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____________Jennifer Kuzma_____________

Name of Faculty Adviser

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Signature of Faculty Adviser

____

Date

Humphrey Institute of Public Affairs

Minnesota Biofuels Policy:

How much can biofuels contribute to carbon dioxide reductions from passenger vehicles?

A THESIS SUBMITTED TO THE FACULTY OF THE GRADUATE SCHOOL OF THE UNIVERSITY OF MINNESOTA

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Mahri Monson

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Jennifer Kuzma, Adviser

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ABSTRACT

In order to avoid catastrophic and irreversible impacts associated with global climate change, major and sustainable reductions in greenhouse gas (GHG) emissions must be made in all sectors relatively quickly. Biofuels have been touted as one significant solution to GHG emissions from the transportation sector, and policies that encourage the production and use of biofuels have been pursued at multiple levels of government. The State of Minnesota has had a renewable fuels standard in the form of a 10% ethanol mandate in place since 1997, and recently applied to the Environmental Protection Agency for a waiver necessary to increase the standard to 20% ethanol. MN is additionally considering the pursuit of an alternative biofuels policy, the low carbon fuel standard. It is important to analyze the potential long term impacts of these two biofuels policies in order to guide decisions that can maximize GHG reductions from the transportation sector. This paper utilizes a unique model based on the system dynamics framework to assess the impact of biofuels consumption in Minnesota on CO_2 emissions, a greenhouse gas that contributes significantly to global warming.

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Table 1. Abbreviations

AFCI	Average fuel carbon intensity
B	Billion
Dmnl	Dimensionless/no units
Gal	Gallon
gCO_2e	Grams of CO_2 equivalent
LCFS	Low carbon fuel standard
LDV	Light duty vehicle fleet
MJ	Mega joule
$MMtCO_2e$	Million metric tons of carbon dioxide equivalent
RFS	Renewable fuel standard
VMT	Vehicle miles traveled

CHAPTER 1: INTRODUCTION AND GHG REDUCTION POLICY FRAMEWORK

Background

The scientific community agrees global climate change caused by anthropogenic sources of greenhouse gas emissions (GHG) is occurring, and the projected rise in average global temperatures as a result of climate change could lead to serious consequences for human health, economies and the environment. The major global issues that could cause human, economic and environmental damage include sea level rise, increased prevalence of extreme weather like hurricanes and tsunamis, changing regional climates and agricultural growth patterns, and loss of biodiversity. Global warming has recently made it onto the popular radar and the issue currently receives wide political focus as a result. Policy makers at all levels of government are focusing on ways to decrease emissions of $CO_{2,}$ one of the main contributors to the greenhouse effect.

The transportation sector is a significant source of CO_2 emissions. In the United States, it accounts for 28% of GHG emissions, second in proportion only to electricity production, which makes up 33% (EPA 2006). Because of transportation's considerable contribution, the federal government and states have explored and continue to consider ways to lower CO_2 emissions from this sector. Biofuels in particular have received much attention as a way to address climate change, while also reducing dependence on foreign oil and providing economic opportunities for American farmers and rural communities. The basic idea is that fuels made from biomass will produce less GHG emissions than petroleum based fuels.

There are a variety of policy options for encouraging the development and use of biofuels in the transportation sector. Traditionally, R&D funding, tax breaks, grants, loans and regulatory mandates have all been used to support the biofuels industry. Two main types of biofuels policies have received much focus recently for their potential to reduce GHG emissions from the transportation sector: the renewable fuel standard (RFS) and the low carbon fuels standard (LCFS). It is important to analyze and compare these two policies with regard to their potential contribution to the overarching goal of reducing CO_2 emissions.

The goal of this analysis is to provide useful insight for the debate on biofuels policies in Minnesota. This paper seeks to add value to this debate in three main ways:

1. By detailing the background and consequences of the most widely implemented biofuels policy to date, the renewable fuel standard, and analyzing the logistics and potential impacts of an alternative policy, the low carbon fuel standard

2. Proposing a methodology of analysis for biofuels policies utilizing a system dynamics framework

3. Providing some basic results with regard to future CO_2 emissions from different biofuels scenarios run in a prototype of a model based on the system dynamics framework

The following section discusses a policy framework that provides context for the analysis of biofuels policies in this paper within the larger issue of GHG reduction policy and climate change mitigation.

Greenhouse Gas Reduction Policy Framework

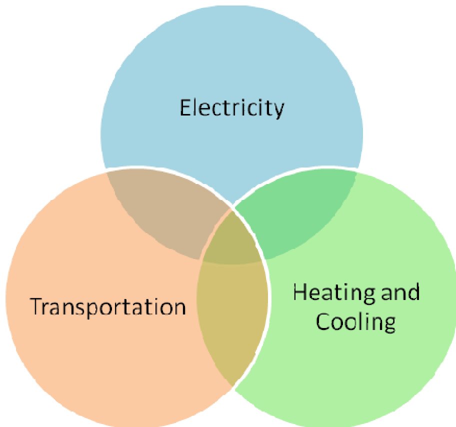
Governments, nonprofit organizations, businesses, communities and individuals around the world are now calling for significant greenhouse gas emissions reductions in order to mitigate global climate change. Efforts to reduce emissions are mainly targeted at three basic energy sectors:

1. Electricity

2. Transportation

3. Heating and cooling

Figure 1. Energy Sectors Overlap



There is some overlap within these sectors, as represented in Figure 1, but they are generally treated as distinct categories. Some examples of overlap include plug-in hybrid electric vehicles which use both electricity and transportation fuel and power plants that produce electricity but utilize the heated water for heating.

There are also three general categories of policies aimed at dealing with GHG emissions (Taff 2008):

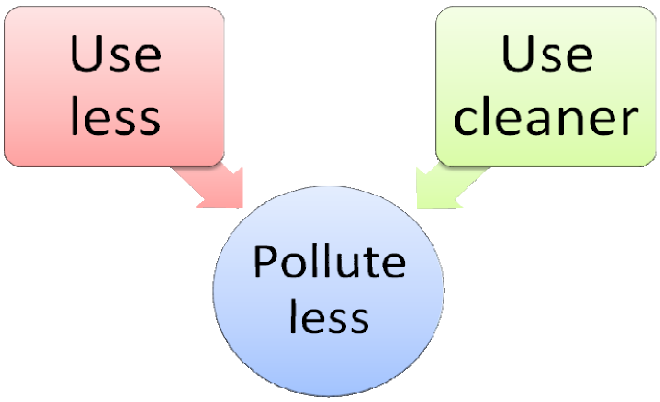
1. Use less

2. Use cleaner

3. Pollute less

All three categories implicitly seek to reduce emissions, but the first two categories utilize an indirect approach while the third category directly addresses the issue. Figure 2 represents the relationship of these three categories to each other.

Figure 2. Categories of GHG Reduction Policies



Within each of these categories, there are specific types of policies which help illustrate the distinction in categories:

1. Use less: efficiency and conservation policies

2. Use cleaner: renewable portfolio standards, renewable fuel standards, and low carbon fuel standards

3. Pollute less: emissions limits and cap and trade programs

Table 2 provides some examples of policies in each of the three energy sectors according to which general category they fall in. Note the applicability of certain types of policies, like conservation and efficiency, in all three energy sectors. In the final category of policy approaches, pollute less, the policy options listed here could be applied in all three energy sectors, either specific to one sector or as a national policy which encompasses all three sectors.

Table 2. GHG Reduction Policies by Category and Energy Sector

	Electricity	**Transportation**	**Heating and Cooling**
Use Less	Conservation Efficient appliances	Corporate average fuel economy standards Reduced vehicle miles traveled Public transit	Conservation Efficient appliances Building energy efficiency audits
Use Cleaner	Renewable portfolio standards	Renewable fuel standard Low carbon fuel standard GHG tailpipe emissions standards (CA Clean Car/ Pavley Standards)	Incentives for renewable options like geothermal heating and cooling
Pollute Less	Emissions limits Cap and trade Carbon tax		

Within the transportation sector, policies aimed at increased fuel economy and lowering vehicle miles traveled fall into the “use less” category. Biofuels policies fall into the “use cleaner” category, whether or not the evidence is clear enough to ensure that biofuels actually are cleaner, i.e. emit less CO_2 on a per energy unit basis. Both the renewable fuels standard and the low carbon fuel standard belong to this category of using cleaner energy in the transportation sector. Neither of these policies, nor any policy within the “use cleaner” category, will necessarily result in lower absolute levels of emissions, because they change the average carbon intensity of the fuel mix but do not explicitly address the total amount of fuel used and therefore the total emissions levels. For this reason, it seems reasonable and logical to pursue policies in all 3 categories within the transportation sector. Lee Freidman of UC Berkley pointed out during a presentation on cap and trade for the transportation sector an analogy between policies in the electricity sector and policies in the transportation sector. Dr. Friedman said in the electricity sector, government policies at a variety of levels have been pursued in energy conservation and efficiency, through efficient appliances and power plant conservation mandates, which fall into the “use less” category. Many states have also enacted renewable portfolio standards which mandate greater use of renewable energy, a “use cleaner” type of policy. The numerous regional cap and trade programs that have sprung up in recent years, as well as federal cap and trade program proposals at the national legislature belong to the “pollute less” category of policy (Friedman 2008).

Freidman pointed out that policy makers and regulated industries are generally comfortable with the prospect that renewable portfolio standards and cap and trade policies specifically are useful and appropriate for reducing GHG emissions from the transportation sector. The analogy to the transportation sector is the renewable fuel standard or the low carbon fuel standard, and cap and trade for the transportation sector (Friedman 2008). I would take Dr. Friedman’s argument one step further to say that a variety of policies from all three categories are generally accepted as productive pursuits in the electricity sector; it would be useful to open up a similar discussion within the transportation sector with regard to climate change mitigation policies.

With the background context of the GHG reduction policy framework addressed above, it is useful to examine traditional biofuels policies and their impacts on the goals of GHG reductions and other environmental and social issues.

CHAPTER 2: TRADITIONAL BIOFUELS POLICY AND TRADITIONAL BIOFUELS

The most widely deployed biofuels policy to date is the renewable fuel standard (RFS), and the most widely produced biofuel is corn grain ethanol. It is important to preface the analysis in this paper with a look at this traditional biofuels policy and the traditional biofuel that has filled it. This chapter will address the RFS and the rise of corn grain ethanol as the most prominent biofuel in order to help guide analysis of this and other policies and biofuels moving forward.

Renewable Fuel Standard

A renewable fuel standard requires that transportation fuel sold in a certain area contain a specified minimum amount of renewable fuel. This policy falls under the "use cleaner" category of GHG reduction policies. Generally, any fuels made from plant or animal products or wastes, as opposed to fossil fuels, are considered renewable fuels under an RFS. The United States has a national RFS, updated under the Energy Policy Act of 2005, which now requires 7.5 billion gallons of renewable fuels be blended into the total supply of gasoline sold in the U.S. by 2012. The U.S. is already on its way to achieving this regulation; in 2006 5.4 billion gallons of renewable fuels were used by refiners, blenders and importers, an amount almost 25% above the required volume for that year (EPA 2007). In addition to the national level, eight states have an RFS in place (Renewable Fuels Association 2008).

In Minnesota, the RFS takes the form of an ethanol requirement. According to the MN RFS statute, as of 1997 all gasoline sold in MN must have 10% denatured ethanol by volume. The State Legislature recently passed a more stringent RFS which will require 20% ethanol starting in August of 2013 (MN Statute 239.791, 2007), pending EPA approval. The vast majority of the MN RFS, as well as other states' RFS, are currently filled by corn grain ethanol.

Corn Grain Ethanol

Ethanol, or EtOH, is an ethyl alcohol made from a chemical reaction where sugar is fermented into a volatile liquid. Ethanol can be combusted as a fuel in internal combustion engines, forming carbon dioxide and water, similar to the combustion of gasoline. The sugar needed to produce alcohol can be utilized from starchy materials, like corn grain, which requires a process of hydrolysis of starch into glucose (Ethanol Information 2008).

The corn ethanol industry is established, financially successful, and growing in the United States. Over $10 billion has been spent on the industry since the year 2000, resulting in approximately 6.5 billion gallons of ethanol capacity (Koplow 2006). In 2004 3.4 billion gallons of ethanol were produced, an amount that constituted approximately 2% of the volume of gasoline sold that year (Farrell et al. 2006). Midwest states, including Minnesota, have gained much from this industry as big corn producers. While the ethanol industry has historically maintained a high level of political support over the years, there is now popular controversy over the previously touted advantages of corn ethanol and some potentially significant disadvantages. Chapter 3 addresses the issues associated with this controversy in more detail.

Federal Ethanol Policy

The ethanol industry has been in the making for almost 30 years. Concerns similar to those of today, i.e. rising gasoline prices, environmental degradation and dependence on foreign sources of oil, resulted in a push for development of fossil fuel alternatives 28 years ago. This push came mostly in the form of government policy. A report put out by the U.S. Department of Agriculture in 1988 summarizes how the corn ethanol industry came into being: "The fuel-ethanol industry was created by a mix of Federal and State subsidies, loan programs, and incentives. It continues to depend on Federal and State subsidies" (Koplow 2006). The first federal policy to favor ethanol was the 1978 Energy Tax Act, which exempted ethanol from the fuel excise tax of $0.04 per gallon at that time. This act enabled the development of the first commercial ethanol production of 20 million gallons that year. Since that time, the corn ethanol industry has enjoyed the support and encouragement of a large array of policies including R&D funding, tax breaks, grants, loans and regulatory mandates. By 1985, 29 states had implemented some type of ethanol incentive. The Volumetric Ethanol Excise Tax Credit (VEETC), enacted by the JOBS Act of 2004, is the contemporary version of the fuel excise tax that benefited ethanol for 26 years. VEETC provides a tax refund of $0.51 per gallon of ethanol blended with gasoline, and constitutes the largest single ethanol subsidy (Koplow 2006).

Minnesota Ethanol Policy

The state of Minnesota has contributed heavily to the development of corn ethanol, spending over $300 million since 1982 on subsidies for plant operators (The Great Corn Rush 2006). In 1980 MN implemented an ethanol blenders' credit for $0.40 per gallon, a credit which was in place for 16 years until it was phased out in 1997 (Koplow 2006). According to the Minnesota renewable fuel standard already mentioned, all gasoline in the state of Minnesota today contains 10% ethanol, and even with this high portion, MN still exports over half of the ethanol it produces to other states (The Great Corn Rush 2006). Minnesota has also established a renewable fuels mandate that in 2013 will require 20% ethanol content in gasoline sold in the state (Koplow 2006), if MN can receive EPA approval for this level of blending. There are currently 17 ethanol plants operating in MN at a total capacity of 680 million gallons per year, spread throughout the southern half of the state. There are also 4 ethanol plants under construction representing a potential addition of 400 million gallons (MDA 2008).

Federal and some state governments have historically placed high value on the existence and success of the corn ethanol industry, as is exemplified by their twenty-eight-plus years of financial support and various mandates. But organizations and individuals are questioning the real benefits of the proliferation of this industry that compel us as a society to continue heavily supporting it. It is useful and appropriate to quantify and qualify these benefits as thoroughly as possible, in order to evaluate corn ethanol's contribution to the goals of rural economic development, energy independence, environmental improvements and global climate change mitigation, and decide accordingly what the next logical steps are regarding renewable fuels. The following chapter will address some of these issues in order to guide analysis of the continuation of current trends and of an alternative biofuels policy.

CHAPTER 3: IMPACTS OF TRADITIONAL BIOFUELS POLICY AND TRADITIONAL BIOFUELS

The prominence of the RFS as the leading biofuels policy and corn grain ethanol as the leading biofuel has had some significant economic and environmental impacts, and the continued growth of both policy and fuel could have even more serious consequences moving forward. This chapter addresses some of the impacts of traditional biofuels policy and the most widely produced biofuel to date. Chapter 3 also examines future trends in ethanol, specifically a switch to cellulosic ethanol. Examination of these consequences and future possibilities provides a useful starting point for this paper's analysis of possible future scenarios under the RFS with corn grain ethanol and cellulosic ethanol.

Energetic Outputs and Environmental Consequences of Corn Ethanol

While rural economic development is an important social and political goal, it is essential to include in an analysis of corn grain ethanol its contributions with regard to energetic output and environmental impacts. Hill, Nelson, Tilman, Polasky and Tiffany from the University of Minnesota conducted a life-cycle accounting of ethanol to determine its net energy output and overall environmental benefits (2006). To achieve such a complete account, their study included all the energy and environmental impacts of ethanol production throughout the process, including the farming of corn, transportation of the feedstock to a processing plant, and processing the corn into ethanol.

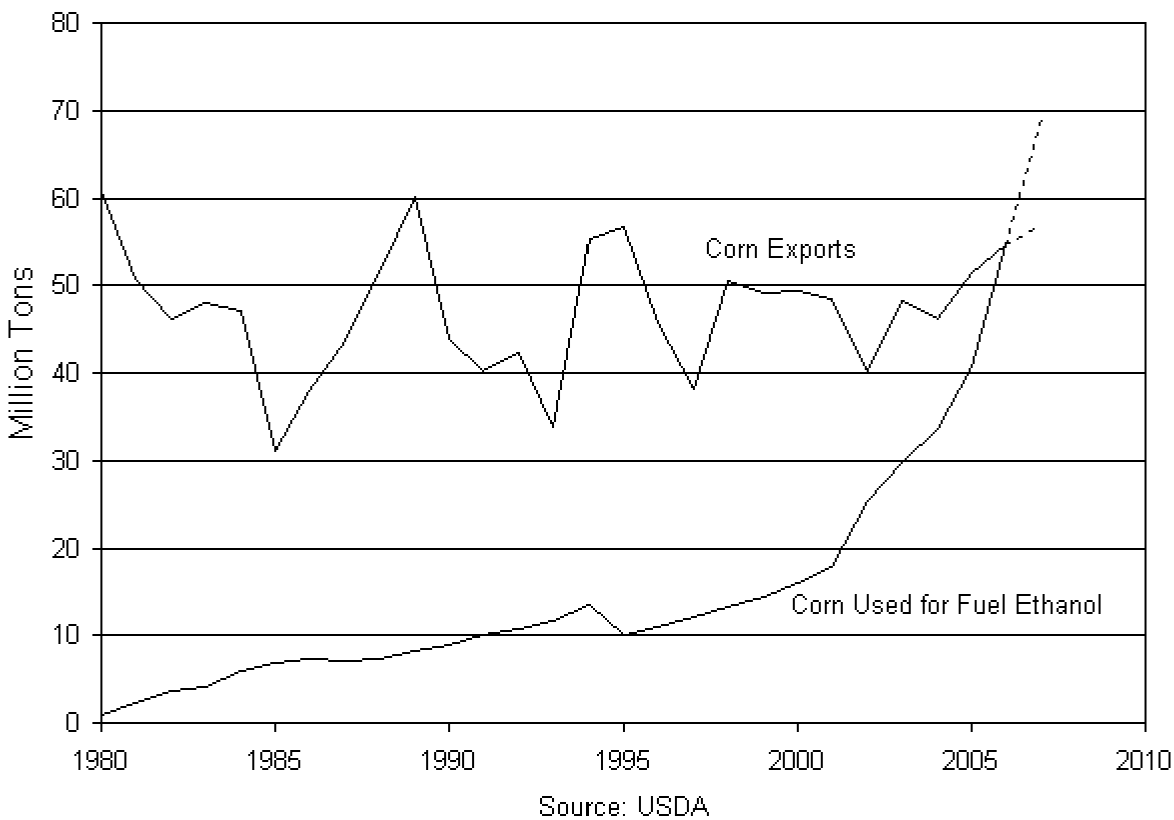
The Hill et al. study finds that corn grain ethanol produces 25% more energy than the energy put into its production, compared, for example, to biodiesel which has a net yield of 93% (2006). One essential service that should be provided by alternative energy sources is reduction of greenhouse gas (GHG) emissions, which fossil fuels emit heavily, and which cause global warming. The Hill et al. study reveals that corn grain ethanol production and use reduces GHG emissions by only 12% compared to the petroleum gasoline it replaces (2006). There are a number of reasons for the relatively low net energy yield and GHG reduction of corn ethanol. Corn is an intensive agricultural crop, and therefore its cultivation has significant environmental impacts. Its production requires heavy inputs of nitrogen and phosphorus in fertilizers, the use of pesticides to keep pests at bay, and the farm equipment used runs on petroleum-based fuel. Another factor limiting the overall environmental benefits of corn grain ethanol is that many ethanol plants are powered by conventional, fossil-fuel electricity, the type of ethanol plant that will be modeled in this analysis. The potential impacts of an alternative to grain ethanol, cellulosic ethanol, are addressed later in this chapter.

Potential Supply of Corn Ethanol

It is also important to consider the possible scale of corn ethanol production. Corn ethanol's potential for displacement of petroleum-based fuel is limited. In 2005, corn grain ethanol production was equal to 1.72% of U.S. gasoline usage, and this amount was made by utilizing 14.3% of the U.S. corn harvest (Hill et al. 2006). Hill et al. addressed the future potential supply of corn ethanol and found that corn ethanol could meet at the most 12% of U.S. gasoline demand, by dedicating all U.S. corn crops to ethanol production. In addition, the 12% displacement of U.S. gasoline demand would represent only a 2.4% net energy gain because of the fossil energy currently used to produce corn grain ethanol (Hill et al. 2006). It is unlikely that we would ever achieve this percentage of petroleum fuel displacement, since corn is an important food crop. Biofuels in general and corn ethanol in particular have been part of a contentious international debate referred to as the "food versus fuel" controversy. There are two main issues at play in this controversy. First, the use of food crops for fuel takes away from the actual food supply. Second, the demand for crops for fuel typically increases the price of that crop, which in turn could increase food prices. Figure 3 shows the increase in the amount of the U.S. corn crop being dedicated to ethanol production since 1980 compared to the total amount of corn exported. In 2006, the amount of corn used for ethanol is the same as the amount of corn exported (Earth Policy Institute 2006).

Figure 3. Tons of corn used for ethanol compared to tons of corn exported

(Earth Policy Institute 2006).



The Future of Corn Ethanol

Ethanol production is expected to increase from current levels by 50% by 2008 (Koplow 2006). Corn ethanol is currently the most dominant alternative fuel in the United States; 99% of biofuels produced in the U.S. come from corn ethanol (Farrell et al. 2006). In light of the recent studies by Hill et al. and others that illuminate the relatively limited energetic productivity, environmental benefits and potential supply of corn grain ethanol, it is now appropriate to focus on developing alternative renewable fuels with greater energetic potential and better environmental impacts.

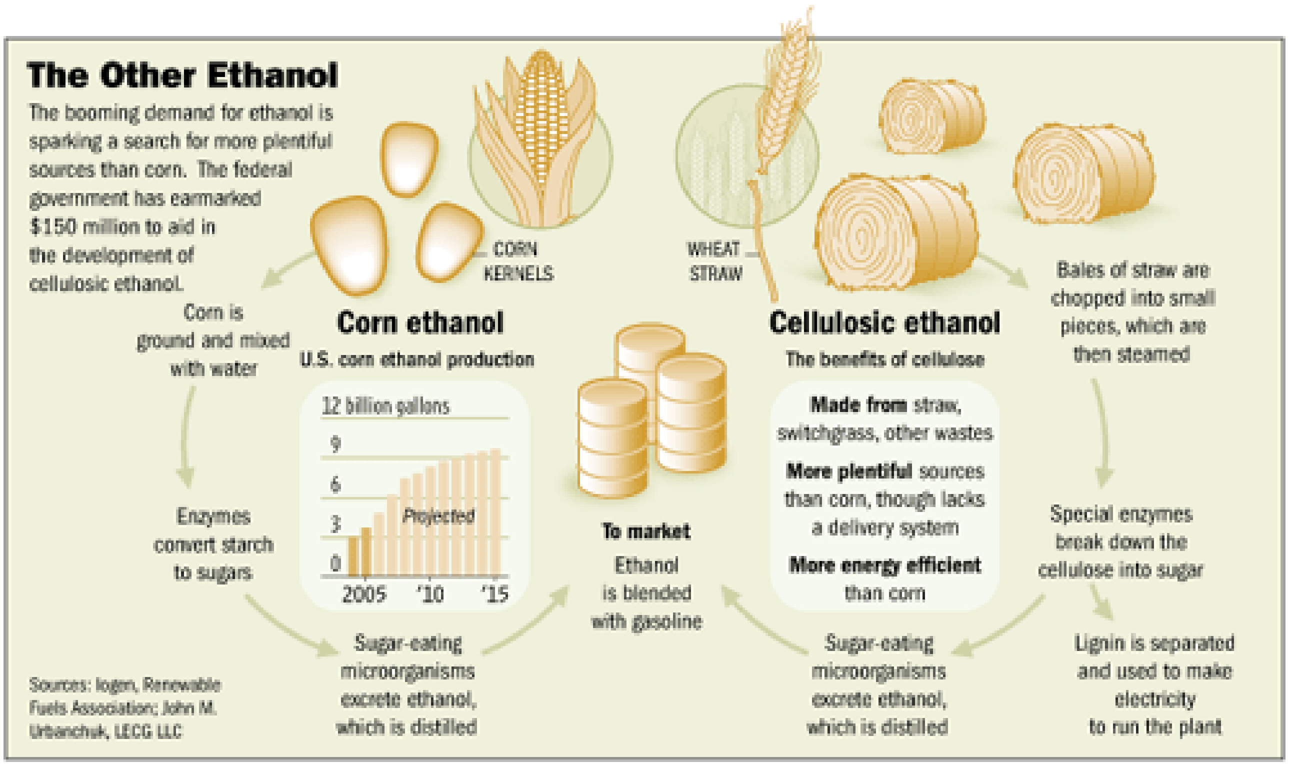
Cellulosic Ethanol

Cellulosic ethanol, which can be produced from a variety of feedstocks including plants, trees, agricultural residues, and municipal waste, may be able to reduce CO_2 emissions. Farrell et al. modeled a potential reduction in GHG emissions associated with cellulosic ethanol of 88% compared to gasoline (Farrell et al., 2006). Technologies for cellulosic ethanol production are currently being utilized in pilot and demonstration projects in the public and private sectors in the U.S. and internationally.

One potential biofuel alternative is cellulosic ethanol. While corn grain ethanol is made by processing only the starch found in corn kernels, cellulosic ethanol is made by processing cellulose which means it can be produced using virtually any organic matter from trees and grasses to agricultural wastes, including the stocks and husks of corn and wheat straw, and even municipal garbage, which include a lot of organic matter. Figure 4 below outlines the processing similarities and differences between corn ethanol and cellulosic ethanol, using wheat straw as an example. A number of companies are pursuing wide scale production of cellulosic ethanol, although there remain some challenges including high costs of processing cellulose and the risk to investors of an unproven market.

Figure 4. Basic Factors of Corn Grain Ethanol and Cellulosic Ethanol Production

(DuPont 2006).



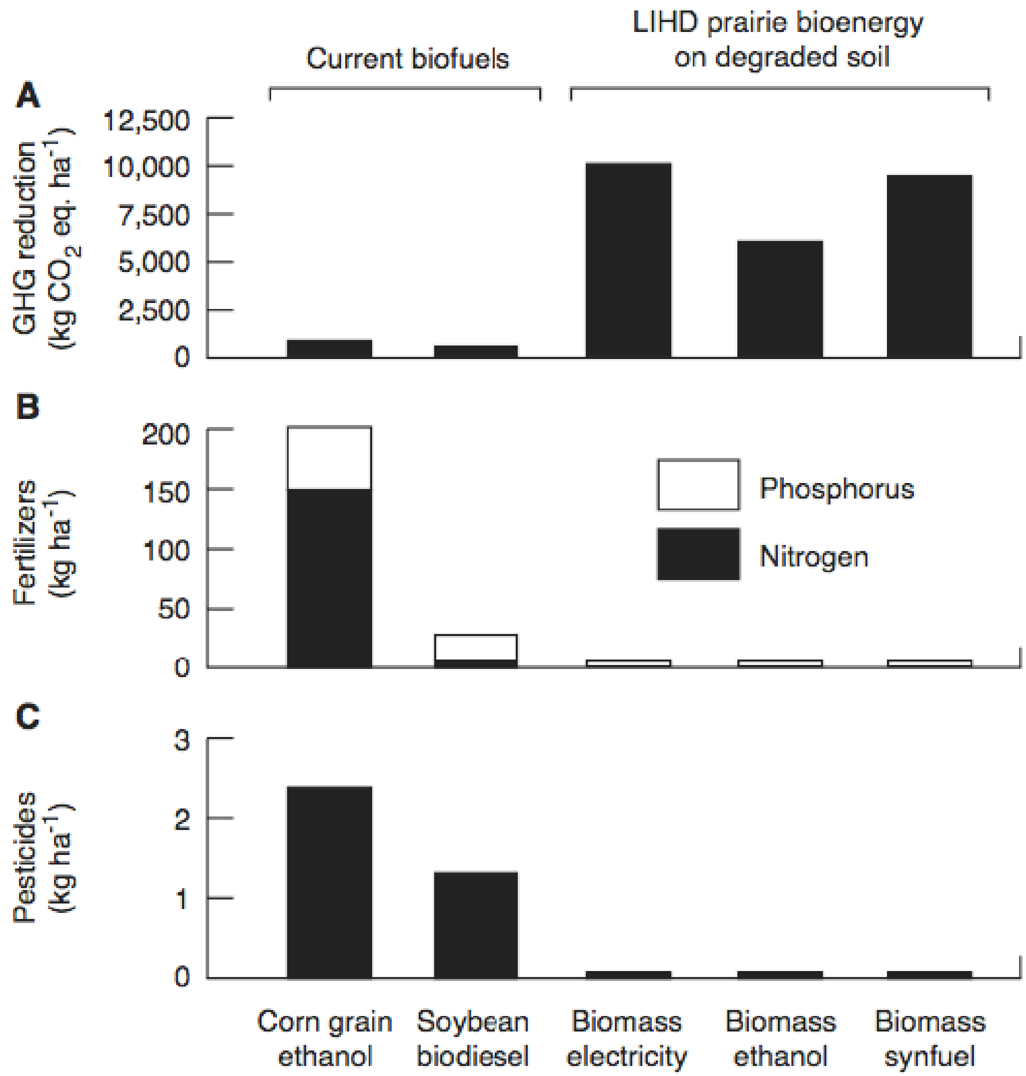
Mixed Grasses for Cellulosic Ethanol

Many of the feedstocks that are being pursued for cellulosic ethanol so far are grown as monoculture crops such as switchgrass, poplar and willow (Mapemba et al. 2006). It is important to consider the energetic, environmental and economic attributes, and potential supply of various feedstocks to decide which ones should be prioritized and pursued for use in the production of cellulosic ethanol. One feedstock with good potential is native prairie grass mixtures. Native grasslands are claimed to provide marked advantages over monocultures in the following ways: mixed communities are less subject to being severely damaged by pests or diseases, which tend to attack one particular species. Diverse mixtures may provide other environmental benefits such as superior wildlife habitat. One of the most important advantages of diverse mixtures of prairie grasses over grass monocultures as feedstocks for biofuels is their tendency to produce higher amounts of total biomass, and therefore more energy (Tilman, Hill and Lehman 2006).

A recent paper from University of Minnesota researchers gives a quantitative analysis of the potential advantages of biofuels produced from low-input high-diversity (LIHD) grassland biomass over corn grain ethanol and biofuels produced from monocultures. The paper is based on experimental plots that were planted in LIDH and monocultures of perennial grassland species in 1994. The plots were planted on agriculturally marginal land without the use of fertilizer. Compared to monocultures of various grasses, Tilman et al. found that LIHD grasses yield 238% more standing biomass, which can be converted into energy. Because LIHD biomass requires no fertilizer and minimal pesticides, its production is significantly more environmentally benign than the growth of corn, which requires heavy fertilizer and pesticide application (see Figure 5). Native prairie grassland mixtures also sequester a significant amount of CO_2, an important service in a world faced with global warming as a result of too much CO_2 in the atmosphere. Tilman et al. found that LIHD sequestered 160% more CO_2 than grass monocultures. LIHD grassland biomass can actually sequester more CO_2 than is emitted from fossil fuels used in their growth, transportation to plants and production into biofuel, making LIHD biofuel net carbon negative. According to models of converting LIHD into biofuels, this implies substantial greenhouse gas (GHG) reductions over corn ethanol (see Figure 5), and an opportunity to provide energy with no net CO_2 emissions. (Tilman et al. 2006). Given the multiple benefits provided by mixed communities over monocultures, policy aimed at feedstock development for cellulosic ethanol should favor diverse prairie grasses.

Figure 5. Comparison of Biomass Energy Options

A modeled comparison of corn grain ethanol, soybean biodiesel, and three types of energy production from LIHD biomass in (A) greenhouse gas (GHG) reduction compared to conventional sources, (B) fertilizer inputs and (C) pesticide inputs (Tilman et al. 2006).



Potential Supply of Biomass

The growth and harvest of mixed prairie grasses in their native habitats throughout the Corn Belt could provide a significant source for cellulosic ethanol.

One potential supply for biomass production for cellulosic ethanol is Conservation Reserve Program (CRP) land. The CRP is a conservation program of the U.S. Department of Agriculture, which pays rent to farmers and landowners to retire agriculturally marginal and environmentally sensitive land from production. There is wide consensus that the CRP provides substantial environmental benefits, including reduction in soil erosion, reduction in pollution associated with lower fertilizer and pesticide use, and provision of wildlife habitat (Lubowski et al., Tiffany et al.). Nationally, CRP enrolls a land area almost the size of Iowa (Lubowski et al. 2006). Much of this land is concentrated in the Great Plains region. There are over 5.3 million acres of land actively enrolled in the Conservation Reserve Program in Minnesota, North Dakota and South Dakota as of April 2006. Minnesota alone has almost 1.8 million CRP acres (Tiffany et al. 2006), which constitutes approximately 34% of the CRP land in the three-state area mentioned above and 5% of the total U.S. CRP land of 34 million acres (Farm Service Agency 2008). CRP land in the Midwest may be ideal for mixed-grasses biomass production because it contains agriculturally marginal land and prairie grasses are native species there. Because growth of native grasses on CRP land would not require foregoing more valuable crops, since the land is already in retirement, it would provide a relatively cheap source of biomass for cellulosic ethanol. Tiffany et al. estimate a cost for biomass of $20 to $30 per ton on CRP land, which includes a CRP rental payment of $20 to $40 per acre, and approximately $50 per ton on non-CRP land. Ideal locations for cellulosic ethanol processing plants would be in close proximity to the feedstocks, like the prairie grasslands of the Corn Belt, in order to minimize the costs of transporting biomass to production plants (Tiffany et al. 2006). Biomass production on CRP land poses a cheap and environmentally friendly feedstock for cellulosic ethanol. Producing native prairie grasslands on non-CRP land should also be explored. This is not currently being done because the rules of CRP at present prohibit harvest, but revision of the rules for multiple-use including biomass production is being explored (Farm Service Agency 2008).

While cellulosic ethanol produced from various low-input feedstocks poses potential improvements over corn grain ethanol, the traditional renewable fuel standard does not necessarily incentivize the development of cellulosic ethanol. The general characteristics of the RFS limit its impact as a tool for climate change mitigation. The RFS does not explicitly address GHG emissions reductions, and therefore does not discriminate among different types of biofuels based on this or any other environmental metric. Different types of biofuels can vary widely in their emissions characteristics based on feedstock type and processing technologies; the ability of a particular biofuel to displace GHG emissions relative to petroleum-based fuels depends on the carbon intensity associated with its production and use across its full life-cycle (Farrell et al. 2007). Given this limitation, it is important to explore alternative biofuels policy options.

CHAPTER 4: ALTERNATIVE TO TRADITIONAL BIOFUELS POLICY: THE LOW CARBON FUEL STANDARD

The low carbon fuel standard (LCFS) is an alternative biofuels policy which has already been passed in California, and is being considered by other states, including Minnesota. The LCFS differs from the RFS in a number of key ways, posing the potential for much different impacts. This chapter describes the LCFS and lists potential advantages relative to the RFS, as well as some disadvantages and limitations. An understanding of the LCFS relative to the RFS is important to the model developed for this analysis, which addresses the impacts of various RFS scenarios on hypothetical LCFS goals for Minnesota.

The LCFS is a “use cleaner” policy aimed at reducing GHG emissions by regulating an industry’s emissions on a per-unit of output basis; this type of policy could be used in a variety of sectors including electricity, industry, and transportation fuels. The LCFS has received focus and support recently in a range of regions and across different levels of government. Outside the U.S., a number of governments are considering implementation or have already instituted some type of LCFS including the European Union, the United Kingdom and British Columbia. U.S. Senators John McCain and Barack Obama promote enactment of a federal LCFS and several U.S. states (Arizona, Illinois, Minnesota, New Mexico, Oregon and Washington) are exploring the possibility as well. California, under executive order from Governor Schwarzenegger in January of 2007, is currently reviewing their transportation fuels LCFS for implementation in early 2010 (Holland, Knittel & Hughes 2007).

The CA LCFS serves as a useful example of the basic principles and components of a low carbon fuel standard for the transportation sector. California is particularly well suited for testing the effectiveness of this policy, since its transportation sector accounts for 40% of the state’s total GHG emissions, as opposed to 28% for the national average (Farrell et al. 2007). The CA rule applies to all liquid fuels sold in the state of California for use in transportation, including passenger vehicles, freight and off-road applications like construction and agricultural equipment. Petroleum gasoline and diesel, as well as any biofuels substitutes for these two main transportation fuels, are regulated by this law. The point of regulation is refiners, blenders and importers of liquid fuels when finished gas or diesel is first manufactured or imported to CA. In addition, non-liquid fuels like hydrogen, electricity, natural gas, propane and others are allowed to participate in the LCFS, and may be required to do so sometime in the future as the number of non liquid fueled vehicles grows (Farrell et al. 2007).

The LCFS has an intensity standard which requires fuel providers to decrease the carbon intensity of average annual fuel sales. California is considering emissions goals which are compatible with what is considered necessary to avoid dangerous climate change: 10% reduction in average carbon intensity by 2020 and an 80% reduction by 2050, relative to 2005 intensity (Farrell et al. 2007). The definition of carbon intensity under this regulation is “the average full fuel-cycle greenhouse gas emissions per unit of transportation fuel energy” (SB 210). The carbon intensity is based on lifecycle analysis, i.e., it measures carbon emissions across the full life cycle of the fuel. This cradle to grave approach, referred to as a life cycle analysis (LCA) includes CO_2 emissions associated with the production, transport, storage and combustion of both the feedstock and the fuel itself (Scopec 2007). The CA rule is quite comprehensive and explicitly includes in the full fuel-cycle “production, extraction, cultivation, transportation, and storage of feedstock; the production, manufacture, distribution, marketing, transportation, and storage of fuel; and vehicle operation including refueling, combustion, conversion, and evaporation.” The full fuel-cycle also encompasses the use and transportation of water, as well as land use changes associated with feedstock and fuel production (SB 210).

The State Air Resources Board will be responsible for determining values for carbon intensity (also known as global warming intensity or GWI) based on the best available empirical data for specific inputs and processes across each fuel’s life cycle. The methodology for determining full fuel-cycle GHG emissions will be updated periodically to account for new and/or improved information (SB 210). If fuel providers do not want to use these default values, and they provide sufficient data, they can certify their particular fuel as having a lower GWI value (Farrell et al. 2007).

There is not yet one standardized way to calculate life cycle emissions. There are a variety of models that take into account various issues, and both setting the boundaries of these models and estimating values can be a challenging and contentious issue. There are basically two conceptual ways to estimate life cycle impacts: well to tank, which documents emissions from production of a fuel to the gas tank, and well to wheel which adds on the combustion impacts associated with actual use of the fuel in a vehicle. Resource extraction is the beginning of an LCA estimate, and this resource extraction can include the impacts of land use change. Recent studies by Fargione et al. 2008 and Searchinger et al. 2008 have estimated LCA numbers for various biofuels that are much higher than previous estimates because they incorporate the long term GHG impacts of converting native ecosystem lands to biomass crops. This is a contentious issue, because it drastically changes the picture of current biofuels; many individuals and organizations do not accept the scientific validity behind these analyses. Nonetheless, this type of inclusive analysis, e.g. far-reaching impacts of land use change, will prove important moving forward as we get better at articulating the true impact of various fuels and use that knowledge to make better informed GHG reduction policy decisions.

There are two basic ways a low carbon fuel standard can impact the overall carbon intensity of the transportation fuel sector: either by driving changes in the portfolio mix of fuels or by driving changes in the carbon intensity of various fuels across their entire life cycle (Taff 2008). In the shorter term, it seems likely an LCFS would instigate changes in the portfolio, so blenders and producers would increase the use of relatively lower carbon fuels and decrease the use of higher carbon fuels according to current life cycle estimates of carbon intensities for certain types of fuels. This would be the most immediate way to achieve the required reductions, but in the longer term, fuels producers would have the incentive to reduce the carbon intensity numbers of different fuels through changes in production technologies or practices. For example, the carbon intensity of corn grain ethanol can have large variations depending on the power and heat sources used in production; an ethanol plant which utilizes corn stover for processing heat and electricity would emit less carbon over the full life cycle than a plant which uses coal fired electricity or even natural gas. In addition, changes in the farming practices of the feedstock could change the carbon intensity of ethanol. Corn grown on agriculturally marginal land, using low or no till practices, may have a lower carbon footprint than conventionally-raised corn. Transportation distance can also have a major impact on carbon intensity; corn grain ethanol produced in the Midwest has a lower carbon intensity when it is used in the same region than when it is transported to California, for instance. A low carbon fuel standard would likely impact the overall carbon intensity in both of these ways: by changing the portfolio and by changing the carbon intensities.

The low carbon fuel standard has a number of general advantages as a biofuels standard; there are a number of additional potential benefits associated with the specific layout of the California LCFS. Many of these assets draw from and leverage advantage in multiple areas at once, e.g. biofuels can be both an environmental benefit as far as decreased air pollution and an economic boon for producers who have a new market for a profitable product. For the sake of simplicity, the advantages are divided into the three categories of analysis below: environmental, economic and political. Benefits specifically attributable to CA's LCFS are explicitly stated as such.

Environmental

The low carbon fuel standard is designed to deal with global climate change, arguably the most pressing contemporary environmental issue. The most important environmental benefit of the LCFS in this respect is that it explicitly addresses CO_2 emissions, the greatest human activity induced contributor to global warming. By setting a required reduction in the carbon intensity of the fuel mix, which increases over time, the LCFS should result in reduced CO_2 emissions (Farrell et al. 2007, Holland et al. 2007). This gives the LCFS a major advantage over a renewable fuel standard, which does not necessarily lead to a decrease in GHG emissions. The LCFS does not commit society to technologies with small or modest GHG benefits. The LCFS takes an additional step to address climate change issues not directly incorporated into the carbon intensity for each fuel; there will be an estimated value of global warming impact associated with crop-based biofuels for direct and indirect land use change (Farrell et al. 2007).

In addition to global warming, there are a variety of other critical environmental issues that are profoundly impacted by biofuels development and policy. Land use and cultivation methods can influence soil quality, water quality, wildlife habitat and biodiversity. In order to protect the environmental quality gains contributed to by land in conservation programs, biofuels produced on protected lands will not be eligible for inclusion in the LCFS. This policy will further aim to address environmental issues by expressly dealing with externalities and unintended consequences associated with biofuels by incorporating these impacts into the market for fuels (Farrell et al. 2007).

In order to achieve the reductions in GHG emissions from the transportation sector necessary for the successful mitigation of global warming, the market needs a significant price or policy signal to promote substantial investments in new fuel and vehicle technologies soon. The LCFS creates a stable economic environment for this kind of investment, and also creates a certain and long-term market for low carbon fuels (Farrell 2007). The market for low carbon fuels may put enough of a premium on cellulosic crops to incentivize farmers to grow the biomass necessary.

Economic

Fundamentally, there is market failure in transportation fuels in that the negative externalities associated with GHG emissions are not accounted for within the market. There is currently little market incentive to develop low carbon alternatives to fossil fuels. The LCFS could address this issue by creating a market for low carbon biofuels while simultaneously penalizing the use of high carbon fuels. In theory, the LCFS would provide an economic disincentive for further development and investment in carbon-intense transportation fuels like heavy oil, tar sands, oil shale and coal which have higher carbon emissions than traditional petroleum fuels. Because of the participation of non-liquid transportation fuels, the LCFS should also increase the number of alternative fuel and hybrid vehicles available and sold in the U.S. (Farrell et al. 2007).

One overall advantage of the low carbon fuel standard is that it is fuel neutral-- fuel providers can choose which fuels and at what volumes they want to sell. From an economic perspective, this allows greater freedom for the market to operate unhindered and better chances of finding the economically efficient allocation of biofuels production and consumption. A volumetric or proportional mandate for a specific fuel, on the other hand, inhibits the laissez faire function of the market and, in essence, constitutes "picking winners". The CA version takes this principle a step further by allowing fuel providers and fuel producers to use electricity, hydrogen, natural gas etc. in the carbon intensity standard, e.g. by allowing trading of carbon intensity credits created by electric vehicles or hydrogen fuel cell powered vehicles (Farrell 2007, Scopec 2007). Compared to a renewable fuel standard, an LCFS is more flexible because it is not limited to biofuels only.

The LCFS also allows flexibility in compliance by sanctioning averaging, banking and trading among the regulated producers and providers. The flexibility of this policy both in fuel type and compliance options leads to a least cost method of abatement because firms are free to negotiate among higher and lower cost abaters, allowing a certain level of CO_2 reduction at a lower cost than mandating each producer to abate the same amount (Farrell et al. 2007). Both petroleum-based fuel providers and biofuels producers can benefit under this policy. There are a variety of ways petro fuel manufacturers can actualize their carbon reducing potential, including blending higher levels of biofuels, buying low-carbon fuels and emissions credits, making refineries more efficient and using lower-carbon sources of energy to run refineries. According to the rules under the CA LCFS which allow for trading, low carbon biofuels firms may have a greater incentive to innovate because they would be able to recoup some of their investments by selling credits to higher carbon fuel producers (UC Experts 2007). The rules and details of trading credits within the LCFS are still under debate and consideration, but allowing trading is one key aspect of allowing the market to decide which firms can lower their carbon intensities at the least cost.

The formulators of California's low carbon fuel standard are taking additional steps to specify an effective policy which is based on sound economic principles. The LCFS will provide an added incentive for innovation in biofuels by offering "innovation credits" which will grant additional carbon credits to novel and highly innovative low carbon fuels. A cost analysis will be conducted on the LCFS at some point in the future, similar to the evaluation of the U.S. Clean Air Act based on the cost-effectiveness approach. This analysis will protect proprietary information and acknowledge uncertainty in the estimates of carbon intensities for newer biofuels; it will also include non-climate related costs and benefits (Farrell et al. 2007).

Political

Politicians, both democratic and republican, have paid particular attention recently to the low carbon fuel standard. Former democratic Senator Tom Daschle has a very optimistic view of the LCFS: “By mandating that a growing percentage of the market for transportation fuel be set aside for low-carbon fuels, such programs would unleash a tidal wave of private-sector investment…the example of these policies could serve as a beacon to the rest of the world and encourage similar behavior elsewhere, including in China and India” (Daschle 2007).

Disadvantages and Further Economic Analysis

To date, there has only been one published economic analysis of the low carbon fuel standard. Holland, Knittel and Hughes (2007) analyze the potential impact of the LCFS by using economic models to simulate the outcomes of a national LCFS with various parameters. This study treats carbon emissions as a negative externality associated with energy production and for simplicity uses only two different fuels, a low carbon and a high carbon fuel. The authors model corn grain ethanol as the low carbon fuel, based on their assumption that corn ethanol is less carbon intense than gasoline, and gasoline as the high carbon fuel. The findings of this analysis are cause for some caution in unbridled enthusiasm for the LCFS. More importantly, however, the Holland et al. study illustrates some key ways this policy can be designed and specified for the best chances of effective CO_2 reduction in an economically sound way. In addition, the results of this analysis could change dramatically with the incorporation of a lower carbon fuel than corn ethanol. Second generation fuels, like cellulosic ethanol, represent significantly lower carbon intensity than corn grain ethanol and may even be carbon negative over their lifetime. As we look to the future of biofuels, the truly low or negative carbon fuels will change the nature of the economics of the LCFS.

In order to comply with the specified level of carbon intensity (the life cycle quantity of CO_2 emitted per energy unit of fuel) established by an LCFS, firms will either have to increase production of low carbon fuels or decrease production of high carbon fuels. Overall, Holland et al. find that the LCFS causes both an increase in the production of low carbon fuels and a decrease in the production of high carbon fuels. Therefore, the net impact could be an increase in emissions if the carbon from increased production of low carbon fuels outweighs the reduction in carbon from decreased production of high carbon fuel. However, using a variety of parameters in their model, the authors determine it is unlikely that CO_2 emissions would increase under an LCFS. In fact, in calibrating the theoretical model to current U.S. supply and demand conditions for ethanol and gas, Holland et al. found one simulation for an LCFS that reduces carbon intensity by 10% that resulted in a 45% decrease in CO_2 emissions. Note that the 10% reduction in carbon intensity by 2020 is exactly what the California LCFS calls for (Holland et al. 2007, Farrell et al. 2007).

Holland et al. articulate economic efficiency problems with the LCFS through high surplus losses and high average costs for carbon reduction. According to one simulation for an LCFS which reduces carbon intensities by 10%, the authors estimated $80-760 billion per year in surplus losses and $307-2272 per ton of CO_2, which may be significantly greater than climate change damage estimates on a per ton of carbon basis. The social welfare impacts depend on elasticity of supply and demand; a given tax or subsidy has a larger impact on output for more elastic supply and demand. The relative elasticities determine whether producers, consumers or both bear the costs of the LCFS through changes in producer and consumer surplus. According to classical economic theory, consumer surplus is the overall benefit consumers achieve from paying an actual price for a good that is lower than what they are willing to pay. This amount or surplus can then be used for economic gain in other areas. Producer surplus is the net revenue producers receive after subtracting all the opportunity costs of their investment. This analysis shows, under most standards (except extremely lenient ones) consumer surplus from energy consumption decreases and producer surplus can decrease or increase (Holland et al. 2007).

According to the Holland et al. economic analysis, the LCFS would be most effective with the low carbon fuel that has a carbon intensity of zero. Since the authors did not model a carbon neutral or negative biofuel, it is possible the incorporation of such a fuel would lead to a more favorable economic analysis of the low carbon fuel standard overall (Holland et al. 2007). Cellulosic ethanol produced from low input high diversity prairie grasses, addressed above, is one potentially carbon neutral biofuel that could be modeled.

The economic analyses conducted by Holland et al. provide a useful starting point for addressing the potential benefits and costs of a low carbon fuel standard. However, these analyses are also very complicated and reproduction seems limited to highly trained economic practitioners. Since the overarching goal of this paper is to contribute useful insight to the biofuels policy debate, the author hopes to build on the existing literature and analysis by applying a different framework to the issue than those addressed above. Specifically, this paper seeks an alternative method of analysis for addressing the impacts of biofuels policies that is more transparent and provides ample opportunity for the user to change assumptions and test different options. The following chapter outlines one possible alternative framework.

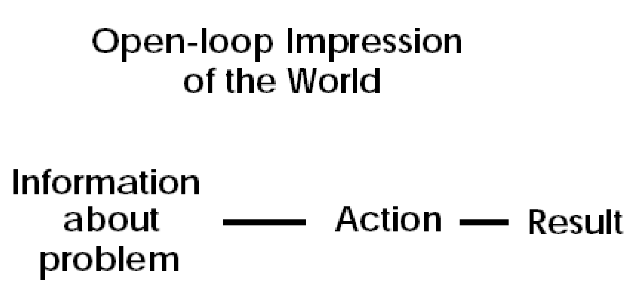
CHAPTER 5: SYSTEM DYNAMICS MODELING FRAMEWORK: AN ALTERNATIVE METHODOLOGY FOR ANALYZING BIOFUELS POLICIES

System dynamics is an analytical tool which presents some benefits as a framework for addressing biofuels policy. This chapter provides a general description of the system dynamics (SD) methodology, addresses some pros and cons, and finally discusses the advantage of utilizing the SD framework for this analysis of biofuels policy in MN.

System dynamics is an approach to studying the behavior of complex systems over time. The system dynamics (SD) method contrasts the prevailing linear, cause and effect approach to a static world represented in Figure 6.

Figure 6. Linear Approach

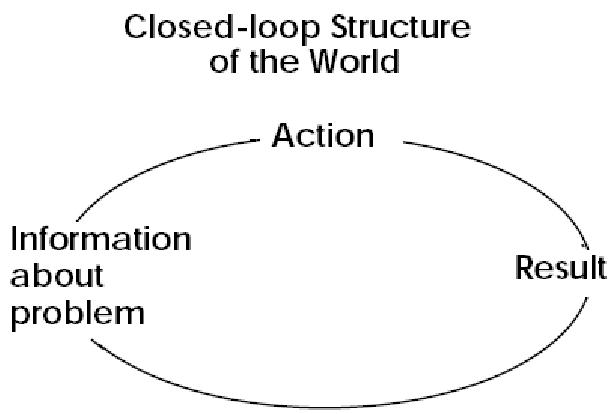
(Forrester 1991)



The SD approach, on the other hand, recognizes and asserts that the world actually operates as a dynamic system within which there is continual feedback and a never ending cycle of interactions, represented in Figure 7.

Figure 7. Cyclical Approach

(Forrester 1991)



The SD method is based in part on the premise that the structure of a system is as important as the individual components of that system in influencing and determining behavior. System dynamics also recognizes that structures are dynamically complex and we need unique conceptual tools and perspectives to address and understand the true nature of systems. SD modeling is a rigorous process of building computer simulations that enable us to test the impacts of various decisions and policies over time and to design more effective structures (Sterman 2000).

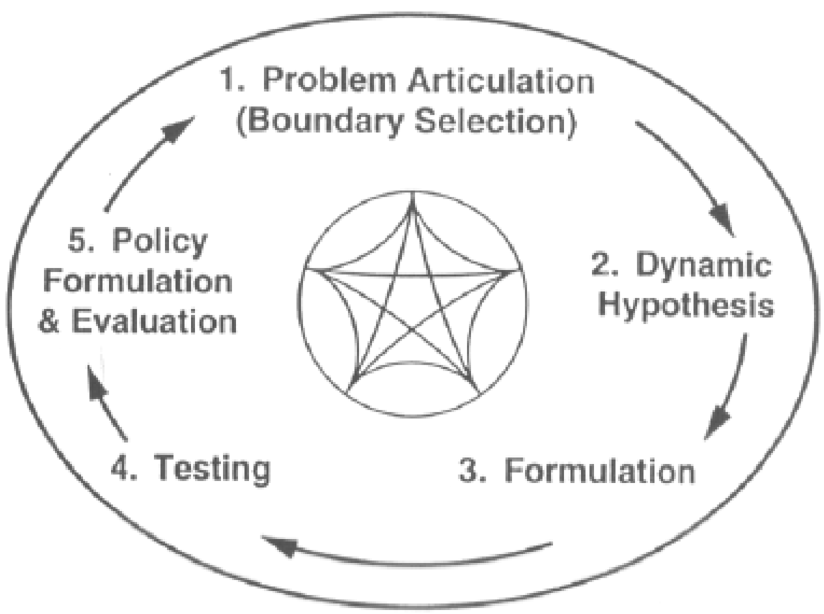
System dynamics has a fundamental basis in scientific methodology; Jay Forrester founded SD at the MIT Sloan School of Management in the 1950s by applying his knowledge about systems from a background in electrical engineering to other systems. Forrester predicted wide applicability of the tool, stating “System dynamics provides a common foundation that can be applied wherever we want to understand and influence how things change through time” (1991, p. 5). Indeed, SD has been used in a variety of settings including business and management, environmental, biological, and ecological issues, economics, engineering, medicine, public policy and other fields.

The System Dynamics Modeling Process

The process of SD mimics the scientific approach to addressing a problem in that it outlines a rigorous format of analysis, based on the use of the best available information and experimentation. The general methodology of system dynamics modeling includes the following five steps, represented in Figure 8 below, in a non-linear and iterative process: 1. Problem Articulation (Boundary Selection); 2. Dynamic Hypothesis; 3. Formulation; 4. Testing; and 5. Policy Formulation and Evaluation. The shape in the middle of Figure 3 represents the interconnectedness of each step with every other step.

Figure 8. SD Modeling Process

(Sterman 2000)



Distinctive Features of System Dynamics

The system dynamics process has some important features that distinguish it from other methods of analysis, and these distinctive features present some advantages for the use of SD modeling in public policy decision making. One of the main features of SD is its emphasis on system structure as the determinant of individual and group behavior. Many disciplines, including economics and politics, have traditionally treated humans as individuals who act rationally in their own best interest, regardless of how the system is set up. This line of thinking leads to solutions that focus on individual choices rather than on the system. The SD focus on understanding the systemic structure makes it a potentially very powerful tool for finding effective ways via public policy to actualize the behavior you want to see. Anderson et al. argue that "strategy change happens [only] when structure changes" (2005 p. 268). Solutions that come out of this approach will likely focus on how designing a different structure can lead to the desired changes in behavior.

Another important feature of SD compared to other analytical tools is the significance it places on endogenous causes of behavior in the system. Instead of looking at exogenous shocks as the main determinants of system problems, SD seeks to model the issues within the system. Economics, for example, tends to attribute many "market failures" to outside causes, asserting that the normal state of the economy is close to equilibrium most of the time. Business sometimes blames government regulation as the main driver of system failure, rather than looking at internal structures as a possible cause. SD practitioners have found over the years that unwanted behavior within a system is often caused by endogenous factors (Forrester 1991). For issues where this is the case, SD offers a valuable tool to find the true causes of problems internal to the system, and has the added benefit of giving power to the policy designers to affect change, instead of just relying on external forces.

System dynamics also distinguishes itself from some approaches by looking at issues in the context of a long-term timeframe; SD incorporates historical experience and its influence on current behavior, and then examines how decisions made today would likely impact the future. Thinking in longer terms is very likely the only way society can solve complex problems with delayed and far-reaching impacts like global warming.

The issue of greenhouse gas emissions reductions from biofuels in the transportation sector is a complex problem with long term consequences. The system dynamics framework offers a unique advantage for addressing MN biofuels policies and their potential impact on CO_2. This analysis applies an SD methodology in order to provide insights to the biofuels policy debate.

CHAPTER 6: DEVELOPMENT OF A UNIQUE MODEL FOR MN BIOFUELS POLICY ANALYSIS

In order to analyze the impacts of MN biofuels policies on CO_2 emissions from the transportation sector, a unique model based on a system dynamics framework was constructed. The goal of this model is to capture a few of the major issues associated with biofuels policy in Minnesota in order to both provide a transparent representation of the structure of the overall issue and to project future CO_2 emissions from the MN passenger transportation sector under a limited number of policy scenarios. Although the model is simple, it provides an example of an alternate framing of the biofuels debate and a template for future analyses that add complexity. This chapter outlines the structure and assumptions of the model constructed for this analysis.

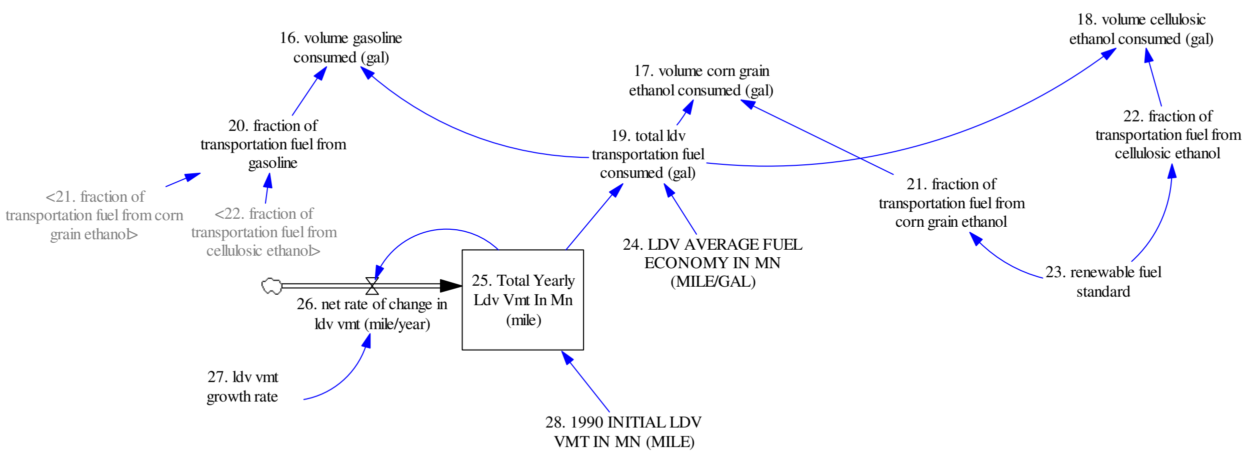
For the sake of simplicity and greatest impact, this analysis focuses only on the light duty vehicle (LDV) fleet, which consists of passenger car vehicles and light trucks in MN. In 2004, emissions from the LDV fleet accounted for approximately 63% of total MN transportation sector GHG emissions (MPCA 2007). The model was constructed using system dynamics modeling software called Vensim. SD models are made up of different kinds of variables that are connected by causal arrows. Variables enclosed in a box represent stocks, or things that accumulate over time as a result of changes in flows, which are variables perpendicular to a stock which control the rate of change in that stock. The changing stocks in a model provide the dynamic change over time captured in the system. The variables are numbered simply for quick identification; the numbers have no significance of their own. Equations, values and sources for each variable are listed at the end of this chapter.

The structure of the model is based on a simple relationship where total LDV transportation fuel consumed is determined by vehicle miles traveled (VMT) and average fuel economy, shown in Figure 9 below. Total Yearly LDV VMT in MN is a stock which changes over time based on an initial VMT level and a rate of change which accounts for the growth rate in LDV VMT.

Within the LDV fleet only gasoline engines are addressed, since diesel engine vehicles account for only 2% of the LDV fleet (UMCTS 2008). The model is limited to three fuels that can be used in gasoline engines: gasoline, corn grain ethanol and cellulosic ethanol. Figure 9 also shows the next level of the model, which divides total LDV transportation fuel into these three fuel types.

The portion of fuel used from each type is driven in the model by a biofuels policy: the renewable fuels standard. Figure 9 shows the impact of the RFS on the fraction of ethanol consumed, and the fraction of gasoline is the fraction left over. Within Vensim, a variable that has already been defined in one place can be copied into another location as a shadow variable; shadow variables are denoted in grey font and with brackets, like "21. fraction of transportation fuel from corn grain ethanol" below.

Figure 9. Model Structure 1

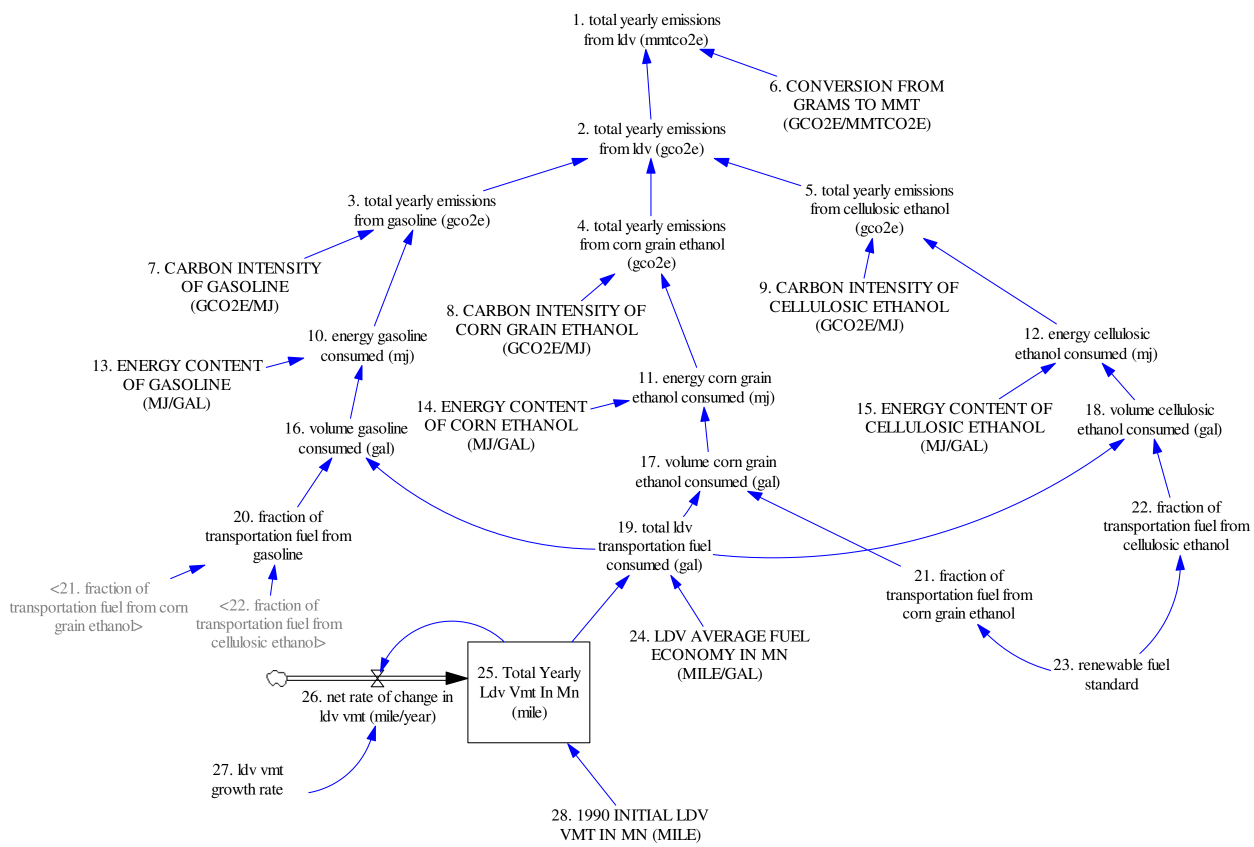


Ethanol and gasoline have different energy contents on a volumetric basis, so the model next converts the volume of each fuel consumed, in gallons, to the energy of that fuel consumed, in mega joules, based on the energy content of each fuel; see Figure 10 below.

Since one goal of the model is to estimate GHG emissions from the LDV fleet in the MN transportation sector, the next portion of the model calculates the total yearly emissions from each fuel based on a life cycle analysis carbon intensity estimate for each fuel type, based on the intensity estimates used in analyses of the CA low carbon fuel standard. Figure 10 shows the total yearly emissions from each fuel as a function of the total energy of that fuel consumed and the per unit of energy carbon intensity, expressed in grams of carbon dioxide equivalent gas (gCO_2e/MJ).

Finally, in order to capture the cumulative GHG emissions from the use of these three fuels, they are summed to total yearly emissions in gCO_2e and then converted to million metric tons of carbon dioxide equivalent ($MMtCO_2e$) in order to compare the value to other estimates and analyses.

Figure 10. Model Structure 2



Finally, in order to see the impacts of biofuels use over time on the rules of a low carbon fuel standard, the average fuel carbon intensity (AFCI), which is the parameter measured in the LCFS, was added to the model and is determined by the weighted average of the carbon intensities of the three different fuels, depending on the portion of each fuel used. Figure 6 shows the AFCI and the model variables that determine it. This portion is represented as a separate page in the model, but it is part of the model. The variables in brackets and grey font are the variables from the main model view.

Figure 11. Model Structure 3

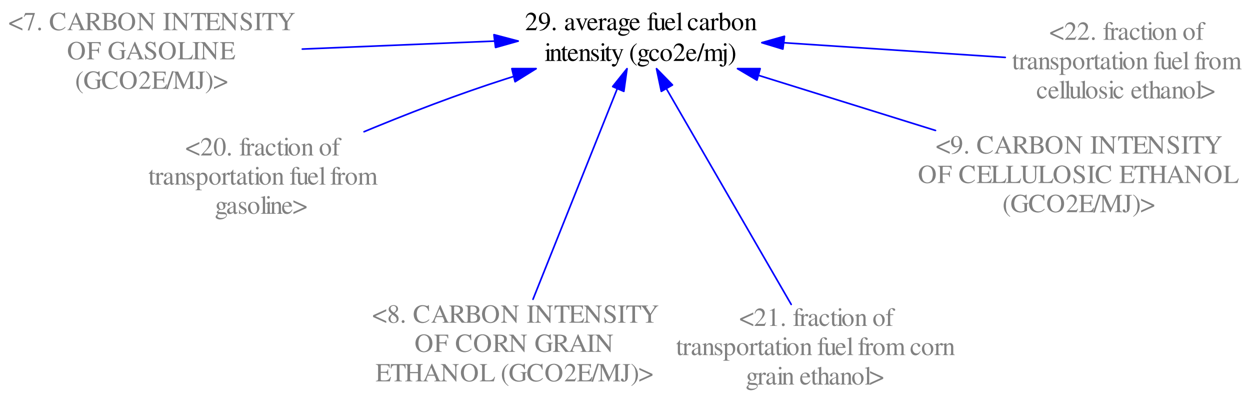
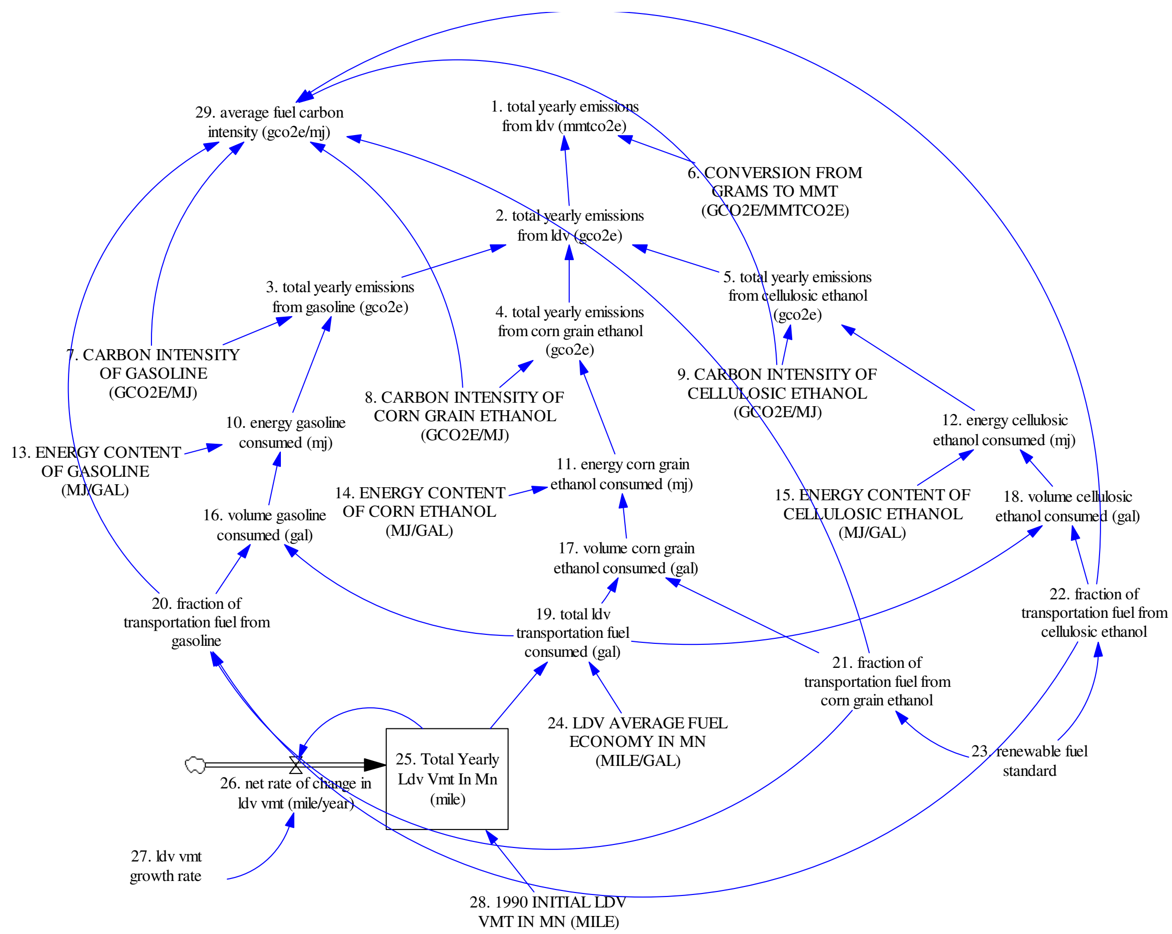


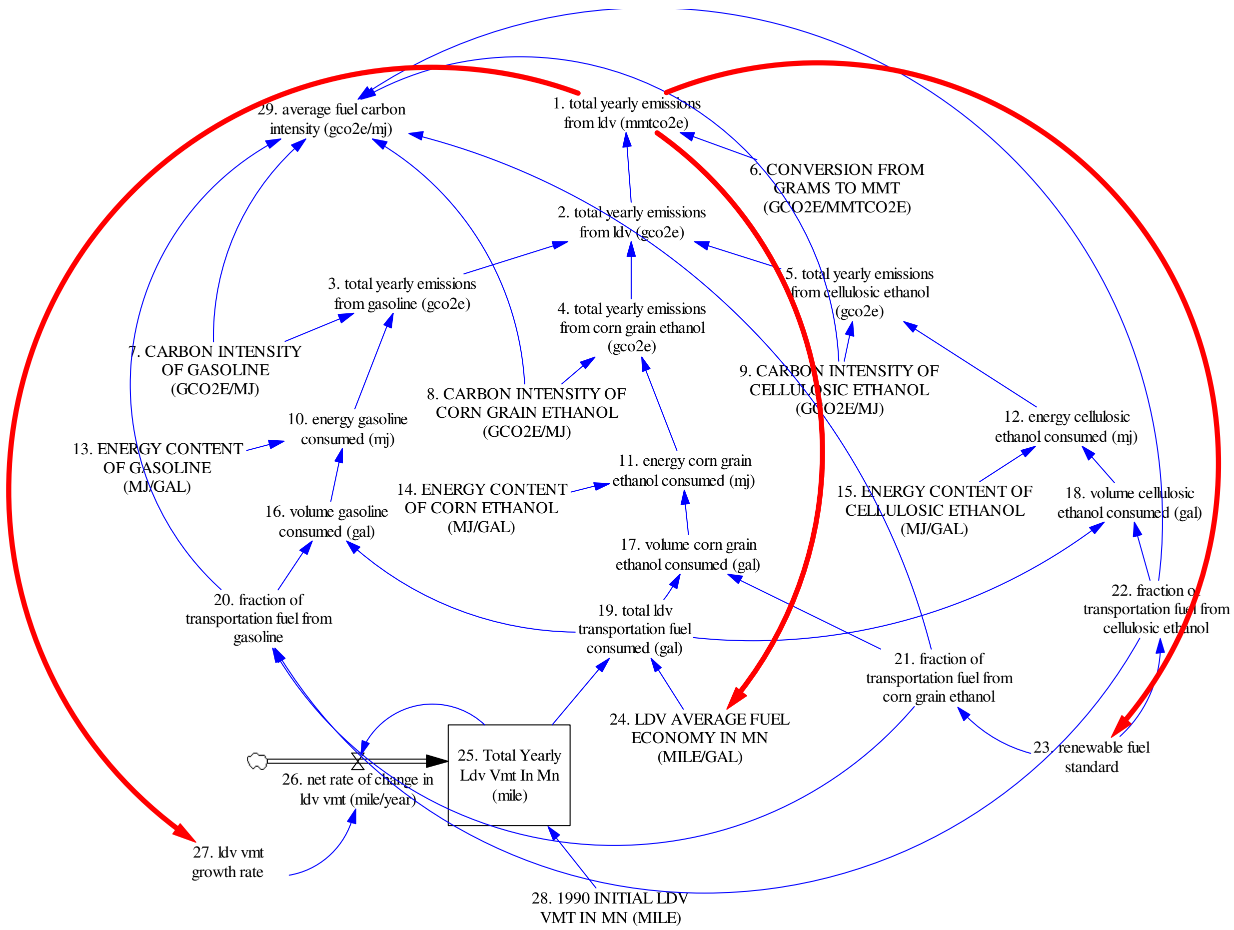
Figure 12 shows the entire model as one view with the average fuel carbon intensity included in the main view. The effect on the model is the same; this is just an alternate view to make explicit all the causal relationships.

Figure 12. Model Structure 4



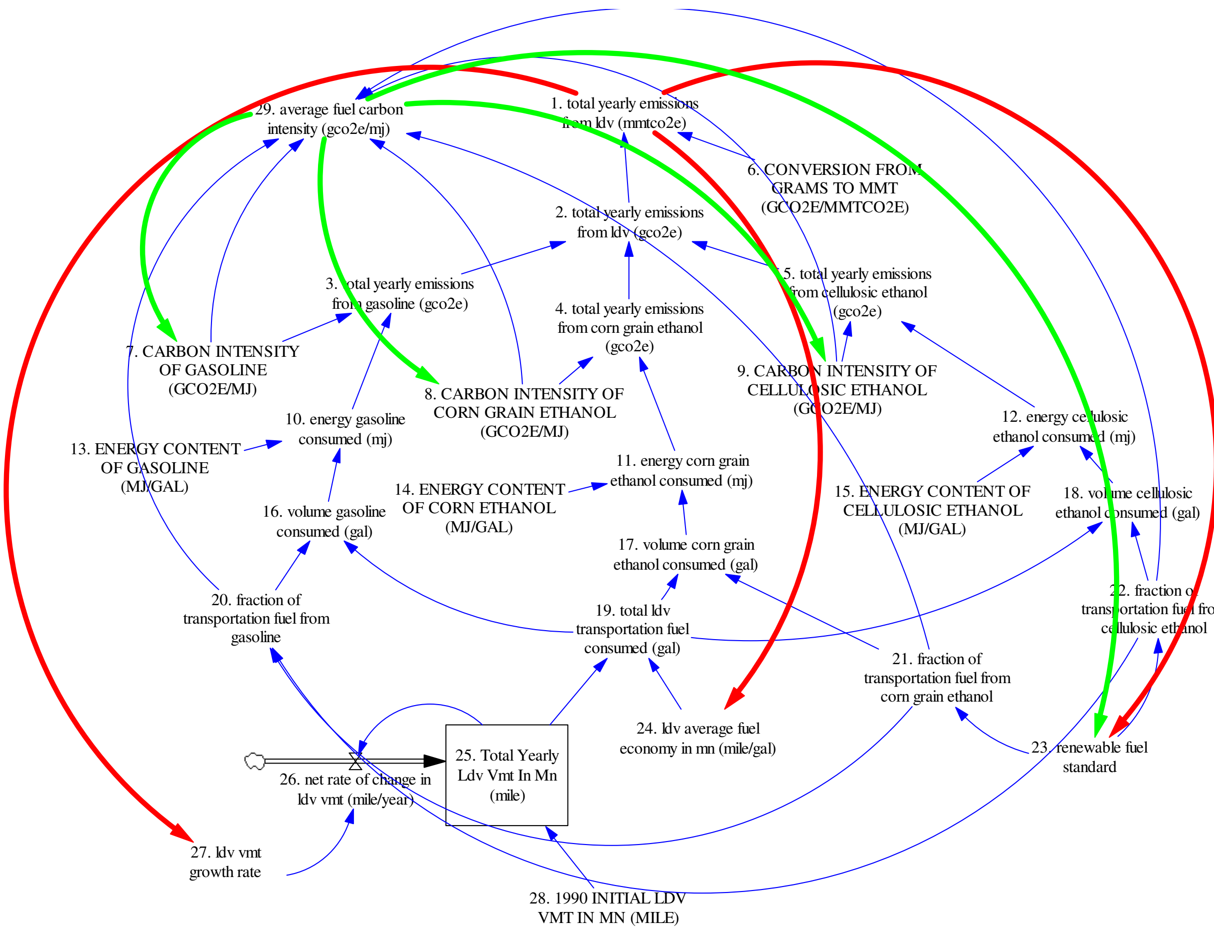
One key concept in a system dynamics model is feedback. Figure 13 shows the key feedbacks from total yearly emissions from the light duty vehicle fleet identified in the model. As policy makers, organizations and constituents assess the trend in emissions, they will make different decisions about the variables which they have some policy control over. For example, a sharp rise in emissions may cause concerned policy makers to pass a more stringent renewable fuel standard, or tighter CAFE standards that result in higher miles per gallon, or efforts to slow the LDV vehicle miles traveled growth rate. All of these policy changes would then in turn lead to further changes in the total yearly emissions.

Figure 13. Key Emissions Feedback



Similarly, the results of a low carbon fuel standard, measured as the average fuel carbon intensity, may lead to policy changes in the carbon intensity of all three fuels modeled here or in the renewable fuel standard. Figure 14 shows the key feedback from average fuel carbon intensity.

Figure 14. Key Low Carbon Fuel Standard Feedback



While the feedback relationships articulated above are extremely important to the biofuels policy system and debate, these relationships are also very difficult to quantify. In order to have a working model, all relationships must be quantified in some way. Therefore, in order to demonstrate the ability to run scenarios and make some estimates of CO_2 emissions from the LDV fleet, the model was quantified without the feedback shown above. Chapter 9, Recommendations, further research and conclusions, suggests some possible approaches to quantifying these policy feedbacks in order to be able to include them in future analyses.

Quantitative Relationships

Within the model, there are exogenous and endogenous variables. Exogenous variables are defined and determined outside the model. For example, the energy content of each fuel is an exogenous variable, taken from MIT information; the model does not determine or change this variable. An endogenous variable is one which is determined within the model, by relationships articulated by the model structure. Total LDV transportation fuel consumed, for example, is an endogenous variable which is a function of average fuel economy and yearly VMT. This model contains 29 variables in total. 11 of these variables are exogenous, and one of the exogenous variables is a policy variable (23. renewable fuel standard) which is set by the author at different levels to test different policies. The remaining 18 variables are endogenous. In order to easily follow the types of variables contained in the model, policy parameter is denoted in red and all other exogenous variables are in yellow. See Figure 15 below.

Figure 15. Quantified Model

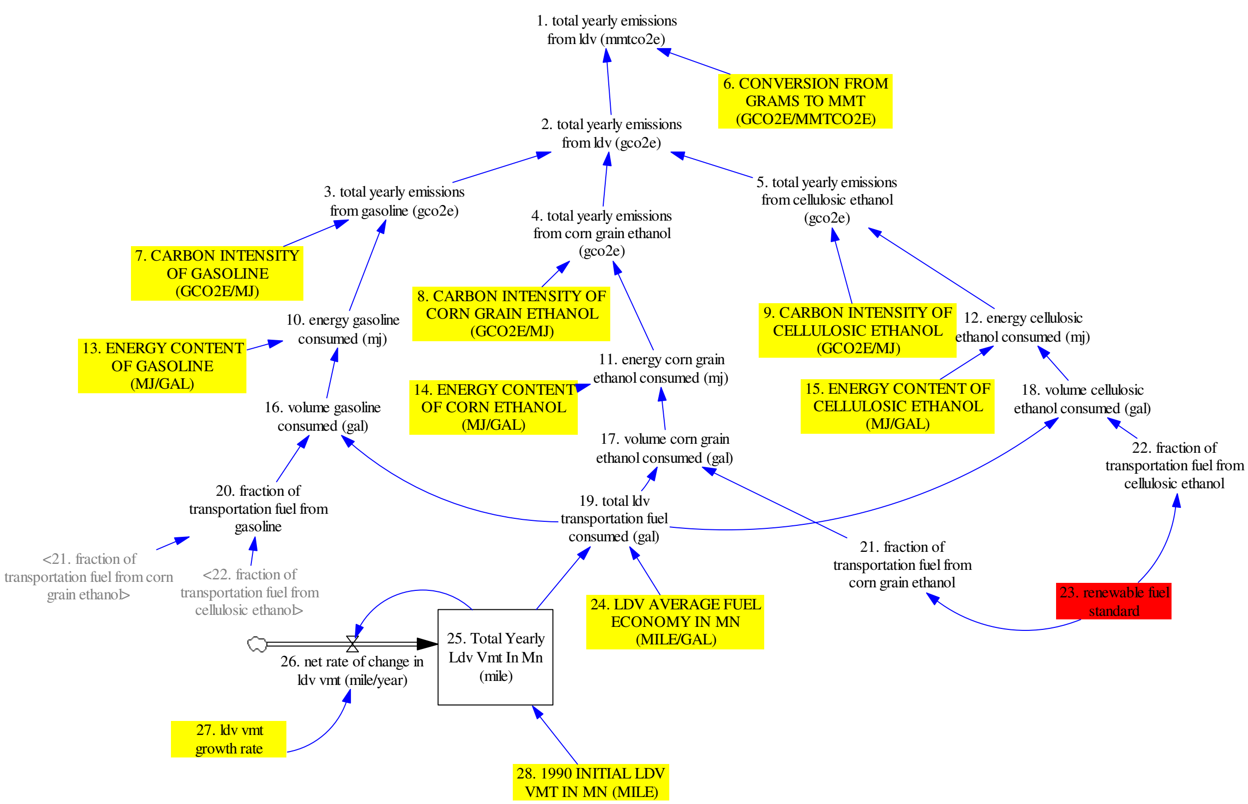


Table 3 lists key endogenous and exogenous variables included in the model, as well as some key variables that were excluded from this model. Some of these excluded variables would be useful for future research; for example, fuel prices and fuel availability would likely have some interesting feedback with renewable fuel standards and low carbon fuel standards. For the base case in the model, Table 4 below lists the exogenous variables, their values and the sources of those values. Table 5 shows the endogenous variables and their equations.

Table 3. List of Key Variables

Endogenous	**Exogenous**	**Excluded**
Yearly VMT	Initial VMT in 1990	Fuel prices
Total transportation fuel consumed	VMT growth rate	Fuel availability
Gasoline consumed	Fuel economy	Feedstock availability
Corn grain ethanol consumed	Carbon intensity of gasoline	Diesel and biodiesel
Cellulosic ethanol consumed	Carbon intensity of corn grain ethanol	Heavy duty and off-road vehicles, aviation
Total yearly GHG emissions	Carbon intensity of cellulosic ethanol	Land use patterns
GHG emissions from gasoline	Energy content of gasoline	Public transit use
GHG emissions from corn grain ethanol	Energy content of corn grain ethanol	Vehicle type and numbers
GHG emissions from cellulosic ethanol	Energy content of cellulosic ethanol	Other GHG reduction policies: feebates, taxes, tailpipe GHG standards, cap and trade, carbon tax
Average fuel carbon intensity	Renewable fuel standard	Population growth

Table 4. Exogenous Variables

Variable Name	Variable Value or Equation	Units	Source
Conversion from grams to MMT	1×10^{12}	$gCO_2e/MMtCO_2e$	MIT 2007
Carbon intensity of gasoline	92	gCO_2e/MJ	Farrell & Sperling 2007
Carbon intensity of corn grain ethanol	72	gCO_2e/MJ	Farrell & Sperling 2007
Carbon intensity of LIHD cellulosic ethanol	0	gCO_2e/MJ	Author's decision based on Tilman et al. 2006 which estimates negative carbon intensity for LIHD cellulosic ethanol.
Energy content of gasoline	121.3	MJ/gal	MIT 2007
Energy content of corn grain ethanol	80.2	MJ/gal	MIT 2007 (assume same energy content for ethanol regardless of source)
Energy content of LIHD cellulosic ethanol	80.2	MJ/gal	MIT 2007 (assume same energy content for ethanol regardless of source)
Renewable fuel standard	.1 (10%)	dmnl	MN State Legislature (assuming the stated 10% standard is fully met[1])
LDV average fuel economy in MN	19.38+STEP(15.62, 2020)	mile/gal	UMCTS 2008 (average mpg from years 1990-2004. Only slight variations occur from year to year. The Energy Independence and Security Act of 2007 sets new CAFÉ standards of 35 mpg by 2020, so the model steps up MN fuel economy to 35 in 2020)
VMT growth rate	0.0237+STEP (-0.0147, 2007)	dmnl	MNDOT 2008 (average growth in VMT from years 1990-2006, then the model steps up according to MNDOT projection of .9% growth starting in 2007)
1990 initial VMT in MN	3.575×10^{10}	mile	UMCTS 2008 (total passenger car VMT (24,456,052,236) plus total light truck VMT (11,296,141,350).)

[1] UMCTS 2008 reports fuel ethanol content ramping up from 1% in 1990 to 6% in 1996, and then 9% in 1997, reaching 10% in 2003.

Table 5. Endogenous Variables

Variable Name	**Units**	**Equation** **(including units)**
Net rate of change in LDV VMT	mile/year	= “25. total yearly ldv vmt in MN (mile)"*"27. LDV VMT growth rate")
Total yearly LDV VMT in MN	mile	= INTEG ("26. net rate of change in LDV VMT (mile/year)", initial value: "28. 1990 initial LDV VMT in MN (mile)"
Total LDV transportation fuel consumed	gal	= "25. total yearly ldv vmt in MN (mile)"/"24. LDV average fuel economy in MN (mile/gal)"
Fraction of transportation fuel from gasoline	dmnl	= 1-"22. fraction of transportation fuel from cellulosic ethanol"-"21. fraction of transportation fuel from corn grain ethanol"
Fraction of transportation fuel from corn grain ethanol	Dmnl	= "23. Renewable Fuel Standard"*1
Fraction of transportation fuel from cellulosic ethanol	Dmnl	= "23. Renewable Fuel Standard"*0
volume gasoline consumed	Gal	= "19. total transportation fuel consumed (gal)"*"20. fraction of transportation fuel from gasoline"
volume corn grain ethanol consumed	Gal	= "19. total transportation fuel consumed (gal)"*"21. fraction of transportation fuel from corn grain ethanol"
volume cellulosic ethanol consumed	Gal	= "19. total transportation fuel consumed (gal)"*"22. fraction of transportation fuel from cellulosic ethanol"
energy gasoline consumed	MJ	= "16. volume gasoline consumed (gal)"*"13. energy content of gasoline (mj/gal)"
energy corn grain ethanol consumed	MJ	= "17. volume corn grain ethanol consumed (gal)"*"14. energy content of corn ethanol (mj/gal)"
energy cellulosic ethanol consumed	MJ	= "18. volume cellulosic ethanol consumed (gal)"*"15. energy content of cellulosic ethanol (mj/gal)"
total yearly emissions	gCO_2e	= "10. energy gasoline consumed (mj)"*"7. carbon

from gasoline		intensity of gasoline (gco2e/mj)"
total yearly emissions from corn grain ethanol	gCO_2e	= "11. energy corn grain ethanol consumed (mj)"*"8. carbon intensity of corn grain ethanol (gco2e/mj)"
total yearly emissions from cellulosic ethanol	gCO_2e	= "12. energy cellulosic ethanol consumed (mj)"*"9. carbon intensity of cellulosic ethanol (gco2e/mj)"
total yearly emissions from LDV	gCO_2e	= "3. total yearly emissions from gasoline (gco2e)"+"4. total yearly emissions from corn grain ethanol (gco2e)"+"5. total yearly emissions from cellulosic ethanol (gco2e)"
Total yearly emissions from LDV	$MMtCO_2e$	="2. total yearly emissions from ldv (gco2e)"/"6. conversion from grams to mmt (gco2e/mmtco2e)"
average fuel carbon intensity	gCO_2e/MJ	="20. fraction of transportation fuel from gasoline"*"7. carbon intensity of gasoline (gco2e/mj)" +"21. fraction of transportation fuel from corn grain ethanol"*"8. carbon intensity of corn grain ethanol (gco2e/mj)"+"22. fraction of transportation fuel from cellulosic ethanol"*"9. carbon intensity of cellulosic ethanol (gco2e/mj)"

Once relationships were defined, the model was set up to run a series of scenarios within a given timeframe.

CHAPTER 7: MODEL SCENARIOS: BOUNDARIES, ASSUMPTIONS AND VALIDATION

As previously stated, one goal of this analysis is to project CO_2 emissions from the transportation sector. This chapter details the scenarios programmed into the model and discusses the model boundaries, assumptions and validation.

Time horizon of model

Dynamic modeling is designed to both help understand problematic behavior that has been experienced, and to help guide policies that may lead to the improvement of problematic behavior. For this reason, the selection of a time horizon is best if it extends far enough in history to capture some emergence of the problem. The timeline should also extend far enough into the future to account for any delayed or indirect consequences of policy changes (Sterman 2000).

The model used in this analysis has a time horizon of 1990 through 2050. The problem of increasing GHG emissions from the transportation sector goes back many decades, but since this analysis seeks mainly to address the impacts of biofuels standards, it does not attempt to model the emergence of the GHG emissions problem. 1990 was chosen as the initial year for this model because it precedes the onset of the renewable fuel standard by a few years; the model can therefore capture some of the impacts of this main policy on GHG emissions. The year 2050 was selected because it is important to look at the long term impacts of biofuels policy changes on GHG emissions which may take decades. This year also lines up nicely with Minnesota's 2007 Next Generation Energy Act, which set a goal of reducing State GHG emissions by 80%, relative to 2005 levels, by the year 2050. By projecting out to the year 2050, the model results can be analyzed for their impact on achieving the State GHG reduction goals. One possible dynamic modeling rule of thumb suggests modeling back approximately half the amount of time you plan to model forward (Wheat lecture 2008).

Scenarios

In order to examine the potential implications of popular biofuels standards, this analysis outlines four general scenarios for the state of MN that address some aspects of the renewable fuel standard and the low carbon fuel standard:

1. Base Case: E10 filled by corn grain ethanol

2. E20 filled by corn grain ethanol

3. E20 filled half by corn grain ethanol and half by cellulosic ethanol

4. E20 filled by cellulosic ethanol

Scenario 1 is the business as usual scenario, assuming we let present trends continue. This is a useful scenario to serve as a base case against which other scenarios can be compared. The current MN state RFS is a 10% ethanol mandate which began in 1997. The model goes from zero ethanol to 10% ethanol starting in 1997; this is an approximation based on data from the University of Minnesota Center for Transportation Studies that fuel ethanol content ramped up from 1% in 1990 to 6% in 1996, and then 9% in 1997, reaching 10% in 2003 (UMCTS 2008).

The State has applied for a waiver from the EPA to certify E20 as gasoline, a waiver necessary in order to ramp up to a 20% ethanol blend by 2013, and the base case addresses the possible future should this waiver not be granted. Scenario 2 examines the future if the waiver is granted and MN achieves a 20% ethanol blend by 2013. With cellulosic ethanol technology developing rapidly and becoming more economical, some policy makers and organizations are predicting a greater prominence of cellulosic ethanol within the ethanol mix. The third scenario examines this prospect by projecting the impacts of a renewable fuel standard of 20% that is filled half by corn grain ethanol and half by cellulosic ethanol from native prairie grass, which could be a carbon negative biofuel (Tilman et al. 2006). In order to see how significant the difference between corn grain ethanol and cellulosic ethanol is with regard to CO_2 emissions under a 20% ethanol mandate, the final scenario analyzes the impact of a 20% ethanol blend filled fully with cellulosic ethanol. Ethanol blending beyond 20% is not modeled because car engines would need modification in order to handle large blends (UMCTS 2008).

Low Carbon Fuel Standard

The four scenarios above explicitly address differences in a renewable fuel standard. Since this analysis addresses the RFS relative to an alternative biofuels policy, the LCFS, the results of each scenario with regard to a hypothetical LCFS are also calculated in the model. In order to analyze these impacts, the average fuel carbon intensity (AFCI) is calculated for each of the four scenarios. The AFCI is the metric for measuring compliance with LCFS goals; the average fuel carbon intensity reflects the average life cycle CO_2 emissions associated with the entire transportation fuel supply per unit of energy contained in that supply. While the CA LCFS uses 2004 to calculate a baseline AFCI by which to measure the achievement of LCFS goals, the UMCTS report models the impacts of a LCFS in Minnesota based on 2007 as the baseline AFCI year (2008). In order to make a comparison of simulated LCFS results to the UMCTS report, this model also uses 2007 as the baseline year for AFCI. The UMCTS analysis used the Stockholm Environment Institute's Long-range Energy Alternatives Planning system (LEAP) model to project emissions and AFCI outcomes. The LEAP model calculated an AFCI for 2007 of 89 $gCO2_2e$/MJ (UMCTS 2008), which is very close to the value calculated by the base case in this model of 90 $gCO2_2e$/MJ.

AFCI

Farrell and Sperling articulate two main ways to calculate the average fuel carbon intensity value:

1. $AFCI_{current} = \frac{ThisYear'sCarbonEmissions(gCO_2e)}{ThisYear'sFuelSales(MJ)}$

2. $AFCI_{historical} = \frac{ThisYear'sCarbonEmissions(gCO_2e)}{BaseYear'sFuelSales(MJ)}$

The CA LCFS analysis calculates AFCI using method 1. based on current values of carbon emissions and fuel sales. A formal economic analysis by Holland et al. uses the second method, which addresses each year's carbon emissions relative to the fuel sold in the base year. Farrell and Sperling point out that if the amount of fuel sold increases over time, it will be more difficult to achieve a LCFS goal that is based on method 1, $AFCI_{current}$. Conversely, if fuel sales are increasing, the 2nd method, $AFCI_{historical}$, represents a more stringent policy (Farrell & Sperling 2007 II, p. 24).

The analysis of LCFS goals in this model utilizes the 1st method, and calculates the AFCI each year based on that year's total carbon emissions divided by the amount of fuel consumed in that same year. Since the carbon intensities for gasoline, corn grain ethanol and cellulosic ethanol do not change throughout the time horizon of the model, this AFCI calculation is approximated by multiplying the proportion of total fuel from each specific by the carbon intensity of that fuel for each of the three fuels, and then adding those values together for each year:

$$AFCI = \left(FractionFuel_{Gasoline} * CarbonIntensity_{Gasoline}\right) + \left(FractionFuel_{CornEthanol} * CarbonIntensity_{CornEthanol}\right) + \left(FractionFuel_{CellulosicEthanol} * CarbonIntensity_{CellulosicEthnol}\right)$$

In this analysis, the AFCI for 3 different years using both methods was calculated, and both methods yielded values that were less than one gCO_2e/MJ apart from each other.

Model Boundaries and Assumptions

Within these four scenarios, distinct boundaries have been set and a number of simplifying assumptions have been made in order to produce a very basic analysis. Internal combustion engine vehicles within the passenger fleet are modeled, but diesel engines are not. In reality, some biofuels are currently used in non-passenger vehicles, mainly from biodiesel in agricultural and other diesel engine fleets, and there is potential for wide application of biofuels in other non-passenger vehicles like off-road vehicles including lawnmowers and snowmobiles. Biodiesel can be and is used by some diesel engine cars in the passenger vehicle fleet. However, diesel engines currently make up only 2% of the passenger fleet in MN. While these other current and potential uses of biofuels are important, for the sake of simplicity and maximum impact, this analysis is limited to a focus on internal combustion engines in the passenger vehicle fleet. In the model, fuel economy is assumed to follow the historic average of 19.38 mpg from years 1990-2004, with only slight variations from year to year. The Federal Energy Independence and Security Act of 2007 set new CAFE standards for 35 mpg by 2020. The new CAFE standards do not specify any plan or rule for how the standards will be phased in. Therefore, this model assumes MN will comply with that standard without predicting how we will get there. The model therefore steps up from 19.38 to 35 mpg in 2020. A smoother transition in reality is likely. The average growth in VMT in Minnesota from 1990-2006 is 2.37% per year, so the model has a yearly growth rate to reflect this from 1990 through 2006 (MNDOT 2008). However, the MNDOT is planning for .9% growth moving forward, based on their analyses and projections, so in 2007 this value in the model is stepped down to .009 for the remainder of the time (MNDOT 2008). Table 6 below articulates three major boundaries of the model, the assumptions that go along with these boundaries, as well as some justification for those assumptions.

Table 6. Major Model Boundaries

Boundaries	**Simplifying Assumptions**	**Reason for Boundary Selection**
MN only	Biofuels consumed in MN are produced in MN	Policy decisions regarding biofuels and climate change mitigation are made at the State level
Light Duty Vehicle (LDV) fleet only	Use average CAFE standards rather than breaking down by vehicle type	In 2004, LDVs contributed the majority of transportation GHG emissions at 63% (UMCTS from MPCA 2007)
Gasoline engines only	3 fuels: gasoline, corn grain ethanol, cellulosic ethanol	Diesel powered vehicles in MN make up only 2% of the size of the LDV fleet: diesel=10^5 and LDV=$4.2x10^6$ (UMCTS 2008)

Limitations

This modeling approach and analysis has some notable limitations. The narrow scope of the model itself, looking only at gasoline engines in the light duty vehicle fleet in the State of Minnesota, limits its ability to accurately account for other important factors in MN's transportation sector. A model which addresses a wider set of issues in the transportation sector, including diesel engines, large engines and trucks, off-road vehicles and aviation, would provide valuable insights to the issue of CO_2 emissions. This analysis is also limited in that it treats only two possible biofuels policies, the renewable fuel standard and the low carbon fuel standard. There are other policies available to address GHG emissions from the transportation sector including feebates, tailpipe CO_2 standards (like that passed in California), fuel economy standards, fuel and vehicle taxes, cap and trade, carbon tax, land use and public transit planning and others. It would be useful to develop a model which analyzes a variety of possible GHG reduction policies with regard to their impact on emissions levels, economic development and other environmental issues.

Validation

In order to check the model's accuracy at modeling GHG emissions from the LDV fleet in the transportation sector before moving forward with additional scenarios, model output from the base case scenario was compared to actual historic data. In order for a model to be useful, the value of a number produced by the model should be within the same order of magnitude as its counterpart in collected data. Since the model built here is an extremely simplified representation of the real world, and does not include feedback, it is not expected to produce results that perfectly or even closely match historic data. The inclusion of a variety of additional variables into the model would likely result in more accurate model output. This simple model, however, with values that are within the same order of magnitude as collected data, can provide a useful basis for comparison of relative values and changes between different scenarios and assumptions. It can yield insight about the relative extent to which different policy decisions can impact GHG emissions from the transportation sector. Four key parameters endogenously calculated in the model are compared to historic data from the year 2000 in order to check to see whether the model reasonably approximates actual trends; see Table 7 below. The 2000 model values are relatively close to historic values for the same year. The discrepancy between model-derived and historic values suggests that the model could be improved by the inclusion of feedback, slightly different exogenous variable values, improved model structure via the inclusion of other important variables like fuel prices, or other changes. However, for the purposes of this model, the relative similarity in model and historic values lends credibility to the use of this model for comparing the results of various scenarios. The results of the scenarios run in this model can yield insights about the relative changes in CO_2 emissions and average fuel carbon intensity that may result from different policy decisions.

Table 7. Model Validation

Comparison of Base Case Model Output to Historic Values for Key Parameters			
Variable Name	**2000 Model Value**	**2000 Historic Value**	**Source of Historic Value**
Total yearly emissions from LDV	24.8 $MMtCO_2e$	22.8 $MMtCO_2e$	UMCTS 2008 [2]
Total LDV transportation fuel consumed	2.337 B gal	2.493 B gal	UMCTS 2008
Volume corn grain ethanol consumed	233.73 M gal	205.65 M gal	UMCTS 2008
Total yearly LDV VMT	45.29 B miles	48.6 B miles	UMCTS 2008[3]
Average fuel carbon intensity (2007)	90 gCO_2e/MJ	89 gCO_2e/MJ (MN 2007)	UMCTS 2008

CHAPTER 8: SCENARIO RESULTS

After validating the base case model output, all four scenarios were run in the model:

1. Base Case: E10 filled by corn grain ethanol

2. E20 filled by corn grain ethanol

3. E20 filled half by corn grain ethanol and half by cellulosic ethanol

4. E20 filled by cellulosic ethanol

Greenhouse Gas Emissions and the Next Generation Energy Act GHG Reduction Goals

Graph 1 below shows the model results of the four scenarios with respect to total CO_2 emissions from the LDV transportation sector in MN. Note the initial, slight drop in emissions in 1997,

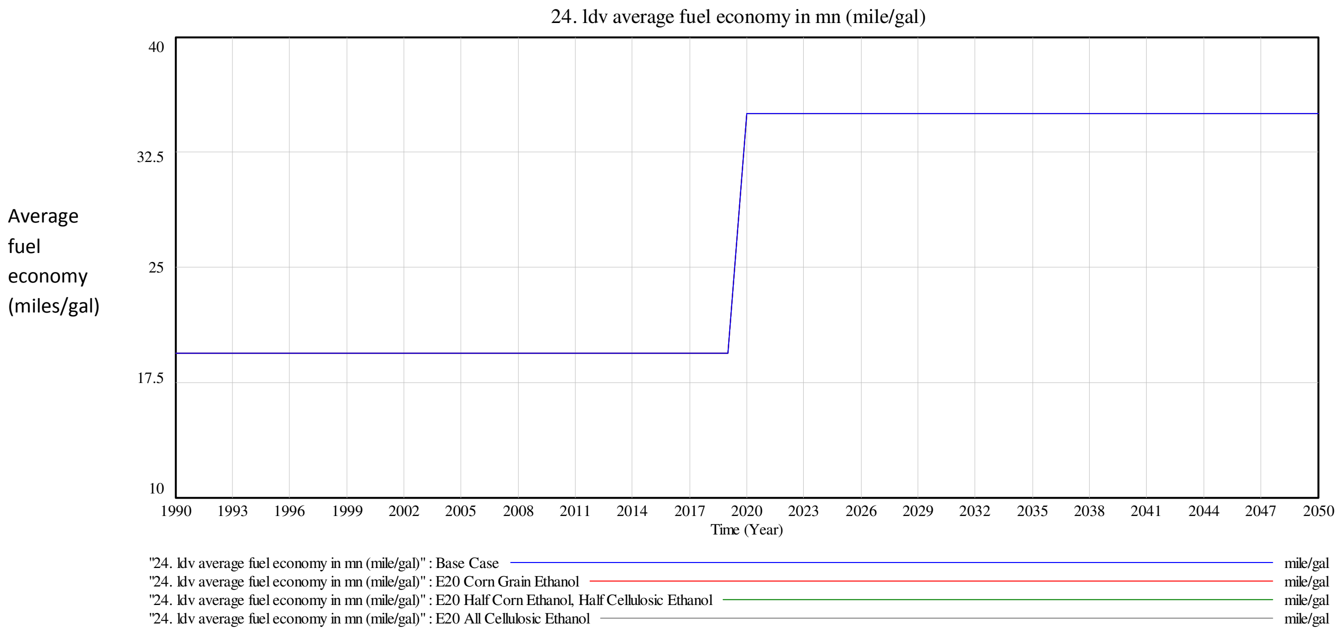
[2] Passenger cars, 11,378,748 tons CO_2e, plus light trucks, 11,399,746 tons CO_2e, = 22,778,494 tons CO_2e=22.8MMt CO_2e
[3] Passenger cars, 27,739,403,072 miles, plus light trucks, 20,862,610,622 miles, = 48,602,013,694 miles = 48.6 B miles

when the 10% ethanol blend is instituted. As a result of increasing VMT, however, this decrease in emissions is brief. For scenarios 2, 3 and 4, when a 20% ethanol blend is mandated beginning in 2013; the decline in total emissions can again be seen to varying degrees, depending on the portion of cellulosic ethanol consumed. For all four scenarios, the improved CAFE standards starting in 2020 have a huge impact on emissions. However, after the initial onset, those emissions again rise at the previous rates based on increases in VMT.

Graph 1. Total Yearly Emissions

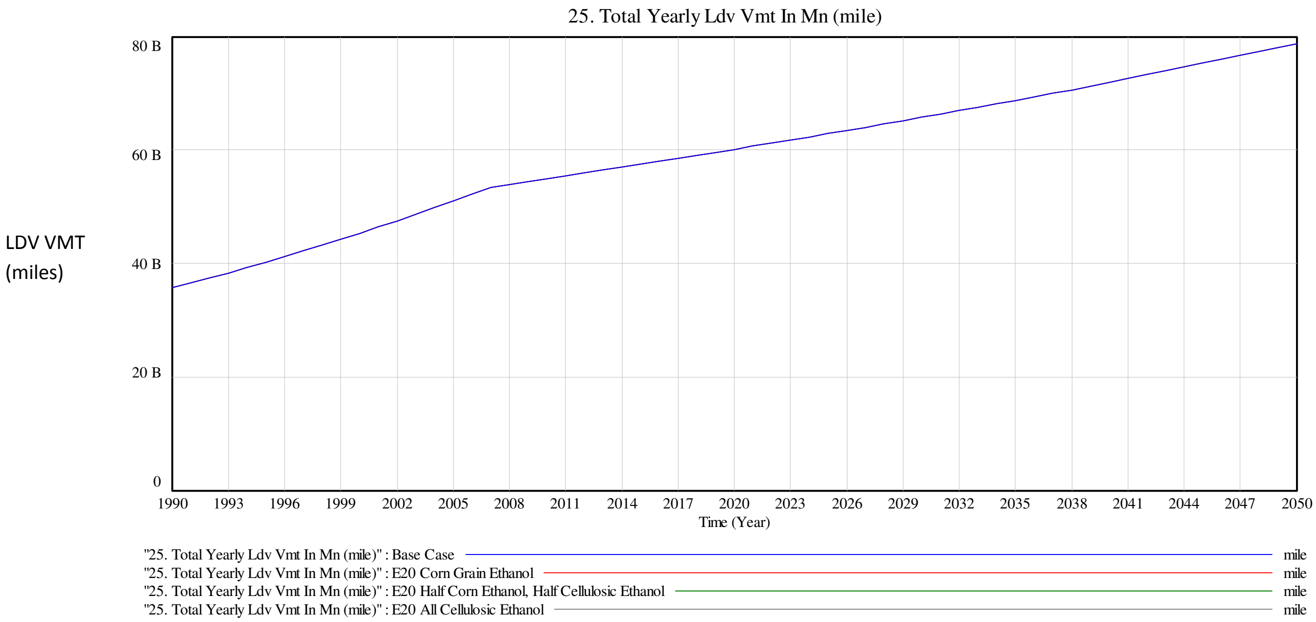
Graph 2 shows the average fuel economy over time; the rapid increase in 2020 to meet the CAFE standard of 35 mpg is the cause of decreased GHG emissions in that year.

Graph 2. Average Fuel Economy



Graph 4 shows the growth in VMT over time; this parameter is the same for all four scenarios. The shape of VMT is similar to the shape of emissions in times that are free of shocks like improved fuel economy and blending onsets, demonstrating visually that VMT is the main driver of emissions growth in all four scenarios.

Graph 3. Vehicle Miles Traveled



Minnesota's Next Generation Energy Act CO_2 reduction goals of 15% by 2015, 30% by 2025 and 80% by 2050 serve as a useful basis for comparison of the total GHG emissions from different scenarios in the model. Table 1 shows the CO_2 emissions for all four scenarios in key Next Generation Energy Act years in order to see how these scenarios might contribute to the reduction goals. The emissions levels necessary to achieve the reduction goals are calculated based on the model's 2005 baseline emissions level of 27.94 (e.g. 27.94-(27.94*.15)=23.75). The units for all values are MMtCO2e.

Table 8. Scenarios relative to Next Generation Energy Act CO_2 Reduction Goals

2005 CO_2 emissions is 27.94 $MMtCO_2e$ in all scenarios	**2015 CO_2 emissions** **Level necessary to achieve Next Gen Act 15% reduction: 23.75**		**2025 CO_2 emissions** **Level necessary to achieve Next Gen Act 30% reduction: 19.56**		**2050 CO_2 emissions** **Level necessary to achieve Next Gen Act 80% reduction: 5.59**	
SCENARIO	**Model level**	**Reduction goal achieved?**	**Model level**	**Reduction goal achieved?**	**Model level**	**Reduction goal achieved?**
Base Case: E10 filled by corn grain ethanol	31.48	No	19.07	Yes	23.88	No
E20 filled by corn grain ethanol	29.88	No	18.1	Yes	22.67	No
E20 filled half by corn grain ethanol and half by cellulosic ethanol	28.17	No	17.06	Yes	21.37	No
E20 filled by cellulosic ethanol	26.46	No	16.03	Yes	20.07	No

For all four scenarios, the Next Generation reduction goals are only met in 2025. While the model is far from reaching the 15% reduction in 2015, with the onset of the improved fuel economy in 2020, the GHG emissions in the model do achieve the 30% reduction in 2025. However, emissions begin to grow again slowly heading out to 2050, so the actual emissions are much greater than the level that would be necessary to achieve the 80% reduction goal. The difference between the total GHG emissions under each of the four scenarios is most notable in the year 2015. By the time the model reaches 2050, without any other policy changes, the difference in total emissions between each scenario is minor.

Average Fuel Carbon Intensity and Low Carbon Fuel Standard

Since this model does not account for any adjustments in the carbon intensity of gasoline, corn grain ethanol or cellulosic ethanol over time, changes in the average fuel carbon intensity are driven by blending rates. Graph 4 shows the AFCI over time; it is static except for times when ethanol blends increase. In 1997, the 10% RFS causes a slight reduction in the AFCI as more corn grain ethanol is used. Scenarios 3 and 4, which utilize cellulosic ethanol with a carbon intensity of 0, significantly reduce the AFCI. The 20% ethanol blend that begins in the year 2013 has a significant impact on the AFCI, as can be seen in the significant drop in that year.

Graph 4. Average Fuel Carbon Intensity

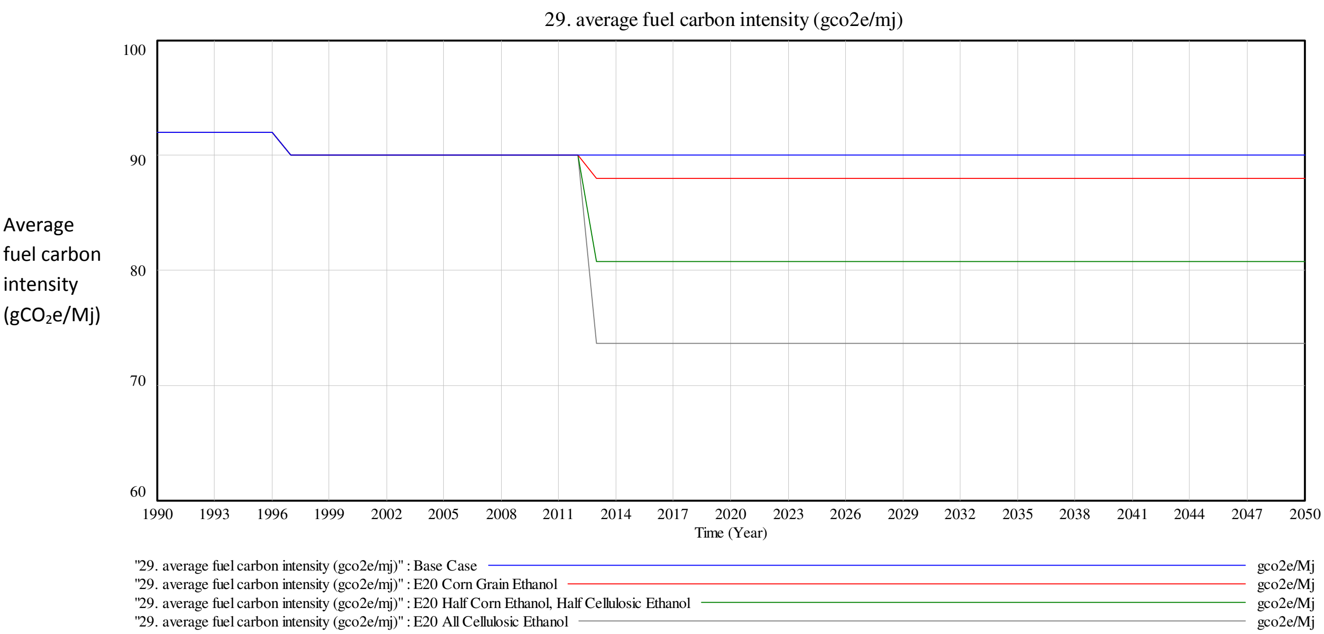


Table 2 below shows the AFCI values under different scenarios and compares them to hypothetical LCFS goals for the state of MN, based on CA standards. The LCFS sets reductions goals for average carbon intensity. i.e., for a 10 % reduction goal, the average fuel carbon intensity in 2015 would need to be 81 gCO_2e/MJ or less because that represents a 10% reduction from the baseline AFCI of 90 gCO_2e/MJ. The LCFS reduction goals are calculated based on the model's 2007 baseline AFCI of 90 gCO_2e/MJ and the CA LCFS goals of 10% reduction by 2020 and 12% by 2025. The units for all values are gCO_2e/MJ.

Table 9: AFCI under different scenarios relative to LCFS goals

2007 AFCI is 90 gCO_2e/MJ for all scenarios	**2015 AFCI** **AFCI necessary to achieve LCFS 10% reduction goal: 81**		**2025 AFCI** **AFCI necessary to achieve LCFS 12% reduction goal: 79.2**	
SCENARIO	**Model level**	**Reduction goal achieved?**	**Model level**	**Reduction goal achieved?**
Base Case: E10 filled by corn grain ethanol	90	No	90	No
E20 filled by corn grain ethanol	88	No	88	No
E20 filled half by corn grain ethanol and half by cellulosic ethanol	80.8	Yes	80.8	No
E20 filled by cellulosic ethanol	73.6	Yes	73.6	Yes

In the base case scenario, an increased use of a lower carbon fuel is represented by the switch to 10% corn grain ethanol in 1997. Since corn grain ethanol has slightly lower carbon intensity than gasoline, this provided some improvement of the AFCI relative to 1996 and earlier. Because corn grain ethanol is blended at a 10% rate throughout the remainder of time in this scenario, there is no improvement of the AFCI relative to 2007 levels. Therefore, under the base case, low carbon fuel standard requirements would not be met for any year.

For all scenarios, there are no policy changes made after 2013, and no changes in carbon intensity of various fuels. Therefore, the AFCI for 2015 in each scenario is the same as the 2025 and 2050 AFCI value for that same scenario. The first two scenarios do not result in the achievement of the LCFS reduction goals. The third scenario, in which half of a 20% ethanol blend is filled by corn grain and half by cellulosic, results in achievement of the 10% AFCI reduction goal by 2015, but not in the 12% reduction goal by 2025, again because the AFCI stays the same from 2013 on. The fourth scenario, in which a 20% ethanol requirement is filled fully by cellulosic ethanol, is the only scenario which represents an achievement of the 12% reduction in AFCI by the year 2025 (and, therefore, the achievement of the 10% reduction by 2015).

Sensitivity Analyses

In order to test the sensitivity of CO_2 emissions from the LDV transportation sector to changes in the growth rate in vehicle miles traveled, the analysis was run with a low (0%) and high (2.37%) growth rate in addition to the original growth rate (.9%), which is the value projected by the MNDOT. All changes in growth rate relative to the historic value (2.37%) are initiated in the model starting in 2007. Particularly projecting far into the future, a 0% growth rate in VMT would significantly reduce 2050 GHG emissions relative to the base case, and a 2.37% increase in VMT each year would nearly double 2050 GHG emissions from the LDV fleet. Table 3 shows that the Next Generation Act GHG reduction goals could be achieved in 2025 with a 0 or .9% growth rate in VMT, but the reduction goals would not be achieved for 2015 or 2050 under any of the VMT growth rates modeled here.

Table 10: Yearly Emissions and VMT Growth Rate

	2015 CO_2 emissions ($MMtCO_2e$) VMT growth rate (starting in 2007)			2025 VMT growth rate			2050 VMT growth rate		
Scenario	**0%**	**.9% (default)**	**2.37%**	**0%**	**.9% (default)**	**2.37%**	**0%**	**.9% (default)**	**2.37%**
Base Case: E10 filled by corn grain ethanol	29.29	31.48	35.4	16.22	19.07	24.83	16.22	23.88	44.88
	Level necessary to achieve Next Gen Act 15% reduction: 23.75			**Level necessary to achieve Next Gen Act 30% reduction: 19.56**			**Level necessary to achieve Next Gen Act 80% reduction: 5.59**		
Reduction Goal Achieved?	No	No	No	Yes	Yes	No	No	No	No

Graph 6 shows yearly LDV CO_2 emissions under the 3 different VMT growth rates addressed by this sensitivity analysis.

Graph 5. Yearly Emissions and VMT

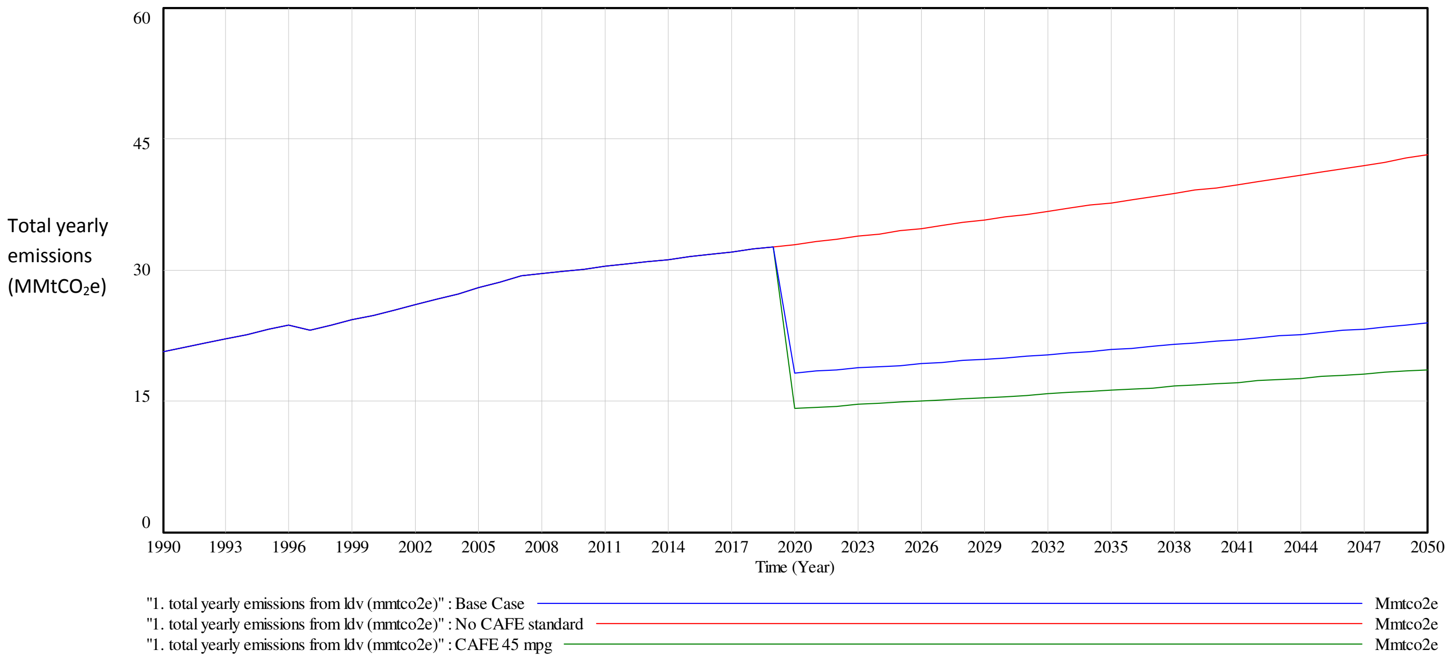
The model was also tested for sensitivity to changes in the average fuel economy in Minnesota. Table 4 shows the change in GHG emission in 2025 and 2050 as a result of different CAFE standards including none, the default value of 35 mpg, and 45 mpg. Under CAFE standards of 35 mpg and 45 mpg starting in 2020, the Next Generation reduction goal for 2025 could be reached, according to this model.

Table 11: Yearly Emissions and CAFE

	2025 CO_2 emissions ($MMtCO_2e$) CAFE improvements (starting in 2020)			2050 CAFE improvements		
SCENARIO	**None**	**35 mpg (default)**	**45 mpg**	**None**	**35 mpg (default)**	**45 mpg**
Base Case: E10 filled by corn grain ethanol	34.44	19.07	14.83	43.13	23.88	18.57
	Level necessary to achieve Next Gen Act 30% reduction: 19.56			**Level necessary to achieve Next Gen Act 80% reduction: 5.59**		
Reduction Goal Achieved?	No	Yes	Yes	No	No	No

Graph 7 shows CO_2 emissions with the three different CAFE improvements modeled here.

Graph 6. Yearly Emissions and CAFE



CHAPTER 9: RECOMMENDATIONS, FURTHER RESEARCH AND CONCLUSIONS

This analysis was designed to test possible CO_2 implications associated with various RFS scenarios deemed technologically possible and politically feasible in the relatively near future. Historically, policy makers have tended to pursue biofuels policies as singular approaches to emissions reductions in the transportation sector, i.e. separate from other policy options aimed at lowering CO_2 emissions from passenger vehicles. Within this singular approach, there are some recommendations that may improve the ability of biofuels policies to contribute to CO_2 reductions. For example, fundamentally, we should not be measuring a renewable fuel standard in gallons or as a percentage of total fuel. Since the energy content of different types of fuels varies significantly, it would be more useful to articulate an RFS based on the amount of energy in MJ or BTUs coming from fossil fuels versus renewable fuels. This minor distinction would be one relatively easy way to clarify our goals and means for biofuels and GHG reduction policies.

One important piece of the CA LCFS legislation is the requirement of regular reports by the State Energy Resources Conservation and Development Commission on the impacts of the

LCFS. Starting in 2013, and every 3 years after, the report will be updated to incorporate new scientific information, findings, and methodologies of quantifying carbon intensity. The report will analyze the emissions impacts, based on full fuel-cycles, associated with fuels used to comply with the LCFS in comparison to historic and projected emissions associated with petroleum-based transportation fuels. The report will also address a variety of environmental impacts, including species, biodiversity, land use, air and water quality, and production and access to food (SB 210). This information should be extremely valuable to policy makers and the state board as they make future decisions about this and other policies. Should MN decide to pursue a LCFS, it would be wise to incorporate a similar evaluation requirement as a way to ensure and promote the achievement of our goals as a state while minimizing any negative impacts associated with this policy.

While it is important to address potential improvements in biofuels policies, it is also essential to analyze how biofuels policies fit into the larger context of CO_2 emissions reduction goals in the transportation sector.

Based on the policy scenarios run in this model and their underlying assumptions, biofuels alone, given current and projected carbon intensity estimates and supply, will not drastically reduce CO_2 emissions from the transportation sector. In this analysis, CAFE standard improvements had the most significant impact on yearly CO_2 emissions; the 2020 increase in average fuel economy to 35 mpg resulted in 44% decreases in annual CO_2 emissions in all four scenarios. Prior to the onset of the CAFE standards, even the most aggressive biofuels policy modeled in this analysis, a 20% RFS filled fully by carbon neutral cellulosic ethanol starting in the year 2013, resulted in a only a 15% decrease in CO_2 emissions from the light duty fleet. Table 12 shows the reductions in CO_2 emissions resulting from key policy changes in the model. Note that in the first policy change, E10, the results are the same for all four scenarios because it predates any changes in CAFÉ or E20. Given the limited potential of biofuels policies alone and the greater potential of other types of emissions reductions policies modeled in this analysis, in the future, biofuels policies should be pursued not by themselves but in conjunction with other policies aimed at drastically reducing CO_2 emissions from the transportation sector in MN, like CAFE standards and VMT reductions.

Table 12. CO_2 emissions reductions as a result of key policy changes

SCENARIO	POLICY CHANGE: E10 CO_2 emissions ($MMtCO_2e$) Pre policy (1996)	E10 Post policy (1997)	E10 Percent reduction	E20 CO_2 emissions ($MMtCO_2e$) Pre policy (2012)	E20 Post policy (2013)	E20 Percent reduction	CAFE CO_2 emissions ($MMtCO_2e$) Pre policy (2019)	CAFE Post policy (2020)	CAFE Percent reduction
Base Case: E10 filled by corn grain ethanol	23.72	23.12	2.6%	30.64	30.92	-0.9%	32.63	18.23	44.1%
E20 filled by corn grain ethanol	23.72	23.12	2.6%	30.64	29.35	4.2%	30.98	17.31	44.1%
E20 filled half by corn grain ethanol and half by cellulosic ethanol	23.72	23.12	2.6%	30.64	27.67	9.7%	29.20	16.31	44.1%
E20 filled by cellulosic ethanol	23.72	23.12	2.6%	30.64	25.99	15.2%	27.43	15.32	44.1%

Further Research

There are a number of specific and general recommendations for further research that could contribute better insights and analytical bases for both the biofuels policy debate specifically and the CO_2 emissions reduction challenge overall.

This analysis provides one possible methodology for analysis of the impacts of various RFS scenarios. It serves as a starting point for analysis of biofuels policies generally; further work would benefit from the inclusion of a variety of issues not included here, and from greatly expanded detail that was beyond the scope of this analysis.

It is important in future research and analysis to find a way to model the impacts of technology improvements that may change the carbon intensity values of different fuels. It would also be useful to develop a rigorous model capable of capturing the interconnections and influences of different policy options that might impact CO_2 emissions from the transportation sector, including changes in VMT and CAFE.

Future research should look at models of all three factors of emissions: fuels consumption, activity and carbon content, as this model only looks at biofuels policies aimed at carbon content, or policies coming from the general emissions reduction policy category of “use cleaner”. In addition, analyses that look at the impacts of changing carbon intensities would add value to understanding the issue, as this model looks only at the impact of changing portfolios on carbon content.

In Chapter 6, figures 13 and 14 show potentially important policy feedback relationships from yearly CO_2 emissions and average fuel carbon intensity to policy decisions in biofuels options like the RFS and LCFS, as well as VMT and fuel economy. While this analysis did not quantify these feedbacks, there are some possible approaches to articulating these relationships. One option would be to conduct a survey of policy makers and citizens with a number of hypothetical future possibilities for CO_2 emissions levels and potential adjustments in RFS or LCFS standards. An estimated relationship between emissions levels and policy adjustments could then be incorporated into the model. Another possibility would be to look at historic evidence from a different environmental issue, and use the resulting pollution level/policy stringency relationships as a proxy for the CO_2 emissions/biofuels policy feedback in future models. For example, yearly changes in water quality measures in Minnesota could be plotted against water quality policy changes over the same period of time. A third way to quantify the policy feedback relationships would be to solicit expert opinion about what levels of emissions would impact policy decisions and to what extent. A nonlinear relationship could be set up in the model so that minor increases in emissions levels would have no impact on policy changes, but larger increases in CO_2 emissions would result in some increase in the stringency of biofuels and other policies. The model could also be set up so the user has the opportunity to adjust this relationship based on their own experience and assumptions about the policy feedback.

Steve Taff of the University of Minnesota and others are working on a project to analyze policy interactions within the transportation sector of a variety of policies that could impact CO_2 emissions, including CAFE, RFS, LCFS, taxes on fuels, taxes on vehicles and cap and trade for the transportation sector. Portions of this model and analysis will be used to further this dynamic modeling of various policies, in order to yield insights about which policies and/or sets of policies should be pursued at the state level to achieve GHG reduction goals while being sensitive to other economic and environmental issues.

There is new research on the CO_2 impacts of land use change and conversion of native ecosystems to cultivated land; this area needs more research. A dynamic model that can account for the cycles in this complex process would be extremely useful.

The purpose of this analysis is to illustrate the use of techniques and methodologies that allow for better analysis. There is a balance and tradeoff when building and using models between complexity and usefulness. A simple model can often be more insightful than a very complex model where it is easy to get bogged down in the details. It is therefore valuable from both a theoretical and practical standpoint to address and test whether a simple model tells the same story as a more complex model.

It is important to examine how different policies interact together. If we continue to pursue policies as singular and independent drivers of behavior, we are very likely to miss the bigger picture and therefore unlikely to achieve our environmental, social and economic goals. Fundamentally, these diverse goals must also be taken into account in a way that incorporates them and allows us to examine tools for achieving multiple goals at once, or at least achieve goals in one area without causing harm to another area we value. Dynamic and holistic modeling approaches provide one beneficial methodology for being able to address multiple goals and issues in a single framework in order to help illuminate ways to actualize the changes we want to see as a society.

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