Annotated Bibliography on the Environmental Effects of Biofuels

For The
Commission for Environmental Cooperation

Prepared by:

Matthew H. Brown
InterEnergy Solutions
July 2008

Table of Contents

Introduction

This annotated bibliography reviews literature from Canada, Mexico and the United States related to the environmental effects of liquid biofuels, defined in most cases as ethanol and biodiesel. It focuses on academic, government or government-sponsored documents and studies developed in Canada, Mexico and the United States. It is not meant to be a comprehensive review of every study in North America on the environmental effects of biofuels, but instead to capture many of the important recent works on the topic.

Many of the studies focus on life cycle analyses, meaning the cumulative net impacts from the: production of biofuels crops; transportation of those crops to processing facilities; production of biofuels and various co-products that come from the biofuel production process, transportation to final customers, and the emissions from the vehicle tailpipe. Some of the studies focus more narrowly on specific elements of environmental effects of biofuels such as the effect on water quality or water supplies as a result of increasing biofuel crop production.

The studies focus on a number of important issues, as described below.

Water quality: Several studies consider the effect of increased biofuel production on water quality. One of the main water quality issues relates to eutrophication, meaning the creation of oxygen-starved areas, within water bodies such as the Gulf of Mexico. These oxygen-starved areas appear to be the result of excess nitrogen fertilizer that leaches off farmers' fields and into waterways.

Greenhouse gas emissions: Studies focus on three greenhouse gases, CO_2, N_20 and CH_4, typically each translated into CO2 equivalents. Greenhouse gases arise from the production of biofuels – particularly the agricultural machinery used in farmers' fields, from disturbance of the soil in conventional agricultural practices, from transportation of feedstock from the farmers' field to the biofuel processing facility, from biofuel processing, and final biofuel transportation. Variations in feedstocks, different agricultural practices such as no-till agriculture and different processing techniques can have a significant impact on greenhouse gas emissions.

Criteria pollutants: Emissions of criteria pollutants come from several stages in the biofuel production and processing process as well as from the vehicle tailpipe. The studies focus in particular on emissions of CO and ozone precursors.

Toxics: Emissions of toxics such as formaldehyde or benzene result from the biofuel production and consumption life cycle.

In general, these studies indicate that the science of life cycle analysis has become much more sophisticated in the last decade. The Canadian GHGenius model, for instance, has been continually updated as it incorporates new knowledge and understanding of the nuance of emissions impacts of different feedstock fuels or co-products that result from the biofuel production process.

The results of these studies vary. General trends are that:

- The feedstock biofuel production is an important consideration because of the emissions impacts of the growth, harvesting and transportation feedstock;

- Greenhouse gas emissions depend a great deal on agricultural practices (the use of conventional or no-till agriculture), process fuels (the use of biomass, natural gas, coal or other fuels as a process fuel), and the use of different types of co-products that result from biofuel production;

- The results from studies of criteria pollutant and toxic emissions vary. All studies show an increase in emissions of nitrogen oxides. Most show decreases in CO and in particulate matter. Results for other pollutants and toxics vary;

- Geography is important; pollutant emissions in non-attainment areas are of particular concern. Although more study is required, it appears that many pollutant emissions occur near ethanol plants in areas that are in attainment for US EPA air quality standards;

- Water quality varies depending on farming practices. Farming practices that use a great deal of nitrogen fertilizer tend to have a negative effect on water quality. Recent farming practices have tended to use less nitrogen fertilizer;

- Water use varies a great deal depending on whether the biofuel is grown on irrigated land or not. In the United States, the vast majority of biofuels are grown on non-irrigated land;

- And, land use issues may be very important but have not been fully explored. A critical issue is what happens when land formerly used for food production is transformed into fuel production. In some cases, this transformation results in new land being brought into agricultural service. If this new land was previously forested, it may increase greenhouse gas emissions.

Biofuel production techniques and farming practices are changing quickly, and becoming more efficient. Thus, studies that rely on old data may need to be updated to account for these greater efficiencies.

This bibliography does not cover a number of important related issues. For instance, it is not focused on the net energy balance of biofuel production – the question of whether the amount of energy used to produce biofuels exceeds the amount of energy contained in the biofuel itself.

A Review of Assessments Conducted on Bio-ethanol as a Transportation Fuel from a Net Energy, Greenhouse Gas, and Environmental Life Cycle Perspective

Source:

Blottnitz, Harro von and Mary Ann Curran. 2007. A review of assessments conducted on bio-ethanol as a transportation fuel from a net energy, greenhouse gas, and environmental life cycle perspective. *Journal of Cleaner Production*. 15: 607-619.

Document Main Point/Goal

This document reviews 47 life cycle assessments worldwide of ethanol emissions and draws overall conclusions from the combined results of these assessments.

Document Primary Argument and Conclusion

The authors conclude that the following general lessons emerge from the 47 studies reviewed:

- Make ethanol from sugar crops, in tropical countries, but approach expansion of agricultural land usage with extreme caution.
- Consider hydrolysing and fermenting lignocellulosic residues to ethanol.
- The Life Cycle Assessment (LCA) results on grasses as feedstock are insufficient to draw conclusions.
- It appears that technology choices in process residue handling and in fuel combustion have key influences on emissions from biofuels.
- Seven of the reviewed studies evaluated a wider range of environmental impacts, including resource depletion, global warming, ozone depletion, acidification, eutrophication, human and ecological health, smog formation, etc., but came up with divergent conclusions, possibly due to different approaches in scoping.
- These LCAs typically report that bio-ethanol results in reductions in resource use and global warming; however, impacts on acidification, human toxicity and ecological toxicity, occurring mainly during the growing and processing of biomass, were more often unfavorable than favorable. It is in this area that further work is needed.

Notable Points Regarding Data that Bear on the Author's Conclusion

This study draws on 47 published assessments that compare bio-ethanol systems to conventional fuel on a life cycle basis, or using life cycle assessment. A majority of these assessments focused on net energy and greenhouse gases.

A Review of Life-Cycle Analysis Studies on Liquid Biofuel Systems for the Transport Sector

Source:

Larson, Eric D. 2006. A review of life-cycle analysis studies on liquid biofuel systems for the transport sector. *Energy for Sustainable Development*. X:2.

Document Main Point/Goal

This article reviews the literature of published life-cycle analyses (LCAs) of liquid biofuels, with a focus on elucidating the impacts that production and use of such biofuels might have on emissions of greenhouse gases.

Document Primary Argument and Conclusion

This document concludes that:

- The LCAs reviewed include almost exclusive contextual focus on Europe or North America, wide ranges in net energy balance results and GHG impacts among different biofuels and even for the same biofuel, and a lack of focus on evaluating GHG impacts per unit of land area.

- The wide range of reported LCA GHG results is due in part to the wide range of plausible values for key input parameters, among which the four most significant parameters exhibiting the greatest variability and/or uncertainty are (1) the climate-active species included in the calculation, (2) assumptions around N2O emissions, (3) the allocation method used for co-product credits, and (4) soil carbon dynamics.

- Finally, from a comparison of GHG impacts of biomass used for transportation fuels against those for stationary applications one concludes that under some conditions biofuels will provide greater GHG mitigation benefits, but under other conditions, biopower will be favored. It is difficult to make broad and unequivocal statements on this point. Case-specific analysis is required.

Notable Points Regarding Data that Bear on the Author's Conclusion

This article provides a useful review of the trends in a number of life cycle analysis studies.

Air Quality and GHG Emissions Associated with Using Ethanol in Gasoline Blends

Source:

Andress, David. 2000. *Air quality and GHG emissions associated with using ethanol in gasoline blends*. Oak Ridge National Laboratory/UT-Batelle Inc. and Office of Fuels Development, Office of Transportation Technologies, Energy Efficiency and Renewable Energy, US Department of Energy.

Document Main Point/Goal

This document describes the increase or decrease in pollutant emissions of as a result of low-level blends of ethanol into gasoline.

Document Primary Argument and Conclusion

This document presents the following chart that describes the increase or decrease in air pollutants as a result of a low-level (E10 or less) blending of ethanol with gasoline.

Pollutant	*Conventional Gasoline*	*Reformulated Gasoline*
Acetaldehyde	Increase	Increase
Benzene	Decrease	Decrease
1.3-butadiene	Decrease	Decrease
Formaldehyde	Increase	Decrease
CO	Decrease	Decrease
NO_x	Increase	No change
Tailpipe VOC	Decrease	No change
Evaporative VOC	Increase	No change
Total VOC	Increase	No change
Particulate matter	Decrease	Decrease
(Peroxyacetyl Nitrate) PAN	Increase	Increase
Isobutene	Decrease	Decrease
Toluene	Decrease	Decrease
Xylene	Decrease	Decrease

Corn-based ethanol in an E10 blend is estimated to reduce greenhouse gas emissions by 12 to 19 percent, depending on whether a wet or dry milling process is used to produce the ethanol. For future cellulosic ethanol used in E10, reductions in greenhouse gas emissions are projected to be between 84 and 130 percent, depending on whether woody or herbaceous biomass is used. Reductions of greater than 100 percent are possible because of co-product credit for the sale of electricity from cellulosic ethanol plants.

Notable Points Regarding Data that Bear on the Author's Conclusion

The analysis is designed as an overview of the topic and relies on a review of literature and tests available at the time the article was written (2000).

An Analysis of the Effects of an Expansion in Biofuel Demand on U.S. Agriculture

Source:

U.S. Department of Agriculture Economic Research Service and The Office of the Chief Economist. 2007. *An Analysis of the Effects of an Expansion in Biofuel Demand on U.S. Agriculture*. Washington, DC. US Department of Agriculture.

www.usda.gov/oce/newsroom/chamblissethanol5-8-07.doc

Document Main Point/Goal

The focus of this document is the economic and supply effects of an expansion of ethanol and biodiesel demand. In addition, it provides analysis of the effect of increased biofuels demand on soil erosion and nutrient loading.

Document Primary Argument and Conclusion

This document concludes that along with bringing new land into production, changes in crop rotations and tillage practices from increased corn production lead to increases in soil erosion and nutrient loading, particularly in the U.S. Corn Belt and Northern Plains.

Tillage may be unmanaged, whereby the soil is turned and weeds and crop residue removed, or a conservation tillage practice may be used. Conservation tillage refers to strategies and techniques for establishing crops in a previous crop's residues, which are purposely left on the soil surface. The principal benefits of conservation tillage are improved water conservation and reduced soil erosion. Additional benefits include reduced fuel consumption, reduced compaction, planting and harvesting flexibility, and reduced labor requirements.

This study focuses on two environmental implications of increased biofuels demand and production.

1. *Nutrient Deposition to Groundwater*. Nutrients that are applied to the soil and not taken up by crops have the potential to contaminate groundwater. All regions in the U.S. show an increase in nitrogen leaching in both scenarios, except for the Mountain and the Pacific regions. Similar results are found for phosphorus leaching, the other major nutrient of concern for water quality.
2. *Soil Erosion*. Management practice, climate, and geography play a role in soil erosion potential. The move away from conservation tillage toward more soil-intensive conventional tillage leads to an increase in soil erosion. The major crop producing regions all show increases in soil erosion, with significantly more erosion in the Northern Plains. The major factor driving this result is the large portion of new acreage planted using conventional tillage.

Notable Points Regarding Data that Bear on the Author's Conclusion

This study models five tillage practices: two unmanaged practices (conventional and moldboard plowing) and three conservation practices (mulch, ridge till, and no-till).

An Overview of Biodiesel and Petroleum Diesel Life Cycles

Source:

Sheehan, John, Vince Camobreco, James Duffield, Michael Graboski, Housein Shapouri. 1998. *An Overview of Biodiesel and Petroleum Diesel Life Cycles*. Golden, Colorado: National Renewable Energy Laboratory sponsored by U.S. Department of Agriculture and U.S. Department of Energy.

Document Main Point/Goal

This study examines biodiesel energy balance, its effect on greenhouse gas emissions, and its effects on the generation of air, water, and solid waste pollutants for every operation needed to make biodiesel and diesel fuel.

Document Primary Argument and Conclusion

The document makes the following major conclusions:

- The benefit of using biodiesel is proportionate to the blend level of biodiesel used. Substituting B100 for petroleum diesel reduces life cycle petroleum consumption by 95%. B20 blends reduce life cycle petroleum consumption by 19%.

- Biodiesel yields 3.2 units of fuel product energy for every unit of fossil energy consumed in its life cycle. B20 production yields 0.98 units of fuel product energy for energy unit of fossil energy consumed. By contrast, petroleum diesel uses 1.2 units of fossil resources to produce one unit of petroleum diesel.

- Biodiesel reduces net CO_2 emissions by 78.45% compared to petroleum diesel. For B20, CO_2 emissions from urban buses fall by 15.66%.

- Emissions of other pollutants vary:

- Life cycle total particulate emissions drop by 35%.
- Life cycle CO emissions drop by 35%
- Life cycle SO_x emissions drop by 8%
- Tailpipe particulate (<10 microns) falls by 68%.
- Tailpipe CO emissions are 46% lower.
- Tailpipe SO_x emissions are eliminated.
- Life cycle NO_x life cycle emissions increase by 13.35%
- Most of this increase in NO_x emissions results from increased tailpipe emissions.
- Life cycle HC emissions are 35% higher but tailpipe emissions are 37% lower.
- All of these emissions effects are proportional to the biodiesel blend; the above is expressed for B100; B20 blends emissions will be one-fifth that of B100.

Notable Points Regarding Data that Bear on the Author's Conclusion

Limitations on the availability of high quality data placed boundaries on the scope of this study. Specifically, because a great deal of data was available from bus engine tests and bus demonstrations of soybean-derived biodiesel, the authors chose to model soybean oil production and conversion to biodiesel based on bus applications. Later studies, also referenced in this bibliography, have refined and revised data on emissions from biodiesel.

Assessment of Net Emissions of Greenhouse Gases from Ethanol-Blended Gasolines in Canada: Lignocellulosic Feedstocks

Source:

Levelton Engineering. 1999. *Assessment of net emissions of greenhouse gases from ethanol-blended gasolines in Canada: lignocellulosic feedstocks*. Ottawa, Ontario, Canada. Agriculture and Agri-Food Canada.

Document Main Point/Goal

This study was undertaken to provide an analysis of the life-cycle emissions and life-cycle energy balance of the production of ethanol from several agricultural lignocellulosic feedstocks and its subsequent use as a motor fuel in blends with gasoline. The study focuses specifically on Southern Ontario, The analysis was performed for four feedstocks: switchgrass, hay, corn stover and wheat straw.

Document Primary Argument and Conclusion

The document concludes that:

- Switchgrass and hay provide lower greenhouse gas emissions than corn stover or wheat straw due to their ability to sequester some carbon in the soil and in plant biomass over the alternative use of the land, which was assumed to be unimproved pasture. The use of the agricultural residues, wheat straw and corn stover, was assumed in this analysis not to provide any additional ability to sequester carbon over and above that which normally occurs due the production of the grain.
- For all of the four feedstocks studied, ethanol produced and blended with gasoline will reduce emissions of greenhouse gases.
- The production of ethanol from corn stover in a full scale plant and blended into gasoline, taking full advantage of ethanol's octane rating, reduce greenhouse gas emissions by 5.8% compared to gasoline.
- If a dedicated crop such as switchgrass is used as the feedstock, the reduction increases to 6.7%.
- The reductions in the year 2010 when the technology was expected to be fully developed increase to 6.2% for corn stover and 6.9% for switchgrass. Greenhouse gas emission reductions for E85 range from 57% for Ontario wheat straw in 2000 to 71.6% for switchgrass in 2010.

Notable Points Regarding Data that Bear on the Author's Conclusion

Energy and emission analysis was conducted in this study for a base case ethanol production volume of 225 ML per year in 2000 and 2010. Further analysis was done to investigate the effects of annual ethanol production volumes of 500 ML, 750 ML and 1,000ML.

Many of the practices modeled here were experimental and had not yet been demonstrated on a large scale. This would include the production and collection of some of the feedstocks as well as the production of ethanol from lignocellulosics.

Biodiesel GHG Emissions Using GHGenius An Update

Source:

(S&T)2 Consultants Inc. for Natural Resources Canada. 2005. *Biodiesel GHG emissions using GHGenius an update*. http://www.ghgenius.ca (accessed October 20, 2007).

Document Main Point/Goal

This document presents the results of a lifecycle emissions analysis of five biodiesel production pathways in Canada.

Document Primary Argument and Conclusion

- This document concludes that all of the biodiesel production and use pathways provide some reduction in greenhouse gas emissions, but the results range from a 36 percent to a 98 percent reduction depending on the fuel pathway. The largest reductions come about when yellow grease (kitchen grease) is used as the feedstock and the lowest reduction comes about when marine-based oils (such as fish oils) are used. The specific emissions life cycle emissions reductions, compared to petroleum diesel are:
    - Canola oil: 70.8 percent reduction
    - Soy oil: 63.1 percent reduction
    - Tallow: 87.9 percent reduction
    - Yellow Grease 97.7 percent reduction
    - Marine Oil 35.8 percent reduction
- The oil extraction processes for all biodiesel production is already quite efficient, so the authors found that even improving extraction process efficiency by 25 percent had less than a 5 percent effect on overall lifecycle emissions.

Notable Points Regarding Data that Bear on the Author's Conclusion

The analysis relies on Natural Resources Canada's GHGenius life cycle emissions model. This model was developed in 1999 has been continually refined since that point. It is capable of estimating life cycle emissions of the primary greenhouse gases and the criteria pollutants from combustion sources.

Carbon-Negative Biofuels from Low-Input High Diversity Grassland Biomass

Source:

Tilman, David. et. al. Carbon-Negative Biofuels from Low-Input High-Diversity Grassland Biomass. 2006. *Science*. December 8. Vol 314.

Document Main Point/Goal

This document presents the results of a lifecycle emissions analysis of the use of native grassland perennials for biofuel crops. This analysis was carried out in the context of concerns that most analysis has focused on biofuel crops that may increase from fertilizers and pesticides, may threaten biodiversity when natural lands are converted to biofuel production and may compete with food production.

Document Primary Argument and Conclusion

This document concludes that:

- Greenhouse gas emissions reductions from the use of the crops examined here are from 6-16 times greater than those from use of corn grain ethanol and soybean diesel in place of fossil fuels.
- These crops had high bioenergy yields that were 238 percent greater than monoculture yields (such as corn grain or soybeans) after a decade.
- Low-impact high diversity crops such as those examined for this study can be produced on abandoned agricultural lands.
- These crops need not compete for fertile soils with food production nor encourage ecosystem destruction.
- These crops can produce carbon-negative biofuels and can reduce agrichemical use compared with food-based biofuels.
- Such crops may also provide other benefits such as stable production of energy, renewal of soil fertility, cleaner ground and surface waters, wildlife habitat, and recreation.
- The authors suggest that the potential for biofuel production and carbon sequestration via these low inputs and high plant diversity be explored more widely.

Notable Points Regarding Data that Bear on the Author's Conclusion

This analysis shows promise for a bioenergy crop that has not been extensively explored. It is based on a controlled and limited test, however, and will require further examination into such issues as total energy production potential.

Cumulative Energy and Global Warming Impact from the Production of Biomass for Biobased Products

Source:

Kim Seungdo and Bruce E. Dale. 2004. Cumulative energy and global warming impact from the production of biomass for biobased products. *Journal of Industrial Ecology*. 7 (3-4): 147-164.

Document Main Point/Goal

This document estimates the cumulative energy and global warming impacts associated with producing corn, soybeans, alfalfa, and switchgrass and transporting these crops to a central crop processing facility.

Document Primary Argument and Conclusion

This document estimates that the life cycle global warming impact associated with producing biomass from these four feedstocks is

- 246 to 286 grams (g) CO_2 equivalent/kg for corn;
- 159 to 163 g CO_2 equivalent/kg for soybeans;
- 124 to 147 g CO_2 equivalent/kg for switch-grass
- 89 g CO_2 equivalent/ kg for alfalfa.

Notable Points Regarding Data that Bear on the Author's Conclusion

The analysis relies on data collected from seven states in the United States: Illinois, Indiana, Iowa, Michigan, Minnesota, Ohio, and Wisconsin.

Effects of Ethanol (E85) versus Gasoline Vehicles on Cancer and Mortality in the United States

Source:

Jacobson, Mark Z.. 2007. Effects of ethanol (E85) versus gasoline vehicles on cancer and mortality in the United States. *Environmental Science Technology*. 41 (11): 4150-4157.

Document Main Point/Goal

This document examines the cancer risk and ozone-related health consequences of large-scale conversion from gasoline to ethanol.

Document Primary Argument and Conclusion

The base-case emission scenario, which accounted for projected improvements in gasoline and E85 vehicle emission controls, found that:

- E85 (85% ethanol fuel, 15% gasoline) may increase ozone-related mortality, hospitalization, and asthma by about 9% in Los Angeles and 4% in the United States as a whole relative to 100% gasoline usage.
- Ozone increases in Los Angeles and the Northeast United States are partially offset by decreases in the Southeast United States.
- E85 also increased peroxyacetyl nitrate (PAN) in the U.S. but was estimated to cause little change in cancer risk.
- Due to its ozone effects, future E85 may be a greater overall public health risk than gasoline.
- Unburned ethanol emissions from E85 may result in a global-scale source of acetaldehyde larger than that of direct emissions.

Notable Points Regarding Data that Bear on the Author's Conclusion

The study relies on a complex global-through-urban air pollution/weather forecast model that is combined with high-resolution future emission inventories, population data, and health effects data to examine the effect of converting from gasoline to E85 on cancer, mortality, and hospitalization in the United States as a whole and Los Angeles in particular.

The study author states that because of the uncertainty in future emission regulations, it can be concluded with confidence only that E85 is unlikely to improve air quality over future gasoline vehicles. Because both gasoline and E85 emission controls are likely to improve, it is unclear whether one could provide significantly more emission reduction than the other. Future and currently unknown emissions regulations that are specifically designed to address air chemistry changes that result from combustion of biofuels could affect these results.

Emissions from 4 Different Light Duty Vehicle Technologies Operating on Low Blend Ethanol Gasoline. Report 04-27 A: Tailpipe Greenhouse Gases (CO_2, CH_4, N_20)

Source:

Baas, Cara and Lisa Graham. 2004. *Emissions from 4 different light duty vehicle technologies operating on low blend ethanol gasoline. Report 04-27: Tailpipe Greenhouse Gases (CO_2, CH_4, N_2O).* Ottawa, Ontario, Canada. Environmental Technology Centre, Emissions Research and Measurement Division, Environment Canada.

Document Main Point/Goal

This document seeks to identify and quantify the emissions impact of ethanol blended fuels on tailpipe and evaporative emissions.

Document Primary Argument and Conclusion

This document concludes that:

- For all vehicles and test temperatures, distance-based CO_2 emission rates were essentially unchanged as ethanol content increased. The effect from the lower energy density of the ethanol blend fuels cancelled out the effect from the lower carbon content per liter of ethanol blend fuel burned.
- In general, increasing ethanol content did not result in any significant changes to CH_4 emission rates. Ethanol blend fuels may reduce CH_4 emissions from 20°C operation with Tier 1 vehicle technology, however there is not enough data to confidently support this theory.
- For all vehicles and test temperatures, the N_2O emission rates from the E0 fuel are not statistically different than those from the ethanol blend fuels.

Notable Points Regarding Data that Bear on the Author's Conclusion

The analysis relies on tests made on the following vehicles that were built to meet specified emissions standards:

Vehicle	Emissions Standard that Vehicle Meets
1998 Ford Escort	US EPA Tier I
2001 Nissan Sentra	California SULEV
2003 Dodge Caravan	US EPA LEV
2000 Mitsubishi Dion	Japanese LEV (vehicle unavailable in North America)

Emissions from 4 Different Light Duty Vehicle Technologies Operating on Low Blend Ethanol Gasoline. Report B: Tailpipe Regulated and Unregulated Gaseous Emissions (CO, NO_x, THC, NMHC, NMOG, Ethanol, Carbonyls, VOC)

Source:

Baas, Cara and Lisa Graham. 2004. *Emissions from 4 different light duty vehicle technologies operating on low blend ethanol gasoline: report B tailpipe regulated and unregulated gaseous emissions (CO, NO_x, THC, NMHC, NMOG, Ethanol, Carbonyls, VO)*. Ottawa, Ontario, Canada. Environmental Technology Centre, Emissions Research and Measurement Division, Environment Canada.

Document Main Point/Goal

This document discusses emissions from low level ethanol fuel blends, with a focus on CO, NO_x, THC, NMHC, NMOG, Ethanol, Carbonyls and VOC.

Document Primary Argument and Conclusion

This document concludes that:

- Observed differences in emission rates were primarily found on the driving cycle that involved cold engine start. The cycles that involved warm engine start and aggressive driving occasionally saw emissions differences.

- Cold temperature operation mainly affected the emission rates in the driving cycle that involved cold engine start. Cold temperature operation rarely affected emission rates after the vehicles had warmed up to operating temperature.

- Increasing fuel ethanol content resulted in a decrease in CO emissions for all vehicle technologies during cold engine start and aggressive driving conditions. This decrease in CO occurred at both 20°C and -10°C operation, but was not always statistically significant

- Increasing fuel ethanol content resulted in an increase in NO_x emissions for all vehicle technologies, particularly during engine start (both cold and warm) and aggressive driving conditions. This effect was stronger at cold operating temperatures, but was not always statistically significant. An exception to this trend was the NO_X emissions from the SULEV vehicle at 20°C operation, which did not appear to be affected by fuel ethanol content.

- Ethanol emissions increased with increasing fuel ethanol content for all vehicle technology. Ethanol emissions were highest for cold engine start; once the vehicles were running at operating temperature ethanol emissions were very low or undetectable. Operation at cold temperature resulted in higher ethanol emission rates as compared to operation at standard temperature.

- The presence of ethanol in the fuel increased the formaldehyde emissions for all vehicle technologies during cold engine start and aggressive driving conditions. These increases were not always statistically significant.

- The presence of ethanol in the fuel increased the acetaldehyde emissions for all vehicle technologies during cold engine start and aggressive driving conditions. These increases were statistically significant for the cold engine start driving cycles but not always statistically significant for the aggressive driving cycles.

- The VOC profiles were very similar among the four fuels for a given vehicle and were typical of a mixture of combustion gases and unburned fuel. The target compounds present were due to the gasoline content of the fuel and decreased with increasing fuel ethanol content.

Notable Points Regarding Data that Bear on the Author's Conclusion

The analysis relies on tests made on the following vehicles that were built to meet specified emissions standards:

Vehicle	Emissions Standard that Vehicle Meets
1998 Ford Escort	US EPA Tier I
2001 Nissan Sentra	California SULEV
2003 Dodge Caravan	US EPA LEV
2000 Mitsubishi Dion	Japanese LEV (vehicle unavailable in N. America

Energy ad Emission Benefits of Alternative Transportation Liquid Fuels Derived from Switchgrass: A Fuel Life Cycle Assessment.

Source:

Wu, May, Ye Wu and Michael Wang. 2006. Energy and emission benefits of alternative transportation liquid fuels derived from switchgrass: a fuel cycle assessment. *Biotechnology*. 22: 1012-1024.

Document Main Point/Goal

This document provides a well-to-wheels analysis to assess the energy and emissions benefits of cellulosic biomass in the US between 2015 and 2030.

Document Primary Argument and Conclusion

The document concludes that cellulosic biofuels blended with gasoline as E85:

- Offer substantial savings in petroleum (66-93%) and fossil energy (65-88%) consumption on a per-mile basis.
- Decreased fossil fuel use translates to 82-87% reductions in greenhouse gas emissions across all unblended cellulosic biofuels.
- Although most earlier studies indicated that producing biofuels could double NO_x emissions compared to conventional petroleum fuels, this study indicates that through reducing use of nitrogen fertilizer in the production stage and use of high efficiency combined cycle gas turbines in the process stage, NOx emissions could be less than expected – increasing by between 27 and 36 percent.
- In urban areas the study shows, for each of the biofuel production options examined, net reductions for almost all criteria pollutants, with the exception of carbon monoxide (unchanged) and VOCs, which may increase in certain processes.
- Conventional and hybrid electric vehicles, when fueled with E85, could reduce total sulfur oxide (SO_x) emissions to 39-43% of those generated by vehicles fueled with gasoline.
- By using bio-diesel in place of diesel, SO*x* emissions are reduced to 46-58% of those generated by diesel-fueled vehicles.
- This study suggests that, for process energy, integrated heat and power co-generation by means of gas turbine combined cycle is a crucial factor in attaining energy savings and emission reductions.

Notable Points Regarding Data that Bear on the Author's Conclusion

The analysis relies on the Greenhouse gases, Regulated Emissions, and Energy use in Transportation (*GREET*) model developed at Argonne National Laboratory. Analysis of biofuel production was based in part on ASPEN Plus model simulation.

Energy and Environmental Aspects of Using Corn Stover for Fuel Ethanol

Source:

Sheehan, John, Andy Aden, Keith Paustian, Kendrick Killian, John Brenner, Marie Walsh, and Richard Nelson. 2004. Energy and Environmental Aspects of Using Corn Stover for Fuel Ethanol. *Journal of Industrial Ecology*. 7 (3-4): 117.

Document Main Point/Goal

This document describes the results of a life-cycle model that the authors developed to predict the energy and environmental impacts of using corn stover to produce ethanol in the United States.

Document Primary Argument and Conclusion

The document concludes that an E85 vehicle generally reduces fossil energy use and greenhouse gas emissions, while air quality impacts are mixed. Specifically:

- For the portion of each kilometer driven on ethanol in an E85 vehicle, that vehicle uses 95 percent less petroleum than the same vehicle driven on gasoline.
- Greenhouse gas emissions (CO_2, N_2O) and CH_4) are 113 percent lower.
- Total fossil energy use (coal, oil and natural gas) is 102 percent lower.
- Emissions of CO, NO_x and SO_x increase while emissions of hydrocarbon ozone precursors decrease.
- Soil organic matter, an important indicator of soil health, drops slightly in the early years of stover collection but remains stable over the 90-year time frame studied.

Notable Points Regarding Data That Bear on the Author's Conclusion

The model accounts for soil carbon dynamics, soil erosion, agronomics of stover collection and transport and bioconversion of stover to ethanol. Because of limitations on data, the model focuses on an assumed situation in which all farmers in Iowa switch from their current cropping and tilling practices to continuous production of corn and "no-till" practices.

Energy Use and Emissions from the Lifecycle of Diesel-Like Fuels Derived from Biomass

Source:

Delucchi, Mark and Timothy Lipman. 2003. *Energy use and emissions from the lifecycle of diesel-like fuels derived from biomass: An appendix to the report "A lifecycle emissions model (LEM): lifecycle emissions from the transportation fuels, motor vehicles, transportation modes, electricity use, heating and cooking fuels, and materials*. Davis, California. Institute of Transportation Studies, University of California Davis.

Document Main Point/Goal

This document seeks to quantify life cycle emissions reductions from biodiesel.

Document Primary Argument and Conclusion

This document concludes that:

In general, and in the absence of engine and catalyst system modification:

- NO_x emissions increase on a linear basis with increasing blends of biodiesel up to a 40 percent blend.
- CO and HC emissions are also reduced through the use of biodiesel in unmodified engines.
- Hydrocarbon emissions reductions are typically on the order of 14-22 percent with 20 percent biodiesel blends.
- Sulfur dioxide emissions decrease by 40 percent
- CO_2 emissions are apparently not substantially affected through the use of biodiesel, but modest increases have been observed with 10 percent and 40 percent blends.
- While most studies have focused on relatively modest blends of biodiesel, at least one study has been conducted on emissions from the use of pure biodiesel. This study, conducted at the University of Idaho with rape methyl ester produced at the university, arrived at the following conclusions with regard to the comparison between 100 percent biodiesel and 100 percent low sulfur diesel:
    - HC emissions fell by 52.4 percent
    - CO emissions fell by 47.6 percent
    - NOx emissions fell by 10 percent
    - PM increased by 9.9 percent.

- These results suggest that PM emissions are reduced with relatively low percentages of biodiesel but increase as the percentage of biodiesel exceeds 20 percent, and increase to the point where they exceed emissions from pure low sulfur diesel with biodiesel contents of 50 percent or greater.

Notable Points Regarding Data that Bear on the Author's Conclusion

The analysis relies on a model developed at UC Davis known as the LEM model. This model serves as the basis for the Canadian GHGenius life cycle emissions model.

Environmental and Economic Evaluation of Bioenergy in Ontario, Canada

Source:

Zhang, Yimin, Siva Habibi and Heather L. MacLean. 2006. Environmental and economic evaluation of bioenergy in Ontario, Canada. *Journal of Air &Waste Management Association*. 57: 919-933.

Document Main Point/Goal

This document presents the results of an environmental and economic analysis of using Canadian-produced biomass in both the transportation and electricity sectors in Ontario, Canada.

Document Primary Argument and Conclusion

This study concludes that implementing a biomass co firing rate of 10 percent in existing coal-fired power plants would reduce annual GHG emissions by 2.3 million metric tons of CO_2 equivalent, or seven percent of the province's coal power plant emissions.

The substitution of gasoline with an ethanol gasoline blend would reduce annual provincial light duty vehicle fleet emissions by between 1.3 and 2.5 million tons of equivalent CO_2, or 3.5 to 7 percent of fleet emissions.

If biomass sources other than agricultural residues were used, additional emissions reductions could be realized.

At $70 crude oil prices, the biomass electricity co firing scenario ($22 per ton of CO_2 equivalent) is more cost effective for mitigating GHG emissions than the stand-alone ethanol production scenario ($92/ton of CO_2 equivalent).

Notable Points Regarding Data that Bear on the Author's Conclusion

The analysis focuses on life cycle GHG emissions and economics in Ontario, Canada. While the methodology could be applied to other geographic areas, the results may or may not be directly applicable to these other regions.

Environmental Aspects of Ethanol Derived from No-tilled Corn Grain: Nonrenewable Energy Consumption and Greenhouse Gas Emissions

Source:

Kim, Seungdo, Bruce E. Dale. 2005. Environmental aspects of ethanol derived from no-tilled corn grain: nonrenewable energy consumption and greenhouse gas emissions.. *Biomass and Energy*. 28: 475-489.

Document Main Point/Goal

This document seeks to define the energy consumption and greenhouse gas emissions effect of the ethanol that is derived from no-till corn production practices.

Document Primary Argument and Conclusion

The document concludes that:

- Using ethanol (E85) fuel in a midsize passenger vehicle can reduce greenhouse gas emissions by 41–61% km driven, compared to gasoline-fueled vehicles. Using ethanol as a vehicle fuel, therefore, has the potential to reduce nonrenewable energy consumption and greenhouse gas emissions.

- The document also concludes that the net energy balance for ethanol is positive; the energy requirement to produce on kilogram of ethanol is 13.4-21.5 megajoules (the variation depends here on the corn milling technologies used) and the energy content of a kilogram of ethanol is 26.8 megajoules.

Notable Points Regarding Data that Bear on the Author's Conclusion

The analysis of GHG relies on a model developed for the purpose of estimating GHG emissions known as DAYCENT.

Environmental Implications of Municipal Solid Waste-Derived Ethanol

Source:

Kalogo, Youssouf, Shiva Habibi, Heather L. MacLean and Satich V. Joshi. 2007. Environmental implications of municipal solid waste-derived ethanol. *Environmental science & Technology*. 41:1.

Document Main Point/Goal

This document provides the results of the authors' modeling of a municipal solid waste (MSW)-to-ethanol facility that employs dilute acid hydrolysis and gravity pressure vessel technology and estimates life cycle energy use and air emissions.

Document Primary Argument and Conclusion

This document concludes that:

- For E85 vehicles, life cycle total energy use per vehicle mile traveled for MSW ethanol is less than that of corn-ethanol and cellulosic-ethanol; and energy use from petroleum sources for MSW ethanol is lower than for the other fuels.
- MSW ethanol use in vehicles reduces net greenhouse gas emission by 65 percent compared to gasoline and by 58% when compared to corn ethanol.
- However, landfilling with landfill gas recovery either for flaring or for electricity production, results in greater reductions in GHG emissions compared to MSW to ethanol conversion.

Notable Points Regarding Data that Bear on the Author's Conclusion

The analysis relies on a modeled MSW facility with specific ethanol production technologies; results may differ with different production technologies.

Ethanol Can Contribute to Energy and Environmental Goals

Source:

Farrell, Alexander E., Richard J. Plevin, Brian T. Turner, Andrew D. Jones, Michael O'Hare, Daniel M. Kammen. 2006. Ethanol can contribute to energy and environmental goals. *Science*. 311 (27): 506-508.

Document Main Point/Goal

The document seeks to define both the net energy balance and CO_2 emissions effects of ethanol on a life cycle basis.

Document Primary Argument and Conclusion

The article makes the following conclusions:

- Studies that show a net negative energy balance and increases in CO_2 emissions tend to rely on old data for corn yield and also ignore the value of co-products such as dried distiller grains or corn gluten feed that are by products of ethanol production.

- The article estimates that corn ethanol reduces petroleum usage by about 95 percent on an energy basis and reduces greenhouse gas emissions by about 13 percent. Current data indicate that only cellulosic ethanol production will yield large greenhouse gas emissions reductions.

- The major contributors to life cycle greenhouse gas emissions are agricultural practices (34% to 44%) and petroleum inputs (45% to 80%).

- The environmental performance of ethanol varies greatly depending on production processes.

- Several key issues remain unquantified such as soil erosion and the conversion of forest to agriculture. The environmental effects of cellulosic ethanol require further study.

Notable Points Regarding Data that Bear on the Author's Conclusion

This document is based on a detailed analysis of the assumptions of six other studies that address net energy and environmental aspects of ethanol. The article seeks to normalize for different units and system boundaries across these studies, as well as assessing the validity of the assumptions for these studies.

Ethanol Fuels: Energy Balance, Economics, and Environmental Impacts are Negative

Source:

Pimental, David. Ethanol fuels: energy balance, economics, and environmental impacts are negative. 2003. *Natural Resources Research*. 12 2: 127-135.

Document Main Point/Goal

This document seeks to define the energy balance from ethanol production as well as the environmental effect of ethanol fuel.

Document Primary Argument and Conclusion

This document argues that:

- Ethanol production increases environmental degradation.
- Corn production causes more total soil erosion than any other crop. Also, corn production uses more insecticides, herbicides, and nitrogen fertilizers than any other crop.
- All these factors degrade the agricultural and natural environment and contribute to water pollution and air pollution.
- Increasing the cost of food and diverting human food resources to costly, inefficient production of ethanol fuel raises major ethical questions.
- The author concludes that the environmental degradation that results from life cycle ethanol production and use would add 23 cents/gallon to the price of ethanol.

Notable Points Regarding Data that Bear on the Author's Conclusion

The analysis relies on specific assumptions and data for crop production, energy use, fertilizer use, irrigation needs and irrigation energy consumption, and emissions impacts from biofuels production.

Ethanol GHG Emissions Using GHGenius An Update

Source:

(S&T)2 Consultants Inc. for Natural Resources Canada. 2005. *Ethanol GHG emissions using GHGenius an update*. http://www.ghgenius.ca (accessed October 20, 2007).

Document Main Point/Goal

This document presents the results of a lifecycle emissions analysis of several ethanol production pathways in Canada. It presents results for E10 produced from corn and wheat, with and without carbon capture in the production process. It also presents emissions results for cellulosic ethanol production from wheat straw and switchgrass, with and without carbon capture.

Document Primary Argument and Conclusion

This document concludes that life cycle greenhouse gas emissions for an E10 mix are lower for cellulosic ethanol than for grain-based ethanol production.

Specifically, greenhouse gas emissions for an E10 ethanol blend compared to gasoline are:

- 4.6 percent lower for corn-based ethanol with carbon capture
- 4.2 percent lower for corn-based ethanol without carbon capture
- 4.4 for wheat-based ethanol E10 blends with carbon capture
- 3.9 percent for wheat-based ethanol with carbon capture
- 6.2 percent lower for wheat straw-based ethanol with carbon capture
- 5.8 percent lower for wheat straw-based ethanol without carbon capture
- 6.4 percent lower for switchgrass-based ethanol with carbon capture
- 6.0 percent lower for switchgrass-based ethanol without carbon capture

This document presents the results of one of the first significant revisions to the data input into the GHGenius model since its beginning in1999. The revisions to the data inputs illustrate a number of the important variables that bear on a life cycle analysis of greenhouse gas emissions from ethanol production. Specifically:

- The energy requirements for new ethanol plants fell significantly between 1999 and 2005. This reduction in energy use has meant that the ethanol production process releases a smaller quantity of greenhouse gas.

- Ethanol production plants produce a very concentrated stream of carbon dioxide which can be captured and liquefied for use in a variety of industrial applications.

- Cellulosic ethanol plants produce co-products including fertilizers and soil conditioners.

- Distillers dried grains (DDG) is a co-product of biofuel production that can be fed to dairy and beef cattle. Evidence since 1999 shows that cattle that consume DDG have lower levels of flatulence – thus reducing total methane emissions.

Notable Points Regarding Data that Bear on the Author's Conclusion

The analysis relies on Natural Resources Canada's GHGenius life cycle emissions model. This model was developed in 1999 has been continually refined since that point. It is capable of estimating life cycle emissions of the primary greenhouse gases and the criteria pollutants from combustion sources.

Ethanol's Energy Return on Investment: A Survey of the Literature 1990-Present

Source:

Hammerschlag, Roel. 2006. Ethanol's Energy Return on Investment: A Survey of the Literature 1990-Present. *Environmental Science and Technology*. American Chemical Society. 40: 1744-1750.

Document Main Point/Goal

This document surveys the literature related to the net energy balance for ethanol. It relates this net energy balance question to the environmental effects of ethanol production and consumption.

Document Primary Argument and Conclusion

This document makes the following conclusions related to future analysis of environmental impacts of biofuels, as well as relationships between net energy balance and emissions of greenhouse gasses:

- The quantity of CO_2 emitted is roughly proportional to the energy content of gasoline or ethanol. This means that an analysis must focus on the energy balance – defined in this case as the energy "return on investment" or proportion of energy input to produce a given level of energy output. An energy return on investment that is greater than about 0.76 (the value of the energy balance for gasoline)indicates that the manufacture of ethanol, when used to displace gasoline, will result in a net reduction of CO_2 emissions.

- Some no-till agricultural processes sequester carbon in soil.

- All agriculture induces both methane and nitrous oxide emissions, both of which are greenhouse gases. As a result, a study of energy balance must be supplemented with an inventory of all three gasses (carbon dioxide, methane and nitrous oxide).

Notable Points Regarding Data that Bear on the Author's Conclusion

This literature survey is primarily focused on the question of ethanol net energy balance, but addresses carbon emissions and land use impacts as well.

Full Fuel Cycle Assessment: Well-to-Wheels Energy Inputs, Emissions, and Water Impacts

Source:

Pont, Jennifer of TIAX, LLC. 2007. *Full fuel cycle assessment: well-to-wheels energy inputs, emissions, and water impacts*. California Energy Commission. Sacramento, California.

Document Main Point/Goal

This document seeks to define the environmental impacts of various alternative fuels that could be used to meet new California standards for reductions of greenhouse gas emissions from vehicles.

Document Primary Argument and Conclusion

This document concludes that:

- Greenhouse gas emissions from biofuels production and use depend on agricultural inputs, allocation to byproducts, and the level and carbon intensity of process energy inputs.

- The GHG emissions from biofuels production and use depend on many other factors. In particular, land use change assumptions can significantly impact GHG emissions for biofuel based pathways. Land use impacts require further study. The present analysis provides only the vehicle emissions and WTT process inputs employed. Emissions impacts associated with changes in land use will be addressed in future updates to the full fuel cycle assessment. Land use issues associated with a modest growth in U.S. based energy crops are likely to be somewhat insignificant because energy crops are likely to replace other crops rather than expand agricultural areas. To the extent that this assumption holds true, the impact of differing agricultural land uses represents a small portion of the WTW impact. Land use impacts associated with biofuels sources outside the U.S. also require further study.

- Some fuel blends such as biodiesel and Fischer Tropsch (FT) diesel result in a decrease in criteria pollutant emissions in today's vehicles. The California Air Resource Board and others are examining the effect on future vehicles. It is not clear whether the new engines will be optimized to reduce emissions below standards or for fuel economy.

- Emissions from marine vessel and rail transport are the dominant source of fuel/feedstock delivery emissions in California. Agricultural equipment is also a significant source of emissions for biofuels. For the assumed transportation distances in California, delivery emissions from fuels transported by rail are comparable to those imported by tanker ship on a WTW basis.

- For midsize autos: Biofuels provide large reductions (~75 percent compared to gasoline) depending on processing intensity because CO2 emissions are recycled through plant photosynthesis.

- For urban buses: A 30 percent renewable diesel blend yields approximately 20 percent reduction while a 20 percent biodiesel blend provides approximately 12 percent reduction.

- For midsize autos, alternative fuel pathways result in criteria pollutant emissions comparable to gasoline pathways. Specifically, California cellulosic ethanol production and use increase NO_x and PM emissions slightly, with the impact decreasing over time.

Notable Points Regarding Data that Bear on the Author's Conclusion

The analysis relies the GREET model designed by Argonne National Laboratory.

Health Canada Ethanol Expert Panel Workshop Report

Source:

Health Canada. 2003. Health Canada ethanol expert panel workshop report. Health Canada. Ottawa. http://www.hc-sc.gc.ca/ewh-semt/air/out-ext/effe/ethanol/index_e.html (accessed November, 2007).

Document Main Point/Goal

This document summarizes the results of a workshop that Health Canada held in May of 2003. The purpose of the workshop was to consider the potential human health impact of possible future widespread use of ethanol.

Document Primary Argument and Conclusion

This workshop concluded that the use of ethanol in gasoline increases emissions of some pollutants and reduces others. Specifically:

- Based on the current state of knowledge in this field, it can be concluded that the use of E10 would result in a 5-15% reduction of CO; an increase or a near-neutral effect for NO_2 emissions; a fairly neutral effect for ozone in smog events; small increases in aldehydes during smog events; possibly large increases in longer-term average aldehyde (e.g., acetaldehyde) levels; small increases in longer-term average levels of peroxyacetyl nitrate; and a small effect on benzene emission levels, dependent on fuel formulation.

- Additional analyses are needed to estimate ambient exposure to ethanol and its atmospheric breakdown products, including constituents such as acetaldehyde, to assess the potential public health impacts of increased ethanol use. In addition, evaluations should consider sensitive subpopulations.

- The case for ethanol as a reducer of regulated and non-regulated exhaust emissions is becoming weaker as the vehicle stock changes and new vehicles take a larger share of the market. By 2010 it is expected that any benefits will probably be minor. With respect to evaporative emissions, emissions of some compounds are higher with ethanol use. There is a need to recognize that these emissions will be even higher with non-tailored ethanol blends, and our technologies to handle these emissions may not be as effective as currently assumed.
    - *Caveats*: There is an agreement that the case for ethanol as a producer of emission reduction benefits is declining. The assumptions made about vehicle stock turnover will affect how quickly this decline will occur. It is important to also consider non-road vehicles, however, as larger benefits might be possible in this area.
    - A second caveat is that the results depend on such factors as temperature, vehicle age, etc. Trends can be shown, but we must also consider modelling some aspects.

- Mixing E10 and conventional transportation fuels (commingling) will have real impacts for the consumer in terms of fuel efficiency and vehicle drivability. These impacts need to be better understood and publicized.

- It is important to consider microenvironments in assessing exposure to ethanol-related emissions. In cases where ambient levels are low and not considered problematic (e.g., ethanol), microenvironments are critical. In other cases (e.g., formaldehyde, acetaldehyde) ambient levels are also important because of the toxicity of the emissions. Different microenvironments will be important for different emissions. Some to consider include: refueling, pedestrian, parking garages, indoor air, and shower/bath.

- There is potential for concern about the effect of ethanol on the general population and on specific sensitive populations such as pregnant women, ALDH deficient individuals, and people taking medication that block ethanol oxidation at the acetaldehyde stage (e.g., disulfiram, used to treat alcoholics). Lack of data on the impacts of ethanol inhalation makes it impossible to provide a definitive answer, but there is a possibility that we need to consider sensitive subpopulations. When addressing some of the broader questions the extent to which this is a high-priority area in filling knowledge gaps is a key consideration.

- Regarding the potential increase in level and breadth of the population exposure to E10 vehicle emissions and the potential risk, the government should be concerned about emissions of acetaldehyde, formaldehyde, peroxyacetyl nitrates (PANs), and ethanol from E10 use. This concern relates only to microenvironments in some cases, and to microenvironments and the ambient environment in others.

- In order to specify potential risks and/or benefits and significant areas of uncertainty, Health Canada should conduct a risk assessment (due diligence) of E10 with particular attention to acetaldehyde, formaldehyde, PANs, and ethanol. This effort should be staged -- moving from inventories to modelling to exposure to toxicology. It is likely, however, that all stages will need to be completed. The only area where fundamentally new research is needed is on the toxicology of ethanol inhalation, and particular attention should be paid to factors (e.g., vapor pressure, or RVP) that can influence emissions of these four chemicals.

Notable Points Regarding Data that Bear on the Author's Conclusion

This report provides a summary of a workshop involving many participants and experts in the field. The report describes these presentations, which were typically summaries of other studies on the topic in existence as of 2003.

Impact of Biodiesel Fuels on Air Quality and Human Health: Summary Report September 16, 1999-January 31, 2003

Source:

Morris, R.E., A.K. Pollack, G.E. Mansell, C. Lindhjem, and G. Wilson. 2003. *Impact of Biodiesel Fuels on Air Quality and Human Health: Summary Report September 16, 1999-January 31, 2003*. Golden, CO. NREL/SR-540-33793. National Renewable Energy Laboratory.

Document Main Point/Goal

This document seeks to define the effects of biodiesel fuel use on air quality.

Document Primary Argument and Conclusion

The document concludes that:

- The use of biodiesel fuel with the Heavy Duty Diesel Vehicle fleet is estimated to cause a very small change (<1%) in all ozone precursor emissions.
- The use of biodiesel is estimated to have no measurable adverse impact on 1-hour or 8-hour ozone attainment in Southern California and the Eastern United States.
- The use of biodiesel is estimated to reduce the peak CO concentrations as well as CO concentrations throughout the Las Vegas area. However, these reductions are extremely small, ranging from 0.01 to 0.03 ppm (< 0.2%).
- The maximum increases and decreases in PM2.5 and PM10 mass concentrations are extremely small. The 100% B20 biodiesel fuel scenario is estimated to reduce exposure to annual and 24- hour emissions limitation exceedances of the U.S. EPA's PM10 standard by 4% and 7%, respectively. The results for the 50% B20 penetration are approximately half those of the 100% B20 penetration scenario.
- The use of a B20 fuel in the Heavy Duty Diesel Vehicle fleet is estimated to reduce the per million risk of premature death due to exposure to air toxics in the Southern California Air Basin by approximately 2% and 5% for the 50% and 100% Heavy Duty Diesel Vehicle fleet penetration B20 scenarios, respectively.

Notable Points Regarding Data That Bear on the Author's Conclusion

The study employed inventory and air quality modeling to analyze the impacts of biodiesel use in the on-road heavy-duty diesel vehicle (HDDV) fleet on:

- Ambient ozone concentrations in the U.S. Northeast Corridor, Lake Michigan and the South Coast (Los Angeles) Air Basin (SoCAB) regions;
- Carbon monoxide (CO) in Las Vegas, Nevada;
- Particulate matter (PM) in the SoCAB; and
- Air toxics, risk, and human health in the SoCAB.

Integrated Carbon Analysis of Forest Management Practices and Wood Substitution

Source:

Eriksson, Erik, Andrew R. Gillespie, Leif Gustavsson, Ola Langvall, Mats Olsson, Roger Sathre, and John Stendahl. 2007. Integrated carbon analysis of forest management practices and wood substitution. *Canadian Journal of Forest Research*. 37(3): 671-681.

Document Main Point/Goal

This document seeks to explain the net carbon emissions that result from alternative forest management strategies and product uses. Biofuels figure among the set of alternative uses for forest products. Other alternatives included the use of forest products as construction material.

Document Primary Argument and Conclusion

The authors conclude that:

- The greatest reduction of net carbon emission occurred when the forest was fertilized, slash and stumps were harvested, wood was used as construction material, and the reference fossil fuel was coal.
- The lowest reduction occurred with a traditional forest management, forest residues retained on site, and harvested biomass used as biofuel to replace natural gas.
- Product use had the greatest impact on net carbon emission, whereas forest management regime, reference fossil fuel, and forest residue usage as biofuel were less significant.

Notable Points Regarding Data That Bear on the Author's Conclusion

The analysis relies on simulations made using three Norway spruce forest management regimes (traditional, intensive management, and intensive fertilization), three slash management practices (no removal, removal, and removal with stumps), two forest product uses (construction material and biofuel), and two reference fossil fuels (coal and natural gas).

Investigating the Sustainability of Lignocellulose-derived Fuels for Light-Duty Vehicles

Source:

Fleming, Jesse S., Shiva Habibi, Heather L. MacLean. 2006. Investigating the sustainability of lignocellulose-derived fuels for light-duty vehicles. *Science Direct*, Elsevier. Transportation Research Part D. 146-159.

Document Main Point/Goal

The paper compares selected life cycle-based (well-to-wheel) studies of fuel/propulsion alternatives for light-duty vehicles with a focus on lignocellulose-derived fuels (hydrogen, Fischer Tropsch liquids, and ethanol).

Document Primary Argument and Conclusion

This document reviews a number of well-to-wheels studies of lignocellulosic ethanol. Of the studies analyzed, all report that these fuel/vehicle options hold the potential for significant reductions in non-renewable energy use and GHG emissions compared to gasoline/diesel fuelled LDVs. This document concludes the following:

- Well-to-wheel GHG emissions were on average 96%, 91% and 86% lower for lignocellulose-derived hydrogen, Fischer Tropsch liquids, and ethanol vehicles, respectively, as compared to the reference gasoline pathway.
- Even though the WTW rankings of each study are generally consistent in terms of which pathways are the most energy and GHG emissions intensive, data for these emerging biofuel pathways are limited and there are significant uncertainties in the results of the studies examined.
- A number of key issues were identified as impacting biofuel study results. These include assumptions regarding propulsion system e□ciency, feed- stock characteristics, land use changes and associated carbon sequestration, N2O emissions due to agricultural practices, co-product credits and allocation, energy accounting practices, and expected progress on commercial-scale fuel production processes and associated infrastructure. In addition, other environmental, as well as economic and social issues surrounding biofuels should be examined.
- Further research, development and deployment of biofuel technologies will facilitate enhanced well to wheels analysis, supporting the life cycle perspective needed to inform decision making on light duty vehicles.

Notable Points Regarding Data that Bear on the Author's Conclusion

The document provides a useful analysis and summary of trends from multiple well-to-wheels studies.

Lifecycle Analyses of Biofuels

Source:

Delucchi, Mark A. 2006. *Lifecycle analyses of biofuels* (draft manuscript). Institute of Transportation Studies, University of California, Davis.

Document Main Point/Goal

This document describes life cycle emissions from seven biofuel pathways using corn, soybeans, switchgrass and wood. It tracks carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_20), carbon monoxide (CO), Nitrogen oxides (NO_x), nonmethane organic compounds (NMOCs), Sulfur dioxide (SO_2), particulate matter (PM), chlorofluorocarbons (CFC-12), hydrofluorcarbons (HFC-134a) and the CO_2 equivalent of all the pollutants listed above.

Document Primary Argument and Conclusion

This document presents detailed results of life cycle emissions analysis of the pollutants listed above and discusses weaknesses and strengths of life cycle greenhouse gas analyses. It also presents, in table format, the basic assumptions used in the major life cycle assessments. The author bases his conclusions about emissions on the Life Cycle Emissions Model (LEM) which he developed along with colleagues.

The author compares his own emissions results to other models.

Source	Ethanol from corn	Ethanol from cellulose	Biodiesel from soy
Other Models	-50% to -10%	-100% to -40%	-80% to -40%
LEM Model	-30% to +20%	-80% to -40%	0% to +100%

The LEM model generally estimates higher lifecycle greenhouse gas emissions from biofuel pathways than do other studies. According to the author, the main reasons for this difference have to do with different treatment of the nitrogen cycle, land use changes, CO_2 equivalency factors, and co-products.

Notable Points Regarding Data that Bear on the Author's Conclusion

The analysis relies on a life cycle emissions model developed by the author. Notably, the Canadian GHGenius model explicitly credits DeLucchi's LEM model as the basis from which the GHGenius model was developed.

Life Cycle Assessment of Net Greenhouse-Gas Flux for Bioenergy Cropping

Source:

Adler, Paul. , Delgrosso, S.J., Parton, W.J. Lifecycle Assessment of Net Greenhouse-Gas Flux for Bioenergy Cropping Systems. 2007. Ecological Applications. 17(3). 675-691

Document Main Point/Goal

The objective of the study was to assess the net greenhouse gas (GHG) emissions of bioenergy cropping systems (corn, soybeans, alfalfa, switchgrass, and hybrid poplar) in Pennsylvania for inclusion in a full Carbon cycle analysis using the DAYCENT model.

Document Primary Argument and Conclusion

This document concludes that:

- The largest source of reduction in GHGs with biofuel production came from fossil fuels that could now be replaced by use of biofuel. Carbon storage in the soil was the second largest source of GHG reduction.
- The greatest source of GHGs was nitrous oxide fluxes from the soil, followed by fossil fuel use for farm machinery and production of nitrogen fertilizer.
- When displacement of fossil fuel was not considered in the analysis and carbon storage in the soil was assumed to have reached its maximum capacity, switchgrass and hybrid poplar were the only cropping systems to remain a sink for GHGs.
- Use of switchgrass and hybrid poplar for production of biofuels has the potential to be GHG neutral and may reduce GHGs.

Notable Points Regarding Data that Bear on the Author's Conclusion

Although crops with higher soil carbon inputs, such as switchgrass and hybrid poplar, will have higher equilibrium soil carbon levels, the document notes that the change in system carbon will approach zero in the long term.

Life Cycle Assessment of Switchgrass- and Corn Stover-Derived Ethanol Fueled Automobiles

Source:

Spatari, Sabrina, Yimin Zhang and Heather L. MacLean. 2005. Life cycle assessment of switchgrass- and corn stover-derived ethanol fueled automobiles. *Environmental science and technology. 39: 24.*

Document Main Point/Goal

This document presents the results of a life cycle analysis of the use of ethanol in vehicles in Ontario, Canada. The analysis looks at two time frames: one near-term (2010) which examines converting a dedicated energy crop (switchgrass) and an agricultural residue (corn stover) to ethanol; and one mid-term (2020) which assumes technological improvements in switchgrass-derived ethanol life cycle.

Document Primary Argument and Conclusion

This document concludes that:

- In the near term (2010) analysis, GHG emissions are 57 percent lower for an E85 vehicle using ethanol derived from switchgrass and 65 percent lower for ethanol from corn stover.
- Corn stover ethanol exhibits slightly lower life cycle GHG emissions, primarily due to sharing emissions with grain production.
- Project emissions in 2020 could by 25 to 35 percent lower than those in 2010 due to projected improvements in crop and ethanol yields. In this mid term scenario, even with anticipated improvements in reformulated gasoline automobiles, E85 automobiles could still achieve up to 70 percent lower GHG emissions across the life cycle.

Notable Points Regarding Data that Bear on the Author's Conclusion

The analysis relies on assumptions that it acknowledges may be uncertain about both energy crops and agricultural residues, since neither is currently being utilized for commercial ethanol production. It also relies on assumptions about commercial scale ethanol production from these feedstocks, since several technology breakthroughs are required to attain the conversion efficiencies assumed in this study.

Life Cycle Assessment of Various Cropping Systems Utilized for Producing Biofuels: Bioethanol and Biodiesel

Source:

Kim, Seungdo and Bruce E. Dale. 2005. Life cycle assessment of various cropping systems utilized for producing biofuels: bioethanol and biodiesel. *Biomass and Bioenergy*. Elsevier. 29: 426-439.

Document Main Point/Goal

This document describes the results of a life cycle assessment of different cropping systems emphasizing corn and soybean production, assuming that biomass from the cropping systems is utilized for producing biofuels (i.e., ethanol and biodiesel).

Document Primary Argument and Conclusion

This document concludes that:

- The benefits of corn stover removal are:

  (1) lower nitrogen related environmental burdens from the soil;
  (2) higher ethanol production rate per unit arable land, and
  (3) energy recovery from lignin-rich fermentation residues.

- The disadvantages of corn stover removal are

  (1) a lower accumulation rate of soil organic carbon and
  (2) higher fuel consumption in harvesting corn stover.

- Planting winter cover crops can compensate for some disadvantages (i.e., soil organic carbon levels and soil erosion) of removing corn stover. Cover crops also permit more corn stover to be harvested. Thus, utilization of corn stover and winter cover crops can improve the eco-efficiency of the cropping systems.

- When biomass from the cropping systems is utilized for biofuel production, all the cropping systems studied here offer environmental benefits in terms of nonrenewable energy consumption and global warming impact. Therefore utilizing biomass for biofuels would save nonrenewable energy, and reduce greenhouse gases.

- Unless additional measures such as planting cover crops were taken, utilization of biomass for biofuels would also tend to increase acidification and eutrophication, primarily because large nitrogen (and phosphorus)-related environmental burdens are released from the soil during cultivation.

Notable Points Regarding Data that Bear on the Author's Conclusion

Nonrenewable energy consumption, global warming impact, acidification and eutrophication are considered as potential environmental impacts and estimated by characterization factors provided by the United States Environmental Protection Agency.

Life-cycle Energy and Greenhouse Gas Emission Impacts of Different Corn Ethanol Plant Types

Source:

Wang, Michael, May Wu and Hong Huo. 2007. Life-cycle energy and greenhouse gas emission impacts of different corn ethanol plant types. *Environmental Research Letters*. United Kingdom. Vol. 2.

Document Main Point/Goal

This document seeks to measure the difference in greenhouse gas emissions from the use of different fuels as a process fuel to produce ethanol. This has become particularly important in recent years because although almost all ethanol plants currently use natural gas as a process fuel, rising natural prices are driving producers to investigate other fuels such as coal or wood chips.

Document Primary Argument and Conclusion

The authors found that these ethanol plant types can have distinctly different energy and greenhouse gas emission effects on a full fuel-cycle basis. In particular, greenhouse gas emission impacts can vary significantly—from a 3% increase if coal is the process fuel to a 52% reduction if wood chips are used.

The results show that, in order to achieve energy and greenhouse gas emission benefits, researchers need to closely examine and differentiate among the types of plants used to produce corn ethanol so that corn ethanol production would move towards a more sustainable path.

Notable Points Regarding Data that Bear on the Author's Conclusion

This paper examined nine corn ethanol plant types—categorized according to the type of process fuels employed, use of combined heat and power, and production of wet distiller grains and solubles.

Net Energy of Cellulosic Ethanol from Switchgrass

Source:

Schmer, M. R. et al. Net energy of cellulosic ethanol from switchgrass. 2008. PNAS. Vol 105: 464-469.

Document Main Point/Goal

This document measured net energy impacts of cellulosic ethanol from switchgrass and provided estimated greenhouse gas emissions from switchgrass-based ethanol.

Perennial herbaceous plants such as switchgrass (Panicum virgatum L.) are being evaluated as cellulosic bioenergy crops. Two major concerns have been the net energy efficiency and economic feasibility of switchgrass and similar crops. All previous energy analyses have been based on data from research plots (<5 m2) and estimated inputs. This study managed switchgrass as a biomass energy crop in field trials of 3–9 ha (1 ha = 10,000 m2) on marginal cropland on 10 farms across a wide precipitation and temperature gradient in the midcontinental U.S. to determine net energy and economic costs based on known farm inputs and harvested yields.

Document Primary Argument and Conclusion

This report summarized the agricultural energy input costs, biomass yield, estimated ethanol output, greenhouse gas emissions, and net energy results. Annual biomass yields of established fields averaged 5.2 -11.1 Mg·ha–1 with a resulting average estimated net energy yield (NEY) of 60 GJ·ha–1·y–1.

Switchgrass produced 540% more renewable than nonrenewable energy consumed. Switchgrass monocultures managed for high yield produced 93% more biomass yield and an equivalent estimated NEY than previous estimates from human-made prairies that received low agricultural inputs.

Estimated average greenhouse gas (GHG) emissions from cellulosic ethanol derived from switchgrass were 94% lower than estimated GHG from gasoline.

Notable Points Regarding Data that Bear on the Author's Conclusion

The authors point out that this is a baseline study that represents the genetic material and agronomic technology available for switchgrass production in 2000 and 2001, when the fields were planted. Improved genetics and agronomics may further enhance energy sustainability and biofuel yield of switchgrass.

Potenciales y Viabilidad del Uso de Bioetanol y Biodiesel para el Transporte en Mexico

Source:

Secretaria de Energia (SENER). 2006. Mexico *Potenciales y Viabilidad del Uso de Bioetanol y Biodiesel para el Transporte en Mexico*. Secretaria de Energia.

Document Main Point/Goal

This document describes many issues related to ethanol and biodiesel in Mexico, with a chapter focused on ethanol and on biodiesel sustainability issues.

Document Primary Argument and Conclusion

This document posits the following conclusions about environmental impacts and concerns:

- The use of stillage (a waste product from the ethanol production process) for fertilizer must be a priority however it needs suitable planning and specific legislation to avoid water contamination.
- For sugar cane, the trend toward green cane harvesting will mitigate the environmental impacts of sugar cane burning. Green cane harvesting involves cutting the cane green while allowing the leafy tops of the cane stalks to fall to the ground to act as a protective blanket for the soil. The cane tops act as an organic mulch, reducing the level of soil erosion and preserve soil nutrition for crop growth. Green cane harvesting also helps to prevent weed germination, reducing the need for herbicides.
- Ethanol-gasoline blends lead to reductions in emissions of CO, HC, toxics and to lower particulate matter emissions. Aldehyde emissions are well below allowed limits and the increase in NO_x emissions is very small.
- Ethanol-gasoline blends are relatively harmless for groundwater and surface water.
- ETBE may present environmental problems that are similar to those that arose from MTBE.

Water Quality and Supply Issues

- Water scarcity in several regions in Mexico will lead to limitations on the potential area for energy crop cultivation. Among the oil crops, sunflower, soy bean and rape seed have relatively high water needs. Jatropha with comparatively high oil yields, may be grown successfully without irrigation in many semi-arid humid regions. Palm oil, as another high yielding crop, can only be cultivated in southern humid regions of Mexico where there should be no conflict with other water uses.

- The use of agrochemicals (i.e. fertilizers, pesticides) can result in water contamination. Biomass processing facilities e.g. palm oil mills could cause significant discharges of organically contaminated waste water.

- Water use for irrigation must be controlled, using whenever possible rainfed production. Irrigation efficiency must be improved.

Ethanol Emissions

- The study uses base data from Brazil and the United States to present potential reductions in greenhouse gas emissions from ethanol production and use in Mexico. The study concludes that potential greenhouse gas emissions reductions are:

    - For sugar cane-based ethanol, emissions reductions ranging from 1.96 to 2.79 kg of CO_2 equivalent per liter of anhydrous ethanol with a likely emissions reduction of 2.72 kg of CO_2 equivalent per liter of anhydrous ethanol.
    - For corn-based ethanol emissions reductions of approximately 1.0 kg of CO_2 equivalent per liter of anhydrous ethanol.
    - For sugar beet-based ethanol emissions reductions of approximately 1.4 kg of CO_2 equivalent per liter of anhydrous ethanol.
    - For sweet sorghum-based ethanol emissions reductions of approximately 2.1 kg of CO_2 equivalent per liter of anhydrous ethanol.
    - For wheat-based ethanol emissions reductions of approximately 1.0 kg of CO_2 equivalent per liter of anhydrous ethanol.

- For cassava-based ethanol emissions reductions of almost zero kg of CO_2 equivalent per liter of anhydrous ethanol. Actual results will depend heavily on the greenhouse gas emissions of the fossil fuels used in the ethanol processing plant.

Biodiesel Emissions

- Projections show that biodiesel emissions could decrease by an average of 100 grams of CO2 equivalent per kilometer driven, or more. Again, the projected emissions reduction depends on the feedstock. Specifically:

    - Soy-based biodiesel emissions are projected to reduce emissions by 60 grams of CO2 equivalent per kilometer driven.
    - Rape seeds biodiesel emissions are projected to reduce emissions by 80 grams of CO2 equivalent per kilometer driven.
    - Palm oil biodiesel emissions are projected to reduce emissions by 120 grams of CO2 equivalent per kilometer driven.

- The document cites tests in Mexico of emissions from B100 and B20 formulations of virgin soy bean oil and waste vegetable oil. All formulations show a very similar picture with reduction in CO emissions of 70 to 90 percent, reductions in total hydrocarbons of 20 percent and a slight decrease in NO_x emissions.

Notable Points Regarding Data that Bear on the Author's Conclusion

The analysis relies on experience and studies from other countries and regions including Brazil, European countries, the United States and South Africa to project results for Mexico. With the exception of the results for CO, NO_x and total hydrocarbons, the data presented in the report is the result of studies in those countries and is not specific to Mexico.

Quantifying Cradle-to-Farm Gate Life-Cycle Impacts Associated with Fertilizer Used for Corn, Soybean, and Stover Production

Source:

Powers, Susan E. 2005. *Quantifying cradle-to-farm gate life-cycle impacts associated with fertilizer used for corn, soybean, and stover production*. Golden, Colorado. National Renewable Energy Laboratory. Technical Report NREL/TP-510-37500.

Document Main Point/Goal

This document addresses the life cycle impacts of nitrogen and phosphate fertilizers. This is important because use of these fertilizers may increase as total biofuel crop production increases. These fertilizers can leach out of soils and into waterways, causing eutrophication of those waterways. Currently a large portion of the Gulf of Mexico is oxygen-starved as a result of nitrogen-induced eutrophication that results from nitrogen runoff down the Mississippi River.

Document Primary Argument and Conclusion

This document examines and makes conclusions based on three scenarios:

1. A corn-soybean crop rotation with conventional tilling practices and no corn stover collection (the base case).

    - The results of this analysis show that it already exceeds acceptable limits for eutrophication potential as well as for water quality.

2. A corn-soybean crop rotation with no till agriculture practices and stover collection at the maximum rate allowable with acceptable erosion levels.

    - Changing the current corn-soybean rotation to also harvest stover for biofuel production increases the eutrophication potential. With the assumptions used in this analysis, the corn-soybean stover scenario results in a 21 percent increase in eutrophication potential.

    - It is likely that careful management of fertilizers used at the farm could help to limit nutrient leaching.

    - This scenario reduces global warming potential relative to the base case (a decrease of 3 percent) and has essentially no impact on acidification. The reduction in global warming potential is related to the reduced level of soil mineralization with no till agriculture practices and the resulting reduction in N_2O emissions.

3. A corn-corn crop rotation with no till and with stover collection at a maximum rate allowable with acceptable erosion levels.

    - The corn-corn rotation almost tripled the total nitrogen and phosphate load over the base case.

- With the very high nitrogen demand in a corn-corn system, it is not likely that fertilizer management practices could be sufficient to overcome the detrimental effects of eutrophication resulting from the high leaching rates.

- The higher nitrogen use in this scenario also increases the use of fossil fuels for fertilizer production and associated emissions of species contributing to acid rain and global warming potentials. The increase in acidification potential (6 percent over the base case) is attributed to increases in no production in soils with increased nitrogen fertilizer use and increased NO_x from fossil fuel consumed to generate the increased energy necessary for fertilizer manufacture. Increases in global warming potential (71 percent over the base case, not including benefits of carbon sequestered in soil or crop) are attributed to methane emissions from natural gas used in nitrogen fertilizer manufacture.

Notable Points Regarding Data that Bear on the Author's Conclusion

The analysis relies on a life cycle assessment model that, among other characteristics, allocated total nutrient loads to either corn or soybean production. Estimates of how much of the nutrient loads should be allocated to corn varied from 60 to 99 percent of the total. This uncertainty is difficult to incorporate into the model.

Regulatory Impact Analysis: Renewable Fuel Standard Program

Source:

United States Environmental Protection Agency. 2007. Washington, DC. *Regulatory Impact Analysis Renewable Fuel Standard Program.*

Document Main Point/Goal

This document seeks to define the environmental impact of the U.S. renewable fuel standard program. This analysis focuses on emissions in the year 2012, when the full 7.5 billion gallon annual renewable fuel standard will be in place in the United States.

Document Primary Argument and Conclusion

This broad and comprehensive document characterizes the changes to motor vehicle fuel required under the renewable fuel standard program; the impact on emissions from vehicles, nonroad equipment and fuel production facilities; air quality impacts; lifecycle impacts on fossil energy and greenhouse gases, and; estimated costs of renewable fuels, gasoline and diesel agriculture sector impacts.

Its primary conclusions related to air quality and emissions are as follows:

- Biofuel use will increase dramatically in some areas but not in other areas. As a result a national air model is not appropriate to measure the impacts of biofuels.
- Small increases in ozone levels are likely to increase because of increases in both VOC and NO_x emissions. However there is uncertainty as to the effect of increased VOC emissions for two reasons:
    - VOC reactivity decreases with greater ethanol content in the VOCs themselves. As a result, the VOCs will likely produce less ozone than they might if they were the result of gasoline combustion.
    - The counties that the study projects will have the biggest increase in biofuel use are also those that currently have ambient ozone concentrations that are well below the ozone standard.
- It appears that a net reduction in particulate matter will result from increased ethanol use. EPA specifies that this result should be considered a rough comparison at this time.
- EPA estimates that an E10 blend will reduce emissions of CO, although specific emissions reductions will vary depending on the vehicle tested. EPA assumes that vehicles that meet EPA Tier I emissions standards will have a reduction in CO emissions of 6.7 percent.
- Studies reveal that ethanol increases the rate of permeation of hydrocarbons through plastic fuel tanks and elastomers used in fuel line connections, as well as

permeating ethanol itself. As a result, EPA has added the effect of non-exhaust VOC emissions in assessing the effect of gasoline-ethanol blends.

- Increased ethanol blending will significantly reduce gasoline aromatic content. This could cause a corresponding reduction in the aromatic fraction of exhaust VOC emissions relative to non-oxygenated conventional gasoline. In addition, ethanol also reduces total exhaust VOC emissions from older vehicles and may do so from newer vehicles.

- With the increased use of E85 (which is inherently a low-sulfur fuel) emissions should be neutral or better than operation on E0 or E10 fuel blends for CO and NO_x. Non-methane organic gas (NMOG) emissions may be higher primarily due to emissions of unburned ethanol at cold starts, while running NMOG emissions are lower with E85, based on certification data.

- Greenhouse gas emissions will decrease as a result of the renewable fuels standard in the United States, according to this EPA analysis. Specifically:

    - CO_2 emissions will decrease by 0.52 percent of US transport sector emissions and 0.17 percent of total nationwide greenhouse gas emissions.

    - Lifecycle emissions of CH_4 and N_20 are higher for renewable fuels than for the conventional fuels they displace. As a result, when accounting for all of these three major greenhouse gases, life cycle emissions still decrease, but by a smaller amount: 0.36 percent of total US transport sector emissions and 0.11 percent of total nationwide greenhouse gas emissions.

Notable Points Regarding Data that Bear on the Author's Conclusion

The analysis is useful for screening purposes in order to give a directional idea of emissions and air quality changes as a result of an increase in the use and production biofuels. This study does not present the results of, for example, a full-scale photochemical ozone modeling effort.

Sensitivity Analysis of GHG Emissions from Biofuels in Canada

Source:

(S&T)2 Consultants Inc. for Natural Resources Canada. 2005. *Sensitivity analysis of GHG emissions from biofuels in Canada*. http://www.ghgenius.ca (accessed October 20, 2007).

Document Main Point/Goal

This document presents the results of a lifecycle emissions analysis of ethanol and biodiesel in Canada. It further analyses the life cycle greenhouse gas emissions effect of the choice of process fuel and of co-products from biofuel production.

Document Primary Argument and Conclusion

This document concludes that all four of the ethanol production pathways studied – corn, wheat, wheat straw and sugar cane – provide a significant reduction in greenhouse gas emissions compared to low sulfur gasoline.

Specifically, greenhouse gas emissions for an E10 ethanol blend compared to gasoline are:

- 4.1 percent lower for corn-based ethanol
- 3.9 percent lower for wheat-based ethanol
- 6.3 percent lower for wheat straw-based ethanol
- 5.9 percent lower for sugar cane-based ethanol

Only a very small portion of the life cycle greenhouse gas emissions from these feedstocks is related to non-CO_2 gases.

- This document also presents data from a 5 percent biodiesel blend. It concluded that total emissions reductions from a B5 biodiesel blend ranged from 2.8 to 4.8 percent depending on the feedstock. Specifically, emissions reductions compared to a 100 diesel blend are as follows, by feedstock:
  - Canola: 3.2%
  - Soy: 2.8%
  - Palm 3.4%
  - Tallow 4.7%
  - Yellow Grease 4.8%

  Tallow and yellow grease (kitchen grease) perform best because there are no feedstock production emissions associated with the production of these waste feedstocks because any emissions are attributed to the original, primary application of the material.

This study also examined the impact of other variables on greenhouse gas emissions as follows:

Effect of Process Fuel Choice

- For biofuel production processes that use fossil fuels, the amount and choice of fossil fuel used in the ethanol production process has a significant impact on total greenhouse gas emissions. Ethanol production plants that use coal for their process energy still reduce total greenhouse gas emissions compared to gasoline, but they produce 25 to 30 percent higher greenhouse gas emissions than those that use natural gas for their process energy.

- The choice of biofuel is less important for biofuel production processes that use bioenergy for the plant process energy requirements. The greenhouse gas emissions benefits are greater in bioenergy-fueled ethanol plants than in ethanol plants fueled by natural gas. This is the case even accounting for the additional greenhouse gas emissions that might arise from the need to transport the feedstock fuel between farmers' fields and the ethanol processing facility, and after considering the effect of replacing the nutrients removed from the soil as a result of combusting biomass.

- The lifecycle greenhouse gas emissions benefits from scenarios that use bioenergy as a process fuel approach the benefits of cellulosic ethanol.

- Greenhouse gas emissions benefits increase if the ethanol plant can use waste heat from another nearby facility.

Impact of Alternative Crop Production Processes

- No-till or reduced-till crop production processes combined with the practice of adding nutrients to the soil (through manure or other means) significantly reduce life cycle greenhouse gas emissions, bringing them close to the level of cellulosic ethanol. These measures cannot be sustained forever because after approximately 20 years the soil reaches a point at which any measures to add carbon to the soil will not be effective.

Effect of Long-distance Transport of Feedstock Fuels

- Transporting biodiesel longer distances than the base case between farmers' fields and the biodiesel processing plant has a very small impact on lifecycle greenhouse gas emissions because longer distances involve a modal shift from trucks to rail; the emissions intensity of rail is approximately 25 percent that of truck freight.

Effect of Co-Products

- The effect of co-products on life cycle greenhouse gas emissions is complex. Specifically:
    - Grain ethanol plants produce a high protein product known as distillers dried grains, and carbon dioxide from the fermentation process. In most cases, the distillers dried grains are assumed to be used as animal feed and the carbon dioxide vented to the atmosphere. Alternative uses of the distillers dried grains can

reduce life cycle greenhouse gas emissions.

- In most, but not all, cases the biodiesel production process produces a protein meal as a co-product. In some cases the production process produces glycerin and fertilizer as co-products.
- Greenhouse gas emissions vary according to the use of the co-product.
  - The greatest emissions benefit comes from using protein meal to displace direct thermal applications. The next greatest emissions benefit comes from using protein meal as animal feed. The next greatest emissions benefit comes from using the protein meal to generate electric power, if a power plant would otherwise use an efficient combined cycle natural gas plant to generate the power.
  - Glycerin production as a co-product of biodiesel may reduce greenhouse gas emissions, but the emissions benefit depends on how much energy it takes during the production process to extract the glycerin.

Notable Points Regarding Data that Bear on the Author's Conclusion

The analysis relies on Natural Resources Canada's GHGenius life cycle emissions model. This model was developed in 1999 has been continually refined since that point. It is capable of estimating life cycle emissions of the primary greenhouse gases and the criteria pollutants from combustion sources.

The Addition of Ethanol from Wheat to GHGenius

Source:

(S&T)2 Consultants Inc. for Natural Resources Canada. 2007. *The addition of sugar beet to ethanol pathway in GHGenius*. . http://www.ghgenius.ca (accessed October 20, 2007).

Document Main Point/Goal

This document presents the results of a lifecycle energy and emissions analysis of a wheat to ethanol pathway to produce ethanol in Canada. It compares the life cycle greenhouse gas emissions from gasoline to the use of wheat Manitoba and Saskatchewan-produced wheat for ethanol production to the use of Ontario corn to produce ethanol.

Document Primary Argument and Conclusion

This document concludes that life cycle greenhouse gas emissions depend on where the ethanol and ethanol feedstock is produced. Ethanol produced in Manitoba, with its high proportion of hydro electricity, results in a larger reduction in greenhouse gas emissions than ethanol produced from corn in Ontario. But, because of the electric generation fuel mix in Saskatchewan, if the wheat ethanol is produced in Saskatchewan then the greenhouse gas emissions are higher than they are for Ontario-produced corn ethanol. Specifically, greenhouse gas emissions for ethanol compared to gasoline are:

- 4.8 percent lower for Ontario corn-based E10 blends
- 4.3 percent lower for Saskatchewan wheat corn-based E10 blends
- 5.0 percent lower for Manitoba wheat corn-based E10 blends

Notable Points Regarding Data that Bear on the Author's Conclusion

The analysis relies on Natural Resources Canada's GHGenius life cycle emissions model. This model was developed in 1999 has been continually refined since that point. It is capable of estimating life cycle emissions of the primary greenhouse gases and the criteria pollutants from combustion sources.

The Addition of Sugar Beet to Ethanol Pathway in GHGenius

Source:

(S&T)2 Consultants Inc. for Natural Resources Canada. 2007. The addition of sugar beet to ethanol pathway in GHGenius. . http://www.ghgenius.ca (accessed October 20, 2007).

Document Main Point/Goal

This document presents the results of a lifecycle energy and emissions analysis of a sugar beet to ethanol pathway to produce ethanol in Canada. It compares the use of sugar beets to produce ethanol to the use of corn or wheat to produce ethanol.

Document Primary Argument and Conclusion

This document concludes that greenhouse gas emissions are lower than they are for gasoline but somewhat higher than they are for either ethanol from corn or ethanol from wheat. Specifically, for E10 (a 10% ethanol blend in gasoline) life cycle greenhouse gas emissions were 2.6 percent lower for sugar beet-based ethanol, 4.3 percent lower for wheat-based ethanol and 4.4 percent lower for corn-based ethanol.

This is the case because sugar beet transportation and processing requirements are higher than either corn or wheat as a result of the higher moisture content in sugar beets. Sugar beets are heavier to transport as a result of their higher moisture content per unit of energy that they contain.

Notable Points Regarding Data that Bear on the Author's Conclusion

The analysis relies on Natural Resources Canada's GHGenius life cycle emissions model. This model was developed in 1999 has been continually refined since that point. It is capable of estimating life cycle emissions of the primary greenhouse gases and the criteria pollutants from combustion sources.

Ethanol is not currently produced from sugar beets in Canada, although there have been proposals to build sugar beet to ethanol plants in Prince Edward Island, Ontario and Quebec. As a result the model cannot rely on an established sugar beet to ethanol processing scheme. The authors relied on a conservative set of assumptions as far as the process efficiency of the ethanol plant while investigating sensitivities to a more efficient production process.

Water Implications of Biofuels Production in the United States

Source:

National Academies of Science. 2007. *Water Implications of Biofuels Production in the United States*. The National Academies. Washington, DC.

Document Main Point/Goal

This document seeks to identify the key water quality and supply issues that arise with a significant expansion of biofuel production, as well as opportunities for shaping policies to help protect water resources.

Document Primary Argument and Conclusion

This document presents several key conclusions:

Each biofuel feedstock presents unique implications for water resources, so any analysis of water quality and supply must examine the issue on a feedstock by feedstock basis.

The implications for water resources are regional in nature. Corn generally uses less water than soybeans in the Pacific and Mountain regions, but the reverse is true in the Northern and Southern Plains. Therefore farmers switching from soybeans to corn will need more water in some regions and less in others. The report divides its discussion into the following categories:

Irrigation

Expansion of agriculture into dry western areas has the potential to dramatically affect water availability. In the next five to ten years, increased agricultural production for biofuels will probably not alter the national–aggregate view of water use. However there are likely to be significant regional and local impacts where water resources are already stressed. Depending on what crops are grown, where the crops are grown, and whether there is an increase in overall agricultural production, significant acceleration of biofuels production could cause much greater water quantity problems than are currently experienced.

Water Use in Biorefineries

The amount of water used in the biorefining process is modest compared to the water used to grow bioenergy crops. However because water use in biorefineries is concentrated into a smaller area, the effects of such facilities can be substantial locally. A biorefinery that produces 100 million gallons of ethanol per year would use the equivalent of the water supply for a town of 5,000 people. Ethanol producers are incorporating water recycling and use reduction measures into their plants.

Water Quality Issues

Among the various potential biofuel crops, corn requires the greatest amount of nitrogen and phosphorous fertilizer per unit of net energy captured in the biofuel. Nitrogen that washes off farmers' fields into bodies of water causes water quality problems; excess nitrogen washing into the Mississippi River is known to cause an oxygen-starved "dead zone" in the Gulf of Mexico. However, there are many management practices that can improve the efficiency of fertilizer application and reduce the need for fertilizer applications.

Soil Erosion and Sedimentation

Sedimentation occurs when soil erodes from land and washes down into surface water bodies. Sediments impair water quality and also carry agricultural and other pollutants. The amount of sediment eroding from agricultural areas is directly related to land use – the more intensive the land use the greater the erosion.

Producing biofuels from perennial crops that hold soil and nutrients in place and require lower fertilizer and pesticide inputs, like switchgrass or poplars is an option to reduce the effects of sedimentation. There are, however, large uncertainties surrounding the production of cellulosic ethanol from such crops. Such crops have very little history of use in large-scale cultivation, so even basic information on water, nitrogen or herbicide use, or impact on soil erosion or even overall yields is preliminary.

Reducing Impacts through Agricultural Practices

Many agricultural practices could simultaneously increase crop yields while reducing impacts on water resources. These include efficient irrigation, erosion-prevention, fertilizer efficiency or no till agriculture techniques.

Policy Options

Future policy options that could help to reduce impact on water supply and quality include:

- Incentives for efficient water use and recycling in ethanol production and processing.
- Policies to encourage best agricultural practices such as soil nutrient management or to reduce soil erosion.
- Policies to encourage production of biofuels from cellulosic feedstocks.

Notable Points Regarding Data that Bear on the Author's Conclusion

The analysis is the result of a colloquium of experts held to facilitate discussion among representatives from federal and state government, non-governmental organizations, academia and industry. The report relies on the outcome of this colloquium, written submissions from participants, peer-reviewed literature and the professional judgments of the authors of this report.

Water Usage for Current and Future Ethanol Production

Source:

Aden, Andy (National Renewable Energy Laboratory). 2007. Water usage for current and future ethanol production. *Southwest Hydrology* September/October 2007: 22-23.

Document Main Point/Goal

The article seek to explain water used for ethanol production for both corn and cellulose-based techniques. The article compares this water usage to water usage in petroleum production.

Document Primary Argument and Conclusion

Water usage is a significant issue in the U.S. for the ethanol industry in part because U.S. ethanol production will increase from 5 billion gallons in 2006 to 11 billion gallons of capacity by 2009. The article makes the following major points.

Water Use in Corn Production:

- As much as 96 percent of field corn used for ethanol production is not irrigated. For the field corn used for ethanol production that is irrigated, water use is approximately 785 gallons of water for each gallon of ethanol produced.

Water Use in Corn Ethanol Production

- 3-4 gallons of water are used per gallon of ethanol produced using dry grind production process (prevalent in 80 percent of U.S. ethanol production facilities)

- 1.9 to 6 gallons of water are used per gallon of ethanol produced from cellulosic material.

- 2 to 2.5 gallons of water are used per gallon of gasoline produced.

Several technical methods to reduce water consumption are under investigation at the National Renewable Energy Laboratory.

Notable Points Regarding Data that Bear on the Author's Conclusion

None noted for this short summary article.

Well-to Wheels Analysis of Advanced Fuel/Vehicle Systems – A North American Study of Energy Use, Greenhouse Gas Emissions and Criteria Pollutant Emissions

Source:

Brinkman, Norman, Michael Wang, Trudy Weber, Thomas Darlington. 2005. *Well-to-wheels analysis of advanced fuel/vehicle systems – a North American study of energy use, greenhouse gas emissions and criteria pollutant emissions*. Argonne, IL, USA. Argonne National Laboratory.

Document Main Point/Goal

This document updates a prior well-to-wheels study from 2001. The goal of this effort was to analyze a both criteria and greenhouse gas emissions from a range of vehicle fuels, including biofuels. It focused on corn-based ethanol and on cellulosic ethanol.

Document Primary Argument and Conclusion

This document makes the following conclusions about biofuel emissions:

- Engines running on cellulosic ethanol shows a 70 percent reduction in greenhouse gas emissions compared with gasoline (the tank-to-wheels analysis). However including the well to tank analysis, total energy use, NO_x, VOC and PM_{10} emissions were higher than those emissions for gasoline. These increases all resulted from fuel production – farming operations and ethanol manufacture). Total energy losses and emissions associated with ethanol manufacture are higher than those associated with gasoline refining.

- Some of the vehicle technologies and fuels evaluated in the study offer moderate reductions in greenhouse gas emissions. Corn-based E85 vehicles achieve moderate, 20 to 30 percent, reductions in greenhouse gas emissions. The reduction achieved by using E85 is only moderate because (1) significant amounts of greenhouse gas emissions are generated during corn farming and in corn ethanol production plants; (2) diesel fuel, liquefied petroleum gas, and other fossil fuels are consumed during corn farming; (3) a large amount of nitrogen fertilizer is used for corn farming, and production of nitrogen fertilizer and its nitrification and denitrification in cornfields produce a large amount of greenhouse gas emissions; and (4) usually, natural gas or coal is used in corn ethanol plants to generate steam. If a renewable energy source, such as corn stover or cellulosic biomass, is used in corn ethanol production plants, use of corn-based E85 could result in large greenhouse gas emission reductions.

- Ethanol-based technology options result in increased total emissions for criteria pollutants, because large amounts of emissions occur during biomass farming and ethanol production. The study estimates total and urban emissions of criteria pollutants separately. Although total emissions are increased by the use of ethanol, a significant amount of the total emissions occurs outside of urban areas (on farms and in ethanol plants that will be located near biomass feedstock farms). While total emission results show the importance of controlling ethanol plant emissions, urban emission estimates show that the negative effects of biofuels (such as ethanol) on criteria pollutant emissions are not as severe as total emission results imply. These emissions are likely to be controlled in the future along with other stationary source emissions.

Notable Points Regarding Data that Bear on the Author's Conclusion

The analysis conducted its analysis in two parts: (1) an analysis of well-to-tank emissions, meaning emissions from the production of fuels and (2) an analysis of tank-to-wheels emissions, meaning emissions from operation of the vehicle on different fuel.

Wood to Ethanol and Synthetic Natural Gas Pathways

Source:

(S&T)2 Consultants Inc. for Natural Resources Canada. 2007. *Wood to Ethanol and Synthetic Natural Gas Pathways*. http://www.ghgenius.ca (accessed October 20, 2007).

Document Main Point/Goal

This document presents the results of a lifecycle emissions analysis for production of ethanol from wood.

Document Primary Argument and Conclusion

This document concludes that greenhouse gas emissions are not significantly different for a wood-to-ethanol pathway than they are for a corn-to-ethanol pathway. Specifically:

- For E10: A corn-to-ethanol pathway yields a 4.3 percent decrease in greenhouse gas emissions compared to gasoline. A wood residue-to-ethanol pathway yields a 4.0 percent greenhouse gas emissions decrease. A wood-to-ethanol pathway yields a 4.6 percent greenhouse gas emissions decrease.
- For E85: A corn-to-ethanol pathway yields a 41.5 percent decrease in greenhouse gas emissions compared to gasoline. A wood residue-to-ethanol pathway yields a 34.1 percent greenhouse gas emissions decrease. A wood-to-ethanol pathway yields a 44.5 percent greenhouse gas emissions decrease.
- The production process for wood-based ethanol requires use. This life cycle emissions analysis assumes that the enzymes are produced off site and transported to the ethanol production plant; this enzyme production and transportation accounts for greenhouse gas emissions that are not part of the corn-to-ethanol production process.

Notable Points Regarding Data that Bear on the Author's Conclusion

Data on wood-to-ethanol processes are sparse. This analysis relies on data developed by the US Department of Energy originally designed for a corn stover-to-ethanol process. The authors discussed this data with researchers at the University of British Columbia in order to assess its relevance to a Canadian wood-to-ethanol process, and determined that it was valid for this analysis.

APPENDIX

The analysis tools and research related to the environmental effects of liquid biofuels has developed over the past decade; researchers have improved their models and identified new and important nuances related to the effects of production, transportation, processing and combustion of biofuels affects the environment. This appendix lists the reports that are described in this annotated bibliography by time period: 2005-2008; 2000-2004; and Pre-2000.

2005-2008

2000-2004

Pre-2000