2-1-2009

Unintended consequences of ethanol production: Geospatial lifecycle analysis

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Recommended Citation

Malone, Amanda Louise, "Unintended consequences of ethanol production: Geospatial lifecycle analysis" (2009). Thesis. Rochester Institute of Technology. Accessed from

Unintended Consequences of Ethanol Production:
A Geospatial Lifecycle Analysis

by Amanda Louise Malone

Masters of Science
Science, Technology and Public Policy
Thesis Submitted in Fulfillment of the
Graduation Requirements for the

College of Liberal Arts/Public Policy Program at
ROCHESTER INSTITUTE OF TECHNOLOGY
Rochester, New York

February 2009

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Acknowledgement

I want to thank everyone in the Public Policy Department for a wonderful experience over the past few years. I want to thank Mark Coleman and Tom Seager for their valuable insight and advice throughout the thesis process. I also want to thank Jamie Winebrake, my thesis advisor, for his help and feedback in the development of the model as well throughout the writing process and for his support and encouragement. Special thanks also has to be extended to the Center for Integrated Manufacturing Studies (CIMS), which provided me with valuable work experience as a graduate student. Finally, I want to say thank you to my parents, sisters, brother, boyfriend and friends who have given me support and encouragement throughout this process.

1 *ABSTRACT*

Ethanol use has been lauded as a way to provide a secure, diverse, environmentally friendly and economically beneficial energy supply for the US. However, along with this praise has been criticism due to potential unintended consequences that may arise from ethanol production and use. This thesis addresses one such unintended consequence: the displacement of emissions from downstream vehicle operation locations to upstream farming and production areas.

The thesis uses the Upstream Ethanol Production (UEP) Model, a geospatial lifecycle model developed for analyzing spatial emissions inventories for ethanol production. The UEP model is based on the US GREET model – the gold standard for total fuel cycle analysis models in the U.S. The UEP allows for key pollutants including CO_2, N_2O, CH_4, CO, VOCs, SO_x, NO_x and PM to be quantified at various locations throughout the ethanol production pathway

Several case studies involving ethanol fuel use in New York State are used to demonstrate the model and explore the upstream versus downstream air emissions associated with the ethanol production pathway. The results indicate the importance of transportation and distribution pathways, as well as feedstock production assumptions, on the overall geospatial impacts of air pollution. Displaced emissions from downstream vehicle operation locations in urban areas to upstream feedstock and ethanol fuel production locations in rural areas are also shown by the results. The results indicate that the use of ethanol at urban areas such as those in New York State to reduce greenhouse gases come at the expense of the rural area air quality. Based on the results, it appears that potential geopolitical conflicts caused by displacement of emissions could influence future energy, environmental, agricultural and economic policymaking at the federal and state levels.

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4 *INTRODUCTION*

In most parts of the United States, vehicle operation is not an option, but a necessity. Americans depend upon vehicles to give them mobility; however, this mobility has created problems for the US. Petroleum consumption by vehicles can contribute to global warming and has made the US dependent upon foreign countries, often located in instable areas of the world, for its oil needs. Not only is the dependence upon foreign nations a political risk for the US, but, it also impacts the US economy putting money that could otherwise be spent on domestic fuels if available, into other countries (Energy Information Administration, 2007c, 2008; Intergovernmental Panel on Climate Change, 2007; US Department of Agriculture, 2006b).

In response to global climate change, oil dependence and struggling rural economies, the US has invested heavily into new fuels and technologies that can be domestically produced such as ethanol. Additionally, legislation has been passed giving incentives for ethanol and other biofuel production and consumption. Record high oil prices exceeding $140 per barrel coupled with heightened concern over climate change, energy security and struggling economies in rural communities, have driven the expansion of the corn ethanol industry in the US, leading many to believe that ethanol has the potential to become a long term solution to the country' s energy needs.

But, while corn ethanol production and use is considered by many to be beneficial (Renewable Fuels Association, 2005a; Urbanchuk, 2006; Michael. Wang, 2005), with its use also comes unintended consequences such as increasing food prices, land use practices and air quality issues from the production of both the feedstock and the fuel for ethanol. This thesis will focus on the third unintended consequence of ethanol production and use by exploring the following hypotheses:

I. **Expanded ethanol use for transportation will shift criteria air pollutant emissions from urban areas where ethanol is used as a fuel to rural areas where feedstock and fuel ethanol are produced.**
II. **Use of ethanol will increase criteria air pollutants along feedstock and fuel transportation routes.**

To test both hypotheses, a geospatial lifecycle analysis will be performed for three case studies using the Upstream Ethanol Production (UEP) model, developed for this research and linked to Argonne National Laboratory's (ANL) Greenhouse gas, Regulated Emissions and Energy in Transportation (GREET) model (Argonne National Laboratory, 2008).

The chapters that remain in this thesis are structured as follows:

II. Describes the relevant information and literature related to ethanol, lifecycle analysis and prior studies performed in regards to lifecycle analysis, GHGs and criteria air pollutants related to the ethanol production.
III. Details the methodological approach taken in the development of the UEP model as well as the cases studies.
IV. Presents the results of the analysis for all cases in regards to GHG and criteria air pollutants.
V. Provides conclusions based on the results as well as policy implications, recommendations and a framework for future research using the UEP model.

5 *LITERATURE REVIEW*

5.1 CHAPTER OVERVIEW

This chapter reviews the background information necessary to evaluate the impacts of the ethanol production process on communities involved in ethanol feedstock and fuel production, and how these lifecycle impacts create unintended consequences for policymakers. First, background issues driving the production and use of ethanol will be explored. Second, an introduction to ethanol will be presented. Third, the current ethanol industry in the US, and the policies related to ethanol production and use will be discussed. Finally, emissions related to ethanol production at all stages will be examined.

5.2 BACKGROUND ISSUES

The production and use of ethanol has been driven by three factors that the US and world are dealing with:

- global climate change;
- foreign oil dependence; and,
- rural economic development.

Global climate change is part of the natural cycle of the earth; however anthropogenic activities such as the use of fossil fuels for energy have impacted this natural process. Greenhouse gases (GHG) such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are emitted into the atmosphere daily by natural sources which include plants, animals and soils (US Environmental Protection Agency, 2008a). Since the Industrial Revolution, anthropogenic activities like the burning of fossil fuels add further to the natural process by emitting additional GHGs and other air pollutants (Intergovernmental Panel on Climate Change, 2007). In moderation, release of gases such as CO_2 is a beneficial process as this is what keeps the earth's surface from freezing over, however when human activities start adding to the natural processes of earth, the atmosphere becomes inundated with gases which trap more heat causing the earth to become warmer (Pew Center on Global Climate Change, 2007).

Today, the US contributes approximately one quarter of the total greenhouse gases globally. The transportation sector alone accounted for nearly 2010.3 million metric tons of carbon dioxide equivalent gases emitted by the US in 2006 or 28 percent of the total carbon dioxide equivalent gases emitted in the US (Energy Information Administration, 2007a). Globally, the transportation sector accounts for approximately 13 percent of the total GHG emitted in 2004. Mitigation programs to reduce GHGs have been implemented in recent years which in the transportation sector primarily focus on advanced vehicle technology and reduction of petroleum based fuels. This strategy also reduces the dependence that the US has on foreign oil suppliers and enhances the energy security.

On a daily basis, the US consumes approximately 20.4 million barrels of oil, while only producing around five million barrels. A significant portion of the US oil supply is imported from foreign countries. While the majority of the oil consumed in the US comes from Canada, Mexico and Caribbean producers, the largest reserves of oil are located in the Middle east (Energy Information Administration, 2007b), a region of the world that is typically unstable. Depletion of domestic sources coupled with high importation and oil field locations have been key drivers in the call for the US to diversify its energy sources.

Additionally, the diversification of energy supplies include using bio-based energies, produced from commodities grown in America's farming communities, which have been struggling economically for some time. Since the mid-1900s, rural communities across the country have been losing farms and population due to lack of jobs. Counties that once depended upon farming are now areas of higher poverty levels, lower incomes, and slow economic growth as compared to counties closer to metropolitan areas (US Department of Agriculture, 2006b). Due to gaps existing between rural and urban areas, the US Department of Agriculture (USDA) has implemented a number of programs to aid in rural development. Some of these programs provide for new markets to open for farmers to sell crops or for industries to grow within the rural areas. Farming communities across the country have felt the impact of the ethanol industry, an indicator that continual expansion is beneficial to rural economics.

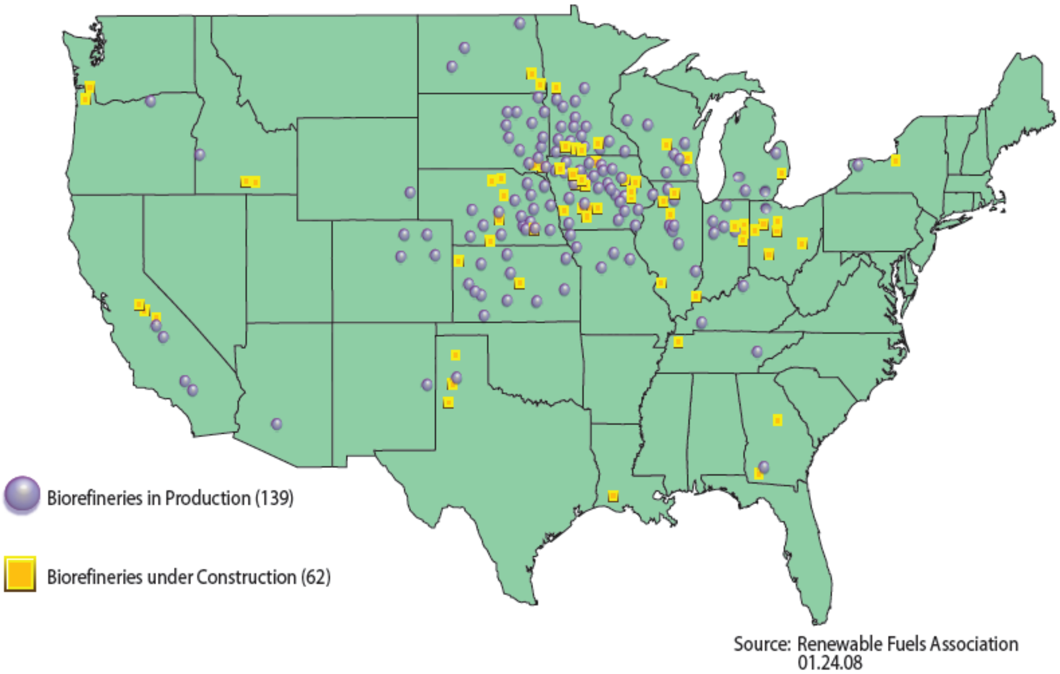
5.3 INTRODUCTION TO ETHANOL

Ethanol (C_2H_5OH) is an alcohol that can be produced from a number of feedstock sources. These sources include sugar and starch crops and cellulosic material. Generally, ethanol supplies are produced primarily using two feedstocks: sugarcane in Brazil and corn in the US. Future feedstocks include cellulosic material such as woody biomass, agricultural waste and grasses (Berg, 2004). Ethanol is a colorless alcohol which can be used as either an oxygenate for gasoline to provide for cleaner burning of the fuel or as a gasoline fuel substitute in amounts up to 85 percent ethanol (Swank, 2004).

Generally, ethanol is considered a cleaner burning fuel compared to its gasoline counterpart, emitting lower amounts of carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NO_x) and particulate matter (PM). In non-attainment areas, typically major cities around the country, ethanol or other oxygenates are required to be added to the gasoline supply to reduce CO emissions from vehicles. Because ethanol is produced from renewable sources, the bio-based fuel is expected to generate less GHGs, however this is a point that is surrounded by much controversy due to the total fuel cycle emissions contributed by the upstream portions of the fuel cycle (e.g., farming and fuel production). This debate is a central research component of this thesis as the upstream portion of the ethanol fuel cycle will be the primary focus.

5.4 THE ETHANOL INDUSTRY

Ethanol has been produced in the US for the past 150 years. Throughout the first half of the 1900s, ethanol was produced and used primarily by Midwest farmers as a fuel oxygenate and eventually a fuel substitute. It was not until the mid-1970s with the energy crises that ethanol was produced for large scale commercial use (Fehner & Holl, 1994; Neeley, 2006). Currently, the US ethanol industry consists of over 134 operating ethanol production facilities with another 77 under construction as shown in **Figure 5-1**. These facilities are located in 26 states across the country (Renewable Fuels Association, 2007b). Ethanol production has increased from 175 million gallons in 1980 to approximately seven billion in 2007 as shown in **Figure 5-2** (Renewable Fuels Association, 2007b).



Source: Renewable Fuels Association 01.24.08

Figure 5-1 Ethanol production facilities operating and under construction

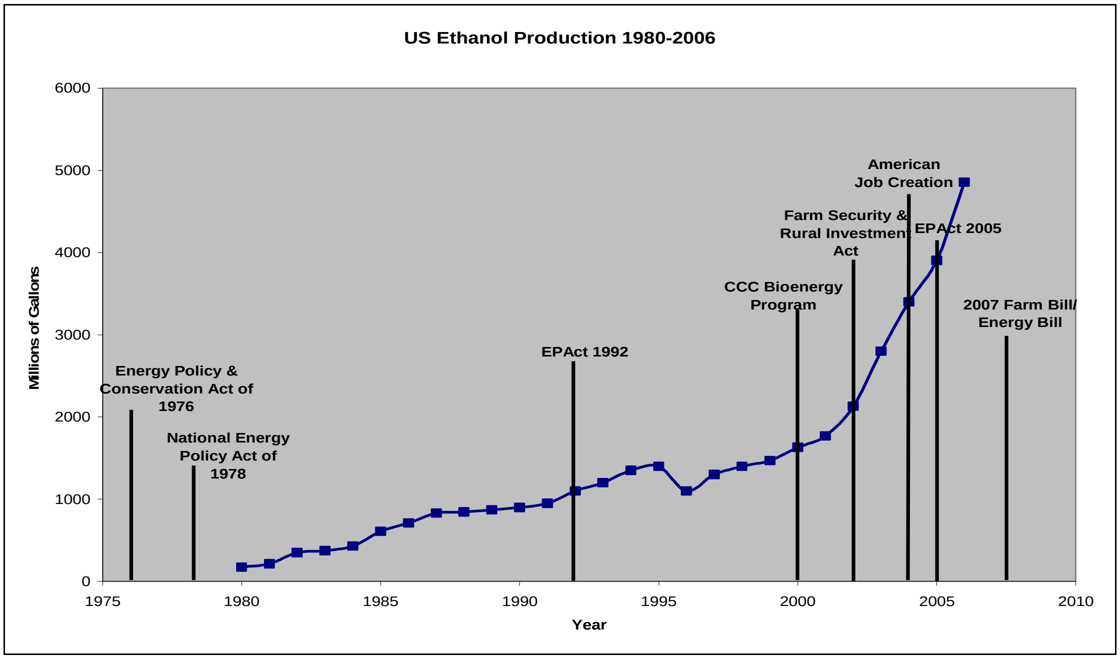


Figure 5-2 Ethanol Production from 1980 to 2006 as well as Federal Energy and Agricultural Policies that Contain Ethanol Mandates and Subsidies.

Most of these facilities are located in rural communities in the Midwest, where corn is abundant, although in recent years the industry has expanded to include states outside the Midwestern Corn Belt. These include New York, Georgia, Kentucky, Texas, Oregon, Washington, and California (Renewable Fuels Association, 2007a).

For many years, fuel grade ethanol has been used primarily in the Midwest, however in recent years its use has expanded to states outside the Corn Belt. Metropolitan areas such as New York City or Los Angeles are located along the East and West Coasts of the US. Typically, areas such as these are also the locations of traffic congestion adding to the air pollution which is present from industrial activities. Technologies and fuels, along with pollution and conservation strategies such as car pooling and mass transit, are being used as a way to mitigate against further air pollution and greenhouse gas release. Ethanol use in cities along the coasts has increased in recent years (National Ethanol Vehicle Coalition, 2008). **Figure 5-3** shows the number of ethanol pumps located in each state of the US. While the number of ethanol refueling stations along the east and west coasts is small in comparison to those in the Midwest, it is expected as the industry grows, E85 will be used in larger amounts in locations farther away from where it is produced. Automobile manufacturers are now making flexible fuel vehicles (FFV), or vehicles that can operate on any blend of gasoline and ethanol up to 85 percent part of the standard package for new vehicles. In 2007, nearly one million alternative fuel vehicles were in existence in the US (US Department of Energy, 2007b). As the automakers accommodate the policy and public need for new automotive technology that will aid in the mitigation of GHGs, the number of ethanol vehicles (FFV) increases. The increase in FFV being manufactured and utilized may cause the ethanol industry to expand and build additional production facilities.

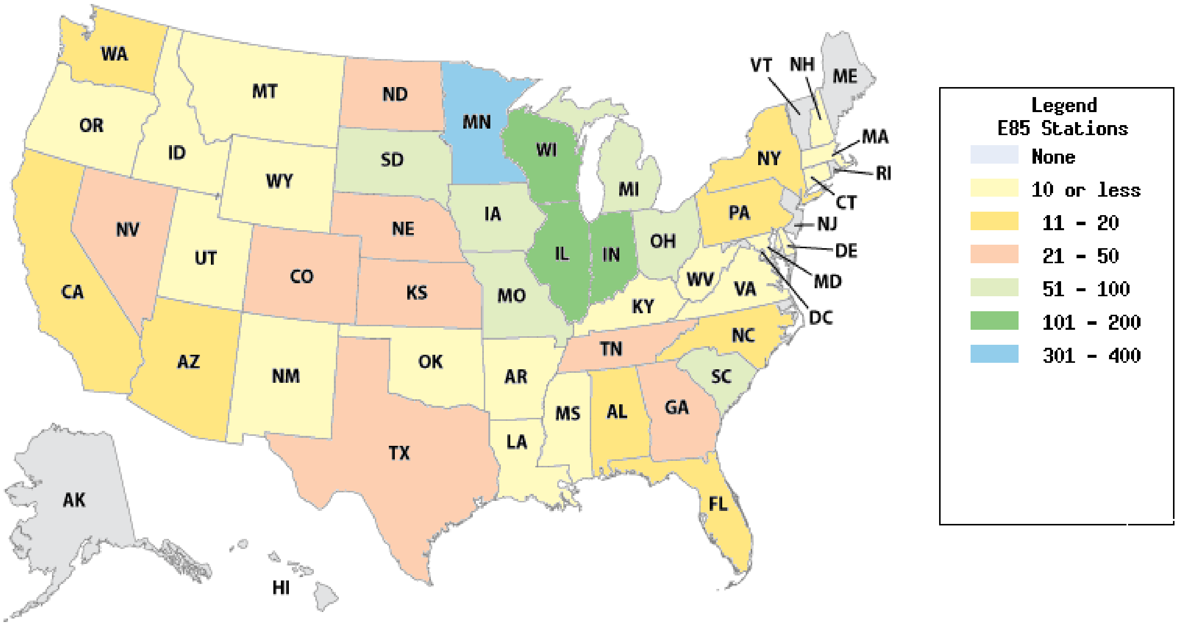


Figure 5-3 E85 Stations across the country

Source: Alternative Fuels Data Center: http://www.eere.energy.gov/afdc/ethanol/ethanol_locations.html

5.4.1 Ethanol Policy

The increase in corn ethanol production facilities and use is driven heavily by government subsidies, much like the sugar ethanol industry in Brazil (Goldemberg, Coelho, & Lucon, 2003). Policies regarding ethanol production and use span across several categories including energy, agriculture and environment. Since the beginning of the 1990’s, ethanol mandates have been part of federal legislation. The *Clean Air Act of 1990 (CAA)* mandated that an oxygenate be added to conventional gasoline. Two additives were used: methyl tertiary butyl ether (MTBE) and low level ethanol. In 1992, the *Energy Policy Act* was passed requiring federal agencies to use alternative fuels in their fleets, this included fuel grade ethanol and other biofuels like biodiesel (Fehner & Holl, 1994; US Department of Energy: Energy Efficiency and Renewable Energy, 2006).

The bulk of the ethanol policies and programs were passed, starting in 2000 with the Commodity Credit Corporation (CCC) Bioenergy Program, a US Department of Agriculture (USDA) Program, which gave bioenergy producers cash incentive to use US grown commodities such as corn and soybeans. In addition to this farm program, the *Farm Security and Rural Development Act* was passed in 2002, giving subsidies to ethanol and biofuel producers, particularly those located in rural farming communities. The *American Job Creation Act of 2004* created a tax credit for ethanol production facilities producing less than or equal to 60 million gallons of ethanol per year (US Department of Agriculture, 2006a) , while the *Energy Policy Act of 2005* mandates that a renewable fuels standard (RFS) be set by the US Environmental Protection Agency (EPA); this was set in April of 2007. The RFS requires that seven and a half billion gallons of fuel grade ethanol be produced and used in the US by 2012. With nearly seven billion gallons produced in 2007, this goal will be surpassed well before 2012 (US Environmental Protection Agency, 2007a).

In 2007, the *Energy Independence and Security Act* (EISA) was signed into legislation by President George W. Bush. EISA set a new mandate for ethanol use at 36 billion gallons by 2022, with nearly 21 billion coming from cellulosic material, a feedstock that has yet to be used in large scale commercial production ("Energy Independence and Security Act of 2007," 2007). Individual states have also implemented ethanol policies that have the potential to affect environment and economy. For instance, New York State has several laws, regulations and incentives requiring state fleets to utilize ethanol and other biofuels in state fleet vehicles, to meet emission levels beyond those set down by the EPA, or giving tax incentives to biofuel producers and those companies and individuals whom invest in biofuels infrastructure (US Department of Energy, 2007a). The intent of many of these policies is to aid in the development of the rural farming communities, that have lost farms, population and tax revenue over the years (US Department of Agriculture, 2006b). Energy policy provisions, like those included in EPAct05, were also established with the intent to curb petroleum consumption and promote the use of domestically produced fuels to aid in diversifying and securing the country's energy supply as well as reduce GHG emissions (Duffield & Collins, 2006).

5.5 UNINTENDED CONSEQUENCES OF POLICY

Each of the above mentioned current and future policies have the potential to create unintended consequences for environment and society. While it is impossible to fully anticipate all consequences of a given alternative or policy, it is the job of policymakers to try to minimize these consequences, which can be both positive and negative and can influence a variety of people and places. The human race's attempts to resolve a social issue, often result in the creation of new problems (Sterman, 2000). The "counterintuitive behavior of social systems" as Jay Forrester (1971) calls it, often results in the public reacting to the policy in an unexpected way; the very same policy used to resolve one problem is the cause of another (Forrester, 1971).

Several examples of unintended consequences exist across all disciplines. Instances of unintended consequences are:

- The evolution of drug-resistant pathogens due to the overuse of antibiotics. As more antibiotics are prescribed, pathogens evolve into a new strain resistant to current drugs used, making the drugs ineffective in fighting the pathogen.
- The evolution of chemically resistant pests and weeds and environmental damage as a result of the use of pesticides and herbicides on agricultural crops. The use of pesticides and herbicides causes pests and weeds to evolve into a resistant form or the chemicals alter the environment causing damage worse than the original problem.
- Automotive safety features preventing cautious driving, thus increasing the risk, rather than benefiting drivers and other individuals. Because safety features are added to vehicles, individuals are not as cautious, causing the risk to both driver and passengers to increase (Sterman, 2000).

A classic case of unintended consequences is the decision to use MTBE as a fuel oxygenate. In the late 1970s, MTBE was used as a replacement for tetraethyl lead as an octane booster in gasoline (Davis & Farland, 2001). As a replacement, MTBE was used in low levels, until 1992 when the CAA mandated that gasoline contain oxygenates. When an oxygenate is added to gasoline, the fuel burns cleaner causing a reduction in the amount of tailpipe emissions such as CO, HC and particulates (Swank, 2004). Although the CAA does not specify which oxygenate to use, MTBE was chosen by many gasoline refiners due to its economic benefits of being less expensive to produce. Gasoline containing MTBE or oxygenates are known as reformulated gasoline or RFG. This is primarily used in areas where air pollution is of great concern, such as major cities (US Environmental Protection Agency, 2007b).

While MTBE can reduce tailpipe emissions from cars, the oxygenate itself has the potential to contaminate ground and drinking water supplies across the country; MTBE dissolves easily in water and remains there for extended periods of time (Agency for Toxic Substances and and Disease Registry, 1997). After years of use, MTBE was found in drinking water supplies in areas using RFG, however at the time, little was known as to the health effects of the chemical (US Environmental Protection Agency, 2007b). Limited information as to the environmental and human health risks posed by MTBE use was known at the time of implementation of the oxygenate requirement (Goldstein, 2001). The public became concerned about the effects of MTBE on human health, particularly after instances of sickness due to exposure. Further testing has been performed, yet a lot remains unknown as to the effects of MTBE (Davis & Farland, 2001). As a result of unknown or unresolved environmental and human health risks, MTBE was phased out of the gasoline supply, first by individual states and eventually by individual oil companies and federal government (Energy Information Administration, Unknown).

The intent of a policy is sometimes buried by the unexpected side effects of the policy. Often, unintended consequences are the result of overlooked, under-researched or the absolute need to resolve a situation immediately, rather than acting on the precautionary principle (Goldstein, 2001). One of the first academics to develop theories related to unintended consequences was Robert Merton (1936), who identified five key causes:

1. Ignorance- all consequences of an action cannot be identified. When analyzing the potential outcomes of an action, consequences of the action will be missed.
2. Error- analyses could be wrong or steps once taken in the past to correct the error may not work for the existing issue.
3. Immediacy of interest – the future consequences of an action are not seen due to the immediate need to resolve an existing issue. A resolution to a problem is created out of haste, with failure to look beyond the current situation.
4. Basic values- current value system may restrict or encourage an action being taken. If the basic values of society are in danger of being changed due to the existence of the issue or solution to the issue, an action may or may not be taken.

5. Self-defeating prediction- society will resolve the issue before the action can be taken (Merton, 1936).

Policies should be carefully considered and all potential consequences and stakeholder concerns should be addressed prior to implementation. In the case of ethanol, unintended consequences can range from emission displacement to increased food prices. Ethanol production from corn has been faulted as the reason for increased food prices across the country (Westcott, 2007). From 2002 to 2007, ethanol use of corn grew by 53 million metric tons; during the same period, demand for corn for other products or by the other countries did not decline. The increasing demand for corn from both ethanol and traditional corn markets has aided the increase in corn prices per bushel harvested (Trostle, 2008). Consumers have experienced increased food prices, particularly in red meats, eggs, poultry, and dairy products, due to the use of corn as feed for farm animals (Alexander & Hurt, 2007). While this thesis will not address the adverse effects the ethanol industry may have on food prices and corn supplies in the US, it will address another potential unintended consequence: displacement of emissions.

The displacement of emissions from tailpipe to production locations can have adverse effects on the locations upstream, which is why observing the lifecycle geospatially is important. While many studies have been performed that observe the economic consequences of ethanol production on locations throughout the lifecycle, few studies have been performed which address the potential implications of ethanol production and use on individual stages geospatially in regards to emissions. Generally, air pollution policies are designed to address local and regional air issues, however do not account for global GHGs, while the same could be said for GHG mitigation policies in regards to local and regional air problems (Schipper, Marie-Lilliu, & Gorham, 2000). Ethanol policies, in the past, have relied upon lifecycle analysis that primarily focus on the reduction of total GHG, a global concern; however these policies have the potential to cause increases in emissions at other locations outside of the vehicle use region. It has been recommended that the entire lifecycle emission balance at each individual location should be carefully considered when making decisions; only fuels and energy derived in a sustainable fashion in regards to society and environment at each location along the supply chain should be used as use of biofuels in general can result in many unintended consequences at locations along the supply chain (Sustainable Production of Biomass Project Group, 2006). The GREET model does acknowledge that location is important when looking at local air pollutants; the model gives two results for each local air pollutant: total and urban emissions which account for the total emissions as well as the emissions occurring in metropolitan areas (M. Q. Wang, 1999), however this does not include rural areas where farming is taking place. It has been found in some studies that use of ethanol as a fuel has the potential to increase health risks in urban areas (Jacobson, 2007), however few studies have been found that address the potential pollution for farming and ethanol production communities caused by the use of ethanol in urban areas .

Existing lifecycle studies view emissions from a total lifecycle (well to wheels) perspective. While some studies acknowledge and account for local pollutants, typically the primary focus is the total lifecycle GHG reduction, and more importantly CO_2 reduction. This research will focus on the criteria air pollutants and GHGs that will be produced at various locations within the ethanol lifecycle.

5.6 EMISSIONS

Most ethanol studies focus on three aggregate stages of the lifecycle as well as the combined total emissions from all three stages. Included in the studies are typically results for the feedstock, fuel production and vehicle operation stages (Delucchi, 2006; Farrell, et al., 2006; M. Q. Wang, 1999). Each stage encompasses all steps and locations within that stage, as shown in **Figure 5-4**. For instance, the feedstock stage for ethanol includes agricultural chemical production and transportation, corn growth as well as corn transport and distribution.

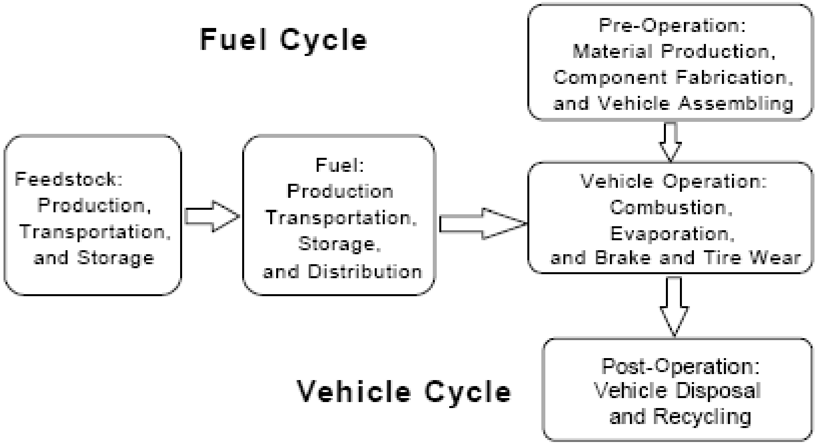


Figure 5-4 Fuel Cycle Stages
Source: (M. Q. Wang, 1999)

Generally, studies focusing on the ethanol lifecycle conclude that corn ethanol production and use results in reduction of GHGs up to 30 percent as compared to conventional gasoline (Delucchi, 2006; Farrell, et al., 2006; Hill, Nelson, Tilman, Polasky, & Tiffany, 2006; Michael. Wang, 2005). While criteria air pollutants are mentioned and calculated in many models, many studies focus primarily on GHGs, due to their global impacts. Criteria air pollutants, generally, exist in local and regional areas and impact those areas, rather than the larger global community. However, many of these studies note that upstream locations such as farms using fertilizer to grow corn or locations where land use changes have occurred play significant roles in the total fuel cycle emissions (Delucchi, 2006).

5.6.1 Feedstock Air Emissions

The feedstock stage contributes to the total lifecycle emissions, emitting large amounts of GHGs and criteria air pollutants. Activities related to the feedstock stage are located in rural communities at farms and on rural highways. Often these locations are represented by the aggregate feedstock stage, rather than as a geospatial location. All feedstock activities do not take place in the same location and may be spread out across an area. Activities included in the feedstock stage for many lifecycle studies are agricultural chemical production and transportation, feedstock growth and transportation of the feedstock from farm to production facility.

Many have cited agricultural chemical use, land use changes and the use of fossil fuels in farming as key sources to the feedstock emissions (Delucchi, 2006; Kammen, et al., 2007; Landis, Miller, & Theis, 2007). Carbon dioxide, while released due to farm equipment operation, is considered to be neutral due to the uptake of carbon by the crops (Renewable Fuels Association, 2005b). Generally, emissions are from the process fuels used in the production of electricity for the chemical facility, from diesel fuel use in the transportation of the chemicals, planting and harvesting of the crops as well as the transportation of the corn to the ethanol facility. Additionally, the utilization of fertilizers, herbicides and insecticides as well as land cultivation stimulate the release of emissions into the air due to biological and chemical processes within the soils and plants (M. Q. Wang, 1999).

The addition of nitrogen fertilizer is a primary source of nitrogen release occurring from the soil resulting in N_2O and NO_x emissions (Kim & Dale, 2007). Since 1990, the N_2O emissions have increased by 15 percent due to the use of synthetic fertilizer addition to soils (Energy Information Administration, 2007a). NO_x is produced due to the photo-degradation of N_2O in the stratosphere (US Environmental Protection Agency, 2008b), as well as the burning of diesel fuel in transportation and farming activities. Both NO_x and N_2O are a result of the combustion processes due to the fuels used to farm and transport corn and agricultural chemicals (Miller, Landis, & Theis, 2007).

Sulfur oxide, PM_{10} and $PM_{2.5}$ are emitted as a result of transportation and farming activities. Tillage of corn fields also contribute to the overall PM emissions (M. Q. Wang, 1999). Additionally, SO_x emissions can result from the combustion of fossil fuels in the power plants, used to produce electricity for chemical production facilities(Energy Information Administration, 2005). Generally, the production of ethanol may increase emissions at the farming location.

5.6.2 Production Facilities

Ethanol production facilities are located in rural communities near the feedstock suppliers. Prior to ethanol production, these communities experienced primarily emissions resulting from farming activities or the solely the feedstock stage. The addition of the production facility adds greenhouse gas and criteria air pollutants to the emission profile of the rural communities.

Production facilities account for a significant portion of emissions for the ethanol fuel process. Depending upon the type of facility, the electricity process fuel used and the amount of co-product credits given to the production of ethanol, the resulting emissions for corn ethanol vary. Corn ethanol can be produced in one of two types of production facilities: wet milling or dry milling. In the past, ethanol was predominantly produced in the wet milling process which also produced other products such as corn gluten, corn meal, and fiber. Today, corn ethanol is primarily produced in dry milling facilities, which result in higher yields of ethanol and only one co-product: dry distiller’s grains and solubles (DDGS). It is generally accepted that dry milling production facilities result in lower operating costs and fewer GHG emissions (Shapouri, Duffield, & Graboski, 2002; Michael. Wang, 2005).

Ethanol facilities have been and have the potential to be the source of volatile organic compounds (VOC), NO_x, sulfur oxides (SO_x), hazardous air pollutants (HAP), PM and CO emissions as well. Dry milling ethanol production facilities in Minnesota have reported on a consistent basis the detectable emission levels of acetaldehyde, acetic acid, ethyl acetate, formaldehyde, ethanol and methanol at several of the stages within the process. While VOC levels can be controlled using available technology solutions like thermal oxidizers (TO), some VOCs are still emitted. Nitrogen oxide is also a common gas emitted by production facilities due to the use of boilers and dryers in dry milling facilities (Brady & Pratt, 2007). Each step within the ethanol conversion process emits pollutants. These include (Aventine Renewable Energy-Aurora West LLC, 2007):

- Grain Receiving, Handling, Storage and Hammermilling: PM, PM_{10}
- DDGS Storage and Loadout: PM, PM_{10}, VOC, HAP
- Fermentation Operations: PM, PM_{10}, VOC, HAP
- Pre-Fermentation, Distillation, DGS Drying Operations: PM, PM_{10}, SO_2, NO_x, CO, VOC, HAP
- Organic Liquid Process and Storage Tanks: VOC, HAP
- Ethanol Loadout: VOC, HAP
- Gas-Fired Boilers: PM, PM_{10}, SO_2, NO_x, CO, VOC, HAP
- Emergency Equipment: PM, PM_{10}, SO_2, NO_x, CO, VOC, HAP
- Equipment Leaks: VOC, HAP
- Cooling Tower: PM, PM_{10}
- WDGS Storage and Loadout: VOC, HAP
- Haul Roads: PM, PM_{10}

Similar estimated emissions are seen within other ethanol production facility permits (Aventine Renewable Energy- Aurora West LLC, 2007). Each production facility has a permitted amount of emissions for each pollutant per year depending on federal and state regulations.

Processing fuels make a considerable difference in the overall lifecycle emissions for ethanol (M. Wang, Wu, & Huo, 2007). To produce ethanol and its co-products, large amounts of fossil fuels are used; coal and natural gas are the primary sources (M. Q. Wang, 1999). In comparison to oil, coal emits almost 20 percent more carbon while natural gas releases approximately 30 percent less (Natural Resource Defense Council & Climate Solutions, 2006).

Generally, natural gas is used more often in production facilities. By using natural gas rather than coal, CO_2 emissions from ethanol production facilities are reduced (M. Q. Wang, 1999). Under EPA standards, facilities containing natural gas boilers are considered to be minor emitters. Further reduction in emissions from production facilities is acquired through the use of co-generation systems (CHP), which produce both steam and electricity. While reduction in emissions is a benefit from the use of natural gas, increases in natural gas prices has some facilities choosing to use coal as a primary source of electricity, despite being considered major emitter under EPA standards (M. Wang, et al., 2007). Ethanol produced in a facility using coal as its processing fuel may result in an increase in GHGs, while natural gas processing energy results in reduced GHGs by approximately 30 percent. Further reduction in GHG for production facilities using co-generation systems is small, yet present.

To reduce emissions, some ethanol production facilities are using gasification systems that burn wood chips to make processing energy. While few of these facilities exist, those that do exist have shown significant reduction in GHG emissions. There is also potential for facilities to burn a portion of the DDGS generated as co-product, which when burned generates more energy than coal or natural gas. Burning of both wood chips and DDGS result in emission reduction greater than 35 percent (39 percent for DDGS and 52 percent for woodchips) (M. Wang, et al., 2007) While the energy source used for production at the ethanol facility will not be studied in this research, the type of source does play an important role in the amount of greenhouse gases and criteria air pollutants emitted by a production facility. For this thesis, only coal and natural gas will be used in the electricity mix for ethanol production.

5.6.3 Transportation of Corn and Ethanol

Transportation and distribution is not considered an individual stage in GREET for transportation of corn or ethanol. Corn is transported on average approximately 50 miles to the production facility from farms using trucks, while ethanol is transported longer distances by truck, train and barge. The current pipeline system used to transport gasoline long distances cannot be used to ship ethanol due to ethanol's affinity to water, that may be present in the pipes (Denicoff, 2007; Reynolds, 2000).

Generally, lifecycle studies such as those performed using the GREET model include the emissions, both criteria air pollutants as well as GHG, from transportation and distribution in the stage which proceeds it, which gives little information on the impact that transportation and distribution has on the fuel cycle emissions. For instance, emissions resulting from the transportation and distribution of corn are calculated as the aggregate feedstock emissions (M. Q. Wang, 1999). Agricultural chemicals, corn and ethanol are transported using diesel burning heavy duty trucks, trains, barges and ocean tankers; additionally, farm machinery used to plant and harvest corn typically use diesel fuel. The combustion of diesel fuel contributes significantly to local air pollutants such as NO_x, SO_x, CO and PM (Bent, Orr, & Baker, 2002; Lloyd & Cackette, 2001; US Environmental Protection Agency, 2003). While diesel combustion does emit GHGs such as CO_2 and N_2O, diesel emissions are responsible for the majority of the emission of criteria air pollutants such as PM, NO_x and SO_x. Lower CO_2 levels are seen when diesel emissions are compared to emissions of conventional gasoline, due to the diesel engines higher efficiency. Diesel engines also emit N_2O, produced as a by-product of NO reaction as well as CO/HC oxidations on metal catalysts (Lloyd & Cackette, 2001).

Particulate Matter is a mixture containing elemental carbon, semi-volatile organic compounds and sulfate compounds. This is released from diesel engines with varying concentrations of each component. Aromatic and oxygen content of the fuel can potentially reduce the formation of PM (W. G. Wang, Lyons, Clark, & Gautman, 2000). PM formation is also dependent on the way in which exhaust from diesel engines mixes in the air and the air temperature (Lloyd & Cackette, 2001).Particulate Matter emissions are partially responsible for haze and black carbon (soot) formation. Black carbon can absorb radiation which further adds to global warming and at times diesel combustion results in visible particle emissions. Of the visible particle emissions (haze, black carbon, smoke) in urban areas, diesel vehicles can contribute 10 to 75 percent depending on air, vehicle and fuel characteristics. Additionally, PM in the atmosphere can also change cloud droplet size and inhibit rainfall (Lloyd & Cackette, 2001).

Nitrogen oxides (NO_x) are precursors to smog formation, typically produced in diesel engines due to higher temperatures and compression ratios which are favorable conditions for NO_x to form in the air (Lloyd & Cackette, 2001; Moomaw, 2002). NO_x results from the reaction of nitrogen with oxygen in the diesel engine combustion process. Fossil fuel combustion contributed approximately 21 million tons of NO_x to the global NO_x emissions in the 1990s (Food and Agriculture Organization of the United States & International Fertilizer Industry Association 2001). Since NO_x standards for diesel on-road vehicles have been set for some time, it is the NO_x emissions from non-road vehicles such as farming and construction equipment that produce the largest amounts of the pollutant (Lloyd & Cackette, 2001).

The combustion of diesel fuel for farming equipment, heavy-duty truck, train and marine vehicle uses, also results in sulfur being released into the air. Sulfur increases the amount of PM emissions from the vehicle and will form sulfur containing compounds including sulfur dioxide (SO_2) and sulfate (SO_3)(US Environmental Protection Agency, 2001). Sulfur contained within diesel fuel has two potential pathways once in the fuel system of a vehicle: 1.) the sulfur can be deposited within the engine, fuel system or exhaust system or 2.) the sulfur can be emitted as SO_2 and particulate sulfates (Lloyd & Cackette, 2001). SO_x contributes to smog formation and acid rain. While fuel combustion is not primary contributor to smog formation and acid rain, it does contribute a great deal to the problem (Ristinen & Kraushaar, 2006). Because sulfur in the exhaust can cause a reduction in the overall effectiveness of other emission controls and due to its impacts environmentally, diesel fuel is now required to contain low amounts of sulfur to reduce both SO_2 and sulfate particulates (Lloyd & Cackette, 2001).

5.6.4 Vehicle Operation Emissions

Combustion of ethanol results in much the same emissions as combustion of gasoline does, however it is at slightly different levels (Graham, Belisle, & Baas, 2008). Generally, it is found by many studies that E85 use in flex fuel vehicles reduces GHG by five to six percent as compared to gasoline use in conventional gasoline vehicles (Kelly, Bailey, Coburn, Clark, & Lissiuk, 1996; Turner, 2006). Some studies find CO and NO_x are reduced during vehicle operation (Graham, et al., 2008; Kelly, et al., 1996) while others studies show an increase in these criteria air pollutants (Jacobson, 2006). Vehicle emissions can be dependent on vehicle maintenance and operation characteristics as well as the type of vehicle being used.

5.7 SUMMARY

Overall, ethanol may result in small reductions of total GHGs and CO_2 emissions (a controversial position as the reductions calculated are dependent on the assumptions made within the LCA model), however other GHG emissions such as N_2O and CH_4 as well as criteria air pollutants may or may not result in reduction. Lifecycle studies are dependent on the assumptions made by researchers within the models used and can affect the conclusions. Upstream emissions are dependent on a number of factors including feedstock characteristics, modes of transportation as well as processing fuels during production, while downstream emissions at the vehicle usage stage is dependent on vehicle type, operation, maintenance and driver habits. Most studies conclusions focus on the total lifecycle energy and emission impacts rather than individual stage contributions. Ethanol fuel not only impacts air quality both positively and negatively, it also affects the landscape, water, wildlife and human population surrounding each stage of production.

At each stage of production ethanol presents various positive and negative impacts The analysis that follows addresses the emissions, both local and global at each of these locations in an attempt to determine the potential emission types and quantity impacts the ethanol production process and use will have on each location in the lifecycle.

6 *METHODOLOGY*

6.1 CHAPTER OVERVIEW

The methodological approach taken to address the geospatial aspects of ethanol production was the development and use of the Upstream Ethanol Production (UEP) model, a geospatial lifecycle model. It is the purpose of this thesis to represent the ethanol lifecycle geospatially in order to determine whether emissions are shifted from downstream vehicle operation locations to upstream locations such as farming and production communities. It is through the quantification of emissions at locations within the upstream portion of the lifecycle that the shift in emissions from vehicle operation to upstream activities may be seen. To do so, the UEP model was constructed and linked to the GREET model, version 1.8 (Argonne National Laboratory, 2008). The UEP model includes geospatial tags for each location in the total fuel cycle. A geospatial lifecycle model provides a unique approach to viewing the emission impacts of ethanol production on specific locations in the ethanol fuel process. The UEP model has the potential to become a linking component between the GREET model and geospatial models such as ArcGIS as shown in **Figure 6-1** , however this is beyond the scope of this research. Ethanol specific data is broken down based on location within the lifecycle. Emissions for GHG and the total criteria air pollutants are separated into distinct calculation and summary pages.

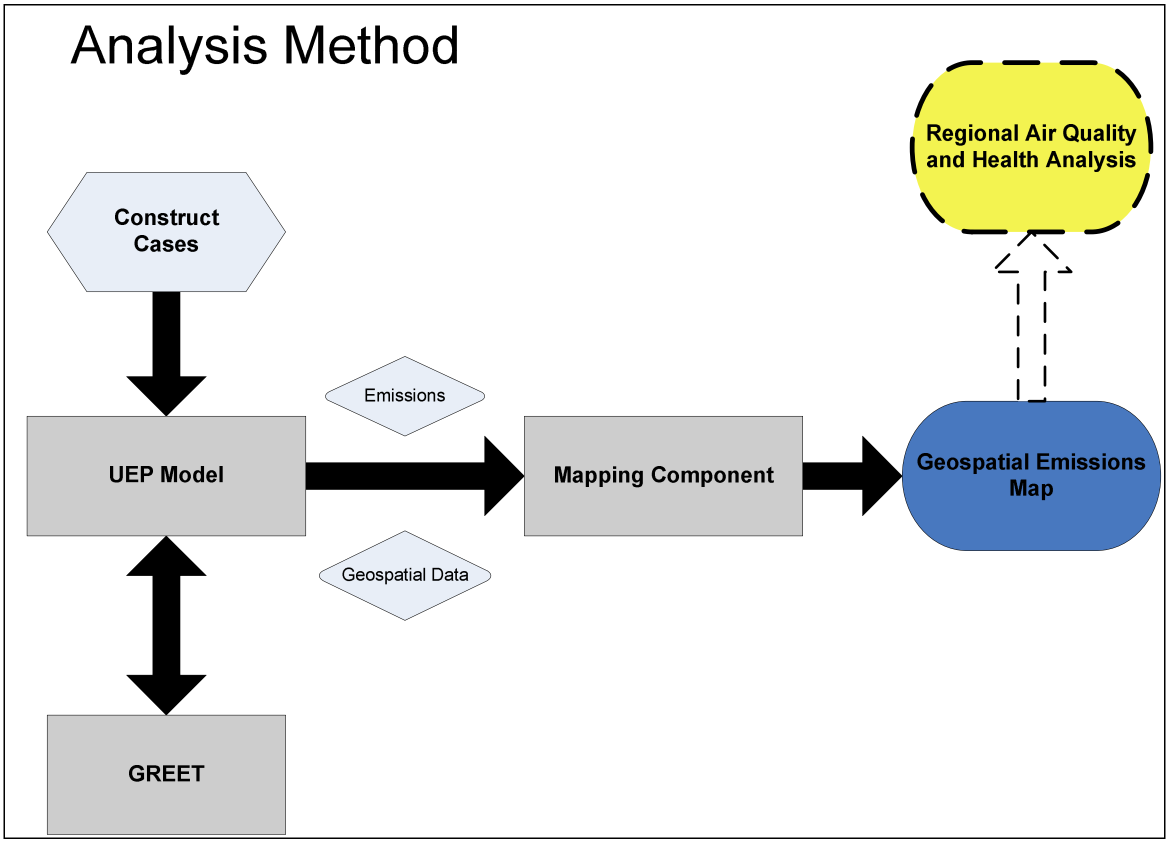


Figure 6-1 Analysis Method diagram displaying the use of the UEP model as a link between GREET and mapping software.

This chapter will begin with an introduction to lifecycle analysis (LCA) and more specifically the GREET model. Following this, the methodological approach taken in the development of the UEP model will be discussed and the final section will describe the case studies used to test the shifting emissions hypothesis as well as to gather information on the contribution of transportation and distribution.

6.2 INTRODUCTION TO LCA: THE GREET MODEL 1.8A

Lifecycle Analysis (LCA) is a decision making tool used to assess the environmental impacts a given product or process has from cradle to grave. From the raw material acquisition to product utilization, there is an environmental burden associated with each step. LCA is a tool used to identify and analyze the location of impacts in a process and where improvements can be made. Decision makers use LCA to select the process or product that results in the least amount of environmental burden (Scientific Applications International Corporation, 2006). The LCA process consists of four steps as shown in **Figure 6-2** and described below:

1. Goal Definition & Scoping- define the product and process and determine boundaries for the analysis.
2. Inventory Analysis- Identify and quantify environmental impacts including emissions and energy consumption.
3. Impact Assessment- Assess the environmental and human health impacts determined in the inventory analysis.
4. Interpretation- Draw conclusions from the impact assessment as to the product or process that will benefit the environment the most (Scientific Applications International Corporation, 2006).

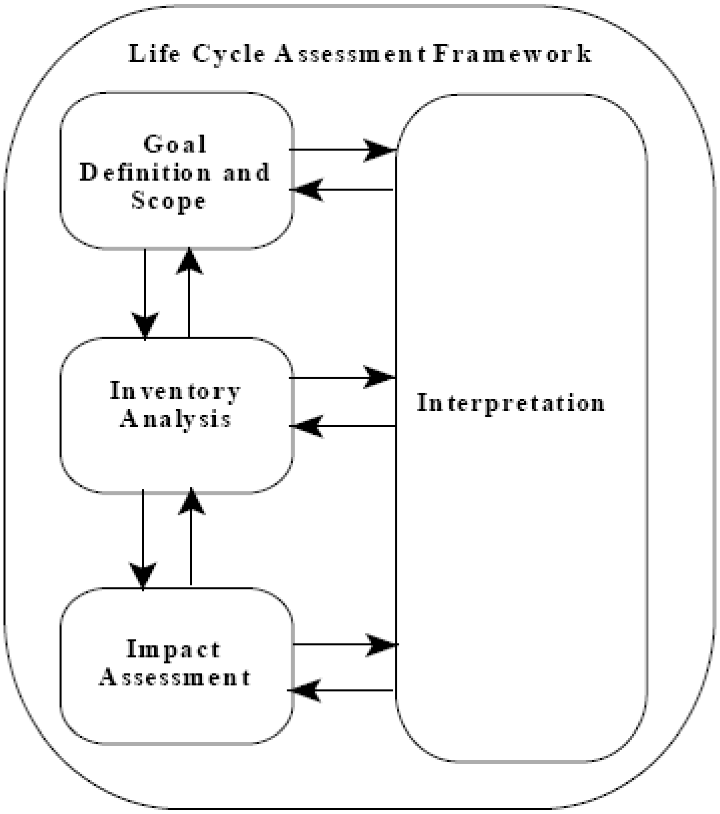


Exhibit 1-2. Phases of an LCA (Source: ISO, 1997)

Figure 6-2 Lifecycle Assessment Process
(Source: (Scientific Applications International Corporation, 2006))

Several fuel LCA models exist including: GREET, Lifecycle Emissions model (LEM), GHGenius, and EIOLCA. This thesis used GREET as a source of information and a model link as it is one of the most accepted and comprehensive transportation fuel lifecycle models available (Argonne National Laboratory, 2007) .

The GREET model was developed by the Department of Energy's Argonne National Laboratory (ANL) in 1996 to analyze the various fuel cycles and vehicle technologies that exist (Argonne National Laboratory, 2008). GREET 1 series calculates the emissions and energy consumption from fuel cycles in light duty vehicles, while the GREET 2 series calculates emission and energy consumption for vehicle production cycle. The emissions calculated in the GREET model are CO_2, CO, NO_x, N_2O, VOC, PM with a diameter smaller than both 10 and 2.5 micrometers (PM_{10} and $PM_{2.5}$, respectively), CH_4 and SO_x. Also calculated within the GREET model is the energy consumption. Energy consumption categories included in the model are total energy, fossil fuel energy, petroleum energy, natural gas and coal energy. Total fuel cycle energy consumption and emissions for approximately 30 fuel cycles and various near and long term technologies are calculated within the GREET model (M. Q. Wang, 1999).

Results from the model include the emissions from three aggregate stages measured in grams per mile. These stages include:

1. Feedstock- material recovery and transport as well as additional resource production and transportation (chemical production for agricultural based feedstocks)
2. Fuel Production- production, transportation and distribution of the fuel
3. Vehicle Operation- Combustion of the fuel, evaporation and brake and tire wear

Figure 6-3 shows the stages included in the GREET 1 series measuring the fuel cycle and the GREET 2 series measuring the vehicle cycle.

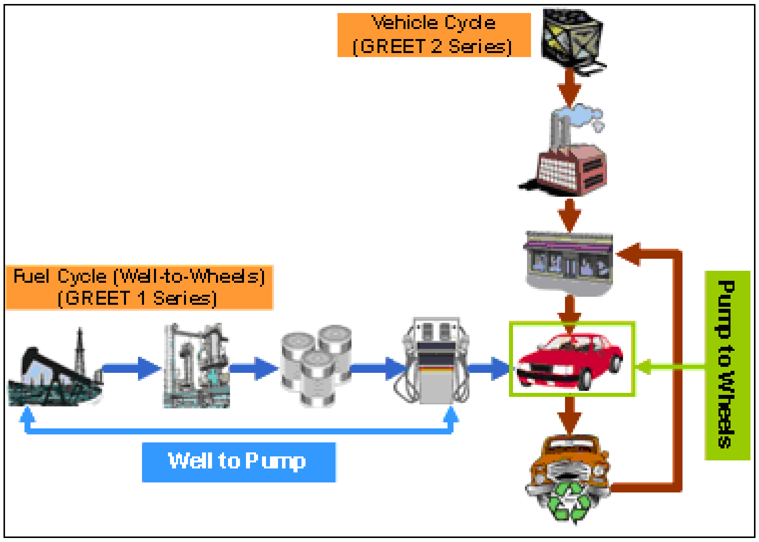


Figure 6-3 GREET 1 & 2 series process

(Source: (Argonne National Laboratory, 2008))

These three stages are added together to give a per mile measurement of the emissions and energy consumption for various fuel cycles. Results for feedstock, fuel production and vehicle operation are presented as individual cycles so that impacts of each aggregate stage can be observed on a per mile basis (**Figure 6-4**).

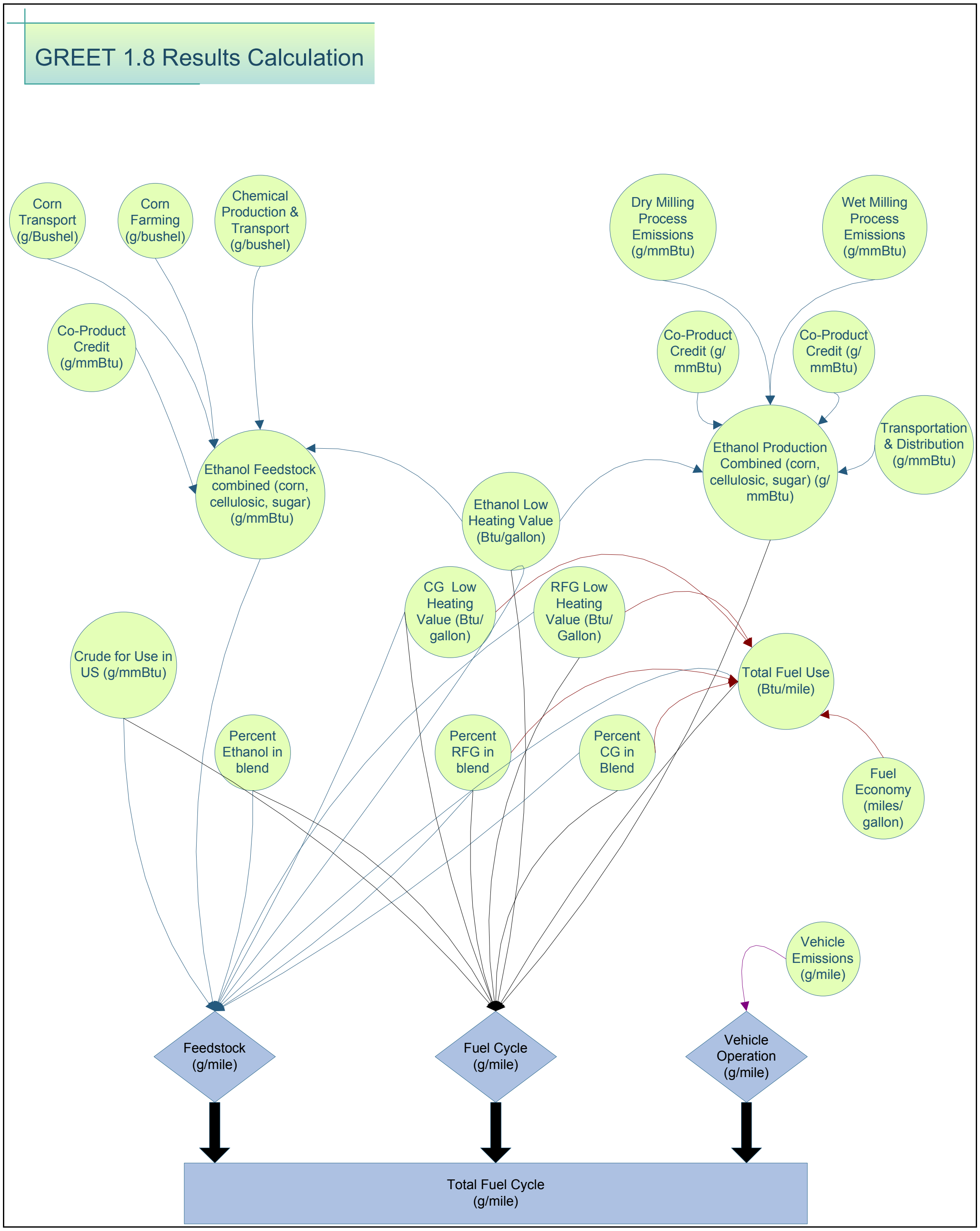


Figure 6-4 Example of GREET 1 results calculation. The blue stages represent the final results for the GREET model.

Other lifecycle models exist, however for the purpose of this thesis only the GREET model was used as a source of data and background model for the UEP model.

6.3 UEP DEVELOPMENT

Generally, the boundaries for this study include locations starting with chemical production and transportation as well as farming, fuel production and transportation of both feedstock and fuel. The final location considered in this study is the vehicle operation location. When the upstream emissions are discussed in regards to the ethanol lifecycle, locations including chemical production and transportation, corn farming and transportation, and fuel production and ethanol transportation are being referred to. Downstream emissions refer to those gases and pollutants emitted at the vehicle operation location. Transportation and distributions impacts will use the upstream portion of the lifecycle as the boundary.

To determine the impact of ethanol use on the emissions at steps and locations within the ethanol fuel cycle as well as to quantify the transportation and distribution impacts to the fuel cycle, the GREET model, version 1.8a, was disaggregated to allow for the emissions for each location to be measured. The functional units being used to measure the criteria air pollutant and GHG emissions at each location is grams of emission per mile driven using E85. Currently, the GREET model accounts for three aggregate stages plus the total fuel cycle emissions in its results. The model contains the information needed to determine the emissions at each location within the fuel cycle. This information includes chemical production and transportation, corn farming and transportation emissions measured in grams per bushel of corn as well as ethanol production and transportation emissions measured in grams per mmBtu. The UEP model is linked to GREET in a way in which the information contained within the GREET model can be used to calculate the grams per E85 mile driven. Generally, the UEP model breaks the lifecycle into the upstream locations containing chemical production and transportation, corn production and fuel production and transportation of feedstock and fuel as well as the downstream portion containing the vehicle operation locations. All activities were “tagged” or labeled with a latitude and longitude representing a specific location geospatially. Each aggregate stage of the GREET model was broken apart into different steps based upon groupings of variables within the GREET model spreadsheet as shown in **Figure** 6-5.

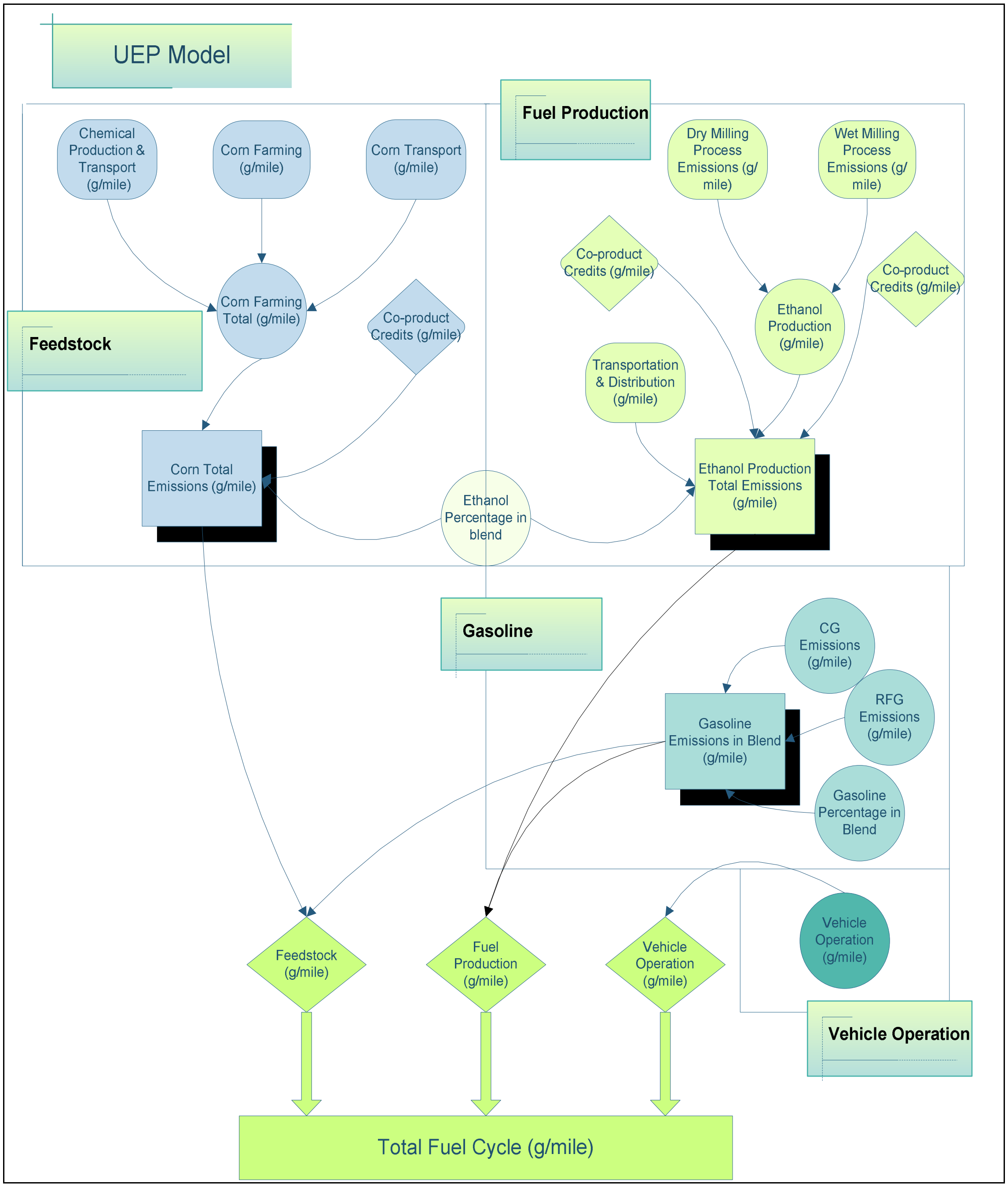


Figure 6-5 UEP Model- variable groupings

6.3.1 *Feedstock*

Generally, the feedstock stage within GREET includes all steps from agricultural chemical production and transportation to feedstock farming, transportation and distribution as an aggregate stage result. In the UEP model, a geospatial tag, including latitude and longitude, was added to each step within the stage, making it necessary for the feedstock emissions to be broken down into three steps: agricultural chemical production and transportation, feedstock farming and transportation and distribution. GREET's "Ag Inputs" page is the location of the information being used to calculate the grams per E85 mile emissions. Within the GREET model, agricultural inputs are measured in grams per bushel of corn, rather than grams per mile. Equation 1 was used to calculate grams of emission per E85 mile for chemical production and transportation as well as the corn farming and transportation emissions in the UEP model.

Equation 1 Grams per Mile Calculations for the Feedstock.

$$GpM = \frac{\left(\frac{GpB}{GapB} * gge\right)}{MPG}$$

In this equation, "GpB" represents grams of emissions per bushel of corn, "GapB" is the gallons of ethanol per bushel of corn, "gge" represents gasoline gallon equivalent, while "MPG" and "GpM" equal miles per gallon and grams per mile, respectively.

Corn farming and transportation information is taken from the GREET model "EtOH" page, measured in grams per bushel of corn. Like the chemical production and transportation, additional calculations were performed to generate results for this section in grams per mile. Equation 1 was used for calculating the grams per mile for this section.

The UEP model assumes that once loaded onto a given mode of transportation, the chemicals, corn and ethanol do not leave that mode of transport until it has reached its next destination. For chemicals, the model assumes that all chemicals are produced at the same domestic location and shipped using the same mode of transport.

6.3.2 *Fuel Production*

Fuel production is measured in grams per million Btus within the GREET model. As with the feedstock steps, a latitude and longitude was added to each of the steps within the fuel production stage . Each step is linked to the UEP model where it is calculated into grams per E85 mile. Gallons of ethanol per bushel, share of production, co-product credits and initial emissions from the production process come from GREET as well as the transportation information. This is true for both wet milling and dry milling. The "EtOH" page of the GREET 1.8a model contains this information. The following equation was used to change the units into grams per E85 mile:

Equation 2: Grams per Mile calculation for fuel production

$$GpM = \frac{\left(\frac{GpmmBtu}{1{,}000{,}000} * LHV_i\right) * gge}{MPG}$$

where, "GPmmBtu" represents grams per million Btus, and "LHV_i" represents the low heating value of fuel "i" in grams per Btu.

Following the calculation of both the feedstock and the production stages, each emission was summed to give a total for each gas and pollutant for each aggregate stage (taken from GREET).

6.3.3 *Vehicle Operation*

Vehicle operation emissions are calculated in grams per mile within GREET. No additional calculations were performed within this stage, due to the fact that the primary focus of this model is to represent the upstream emissions for ethanol geospatially. Downstream emissions from vehicle use were calculated in grams per mile as it is within the GREET model. Data for vehicle operation was taken directly from GREET "Vehicles" page and used in the final calculations for the UEP model. All data pertaining to vehicles including MPG and emission rates remain as the default values contained within the GREET model.

6.3.4 Total Emissions for Each Stage

Gasoline, a 50/50 mix between conventional gasoline and reformulated gasoline (RFG) was determined. GREET allows for the user to change the share of RFG in the conventional gasoline blend. The conventional gasoline and RFG cycle was disaggregated to include emissions from recovery, crude oil transport, refining, finished gasoline transport and distribution as well as vehicle operation. Because crude oil is recovered and brought to the US from both foreign and domestic sources, the UEP model assumes that the US terminal is the end of the recovery stage and uses this location as the recovery emission location. As with the ethanol steps presented previously, geospatial tags (e.g. latitude and longitude per location) were added to the stages related to the gasoline fuel cycle. Equations to determine gasoline grams per mile emissions at each location were much the same as the equations used for ethanol (Equation 2). The total gasoline emissions were calculated using a weighted average of RFG and CG. E85 was calculated as well. As with the total gasoline mix, E85 was calculated using a weighted average of CG and ethanol

The total lifecycle emissions were calculated by summing the total emissions from each stage for each greenhouse gas as well as criteria air pollutants. This served as a way to confirm that the calculations within the model are correct as the total lifecycle emission per GHG or criteria pollutant should equal the result from GREET.

Known Limitations

It must be noted that emissions for all individual steps within the aggregate stage cannot account for the gasoline emission portion of the E85 because no comparable step exists within the gasoline lifecycle. For instance, comparable steps exist between E85 and gasoline for feedstock recovery. Ethanol has corn farming while gasoline has crude oil recovery, however gasoline has no chemical production in its feedstock stage. For this reason, the initial LCA (grams per mile) results will account for comparable emissions; systems results and upstream results will only account for 85 percent ethanol emissions.

6.4 LOCATIONS

As part of the UEP model, geospatial tags were added to each step within each stage. To tag each location, latitude and longitudes for all cities in the US were found and added to the model. A zip code list was found online at the iBegin.com geocoder website (ibegin geocoder, 2008). Currently, ethanol is primarily produced in and from corn grown in the Midwest; however, as the industry and use of ethanol expands, cities outside the corn belt will begin planning, constructing and operating ethanol production facilities. By including all zip codes in the US, impacts of existing and future ethanol facilities can be analyzed based on where agricultural chemicals are produced and transported from, where corn is grown and shipped to and where ethanol is produced and transported to and used. Locations for gasoline refineries and refueling stations were also tagged within the model. While the model is currently not linked to mapping software the addition of geospatial tags allows for the UEP model to be linked to mapping software in the future.

Transportation distances between the locations are calculated in the UEP model using the Spherical Law of Cosines or "as a crow flies" calculation, which utilizes the latitude and longitude for two points to determine the shortest distance between them. This calculation results in distances that are less than a distance mapped out using roads, tracks, and waterways as the Spherical Law of Cosines uses a straight line between two points, which is not the case for the nation's transportation routes. Equation 3 shows the Spherical Law of Cosines.

Equation 3: Spherical Law of Cosines

$$d = a\cos(\sin(lat1) * \sin(lat2) + \cos(lat1) * \cos(lat2) * \cos(long2 - long1)) * R$$

The coordinates for two locations are represented in Equation 3 by "lat1, long1" and "lat2, long2" and are used to determine distance "d" by multiplying the location by the earth's radius "R" in miles.

Prior to calculation of distances, each latitude and longitude was converted into radians from degrees. This is represented in Equation 4.

Equation 4: Radian calculation

$$Ra = \frac{n \deg}{180}$$

Where, “Ra” represents radians and “n deg” represents the latitude and longitude in degrees. All distances are used as the transportation distances for input into the GREET model. Because the distance does tend to be shorter than actual distances, users have the option to input their own distances.

For simplicity, the UEP model assumes that once a product is produced it is transported to one sole location by only one mode of transport. For instance, agricultural chemicals which include fertilizer, herbicides and insecticides are domestically produced in one facility and shipped by one mode of transportation per intermediate and final step. Realistically agricultural chemicals, corn and ethanol are produced in various places and are mixed within the market.

6.5 SYSTEMS

Because the grams per mile only applies to one vehicle operating on E85 or gasoline, to fully understand the impact of several vehicles in a city using the fuel, it was necessary to calculate a systems wide number. A system wide view refers to the use of E85 by the total vehicle population in a location. For instance, if New York City is the location for E85 use, total emissions based on one car would not be all that much, however when it is considered that New York City has over one million vehicles registered, the impact can be spoken of in terms of metric tons rather than grams per mile. To determine systems wide impact measured in metric tons per year, Equation 5 was used:

Equation 5: System wide emissions (Metric Tons per Year)

$$E_{yr} = \frac{\left(E_{E85} * (VP * MpY)\right)}{1{,}000g * 1{,}000kg}$$

where, “E_{E85}” represents emissions from E85 measured in grams per mile, “VP” equals vehicle population in a location, “MpY” is the average annual mileage per vehicle while “g” and “kg” represent grams and kilograms, respectively. The results, “E_{yr}” represent the emissions measured in metric tons per year.

It is assumed that all ethanol produced at the given facility is transported and used in one location. However, it is recognized that ethanol produced at one facility, which produces 50 million gallons or more of ethanol per year, is typically dispersed among many locations for use. The systems results only account for use in New York City as the UEP model does not account for plant size or distribution to various locations (See Chapter 8: Future Research for additional discussion).

6.6 CASES

To test both hypotheses, three ethanol cases and a gasoline case were developed and analyzed. The independent variables being utilized within this analysis include locations, resulting distances and transportation modes, while the dependent variable is the criteria air pollutants and GHG emissions measured in grams per E85 mile for the total fuel cycle and for the upstream emissions. The cases are described in the following sections and the locations as well as mode parameters for the three ethanol cases and the gasoline case are shown in **Table 6-1** and **Table 6-2.**

Table 6-1 Cases used in Analysis

Case	1	2	3
Chemical Location	North Bend, OH 45052	North Bend, OH 45052	North Bend, OH 45052
Mode	Truck	Truck	Truck
Farm Location	Cascade, IA 52033	Avon, NY 14414	West Manchester, OH 45382
Mode	Truck	Truck	Truck
Stack Location	Monticello, IA 52310	Caledonia, NY 14423	Eaton, OH 45320
Mode	Truck	Truck	Train
EtOH Plant	Cedar Rapids, IA 52401	Medina, NY 14103	Medina, NY 14103
Mode	Train	Truck	Truck
Bulk Terminal	Linden, NJ 07036	Linden, NJ 07036	Linden, NJ 07036
Mode	Truck	Truck	Truck
Vehicle Operation Location	New York City, NY 10001	New York City, NY 10001	New York City, NY 10001

Table 6-2: Gasoline Case Study

Case	Gasoline Case
US Terminal	Freeport, TX 77541
Mode	Pipeline
Refinery Location	Beaumont, TX 77701
Mode	Pipeline
Bulk Terminal	Linden, NJ 07036
Mode	Truck
Vehicle Operation Location	New York City, NY 10001

Gasoline: For gasoline, a baseline gasoline study was analyzed. The pathway which the gasoline takes from start to finish is shown in **Figure 6-6**. This study assumes that gasoline used in New York City is first sent as crude oil to a US terminal in Freeport, Texas "A" from a variety of domestic and foreign locations. From the US Terminal, the oil is shipped via pipeline to Beaumont, Texas, point "B", where it is refined and transported by pipeline as motor gasoline to a bulk terminal in Linden, New Jersey, "C". The vehicles operating on this gasoline were located in New York City ("D") which is supplied by the terminal in Linden via truck distribution.

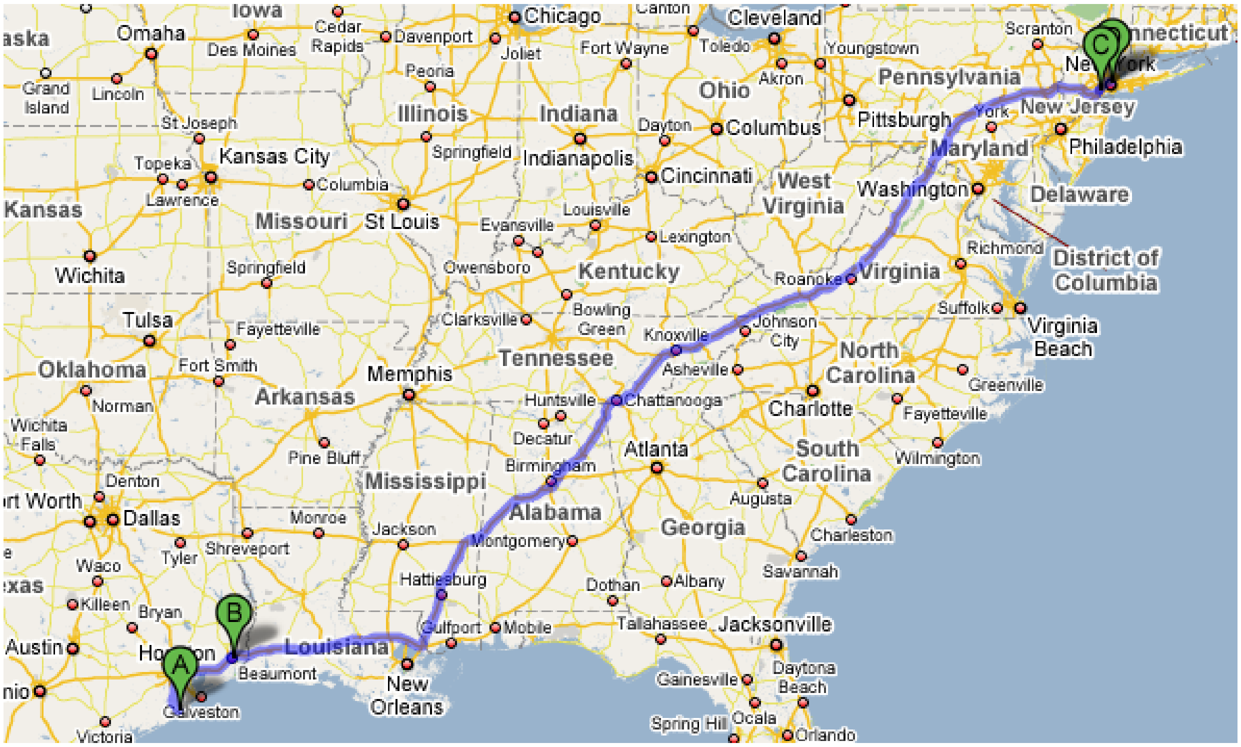


Figure 6-6 Location within the Gasoline Base Case

1. *Current Industry*: To compare ethanol with the gasoline case, Case 1 was designed in a way in which ethanol and gasoline are transported approximately the same distance from recovery to end use. By doing this, the first hypothesis related to the displacement of emissions from vehicle operation locations to farming and fuel production locations can be analyzed. Currently, ethanol is produced in the Midwest and transported to locations outside of the Midwest as well as in the local area. To analyze the current state of the ethanol industry, an ethanol plant in the Midwest is chosen. The plant is located in Cedar

Rapids, Iowa, represented by point "D" in **Figure 6-7**. The feedstock for this plant is acquired from the local area within a 50 mile radius of the plant and transported by truck to the ethanol facility. A farm is Cascade, Iowa, point "B" is chosen and the stack location is in Monticello, Iowa, "C". It is assumed that the agricultural chemicals were produced at one facility in North Bend, Ohio ("A") and transported via truck to the farm directly. The ethanol facility was a dry milling facility, since this represents the majority of the ethanol production facilities existing today. Ethanol was produced and transported by train to a bulk storage terminal in Linden, New Jersey, represented by point "E" and then distributed to the refueling stations in New York City ("F") by truck. The refueling station location represents the location of the vehicle operation.

Figure 6-7 Locations within the Current Industry case

The two other cases (Cases 2 and 3) were designed to test the overall sensitivity of the ethanol lifecycle to the location and transportation distances, as ethanol is expected to be produced in areas outside of the Midwest, where corn may need to be shipped in and the production may be closer to the congested areas of use. Cases 2 and 3 will be used determine the impact of transportation and distribution on the lifecycle emissions as well as upstream emissions.

2. *Expanding Industry:* As the ethanol use expands across the US, the location of ethanol facilities will also move out of the Midwest towards the coasts of the country. Ethanol production facilities are being built in states along the East and West Coasts, where

ethanol has the potential to curb GHG and criteria air pollutant emissions in major cities. In New York, two corn ethanol plants exist. To analyze the impact ethanol production and use in New York State, parameters specific to NY are used. Corn was grown in Avon, NY shown at point "B" in **Figure 6-8** using agricultural chemicals produced in North Bend, OH, point "A". The corn was transported by truck to storage (stacks) in Caledonia ("C") and eventually moved by truck to the ethanol production facility in Medina, NY, point "D". Ethanol was shipped by truck to Linden, New Jersey ("E") and then distributed to refueling stations in New York City ("F") by truck.

Figure 6-8 Locations within the Expanding Industry Case

3. *Feedstock Importation:* **Figure 6-9** shows the path taken in the ethanol lifecycle for Case 3 in which corn is imported. Agricultural chemicals were produced in North Bend, Ohio, "A" and transported by train to a farm location in West Manchester, Ohio, "B". Corn grown at this farm was first transported by truck to corn stacks located in Eaton, Ohio ("C") and then moved by train to the Medina, NY ethanol production facility represented by point "D". Ethanol was transported via truck to the bulk terminal in Linden, New Jersey ("E") and eventually distributed for refueling in New York City, point "F", by truck.

Figure 6-9 Locations within the Feedstock Import Case

Case parameters were input into the UEP model, analyzed and compared to each other. All cases were analyzed for all criteria air pollutants and GHGs, however in terms of shifting emissions and local impacts caused by the use of ethanol at the vehicle operation location, the most important emissions are those of the criteria air pollutants such as VOC, CO, NO_x, PM_{10}, $PM_{2.5}$, and SO_x. The results are presented in Chapter IV, which is broken down into individual vehicle and system wide results for the total ethanol fuel cycle as well as the upstream process alone.

7 *RESULTS*

7.1 CHAPTER OVERVIEW

This chapter summarizes the results for all ethanol and gasoline cases analyzed using the UEP model. Remember from the previous chapter than three ethanol cases and one gasoline case were analyzed within the UEP model to determine whether a shift in emissions from the vehicle operation location to the upstream locations such as farming and production occurs. The cases analyzed were designed to study the current and expanding corn ethanol industry in the US. Cases used include:

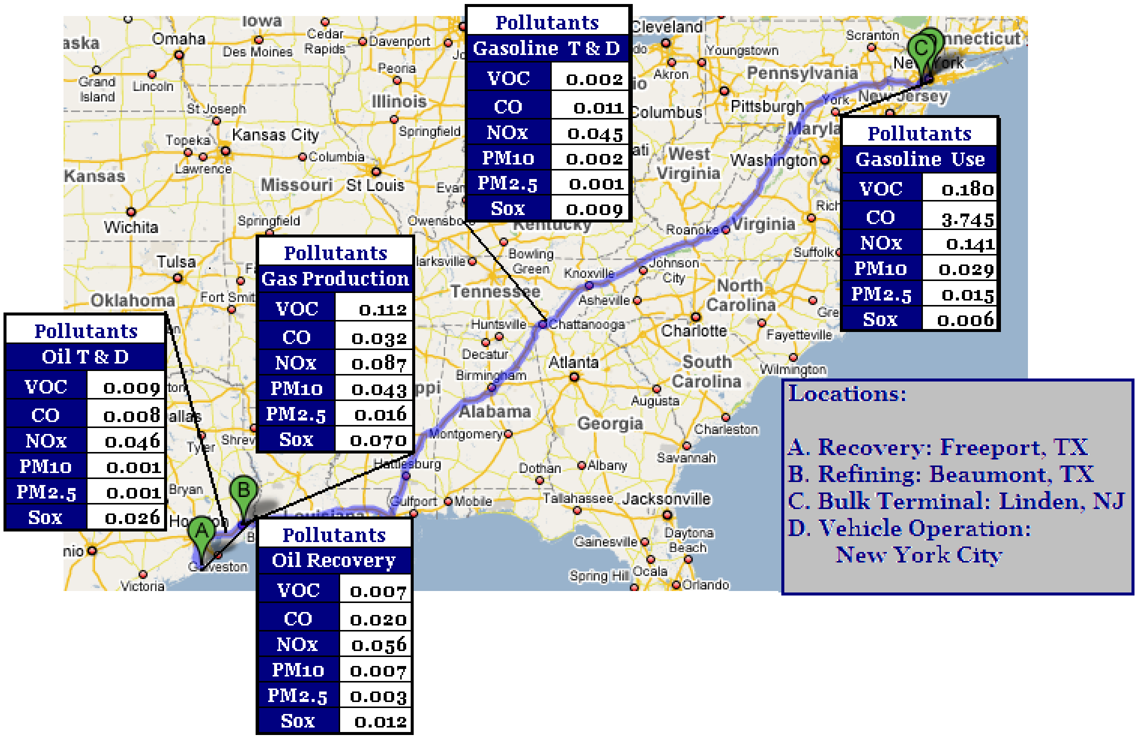
- Gasoline
- Current Ethanol Industry
- Expanding Ethanol Industry
- New York Feedstock Importation

The following sections describe the results based on grams of emissions per mile of E85 use, metric tons per year for a fleet of vehicles operating on ethanol as well as emissions related to only the upstream portion of the fuel cycle for ethanol.

7.2 EMISSION DISPLACEMENT

The criteria air pollutants and greenhouse gases measured within the GREET and UEP models include: VOC, CO, NO_x, PM less than 10 and 2.5 micrometers (PM_{10} and $PM_{2.5}$) and SO_x as well as N_2O, CH_4 and CO_2. Generally, little to no displacement occurred for most of the criteria air pollutants and greenhouse gases, with the exception of VOCs, SO_x and CO_2. Additional release of criteria air pollutants and gases at upstream locations were seen for all cases which caused the total fuel cycle emissions to be greater for ethanol than for gasoline.

Results for the gasoline case show large contributions of VOC and CO emitted at the vehicle operation location. Approximately 0.18 grams of VOC and 3.74 grams of CO are released at the vehicle operation location as shown in **Figure 7-1**. **Figure 7-2** shows the contribution of emissions by each location in the lifecycle. Volatile organic compounds and CO are contributed to the total fuel cycle emissions in amounts exceeding 50 percent by the vehicle operation in New York City, whereas contributions exceeding 30 percent of the lifecycle emissions result for NO_x, PM_{10} and $PM_{2.5}$. Sulfur oxide emissions at the vehicle operation location are 0.120 grams per mile of use or below 10 percent of the total SO_x emissions resulting from the gasoline lifecycle. The majority of the SO_x emissions are contributed during the production in Beaumont, Texas and transportation steps of the gasoline lifecycle. Volatile organic compound and PM emissions for gasoline are also contributed heavily by the production of gasoline at refineries. Transportation and distribution of crude oil and gasoline by pipeline contributes 0.046 grams per mile and 0.045 grams per mile to the total fuel cycle or approximately 10 percent to the total fuel cycle emissions.



Pollutants	Oil Recovery
VOC	0.007
CO	0.020
NOx	0.056
PM10	0.007
PM2.5	0.003
Sox	0.012

Pollutants	Oil T & D
VOC	0.009
CO	0.008
NOx	0.046
PM10	0.001
PM2.5	0.001
Sox	0.026

Pollutants	Gas Production
VOC	0.112
CO	0.032
NOx	0.087
PM10	0.043
PM2.5	0.016
Sox	0.070

Pollutants	Gasoline T & D
VOC	0.002
CO	0.011
NOx	0.045
PM10	0.002
PM2.5	0.001
Sox	0.009

Pollutants	Gasoline Use
VOC	0.180
CO	3.745
NOx	0.141
PM10	0.029
PM2.5	0.015
Sox	0.006

Locations:

A. Recovery: Freeport, TX
B. Refining: Beaumont, TX
C. Bulk Terminal: Linden, NJ
D. Vehicle Operation:
New York City

Figure 7-1 Gasoline Location Criteria Air Pollutant Emissions (Grams per Mile)

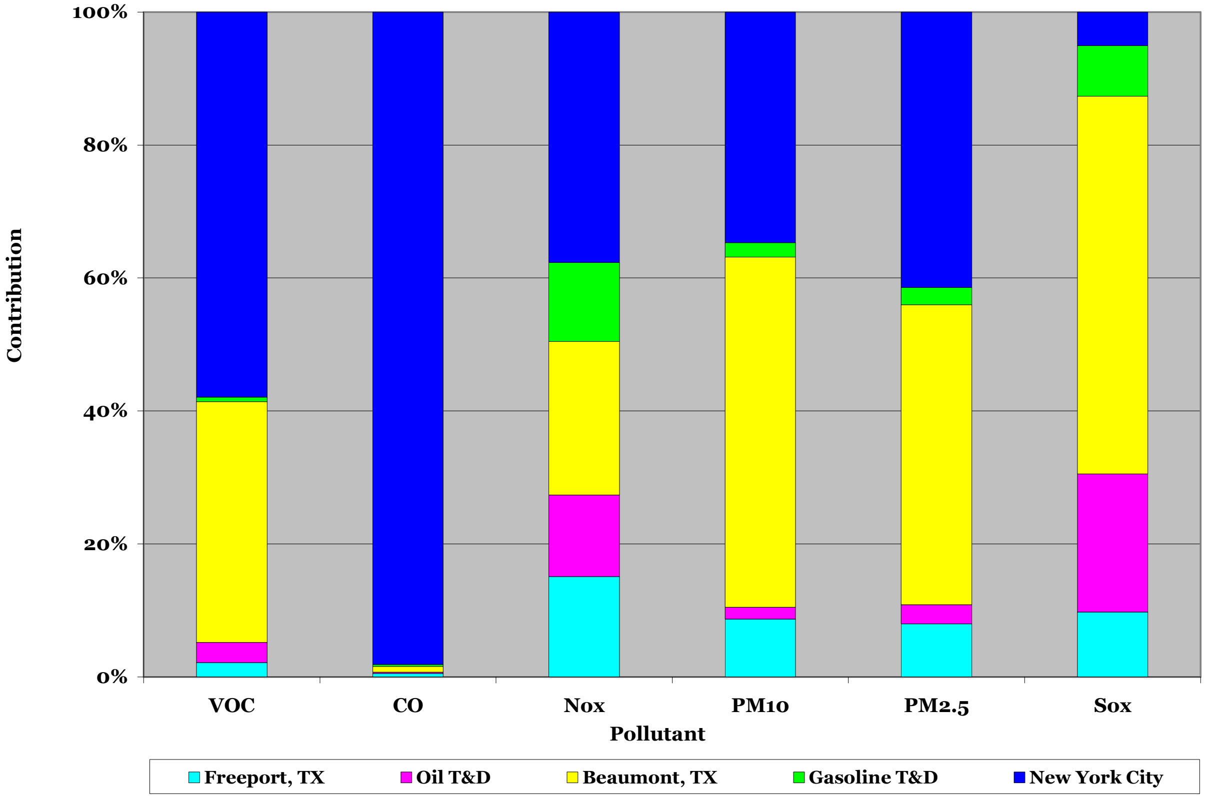


Figure 7-2 Gasoline Location Contribution to Total Fuel Cycle

While it is realized that location does not play an important role in the distribution of GHGs as they are global pollutants that present the same impacts regardless of release location, the UEP model still accounts for the release of these. Greenhouse gases for the gasoline case were primarily found in New York City due to vehicle operation, with the exception of the CH_4 emissions. Methane emissions were contributed primarily at the crude oil recovery location in Freeport, Texas as well as the refining location in Beaumont, Texas in amounts of 0.036 grams and 0.075 grams per mile of gasoline use, as shown in **Figure 7-3** and **Figure 7-4**. Nitrous oxide is emitted primarily at the vehicle operation location in New York City, with less than 10 percent being contributed by the refinery in Beaumont, Texas.

Carbon dioxide, also shown in **Figure 7-3** and **Figure 7-4**, is much like N_2O, with the majority of the emissions being contributed at the vehicle operation location. Just below 15 percent of the total fuel cycle CO_2 emissions are contributed by the refinery and below five percent are found at the recovery location.

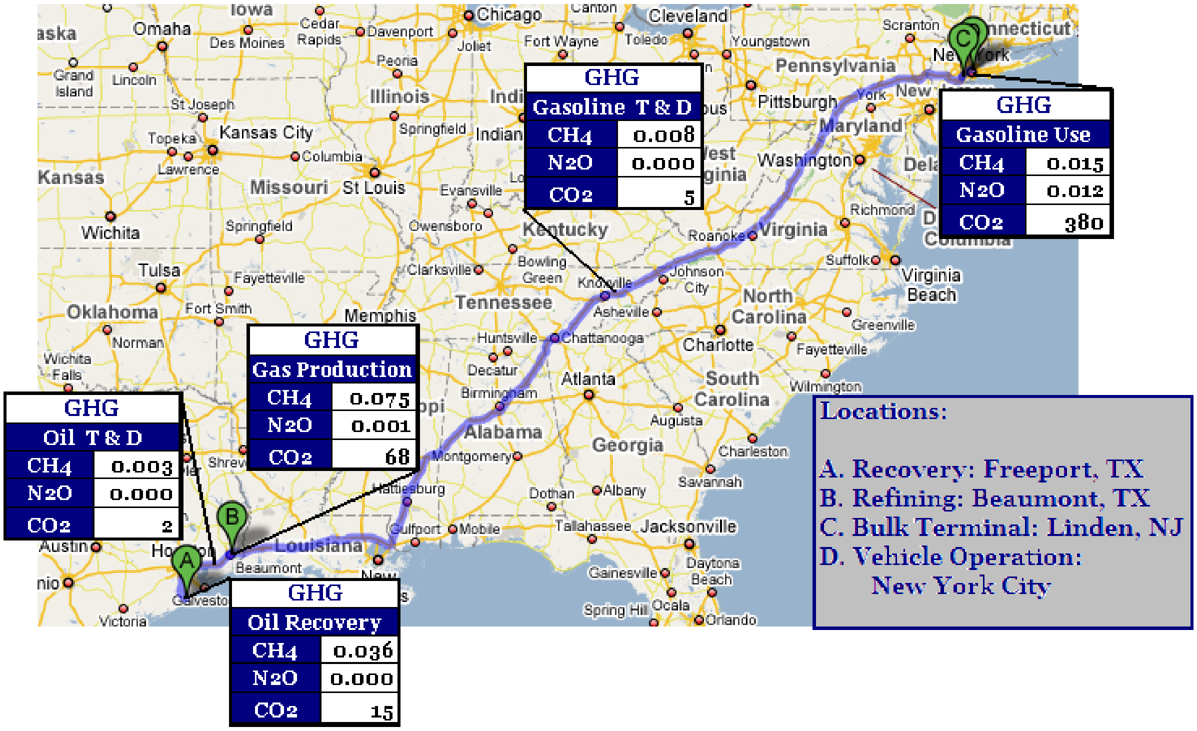


Figure 7-3 Gasoline Location Greenhouse Gas Emissions (Grams per Mile)

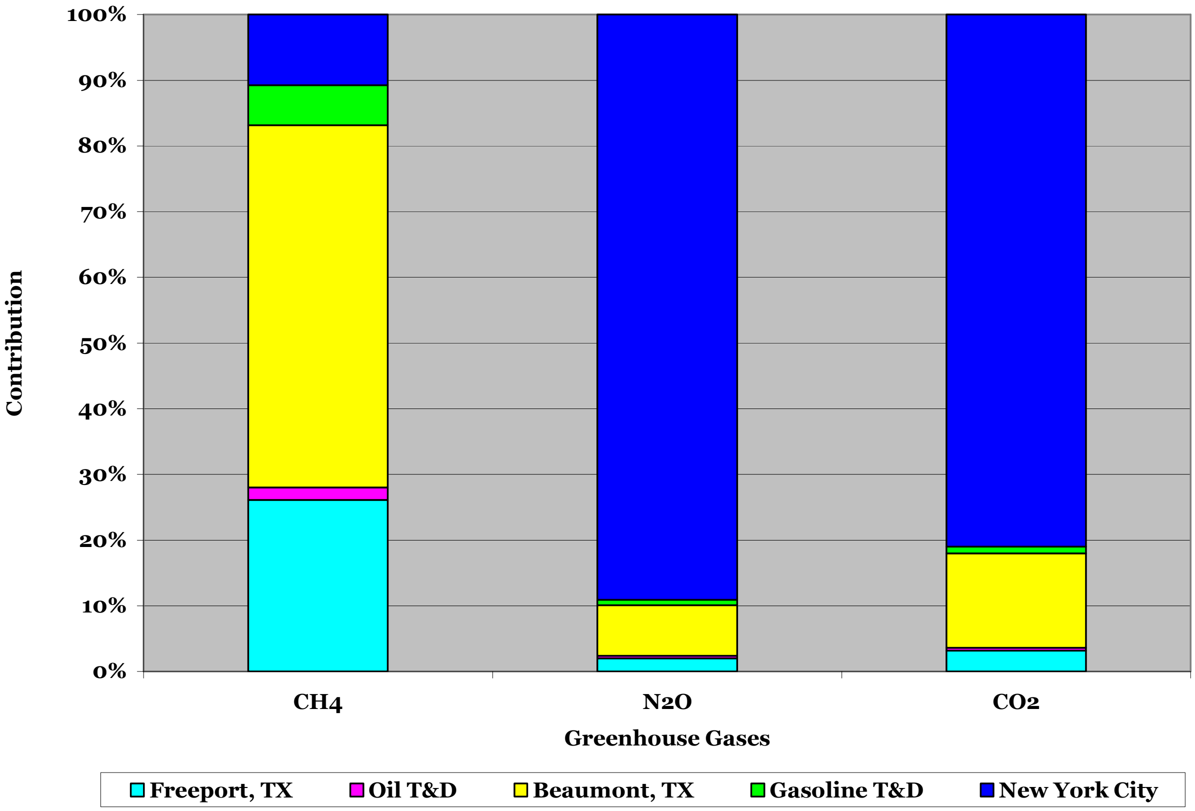


Figure 7-4 Gasoline Location Contribution to Total Fuel Cycle Greenhouse Gases

Criteria air pollutant emissions for Case 1, the current ethanol industry, results in higher total fuel cycle emissions for all pollutants as compared to the gasoline case; however two of the pollutants, VOC and SO_x showed reduction at the vehicle operation location. **Figure 7-5** shows the criteria air pollutant emissions for all pollutants at each step of the lifecycle for ethanol. As can be seen, VOC results in 0.171 grams per mile emissions due to vehicle operation in New York City which is approximately 0.001 grams per mile less than the VOC emissions for gasoline at the same location, while SO_x emissions are approximately 0.004 grams per mile lower at the vehicle operation site for ethanol use as compared to gasoline. Higher VOC and SO_x emissions for the total ethanol fuel cycle in Case 1 indicates that additional amounts of each pollutant are emitted at locations upstream from the vehicle operation location and that emission reduction of these two pollutants at the vehicle operation location does result in displacement of the pollutants to upstream locations. If the contribution of each stage within the lifecycle is observed in **Figure 7-6** , the difference between contribution at locations for ethanol and gasoline is immediately noticeable. With the exception of CO, all other pollutants show large contributions by the farms and production facilities with little lower emissions being contributed by the vehicle operation location in New York City. For all other pollutants including CO, NO_x, PM_{10} and $PM_{2.5}$, emissions are not displaced; rather emissions are only added at upstream locations, resulting in total fuel cycle emissions for these pollutants to be higher than the comparable gasoline pollutant emissions. Approximately 60 percent or more VOC, PM_{10} and $PM_{2.5}$ pollutants are released from the production facility activities in Cedar Rapids, Iowa, while NO_x and SO_x are contributed in amounts exceeding 30 percent of the total fuel cycle emissions. Larger amounts of NO_x and SO_x emissions are also contributed by the farm located in Cascade, Iowa. This location results in 0.044 grams of NO_x and 0.016 grams of SO_x per mile of E85 use or 35 and 45 percent of the total fuel cycle emissions for the respective pollutant. Like the gasoline case, Case 1 NO_x contributions by transportation and distribution of feedstock and fuel are between five and 15 percent; however in this case feedstock and fuel are transported and distributed using truck and train.

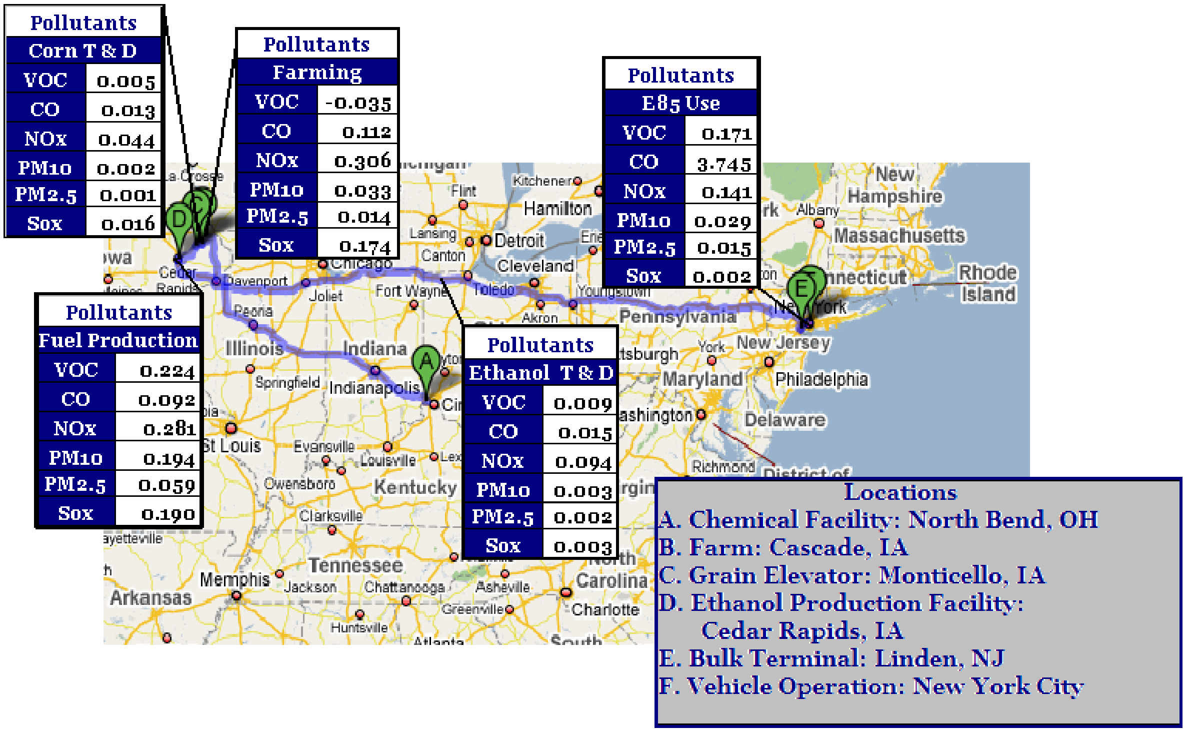


Figure 7-5 Case 1 Location Criteria Air Pollutant Emissions (Grams per Mile)

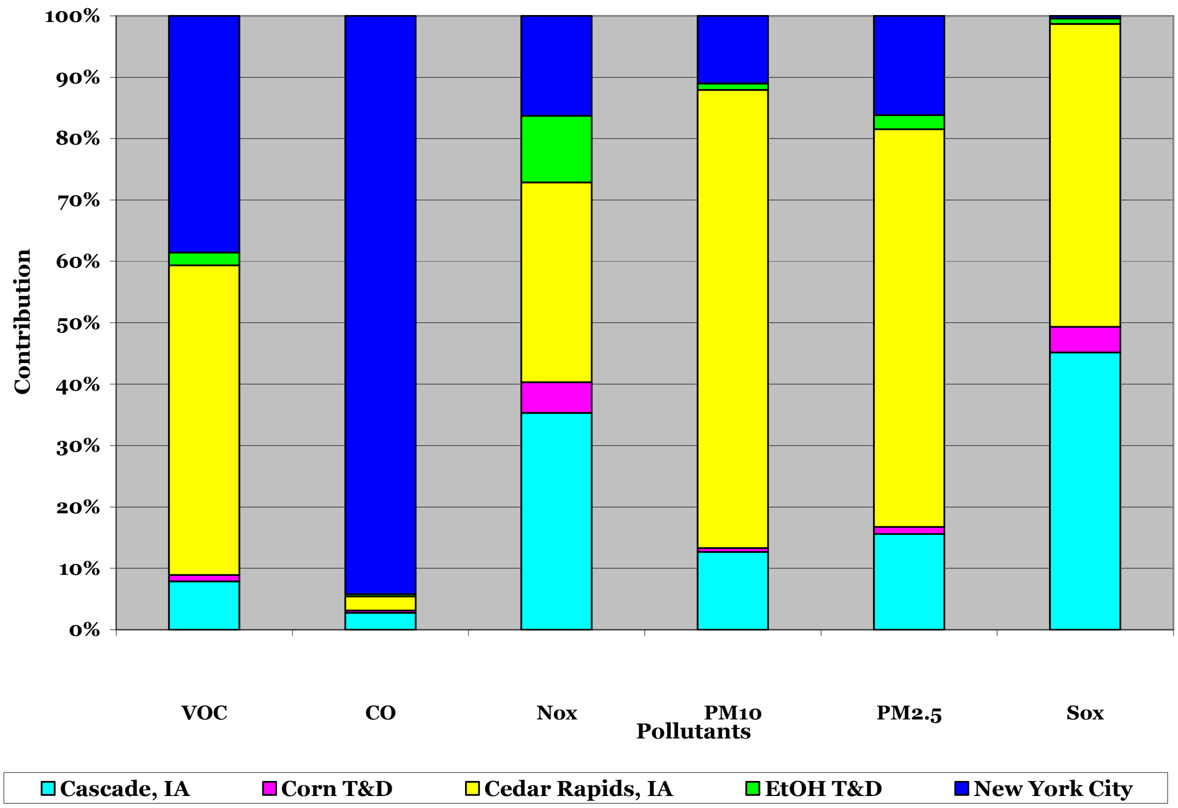


Figure 7-6 Case 1 Location Contribution to Total Fuel Cycle Criteria Air Pollutants

1. Contributions calculated using absolute values. VOC is negative at the farming location in Cascade, IA (see values in Figure 4-5)

As with the majority of the criteria air pollutants, emissions for CH_4 and N_2O, show no displacement of emissions from the vehicle operation location in New York City, rather additional emissions are created as a result of farming of corn and production of ethanol in Iowa. The N_2O emissions for Case 1 are primarily found at the farming location in Cascade, Iowa for the ethanol fuel cycle. **Figure 7-7** and **Figure 7-8** show the emissions and the contributions for CH_4 and N_2O. As can be seen, 0.149 grams of N_2O are emitted at the farm, with 0.003 grams and 0.012 grams emitted at the production facility in Cedar Rapids and vehicle operation location in New York City, respectively. Approximately 90 percent of the total N_2O emissions for Case 1 are emitted at the farm. Methane for Case 1 appears to be similar to gasoline, with approximately 70 percent of the CH_4 gases released at the production facility.

At the vehicle location, CO_2 emissions are reduced in comparison to the gasoline case, and total fuel cycle CO_2 emissions are reduced. The results for CO_2, as with VOC and SO_x, indicate a shift in emissions from downstream vehicle operation sites to upstream production sites. Farming CO_2 emissions are lower than that of the oil recovery stage for gasoline, however this is due to the credits given to capture of carbon by corn crops. **Figure 7-7** and **Figure 7-8** show the emissions for Case 1 as well as the contributions of each stage to the total CO_2 profile presented by the ethanol fuel cycle. Approximately 60 percent of the total fuel cycle CO_2 emissions are contributed by the vehicle operation stage while the remaining 40 percent is split between farming and production in Iowa as well as transportation and distribution by both truck and train.

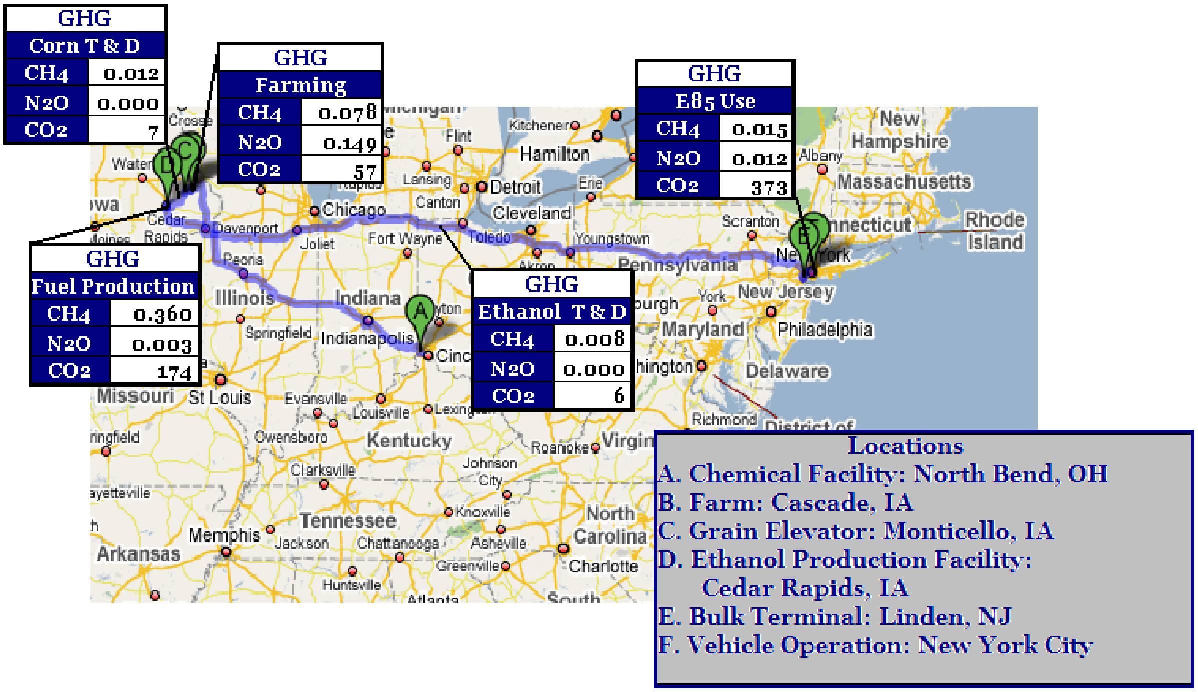


Figure 7-7 Case 1 Location Greenhouse Gas Emissions (Grams per Mile)

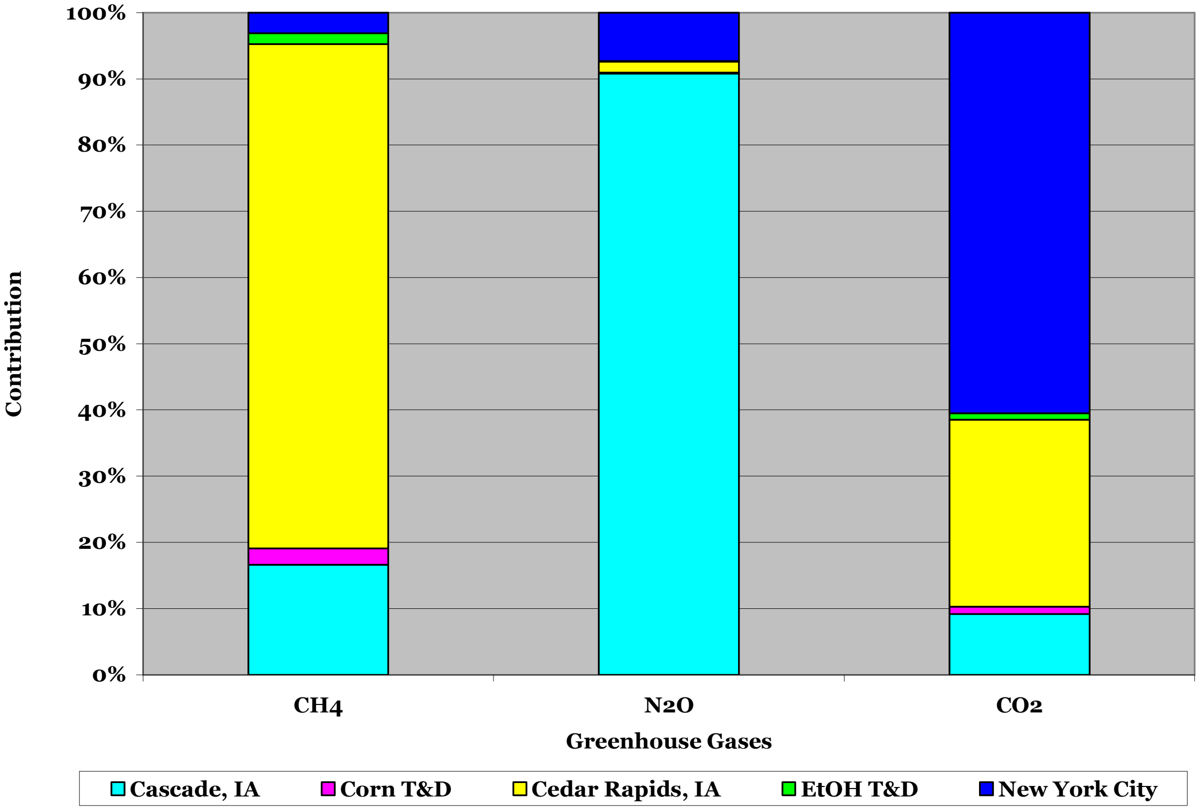
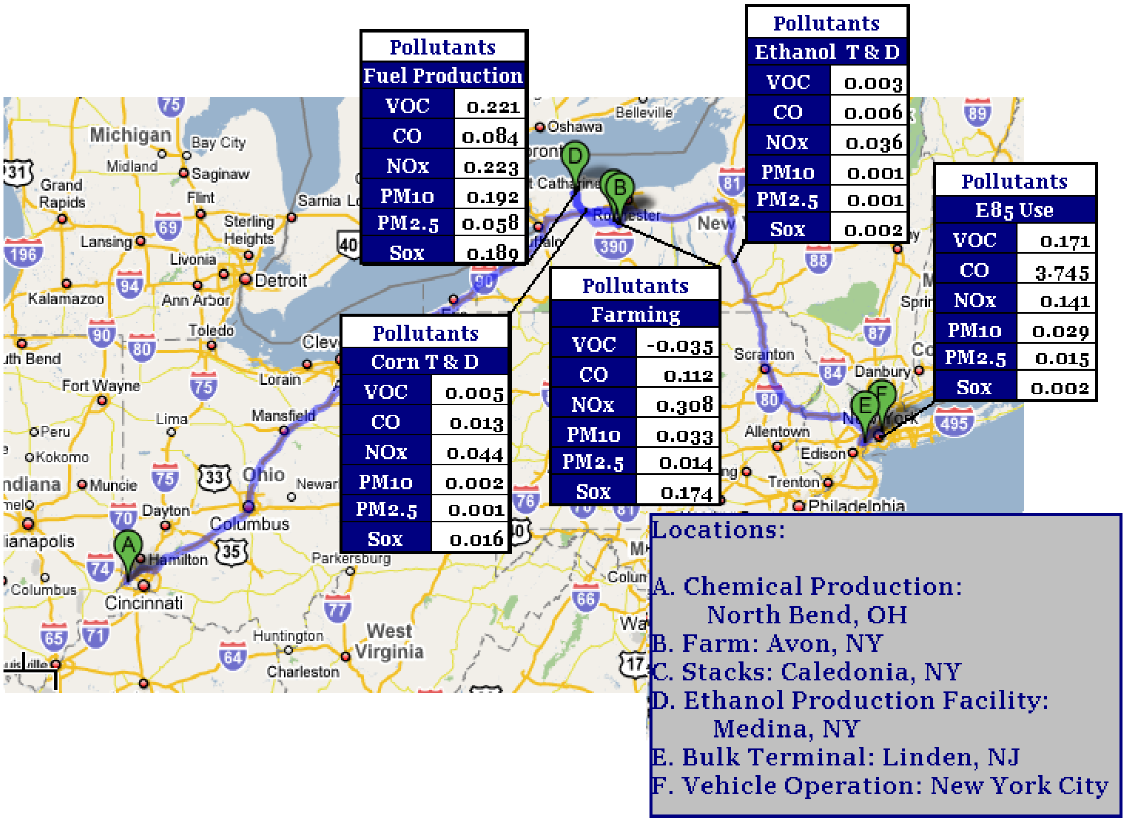


Figure 7-8 Case 1 Location Contribution to Total Fuel Cycle Greenhouse Gases

Much like Case 1, Cases 2 and 3 generally show the same results for criteria air pollutants and greenhouse gas emissions. Volatile organic compounds, SO_x and CO_2 all show a reduction at the tailpipe location in New York City with increases for these same emissions at upstream locations including farms in both Western New York and Ohio as well as the production facility location in Medina, New York. All other emissions for both criteria air pollutants and greenhouse gases show no reduction in New York City, however do show additional emissions for all pollutants and gases being released at the farming and production facility locations in comparison to the comparable locations in the gasoline case. The emissions results for Cases 2 and 3 are shown in **Figure 7-9**, **Figure 7-10**, **Figure 7-11** and **Figure 7-12**.



Pollutants	Fuel Production
VOC	0.221
CO	0.084
NOx	0.223
PM10	0.192
PM2.5	0.058
Sox	0.189

Pollutants	Ethanol T & D
VOC	0.003
CO	0.006
NOx	0.036
PM10	0.001
PM2.5	0.001
Sox	0.002

Pollutants	E85 Use
VOC	0.171
CO	3.745
NOx	0.141
PM10	0.029
PM2.5	0.015
Sox	0.002

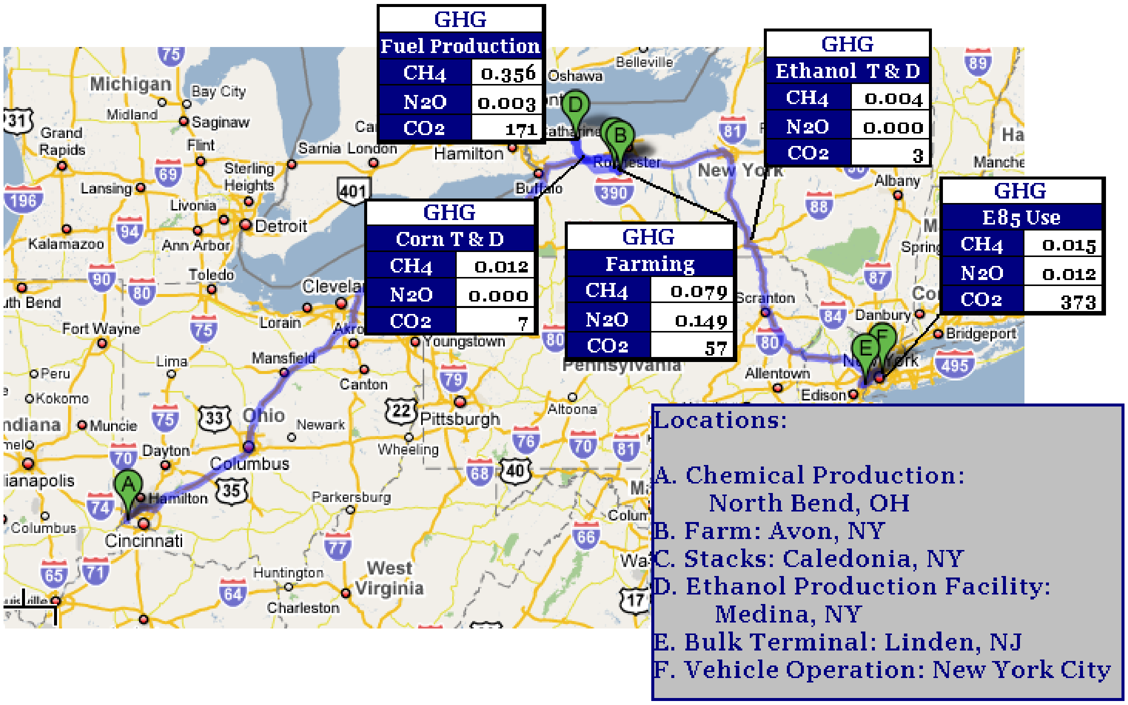
Pollutants	Farming
VOC	-0.035
CO	0.112
NOx	0.308
PM10	0.033
PM2.5	0.014
Sox	0.174

Pollutants	Corn T & D
VOC	0.005
CO	0.013
NOx	0.044
PM10	0.002
PM2.5	0.001
Sox	0.016

Locations:

A. Chemical Production:
North Bend, OH
B. Farm: Avon, NY
C. Stacks: Caledonia, NY
D. Ethanol Production Facility:
Medina, NY
E. Bulk Terminal: Linden, NJ
F. Vehicle Operation: New York City

Figure 7-9 Case 2 Criteria Air Pollutants Emissions (Grams per Mile)



GHG	
Fuel Production	
CH4	0.356
N2O	0.003
CO2	171

GHG	
Ethanol T & D	
CH4	0.004
N2O	0.000
CO2	3

GHG	
Corn T & D	
CH4	0.012
N2O	0.000
CO2	7

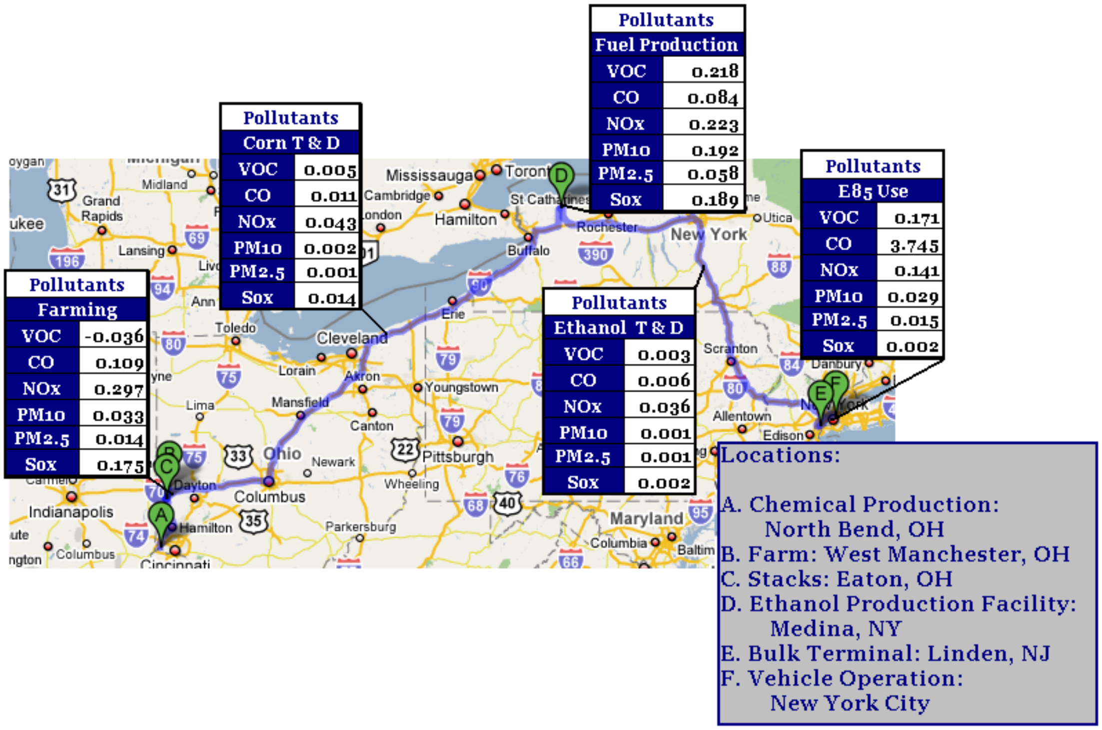
GHG	
Farming	
CH4	0.079
N2O	0.149
CO2	57

GHG	
E85 Use	
CH4	0.015
N2O	0.012
CO2	373

Locations:

A. Chemical Production:
North Bend, OH
B. Farm: Avon, NY
C. Stacks: Caledonia, NY
D. Ethanol Production Facility:
Medina, NY
E. Bulk Terminal: Linden, NJ
F. Vehicle Operation: New York City

Figure 7-10 Case 2 GHG Emissions (Grams per Mile)



Pollutants	
Fuel Production	
VOC	0.218
CO	0.084
NOx	0.223
PM10	0.192
PM2.5	0.058
Sox	0.189

Pollutants	
Corn T & D	
VOC	0.005
CO	0.011
NOx	0.043
PM10	0.002
PM2.5	0.001
Sox	0.014

Pollutants	
E85 Use	
VOC	0.171
CO	3.745
NOx	0.141
PM10	0.029
PM2.5	0.015
Sox	0.002

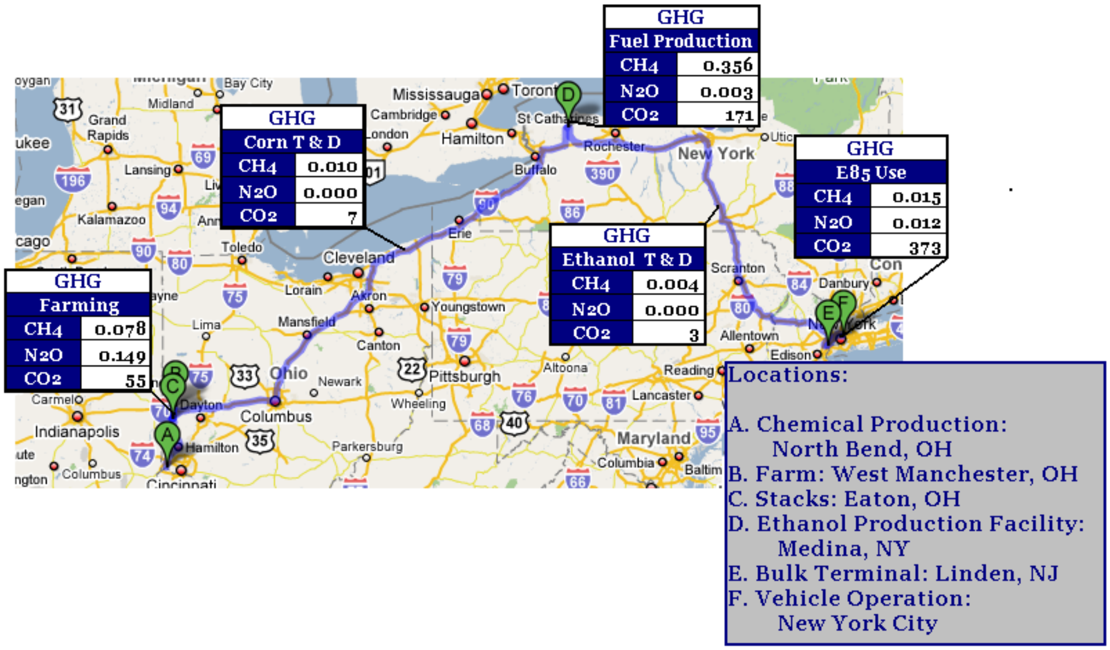
Pollutants	
Farming	
VOC	-0.036
CO	0.109
NOx	0.297
PM10	0.033
PM2.5	0.014
Sox	0.175

Pollutants	
Ethanol T & D	
VOC	0.003
CO	0.006
NOx	0.036
PM10	0.001
PM2.5	0.001
Sox	0.002

Locations:

A. Chemical Production:
North Bend, OH
B. Farm: West Manchester, OH
C. Stacks: Eaton, OH
D. Ethanol Production Facility:
Medina, NY
E. Bulk Terminal: Linden, NJ
F. Vehicle Operation:
New York City

Figure 7-11 Case 3 Criteria Air Pollutant Emissions (Grams per Mile)



GHG

Fuel Production	
CH4	0.356
N2O	0.003
CO2	171

GHG

Corn T & D	
CH4	0.010
N2O	0.000
CO2	7

GHG

E85 Use	
CH4	0.015
N2O	0.012
CO2	373

GHG

Ethanol T & D	
CH4	0.004
N2O	0.000
CO2	3

GHG

Farming	
CH4	0.078
N2O	0.149
CO2	55

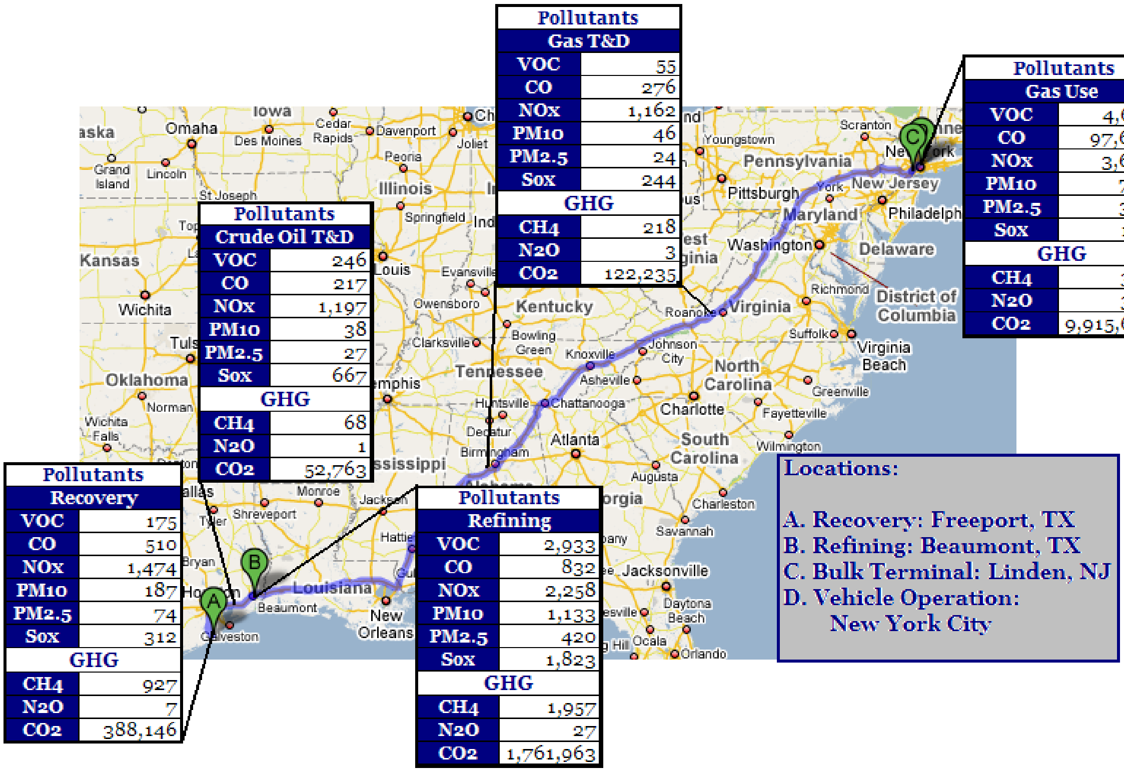
Locations:

A. Chemical Production:
North Bend, OH
B. Farm: West Manchester, OH
C. Stacks: Eaton, OH
D. Ethanol Production Facility:
Medina, NY
E. Bulk Terminal: Linden, NJ
F. Vehicle Operation:
New York City

Figure 7-12 Case 3 GHG Emissions (Grams per Mile)

The previous results are further reinforced when the entire system is looked at. If the results are expanded to include all 1,378,970 standard vehicles registered in New York City (New York State Department of Motor Vehicles, 2008), each traveling an assumed 15,000 miles per year, the amount of pollutants and gases released at specific location, like the production facility in Cedar Rapids, Iowa for Case 1 become large. To measure the systems results, the functional unit was changed from grams per mile of E85 used to metric tons of pollutant or gas emitted per year.

Figure 7-13 shows the systems results for Gasoline. As can be seen, the vehicle fleet in New York City emits 9.9 million metric tons of CO_2 per year, whereas the same fleet operating on ethanol emits approximately 200,000 metric tons per year less or 9.7 million metric tons per year shown in **Figure 7-14**. The same can be seen with VOC and SO_x. At the vehicle operation location VOC and SO_x emit approximately 227 and 119 metric tons fewer pollutants, respectively. To gain this reduction, emissions upstream, like the grams per mile results showed, increase in locations such as the production facility in Cedar Rapids. At the production facility, VOC and SO_x are emitted in amounts of 3597 and 3858 metric tons more than at the gasoline refinery. The increase is not for GHGs, rather the increase occurs in criteria air pollutants or local pollutants that directly affect the areas near the source and can be dispersed over a larger area as well.



Pollutants Recovery	
VOC	175
CO	510
NOx	1,474
PM10	187
PM2.5	74
Sox	312
GHG	
CH4	927
N2O	7
CO2	388,146

Pollutants Crude Oil T&D	
VOC	246
CO	217
NOx	1,197
PM10	38
PM2.5	27
Sox	667
GHG	
CH4	68
N2O	1
CO2	52,763

Pollutants Refining	
VOC	2,933
CO	832
NOx	2,258
PM10	1,133
PM2.5	420
Sox	1,823
GHG	
CH4	1,957
N2O	27
CO2	1,761,963

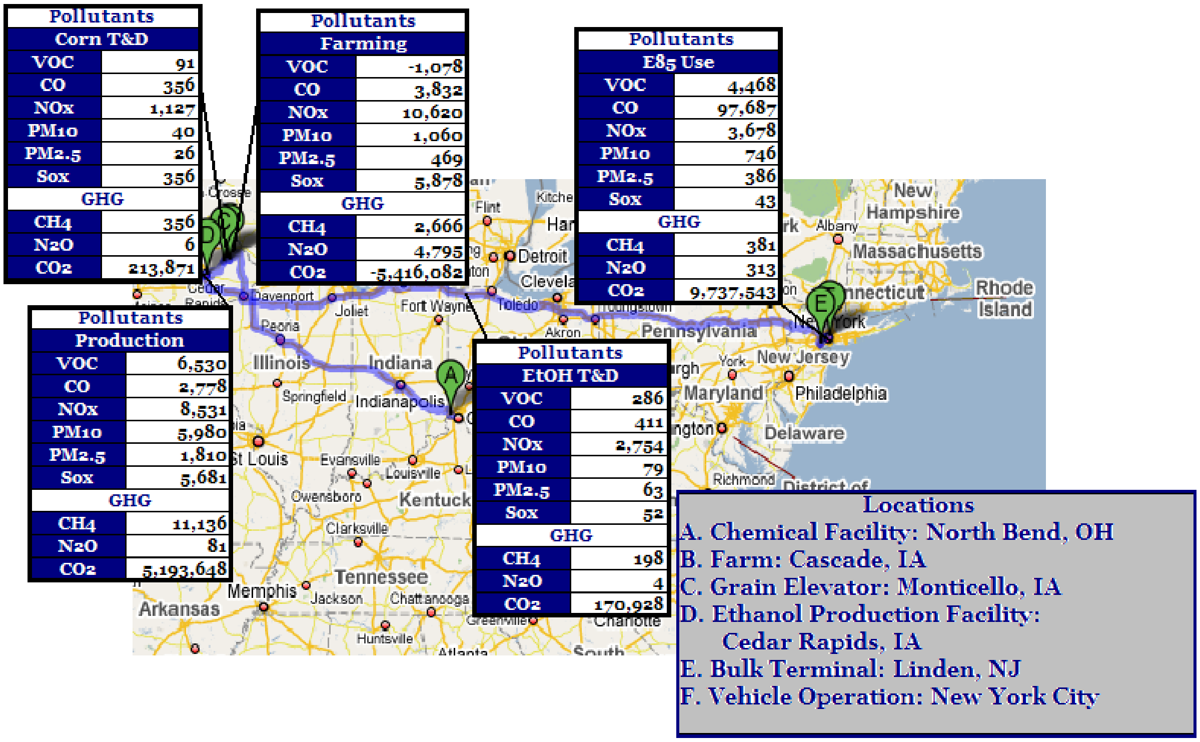
Pollutants Gas T&D	
VOC	55
CO	276
NOx	1,162
PM10	46
PM2.5	24
Sox	244
GHG	
CH4	218
N2O	3
CO2	122,235

Pollutants Gas Use	
VOC	4,695
CO	97,687
NOx	3,678
PM10	746
PM2.5	386
Sox	162
GHG	
CH4	381
N2O	313
CO2	9,915,665

Locations:

A. Recovery: Freeport, TX
B. Refining: Beaumont, TX
C. Bulk Terminal: Linden, NJ
D. Vehicle Operation:
New York City

Figure 7-13 Gas Systems Results (Metric Tons per Year)



Pollutants	Corn T&D
VOC	91
CO	356
NOx	1,127
PM10	40
PM2.5	26
Sox	356
GHG	
CH4	356
N2O	6
CO2	213,871

Pollutants	Farming
VOC	-1,078
CO	3,832
NOx	10,620
PM10	1,060
PM2.5	469
Sox	5,878
GHG	
CH4	2,666
N2O	4,795
CO2	-5,416,082

Pollutants	E85 Use
VOC	4,468
CO	97,687
NOx	3,678
PM10	746
PM2.5	386
Sox	43
GHG	
CH4	381
N2O	313
CO2	9,737,543

Pollutants	Production
VOC	6,530
CO	2,778
NOx	8,531
PM10	5,980
PM2.5	1,810
Sox	5,681
GHG	
CH4	11,136
N2O	81
CO2	5,193,648

Pollutants	EtOH T&D
VOC	286
CO	411
NOx	2,754
PM10	79
PM2.5	63
Sox	52
GHG	
CH4	198
N2O	4
CO2	170,928

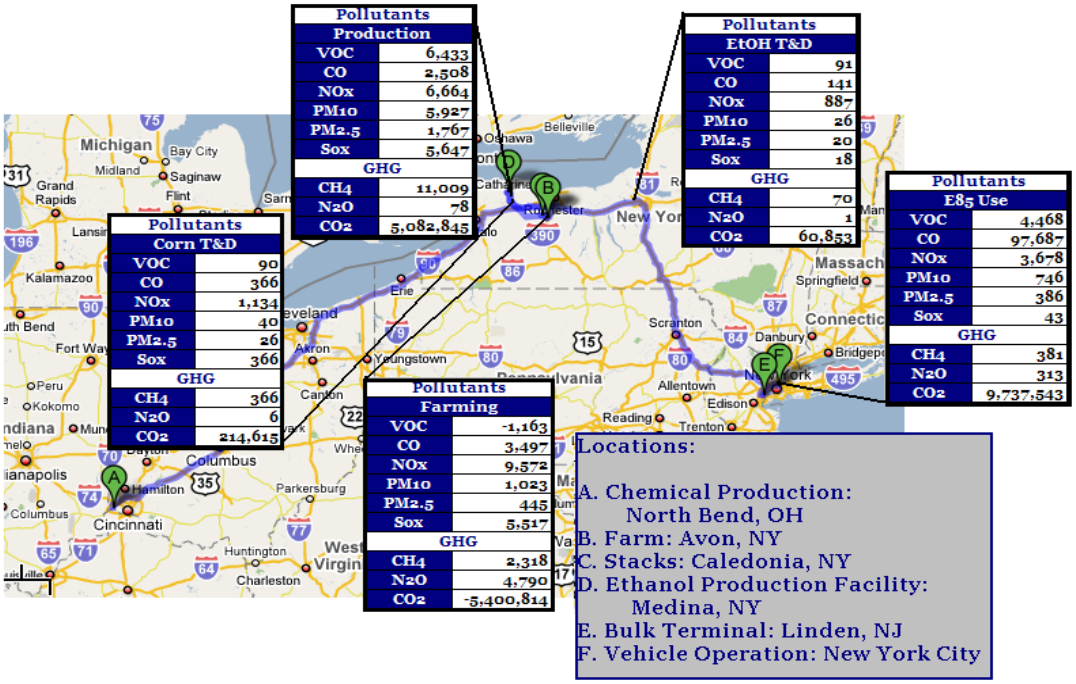
Locations

A. Chemical Facility: North Bend, OH
B. Farm: Cascade, IA
C. Grain Elevator: Monticello, IA
D. Ethanol Production Facility: Cedar Rapids, IA
E. Bulk Terminal: Linden, NJ
F. Vehicle Operation: New York City

Figure 7-14 Case 1 System Results (Metric Tons per Year)

It must be remembered that ethanol facilities are typically located in areas where prior to the construction of the facility, few industrial pollutants were present in the air. Generally, these locations are farming communities much like Cascade, Iowa, Avon, New York and West Manchester, Ohio where emissions associated with the production of crops were present before the ethanol facility. By placing ethanol facilities in farming communities additional emissions are added to profile.

Consider Case 2 as an example. It is assumed that prior to the construction and operation of the ethanol facility, the small western New York town of Medina, only consisted of those emissions associated with agricultural crop production, meaning farming and commodity transportation. These are located at points "B" and "C" in **Figure 7-15**. With the addition of the production facility, emissions at point "D" are added. This means that over 6,000 metric tons of VOC and NO_x, over 5,000 metric tons of PM_{10} and SO_x and over 1,500 metric tons of $PM_{2.5}$ and CO are released per year in Medina as a result of ethanol production. Greenhouse gases are also released in amounts of 11,000 metric tons of CH_4, 78 metric tons of N_2O and just below 5.08 million metric tons of CO_2 per year. With this said, it must be noted that ethanol in all cases analyzed is assumed to be made using fossil fuels as process energy, therefore part of the emissions represented at the production location can be attributed to coal and natural gas power plants which are not necessarily in the surrounding area near the production facility (GREET defaults were used for coal and natural gas shares). All of these emissions are added to the already existent feedstock emissions to make up the entire upstream activity emissions for ethanol. In all ethanol cases analyzed communities see an addition of emissions to the current emission profile with the operation of an ethanol facility, and potential expansion of the farming and transportation activities.



Pollutants	Production
VOC	6,433
CO	2,508
NOx	6,664
PM10	5,927
PM2.5	1,767
Sox	5,647
GHG	
CH4	11,009
N2O	78
CO2	5,082,845

Pollutants	EtOH T&D
VOC	91
CO	141
NOx	887
PM10	26
PM2.5	20
Sox	18
GHG	
CH4	70
N2O	1
CO2	60,853

Pollutants	Corn T&D
VOC	90
CO	366
NOx	1,134
PM10	40
PM2.5	26
Sox	366
GHG	
CH4	366
N2O	6
CO2	214,615

Pollutants	E85 Use
VOC	4,468
CO	97,687
NOx	3,678
PM10	746
PM2.5	386
Sox	43
GHG	
CH4	381
N2O	313
CO2	9,737,543

Pollutants	Farming
VOC	-1,163
CO	3,497
NOx	9,572
PM10	1,023
PM2.5	445
Sox	5,517
GHG	
CH4	2,318
N2O	4,790
CO2	-5,400,814

Locations:

A. Chemical Production: North Bend, OH
B. Farm: Avon, NY
C. Stacks: Caledonia, NY
D. Ethanol Production Facility: Medina, NY
E. Bulk Terminal: Linden, NJ
F. Vehicle Operation: New York City

Figure 7-15 Case 2 Systems Results for Criteria Air Pollutants and Greenhouse Gases

7.3 TRANSPORTATION

Transportation and distribution for corn and ethanol in all cases resulted in emissions of five percent or less for the total fuel cycle with the exception of NO_x and CO. The previous section discussed the shifting of emissions from downstream to upstream. It also discussed briefly the impact that transportation and distribution have on the total fuel cycle emissions for ethanol. Generally, the results for all three cases imply that most pollutants released during the transportation and distribution of corn and ethanol are small and contribute to less than one percent to the total fuel cycle emissions. However, pollutants such as NO_x may contribute more. Nitrogen oxide presents more emissions to the total lifecycle than any other criteria air pollutants, primarily due to the combustion of diesel fuel throughout the transportation process.

As part of the ethanol total fuel cycle, the significance of the contribution are small, however if only the upstream portion of the lifecycle were to be analyzed, the contribution of transportation and distribution becomes slightly larger. It is recognized that the stationary locations, particularly the production facility, account for the greatest impact on the upstream portion of the lifecycle, as can be seen in all figures that follow, however this section will highlight the transportation and distribution impacts in relation to criteria air pollutants. Greenhouse gases show little impact in both the upstream and total fuel cycles for ethanol related to transportation and distribution. Only criteria air pollutants will be observed in this section. **Figure 7-16** presents the upstream stage contributions to the ethanol lifecycle measured in grams per E85 mile for Case 1. Looking at the NO_x, and CO emissions for Case 1 transportation and distribution of corn results in approximately five percent NO_x and CO contributions, while ethanol transportation contributes nearly 12 percent to the NO_x emissions and another five percent to the CO emissions.

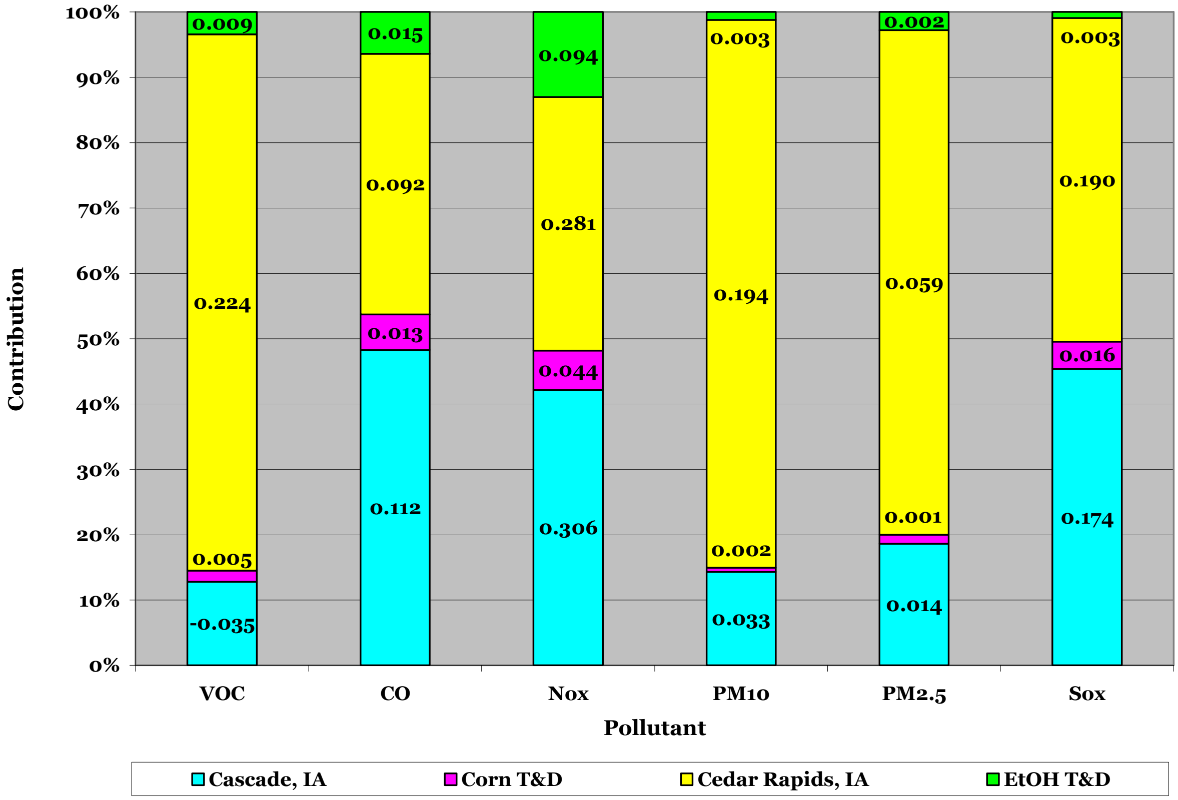


Figure 7-16 Case 1 Upstream Contribution by Stage for Criteria Air Pollutants

1. Values on graph are measured in grams per mile of ethanol used.
2. Emission contributions are calculated using absolute values.

Cases 2 and 3 show transportation and distribution impacts for the upstream portion of the ethanol lifecycle; as can be seen in **Figure 7-17** and **Figure 7-18**, the impact of transportation and distribution is less than 10 percent for both cases for corn and ethanol transportation in comparison to case 1.

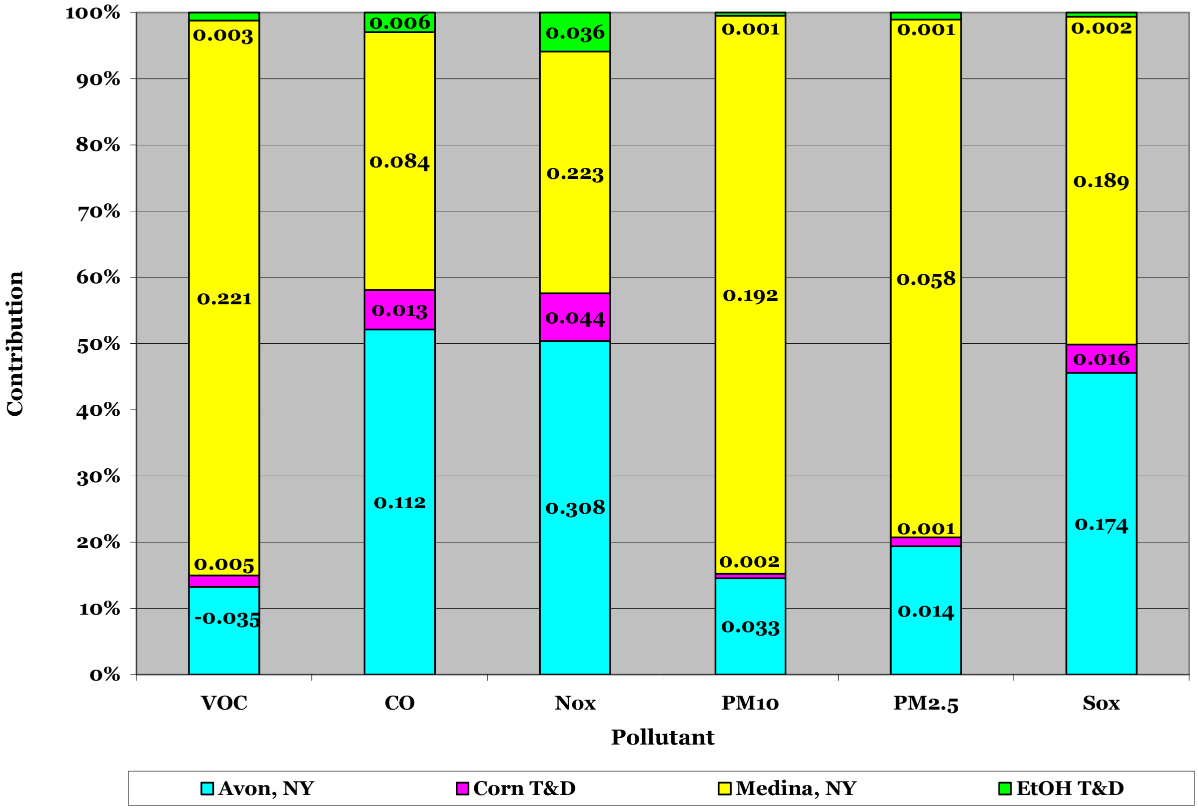


Figure 7-17 Case 2 Upstream Contribution by Stage for Criteria Air Pollutants

1. Values on graph are measured in grams per mile of ethanol used.
2. Emission contributions are calculated using absolute values.

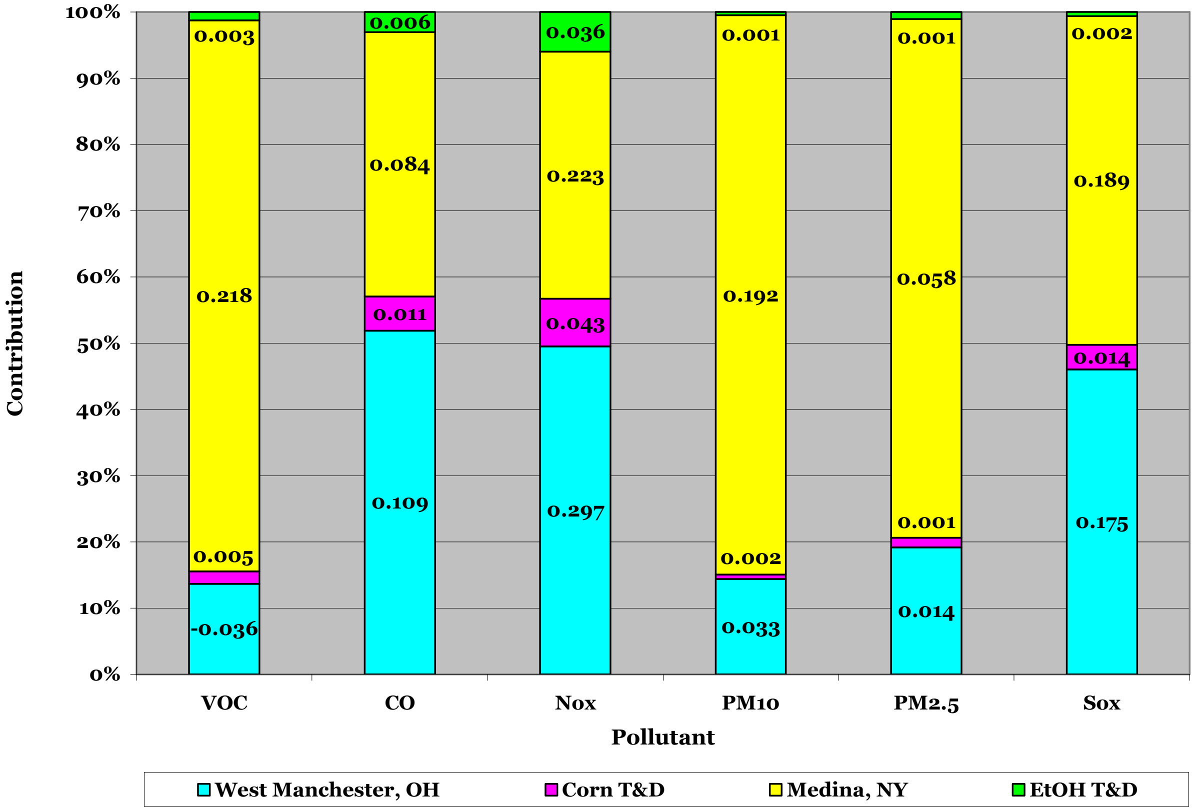


Figure 7-18 Case 3 Upstream Contribution by Stage for Criteria Air Pollutants

1. Values on graph are measured in grams per mile of ethanol used.
2. Emission contributions are calculated using absolute values.

While the transportation and distribution emissions from the upstream portion of the ethanol fuel cycle suggest that mode and distance may play a role in the significance of the contribution made by this stage, to understand the impact of distance and the impact that ethanol transport will have on communities situated along the transportation routes for farm and fuel products, trans-route emissions measured in metric tons per mile transported were also calculated. These results suggest that mode makes a difference in the amount of pollutants released per mile transported.

Generally, all ethanol cases had results in which most criteria air pollutants and greenhouse gases, with the exception of NO_x and CO_2, measured less than 10 metric ton per mile transported for the transportation and distribution of corn and ethanol. Case 1, shown in **Table 7-1**, had the high NO_x results for corn transportation and the lowest for ethanol transportation despite the ethanol being transported the farthest distance and the corn being transported the shortest. Carbon dioxide appears to be the same as the NO$_x$ results in that Case 1 results in high CO$_2$ emissions for corn transport, 5346.76 metric tons per transportation mile per year and the lowest CO$_2$ emissions for ethanol transport, 185 metric tons for the trans-route.

Table 7-1 Case 1 Trans-route Emissions

Mt per Mile[1]	Corn	Ethanol
Trans-Miles	39.6	922
Pollutants		
VOC	2.28	0.31
CO	8.91	0.45
NOx	28.17	2.99
PM10	1.00	0.09
PM2.5	0.66	0.07
Sox	8.91	0.06
GHG		
CH4	8.91	0.21
N2O	0.15	0.00
CO2	5346.76	185.35

Case 2 resulted in the the highest transportation emissions for corn of all three ethanol cases analyzed. Recall that corn is transported from field to production facility approximately 40 miles by truck. In this case, 28.36 metric tons of NO$_x$ per transportation mile are emitted, while just over three metric tons of NO$_x$ are released by the transportation of ethanol, despite the ethanol being transported a shorter distance than that in Case 1 (**Table 7-2**).

Table 7-2 Case 2 Trans-route Emissions

Mt per Mile	Corn	Ethanol
Trans-Miles	39.8	293
Pollutants		
VOC	2.26	0.31
CO	9.15	0.48
NOx	28.36	3.03
PM10	1.00	0.09
PM2.5	0.66	0.07
Sox	9.15	0.06
GHG		
CH4	9.15	0.24
N2O	0.14	0.01
CO2	5365.36	207.61

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[1] Measured as metric ton per mile transported per year

Case 3 results in the lowest corn transport emissions and higher ethanol transport emissions of NO_x in comparison to Case 1. Case 3 transports corn the greatest distance of all the cases, however the mode by which the corn is transported differs in that Case 3 uses train to transport the corn 414 miles from West Manchester, Ohio to Medina, New York, whereas corn in cases 1 and 2 utilized truck transportation to ship corn less than 40 miles to the farm.

Carbon dioxide results for Cases1, 2 and 3 are similar in trend to those for NO_x. Generally, Case 1 results in the high corn transport emissions and the lowest ethanol trans-route emissions, however Case 2 has the highest corn and ethanol transport emissions. Case 3 resulted in NO_x and CO2 emissions from corn transport being lower than those for Cases 1 and 2 (**Table 7-3**).

Table 7-3 Case 3 Trans-route Emissions

Mt per Mile	Corn	Ethanol
Trans-Miles	414.5	293
Pollutants		
VOC	0.25	0.31
CO	0.72	0.48
NOx	2.69	3.03
PM10	0.10	0.09
PM2.5	0.07	0.07
Sox	0.72	0.06
GHG		
CH4	0.72	0.24
N2O	0.02	0.01
CO2	523.39	207.62

Noticeable when studying only the upstream portion of the ethanol lifecycle is similarity of the upstream stages to other biobased products. The ethanol upstream portion of the lifecycle can represent more than the ethanol lifecycle, it can also be representative of other crop and biobased product lifecycles and conclusions about transportation and distribution of these products can be made. The significance of the upstream activity emissions recognize that the upstream steps such as the transportation and distribution of ethanol can be significant contributors to the emissions released in the farming communities across the country. Upstream activities found within the ethanol fuel cycle, are not exclusive to ethanol and are in fact used in many other product streams making research into the upstream lifecycles important when it comes to criteria air pollutants which are released in local communities and may impact local air quality in farming and production communities.

7.4 GENERAL CONCLUSIONS

Based on the results, two general conclusions can be drawn. First, ethanol use causes a displacement of VOC, SO_x and CO_2 from downstream vehicle operation locations to upstream locations such as farming and production sites. Other emissions also increase at upstream locations, however no reduction is seen at the tailpipe in comparison to gasoline, so displacement does not occur. Second, transportation and distribution generally contributes between one and five percent to the total fuel cycle emissions, however for pollutants such as NO_x and CO, percentages contributed were seen as high as 10 percent for the total fuel cycle and 15 percent for only the upstream portion of the fuel cycle.

8 *CONCLUSIONS, POLICY IMPLICATIONS & RECOMMENDATIONS*

8.1 CHAPTER OVERVIEW

The general conclusions of this research along with the potential policy implications and recommendations to aid in the mitigation against the unintended consequences that could result due to the production of corn ethanol and the use of the ethanol in vehicles are summarized in this chapter. An overview of the analysis performed, the results found and final conclusions of these results will be given. The final sections of the chapter cover the policy implications of emission displacement as well as transportation concerns and finally the policy recommendations to potentially aid in the mitigation of the unintended consequences of ethanol production emission displacement.

8.2 SUMMARY OF ANALYSIS

Ethanol use has been lauded as a way to provide a secure, diverse, environmentally friendly and economically beneficial energy supply for the US; however it has many critics against its use due to the many unintended consequences that may occur. These include the increasing food prices, net energy balance and adverse environmental consequences such as water contamination from corn and ethanol production. One potential unintended consequence that has received little attention is the emission displacement from the downstream locations such as vehicle operation to the upstream locations such as farming and production locations. It is the hypothesis of this thesis that the use of ethanol as a fuel will result in a shift of emissions to upstream locations such as farming communities where feedstock is grown and in many cases production facilities are located. As a result of ethanol use and the displacement of emissions, there is potential for geospatial conflicts to arise when formulating and implementing future energy, environmental and agricultural policies. Additionally, this research also tested the significance of transportation and distribution contributions to the ethanol upstream and total fuel cycle emissions.

To study the potential shift in emissions, a geospatial lifecycle analysis was performed. The UEP model was developed and used to analyze three ethanol cases and one gasoline case in regards to criteria air pollutant and GHG emissions at each stage of the fuel cycle. The GREET model was used as a source of data, however could not be used as the primary model to analyze these cases as the GREET model results in three aggregate stages: feedstock, fuel production and vehicle operation. For this research, transportation and distribution of feedstock and fuel was recognized as individual stages of the fuel cycle. The three ethanol cases used include: Case 1 which represents the current industry, Case 2, representing the expanding industry and Case 3, representing the importation of the feedstock for the expanding industry. Case 3 is a likely situation for New York State, as only one corn crop is grown per year, and the growing season is short. Unlike facilities in the Midwest, corn is not in abundance in New York; therefore importation of corn from elsewhere must take place. The gasoline case made gasoline in the south and transported it via pipeline to the New York City where it was used. The resulting functional units dependent upon the location, distance and mode of transportation are grams per mile of E85 used as well as metric tons of emissions per year and metric tons of emissions per mile (Trans-route).

8.3 RESULTS, IMPLICATIONS AND RECOMMENDATIONS

The results presented in the previous chapter imply that ethanol use in cities and states across the country increases the criteria air pollutant and GHG emissions at locations associated with upstream activities such as farming and production. Two criteria air pollutants, VOC and SO_x and one GHG, CO_2 are displaced by the use of ethanol in vehicles. The increase at the these locations has the potential to adversely affect the air quality of locations where feedstock such as corn are grown and ethanol is produced, not to mention those locations along the transportation route. The general conclusions drawn from this research are as follows:

A. **Ethanol use as a fuel in congested areas such as New York City, will reduce total GHG (primarily made up of CO_2) and two criteria air pollutant emissions (VOC and SO_x) at the vehicle operation location, however other criteria air pollutant and GHG emissions in locations upstream increase.**

Generally, CO_2 emissions at the tailpipe are decreased by the use of ethanol, but in order to gain this reduction emissions of criteria air pollutants such as VOCs, NO_x, CO, PM_{10}, SO_x and to some extent $PM_{2.5}$ as well as GHGs including N_2O and CH_4 are increased at farming and fuel production sites. This is seen in both the grams per mile results and more dramatically in the systems wide results. At the tailpipe, VOC, SO_x and CO_2 are the only pollutants and GHGs that show a reduction. In all cases, criteria air pollutants showed increases for the total fuel cycle emissions, primarily due to the increase in emissions at locations elsewhere in the fuel cycle. Carbon dioxide was the only GHG to show a decrease in total fuel cycle, primarily due to the displacement credits and carbon capture that is given to the CO_2 calculations. Without these credits, CO_2 emissions would also exceed those emissions for the gasoline total fuel cycle. The other two GHGs measured in this research showed no change at the tailpipe and increase in total fuel cycle emissions.

What both the individual and system wide sets of results show is that farming activities contribute large amounts of NO_x, SO_x and N_2O. The NO_x emissions are due to the use of diesel in farming equipment as well as the production, transportation and use of fertilizers, herbicides and insecticides. As discussed in the chapter 2, diesel fuel emits large amounts of NO_x due to presence of ideal conditions within the fuel combustion system (Lloyd & Cackette, 2001; Moomaw, 2002). Additionally fertilizer use and transportation of agricultural chemicals release NO_x. Agricultural chemical release NO_x as a result of use on the crops; the rate of NO release is dependent upon the carbon content in the soil as well as the drainage system used and the amount of chemicals applied to the crop (International Fertilizer Industry Association, 2007). Sulfur oxides are primarily released during the agricultural chemical production and transportation step within the feedstock stage. This is further demonstrated by the upstream emission results, showing chemical production and transportation as having a large impact on upstream location emissions. Nitrous oxide is the primary GHG released at the farming locations. The farming contributions to the N_2O emissions are very large and constitute a majority of the N_2O emissions for the entire lifecycle. Due to plant growth as well as agricultural chemical use, emissions at farming locations tend to be high.

The production location is the other stationary site within the ethanol fuel cycle that emits large amounts of criteria air pollutants and GHGs. This stage contributes large amounts of VOC, CO, PM_{10}, $PM_{2.5}$, SO_x and CO_2. Emissions at this stage can be partially attributed to the use of natural gas and coal from power plants to operate the production facility. While the impact of these two fossil fuels was not studied within this research, they should be recognized as large contributors to PM and SO_x emissions. If other fuels were used as process energy, the emissions at this location may be lower, however that is out of the scope of this research. Currently, the ethanol industry primarily uses fossil fuels as the main source of process energy, which is why the parameters pertaining to both of these fuels were not changed from the default GREET settings. Volatile organic compounds are contributed in high amounts at this location as well. This is due to the fermentation processes and drying of co-products that occur within the production process. With this said, ethanol facilities are equipped with control systems that prevent the release of high levels of VOC into the air. In 2002, production facilities in Minnesota were mandated to install thermal oxidizers to control VOC emissions from stacks at the ethanol plants, after it was recognized that emissions from these production facilities were often underestimated and exceeded emission levels permitted. However, even with control systems in place, VOC emissions tend to still be underestimated and may continue to exceed regulatory standards for the given plant (Brady & Pratt, 2007).Overall, emissions at the stationary points within the ethanol fuel cycle emit the most criteria air pollutants and GHGs.

Geopolitical Implications

The increased emissions at the upstream locations such as farming communities has the potential to cause geopolitical tensions to arise in relation to the formulation and implementation of energy, environmental and agriculture policies in the future. Often, when geopolitical conflicts are described in relation to energy resources, the term refers the geospatial mismatch between where resources are located and where the energy resources are needed on a global scale (Mandelbaum, 2005). However, in the case of this research, the geopolitical conflicts that will arise are in regards primarily to the domestic political system. In policymaking, geopolitical conflicts draw boundaries between state and federal issues and often do not follow party lines. As Tip O'Neill once stated "All politics is local"(PBS, 2001); when a decision of a policymaker is made, it should reflect the interest of local constituents who put him or her into office. In American politics, a decentralized political system, close attention is paid to the geospatial implications of a given policy (Trubowitz, 1998). An example of this can be seen in the case of nuclear waste and Yucca Mountain.

More than 20 years ago, Yucca Mountain, Nevada, a federally owned geologic location once used as a nuclear test site, was chosen to become the site for the nation's central nuclear waste repository. Currently, nuclear waste is stored on-site at nuclear power plants and at other locations such as defense facilities using nuclear products. There are over 120 of these sites across the country that are generally located near populated areas and key water bodies, posing high risks to the humans and ecosystems surrounding them. To protect human and environmental health and safety as well as national security, a geologic location was chosen to become a storage area for the nuclear waste that takes thousands of years to become stable (US Department of Energy, 2008). While many of the country's politicians, government officials and scientists, agree that Yucca Mountain is a suitable place for such a task, officials in Nevada and surrounding villages, towns and cities see the idea differently. Constituents within these towns and cities, as well as those cities and towns along the routes in which the nuclear waste would be shipped, are concerned with the potential of a nuclear leak contaminating resources vital to human survival including the water supply which is limited. In addition to this, the fact that Nevada has no nuclear power plants, yet will receive the waste from plants around the country, has also been raised (Nevada Agency for Nuclear Projects, 2002). Opposition to the project by the State of Nevada and Congressional members from the state as well as surrounding areas have tied the issue up in Congress and courts for over a decade.

While the issues behind the Yucca Mountain problem, deal with hazards far more extreme if something were to go wrong, the geopolitical conflicts that the project has faced are not all that uncommon in US or global policymaking and are not all that different than those political conflicts that ethanol faces today in regards to economics and has the potential to face in the future in relation to upstream emissions. This research dealt with only one potential problem, shifting emissions, that could cause a political conflict based on location within the production stream for ethanol, however it is important to remember that ethanol political conflicts, like many issues, have been present in US politics for many years. Recently, the alcohol fuel has gained much attention due to rising food prices and global food shortages blamed on among other things the use of corn for energy production rather than to make food goods as well as the land use issues which cause the displacement of a given crop in order to grow corn for ethanol. The food versus fuel debate has gone on for years, however with the rapid expansion of the industry coupled with rising global populations the debate between ethanol supporters and critics have escalated, causing many within Washington, DC and state capitals around the country to question and call for re-evaluation of current policies and to call for careful consideration of ethanol policies in future agricultural, environmental and energy policy formulation and implementation. Those groups benefiting economically from ethanol production, namely the Midwestern corn farmers, the ethanol industry and farming communities, favor continued expansion of ethanol use, however the rest of the country and world sees ethanol production and use as the reason for shortages and consequently higher food prices. This puts a divide between the Midwest ethanol industry and the rest of the country as well as the world.

Much like the food versus fuel debate that has surrounded fuel ethanol as of late, the displacement and creation of emissions could also fuel a similar debate in regards to future health and air quality issues in areas where production of feedstock and fuel occur. While feedstock growth emissions will not be of great concern until more and more croplands are shifted to energy crop production, the primary concern and the one that may appear more often may be in relation to the production. As ethanol production facilities become located within rural communities and operation takes place, additional pollutants are added to the existing emission profiles as this research has shown. With the addition of criteria air pollutants, degradation of air quality may occur affecting both human and environmental health. Soon areas where few industrial related pollutants were present will see an influx of pollutants that were once present primarily in major cities and industrial sites. This scenario may play out in the Medina's and Cedar Rapid's of the US and cause citizens to call on their elected officials to re-evaluate policies and to consider this shift in emissions when new energy, agricultural or environmental policy comes to the legislature. The policies that will arise will be tailored by politicians and lobbying groups representing regions of people to reflect the interests of the voting public (Trubowitz, 1998). In the case of air emissions, the geospatial aspects may create a suite of legislation tailored to compensate communities and renew air quality in rural America through incentives, tax credits and regulations that may or may not affect the groups benefiting from ethanol production and use.

Ethanol, like most issues dealt with in American politics, is complex and has many different interest groups involved. When the economic and national security issues are added to the emission displacement, the geopolitical conflicts remain, however conflicts between community members benefiting economically from ethanol production and those who are not as well as between national welfare and community welfare will only complicate the matter. While ethanol provides benefits to communities where production facilities operate as well as where feedstocks are grown, one may question whether these benefits outweigh the benefits of quality air to breath. What may result from this is a conflict first based on geospatial concerns between locations of increasing emissions such as rural communities in the Midwest and areas where ethanol use is slightly reducing SO_x and VOC emissions as well as the global community which may experience a drop in CO_2 emissions produced yearly due to the use of ethanol in vehicles. Second, political conflicts may arise within communities where corn farmers and ethanol producers who benefit economically may have conflicting interest with the residents and other farmers of the community who will have to deal with air pollution and other economic fallout from the production and use of corn and ethanol. Third, conflict between oil producing states and ethanol producing states may also arise. This could be both a conflict in regards to emissions and economy. An increase in ethanol production and a decrease in oil refining should also cause a decrease in emissions in those oil producing areas, while increasing emissions elsewhere. This could also cause an economic conflict as increased production and use of ethanol should decrease the amount of gasoline produced, which may result in the reduction of jobs due either the reduction in production at refineries or the closing of refineries all together. This would also impact communities economically.

Additionally, matters of national energy security and diversity will also play into the arguments which will play out in the political arena, with elected representatives arguing that ethanol use protects national security and diversifies that US energy supply. While few argue this point, some may argue that large scale ethanol production and use may not be the best way to reach these goals and that research and development into more sustainable forms of energy may be in the country's best interest.

Overall, the future political landscape, in regards to ethanol, may see the unintended consequences of ethanol production in regards to emissions displacement and food issues.While geopolitical conflicts will exist between areas of the country and the world, this research in no way suggests that the US should abandon ethanol. However, it does imply that ethanol production and use should be carefully considered in regards to the emissions reduction and that continued construction and operation of new ethanol production facilities, particularly in areas of the country where feedstock resources are less abundant than the Midwest, should be done so in the most stringent environmentally safe ways as to protect the health of both humans and the ecosystems of the area. Future policies should consider the air quality impacts caused by ethanol and should formulate policies that can capture both ethanol's positive and negative environmental qualities. Three recommendations for national policy include implementing a tax on ethanol that would compensate those areas impacted by the production emissions, cut subsidies for oil companies or implement an incentive program for those ethanol and farming companies that use the best possible practices and technologies to reduce emissions and aid in the improvement of community air quality.

Recommendations

I. Ethanol Production Tax

Because abandoning ethanol production is not the best solution considering the GHG and gasoline reduction and economic benefits it does present, a policy recommendation is to implement a tax on corn grown specifically for ethanol production and ethanol coming out of the production plant. Much like alcohol produced for consumption is taxed; ethanol used for fuel could be taxed with the revenue generated from this tax sent back to communities experiencing air quality and environmental impacts caused by the upstream activities of the ethanol production process. This would act as compensation, to aid in the building of sustainable communities as well as a way to reduce the environmental impacts of ethanol production by having additional revenue to aid in the improvement of air quality in the areas.

However, like all policies, this too has the potential to cause unintended consequences. A tax on ethanol production has the potential to negatively impact communities economically as the ethanol industry is considered to be an infant industry. Taxing ethanol would discourage growth and continued production within the industry. This may cause ethanol production facilities owned by farmer co-ops to end production, leaving only those larger corporate companies to produce and profit from ethanol and the amount of ethanol produced would be limited. Ultimately, this kind of tax has the potential to impact the GHG mitigation programs dependent upon using ethanol to reduce oil consumption.

II. Gasoline Tax

An alternative to taxing the ethanol industry is to tax the oil industry, or give subsidies currently given to the oil industry to the ethanol industry and use the revenue as compensation for those communities producing ethanol. This would allow for ethanol to continue to produce at capacity without additional economic burdens and allow communities to benefit economically. Communities will be able to use the additional revenue to support emission reduction and environmental programs.

Like the ethanol production tax, this policy alternative has its own set of unintended consequences that are also related to economics. By cutting subsidies or taxing the oil industry, companies could choose to cut jobs or close facilities to save money. This would negatively impact the communities where oil and gasoline production activities take place.

III. Ethanol Emission Reduction Incentive

Providing incentives to companies to reduce emissions or to compensate communities by funding other emission reduction strategies could be another way to still effectively reduce GHGs from tailpipe emissions, while also aiding in the upstream air quality. Ethanol production and farming companies producing fuel ethanol in a way that is environmentally sustainable, or using technologies that reduce emissions could be given tax credits or incentives to continue emission reduction strategies. "Green" manufacturing and farming practices or community projects funded by a company have the potential to reduce emissions at each location and aid in the global fight to reduce GHG emissions and the local struggle for air quality improvements.

The second conclusion is as follows:

B. Transportation and distribution emissions have the potential to contribute zero to 15 percent of criteria air pollutants (depending on the pollutant) to the air near or participating in feedstock and fuel production and transportation.

The UEP model was built to disaggregate the GREET model in a way that the transportation components of the lifecycle could be quantified and the locations in the lifecycle can be identified by a geospatial tag. It can be seen in the results that overall the ethanol feedstock and fuel transportation and distribution does not contribute large amounts to all criteria air pollutants and gases, however NO_x and CO see some difference in this. The transportation and distribution NO_x and CO emissions for Case 1 suggests that emissions are highly dependent upon distance and mode traveled, as well as the product being transported. Surprisingly, what was found in this research is that on a per mile transported basis, those cases using train rather than truck to transport corn or ethanol a long distance, actually resulted in emissions of both criteria air pollutants and greenhouse gases being lower than the cases where the distance was shorter but truck was used to transport the product. This suggests that the mode chosen plays a very important role in the amount of pollutants and gases released by transportation and distribution of a product. When looking at the three ethanol cases, Case 3 transported corn over 400 miles from Ohio to western New York, however this case showed the least amount of emissions due to the use of train rather than truck used in Cases 1 and 2, which transported corn approximately 40 miles. When the results are looked at from an E85 mile contribution perspective, cases such as Case 1 imply that longer distances contribute more to the overall lifecycle emissions, however if the transportation is looked at solely the results suggest that mode makes a rather large impact to the transportation emissions being released on the transportation route. Shorter distances using truck generally result in higher emissions, while longer distances using train, which can transport more and is more efficient, result in lower emissions along the transportation route. While the total fuel cycle emissions contributed by the transportation and distribution is relatively low in comparison to the stationary emission contributions, when only the upstream emissions are accounted for the contributions from transportation and distribution particularly NO_x and CO, can contribute between five and 15 percent to the upstream emissions.

Noticeable about the ethanol upstream results is that the emissions contributed by the upstream portion of the lifecycle can represent other agricultural products as well as manufactured products. It is assumed that most agricultural crops have similar feedstock steps as corn and that biobased products have a similar lifecycle represented by the upstream portion of the ethanol fuel cycle. If this assumption is accurate, then the stationary activities such as farming and production as well as the mobile activities such as transportation can contribute significantly to the local air pollutants for one location. For instance, in all cases, production of ethanol contributes significant amounts of VOC, particulate matter, NO_x, and SO_x emissions at the production facility, while transportation and distribution emit larger amounts of NO_x and CO into the air in farming communities as well as along the transportation route. Again, these results imply that it may be of particular interest to pay attention to the lifecycle of biobased products and commodities when it comes to energy use. Reducing distance or changing the mode used to transport a product may significantly reduce the emissions at each point of the route.

Transportation Implications

As with stationary locations, which were the primary focus of the geopolitical implications caused by ethanol production and use, transportation and distribution of the corn feedstock and ethanol fuel will also play into the idea of shifting emissions. While the contributions of transportation and distribution is generally smaller than the contributions of a stationary source such as a farm or production facility, the contributions of this stage are none the less important as these emissions can represent more than just the ethanol upstream emissions. As previously stated the mode by which the product is transported plays an important role in the transportation emissions. If a product is to be shipped by truck, it may be more environmentally sound to ship the product to areas closest. Going along the same lines as the slogan "think globally, act locally", the research suggests that it may be impractical to ship products by truck, whether raw feedstock or a finished food or manufactured product long distances. Today, the average food product is shipped approximately 1,500 miles before reaching its final destination (Norberg-Hodge, Merrifield, & Gorelick, 2002), a practice that appears to do everything but be sustainable in relation to pollutants and GHGs . With continued support for practices that reduce CO_2 and other pollutants, it could be suggested that transportation policies at both the public and private levels should be re-evaluated to aid in goals of ecologically sound and sustainable practices at all levels of government.

Recommendations

I. Transportation Education and Incentives

In order to reduce transportation emissions for food products and other biobased goods, public and private sector policies could be designed. First, education of business leaders in regards to the environmental costs of shipping of products, both short and long distance, should occur by experts in the energy, environmental and economic fields as well as the government. While it may be economically beneficial to the company to ship goods a long distance, the costs to communities and towns near the areas should be stressed in terms of air quality as well as the company's potential impact on the local economy. Second, the private sector could be given an incentive or tax credit if that business uses practices that will revitalize the local economy and aid in reduction of national and regional air quality threats caused by transportation emissions. These practices include selling their products locally or regionally, rather than shipping the product thousands of miles, as well as using green practices or compensating the community for air quality reductions that may be caused by a given process or practice performed by the company.

The solution to the world's GHG and criteria air pollution problems cannot and will not be solved by depending upon one solution, rather a variety of alternatives that are suitable for a given area should be stressed. Corn ethanol production and use may not be the solution for the entire country; however it may be part of the solution. All the impacts of ethanol production need to be recognized and alternatives need to be considered.

8.4 FUTURE RESEARCH

The purpose of this thesis was to determine whether the use of ethanol would create a displacement of emissions from the vehicle location to the farming, and feedstock location upstream. Information was gathered from the use of a geospatial lifecycle model; however the UEP model and the analysis that was performed are only the first steps. Future research should include updates to the UEP model, links to mapping components such as Geographical Information Systems (GIS), systems expansion to include more than one farm, production facility, and links to health and air quality data.

First, the UEP model should be expanded to include more than one farming location, production facility, and vehicle operation location, as well as a mix of transportation modes for feedstock and fuel. While the UEP model does yield information for a chosen route in which the ethanol lifecycle follows geospatially, the model is simplified, and to fully understand the impacts of the industry, it may be necessary to expand the model to look at the industry as a system. This means that in order to capture the full impacts of the industry, corn should be grown in several locations, ethanol production should occur in more than one location and E85 should be used in vehicles in more than one city. The model should also take into account ethanol production facility size and divide plant output among several locations, rather than a single location.

Second, research regarding other industries in which corn is used as an intermediate product, such as the food industry should be performed. To effectively understand the impacts the ethanol industry will have, it is useful to understand the impacts that other industries that would otherwise use the corn have on air pollutant and GHG release. A comparative LCA between the ethanol lifecycle and other corn based product lifecycles should be performed.

Third, the UEP model should be linked to mapping software in order to take into account the geospatial emissions in a more visual way. While the UEP model already contains information pertaining to the latitude and longitude of each location in the ethanol fuel cycle, to enhance the analysis and presentation of results a GIS map could be added. By adding a mapping component to the UEP model, the geospatial aspects of ethanol production can be demonstrated and trends, relationships and patterns within the data can be seen geospatially. Geography plays an important part in decision making for both the private and public sectors, by linking the UEP model to the mapping software like ArcGIS, the geospatial analysis results and conclusions can be enhanced. The scenarios that can be analyzed within the UEP model can be refined and go more in depth to such issues as air quality in a region or health impacts of a given industry by linking the lifecycle information to health and air quality data. This can be done within GIS or other mapping software, allowing, again for the trends, patterns and relationships between location, production lifecycle and health and air quality concerns and issues to be analyzed.

Finally, future analyses should account for changes in electricity process fuels and the UEP model should be expanded to account for the power plants that produce the electricity for manufacturing facilities. Because the process fuel used can contribute emissions to the fuel cycle, it is necessary to acknowledge these plants when performing the analysis. The emissions may change drastically if non-fossil fuel sources of electricity are used.

8.5 FINAL THOUGHTS

The research presented in this thesis suggests that ethanol production and use will cause emissions in rural communities to increase due to the potential increase in corn farming activities and addition of production facilities as well increased transportation. Trade-offs between environmental and social issues will be made as ethanol production and use expands. Environmentally, ethanol may reduce GHGs and a few air pollutants at a vehicle operation location, however this comes at the expense of those communities upstream. Economically, those same rural communities with the increased local air emissions may be benefiting from the additional revenue brought to the community through the ethanol production facility that provides new income for farmers producing corn, extra tax revenue for farming communities and new jobs for struggling rural communities where jobs may have been limited. Government, at all levels, needs to be involved with formulating and implementing policies that take into account both social and environmental impacts as well as the geospatial impacts caused by ethanol production and use.

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Appendix I: Case 2 and Case 3 Results

The following graphs are the emission results for Cases 2 and 3. Included in these results are the criteria air pollutant emissions and greenhouse gas emissions in grams per mile as well as the contribution of each stage to the total fuel cycle emissions in both cases for all pollutants and gases. Please refer to Chapter IV for a table of the grams per mile results as well as the system results for the locations used for each case.

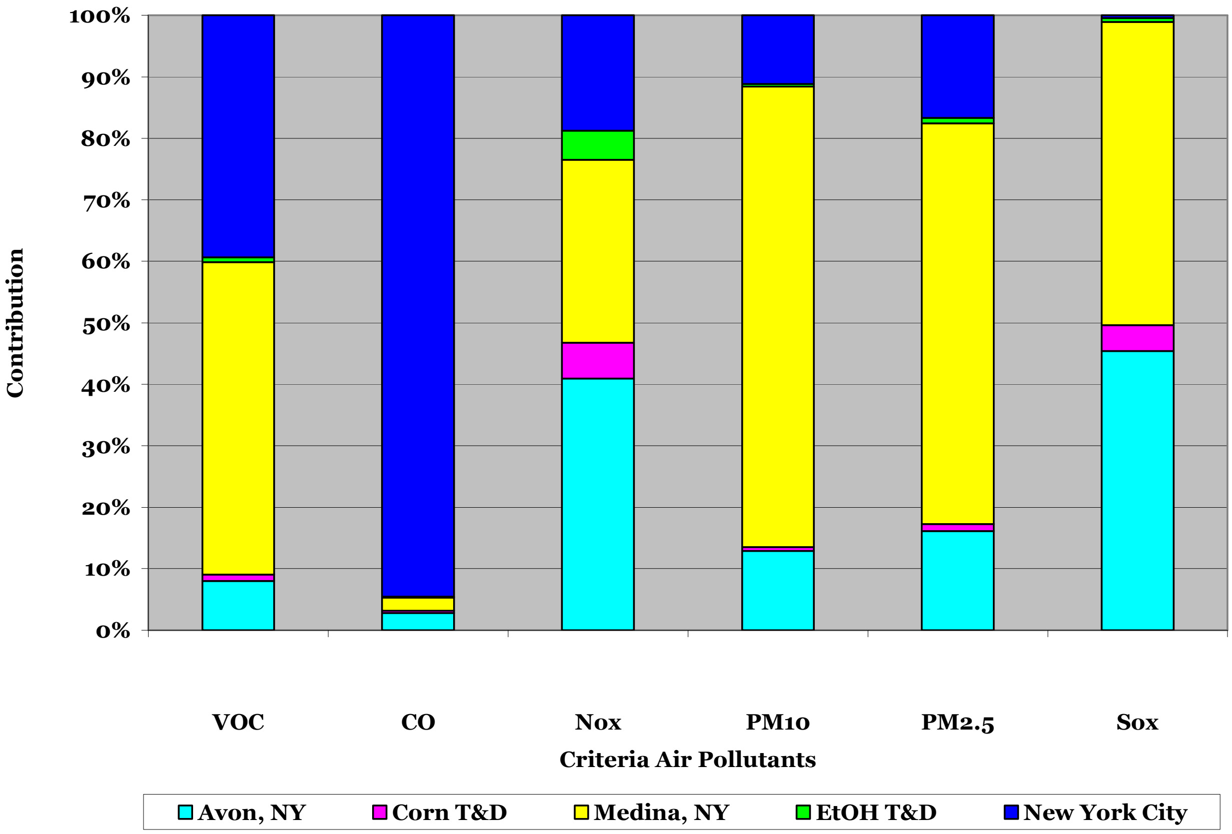

Figure 0-1 Case 2 Stage Contributions to Criteria Air Pollutant Emissions

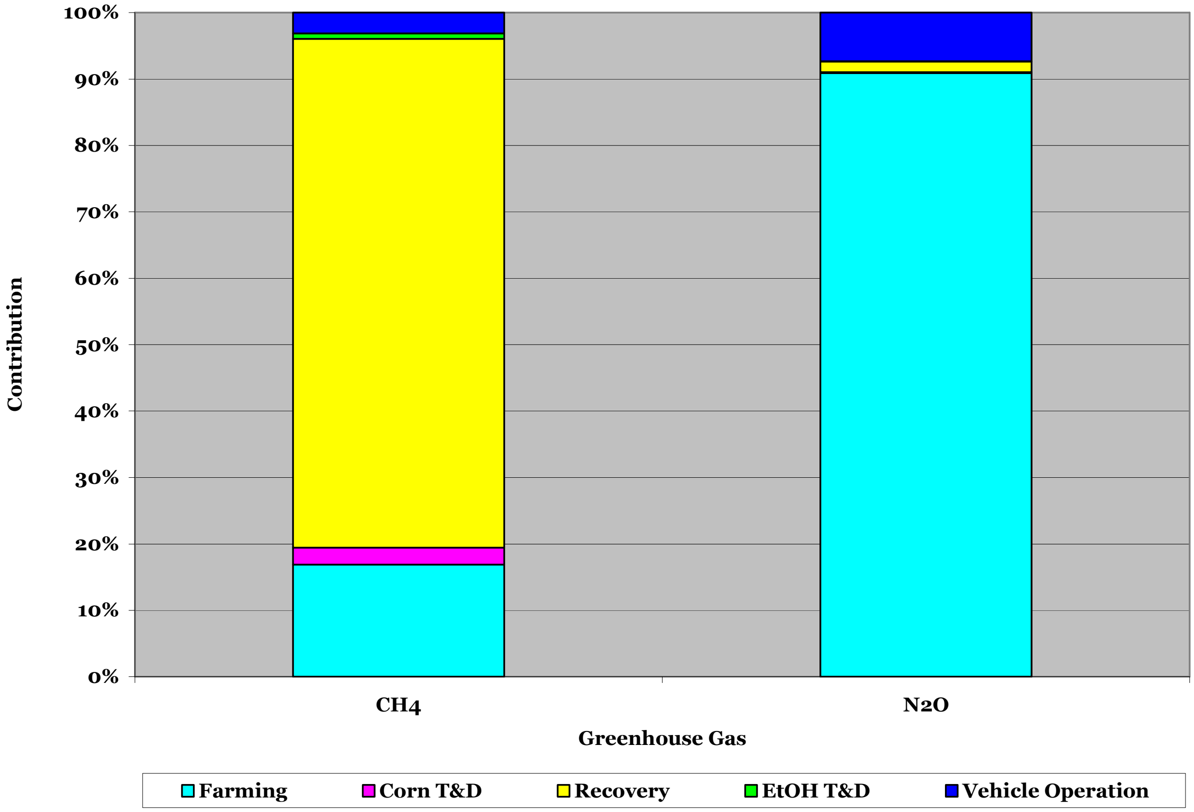

Figure 0-2 Case 2 Stage Contributions to Methane and Nitrous Oxide Emissions

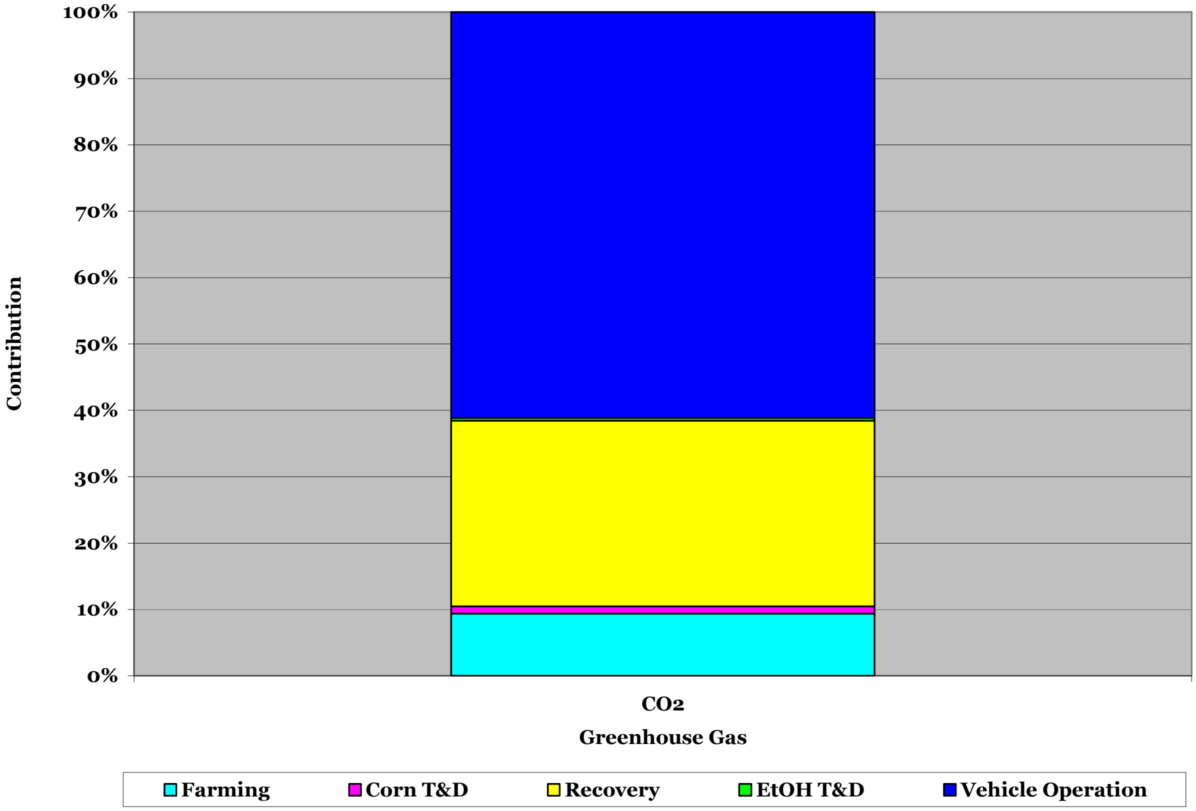

Figure 0-3 Case 2 Stage Contributions to CO_2 Emissions

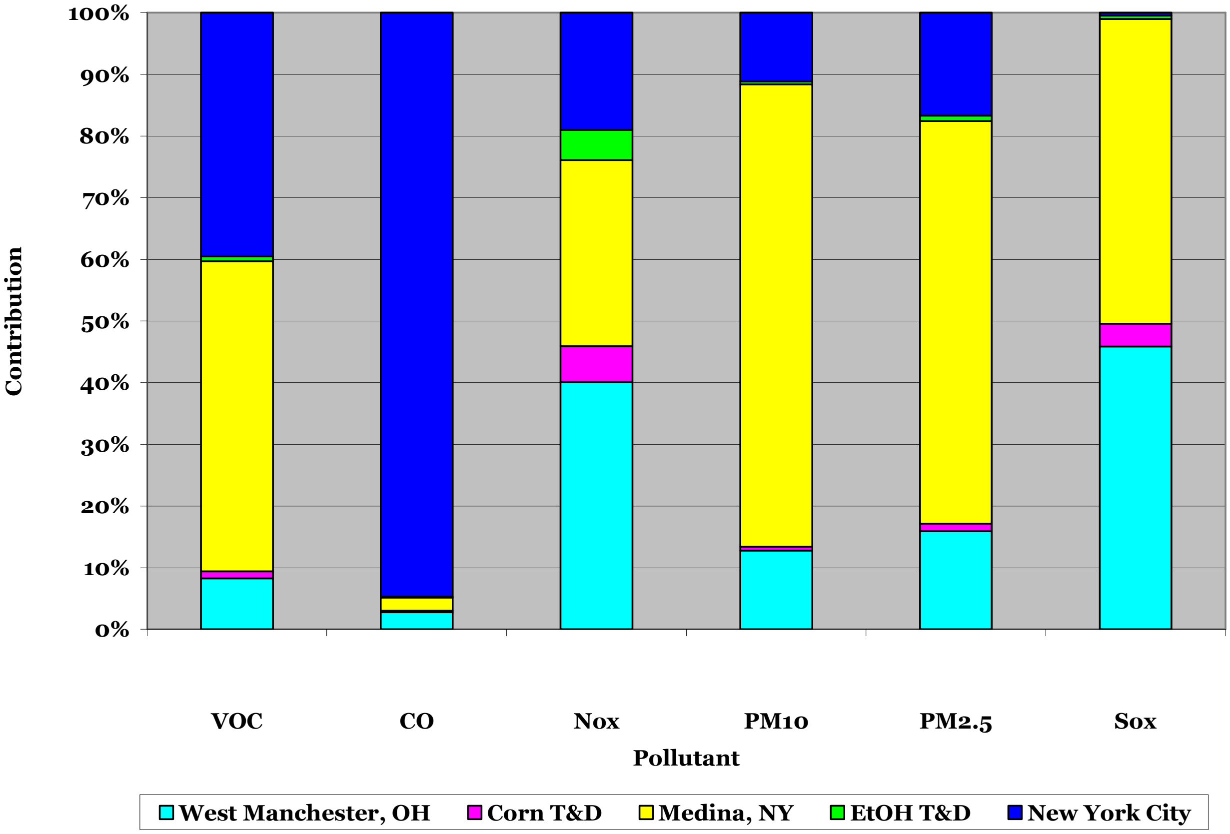

Figure 0-4 Case 3 Stage Contributions to Criteria Air Pollutants

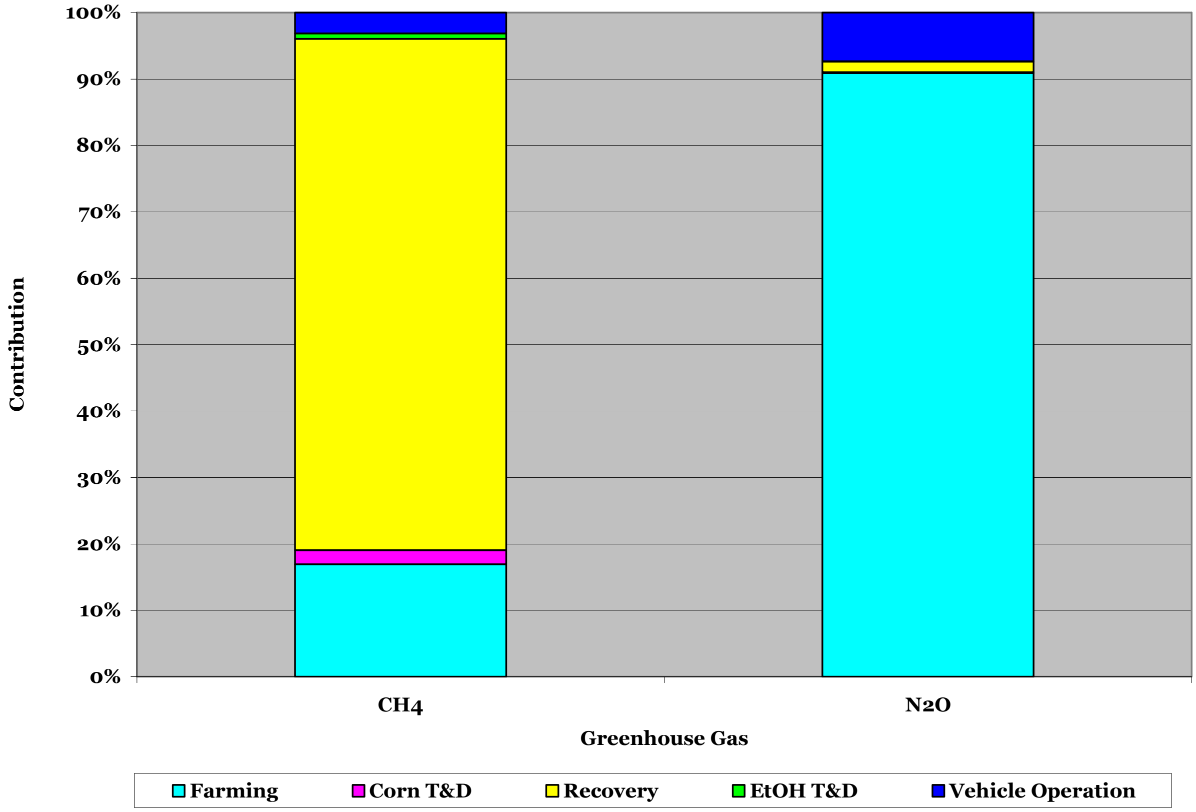

Figure 0-5 Case 3 Stage Contributions to Methane and Nitrous Oxide Emissions

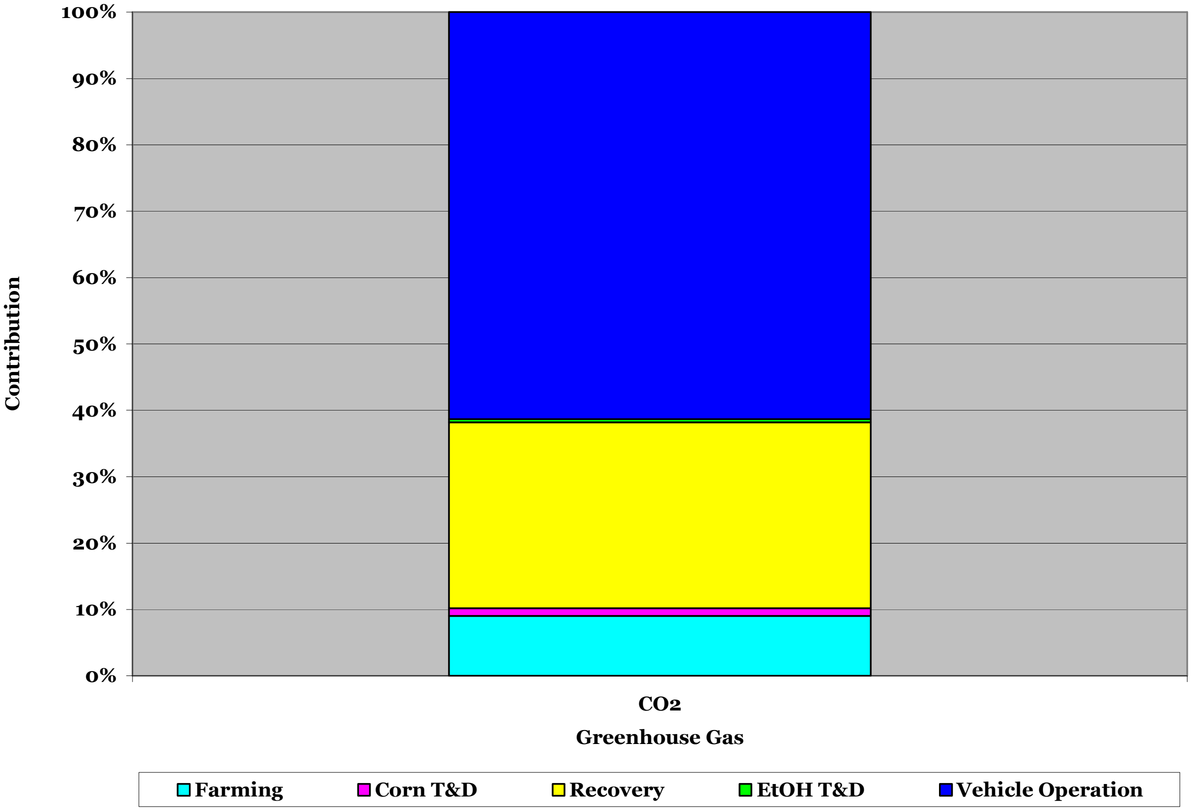

Figure 0-6 Case 3 Stage Contributions to CO_2 Emissions