (RFS)



Total gasoline consumed in the "Business as Usual" scenario, which has only an increase in the vehicle population, meaning no technology improvements, is 130 billion gallons in the year 2000 and reaches almost 215 billion gallons by the year 2050 (*See Figure 40*). Total gasoline consumed in the "RFS" scenario begins at 128.9 billion gallons in 2000, reaches a minimum of 138 billion gallons in 2022 and increases to 191 billion gallons by 2050.

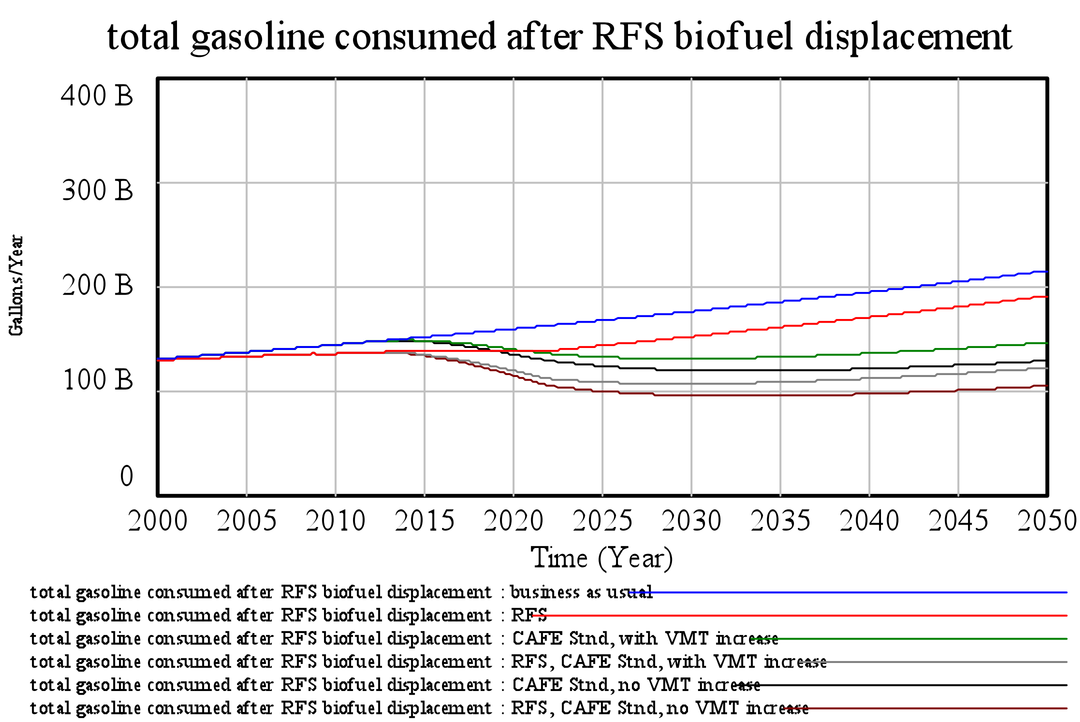
Figure 40. Total Gasoline Consumed after RFS Displacement: 2000-2050 (RFS)



CAFE Standard and RFS Sectors:

The model was next ran with both the RFS and CAFE standard implemented as passed in the Energy Independence and Security Act (EISA) of 2007. The amount of gasoline displaced from these runs from largest to smallest as compared to the baseline “Business as Usual” scenario is as follows: “RFS, CAFE Stnd, no VMT increase,” “RFS, CAFE Stnd, with VMT increase,” “CAFE Stnd, no VMT increase,” “CAFE Stnd, with VMT increase,” and “RFS.” Gasoline consumed in the year 2000 is 130 billion gallons. Three of the five runs yield gasoline consumption in the year 2050 at a volume less than gasoline consumption in the year 2000 in spite of increases in vehicle population and vehicle miles traveled. Gasoline consumption in 2050 in the “RFS, CAFE Stnd, no VMT increase” run is 104.4 billion gallons, which is 110.3 billion gallons less than the 214.7 billion gallons of gasoline consumption in 2050 in the “Business as Usual” Scenario (*See Figure 41*). Gasoline consumption in 2050 is

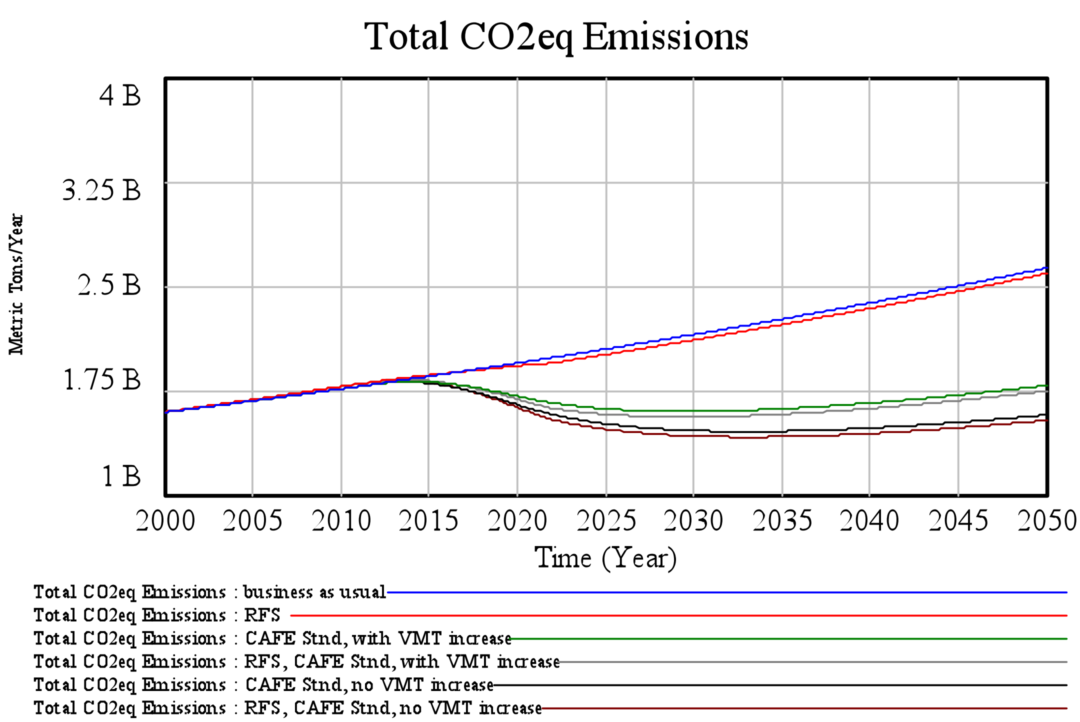
Figure 41. Total Gasoline Consumed after RFS Displacement: 2000-2050 (RFS, CAFE)



121.5 billion gallons in the "RFS, CAFE Stnd, with VMT increase" run, 128.5 billion gallons in the "CAFE Stnd, no VMT increase" run, 145.6 billion gallons in the "CAFE Stnd, with VMT increase" run, and 190.6 billion gallons in the "RFS" run.

The amount of total CO_2eq greenhouse gas emissions and average CO_2eq emissions per vehicle from these runs from smallest to largest as compared to the baseline "Business as Usual" scenario is as follows: "RFS, CAFE Stnd, no VMT increase," "CAFE Stnd, no VMT increase," "RFS, CAFE Stnd, with VMT increase," "CAFE Stnd, with VMT increase," and "RFS." Total CO_2eq greenhouse gas emissions in the year 2000 is 1.59 billion metric tons of CO_2eq greenhouse gas emissions (*See Figure 42*). Two of the five runs yield total CO_2eq greenhouse gas emissions in the year 2050 at an amount less than total CO_2eq greenhouse gas emissions in the year 2000 in spite of increases in vehicle population. Total CO_2eq greenhouse gas emissions in 2050 in the "RFS, CAFE Stnd, no VMT increase" run is 1.54 billion metric tons, which is 1.09 billion metric tons less than the 2.63 billion metric tons of CO_2eq greenhouse gas emissions in 2050 in the "Business as Usual"

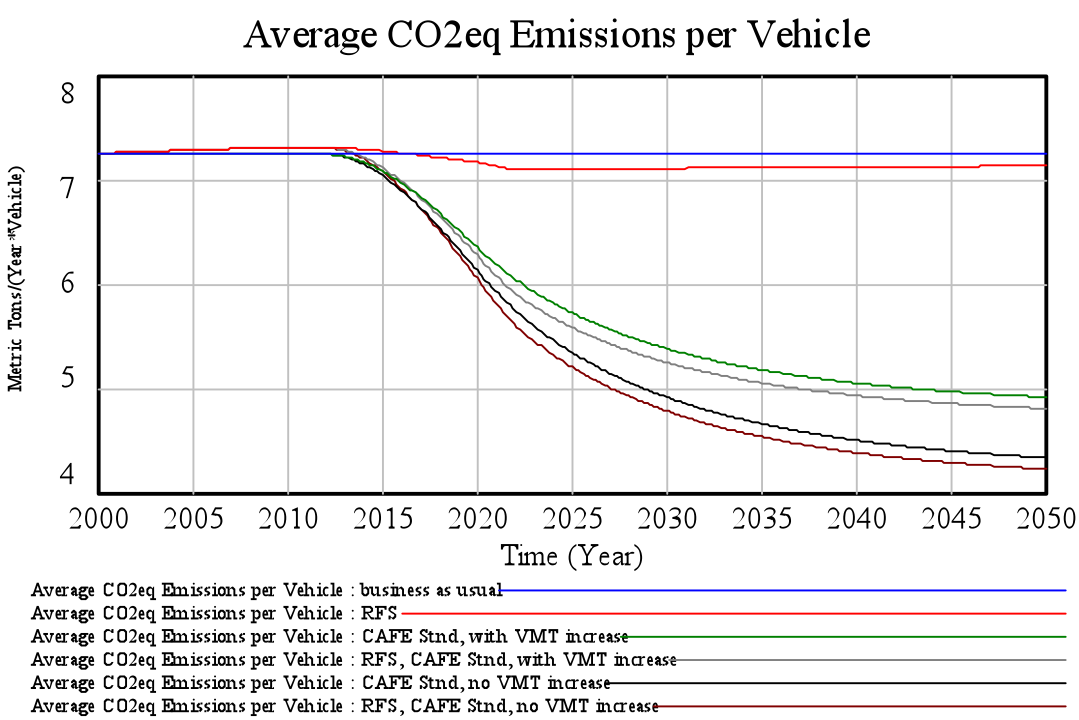
Figure 42. Total CO_2eq Emissions: 2000-2050 (RFS, CAFE)



scenario. Total CO_2eq greenhouse gas emissions in 2050 is 1.57 billion metric tons in the "CAFE Stnd, no VMT increase" run, 1.75 billion metric tons in the "RFS, CAFE Stnd, with VMT increase" run, 1.79 billion metric tons in the "CAFE Stnd, with VMT increase" run, and 2.59 billion metric tons in the "RFS" run.

In the "Business as Usual" scenario, average CO_2eq greenhouse gas emissions per vehicle remain steady at 7.24 metric tons (*See Figure 43*). Average CO_2eq greenhouse gas emissions in 2050 in the "RFS, CAFE Stnd, no VMT increase" run is 4.23 metric tons, 4.34 metric tons in the "CAFE Stnd, no VMT increase" run, 4.81 metric tons in the "RFS, CAFE Stnd, with VMT increase" run, 4.92 metric tons in the "CAFE Stnd, with VMT increase" run, and 7.13 metric tons in the "RFS" run.

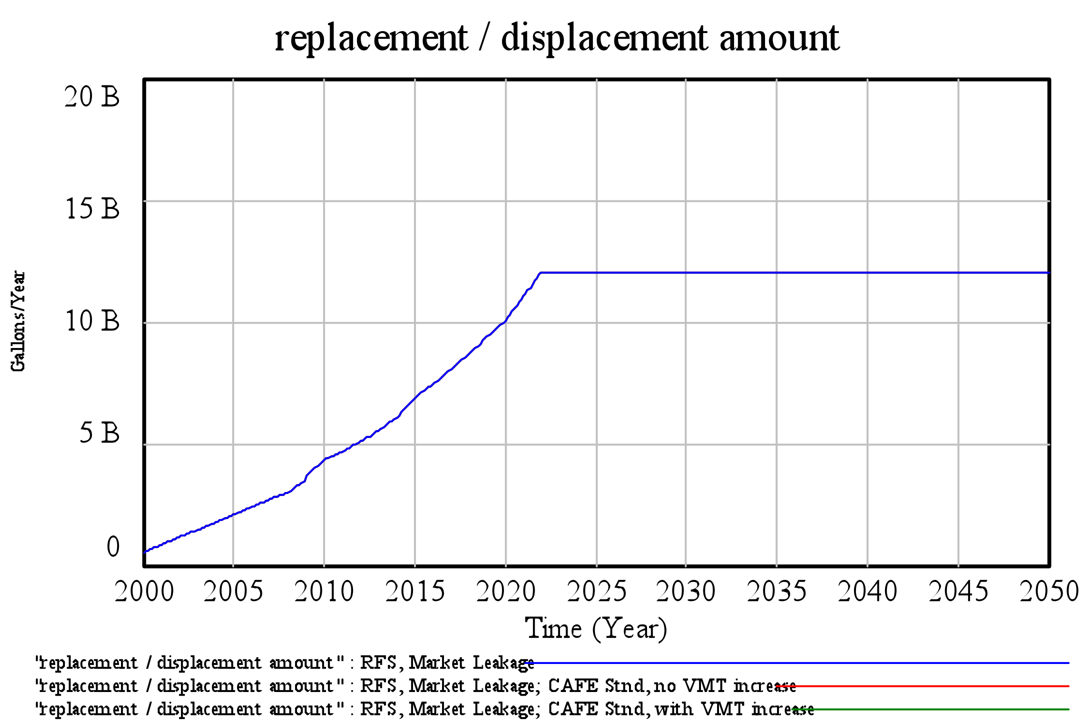
Figure 43. Average CO_2eq Emissions per Vehicle: 2000-2050 (RFS, CAFE)



CAFE Standard and RFS Sectors, Market Leakage:

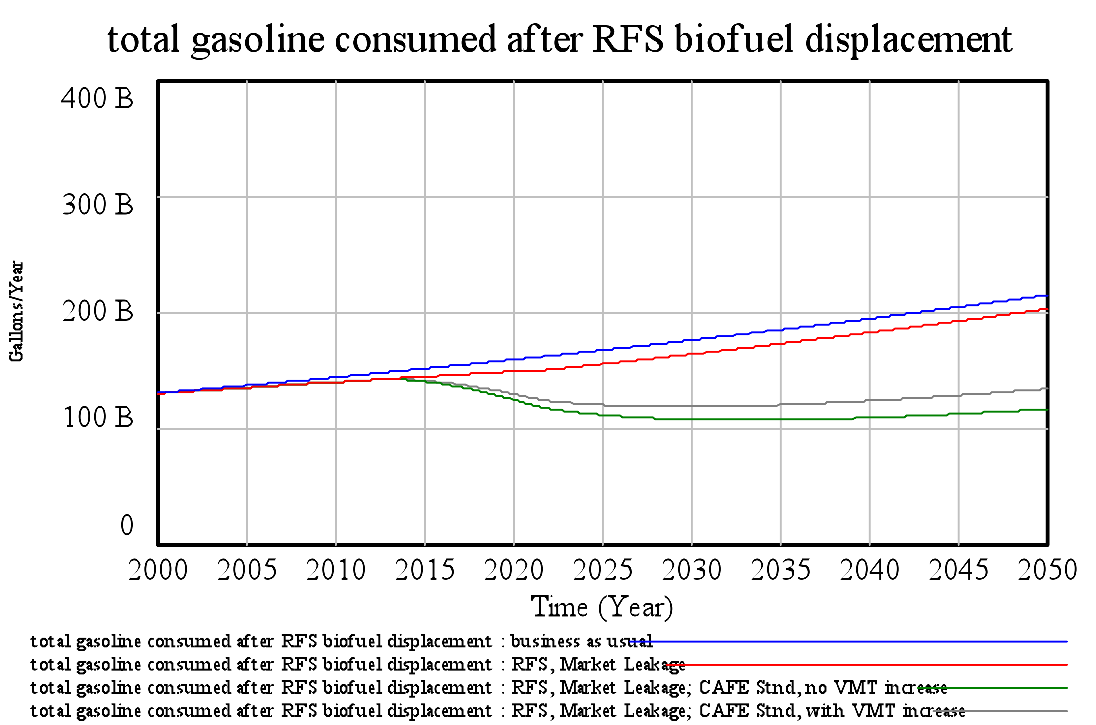
The model was then adjusted and next ran to account for leakage or market effects of biofuels in the domestic fuel market. Market leakage was modeled at 50 percent which means that one energy equivalent gallon of ethanol replaces only 0.50 gallons of gasoline while the rest, 0.50 gallons, is displaced. In other words, the presence of biofuels in the domestic fuel market will not merely replace gasoline one-to-one as was previously modeled, so total fuel consumption does not remain constant. The 'replacement / displacement amount' is calculated by multiplying the variable 'total gallons of gasoline displaced by RFS' by the amount of market leakage, 0.50. In this case, replacement, which is the amount of gasoline replaced by biofuel, and displacement, which is the leakage or amount total gasoline consumption increases by, is the same. In 2022, when 36 billion gallons of biofuels are mandated by the RFS, displacement is 12.05 billion gallons (*See Figure 44*).

Figure 44. Replacement / Displacement Amount: 2000-2050 (RFS, Market Leakage)



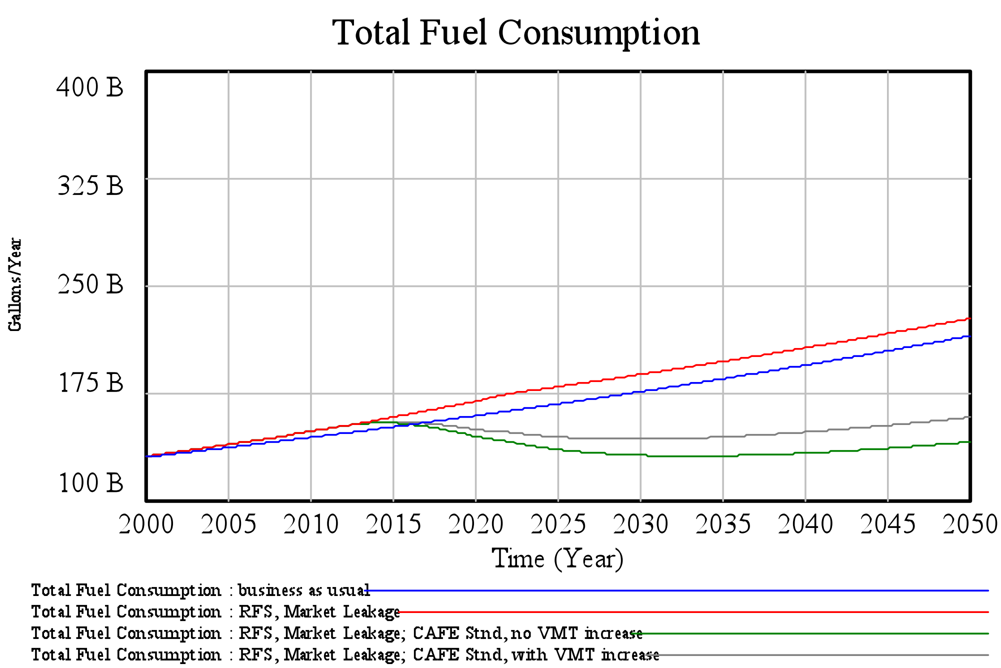
The amount of gasoline displaced from these runs from largest to smallest as compared to the baseline "Business as Usual" scenario is as follows: "RFS, Market Leakage; CAFE Stnd, no VMT increase," "RFS, Market Leakage; CAFE Stnd, with VMT increase," and "RFS Market Leakage." Conventional gasoline consumed in the year 2000 is 130 billion gallons. One of the three runs yield gasoline consumption in the year 2050 at a volume less than gasoline consumption in the year 2000 in spite of increases in vehicle population and vehicle miles traveled, while another run is very close. Conventional gasoline consumption in 2050 in the "RFS, Market Leakage; CAFE Stnd, no VMT increase" run is 116.5 billion gallons, which is 98.2 billion gallons less than the 214.7 billion gallons of gasoline consumption in 2050 in the "Business as Usual" Scenario (*See Figure 45*). Gasoline consumption in 2050 is 133.7 billion gallons in the "RFS, Market Leakage; CAFE Stnd, with VMT increase" run, and 202.7 billion gallons in the "RFS, Market Leakage" run.

Figure 45. Total Gasoline Consumed after RFS Biofuel Displacement: 2000-2050 (RFS, Market Leakage)



Because biofuels do not merely replace gasoline one-to-one as was previously modeled, total fuel consumption does not remain constant. In the "Business as Usual" scenario, total fuel consumption in the year 2050 is 214.7 billion gallons. Total fuel consumption in 2050, which includes both conventional gasoline and biofuels, in the "RFS, Market Leakage; CAFE Stnd, no VMT increase" run is 140.6 billion gallons, which is 74.1 billion gallons less than the 214.7 billion gallons of total fuel consumed in 2050 in the "Business as Usual" scenario (*See Figure 46*). Total fuel consumption in 2050 is 157.8 billion gallons in the "RFS, Market Leakage; CAFE Stnd, with VMT increase" run, and 226.8 billion gallons in the "RFS, Market Leakage" run, an amount which is higher than the amount in the "Business as Usual" scenario, by 12.1 billion gallons, the amount of displacement calculated above resulting from the leakage or market effects of biofuels in the domestic fuel market.

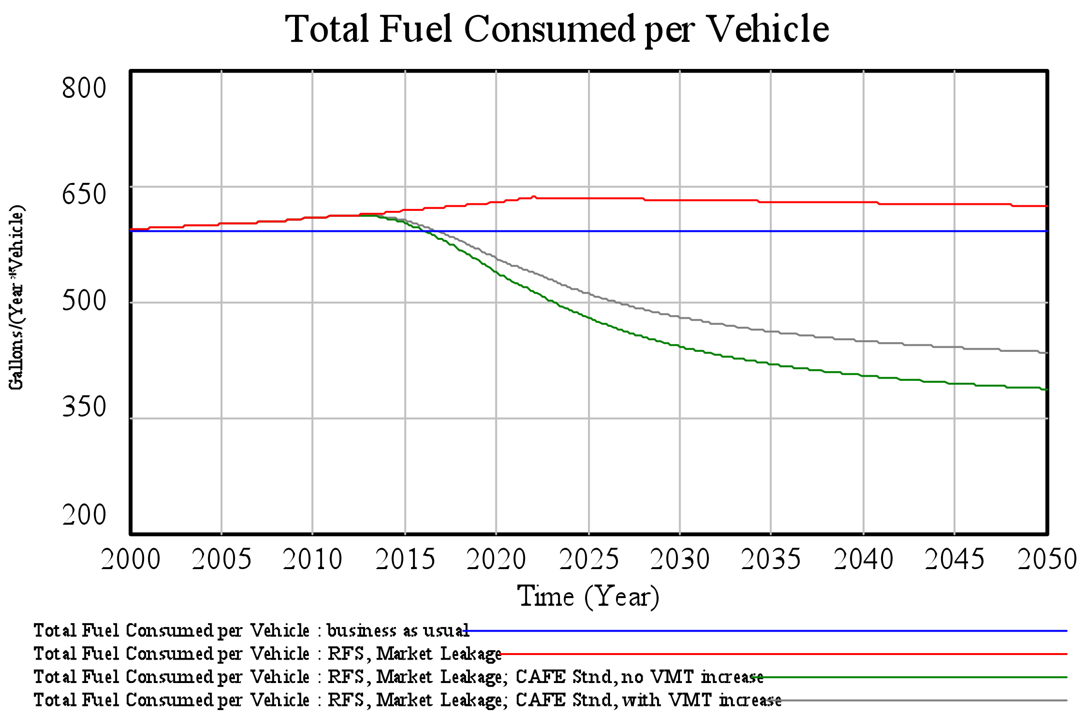
Figure 46. Total Fuel Consumption: 2000-2050 (RFS, Market Leakage)



Total fuel consumed per vehicle does not remain constant either (*See Figure*

47). In the "Business as Usual" scenario, total fuel consumption per vehicle remains constant at 591.1 gallons per vehicle. Total fuel consumed per vehicle in 2050,

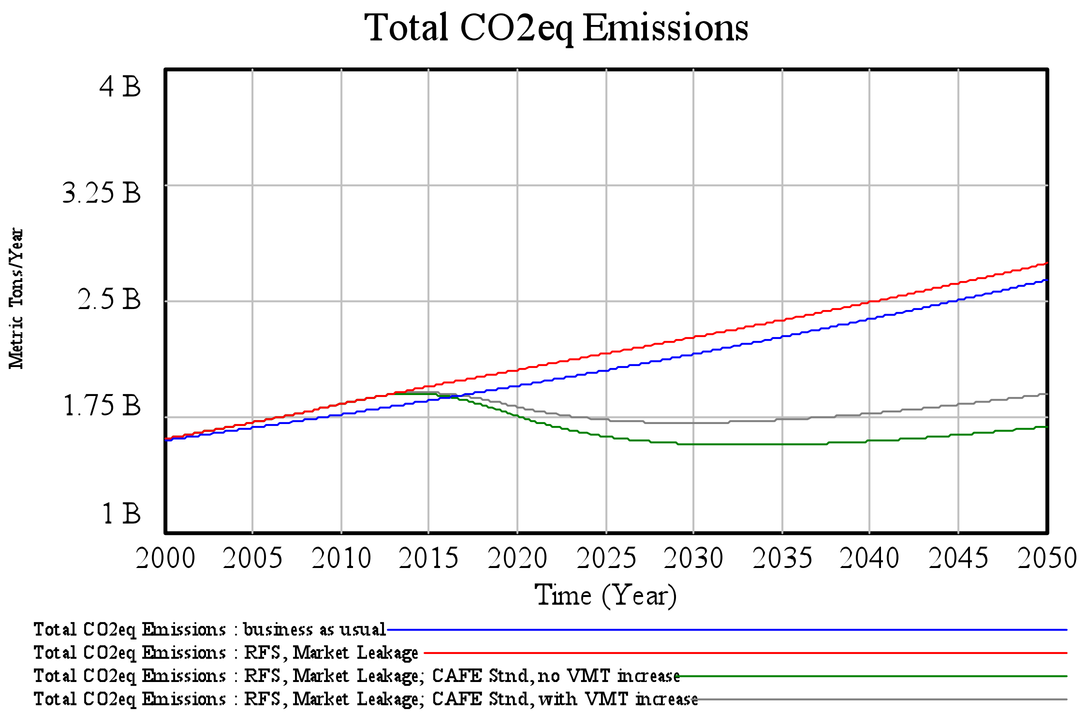
Figure 47. Total Fuel Consumed per Vehicle: 2000-2050 (RFS, Market Leakage)



which includes both conventional gasoline and biofuels, in the "RFS, Market Leakage; CAFE Stnd, no VMT increase" run is 387.1 gallons, which is 204 gallons less than the 591.1 gallons of total fuel consumed per vehicle in the "Business as Usual" scenario. Total fuel consumption in 2050 is 434.6 gallons in the "RFS, Market Leakage; CAFE Stnd, with VMT increase" run, which is 156.5 gallons less than in the "Business as Usual" scenario; and 624.3 gallons in the "RFS, Market Leakage" run, which is 33.2 gallons more than in the "Business as Usual" scenario.

The amount of total CO_2eq greenhouse gas emissions and average CO_2eq emissions per vehicle from these runs from smallest to largest as compared to the baseline "Business as Usual" scenario is as follows: "RFS, Market Leakage; CAFE Stnd, no VMT increase," "RFS, Market Leakage; CAFE Stnd, with VMT increase," and “RFS Market Leakage.” Total CO_2eq greenhouse gas emissions in the year 2000 in the “Business as Usual” scenario is 1.59 billion metric tons of CO_2eq greenhouse gas emissions (*See Figure 48*). None of the runs yield total CO_2eq greenhouse gas emissions in the year 2050 at an amount that is less than total CO_2eq greenhouse gas

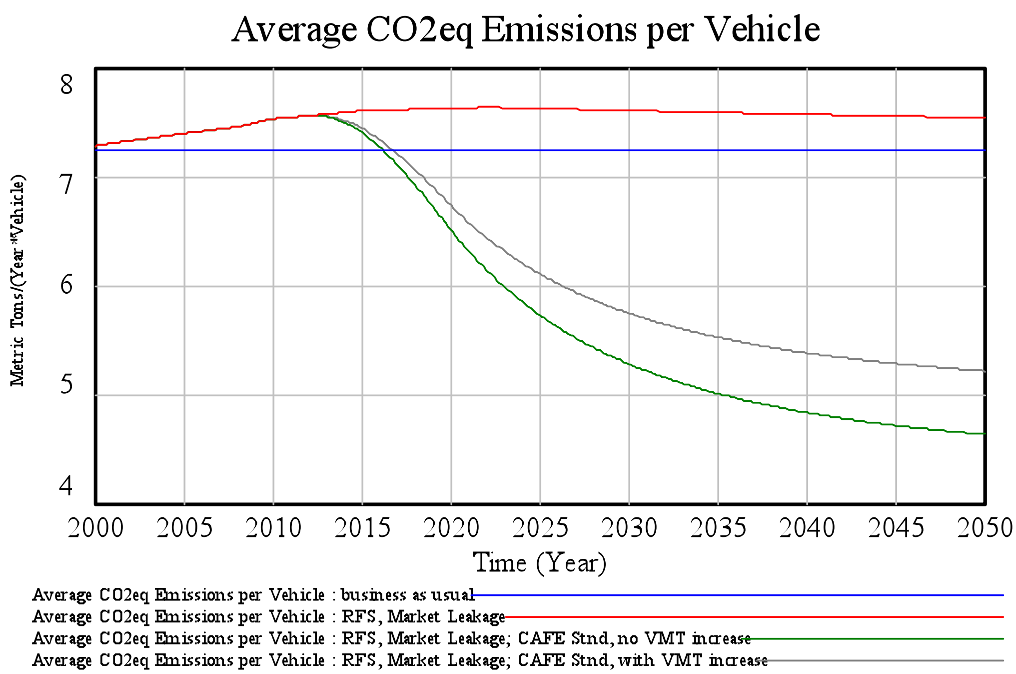
Figure 48. Total CO_2eq Emissions: 2000-2050 (RFS, Market Leakage)



emissions in the year 2000. Two of the runs yield total CO_2eq greenhouse gas emissions in the year 2050 at an amount that is less than total emissions in the “Business as Usual” scenario in 2050. Total CO_2eq greenhouse gas emissions in 2050 in the “RFS, Market Leakage; CAFE Stnd, no VMT increase” run is 1.68 billion metric tons, which is 0.95 billion metric tons less than the 2.63 billion metric tons of CO_2eq greenhouse gas emissions in 2050 in the “Business as Usual” Scenario.” Total CO_2eq greenhouse gas emissions in 2050 is 1.89 billion metric tons in the “RFS Market Leakage; CAFE Stnd, with VMT increase” run, and 2.74 billion metric tons in the “RFS, Market Leakage” run.

In the “Business as Usual” scenario, average CO_2eq greenhouse gas emissions per vehicle remain steady at 7.24 metric tons (*See Figure 49*). Average CO_2eq greenhouse gas emissions in 2050 in the “RFS, Market Leakage; CAFE Stnd, no VMT increase” run is 4.63 metric tons, 5.22 metric tons in the “RFS, Market Leakage; CAFE Stnd, with VMT increase” run, and 7.54 metric tons in the “RFS, Market Leakage” run.

Figure 49. Average CO_2eq Emissions per Vehicle: 2000-2050 (RFS, Market Leakage)

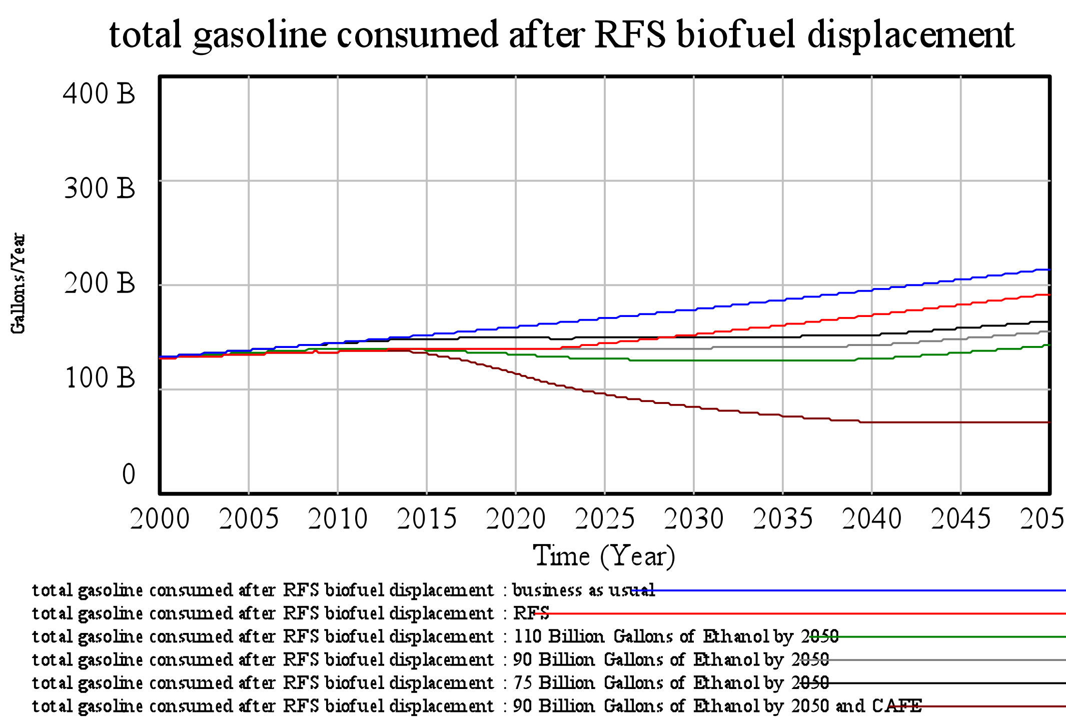


Biofuel Sector:

The last portion of the model ran consisted of examining reductions in greenhouse gas emissions and gasoline consumption that can occur with the use of renewable biofuel, advanced biofuel, and cellulosic biofuel at high, yet reasonable levels above what is mandated by the RFS. Specifically, the consumption of 110 billion gallons of biofuel by the year 2050. Advanced and Cellulosic biofuels comprised 75 billion gallons of the total and corn ethanol comprised 35 billion gallons of the total. Additionally, the model was run with 75 billion gallons of advanced and cellulosic biofuels being consumed and the RFS mandated 15 billion gallons of corn ethanol. This 90 billion gallon scenario was also run with the CAFE standard policy implemented with no vehicle miles traveled increase. Lastly, the model was run without corn ethanol or, in other words, with only 75 billion gallons of advanced and cellulosic biofuels being consumed.

The figure below shows the amount of gasoline consumed after biofuel displacement as compared to the "Business as Usual" scenario (*See Figure 50*). In the "Business as Usual" scenario, gasoline consumed in the year 2000 is 130 billion

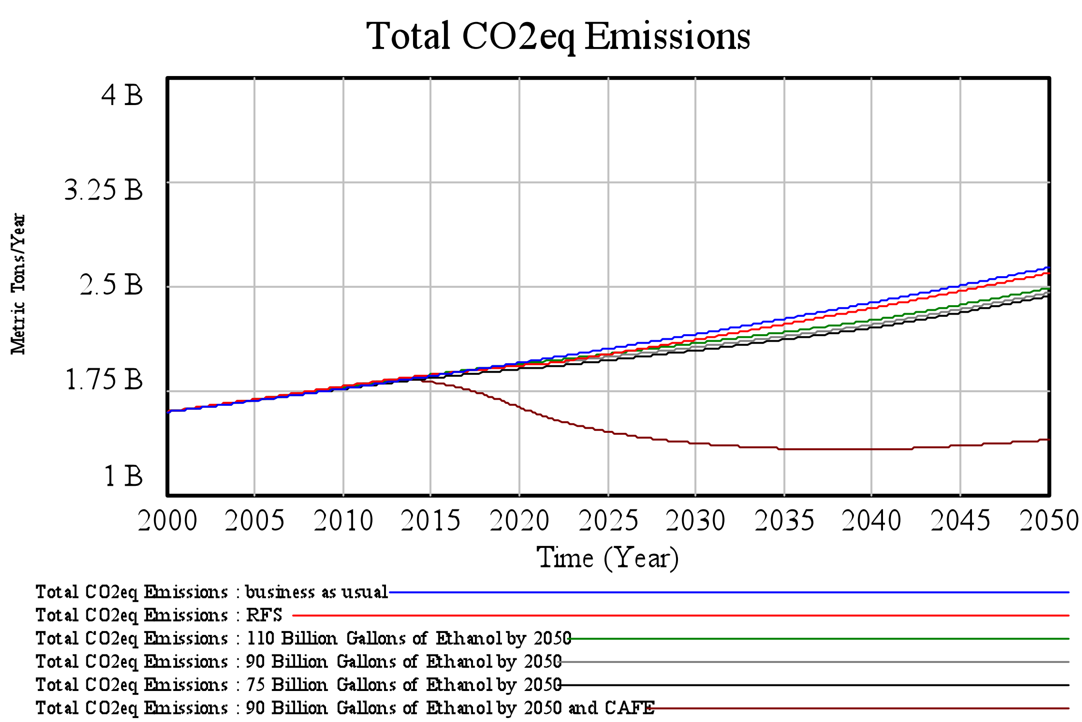
Figure 50. Total Gasoline Consumed after Biofuel Displacement: 2000-2050 (Biofuel, CAFE)



gallons and 214.7 billion gallons in the year 2050. Gasoline consumption in 2050 is 190.6 billion gallons in the "RFS" run, 164.5 billion gallons in the "75 Billion Gallons of Ethanol by 2050" run, 154.4 billion gallons in the "90 Billion Gallons of Ethanol by 2050" run, and 141.1 billion gallons in the "110 Billion Gallons of Ethanol by 2050" run. Gasoline consumption in 2050 in the "90 Billion Gallons of Ethanol by 2050 and CAFE" run, which did not include possible VMT increase, was 68.3 billion gallons.

The amount of total CO_2eq greenhouse gas emissions and average CO_2eq emissions per vehicle from these runs from smallest to largest as compared to the baseline "Business as Usual" scenario is as follows: "75 Billion Gallons of Ethanol by 2050, "90 Billion Gallons of Ethanol by 2050," "110 Billion Gallons of Ethanol by 2050," and "RFS" (*See Figure 51*). This is in reverse order as compared to gasoline

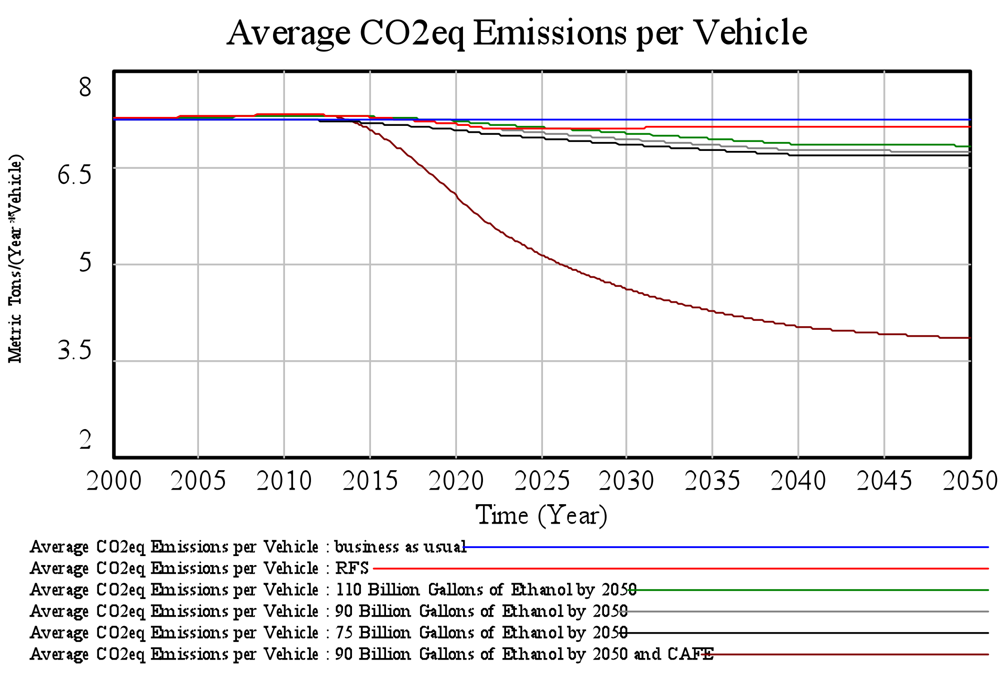
Figure 51. Total CO_2eq Emissions: 2000-2050 (Biofuel, CAFE)



consumption reduction benefits due to the higher greenhouse gas reduction levels of advanced and cellulosic biofuels. In the "Business as Usual" scenario, total CO_2eq greenhouse gas emissions in the year 2000 is 1.59 billion metric tons of CO_2eq greenhouse gas emissions and 2.63 billion metric tons in 2050. Total CO_2eq greenhouse gas emissions in 2050 is 2.59 billion metric tons in the “RFS” run, 2.48 billion metric tons in the “110 Billion Gallons of Ethanol by 2050” run, 2.45 billion metric tons in the “90 Billion Gallons of Ethanol by 2050” run, and 2.43 billion metric tons in the “75 Billion Gallons of Ethanol by 2050” run. The “90 Billion Gallons of Ethanol by 2050 and CAFE” run results in 1.39 billion metric tons in 2050.

In the “Business as Usual” scenario, average CO_2eq greenhouse gas emissions per vehicle remain steady at 7.24 metric tons. Average CO_2eq greenhouse gas emissions in 2050 is 7.13 metric tons in the “RFS” run, 6.83 metric tons in the “110 Billion Gallons of Ethanol by 2050” run, 6.74 metric tons in the “90 Billion Gallons of Ethanol by 2050” run, and 6.68 metric tons in the “75 Billion Gallons of Ethanol by 2050” run (*See Figure 52*). The “90 Billion Gallons of Ethanol by 2050 and CAFE” run results in 3.84 metric tons in 2050, a roughly 47 percent decrease from baseline.

Figure 52. Average CO_2eq Emissions per Vehicle: 2000-2050 (Biofuel, CAFE)



Section Summary:

Climate change and oil dependency are two of the greatest national security threats of our time. Today, the U.S. transportation sector, of which oil meets 96 percent of its energy needs, accounts for approximately 30 percent of all U.S. greenhouse gas emissions and petroleum accounts for 43 percent of all U.S. greenhouse gas emissions resulting from fossil fuel combustion (Friedman 2008, 325). This high reliance on oil is particularly alarming because the United States contains less than 3 percent of proven oil reserves and the volatile Middle East contains over two-thirds of oil reserves ("Oil Market Basics: Supply"; Cooper 2007, 2). Scientific evidence regarding climate change has asserted that global emissions of greenhouse gases into the atmosphere must be reduced by at least 80 percent below 2000 levels by 2050 in order to have a 50 percent chance to stabilize the climate against global warming (Environmental News Network 2007). Two avenues that can reduce greenhouse gas emissions in the U.S. transportation sector were examined in this thesis. The use of lower-carbon fuels was examined in light of the RFS policy and improvements in vehicle fuel efficiency were examined in light of the CAFE standard policy.

The goal of this thesis was to utilize a system dynamics approach to examine total greenhouse gas emissions and gasoline consumption in the U.S. transportation sector and how CAFE standard and RFS policy as enacted in the Energy Independence and Security Act of 2007 alters total greenhouse gases emitted and gasoline consumed as compared to what would occur in a business as usual scenario had these policies not been implemented. The U.S. vehicle population growth and average fuel efficiency were modeled through the use of a co-flow system dynamics structure. The CAFE standard and RFS policy choices were input into that system. Due to the rate of auto fleet turnover in the U.S., the full benefits from the CAFE standard will not be fully seen until around 2050, which is 43 years after the CAFE standard legislation was passed.

The CAFE standard was further examined in light of a ~20 percent loss in gasoline savings attributed to the Jevons paradox or rebound effect seen from consumers driving more miles as a result of improved fuel efficiency. The RFS was further examined in light of a 50 percent leakage or market effect caused by the presence of biofuels in the domestic fuel market. Market leakage was modeled at 50 percent which means that one energy equivalent gallon of biofuel replaces only 0.50 gallons of gasoline while the rest, 0.50 gallons, is displaced. In other words, biofuels do not merely replace gasoline one-to-one because the presence of biofuels in the domestic fuel market affects fuel price and consequently total fuel consumption. Fuel consumption and vehicle miles traveled, which do not remain constant under either policy option when these rebound and market effects are modeled respectively, were modeled at the vehicle population level and single vehicle level. Annual CO_2eq greenhouse gas emissions were likewise modeled at the vehicle population level and single vehicle level.

The results of this model show that with a comprehensive approach, the CAFE Standard and RFS policy without the rebound or market effects modeled, "RFS, CAFE Stnd, no VMT increase," has the potential to reduce greenhouse gas emissions in the U.S. transportation sector by 3.8 percent below 2000 levels by 2050 (*See Table 10*). When the CAFE standard and RFS are implemented and when accounting for the Jevons effect and leakage, CO_2eq greenhouse gas emissions increase by a total of 0.3 billion metric tons from the initial level of 1.59 billion metric tons in the "Business as Usual" scenario in the year 2000 to 1.89 billion metric tons in 2050 in the "RFS, Market Leakage; CAFE Stnd, with VMT increase" scenario. This results in a savings of 0.74 billion metric tons of CO_2eq greenhouse gas emissions in the year 2050.

Table 10. Summary Table of Results for all Simulation Runs, GHG Emissions

Summary Table of Results for all Simulation Runs						
	Total CO_2 Emissions (Billion Metric Tons per Year)			Average CO_2 Emissions/Vehicle (Metric Tons per Vehicle per Year)		
SCENARIO	**2000**	**2022**	**2050**	**2000**	**2022**	**2050**
Business as Usual	1.59	1.99	2.63	7.24	7.24	7.24
CAFE Standard Sector						
no VMT increase	1.59	1.59	1.57	7.24	5.75	4.34
with VMT increase (Jevons Paradox, ~20% gasoline savings loss)	1.59	1.66	1.79	7.24	6.05	4.92
RFS Sector						
RFS	1.60	1.95	2.59	7.25	7.10	7.13
RFS, Market Leakage (50%)	1.60	2.09	2.74	7.28	7.64	7.54
CAFE Standard and RFS Sectors						
RFS, CAFE Stnd, no VMT increase	1.60	1.54	1.54	7.25	5.61	4.23
RFS, Market Leakage; CAFE Stnd, no VMT increase	1.60	1.69	1.68	7.28	6.15	4.63
RFS, CAFE Stnd, with VMT increase	1.60	1.62	1.75	7.25	5.91	4.81
RFS, Market Leakage; CAFE Stnd, with VMT increase	1.60	1.77	1.89	7.28	6.45	5.22
Biofuel Sector						
110 Billion Gallons (*corn 35B, advanced 35B, cellulosic 40B by 2050*)	1.60	1.97	2.48	7.25	7.16	6.83
90 Billion Gallons (*corn 15B, advanced 35B, cellulosic 40B by 2050*)	1.60	1.95	2.45	7.25	7.10	6.74
75 Billion Gallons (*advanced 35B, cellulosic 40B by 2050*)	1.59	1.92	2.43	7.24	7.01	6.68
90 Billion Gallons, with CAFE, no VMT increase (*corn 15B, advanced 35B, cellulosic 40B by 2050*)	1.60	1.54	1.39	7.25	5.61	3.84

The results of this model also shows that the CAFE standard is a more effective policy choice as compared to the RFS as enacted when the policy goal is to reduce greenhouse gas emissions. The RFS, without leakage modeled, which consists of 36 billion gallons of biofuels, results in emission savings of 0.04 billion metric tons in the year 2050. A significant increase in the use of biofuels from 36 billion gallons to 110 billion gallons, without leakage modeled, results in additional savings of 0.11 billion metric tons or 0.15 billion metric tons total in 2050. When leakage is modeled in the RFS, greenhouse gas emissions are higher than emissions in the "Business as Usual" scenario. In the year 2050, emissions are higher by 0.11 billion metric tons from the presence of the RFS policy.

When the CAFE standard is examined by itself, accounting for the Jevons effect, CO_2eq greenhouse gas emissions increase by a total of 0.2 billion metric tons over a fifty year period from the initial level of 1.59 billion metric tons in the "Business as Usual" scenario in the year 2000 to 1.79 billion metric tons in 2050 in the "CAFE Stnd, with VMT increase" scenario. The implementation of the CAFE standard policy results in a savings of 0.84 billion metric tons of CO_2eq greenhouse gas emissions in the year 2050. In comparing CO_2eq greenhouse gas emissions per vehicle per year to the baseline, the CAFE standard, with the Jevons effect modeled, lowers average CO_2eq greenhouse gas emissions per vehicle by 2.32 metric tons in 2050, the RFS, with leakage modeled, raises average CO_2eq greenhouse gas emissions per vehicle by 0.3 metric tons in 2050, and a combination of both policies lowers average CO_2eq greenhouse gas emissions per vehicle by 2.02 metric tons in 2050.

The volume of gasoline replaced by the 36 billion gallon RFS is 24.1 billion gallons per year; that is 14.9 percent of fuel needs in the year 2022, and 11.2 percent of fuel needs in the year 2050 (*See Table 11*). The CAFE standard and RFS policy combined, without the rebound and market effects modeled, result in the need for 51.4

Table 11. Summary Table of Results for all Simulation Runs, Gasoline Consumption

Summary Table of Results for all Simulation Runs						
	Conventional Gasoline (excludes biofuel) Consumed (Billion Gallons per Year)			Total Fuel (includes biofuel) Consumed/Vehicle (Gallons per Vehicle per Year)		
SCENARIO	**2000**	**2022**	**2050**	**2000**	**2022**	**2050**
Business as Usual	130	162	215	591	591	591
CAFE Standard Sector						
no VMT increase	130	129	129	591	470	354
with VMT increase (Jevons Paradox, ~20% gasoline savings loss)	130	136	146	591	494	401
RFS Sector						
RFS	129	138	191	591	591	591
RFS, Market Leakage (50%)	130	150	203	594	635	624
CAFE Standard and RFS Sectors						
RFS, CAFE Stnd, no VMT increase	129	105	104	591	470	354
RFS, Market Leakage; CAFE Stnd, no VMT increase	130	117	117	594	514	387
RFS, CAFE Stnd, with VMT increase	129	111	122	591	494	401
RFS, Market Leakage; CAFE Stnd, with VMT increase	130	123	134	594	538	435
Biofuel Sector						
110 Billion Gallons (*corn 35B, advanced 35B, cellulosic 40B by 2050*)	129	130	141	591	591	591
90 Billion Gallons (*corn 15B, advanced 35B, cellulosic 40B by 2050*)	129	138	154	591	591	591
75 Billion Gallons (*advanced 35B, cellulosic 40B by 2050*)	130	148	164	591	591	591
90 Billion Gallons, with CAFE, no VMT increase (*corn 15B, advanced 35B, cellulosic 40B by 2050*)	129	105	68	591	470	354

percent less conventional gasoline, or 111 billion gallons, in the year 2050 than would have been needed if those policies had not been implemented. Those two policies combined have the potential to reduce gasoline consumption in the U.S. transportation sector by 26 billion gallons below 2000 levels by 2050. When leakage and the Jevons effect are accounted for in the model, conventional gasoline consumption increases by a total of 4 billion gallons over a fifty year period from the initial level of 130 billion gallons in the "Business as Usual" scenario in the year 2000 to 134 billion gallons in 2050 in the "RFS, Market Leakage; CAFE Stnd, with VMT increase" scenario. That scenario results in conventional gasoline savings of 81 billion gallons total, or the need for 37.7 percent less conventional gasoline in the year 2050 than would have been needed in the "Business as Usual" scenario. Fuel savings per vehicle is 156 gallons in 2050 under that scenario. The CAFE standard results in a savings of 69 of the 81 billion gallons while the RFS results in a savings of 12 billion gallons. The amount of conventional gasoline displaced from the 36 billion gallon mandated RFS is 12.05 billion gallons. Again, the results show that the CAFE standard is a more effective policy choice as compared to the RFS as enacted when the policy goal is to reduce gasoline consumption, but here both policy choices result in positive gasoline savings.

The CAFE standard and RFS, without rebound and market effects modeled, combined with a total biofuel use of 90 billion gallons in 2050, 15 billion gallons renewable biofuel, 35 billion gallons advanced biofuel, and 40 billion gallons cellulosic biofuel, has the potential to reduce greenhouse gas emissions by 12.6 percent below 2000 levels in 2050. The volume of gasoline displaced by 90 billion gallons of biofuel in 2050 is 60.3 billion gallons per year, or 28.2 percent of total fuel needs. The CAFE standard and RFS policy combined with a total biofuel use of 90 billion gallons in 2050 result in the need for 68 percent less conventional gasoline in the year 2050 compared to the baseline for a total savings of 147 billion gallons.

IV. CONCLUSION

Conclusion

In 2007, Congress passed a comprehensive energy bill, titled, the "Energy Independence and Security Act" (EISA). In EISA, there were two policy provisions, the Renewable Fuels Standard and Corporate Average Fuel Economy Standard, which were analyzed in this thesis for the standards' respective ability to reduce greenhouse gas emissions and gasoline consumption in the U.S. transportation sector. Congress increased CAFE standards by requiring automakers to attain fleetwide gas mileage of 35 miles per gallon by the year 2020, and amended the RFS by increasing the required volume of biofuels used in our fuel supply to 36 billion gallons of renewable fuel by 2022. Due to the rate of auto fleet turnover in the U.S., the full benefits from the CAFE standard will not be fully seen until around 2050, which is 43 years after the legislation was passed.

The CAFE standard is more adept at reaching the policy goals of reducing greenhouse gas emissions and gasoline consumption as compared to the RFS policy. Both policies combined have the potential to reduce greenhouse gas emissions and gasoline consumption in the U.S. transportation sector by 2050 to levels near what were emitted and consumed respectively in the year 2000. When accounting for both rebound and market effects, the CAFE standard and RFS policies combined can reduce gasoline consumption more by an additional 12 billion gallons in 2050 as compared to the CAFE standard alone. However, an additional 0.10 billion metric tons of CO_2eq greenhouse gas emissions can be reduced in 2050 with the continuous use of the CAFE standard alone as compared to a combination of both policies.

The weakest policy provision in terms of reducing greenhouse gas emissions relates to renewable biofuel, or corn-based ethanol. The final rule promulgated by the EPA for the RFS program set the 2005 baseline lifecycle greenhouse gas emissions for gasoline at 98 kilograms of CO_2eq emissions emitted per million metric Btu's which is equivalent to 12.25 kilograms CO_2eq emissions emitted per gallon of gasoline consumed. New conventional ethanol facilities producing corn-based ethanol must achieve at least a 20 percent reduction in greenhouse gas emissions compared to baseline lifecycle greenhouse gas emissions for gasoline. As defined in the RFS final rule, the heat content of gasoline is 115,000 Btu's and the heat content of ethanol is 77,000 Btu's, so, roughly, 1.49 gallons of ethanol is the energy equivalent of 1 gallon of gasoline. Due to the ratio of the lower energy content of ethanol and the specified greenhouse gas emission reduction level for renewable biofuel or corn ethanol, greenhouse gas emissions for renewable biofuel must be above a 33 percent reduction level in order to have a positive impact on net greenhouse gas emissions. Renewable biofuel does have a positive impact in regards to reducing gasoline consumption. A significant increase in the production levels of advanced and cellulosic biofuels, leakage not modeled, can result in substantial gasoline savings of 28 percent or 61 billion gallons, but only slight greenhouse gas emission reduction benefits occur. Biofuels are more adept at reaching the policy goal of reducing the consumption of conventional gasoline as compared to reducing greenhouse gas emissions.

While neither the CAFE standard nor RFS is a long-term solution to the United States' dependence on oil, both policies combined can presently serve to mitigate climate change and extend our finite supplies of oil. In the future, hydrogen, electricity, or other forms of alternative transportation will likely come to fruition. In the meantime, biofuels are the only viable substitute for petroleum in the U.S. transportation sector, which is 96 percent dependent on petroleum, and improved vehicle fuel efficiency can help to more effectively use our finite supplies of oil until alternative transportation come to fruition.

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