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Indiana Biofuels

Opportunity and Challenges

V600 Capstone

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V600 is an interdisciplinary course designed to give students exposure to the realities of the policy process through detailed analyses of case studies and projects. The course integrates science, technology, policy, and management. Dr. Clint Oster and Dr. J.C. Randolph instructed V600 Section 11068 in spring, 2008 and the following School of Public and Environmental Affairs' Master's candidates contributed to this study:

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Acronyms

AFS: Stoichiometric Air-Fuel Ratio
AQUIRP: Auto/Oil Air Quality Improvement Research Program
ARS: Agricultural Research Service
ASTM: American Society of Testing Materials
BEA: Bureau of Economic Analysis
BER: Biomass Energy Reserve Program
BIP: Biofuels Innovation Program
BMP: Best Management Practices
BP: British Petroleum
BTE: Brake Thermal Efficiency
BTEX: Benzene, Toluene, Ethylbenzene, and Xylene
Btu: British Thermal Unit
C-5: Five-Carbon Sugar
C-6: Six-Carbon Sugar (Glucose)
CBP: Consolidated Beioprocessing
CDS: Condensed Distillers' Solubles
CFEIS: Certification and Fuel Economy Information System
CFPP: Cold filter plug point
CGF: Corn Gluten Feed
CGM: Corn Gluten Meal
CHP: Combined Heat and Power
CO: Carbon Monoxide
CO2: Carbon Dioxide
CPI: Consumer Price Index
CRP: Conservation Reserve Program
CSXT: CSX Transportation
CTL: Coals-to-Liquid
DCGF: Dry Corn Gluten Feed
DDG: Distillers' Dried Grains
DDGS: Distillers' Dried Grains with Solubles
DDS: Distillers' Dried Solubles
DG: Distillers' Grains
DOE: Department of Energy
DS: Distillers' Solubles
DWG: Distillers' Wet Grains
EBI: Environmental Benefits Index
EERE: Office of Energy Efficiency and Renewable Energy
EIA: Energy Information Administration
EISA: Energy Independence and Security Act of 2007
EPA: Environmental Protection Agency
EPACT: Energy Policy Act of 2005
EQSC: Environmental Quality Service Council
ER: Energy Balance Ratio
ES/EF-B: Enzymatic Hydrolysis-Ethanol Fermentation Approach
ESCSPP: Energy Security and Climate Stewardship Platform Plan
ETBE: Ethyl Tert-Butyl Ether
FAO: Food and Agriculture Organization of the United Nations
FFV: Flex-Fuel Vehicle
FSA: Farm Service Agency
FT: Fischer-Tropsch
GAO: Government Accountability Office
GHG: Greenhouse Gases
GMC: Genetically Modified Crops
GPM: Gallons per Minute
GPY: Gallons per Year
GTL: Gas to Liquids
GWR: Gross Weight on Rail
HC: Hydrocarbons
HEC: Herbaceous Energy Crops
HHV: High Heating Value
IATA: International Air Transport Association
IEDC: Indiana Economic Development Corporation
INDOT: Indiana Department of Transportation
IPCC: Intergovernmental Panel on Climate Change
IPM: Integrated Pest Management
ISDA: Indiana State Department of Agriculture
ISEC: Indiana Sustainable Energy Commission
KHT: Kaldor Hicks Tableau
LHV: Low Heating Value
LIHD: Low-Input High-Density
LORRE: The Laboratory of Renewable Resources Engineering
MGTM/M: Millions of Gross Ton Miles per Mile
MGY: Million Gallons per Year
MJ/k: Mega-joules per Kilogram
MJ: Mega-joule
MTBE: Methyl Tert-Butyl Ether
MTOW: Maximum Take-Off Weight
NAFTA: North American Free Trade Agreement
NASS: National Agriculture Statistical Service
NEB: Net Energy Balance
NEVC: National Ethanol Vehicle Coalition
NFPA: National Fire Protection Agency
NOx: Nitrogen Oxides
NRCS: Natural Resources Conservation Service
NREL: National Renewable Energy Laboratory
NS: Norfolk Southern
OECD: Organization for Economic Cooperation and Development
OED: Indiana Office of Energy and Defense Development

OPEC: Organization of Petroleum Exporting Countries
ORD: Office of Rural Development
PADD: Petroleum Administration for Defense District
PAH: Polyaromatic Hydrocarbons
PM: Particulate Matter
ppm: parts per million
REMI: Regional Economic Modeling, Inc.
RFS: Renewable Fuel Standard
RIMS II: Regional Input-Output Modeling System
SARA: Superfund Amendments and Reauthorization Act
SEPTC: Small Ethanol Producer Tax Credit
SOC: Soil Organic Carbon
SOx: Sulfur Oxides
SRWC: Short-Rotation Woody Crops
SYNFUELS: Synthetic Fuels
TAME: Tertiary Amyl Methyl Ether
TSCA: Toxic Substances Control Act
UIUC: University of Illinois at Urbana-Champagne
USAF-AB: Air Force Advisory Board
USDA: United States Department of Agriculture
USGS: United States Geological Survey
VEETC: Volumetric Excise Tax Credit
VOC: Volatile Organic Compounds
WCGF: Wet Corn Gluten Feed
WVR: Weight-to-Value Ratio

Executive Summary

Biofuels are an important topic for current policy consideration as their use may diversify the US energy supply and improve air, soil, and water quality. As a key agricultural state, already equipped with multiple biodiesel and bioethanol plants, Indiana is uniquely positioned to take a leadership role in biofuels innovation.

This analysis examines Indiana's potential in the biofuels market over the next 20 years. It focuses on production of transportation fuels from agricultural products, and does not take into consideration the potential for biofuels extraction from animal or other waste products. Compatibility with current agricultural practices is another key consideration of the report. As such, the report focuses on corn ethanol, soy biodiesel, and cellulosic ethanol produced from corn stover and switchgrass. Several feedstocks are more efficient sources of biofuels, but the timeframe of the analysis precludes more in-depth consideration of these crops. The report looks at the lifecycle of biofuels in the state of Indiana and takes into consideration a variety of ecological, technological, social, and economic considerations. Suggested directions for continued research conclude this summary.

Policy Recommendations Regarding Biofuel Feedstock Selection:
<u>Transition Feedstocks</u>: Neither soy biodiesel nor corn ethanol is an efficient biofuel. Therefore, production should be transitioned away from these feedstocks to other, more sustainable, alternatives.

- Biodiesel: There is no clear best option feedstock for biodiesel production. However, the possibilities of using rapeseed following the European model should be considered in the long term.
- Bioethanol: Cellulosic feedstocks (plant material rather than seed material) for bioethanol are far more ecologically and economically sound than the current feedstock, corn. The most ideal crops in this regard are grasses such as *miscanthus* and switchgrass, and possibly some fast growing trees. However, aside from switchgrass, the technology does not yet exist to make these feedstocks feasible within the 20-year scope of this analysis. These crops would also require economic incentives to induce land-use shifts.
- Given current land use patterns, technological infrastructure, economic feasibility, and current legislative environment, the most strategic cellulosic feedstock is corn stover, a current by-product of corn agriculture. Corn stover can be grown, harvested, baled, and transported using current knowledge and technology. It is a good transition feedstock to future use of dedicated biomass crops as it allows farmers to continue growing corn while the technology for processing cellulosic ethanol develops and thus is less of an investment risk for farmers.

<u>Note on in-State Variation of Feedstocks</u>: Indiana has two distinct bio-regions due to differences in glaciations; thus different recommendations are presented for the north and the south of the state.

- Northern Indiana: Continued production of corn ethanol is inevitable, and corn stover collection is best suited to the flat croplands of northern Indiana. In the long term, we recommend that future research for fuel feedstocks in northern Indiana place a distinct

emphasis on more productive feedstocks. Research shows rapeseed and miscanthus may be the best feedstocks for biodiesel and ethanol respectively.
- Southern Indiana: Corn stover collection is recommended as means only of providing feedstock for cellulosic plants only until dedicated crops can reach full productivity. Since southern Indiana has a great deal of abandoned and reforested agricultural land and relatively poor soils, switchgrass is a more suitable biofuels crop, particularly as it offers one of the best input-output energy ratios (540 - 700% more energy produced than is used to turn it into fuel).

<u>Transition Biofuel Production</u>: Current methods of production for biodiesel and bioethanol are not optimal. Heading forward, Indiana should consider the following recommendations.

- Biodiesel: Rather than producing biodiesel with sub-efficient crops, Indiana should spearhead initiatives to standardize the quality of biodiesel blends. More importantly, this move will expand the market for biodiesel since a standardized fuel will encourage name-brand fuel corporations and engine manufacturers to approve its use.
- Bioethanol: The key barrier yet to be overcome for the use of cellulosic crops for biofuels is the lack of effective technology to convert these materials into fuel. Current conversion processes (thermo-chemical and bio-chemical by acid hydrolysis) do not make efficient use of biomass. However, the preferable process of bio-chemical conversion by enzymatic hydrolysis is still in its infancy. Though breakthrough in identifying cellulosic enzymes of key utility is expected by 2012, the current technological capacity to process cellulosic materials is limited.

<u>State Mediation of Transition</u>: In order to further promote the use of transition feedstocks and production processes discussed above, the State is encouraged to:

- Provide property tax exemptions for the first cellulosic ethanol plants.
- Consolidate efforts to promote ethanol-blend fuel use. Gas-biofuel blends up to E10 (10% ethanol) are compatible with existing spark-ignition engine technology and can be stored, transported, and delivered with current gasoline infrastructure. The use of higher percentages is only feasible in engines designed as “flex-fuel” or engines that have been modified. Promotion of blends greater than E10 will likely require state encouragement, such as tax credits for purchases and expansion in the availability of E85 pumps. For this reason, this report suggests the state focus on the promotion of E10.
- Work in tandem with the federal government on joint initiatives including: aggressive pursuit of research funding incentives for cellulosic ethanol; the creation of a federal-state pilot program to produce cost competitive corn stover ethanol in Indiana in 2-3 years; and utilization of Energy Frontier Research Centers and DOE awards to accelerate cellulosic breakthroughs.

Policy Recommendations to Optimize Broader Societal Impacts of Expanded Biofuel Production:

<u>Impacts on Employment</u>: The large-scale production of biofuels has the potential to create employment gains in Indiana. Some studies show that an ethanol plant will produce 19-22 direct, indirect, and induced jobs per million gallons per year of plant capacity. Though results vary greatly depending on the projection model used, all models project positive job creation, especially if:

- New ethanol production facilities are required to hire from the local labor pool.

- Small-scale/family farmers are protected to prevent job losses as economies of scale in the biofuel market will tend to favor larger growers.

Impacts on the Environment: It is important to take into account both the impact of agrochemicals on water and soil quality as well as the carbon sequestration lost when former fallow land, especially land currently in the Conservation Reserve Program (CRP), is brought into production to meet biofuel demand. These indirect land use changes may cause effects of such a significant magnitude that they negate any greenhouse gas reductions from ethanol consumption relative to fossil fuels. Therefore:

- The state should mandate riparian buffers along Indiana's waterways, and encourage planting switchgrass in these zones. This will decrease erosion and chemical runoff from agricultural fields and will serve as a biological bufferzone to maintain water purity. Further, if switchgrass is planted, it will eventually provide an additional revenue stream for farmers as a cellulosic feedstock.
- Indiana may want to consider state-level replacement assistance to encourage conservation of wetlands and grasslands that may lose CRP funding.
- Indiana should encourage farmers to implement best management practices that minimize the environmental footprint of their agricultural production.

Policy Recommendations to Optimize Future Preparedness for Indiana:

Though this report is framed in the context of the most up-to-date available data, the field of biofuels research is fast evolving and it is likely that some of the recommendations presented here will be superseded by future research results. For this reason it is vital that, in the interests of state preparedness, Indiana implement some forward-thinking policies. To this end we recommend the state:

- Support research and development efforts in the field, particularly as it relates to the development of enzymatic hydrolysis for cellulosic production. Research should also be supported for other alternative-fuel feedstocks such as animal or municipal wastes as well as lesser-studied crops such as short-rotation woody crops.
- Increase public education initiatives regarding biofuels

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1. Introduction

Energy is a hot topic these days. Rising oil prices and concerns about greenhouse gases and climate change spark daily debate and provide impetus to examine alternative energy sources. This has taken the world beyond fossil fuels and towards more environmentally friendly renewable fuels from sources such as solar, hydropower, geothermal, and wind. Biofuels represent one potential source in an ever-diversifying national energy portfolio. They have received increasing attention—both at the federal and state levels. Indiana, with its comparative advantage in corn and soybeans, is at the forefront of the biofuels push. Increasingly, corn ethanol and soy biodiesel are fueling the transportation sector just as new production facilities dot the Indiana landscape. Although it is easy to become excited at the opportunities biofuels present, it is nevertheless crucial to examine the implications of their production and use. What are the costs? Are biofuels really cleaner than fossil fuels? Are they more efficient? What will be the consequences for land use? How will the market and food prices react? Can biofuels really displace oil consumption? Does Indiana have the technology to make biofuels cost-competitive with oil? If not, what will it take to get there?

This report seeks to answer such questions and more. While there is, indeed, a future for biofuels in Indiana over the next 20 years, it is not as simple as growing more corn or soybeans. Certainly, these crops will play an important role in launching biofuels to the forefront of national exposure, but by relying solely on them, neither Indiana nor the US will be able to meet exploding domestic and world demand. Additionally, there are serious environmental and land use concerns. As such, this report explores the possibility of embracing first-generation biofuels—like corn ethanol and biodiesel—as a stepping stone to those of the second generation, which depend on advanced methods to make use of the non-seed, cellulosic components of crops.

Below, this report describes the current fuel situation and places biofuels in a global, national, and state context. Second, it highlights popular biofeedstocks and describes some lesser-known alternative crops, all the while discussing energy efficiencies, land use, and environmental best management practices. Third, the paper discusses production techniques for corn-based ethanol, biodiesel, and cellulosic ethanol. Fourth, it outlines engines technology and provides the outlook for certain biofuels blends and their compatibility with vehicles on the road today. Fifth, logistical considerations point to the most cost-effective and efficient methods of transporting and distributing biofuels across Indiana. Sixth, a site suitability analysis reveals premiere locations for potential cellulosic production plants. Seventh, a net energy balance description and illustrative cost-benefit analysis follow and provide additional economic considerations for decision makers. Finally, the report gives policy recommendations and describes the path forward for Indiana over the next 20 years.

2. The Current Situation

In the 2008 State of the Union Address, President George W. Bush stated that "our security, our prosperity, and our environment all require reducing our dependence on oil." [1] This message is also popular among presidential contenders. Republican candidate John McCain believes US "national security depends on energy security, which we cannot achieve if we remain dependent on imported oil from Middle Eastern governments who support or foment by their own inattention and inequities the rise of terrorists..." [2]. Democratic presidential candidates differ little from Republicans on the foreign energy dependence threat, but add more of a climate change twist. Barack Obama claims "our nation is confronted by two major energy challenges—global climate change and our dependence on foreign oil" [3]. Similarly, Hillary Clinton has plans to "reduce America's reliance on foreign oil and address the looming climate crisis" [4].

Despite this fashionable political rhetoric—which may be necessary in mobilizing public support for key changes in energy policy—it is important to identify the crux of the oil issue. Not until policy makers accurately define the problem can they successfully formulate solutions. So, is there any truth to foreign oil dependency? This section will highlight the competing sides to this debate, present the real threats to national security stemming from the oil market, and propose definitive policy alternatives for countering these threats.

2.1 The Energy Independence Debate

With calls to eliminate foreign oil imports and simultaneously decrease consumption, there is the unmistakable conviction in America that Middle Eastern countries will use oil as a weapon to destroy the US economy [5]. True, it is impossible to ignore the increasing volume of imports accounting for over half (about 13 million barrels per day) of the over 20 million barrels a day which Americans consume [6, 7, 8]. Furthermore, many believe the increasing price of oil highlights the malevolent intent of Persian Gulf countries to maximize profits by transferring wealth from the wallets of gas-hungry US consumers. This leads many US citizens to believe that there is an increasing shortage of petroleum and a widening gap between supply and demand; as such, something must be done soon to counter the problem, whether it means decreasing consumption or increasing domestic oil production [5].

While some of these concerns are not without merit, they also do not tell the whole story, or they overstate the threat to national security. The reality is that the US is not at the mercy of hostile producers in the Middle East. The oil weapon aimed at crippling our economy does not exist [5, 9]. Furthermore, "it is a serious mischaracterization to portray oil-exporting countries as behaving in ways that are systematically or consistently hostile to the United States." [9] Just as liberals would concede that self-interested producers in the Organization of Petroleum Exporting Countries (OPEC) are motivated by profit and would not want to lose customers by driving prices so high that Americans start exploring substitutes for oil, realists would underscore the idea that OPEC would not produce in a way that is hostile to its states' interests [9, 10]. Under either paradigm, OPEC cannot act hostile to the US without hurting itself financially, for if prices go too high, it will lose customers and big revenues. When considering that the top two exporting countries to the US are Canada and Mexico (Saudi Arabia is only third on the list), it is hard to argue that imported oil presents an immediate threat to national security. Additionally, non-OPEC countries account for more than five million gallons of daily US-imported oil, whereas OPEC countries only account for less than five million gallons per day [8]. Interestingly enough, many Americans believe Iran uses oil as leverage despite the fact that our country does not import a drop of oil from Iran [10, 11]. Yet, conventional wisdom persists in exaggerating this US reliance on Middle Eastern oil.

2.2 Threat Number 1: OPEC

The actual threat to the US and world economy is OPEC, which essentially dictates price adjustments to the global oil market by deciding output levels as an alliance of 12 countries. M.A. Adelman, an economist at the Massachusetts Institute of Technology, argues this:

> The real problem we face over oil dates from after 1970: a strong but clumsy monopoly of mostly Middle Eastern exporters cooperating as OPEC. The biggest exporters have acted in concert to limit supply and thus raise oil's price—possibly too high even for their own good. The output levels they establish by trial-and-error are very unstable. OPEC has damaged the world economy, not by malice, but because its members cannot help but do so [5].

Critics of this statement may point to the malice of the OPEC oil embargo of 1973 as a strong counterpoint. While this is clearly an example of coordinated state action attempting to hurt US consumers—and show discontent with America's support of Israel in the October War—there is nevertheless evidence that the embargo was not the only variable causing the recession through 1974. Scholars note that the US economy bounced back in 1975, as petroleum prices kept rising [9]. Furthermore, there were other factors influencing "stagflation," including Vietnam, Richard Nixon's monetary policy, and Lyndon Johnson's Great Society Program [10]. Adelman observes that "the miserable, mile-long lines outside of US gasoline stations resulted from domestic price controls and allocations, not from any embargo." [5] He also comments on the superseding psychological effect, causing panic and increased prices. Others liken the 1973 shock to something on the psychological magnitude of a 9/11 or Hurricane Katrina [12]. If nothing else, the tripling of world oil prices following the embargo demonstrated the new market power the cartel held, where prior to 1974 the US dominated the oil market as the world's largest producer [13]. There was a new economic player on the world stage [10].[1]

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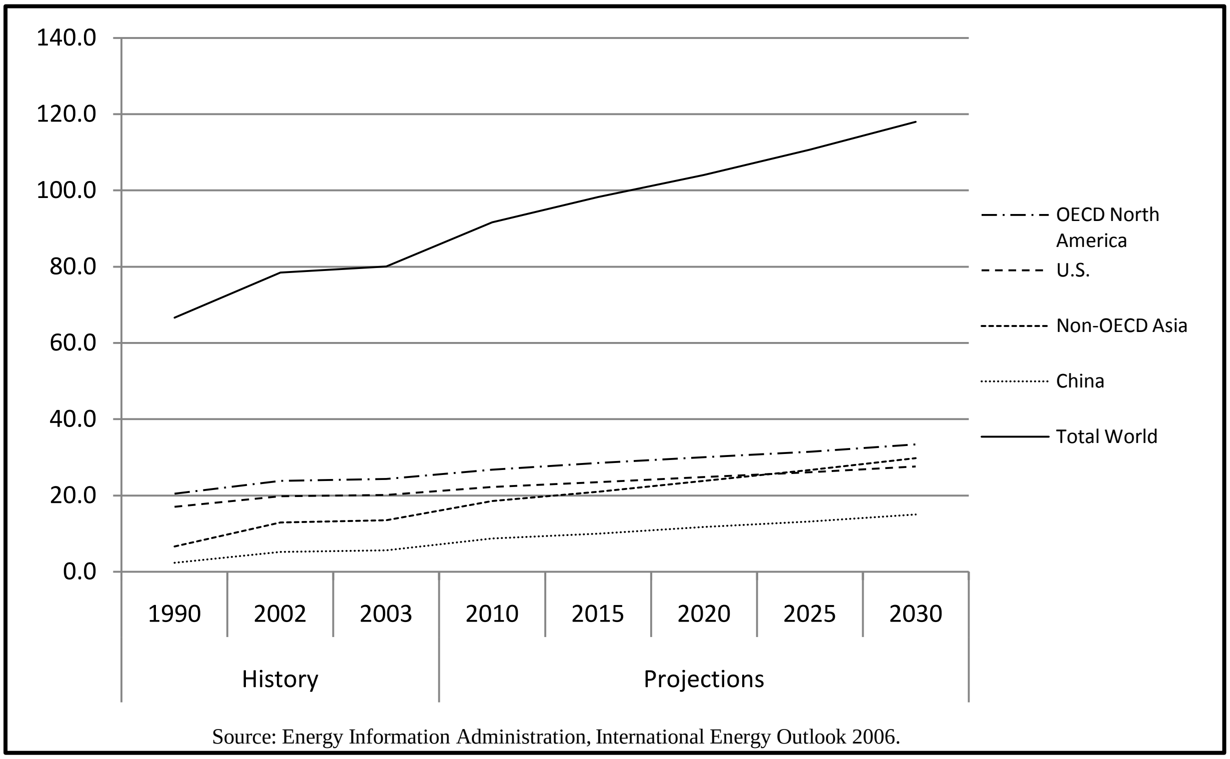
[1] Gilpin notes how a change in relative oil prices in 1973 had a dramatic impact on the international political economy as the world plunged into a decade of "stagflation." He further remarks on the importance of the Yom Kippur War in sparking the world market dive after a decade of inflation in the 1960s.



Source: Energy Information Administration, International Energy Outlook 2006.

Figure 1: Oil Consumption (Millions Barrels per Day)

Nevertheless, evidence exists that the US and the world are better equipped to deal with future supply disruptions than they were in 1973 and 1979, when there were sudden price hikes. *The Economist* observes that "notwithstanding the specter of past oil shocks, crude prices have risen to ever-dizzier heights without derailing a five-year period of strong global growth." [14] A recent study presented to the Brookings Panel on Economic Activity supports this claim. Author William Nordhaus finds that the most recent oil shock of 2002, in the days leading up to the Iraq War, revealed a peculiar robustness in the economy not seen in the past [12]. This robustness, characterized as the "Great Moderation," showed that while inflation and productivity in 2002 behaved similarly to the shocks of 1973 and 1979, there was still less volatility of inflation, unemployment, and output in the world market, to the point where expansion—rather than recession—followed the shock [12]. Interestingly, Nordhaus concedes that the shock was smaller and more gradual than in the past; however, he published his article just prior to the US recession caused by the sub-prime mortgage crisis in the last quarter of 2007, and may not have taken into account lagging effects [12]. Although his view that international monetary policy today does a better job of reacting to one-time shocks than the Federal Reserve did in the 1970s is well founded,[2] questions about America's ability to manage a more serious, sudden supply disruption still persist [10, 12].

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[2] Ironically, we may attribute at least part of this greater stability of the international monetary system to the 1973 oil crisis itself, which—together with the huge surplus of OPEC and the breakdown of fixed exchange rates—effectively led to the establishment of an international monetary regime.

This concern about supply disturbances returns the focus once again to OPEC, which has been constraining production ever since its members agreed to cut output in 1973 [5]. Currently, refinery capacity is woefully inadequate to meet world demand, which is rising dramatically with the ascent of developing countries like China and India [6, 9].

OPEC—or any non-OPEC exporting country, for that matter—is unlikely to expand capacity enough to meet the anticipated exponential jump in global demand. As countries in Asia industrialize, OPEC is quickly losing its power to manipulate oil prices and make them lower by expanding oil shipments, as it has been able to do more easily in the past. Today, its spare capacity in the form of proven reserves has decreased to two percent of world demand from 25 percent in 1980, leaving it less able to free reserves as readily [9]. Inconsistent state output adjustments that attempt to achieve market equilibrium instead distort the world market and further escalate uncertainty about oil supply, which causes price increases [15]. Because OPEC earns windfall profits with higher oil prices, it has little incentive to expand capacity or invest in discovering new reserves. Therefore, there is a great deal of short-term uncertainty about the ability of supply to meet demand, leaving ample room for wide price fluctuations—this despite the fact that some economists believe the world's oil supply will never be exhausted, or at least that humans will never fully develop the means to do so [5]. With uncertainty comes speculation, and with speculation, economic instability. Although the change in oil supply in 1973 was trivial in size, it nevertheless sparked a buyer's panic that had tremendous price effects [5].

2.3 Threat Number 2: Petrodollars that Threaten Democratic Development

Like any developing country depending on one commodity for economic growth, countries that depend on petrodollars tend to lack basic freedoms and veer from the democratic model. This is the so-called "oil curse," which lends credence to the "mounting evidence that resource wealth—and, by implication, the increase of that wealth through higher resource prices—undermines the political development of resource-rich countries." [9] Of the 12 OPEC countries, only Indonesia is "free," according to Freedom House. While Freedom House considers Kuwait, Venezuela, and Nigeria "partly free," the rest of the OPEC countries are "not free." The average scores for political rights and civil liberties (where one is "most free" and seven is "least free") are five and 5.1, respectively [17]. These countries do not fare much better with respect to corruption. According to Transparency International's Corruption Perceptions Index 2007, the 12 OPEC nations average 3.1, on a scale of 1 to 10, where 10 is the least corrupt (the US is at 7.2) [17]. Only those states with small populations seem to escape the oil curse; by contrast, where oil elites compose a small portion of a large population, equity is conspicuously absent and political development seems to suffer [9].

In Iraq, corruption and a high natural endowment of oil seem to be linked. Recently, two members of the Senate Armed Services Committee sent a request to the General Accountability Office (GAO) to provide a full account of how the Iraqi government is spending a surplus of oil revenue, which has come as a result of improved security for production and higher oil prices [18]. Despite revenues that could rise above $56 billion in 2008, GAO believes Iraq had spent only 4.4 percent of its 2007 reconstruction budget by August of that year [18]. Of course, this raises grave concerns about the degree of corruption and where the Iraqi government is spending the money. According to military officials, at least one third of fuel from Iraq's largest refinery in the city of Baiji finds its way to the black market, a pervasive problem across the country. Much of the money in the black market ends up fueling the insurgency and threatening US and Iraqi soldiers [19]. The relative increase in the price of oil does not help, as "oil price movements and democratic change will move in opposite directions." [9] The curse of oil *does* threaten US national security interests, albeit in more indirect ways—through black market cash flows reaching those who wish to do harm.

2.3 Threat Number 3: Transportation Emissions and Global Climate Change

The Energy Information Administration (EIA) believes global oil consumption in 2030 will almost double from 1990 figures to 118 million barrels per day, an annual increase of 1.4 percent. Two-thirds of this consumption will come from the transportation sector alone. Clearly, this has enormous implications for carbon dioxide in the atmosphere, which ice core research reveals is at an all-time high [20]. Among scientists, consensus is emerging that these heat-trapping gases from fuel combustion—among other sources—are inducing climate change [6]. As countries like China and India push global oil demand, they will also emit vast quantities of carbon dioxide and other damaging greenhouse gases (GHG) with increased industrialization, particularly in the transportation sector. China, for example, has a population of 1.3 billion (four times the population of the US) and eight automobiles for every one thousand people. When one contrasts this figure with America's 780 vehicles per thousand, it is frightening to imagine the future scope of the environmental problem [6]. When considering the US alone is responsible for 27 percent of carbon dioxide in the atmosphere, the implications of adding China—which has already surpassed the US in emissions—to the equation are frightening indeed [21].

There is some evidence questioning global warming causation. For example, the historian Brian Fagan grants that solar radiation is at its highest level in the past 8,000 years, which accounts for less than half of the variability in global warming; this implies that humans may not have much control over the problem [22]. In the long run, however, it seems more prudent to safeguard against a large magnitude of risk—to address the remaining half of variability that *can* be controlled. The Intergovernmental Panel on Climate Change (IPCC) believes "continued GHG emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would *very likely* be larger than those observed during the 20th century." [23] Such warming could cause floods displacing 100 million people, water shortages for one in six people worldwide, extinction of 40 percent of terrestrial animal species, and droughts affecting tens of millions of humans [24]. With more than half of GHG emissions between 1970 and 2004 coming from carbon dioxide from fossil fuel use, there are certainly important national security interests at stake.

2.4 Alleviating Oil's Stronghold

How should Americans define energy independence in light of these three primary national security threats? It does not rely on eliminating oil imports—from the Middle East or anywhere else—or oil consumption. They cannot be eradicated completely. According to Larry Burns, Vice President of Research & Development and Strategic Planning at General Motors, the automobile industry is 98 percent dependent on oil [14]. Thus, a complete transition to alternative fuels is nowhere near realistic. To satisfy our continuing need for petroleum, US policymakers should continue to strengthen North American Free Trade Agreement (NAFTA) trade ties. Canada and Mexico alone—with combined exports of 3.4 million barrels a day in 2006—are gaining ground on OPEC. Efforts should be made to improve the same types of technology that made possible drilling 10,000 feet deep offshore in the Gulf of Mexico or extracting oil from sand deposits in Canada [5]. Greater R&D will spark the innovation that enhances capacity of proven reserves and diverts petrodollars from the extralegal sectors of OPEC countries wishing to do the US harm.

With this in mind, oil independence really means avoiding the dependence costs related to the distorting effects that the OPEC oligopoly has on the market. It should mean reducing US vulnerability to dependence costs to a low enough level where they have no substantive effect on economic, military, or foreign policy [13]. Taking this one step further, a measurable goal suggests that "the annual economic costs of oil dependence will be less than one percent of GDP, with 95 percent probability by 2030." [13] America's ability to avoid disruption costs that are less than one percent of GDP entails undermining the market share power of OPEC—and thus US vulnerability to high oil prices—by challenging the long-term perspective of oil as the only fuel source. Put simply, the US should improve energy efficiency by finding fuel substitutes and improving fuel economy [13]. A strategy that will reduce the demand for oil and increase price elasticity by finding conventional and unconventional substitutes for oil may be effective [13, 25]. Much as a wise investor builds a diverse portfolio of securities, the US must also diversify its energy portfolio—all the while not neglecting its oil "inventory." One of the options in a potentially robust US energy portfolio includes biofuels, an alternative for which the State of Indiana is particularly well suited.

2.5 Indiana's Liquid Fuel Situation and Outlook

There is good reason for Hoosiers to embrace the high cost of oil—realizing the potential for innovation under market pressure—as it will likely provide incentive to shift toward fuel alternatives such as biofuels. The collapse of oil prices in the mid-1980s diminished the economic incentives and political wherewithal to continue investing in energy efficiency [9]. Now, Indiana policy makers can use high prices as a reason to invest in measures that will slow and reverse consumption, and with it, the damage that GHG emissions are causing to the environment.

In 2005, Indiana ranked eighth in the United States in per capita energy consumption. The Hoosier state is also one of the country's top consumers of distillate fuels, diesel included [26]. Indiana petroleum consumption in 2005 alone amounted to 2.1 percent (160,785,000 barrels) of total US consumption. Specifically, the transportation sector's needs accounted for 73 percent of petroleum use in the state [26]. If EIA predictions regarding total future US consumption hold true, and Indiana's share of oil consumption remains roughly at two percent of the US share in 2030, the state can expect an average daily petroleum consumption totaling 552,000 barrels.

Despite tremendous anticipated future consumption, Indiana does have tools to meet this challenge. For instance, the state is home to a British Petroleum (BP) oil refinery in the city of Whiting, which hosts a refining plant with the largest processing capacity outside of the Gulf Coast area. The Whiting plant largely accounts for Indiana's crude oil refinery capacity of 433,000 barrels per day, which makes up for Indiana's weak crude oil reserves, numbering only 12 million barrels in 2006, or 0.1 percent of the national total [26]. Although plant output is currently fairly low, BP announced plans in 2006 to invest $3 billion in reconfiguring the plant to bring greater quantities of heavy crude oil from Canada, which increasingly supplies the Midwest via a pipeline originating in Alberta [26]. This should ease some of the strain of importing crude oil from the Gulf Coast region. However, Indiana, as part of the Midwest region, may also be able to meet a portion of its consumption demand through alternative renewable energy sources.

World signals and policy mandates have actually encouraged the production of alternative fuel sources to a substantial degree in the US. For example, ethanol production in the Petroleum Administration for Defense District (PADD) 2 (the Midwest region) jumped from 38.7 million barrels of ethanol produced per year in 2000 to 80.6 million barrels in 2004, a 108.3 percent increase. For comparison, overall ethanol production from 1995-1999 only grew by 10.1 percent [27]. The PADD 2 Midwest region also accounts for 99.2 percent of all US fuel ethanol production [27]. In this case, biofuels are largely the focus of the Midwest region that boasts a great deal of agricultural wealth and capacity.

Indiana, the country's fifth-largest corn grower, is turning towards alternative renewable fuels to meet the state's increasing demand [28]. The state shows tremendous potential for producing ethanol and currently has six operational ethanol plants, with an additional six under construction and four more proposed [29]. Already, these plants produce an estimated 455 million gallons of ethanol annually, and those coming on line this year will produce an additional 605 million gallons [29]. As the fourth-largest soybean state, Indiana also has four biodiesel plants already producing 108 million gallons annually [29]. Given that the generally agreed maximum amount of US corn ethanol production is 15 to 16 billion gallons per year—and that the federal government has mandated the use of 7.5 billion gallons of renewable fuels by 2012—Indiana's anticipated contribution to the national alternative energy supply is impressive [30].

Despite Indiana's agricultural capacity to make biofuels a meaningful contributor to the state's energy profile, there are important questions regarding future production, distribution, and use. Various crops other than corn and soy can be used to produce ethanol and biodiesel. In addition, different production techniques are needed to process different crops. The logistical concerns of transporting and distributing biofuels are generally different than those of traditional fuels, and vehicles themselves may need modifications to use these fuels. It is prudent to consider how Indiana's path towards increased biofuels production could best be shaped over the next twenty years. From an analytic perspective, economically viable biofuels production must have; minimal or even positive environmental impacts; a favorable energy balance; and minimal risks associated with production, including negligible risks to food supply. Systematic analyses of these and other parameters over the life cycle of biofuels may suggest sound policy recommendations to better guide Indiana's biofuels path over the next twenty years.

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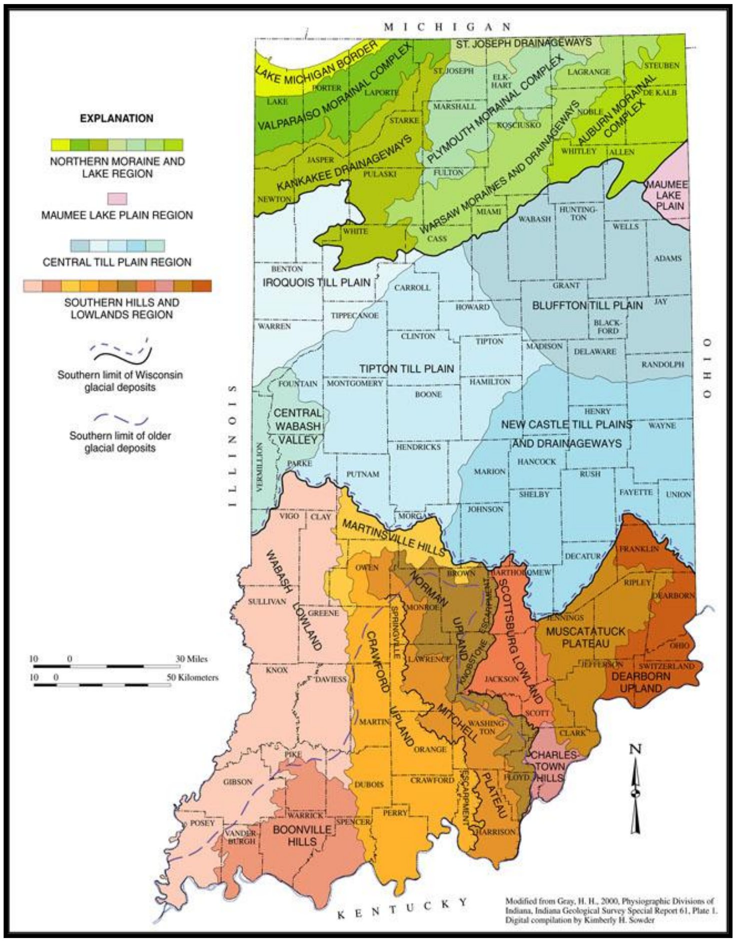
3. Feedstock Agriculture

3.1 Environmental Background of Indiana

3.1.1 Indiana's Natural History and Climate

The state of Indiana lies in the north-central region of the United States, commonly referred to as the Midwest. It is 275 miles long, approximately 143 miles wide, and spans 36,550 square miles [1]. The elevation across the state varies, with areas ranging from 581 feet about sea level at Lake Michigan to more than 1,250 feet above sea level along the eastern border of the state; the average elevation is 700 feet above sea level [2]. Indiana is unique geologically and has a significant natural north-south divide due to the glacial history of the state. While most of the state falls within the Glacial Plains, the southern portion was never glaciated, resulting in different soil types in the north and the south. Much of the north is prosperous farmland, while relatively less land is agriculturally productive in the southern half of the state. These different soils result in different soil nutrient compositions and climates in Indiana's 12 uniquely classified natural regions [3].



Modified from Gray, H. H., 2000, Physiographic Divisions of Indiana, Indiana Geological Survey Special Report 61, Plate 1. Digital compilation by Kimberly H. Sowder

Figure 2: Indiana Glacier Coverage [9]

Indiana's climate is seasonal and average temperatures range from 22-103 degrees Fahrenheit. The average summer temperature is 70-80 degrees and the average winter temperature is 25-35 degrees Fahrenheit. The first freeze often occurs in mid-October, and the last freeze occurs at the end of April [4]. The number of days below freezing is approximately 90 in Northern Indiana and 20 in the southern part of the state [5, 1]. Mean annual rainfall ranges from 35 inches in the north to 45 inches in the south; the heaviest rains occur during the spring months. The average annual snowfall is higher for northern Indiana with 40 inches total while the south receives only 15 inches in a good snowfall year. Drought conditions are infrequent in Indiana, and most droughts that do occur are moderate. The last major drought occurred in the 1930s [6]. The winds predominantly originate in the southwest with an average velocity of 7-10 miles per hour [5, 1].

3.1.2 Glacial History and Impacts

The Laurentide Glacier reputedly passed over northern Indiana during consecutive periods of cooling and warming, and the Illinoian Glaciation covered the majority of Indiana [1]. During this time, ice sheets extended down to the southern border of the state, and only a small stretch of land in south-central Indiana remained ice free. After the Illinoian ice sheet retreated approximately 22,000 years ago, the Wisconsinan Glaciation reached its southernmost extent in Indiana [7]. Both of these glaciations completely covered northern Indiana, flattened out ridges, and filled in valleys. When the ice sheets over Indiana melted 16,000 years ago, they left significant glacial deposits of finely ground rocks, which helped create the rich soils of northern Indiana [7, 8].

3.1.3 Soil Type

There are 357 soil types in Indiana, and many of these occur over small areas of land. Silt loam soils dominate Indiana and range from silty clay loam to fine sandy loam. Indiana's state soil is Miami soil, which formed in calcareous, loamy till on the Wisconsin Till Plains. Miami soil is a brown silt loam on the surface with dark yellowish brown clay loam subsoil; it is fertile and has a moderate water capacity. These soils are used extensively in agriculture, specifically for corn, soybean, and winter wheat production. These soils are prime farmland and are responsible for Indiana's productive agriculture. On steeper areas they are also used as pasture, hay land, or woodlands [10]. While soils vary across the state, differences in soil fertility depend on the mineral content deposited by glacial movements.

3.1.4 Ecoregions

Indiana's unique natural areas result from glacial history and subsequent soil types. A natural area is a generalized unit of a landscape where a compilation of climate, soil type, glacial history, topography, exposed bedrock, pre-settlement vegetation, flora and fauna distribution, species composition, and physiography represent natural characteristics of the landscape [3]. For additional information on Indiana's ecoregions, see Appendix A.

3.2 Current Land Use

Of the nearly 23 million acres which make up Indiana's total land area, farms comprise 15,058,670 acres, of which 12,909,002 acres are in cropland [14, 15].

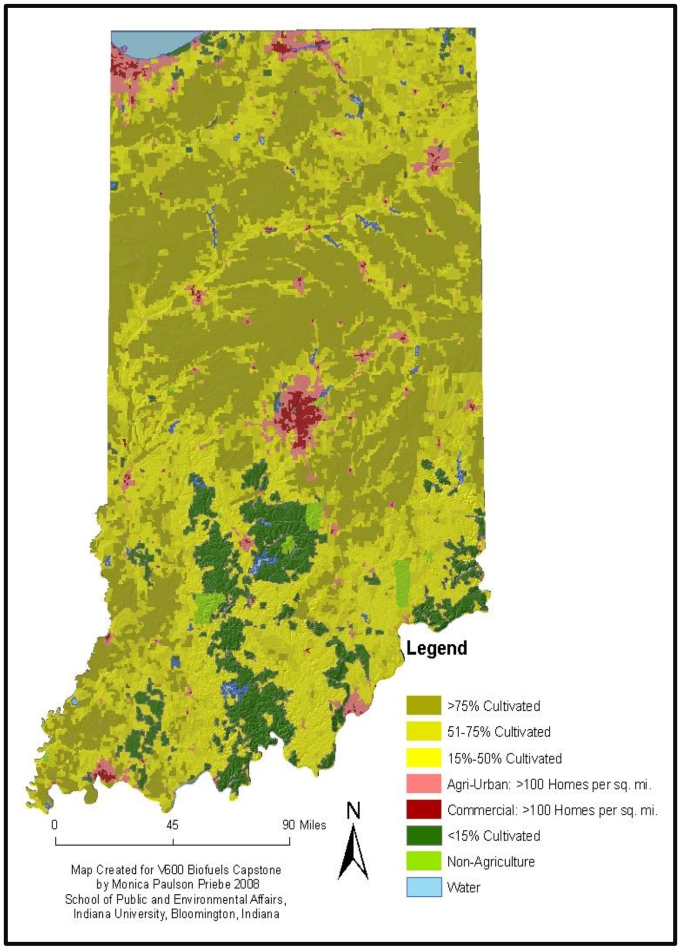


Figure 3: Current Indiana Land Use [11, 12, 13]

The remainder of farm acreage consists of 1,153,779 acres of woodland, 427,190 acres of pastureland and rangeland, and 568,699 acres in housing lots and other nonproductive land uses [15]. Furthermore, as of January 2008, a total of 296,037 acres of cropland were enrolled in Conservation Reserve Programs (CRP), described in further detail in the *Changes in Land Use* section [16].

In 2007, Indiana farmers planted 6,200,000 acres of corn and 5,000,000 acres of soybeans, which together occupied approximately 87 percent of total cropland [17]. The remainder of cultivated cropland consisted primarily of hay (660,000 acres), wheat (420,000 acres), and oats (25,000 acres) [18]. Current estimates of 2008 prospective plantings expect corn acreage to decline to 5,700,000 acres and soybean acreage to increase to 5,500,000 acres. Oat and wheat acreage is also expected to increase (to 30,000 and 550,000 acres, respectively), while hay is predicted to decline slightly to 650,000 acres [18].

3.3 Biofuels and Biofeedstocks

3.3.1 Methodology

This report considered many sources for biofuels feedstocks. Researchers then narrowed down potential feedstocks based on their biological feasibility for Indiana's climatic and soil conditions. Further consideration looked into the amount of chemical inputs needed to grow the crop, invasive potential, and crop establishment in Indiana. Many feedstocks are just beginning to gather support and little research on them is available. Where little or no conclusive research exists, researchers cannot make recommendations on the effectiveness of these crops. The following section lists these crops but does not analyze them in depth.

Biofuels feedstocks for this purpose can be broadly categorized as oil and seed crops, cellulosic annuals, cellulosic perennials, short rotation woody crops (SRWCs), algae, and waste materials. The oil and seed crops that were initially considered include corn (*Zea mays),* soybeans (*Glycine max),* sweet sorghum (*Sorghum bicolor),* grain sorghum (*Sorghum spp.),* wheat (*Triticum spp*.), rapeseed (*Brassica napus*), and flaxseed (*Linum usitatissimum)*. Cellulosic annuals include the agricultural residuals from wheat and corn stover. Cellulosic perennials include cordgrass (*Spartina pectinata*), switchgrass (*Panicum virgatum*), and miscanthus (*Miscanthus giganteus*). SRWCs considered include poplar (*Populus spp.)* and willow (*Salix spp.).* Algae as well as forestry residue and municipal urban waste were also considered as feedstock sources.

3.3.2 Infeasible Crops

Insufficient research meant that some of these crops, such as cordgrass and all SRWCs with the exception of willow and poplar, could not be seriously considered in this report. While further research and development into these fields may yield more information and efficient planting, harvesting, and production methods, current research is not sufficient for making recommendations.

Some crops are less desirable from a biological perspective due to large chemical input requirements, invasive potential, and relative energy yield inferiority. Biofuels studies currently use two varieties of sorghum as feedstocks. The sweet sorghum variety produces ethanol from fermented stalk juice. The seeds or stalks of grain sorghum can produce ethanol, but because the stalks and seeds mature at different times, they cannot originate from the same planting [19]. Both sweet and grain sorghum have a large genetic base, and some have drought-resistant hybrids which would grow in Indiana. However, *Sorghum bicolor drummondii* is a noxious weed, whose widespread cultivation could result in natural hybridization, high invasive potential, and significant economic and environmental costs [20, 21]. There is also little agreement on potential yields [22, 19]. While insecticide and herbicide recommendations vary by region and circumstance, there is general agreement that grain sorghum has high fertilizer requirements ranging from 80-100 pounds per acre of nitrogen and up to 80 pounds per acre of phosphorus and potassium [23, 24]. Sweet sorghum has much lower chemical requirements of only 40 pounds each of nitrogen, potassium, and phosphorus per acre per year [25]. While these requirements are lower than large-scale corn production, there are other feedstocks which have lower input requirements. Sweet sorghum is high in sugar content which increases efficiency in processing; however, because of the nature of the stalk, the juice must be fermented almost immediately after harvest [26]. This biological constraint requires multiple small fermenting facilities which may not be economically and logistically feasible for wide scale biofuels production and use. Neither variety of sorghum is a feasible feedstock because of the high chemical and production infrastructure requirements.

Biologically some feedstocks do not produce as much energy as other sources or have biological limitations preventing their widespread use in Indiana. Wheat and wheat stover have very low yields compared to similar crops [27]. While farmers can easily grow these crops, there are more efficient biofuels crops if Indiana plans to change its agricultural practices. While Indiana farmers can grow both miscanthus and algae, the hybrid miscanthus currently used in feedstocks has low recruitment after fall planting and colder winters can inhibit plant growth [28]. However, pilot studies at the University of Illinois are developing miscanthus as a potential biofuels feedstock in the Midwest, and the future for it appears promising. Further information on this work can be seen in Appendix B. Flaxseed is a feedstock with significant biological limitations. Little crop residue remains on the field after harvest which increases runoff and wind erosion of bare topsoil [29]. It is also susceptible to diseases such as crop rust, a fungus that overwinters in flax debris, and fararium wilt, a seed and soil-borne fungus that limits flaxseed planting to only once every three years on the same field [30].

Outdoor production of algae depends either on its close proximity to a large CO_2 emitter or the introduction of CO_2 purchased from an alternate source [31]. Outdoor production requires a great deal of water inputs because evaporation is an ongoing process. Although greenhouses can mitigate this evaporation, it is prohibitively expensive to enclose the acreage necessary for large-scale production. Additionally, the duration of favorable weather limits outdoor production. Outdoor growth also increases the potential for genetically modified species to encroach upon indigenous species or vice versa. Indoor production of algae is inefficient according to two separate lines of research. Biological engineering is now the largest hurdle and requires expensive genetic manipulation to produce an ideal strain [31]. There are also a number of physical engineering challenges in bioreactor development. Current advances with Light Emitting Diodes have significantly reduced the energy inputs of bioreactor algal growth but this technology is not yet widely available [32].

Several firms are currently refining processes for growing mass quantities of algae in desert environments with minimum inputs [33]. Future algae production could yield biodiesel, ethanol, and hydrogen with unprecedented efficiency and provide significant potential to mitigate numerous environmental degradations [32, 34]. Although algae cannot currently yield industrial-scale benefits, Indiana could consider incorporating algae into its biofuels portfolio in the future.

3.3.3 Feasible Feedstocks

3.3.3.1 Short-Term Feedstocks

Short-term feedstocks are available for immediate use or are feasible in Indiana within five years with sufficient policy and economic incentives. Short-term feedstocks have a significant wide scale ecological footprint. Because corn and soybeans are already well established in the state, immediate use of these crops may help to initiate widespread biofuels production. Although corn ethanol production is underway in Indiana and surrounding states, corn is a highly chemically dependent crop. This increases production costs, decreases land fertility, and negatively impacts water resources and biodiversity. High chemical application rates increase costs attributed to equipment, application time, and fuel to cover fields with multiple applications. However, corn has one of the lowest energy yields, compared to other crops (75 GJ of biofuel and 15 GJ in co-products) [35].

Soybeans, like corn, are well established within Indiana. While not as chemically intensive, soy still needs relatively high amounts of insecticides and fertilizers. Studies indicate that farmers use on average 1.2 kg/ha of insecticide, 10 kg/ha of nitrogen, and 15 kg/ha per year of phosphorus [35]. The reduced reliance on chemical inputs is a benefit; however, the energy yield of soy biodiesel is lower than that of corn [35]. Harvesting of soybeans also occurs in the fall and leaves the ground prone to runoff and wind erosion of topsoil over the winter.

3.3.3.2 Transition Feedstocks

Since soy biodiesel and corn ethanol production are not currently energy efficient and create harmful environmental effects, they should only serve as short-term feedstocks until Indiana transitions to more environmentally sound and economically lucrative crops. The most efficient feedstocks, and arguably the most environmentally sound on a large scale, are biomass for cellulosic ethanol production. However, this production process is still being refined and production plants are not yet operating in Indiana.

Corn and soy production in Indiana creates a unique opportunity for cellulosic production. The corn stalk, known as corn stover, normally remains on the field after grain harvest; it either remains on the surface where it slowly breaks down and sequesters carbon, or it is tilled into the soil where it breaks down more quickly and facilitates new crop growth during the next growing period. However, it also emits carbon into the atmosphere [36]. Farmers can remove this agricultural residue from fields and use it as an initial feedstock for cellulosic ethanol plants. Cellulosic and grain ethanol production can occur simultaneously since farmers harvest corn and stover at the same time. Corn stover produces 130 gallons of ethanol per ton of dry corn stover [36].

While this serves as a good transition crop, it also has environmental drawbacks, including the same high inputs for corn and increased wind and water erosion [36]. Some states provide incentive programs or require that a certain amount of stover remains on the ground to accumulate carbon.

3.3.3.3 Possible Long-Term Feedstocks

Sustained long-term projections for Indiana biofuels production will require farmers to switch to lower input, higher energy yield plants. Cellulosic ethanol feedstocks are the most promising for long-term biofuels production. Unlike corn, switchgrass and SRWC harvests leave roots in the field to regenerate from year to year and have major ecological and economic benefits [36]. The most significant benefits include reduced plowing, planting, and chemical applications, and the rapid re-growth of perennial crops.

Switchgrass is native to North America and has varieties native to Indiana. Because these plants evolved in the eco-regions of Indiana, they are highly resistant to fungi and other pests, which significantly reducing the need for insecticides and fungicides. They also utilize marginal lands far better than row crops. After planting, switchgrass needs approximately two years to establish a root system before its first harvest [37]. Once established, there is also little need for herbicides. The first planting year requires only 2.7 lbs per acre of herbicides, minimal fertilizer, and no pesticides [28]. Perennial crops, because of their established root systems, significantly decrease runoff, soil erosion and soil compaction, and increase carbon sequestration [38]. They may also increase wildlife habitat in the fall and winter seasons, depending on when harvest occurs. However, switchgrass is a clump grass that—when seeded in high concentrations—creates a thick, nearly impenetrable mass and may reduce some species' ability to take cover [38].

An alternative to cellulosic feedstocks such as switchgrass is fast-growing trees. Willow and poplar have the most significant amount of research and greatest development potential out of the 125 tree species examined for biofuels production in Indiana [39]. Both poplar and willow grow rapidly and accumulate mass quickly. They require far fewer chemical inputs than other feedstock crops. Poplars require nitrogen inputs every other year throughout their growth cycle, especially in their fifth and sixth year, to maximize biomass accumulation [40]. Poplar varieties are extremely sensitive to shade, and herbicides are frequently used in the first two years or until canopy covers the bare ground [40]. The United States already grows many poplar varieties, including black cottonwood. While farmers can grow poplar without irrigation and with dry-land fertilization techniques, optimal harvests may not be regularly achieved by this method. While both poplar and willow are fast growing, the first harvest occurs seven to ten years after initial planting [40].

Farmers can harvest the same stand of woody biomass multiple times if harvests occur in the winter, allowing the roots to regenerate (coppace) [40]. The long growing period and harvest cycle restrict plots of land to one crop. The land is much harder to convert back to other uses after harvest because of underground biomass and stumps [40]. This inadvertently makes farmers less able to respond to changes in market prices for crops since they have to dedicate land for extended periods of time to poplar production. Grazing of young trees by rodents, deer, and other mammals poses a serious risk to the viability of a stand of poplar. Antler rubs can kill even large trees. In many areas, electric fencing or brush fences are effective deterrents. The use of electric fences raises further environmental as well as economic concerns, stemming from wildlife impacts and sustained electricity use.

Switchgrass and SRWC provide a long-term alternative for Indiana ethanol production. Additionally, rapeseed cultivation may be a viable alternative for biodiesel in the future. Canola oil is a popular product of rapeseed, which grows in Minnesota and Canada. Rapeseed has a high oil content (40-44 percent) that produces 182 gallons of biodiesel per acre. Like other alternative crops, it requires fewer chemical inputs. A rapeseed field needs only 1.1 1bs of herbicide per acre and only one application of phosphorus and nitrogen. Rapeseed has a five-month long growing season, followed by an annual fall harvest. While infrastructure exists for planting and harvesting rapeseed, it is not yet widespread in Indiana and would require investments in both equipment and human capital.

3.4 Preparing Biofeedstocks for Transportation

Crop harvest and preparation for transportation to a production facility are crucial steps in biofuels production. Many factors influence the cost of preparing cops for transportation to a facility. These factors include the material yield and physical properties of the crop, the sequence of field operations, equipment and other capital costs, work and efficiency rates, and other costs such as insurance, wages, fuel, taxes, and interest [41]. Traditional crops such as corn and soybeans utilize conventional harvesting techniques and some biomass crops also have the ability to use similar processes and equipment.

3.4.1 Corn

Grain corn serves as the feedstock for the majority of ethanol produced in Indiana. Since Indiana farmers already grow corn, it is fairly simple to harvest using existing machinery and techniques. Farmers drive combines with special corn header attachments; this equipment strips the corn kernels from the stalk and deposits them into a collection bin behind the combine [42]. The corn is then ready for transportation to storage facilities, usually grain elevators [43].

3.4.2 Soybeans

Like corn, soybeans are an established crop in Indiana. Consequently, farmers can easily use equipment they already possess to harvest the crop. In order to harvest soybeans during the fall, farmers use a combine that separates the beans from the pods, and deposits them into a hopper behind the combine [44]. Grain elevators then store bushels of soybeans ready for transportation to a production facility.

3.4.3 Corn Stover

As Indiana moves its source of biofuels feedstocks away from traditional crops such as corn and soybeans in favor of cellulosic processes, farmers can easily harvest biomass with traditional or slightly modified harvesting equipment.

A corn stover harvest requires a variety of different farming techniques including chop shredding, mowing, raking, and baling [41]. A 2002 study determined that, in Indiana, the cost of shredding corn stalks is \$7.85 per acre. Mowing corn stover with discs and sickle bars costs \$9.72 per acre and \$8.50 per acre respectively. Raking corn stover costs considerably less at \$5.03 per acre, while baling in round and rectangular bales costs \$3.35 per acre and \$3.41 per acre respectively [41]. Because of the quantity of stover needed to remain on fallow fields to prevent soil erosion and nutrient loss, the efficiency yield of corn stover is about one-third of the biomass on the field [41].

Corn stover harvests occur in the fall when the crop is considered dry or has 20-25 percent moisture. Harvest time can last from several days to several weeks [45]. Farmers can also harvest corn stover under wet conditions, when the stover has greater than 45 percent moisture [45]. The two different methods of corn stover harvest depend, in part, on whether farmers prefer to make one or two complete passes through the field. The typical harvest procedure is to cut the stalk from its base, shred it, and lay it on the field to dry. Once the stover dries, a raking device collects the biomass from the field, while a machine compacts the stover into bales for easy transport [45]. A second method requires only one complete pass through the field. The combine cuts the stalk from its base and collects it in a windrow behind the machine. The disadvantage of the one-pass technique is that it requires significantly more drying time because the stover is tightly packed together. Similar to the previous method, once the stover is collected in the windrow, a machine collects the biomass and bales it [41].

The baler creates either round or rectangular bales of stover. The bale size of corn stover ranges from stackers (one half to one ton) to one-ton rectangular bales (four x four x eight feet) to one-half ton round bales [46]. The study assumed that farmers would store the corn stover at a distance of five miles from the field, where it would remain until transportation to a production facility. The stover would be stored in a shed in order to protect the crop from rain, snow, and freezing temperatures. The harvest estimates did not, however, include storage costs, which would increase the total cost of corn stover preparation [41].

Recently, Iowa State University researchers created a combine attachment which simultaneously harvests the corn grain and cuts the stover, depositing it into a wagon behind the combine [42]. The additional cost for the attachment is $10,000-$15,000, which is considerably less than the cost of a separate combine to harvest corn stover [42].

The choice of corn stover storage technique depends on whether the harvest was wet or dry, and there is some debate over the preferred method. Farmers can store dry corn stover in bales; however, large round bales tend to lose 10-23 percent of their contents in storage [45]. Conversely, bales of wet stover result in higher yields and lose less of their contents in storage [45]. Wet corn stover harvest occurs immediately after the grain harvest, making the process more efficient [45]. However, these harvests require an anaerobic storage environment to successfully preserve the crop; wrapping the bale in plastic is one method of achieving this environment [45].

3.4.4 Switchgrass

Cellulosic energy crops such as switchgrass can also be harvested to produce biofuels. One benefit of using switchgrass is that farmers are able to use existing hay equipment to harvest the feedstock [47]. Once farmers have collected the switchgrass, they bundle it into large round bales weighing approximately 992 lbs [48]. Switchgrass can either be baled loosely in twine or wrapped in plastic. Loose bales result in a significant amount of crop loss in transportation. However, the use of plastic-wrapped bales may have indirect environmental consequences [49].

3.4.5 Woody Biomass

SRWCs such as poplar and willow serve as additional cellulosic feedstocks. However, since cellulosic technology is relatively new, little information is available regarding harvesting methods for these crops. Farmers are able to use existing equipment, but this equipment requires modifications to cut and chip trees simultaneously [50]. North Carolina State University researchers are working on the development of a harvesting mechanism for woody biomass. The machine will cut trees up to six inches in diameter, chop the logs into chips, and deposit them into a collection bin [51].

3.5 Environmental Impacts

3.5.1 Changes in Land Use

One of the driving factors behind the growing interest in renewable transport fuels is concern over the environmental consequences of petroleum-based fuel consumption [52]. However, biofuels development is not without its own suite of environmental impacts. Thus, determining whether or not biofuels produce net ecological benefits relative to fossil fuels requires an evaluation of the potential positive and negative consequences of changes in land use, water quality and consumption, soil erosion and nutrient loss, greenhouse gas emissions, and biodiversity.

Since the passage of the Renewable Fuel Standard (RFS) as part of the Energy Policy Act of 2005, demand for agricultural feedstocks used in biofuels production has risen sharply. Initially mandating a supply of 7.5 billion gallons of biofuels per year by 2012, RFS expanded to require 36 billion gallons per year by 2022, of which 15 billion gallons must consist of ethanol generated from corn starch [53, 54]. While RFS also includes biodiesel and cellulosic biofuels supply mandates totaling 21 billion gallons per year, increased corn ethanol production will meet the majority of biofuels demand since the majority of new facilities coming online use corn as a feedstock [54, 55].

The Conservation Reserve Program

Enacted in 1985, CRP provides financial incentives to farmers who retire highly erodible or ecologically sensitive cropland from production in order to promote soil and water conservation. Another meaningful goal of the program was to reduce the overproduction of American commodities [62]. The Farm Service Agency (FSA) administers CRP and offers farmers the ability to enroll in several subprograms with different options. Most CRP contracts last for 10-15 years and rental payments are based on the individual property's ecological value, measured in terms of an Environmental Benefits Index (EBI). Landowners receive assistance in establishing approved conservation practices on their land, but incur financial penalties for early contract termination. CRP enrollment is capped at 39.2 million acres, and as of January 2008, there were 34,656,303 acres in active contracts nationwide [63, 16].

Continuation of CRP depends upon its renewal with the 2007 Farm Bill, which is still under consideration in Congress. The House Agricultural Committee Chairman, Collin Peterson supports a new 10-year plan which limits agricultural subsidies. These changes would decrease agricultural profits by nearly half and limit CRP to 32 million acres, a reduction of seven million acres from the 2002 Farm Bill [64].

3.5.2 Corn and Corn Stover

Increasing the corn supply to meet projected ethanol demand will require substantial land use shifts such as altering crop rotations and tillage practices, crop displacement, and bringing new land into production, potentially including land under contract with CRP [55, 56]. The net environmental impacts of this land reallocation to corn will depend on the distribution of new production among these different approaches. Farmers, seeking to increase corn yields on cropland already in production, may choose to switch some or all of their acreage out of traditional corn-soybean rotations to shorter rotations of two years of corn, one year of soybeans, or even into continuous corn production [56]. More intensive corn production will undoubtedly have yield implications and some farmers may increase nitrogen fertilizer applications and/or forego conservation tillage in an attempt to compensate for losses in productivity [56]. Such compensatory measures, in turn, may result in soil erosion, loss of organic carbon, water quality degradation from nutrient, sediment, and pesticide runoff and infiltration, and air quality degradation from nitrous oxide emissions from fertilizer application [56, 57].

Corn stover has gained considerable attention as a potential biomass feedstock due to its high biomass content and abundance; it is likely to be widely adopted for cellulosic energy production [58, 59]. While it is unlikely that expanded use of corn stover for fuel production would stimulate an increase in corn acreage, it could indirectly affect the amount of cropland allocated to corn. Crop residues which remain on the field after harvest help protect soils from erosion and aid in the maintenance of soil nutrients, organic matter, and microbial communities [60, 58]. Removing these residues, however, can result in decreased crop yields, increased soil compaction, and soil and water degradation. These effects may, in turn, stimulate increased reliance on fertilizer and intensive tillage practices to maintain productivity. It is estimated that roughly 20-30 percent of corn stover can be removed without introducing these negative impacts [60]. However, crop yields will likely fall if greater amounts of stover are harvested to meet cellulosic feedstock demand

In the short term, most of the additional land converted to corn from cropland already in production will come at the expense of soybeans [57]. Relative to corn, soybean production is much less environmentally harmful in terms of fertilizer and pesticide impacts on air and water quality [62]. In the longer term, however, depending on commodity prices and conservation subsidy trends, farmers may decide to bring marginal land into corn production, including idle cropland, pastureland, and CRP land.

Corn production on fallow land has a higher net environmental impact than crop displacement or rotational shifts on active cropland [55]. This is primarily due to significant carbon emissions from the removal of the existing plant community and losses in soil organic carbon (SOC) during the first few years of cultivation following tillage [65]. Consequently, these indirect emissions may be significant enough to negate any GHG reductions from ethanol consumption relative to fossil fuels. Corn yields on marginal lands may be high (because they have experienced less nutrient depletion) or low (because they are less productive in general) and therefore, may or may not require additional inputs. Overall, the increased rates of GHG emissions and soil and nutrient loss from increased corn cultivation are disproportionately greater than the rate at which existing cropland and marginal lands are reallocated to corn production [53]. Furthermore, many marginal lands, particularly those under CRP contracts, are highly erodible or ecologically sensitive; thus bringing these lands into production would negate the conservation benefits realized by retiring them from production.

3.5.3 High Energy Crops and Woody Biomass

In contrast to the overall negative land use and environmental impacts of increased grain corn cultivation for biofuels production, herbaceous energy crops (HEC) like switchgrass and SRWC like poplar and willow may have positive environmental benefits, including soil stabilization, increased soil organic matter and below-ground carbon sequestration, reduced sediment and pesticide runoff (following initial establishment), and lower cultivation, nutrient, and water requirements [48, 66, 67]. Thus, if HEC and SRWC replace traditional food crops on existing cropland, the net land use benefits would tend to be positive. However, in the near term, HEC and SRWC will have difficulty competing for cropland with conventional food crops like corn and soybeans. Dedicated energy crops take longer to establish and, at present, involve higher fuel production costs [59]. Consequently, until cellulosic biofuels production becomes more commercially viable, the opportunity costs to farmers of growing biomass energy crops on high quality agricultural land will remain prohibitively high [59].

In the long run, however, HEC and SRWC are likely to become more attractive feedstocks for biofuel production, and heightened demand for these products could result in an increase in total cropland acreage [58]. While HEC and SRWC produce many positive environmental benefits when replacing traditional food crops on *existing* cropland, an overall increase in cropland acreage would likely result in an increase in the conversion of natural forests, grasslands, and wetlands to crop production [58]. This could have important negative impacts on wildlife habitats and the ecosystem services provided by these natural areas, including water and air quality regulation and nutrient cycling [58].

HEC and SRWC production may be most successful, initially, on marginal lands [66]. Growing energy crops on marginal land, particularly highly erodible land (HEL), could reduce land conversion pressure on high quality agricultural lands and natural ecosystems while contributing to environmental objectives such as soil and water conservation [58]. Some HEC are already being grown on marginal lands for conservation objectives under CRP; indeed, perennial grasses have been planted on millions of acres of CRP land as an erosion control mechanism [48]. At present, farmers are not permitted to harvest these grasses on CRP land and sell the biomass for biofuels production. However, the House of Representatives version of the 2007 Farm Bill contains provisions that would allow farmers with CRP contracts to establish “biomass energy reserves” of dedicated energy crops for commercial cellulosic biofuels production [68]. Nevertheless, the Senate version of the Bill contains no such provisions, and the two versions have yet to be reconciled in conference committee.

While it is difficult to speculate as to the land use implications of the Farm Bill before both houses of Congress approve a final version, it is clear that allowing biomass harvesting on CRP land could influence a farmer’s decision whether or not to re-enroll his land in a CRP contract or to enter into a new contract. While an increase in HEC or SRWC acreage on CRP land could certainly provide positive environmental benefits compared to traditional food crop cultivation, it is unclear what sorts of potentially negative impacts (particularly with respect to soil and water quality and wildlife habitat) might arise from the growth and repeated harvesting of dedicated energy crops on CRP land, since plantings intended for biomass harvest are managed somewhat differently than those established for conservation and wildlife benefits [58].

3.5.4 Carbon Sequestration

The carbon sequestration abilities of agricultural land and farmland are important to consider when addressing land use changes. The global carbon cycle is the flow of carbon amongst terrestrial, atmospheric, and oceanic systems [69]. Of particular importance is the terrestrial component of the cycle and how the production of biofuels affects its sequestration capabilities. Soils and plant biomass contain approximately 2.7 times more carbon than the atmosphere, making them the two largest biologically active stores of terrestrial carbon [70]. Hence, their potential as carbon sinks, as well as sources, has a large impact on the global carbon cycle and GHG emissions.

Forests and agricultural lands sequester carbon through two means: vegetation and soil sequestration. Carbon sequestration by vegetation occurs through the process of photosynthesis. Photosynthesis enables plants to incorporate carbon atoms into their cells [69]. Plants then act as a carbon sink, retaining the carbon within their biomass. While forests serve as the greatest terrestrial sinks of carbon, agricultural land is a significant source as well. This is especially true of lands which experience longer harvest cycles and lower tillage rates.

Soil sequesters carbon from decomposed or partially decomposed vegetation, decomposers themselves, and plant roots [71]. The available research on soil carbon sequestration is minimal because the processes involved in the carbon cycle within soil are not readily understood. However, the amount of carbon storage capacity in soils is determined by what is found in organic materials [72]. These include plant, animal, and microbial debris in all stages of decomposition [73]. Some believe the amount of carbon sequestered in soil is greater than that sequestered in living vegetation [73]. Therefore, converting many types of land, not just forest land, has the potential to drastically reduce the amount of carbon retained within the terrestrial system.

Specifically, soils disturbed by cultivation have enhanced conditions for decomposition, which lead to greater rates of soil respiration [72]. Not only is the amount of carbon in the sink decreasing because of a loss of biomass, but there is also a forward feedback component happening in which the tilled soil is experiencing greater nutrient cycling. This allows for increased decomposition and more carbon release.

Best Management Practices (BMPs) such as reduced tillage and sustainable harvesting cycles have been introduced to deal with biomass and soil carbon losses. While following BMPs for growing and harvesting energy crops would alleviate some of the aforementioned concerns with carbon losses in agricultural land, the larger issue is the amount of land that will be dedicated to energy crops. Projected increases in the prices of corn, wheat, and soybeans have the potential to provide incentives to farmers to convert retiring CRP land into agricultural land. The increase in the amount of land moved into the agricultural sector will enhance the amount of carbon released into the atmosphere. While using abandoned agricultural or marginal land for growing energy crops will reduce the impact, biofuels produced from residual or municipal wastes that require little or no additional land use are most attractive from a carbon perspective.

3.5.5 Water Demand

The expansion of biofuels production requires an examination of water resource availability. Water enters the soil through irrigation and precipitation. The plant retains some water, and the rest leaves the surface soil through runoff, infiltration to the aquifer, and through processes such as evaporation and evapotranspiration [74]. The average volume of runoff from a specific site is determined by a runoff coefficient, the average annual amount of precipitation multiplied by the area of the site itself (R= C*P*A). Runoff coefficients vary by place and depend upon slope, soil texture, and land use type. Less permeable soil and steep slopes originate more runoff. For example, hilly cultivated land (10-30 percent slope) with a high concentration of clay (little permeability) will be characterized with a high runoff coefficient (on average 0.6), while the runoff coefficient for the flat (0-5 percent slope) woodland with open sandy loam is 0.1 [75]. The slope varies from 0-8 percent in northern Indiana counties and up to 44 percent in southern counties [76]. Infiltration in the aquifer is another way water leaves the surface soil. Factors such as soil composition and moisture conditions near the ground surface affect the infiltration rate, the measure of the rate at which a particular soil absorbs rainfall and irrigation [77].

Water loss into the atmosphere takes place either through evaporation or evapotranspiration processes. Evaporation takes place directly from the soil and its rate depends on soil texture, temperature, moisture, and other climatic conditions. Evapotranspiration is an evaporation process occurring from plants; water loss through this process depends on plant height, albedo,[3] canopy resistance,[4] etc [77]. Water balance availability in a specific agricultural site depends upon a number of factors including climatic conditions, location, type of crop, soil composition, slope, and the amount of precipitation. Consequently, these factors determine necessary levels of irrigation.

Indiana is among the least irrigated states in the US due to favorable climatic conditions [74]. According to US Geological Survey (USGS), Indiana's estimated total water withdrawal in 2000 amounted to 10.1 billion gallons per day (11,300,000 acre-feet annually), but extracted only 101 million gallons for irrigation purposes [78]. In 2000, Indiana's application of 0.45 acre-feet of water for irrigation was the eighth lowest quantity used in the US [78]. According to the US Department of Agriculture (USDA) there were only 313,130 acres of irrigated land in Indiana in 2002 out of the 15,058,670 acres of agricultural land [15]. Overall water demand is not as big of a concern in Indiana.

Different crops require different amounts of water. Corn requires around 642,000 gallons of water per acre, not including water loss through runoff and aquifer infiltration. This is approximately 168 gallons per pound of corn produced, and indicates about 23.6 inches of rainfall is necessary for corn production during the growing season [79]. According to Pimentel et al., corn can suffer from lack of water even if the annual precipitation is 39.4 inches [79]. Therefore, though precipitation in Indiana is adequate for corn production and existing practices

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[3] Food and Agriculture Organization (FAO) defines albedo as reflectance of the crop-soil surface. The albedo is affected by the fraction of ground covered by vegetation and by the soil surface wetness.

[4] The resistance of crop to vapor transfer is affected by leaf area (number of stomata), leaf age and condition, etc.

prove this, increased corn production in relatively dry areas of the state may require additional irrigation infrastructure and additional water withdrawal. Soybeans require approximately 491,000 gallons per acre, but yield per acre is less than half that of corn in weight. As a result, one pound of soybeans requires approximately 240 gallons of water [79]. Most other crops grown in Indiana demand less water than corn and soybeans. For example, one pound of wheat or alfalfa requires about 110 gallons of water, a pound of sorghum requires 130 gallons of water, and one pound of potatoes requires 60 gallons of water [79]. Although these plants utilize a relatively small amount of agricultural land in comparison to corn and soybeans, their replacement with more water intensive crops would result in increased water use.

Switchgrass requires less water and is more drought tolerant than corn [80]. Switchgrass is climatically adapted throughout most of the United States and it may grow on somewhat dry to poorly drained, sandy to clay loam, soils [37]. Poplar and willow are both phreatophytes,[5] and intensive users of water. Phreatophytes transpire about 30 inches of groundwater per year, and are frequently used to extract contaminants from soil or groundwater [81]. Sharma et al. demonstrated the presence of a three-year old poplar plantation ten feet from the boundary of wheat field caused 7.5 percent higher water use, increasing to 12.7 percent for a four-year old plantation 20 feet from the field [82]. While the well adapted root systems of these SRWCs prevent the need for irrigation, their juxtaposition to other crops will affect water demand of the adjacent crop. SRWCs require water over a longer growing period than annual crops, and also create a canopy that may decrease infiltration by interrupting rainfall. Therefore, large plantations for these feedstocks may affect water storage, especially in drier regions [83]. Although no or very little irrigation is needed for growing switchgrass, poplar, and willow, water use of these crops requires further research [83].

3.5.6 Water Quality

The rapid incorporation of biofuels into Indiana's energy portfolio has significant impacts on agricultural production in the state. Increased demand for corn and soybeans as feedstocks for ethanol and biodiesel impacts the prices farmers receive. As prices increase, more producers enter the market, and land use changes as a result. Demand for grain ethanol contributed to over a 17 million acre or 15 percent increase in corn acreage in the US between the 2006 and 2007 [17].

Rapid expansion of corn production leads to land use change in the form of adjustments to crop rotation, conversion of cropland used as pasture, land in fallow, acreage returning from CRP, and shifts from other crops [84]. These are just a few of the indirect effects from biofuels production. Water quality impacts must also be taken into account. Increased corn and soybean production leads to increases in fertilizer and other agrichemical inputs and exposes more bare ground to soil erosion and runoff. Fortunately, solutions are available which help mitigate problems associated with corn and beans and eventually provide environmentally beneficial alternatives to these feedstocks. BMPs help allay the harmful properties of agricultural inputs until economically efficient production of cellulosic ethanol is possible.

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[5] Deep-rooted plants that obtains water from a permanent ground supply or from the water table [81].

3.5.7 Fertilizer Inputs

Destruction of natural ecosystems in favor of farming operations damages soil quality, throws off normal nutrient cycling, and disrupts the food web. As a result, farmers must ensure their crops are receiving adequate nutrients to produce maximum yields. Nitrogen and phosphorous are the primary fertilizers applied to crops in Indiana, and the low costs associated with them have not promoted conservative use in the past. To make matters worse, increasing prices for corn and soybeans give farmers an even greater incentive to over apply these chemicals. From a farmer's perspective, it is a wise investment, but from an ecological perspective, over application can be highly destructive to the quality of ground, surface, coastal, and estuarine waters.

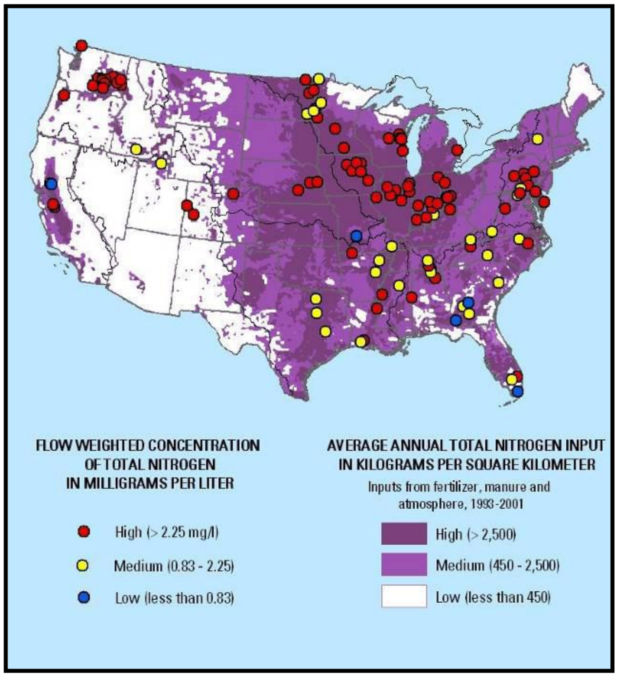

Figure 4: Nitrogen fertilization rates and stream concentrations [74]

Aquatic plants, similar to terrestrial plants, grow better under elevated levels of nitrogen and phosphorous, and over application of these chemicals runs off into surface water, creating problems with excessive algae growth and oxygen deprivation. Currently, over 60 percent of coastal rivers and bays in the US are moderately to severely degraded due to nutrient loading [85]. Since watersheds like the Mississippi and Missouri Rivers extend through great reaches of the country, nutrient loading is never a localized problem.

Fertilizer treatment is highest for corn, especially nitrogen inputs. Corn utilizes high inputs of nitrogen because it is such an inefficient user of the fertilizer. In fact, 40 to 60 percent of the nitrogen applied to corn generally runs off into surface waters [86]. Application and loss of fertilizers varies by agricultural management practices, but on average corn loses 20-40 lbs per acre of nitrogen and 2-15 lbs per acre of phosphorous, while soybeans lose 15-30 lbs per acre of nitrogen and 1-8 lbs per acre of phosphorous [87, 88]. Expansion of corn production necessitates increased farm tillage, which results in greater nitrogen and phosphorous loss per acre [87]. Again, appropriate farming techniques such as the use of riparian buffers and precision farming can minimize these inputs, but the future of cellulosic production still looks brightest for water quality.

Switchgrass requires some additional nitrogen and phosphorous for most favorable yields, but requires far less nitrogen than corn, and generally little phosphorous [87]. While little yield differential was observed with additions of phosphorous to switchgrass, the addition of nitrogen to this perennial grass is much more complex [89]. Nitrogen application rates vary from zero to greater than 350 lbs per acre depending on the use of switchgrass as a cash crop, harvest timing, and frequency [90]. Late harvesting of switchgrass during late fall or early winter months can reduce the potential for nitrogen and phosphorous runoff and leaching. Although the feedstock is drier and easier to transport, a late harvest reduces the total biomass harvested [91, 92]. No specific numbers are available for average nitrogen loss, but the loss of phosphorous from perennials such as switchgrass and other hay crops is around 0.18 to 1.8 lbs per acre [88]. Not all nitrogen and phosphorous runoff can be traced to agricultural inputs since these are also naturally occurring elements in plants.

Nutrient inputs for SRWCs are minimal, and trees such as poplar are highly productive crops with substantial nutrient requirements. They result in a variety of environmental benefits, including the absorption of excess nutrient runoff from other crops [93]. The high nutrient requirements for SWRCs and their frequent use as riparian buffers indicates there would be little runoff of additional fertilizers from their production. If poplar farming techniques use fertilizers, nitrogen application is minimal with one to two applications of up to 50 lbs per acre during the entire lifecycle of the plant [94].

3.5.8 Pesticide Inputs

Per definition by the Environmental Protection Agency (EPA), a pesticide is any substance or mixture of substances intended for preventing, destroying, repelling, or mitigating any pest. Pests can be insects, mice and other animals, unwanted plants (weeds), fungi, or microorganisms like bacteria and viruses, or prions.[6] Though often misunderstood to refer only to *insecticides*, the term pesticide also applies to herbicides, fungicides, and various other substances used to control pests. Under US law, a pesticide is also any substance or mixture of substances intended for use as a plant regulator, defoliant, or desiccant [96]. These formal definitions generally suggest stringent regulation, and agricultural pesticide use is monitored and enforced under the Federal Insecticide Fungicide and Rodenticide Act (FIFRA). Fortunately, problems with agrichemicals such as herbicides, insecticides, and fungicides have receded over the past 40 years, but the problem still exists, and expansion of agricultural land to accommodate the burgeoning biofuels market potentially increases these problems.

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[6] Prions are proteinaceous particles that lack nucleic acid which can invade and attack the central nervous system of humans and animals [95].

Corn uses more herbicides and pesticides than any other crop and has the highest rates of runoff and soil erosion, leading these chemicals straight into surface waters [97]. The variety of pesticides used in corn production has more environmentally harmful consequences than those used to grow soybeans and other crops. Corn production involves the use of atrazine, acetochlor, metalochor, glyphosate, and a small amount of other chemicals, while soybeans only use glysophate and a small amount of other chemicals [61]. These pesticides have the same effects in water as they do on the fields; instead of being intentionally used pesticides, they become unintentional biocides which reduce biodiversity and disrupt natural nutrient cycling and filtration of water.

Order of magnitude lower application rates of pesticides and lower runoff coefficients make perennial grass crops much more favorable than corn or soybeans [74]. Poplars generally require herbicides during the first year to control weeds, but after year two or three, the canopy is developed enough to shade out competition. Insecticides are applied to poplars only if necessary, and similar herbicide and insecticide practices are expected with other SRWCs [94].

3.5.9 Erosion, Turbidity, and Sedimentation

The degree of soil erosion and sedimentation in surface waters depends on soil quality, plant cover, root structure, precipitation, and slope of the land. Turbidity and sediment buildup in streams and lakes are not the only problems associated with erosion. Nutrients and pesticides can also bind to soil particles and make their way into the water via erosion [74]. High levels of turbidity from sedimentation result in low levels of light penetration, which reduces energy absorption by benthic ecosystems and can decrease photosynthesis in water, leading to lower levels of dissolved oxygen content. High turbidity can also affect respiration of sensitive species, and overall it decreases water quality in the stream leading to decreased biodiversity.

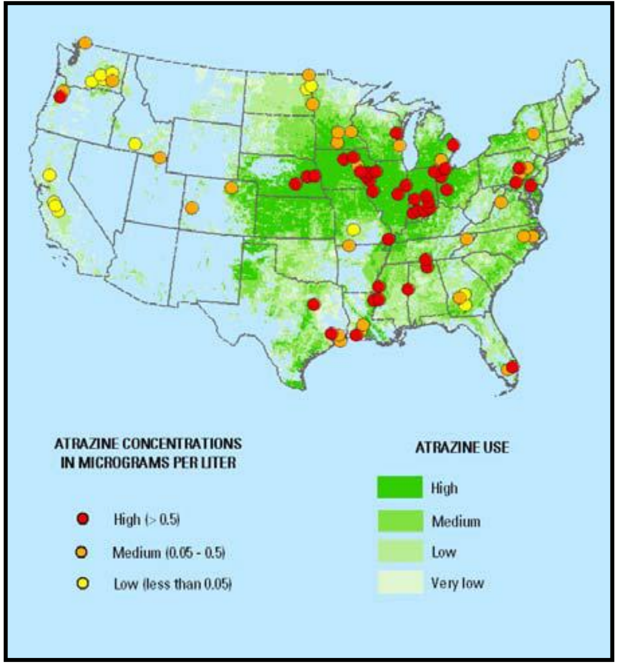


Figure 5 **Image: Atrazine application rates and stream concentrations of atrazine. Source: [74]**

Accelerated erosion is induced by any practice which denudes the soil of its protective vegetative cover, and it becomes even more problematic as the slope of the land increases [98]. Cultivation of row crops such as corn and soybeans leaves large proportions of topsoil exposed. If proper soil conservation practices are not implemented, then accelerated erosion will drain the ground of its natural fertility [98]. Annual crops also do not have the potential to develop root systems as sophisticated as perennial grasses and woody crops. Several studies note that perennial grasses and SRWCs provide greater water quality benefits than corn and soybeans. Farming these perennial crops stands to improve soil quality, reduce runoff, and enhance water quality. As a result, grasses and short rotation trees are often planted along riparian zones to reduce non-point source pollution and protect stream banks [99, 100]. These crops would provide the same benefits if utilized as biofuels feedstocks.

Corn's root structure and row cropping cause it to have the highest rate of runoff and soil erosion among biofuel feedstocks discussed in this report [97]. The Iowa Natural Resources Inventory estimates every year an acre of corn loses 4.9 tons of soil to erosion, a conservative figure compared to Pimentel's estimate of about nine tons per acre [101]. Erosion of topsoil and overall deterioration of soil quality from corn and soybeans are expensive problems for farmers to remediate, and sedimentation in surface waters contributes to deterioration of aquatic ecosystems. Downstream sediment deposits gradually accumulate, and expanded corn production would accelerate this process. Buildup of sediment deposits reduces stream flows and shrinks reservoirs, and when coupled with problems from turbidity, overall declines in biodiversity and water quality result [98].

Increased production of corn means increased availability of corn stover, and when cellulosic ethanol production commercializes, corn stover could initially be the primary feedstock for Indiana. The abundance of corn stover makes it an attractive option, but consideration of runoff and sedimentation complicates its use. Farmers leave stover on the field and plow it into the ground to increase soil organic carbon content and reduce runoff. If the stover is removed, these benefits are negated, but proper management protects water quality and mitigates problems associated with its use as a feedstock. Minimum or no till farming and leaving sufficient crop residue on the field (about 30 percent) help maintain nutrients in the soil and prevent erosion [101].

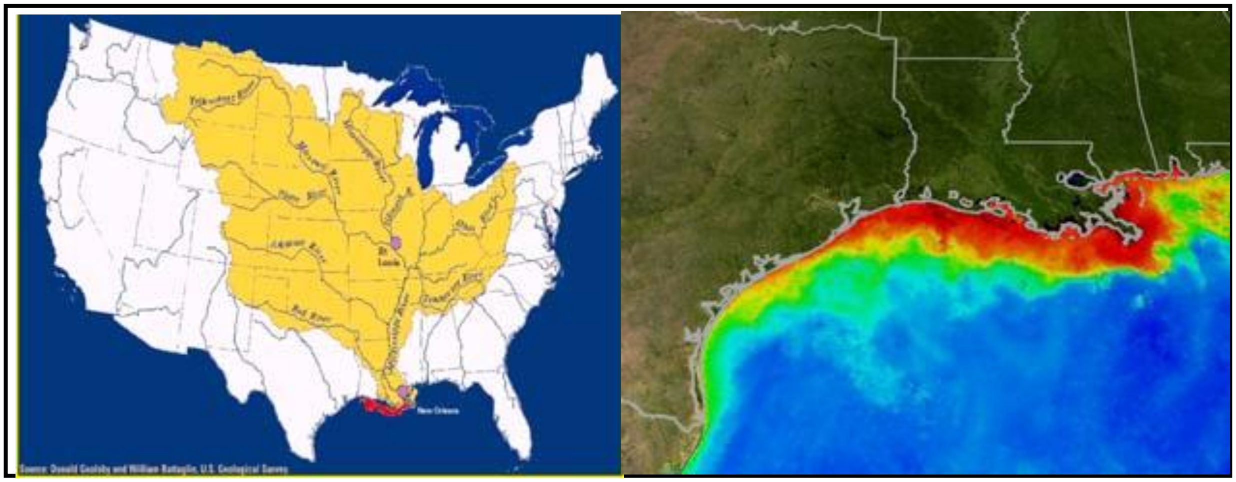
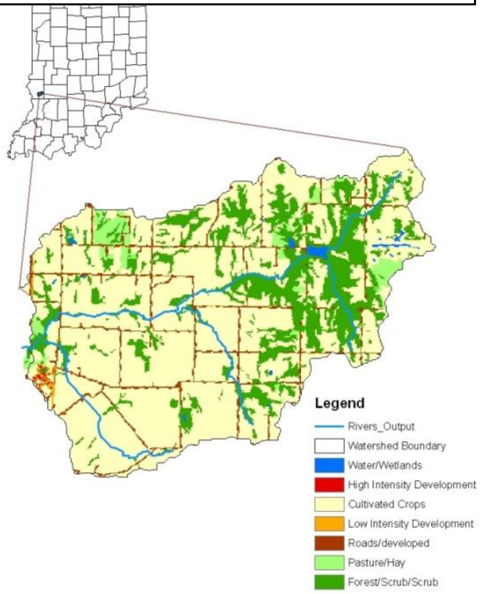


Figure 6: Image (left): Mississippi River watershed. Source: Image (right): Areas of low oxygen (red and orange) off the coast of Louisiana. Source: [103]

3.6 Hypoxia: Local Decisions Causing National Problems

Figure 6 shows the majority of Indiana is part of the Mississippi River Basin. The Mississippi watershed contains the best suited cropland in the country for grain production and with corn agriculture expanding as it is, this area will experience significant land use change [104]. Eutrophication, or nutrient enhancement, of estuarine and coastal waters causes algal blooms,

Figure 7: Middle Fork Creek Watershed, Sullivan County, Indiana [13, 113, 114]



oxygen depletion, and overall fishery habitat decline [105, 86, 106]. Nutrient loading from Indiana will worsen algal blooms in receiving waters. Hypoxia in the Gulf of Mexico occurs when algae dies, sinks to the bottom, and decomposes. Algal decomposition consumes oxygen in the bottom water, creating a lethal situation for resident plants and animals [74]. Nitrogen is the primary contributor to coastal hypoxia, but phosphorous loading also leads to severe degradation of freshwater lakes, rivers, and some estuarine and coastal waters, especially those receiving heavy loads of nitrogen as well [107, 108, 109].

Indiana must be cognizant of the interstate implications of biofuel policies and agricultural practices. Geo-political boundaries do not confine environmental problems and decision making requires an ecosystem management approach. Effects from nutrient loading in Indiana's surface water must be considered in the context of existing national goals to reduce nitrogen and phosphorous loading in the Mississippi River Basin by 40 percent or more [110]. The "dead zone" surrounding the Mississippi River Delta is destroying coastal ecosystems and damaging local economies. Indiana must consider the extent of eutrophication in the Mississippi River and hypoxia in the Gulf of Mexico when developing the biofuels market. The state should take similar precautions for northern Indiana watersheds flowing into the great lakes ecosystem.

3.7 Watershed Scale Water Quality Analysis for Potential Agricultural Shifts

3.7.1 Introduction

A watershed is any area of land that drains to a common point, and their delineation is important for studying the ecological implications of human activity at a biologically meaningful scale [111]. Land use within watershed boundaries directly affects the network of surface waters capturing runoff from the drainage basin. Point and non-point sources of pollution, including agricultural inputs, contribute nutrients, bacterial, and chemical contaminants to US waterways [112]. Watershed scale analysis is used to characterize human, aquatic, and terrestrial features, conditions, processes, and interactions collectively known as ecosystem elements [111]. Individual watershed analysis allows better estimation of direct, indirect, and cumulative effects from management practices and land use patterns [111].

Watershed scale analysis is intended to serve as a model for watershed planning that allows for a variety of human activities while providing for the highest quality water resource attainable.

Management at this scale includes all activities aimed at identifying and minimizing contaminants to a water body from its watershed [112].

3.7.2 Methods

The L-THIA modeling tool is used to estimate non-point source (NPS) pollution from a variety of different land use classifications [113]. Researchers utilized a web-based version of L-THIA for assessment of Middle Fork Creek watershed after it was delineated using the watershed delineation tool available with L-THIA [115]. The researchers selected Middle Fork Creek watershed based on the broad spectrum of potential land use changes from further development of biofuels feedstocks. The 2001 land cover data guided the decision, because it revealed significant acreage of agricultural lands, forest, pasture, and grasslands in the watershed [116]. After delineating the watershed, land use categories are imported into L-THIA to run the NPS pollution model. Eight different land uses exist in the Middle Fork Creek watershed, and are also subdivided by soil type. Hydrologic soil groups B and C make up the watershed, and are described as: B – moderate to well-drained; moderately fine to moderately coarse texture; moderate permeability; C – poor to moderately well-drained; moderately fine to fine texture; low permeability [117]. Standard runoff coefficients and NPS pollutant concentrations for each land use and soil type combination are built into the L-THIA model. L-THIA uses these standard runoff and pollutant values in conjunction with average annual precipitation to estimate each land use's contribution to NPS pollution in the watershed.

Land Use	Hydrologic Soil Group	Scenario One (acres)	Scenario Two (acres)	Scenario Three (acres)
Water/Wetlands	C	88.4	88.4	88.4
Commercial	C	14.8	14.8	14.8
Agricultural	B	212.1	248.1	212.1
Agricultural	C	10375.2	11410.6	5187.6
High Density Residential	B	1.4	1.4	1.4
High Density Residential	C	61.7	61.7	61.7
Low Density Residential	B	13.8	13.8	13.8
Low Density Residential	C	767.1	767.1	767.1
Grass/Pasture	B	36	0	36
Grass/Pasture	C	535.4	0	5723
Forest	B	84.7	84.7	84.7
Forest	C	3336.9	2836.9	3336.9
Industrial	C	26.9	26.9	26.9
	Total Area	15554.4	15554.4	15554.4

Figure 8: Middle Fork Creek Land Use Input Scenarios

The first scenario represents current land use within the Middle Fork Creek watershed, and served as the baseline for the analysis. Scenario two illustrates potential watershed impacts if corn and soybean agricultural land expands. Agriculture makes significant contributions to the degradation of waters in the United States, and high grain prices resulting in part from the biofuels boom, are causing farmers to push back tree lines and convert pasture and grassland into agriculture. Scenario two converts all pasture and grassland and 500 acres of forest into agriculture in the Middle Fork Creek Watershed. Scenario three looks at the potential impacts from expanding the production of perennial grasses for the production of cellulosic ethanol. The L-THIA model groups pasture and grassland together into one land use category, so the inputs and runoff values in scenario three would be different under a more realistic biofuels scenario. Fecal coliform runoff would be lower than the output states since much of it comes from the manure of pasture livestock (there would be no pasture, only expanded grassland), and nitrogen and phosphorous runoff would be higher since farmers would likely fertilize their perennial grass crops. Scenario three converted 50 percent of the agricultural land from scenario one into grass and pasture. This hypothetical conversion is not based on likely scenarios in the near future, but illustrates the benefits derived from alternative cropping systems in the event Indiana decides to promote cellulosic ethanol production from perennial grasses in the long term.

3.7.3 Results/Discussion

The results table evidences the detrimental impacts of expanding agricultural production in Indiana, and the potential benefits of pursuing a future in cellulosic ethanol production from perennial grasses. The results from scenario two show increased losses of all major NPS pollutants from the watershed (except pesticides since they are not built into L-THIA), and scenario three shows decreases in the same NPS pollutants.

If corn and soybean agriculture continues to expand in Indiana, the quality of water resources is expected to decline. However, the implementation of better agricultural management practices and a shift to perennial crops for cellulosic ethanol production would improve the quality of water resources. The Middle Fork Creek watershed is a microcosm of the greater web of surface water in Indiana, and small headwater streams similar to this creek, must be carefully managed since they are delicate ecosystems and major contributors to NPS pollution. Quality of water resources has serious implications for human health and the environment alike, and policy decisions affecting agricultural production must be mindful of these implications. Many watershed scale projects are now a preferred unit of analysis due to the advantages over classical land management and protection units artificially defined by manmade boundaries [111]. The benefits include a defined land area with a unique set of features and the recurring processes affecting a common array of dependent plants and animals.

	Scenario One	**Scenario Two**	**Scenario Three**
Total Annual Runoff (acre-feet)	8,675	9,043	7,090
Nitrogen Losses (lbs.)	89,625	97,499	51,412
Phosphorous Losses (lbs)	25,903	28,410	13,602
Suspended Solids Losses (lbs)	2,130,156	2,336,353	1,118,658
BOD Losses (lbs)	118,278	125,562	82,839
Fecal Coliform Losses (millions of coliform)	53,099,194	52,813,526	28,498,666
*BOD = Biochemical Oxygen Demand (uptake of oxygen from biological organisms)			

Figure 9: Middle Fork Creek L-THIA Output

3.7.4 Groundwater

Microorganisms convert excess nitrogen fertilizer in the soil to nitrate, which is then converted to nitrite under anaerobic conditions in the soil or groundwater [74]. EPA considers wells containing over 10 milligrams per liter of combined nitrate and nitrite concentration as impaired, and recommends the water be treated before it is consumed. When ingested, nitrite binds to hemoglobin and prevents oxygen transport. Nitrite-induced oxygen depletion is commonly manifested as “blue baby syndrome” in infants [74].

Similar to nutrient loading of surface water, the quantity of nitrates and nitrites infiltrating groundwater from different crops is again a product of the crop’s ability to process the nutrients and the quantity of fertilizer being applied. One study shows a strong correlation between nitrate contamination of shallow groundwater and increased nitrogen use, a common situation for well-drained surficial soils over unconsolidated sand and gravel aquifers in northern Indiana [119]. Vulnerability of Indiana's groundwater to nitrate pollution is mapped in Figure 10. The image is from a study utilizing two modified modeling techniques (DRASTIC and SEEPAGE). The DRASTIC model shows 58 percent of groundwater systems in Indiana as moderately vulnerable, and 23 percent under high and very high risk. The SEEPAGE approach indicates 75 percent of the state has moderate vulnerability [118].

Corn is again the most detrimental feedstock in terms of groundwater contamination. Corn's inefficiency in processing nitrogen along with high application rates allows groundwater infiltration of nitrogen fertilizer. Soybeans, just as other legumes, have evolved a symbiotic relationship with nitrogen fixating bacteria which allows them to utilize nitrogen straight from the air. Nitrogen fixation in beans precludes fertilizer application rates as high as corn. Application of nitrogen to perennial grasses is high under certain conditions, but their extensive root systems and ability to store nutrients in their roots over winter make them more efficient users of nutrients [120]. Moreover, application of nitrogen to grasses is most important during their establishment, and high application rates during this time increase potential groundwater contamination. Studies show that nitrogen leaching is low in willow crops even at high application rates (around 270 lbs per acre once during three to four year rotation), indicating that nitrate and nitrite groundwater infiltration will not be a major problem from these crops [121, 122]. Similarly, poplars have high nutrient demand and are commonly used as riparian buffers, again indicating little potential for significant groundwater contamination [93].

Solubility of pesticides determines their potential groundwater infiltration. Similar to nitrogen, a study shows a strong correlation between pesticide contamination in groundwater, application rates of pesticide, and presence of highly permeable soils with poor drainage [123]. Application rates of these chemicals were previously discussed, and are used as a proxy for potential groundwater contamination, with corn being the worst and the perennial grasses and trees the best. If crop rotation diminishes, continuous corn persists, and agricultural land expands, then groundwater contamination becomes more problematic.

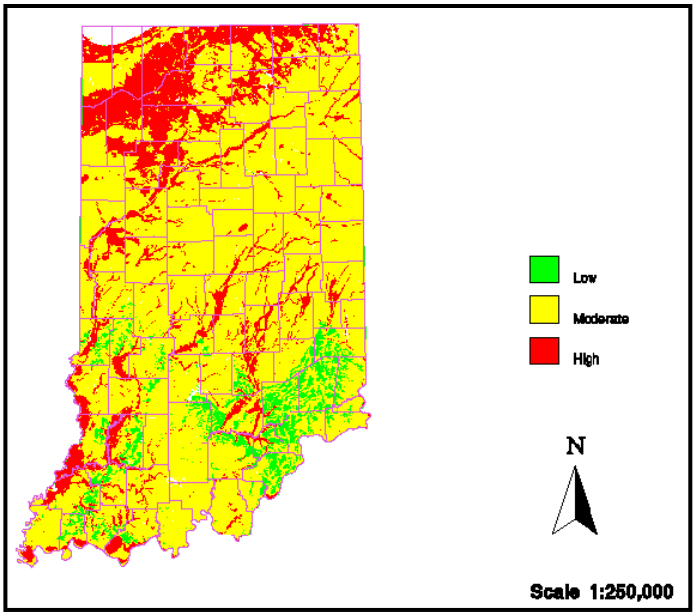


Figure 10: Groundwater vulnerability map to nitrate pollution using modified SEEPAGE modeling technique. [124]

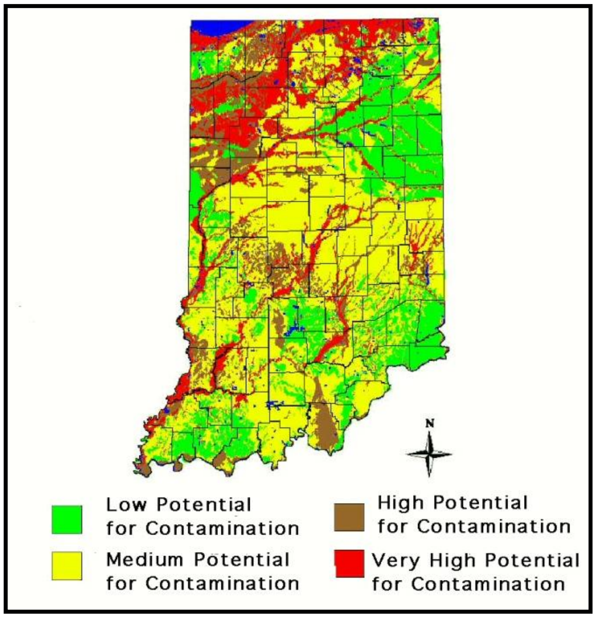


Figure 11: Area Map of Contamination Potential [124]

3.7.5 Biodiversity

Biodiversity is the overall diversity of life in a given place [125]. While difficult to ascertain, scholars describe biodiversity by the given number of species in a particular location. Biodiversity is critical for the proper functioning of healthy ecosystems and can add resilience to these systems during instances of disturbance. A variety of organisms help maintain ecosystem functioning and perform important ecosystem services such as watershed protection, nutrient cycling, and flood control. These ecosystem processes require the participation of myriad species to make them work. For instance, the seemingly simple process of plant growth requires an entire host of species, including many decomposers and pollinators [125]. Economic values of services that species perform are difficult to quantify, yet their loss may be costly.

As human populations increase globally, [126] natural ecosystems and biodiversity sustain large amounts of degradation due to increased land use. Humans are altering natural ecosystems at an unprecedented rate. Deforestation, eutrophication, and species extinction are a few examples of widespread damage to global ecosystems. When biodiversity in an ecosystem is lost, ecosystem functioning and services begin to degrade, and cascading effects occur, such as the disruption of the food web. Effects of such degradation may not be evident until after the biodiversity has been lost, when it may be too late to mitigate the damage [127].

Biofuels production stands to increase the amount of land devoted to agriculture in Indiana. CRP, forest, grassland, and pasture may be converted to row crops or other cellulosic feedstocks, thereby decreasing the area of previously existing ecosystems. Agricultural expansion degrades viable food, shelter, and water for Indiana’s wildlife. Replacing natural forests and grasslands with agricultural monocultures decreases the diversity of plants growing in an area, and consequently fewer animals can then be supported. Biofuels policy, and any potential expansion of agriculture that results, must be considered in the context of biodiversity and the valuable services it provides.

3.7.6 Invasive Potential of Cellulosic Biofuels Crops

Certain cellulosic biofuels crops have traits which increase invasive potential [128]. Once an invasive species escapes and spreads into larger areas, it is nearly impossible to eradicate [129]. Various species of miscanthus are under consideration as potential biofuels feedstocks. Miscanthus exhibits several traits that make it potentially invasive including “the ability to re-sprout from rhizomes, efficient photosynthetic mechanisms, and rapid growth rates.” [129] Switchgrass has many of the same potentially invasive traits as miscanthus. Therefore, it has the potential to become a weedy plant and invasive if it outcompetes predators and natural competitors [129]. Since there is little invasive species research, policymakers should consider invasive potential when evaluating transitions to alternative biofuels feedstocks.

3.7.7 Genetically Modified Crops (GMCs)

GMCs resist insects and weeds, survive harsh environmental conditions, and have increased yields and nutritional values. Researchers can genetically modify the lignin content of cellulosic crops to speed up breeding cycles, abate environmental pollution, and enhance landscape restoration value [130]. Although Indiana does not plant GM poplar, some scientists believe that poplar may be a good biofuels source. Purdue University researchers are attempting to genetically modify lignin to release cellulose in fermentable sugars that can be converted to ethanol [131]. Proponents believe that pest-resistant GMCs are much safer to the surrounding environment and society than pesticides. According to EPA, 10,000-20,000 cases of pesticide poisoning in agricultural workers occur annually. Pesticide use kills approximately 70 million birds annually in the US [132]. According to Halford and Shewry, farmers who grow GMCs apply less poisonous and rapidly degradable herbicides, which decrease threats to the environment [133]. Additionally, GMCs may provide food security for the world's dramatically increasing population [132].

Farmers can grow GMCs easily, which creates a comparative advantage over those who rely on traditional growing methods [33]. Broader GMC cultivation may occur as biofuels crop production increases. The most popular GMCs are soybeans and corn. Poplar makes up almost half of GM trees worldwide, and the US engineers 36 percent of poplar biotechnology [134]. Transgenic switchgrass technology is unavailable due to its complexity and lack of research [135].

Indiana's application of GMCs has increased during the previous decade. According to the National Agricultural Statistics Service (NASS) in 2007, 59 percent of corn and 94 percent of soybeans were GMCs in Indiana [136].

Crop/year	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
Corn	11%	12%	13%	16%	21%	26%	40%	59%
Soybean	63%	78%	83%	88%	87%	89%	92%	94%

Figure 10: Biotechnological Varieties: Percent of Corn and Soybean GMCs in Indiana [136]

3.8 Social and Economic Impacts: The World and Food Security

3.8.1 Food Alarmists

There is a debate surrounding the impact of biofuels demand on agricultural commodity and food prices. Historically, food shortages in less-developed countries have resulted from transportation and equity problems [137]. Although world population has doubled in the past 40 years, food production has remarkably kept pace with this increase. Today's global agricultural system is capable of producing enough food to supply everyone with a daily caloric intake of 3,200, but this may change [138]. *The Christian Science Monitor* reports that "the era of cheap food is over and we are going to have to get used to it." [139] The concern is for those 2.7 billion people in the world who live under the poverty level, for whom increasing food prices can be disastrous. There are still more than 800 million people around the world who are malnourished and/or hungry [140]. Food prices are rising in China, India, and the US, countries that contain 40 percent of the world's population [141].

During the past year, basic grain prices for wheat, corn, and soybeans have increased dramatically. Corn now costs more than $3 per bushel; soybeans more than $9 per bushel. Because feed grains are a major input for meat, dairy, and poultry production, their price increases cause retail prices to spike. In the US, 2007 dairy prices were up 13 percent and egg prices have risen 42 percent [142].

There is also concern about the decrease in the amount of food aid sent abroad. Studies indicate the 32 million tons of corn converted to fuel in 2004 only amounted to 12 percent of the total US supply; however, it could have fed 100 million people at average worldwide consumption levels [143]. The US remains the leading grain exporter, shipping more than Canada, Australia, and Argentina combined. Thus, what happens to the US grain crop affects the entire world. With the massive diversion of grain to produce fuel for cars, exports will likely drop [141].

3.7.5 Biofuels Proponents

In the other side of the debate, the argument that decreases in US exports will lead to more hunger in the world is highly exaggerated. According to the Institute for Agriculture and Trade Policy, most US exports of corn and soybeans go to wealthy countries. Twenty percent of total US corn is exported directly to 28 Organization for Economic Cooperation and Development (OECD) countries as animal feed. In 1996, only 0.3 percent of corn exports went to countries where undernourishment affects at least 20 percent of the population. About one-third of the US soybean crop is exported, of which OECD countries import 70 percent. In 1998, a year of record-low soybean prices, the 25 most undernourished countries received less than 0.027 percent of total US soybean exports [144].

Many factors outside of the price of grains influence retail food prices. John Urbanchuk of LECG, LLC states that "rising energy prices had a more significant impact on food prices than did corn" Energy prices affect the Consumer Price Index (CPI) two times more than do food prices [145].

A USDA report shows

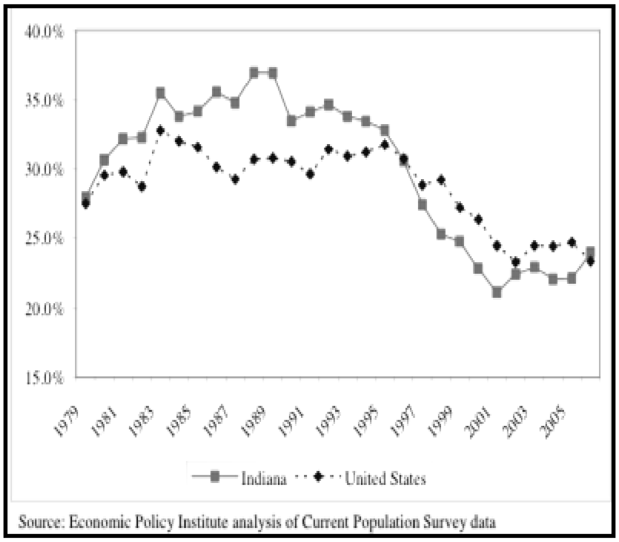
> labor costs account for 38 cents of every dollar a consumer spends on food. Packaging, transportation, energy, advertising, and profits account for 24 cents of the consumer food dollar. In fact, only 19 cents of every consumer dollar can be attributed to the actual cost of food inputs like grains and oilseeds. As an example, a standard box of corn flakes contains approximately 10 ounces of corn, or about 1/90th of a bushel. Even when corn is priced at $4 per bushel, a box of corn flakes contains less than a nickel's worth of corn [146].

3.8.3 Rising Food Prices

Nearly 24 percent of Indiana residents currently live below the poverty line ($20,615 for a family of four in 2006), and recent trends show increasing numbers [147]. Indiana low-wage worker incomes have dropped two to four percent since 2000. Medium-income groups lost $4,000 in annual income since 2000 and by 2006; they earned only 93 percent compared to their national counterparts. Additionally, in the last six years, Indiana lost 110,000 jobs in the manufacturing sector [147].

Rising food prices are a substantial burden for those living at or below the poverty level. The US Department of Labor released Consumer Expenditures 2005, a survey of the percent of income which goes towards routine expenses. The quintile of workers earning an average income of $9,676 spent an annual average of $3,047 on food, or 31 percent of income. The second lowest quintile earning an average income of $25,546 spent $4,064, or 16 percent of earnings on food. However, both groups had expenditures in excess of income. The lowest quintile spent nearly $10,000 more per year, and the second lowest quintile spent an average of $3,000 more per year than they earned [148].

With Indiana's poverty rate approaching 25 percent, the diversion of crops to biofuels production, along with increasing food prices, may have disastrous effects on the lowest 40 percent of income earners. With the US on the verge of an economic recession, rising food prices may result in further divergence between rich and poor, particularly in Indiana.



Source: Economic Policy Institute analysis of Current Population Survey data

Figure 11: Percentage of Workers Earning Below Poverty Wage, Indiana and U.S., 1979-2006 [147]

3.8.4 Economic Impacts

The economic section below discusses the potential future of Indiana farming. USDA does not anticipate a Midwest shift to cellulosic ethanol production over the next eight years [59]. As such, costs associated with land conversion and retraining do not appear to be significant in the short term. However, ethanol mandates and subsidies may affect agricultural subsidies in the 2007 Farm Bill, which is still under debate in Congress. The new Farm Bill proposes caps and limits on agricultural subsidies, which could have an enormous impact on Indiana agriculture. Indiana currently receives the seventh largest agricultural subsidy payment in the United States, estimated at $495,490,202 in 2008 (including CRP subsidies)[7] [149].

The Energy Policy Act of 2005 required that renewable fuels make up 4 billion fuel gallons in the US by 2006. The Energy and Independence Security Act (EISA) signed December 19, 2007, increased this number to 36 billion gallons of renewable fuel by 2022. The mandate specifies that 15 billion gallons (42 percent) of the requirement be met by corn ethanol. The remaining 21 billion gallons will be met through cellulosic biofuel and biomass-based diesel [54].

3.8.4.1. Corn

EISA will affect corn and soybean production the most in forthcoming years, since cellulosic ethanol cannot be produced commercially with current technology and corn prices are at record highs. In 2005, the US diverted 14 percent of the corn crop to ethanol production. Under EISA, 7.5 billion gallons of ethanol will be produced by 2012, requiring 2.5 billion bushels of corn, which is an increase of 1 billion bushels [150].

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[7] This number was calculated using the 2005 subsidy reported by American Farmland Trust and inflating by a standard 2%.

In short-term pursuit of profit, farmers will convert acreage to corn to capture the rising market prices. However, many Midwest farmers plant seasonal rotations between corn and soy depending on which fetches the highest market price. USDA conducted a 2007 study on the agricultural effects of EISA. Under the assumption of a 15 billion gallon ethanol mandate, corn acreage will rise by 2.3 percent in each Midwest state by 2016. USDA also evaluated a 20 billion gallon scenario, which is plausible if market conditions and ethanol subsidies induce the market to go beyond EISA requirements. With the 20 billion gallon scenario, corn acreage will increase by 6.8 percent in Midwest states by 2016 [59]. These scenarios are extraordinarily difficult to predict and are affected by the dollar's exchange rate and international supply and demand for commodities. For instance, with the tumbling dollar and international demand for soy oil, experts predict soybean prices could go as high as $16 per bushel in 2008 [151].

In 2007, 6,200,000 acres in Indiana were devoted to corn, up from 5,500,000 the previous year (11 percent increase) [17]. This was coupled by a decline in soybean acreage from 5,700,000 acres in 2006 to 5,000,000 in 2007 (13 percent decline) [17]. Ethanol may induce higher corn prices in the coming years, which would result in decreased soybean production. This low quantity of soybeans would normally result in rising soybean prices (a cyclical give and take between corn and soy); however, substitute ethanol byproducts such as Dry Distillers' Grains (DDG) from biofuels production has the potential to actually reduce the demand for soy. Livestock ranchers can substitute DDG for soybean-based feed and do it at a lesser price [59].

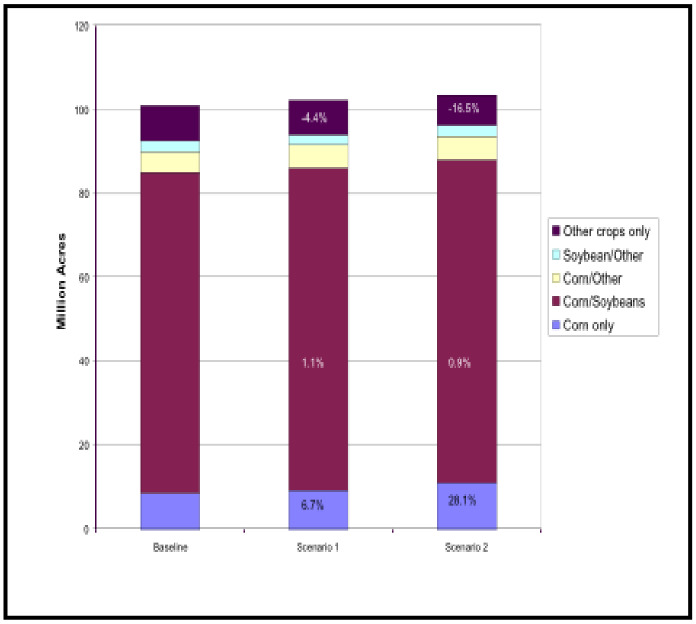

Figure 12: Distribution of crop rotations in the corn belt, with percentage change from baseline for each rotation. [59]

USDA predicts that Corn Belt farmers will increase corn acreage primarily through monoculture, reduced production of other crops, and marginal-land farming. Therefore, Indiana should not expect extreme shifts in land use patterns over the next 20 years.

Under the 15 billion gallon scenario, Indiana corn acreage would increase to 6,342,600 and the 20 billion gallon scenario would increase acreage to 6,621,600.[8] These shifts are not as large as expected, partially due to the USDA model's assumptions of decreasing corn exports, decreasing feed demand (due to higher prices, lower livestock production, and DDG), and consistency of CRP funding (an assumption that will likely be false) [59]. Increases in corn acreage come primarily from a shift away from wheat and other crops.

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[8] These numbers were calculated with acreage data and growth rates from the pervious page provided by "An Analysis of the Effects of an Expansion in Biofuel Production on U.S. Agriculture."

In 2007, Indiana corn yields rose to 160 bushels per acre [152, 153] resulting in Indiana corn pre-subsidy revenues of $3,237,600,000.[9] Indiana is the seventh largest recipient of agricultural subsidies in the United States. The 2002 Farm Bill locked in corn subsidies at $2.63 per bushel for 2004-2007 [154]. Indiana's increase in corn yields led to a $16,306,000 per acre subsidy in 2007. Moreover, warehousing, emergency assistance, farm loans, and other subsidies are available to Indiana farmers which are significantly more beneficial than the per bushel subsidy. In 2005, total Indiana corn subsidies amounted to $721,783,401, while in 2004 Indiana corn subsidies amounted to only $375,308,558 [155]. Since figures are not available for the 2007 crop, the 2004 figure was compounded at 2 percent inflation to provide a *conservative estimate* for the 2007 crop at $398,280,444. Thus, the total revenue (not accounting for production costs) of the 2007 Indiana corn crop is approximately $3,635,880,444.

3.8.4.2 Soybeans

In 2007, Indiana devoted approximately 5,000,000 acres of land to soybean production [17]. Due to ethanol production and increasing corn prices, USDA predicts that EISA's 15 billion gallon corn ethanol mandate will induce a 0.7 percent increase in soybean acreage by 2016 [59]. If market conditions for ethanol improve and agricultural subsidies continue, there is potential for 20 billion gallons of ethanol production by 2016. In this scenario, soybean acreage would decrease by 0.4 percent [59]. Soybean production will not be significantly harmed in either scenario due to land diversion from *other* non-biofuels crops and cattle/poultry farming in the state over the long run.

Professor Chris Hurt, Editor of the Purdue University Agricultural Economics Report, valued the 2007 soybean crop between $8.25 - $8.50 per bushel at harvest, potentially rising to $10 per bushel [152]. The $8.50 per bushel figure is used as a conservative estimate for all following calculations. Indiana soybean yields in 2007 were 50 bushels per acre [156].

Revenue from the 2007 Indiana soybean crop is estimated at $2,125,000,000.[10] The 2004 soybean subsidy was $82,202,338 [149]. Using 2 percent inflation, the subsidy rises to $87,233,778 in 2007. Thus, the 2007 Indiana soybean crop revenue is approximately $2,212,233,778.

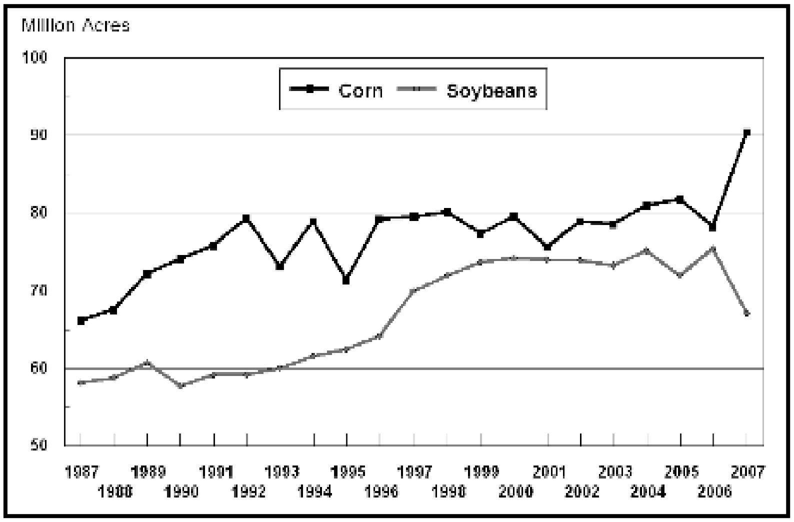

Figure 13: U.S. Corn and Soybean Planted Average [17]

These numbers illustrate that higher corn yields and corn prices

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[9] These numbers were calculated based on the acreage, price, and yield figures for 2007 previously presented.

[10] This number was derived from information previously given in the document.

are forcing farmers to shift away from soybeans in the short-term. This phenomenon is not unique to Indiana; the national shift towards corn production over the last two years has been significant. However, as mentioned prior, the low value of the American dollar and reduced soy production will likely drive the soybean price to all-time highs in 2008, resulting in a future shift back to soy planting.

3.8.4.3 Cellulosic Crops

Cellulosic biofuels add to the complexity of agricultural economics. Technology does not currently exist to produce fuel from many of these crops, but it is expected that breakthroughs in identifying cellulosic enzymes could occur within the next four to ten years. This creates a considerable amount of uncertainty in the market for these crops and land use predictions for Indiana.

Switching from corn or soy to cellulosic crops depends, in part, on crop profitability. Complications arise in determining profits for cellulosic crops because they currently have no market. Several studies have attempted to determine the pricing structure for these crops, which are highly dependent on mandates, ethanol subsidies, transportation costs, and conservation program payments [157, 158, 49]. Agricultural subsidies are a significant, if not the only, source of profit for Indiana farmers. The opportunity cost of a farmer switching to cellulosic crop growth and losing his or her subsidy is, therefore, substantial. However, two large unknowns could make it a profitable switch: the 2007 Farm Bill and the renewal of CRP.

Indiana CRP payments increased to $92 per acre in 2008 [159]. As of January 2008, 295,947.4 Indiana acres were enrolled in CRP, with total payments of $27,227,160 [159]. In 2008 26,046 acres of Indiana CRP land will expire [159]. With the forthcoming reduction in the CRP budget, it is reasonable to assume that it will be increasingly difficult for farmers to be granted new acreage or renew CRP contracts. Based on CRP reduction, the profitability of harvesting cellulosic crops depends upon the profitability of the crops themselves.

USDA gathered data concerning switchgrass from two studies completed at the University of Nebraska and Iowa State University. The Iowa State study found that switchgrass costs ranged from $121 per acre (yield: 1.5 tons per acre) to $241.16 per acre (yield: 6 tons per acre). The Nebraska study found switchgrass production costs of $112 per acre (yield: 3.4 tons per acre) [59]. A similar study was conducted by the Department of Agricultural and Consumer Economics at UIUC and indicated switchgrass costs at $147 per acre for a yield of 2.58 tons per acre [158]. Depending on the desired yield, switchgrass costs run between $112 - $241 per acre, meaning the market price must significantly exceed these costs for farmers to switch to perennial grasses.

Switchgrass production has both benefits and drawbacks. Benefits include low maintenance, less prone to external shocks (drought, flooding), environmental improvements (over corn and soybeans), complementary equipment (between hay and alfalfa), annual harvests, and potentially reduced per acre costs. The primary drawbacks of switchgrass are storage and transportation. Iowa State University estimated that hauling 20 tons of switchgrass 30 miles would cost $173. Storage estimates were an additional $17 per ton [160]. As a result of transportation difficulties, cellulosic fuel production facilities must be located near switchgrass farms to make them profitable; Indiana currently has no cellulosic ethanol plants.

Woody residue cellulosic crop growth is unlikely in Indiana. Even if farms could renew CRP payments, willow can only be harvested every three years and poplar every seven to ten years [59]. Moreover, farmers would be required to invest in completely new equipment to plant, harvest, chip, and remove post-harvest tree stumps. This would require farmers to invest significant upfront capital and forgo revenue for three to ten years before first harvest. Similarly, transportation and storage issues also occur with woody crops.

It is unlikely that profit potential will induce Indiana farmers to switch to cellulosic fuel crops in the short term. The construction of cellulosic plants, the advent of new technology, the 2007 Farm Bill, and increasing mandates for cellulosic ethanol could change this situation. However, market trends indicate that Indiana farmers will convert cropland from soybeans to corn in the short term and from other crops to corn and soybeans in the long term.

The short-term future of cellulosic ethanol in Indiana likely rests on corn stover, the field residue from corn harvesting. Stover is free to produce and the farmer only incurs additional costs to bail, store, and transport the stover, and replenish soil nutrients.

3.8.4.4 Market Implications from Expanding Biofuels Production

Corn and soybeans are major inputs for cattle ranching and poultry production. Farmers can use DDG as a substitute feed. However, DDG has a lower protein count, quality variability, and shipping and storage issues. Livestock and poultry will be additionally burdened by the rising value of agricultural land and those who rent land will experience higher rents. Increasing costs will make small livestock, dairy, and poultry operators particularly vulnerable and favor large-scale producers who experience economies of scale [59].

Small-scale dairy farming is still a common practice, whereas cattle, poultry, and hog farming are generally much larger operations. Additionally, dairy cattle are the most sensitive to fluctuations in feed quality. Poor quality or quantity of feed will affect milk production. As such, this industry is particularly vulnerable to rising feed prices associated with corn and soy diversion to biofuels [59].

Ethanol may divert upwards of 47 percent of domestic corn production by 2016, which will lower exports. Under the 15 billion gallon EISA mandate, corn and soybean exports will decrease 4.8 percent and 2.8 percent respectively by 2016. If consumer demand and subsidies increase ethanol production to 20 billion gallons, corn and soybean exports will decline by 12 percent and 5.3 percent respectively [59]. This will offset the US economy to some degree; however, the higher prices for corn and soybeans will allow US agricultural export value to increase slightly, despite reductions in quantity.

3.9 Conclusions

3.9.1 Best Management Practices

A strict environmental perspective suggests all agricultural producers in Indiana should stop growing corn and soybeans and start planting perennial grasses and SRWCs. However, political and economic influences prevent this from happening. As such, existing and planned biofuels production necessitates implementation of BMPs for corn and soybeans, and eventual shifts to perennial grasses and SRWCs are necessary once commercial production of cellulosic ethanol commences. Production of cellulosic feedstocks provides many long-term benefits including multiple revenue streams for farmers and a variety of ecosystem services which result in improved surface and groundwater quality [161].

Agricultural policy goals should include reductions in nutrient loading, pesticide use, and erosion. More efficient fertilization techniques reduce nutrient loading from existing corn and soybean operations. Farmers should utilize enhanced efficiency fertilizers that match application rates to nitrogen uptake patterns of various crops, as well as controlled release fertilizers which have insoluble coatings to prevent nitrogen dissolution [74]. Injecting fertilizer below the ground to shield it from wind and water reduces its potential to runoff, and is another BMP option [74].

Similar to fertilizer management, pesticide management is all about efficiency. Efficient application of agrichemical inputs saves farmers money and prevents undue harm to the environment. Integrated pest management (IPM) is an increasingly popular management technique for insects. IPM restricts the use of pesticides to a last resort for insect problems and focuses on preventive measures. Similarly, herbicides and fungicides should only be applied as needed. Varying crop densities and planting patterns (alternatives to row cropping) helps suppress weed development as well as utilization of ground cover (i.e. mulching).

Surface cover and conservation buffers prevent soil erosion most effectively. Crop residue and winter cover crops are the most popular means of maintaining surface cover throughout the year. A variety of conservation tillage techniques can help maintain surface cover and the integrity of the soil. Incentives already exist for “no till” and “strip till” techniques, which are common alternatives to full-width tillage and will be especially important when corn stover enters the feedstock market [74]. No till farming is already widely utilized in Indiana and should continue to be encouraged [162]. Riparian buffers shield surface waters from non-point source runoff, and development of the market for cellulosic ethanol makes their use more attractive. SRWCs and perennial grasses are effective riparian buffers since they improve soil and water quality, expand wildlife habitat, and increase land use diversity [163]. One study shows switchgrass used as a riparian buffer has eight times the below-ground biomass and up to 55 percent more SOC than adjacent cropped fields [164]. Promoting the use of perennial grasses and woody crops as conservation buffers poises farmers to receive new revenue streams once the cellulosic ethanol market opens.

Protection of Indiana’s environment will require a broad suite of conservation practices integrating nutrient, pesticide, and sediment management. Existing crops need more intense management; superior feedstocks require agricultural incentives, and improved agricultural technologies require diffusion. Low-input high-density (LIHD) cropping systems, precision agriculture, and diversified agricultural landscapes are receiving more attention, considering the variety of feedstocks that produce biofuels [165].

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4. Production

4.1 Introduction

This chapter investigates the production technologies utilized in the production of biofuels. The section is separated into three parts each describing a specific production technology. The techniques described include ethanol production from starch feedstocks such as corn, biodiesel production from feedstocks such as soy, and cellulosic ethanol production from feedstocks such as corn stover and switchgrass. Within each subsection, the current production method is defined, followed by a description of costs, by-products, and emissions. Ethanol production from starch feedstocks can use either the dry milling or wet milling technique. Cellulosic ethanol production describes both the biochemical and thermochemical processes. Finally, the information highlighted in this section outlines conclusions for the future of biofuels production within the state. The conclusions are also guided by the information contained in the Biofeedstocks chapter, in regards to the types of biomass that can be successfully grown in Indiana.

4.2 Corn Based Ethanol

In the US ethanol represents 99 percent of the total biofuels market; corn being the predominant feedstock accounting for 98 percent of ethanol production [1, 2]. In 2006, the US devoted 17 percent of its domestic corn crop to ethanol production, creating 4.6 billion gallons of ethanol [1]. By 2009, ethanol production is projected to exceed 10 billion gallons per year utilizing over 30 percent of the US corn crop [3].

Despite the impressive growth in ethanol production over the past 30 years, ethanol still comprises only a marginal proportion of US transportation fuel consumption [4]. In 2005, ethanol displaced two to three percent of the country’s gasoline, and by 2012 ethanol is expected to displace approximately eight percent of US gasoline [3].

4.2.1 Production Process

Production of ethanol uses two techniques; wet milling and dry milling. Currently 82 percent of ethanol is produced via the dry milling process, with the remaining 18 percent from wet milling [5]. Wet milling plants are typically larger than dry milling facilities, due to the greater complexity of the production process. US wet mill production capacity ranges from 50 to 330 million gallons per year (MGY). Existing dry mills have capacities ranging from five to 30 MGY [6]. The majority of new ethanol facilities use the dry milling process [6].

4.2.1.1 Dry Milling

The first phase of the dry milling process involves grinding the corn kernels into “meal.” [5] Manufacturers create a “mash” by combining the meal with water [5]. Enzymes are added to the mash to convert starch into dextrose [5]. Ammonia is also combined with the mash to control pH levels. Prior to fermentation, high-temperature cookers process the mash in order to minimize bacteria levels [5]. After cooking, the mash is then cooled and transferred to fermenters [5]. The addition of yeast converts the mash to ethanol and several by-products [5]. To facilitate the fermentation process, the mash is agitated and maintained at a cool temperature [5]. Fermentation is complete within approximately 40 to 50 hours, transforming the mash into a "beer." Distillation columns receive the beer where the ethanol is separated from the "stillage," a by-product of the fermentation process [5]. Using conventional distillation methods, the ethanol is distilled to 190 proof [5]. A molecular sieve system dehydrates the 190 proof ethanol to approximately 200 proof [5]. Finally, a denaturant like natural gasoline is added, making the ethanol undrinkable, thus preventing application of the beverage alcohol tax which would unnecessarily increase the cost of ethanol production [5].

4.2.1.2 Wet Milling

The wet milling process consists of six steps: "grain cleaning, steeping, germ separation and recovery, fiber separation and recovery, gluten separation and recovery, and starch separation." [7] When the corn arrives at the production facility, the first step is to clean the grain and remove unwanted materials such as stone and grit. Following grain cleaning, the corn steeps in a solution of water and diluted sulfurous acid for one to two days. This chemical process softens and breaks down the grain and allows starch separation for milling [7]. Hydrocyclone machines separate the softened, ground grain from the corn germ. The germ is then washed in water, dried, and screened.

In order to extract the fiber from the germ, the remaining solids (fiber and the conjoined gluten and starch) are ground again, washed in water, and separated through a number of tanks and sieves. The resulting fiber is then recovered and dried. A centrifuge, referred to as a mill-starch thickener, separates gluten from the mill starch after removal of the fiber [7]. The final step of the wet milling production process includes starch washing and recovery. Several hydrocyclones wash the starch in stages, and water carries away waste materials. Water reenters the system after washing. The final end product of the wet milling process is starch slurry which ferments into ethanol [5].

4.2.2 Production Costs

4.2.2.1 Dry Milling

The USDA Office of Energy Policy and New Uses examined corn ethanol production costs based on a 2002 survey of 21 dry milling facilities in the US. Ethanol production facilities incur variable and capital costs. Variable production costs include the cost of corn feedstock after subtracting profits derived from by-products, the operating expenses required to run the production facility (such as labor, administration, and maintenance), and process inputs (such as chemicals, yeast, and enzymes). The variable cost per gallon in 2002 for dry milling plants was $0.96 [6].

In 2002, feedstock costs for corn ethanol production were $0.80 per gallon of ethanol. By-products reduce the net feedstock costs to $0.39-$0.68 cents per gallon for the dry milling process. Improvements in by-product technology may continue to offset the net cost of feedstock [6].

Total cash operating costs, which include utilities, non-feedstock inputs of production (such as enzymes), and administrative costs were $0.41 per gallon for dry milling plants in 2002 [5]. Energy costs comprise the largest share of the total operating budget, averaging $0.17 per gallon [5]. The USDA study found that larger production plants saved $0.05 per gallon on energy costs compared to smaller facilities due to efficiency gains [5]. From 1998 to 2002, total energy costs for ethanol facilities increased 50 percent. This was due to a 61 percent increase in the price of natural gas, which is utilized during the production process [5].

The second cost component of ethanol production relates to capital expenditures, such as plant construction and expansion. USDA found that construction costs for new dry milling plants varied from $1.05 per gallon to $3.00 per gallon [5]. Comparatively, the cost of expanding production capacity of current plants was on average $0.50 per gallon, significantly less than new construction costs [5].

4.2.2.2 Wet Milling

Corn ethanol wet milling production costs were not included in USDA's 2002 study given a lack of participation of such facilities. However, data from a previous USDA study in 1998 does include wet milling production costs [8]. The variable costs for wet milling production facilities, comprised of net feedstock costs and total cash operating costs, were $0.94 per gallon [8]. Dry milling variable costs for that same year were $0.95 per gallon of ethanol [8]. Corn feedstock costs in wet milling plants exceeded corn feedstock costs for dry milling facilities by nine cents per gallon [8]. Total cash operating costs in 1998 were $0.46 cents per gallon for wet milling facilities, compared to $0.42 cents per gallon for dry milling plants [8]. Wet milling plants have lower energy expenditures than dry milling plants given their use of cogeneration but have higher costs than dry milling plants in every other operating cost category. Capital costs associated with wet milling production facilities are greater than those of dry milling plants of equivalent scale.

4.2.3 Closed-Loop Technology

Given the costly natural gas inputs required to operate ethanol production facilities, E3 BioFuels-Mead, LLC developed an ethanol production technology called the "closed-loop system." E3 Biofuels contends the closed-loop system consumes fossil fuels 20 times more efficiently than traditional ethanol plants [9]. Closed-loop systems produce energy by mixing cattle manure with a thin stillage, a by-product of ethanol production. An anaerobic digester decomposes the mixture, resulting in the production of a biogas. The biogas, a combination of methane, carbon dioxide, and minute levels of other gases, helps power the ethanol production facility. To complete the loop, cattle feed on wet distillers' grain, a by-product of the ethanol production process [9]. In addition to replacing fossil fuel inputs, closed-loop technology reduces the amount of methane released into the atmosphere. The first closed-loop plant opened in Mead, Nebraska in 2007, yielding approximately 25 million gallons of ethanol per year, requiring manure from 28,000 cattle [9].

As of 2004, only two Indiana counties had cattle stocks greater than 28,000 head: Elkhart (44,000 head) and Lagrange (34,300 head) [10]. The state ranked 36th in the nation for calve and cattle inventory (850,000 head), however, the state ranked fifth in hog inventory (3,350,000 head) [10]. The average weight of a hog in Indiana is 264 lbs while the average weight of a steer is 1,295 lbs [10]. A closed-loop plant with comparable output to Mead's would require 140,000 hogs to produce enough manure for operation given the average weight of hogs and steer in Indiana. Indiana counties such as Carroll (232,653 head), Clinton (182,716 head), and Decatur (154,586 head) have the hog livestock capacity to generate enough manure to operate a closed-loop plant comparable to the E3 Biofuels facility [10]. One thousand pounds of hog produces 29 cubic feet of biogas per day, which is comparable to the 30 cubic feet produced by 1000 pounds of cattle [11]. This suggests closed-loop technology is cost effective and could be a feasible option in Indiana.

4.2.4 Production By-Products

4.2.4.1 Dry Milling

The two main by-products of the dry milling process are distillers' solubles (DS, also called thin stillage) and distillers' grains (DG). These two by-products are converted into several forms: Condensed Distillers' Solubles (CDS, also called syrup or stillage), Distillers' Dried Solubles (DDS), Distillers' Wet Grains (DWG), Distillers' Dried Grains (DDG), and Distillers' Dried Grains with Solubles (DDGS).

Distillers' Solubles

DS are the liquid removed during the fermentation process. DS typically contain five percent dry matter including fiber, oil, protein, and yeast cells [12]. DS are dried, reducing the water content to 55-77 percent, creating CDS. CDS can be sold as cattle feed. However, distribution may be limited to close proximity because of its high water content. A survey conducted by the National Agricultural Statistics Service estimates the average price of CDS is $17 per ton [13].

Distillers' Grains

DG are the solid by-products of ethanol production, containing all the remaining components of the corn, except starch. After separation from alcohol in the fermentation/distillation process, DG are sent to a centrifuge to remove the DS. DWG which are not dried, typically have 50-70 percent water content. Due to their high water content, DWG cannot be stored for more than a few days without additional treatment, such as mixing with hay. Additional treatments extend the storage period of DWG from 60 to 200 days, but additional research is needed to determine appropriate storage time limits [14]. Due to storage issues and high water content, the distribution of DWG may be limited to local markets.

DDG are produced by drying DG. DDG have a water content of approximately ten percent, while maintaining similar nutrient values to DWG [15]. DDG are sold widely as livestock feed for approximately $140 per ton [16].

DDGS are the most valuable and widely sold by-products of dry grind corn ethanol production. Approximately 71.2 lbs of DDGS are produced per 220 lbs of corn. As its name indicates, DDGS are a combination of DS and DG, and contain all the nutrients of corn except starch. Since the moisture content of DDGS (10 percent) is slightly lower than that of corn (13-16 percent), the weight-nutrition ratio of DDGS is significantly higher than whole or dry-rolled corn, a major component of conventional feed [17, 18].

4.2.4.2 Wet Milling

There are three main by-products of the wet milling process; germ, corn gluten feed (CGF), and corn gluten meal (CGM).

Germ

After the steeping process, the germ (seven to eight percent of a kernel on a dry weight basis) is separated from the kernel [7]. Germ has high oil content, typically 45 percent on a dry weight basis, and low protein content of about ten percent dry weight basis [7]. Germ may be sent to other facilities for oil extraction or the oil can be extracted on-site. After oil extraction, the corn germ meal can be sold as a high-protein livestock feed or added to corn gluten meal (CGM) [17, 19]. One bushel of corn generates 1.73 lbs of corn oil and 1.83 lbs of corn germ meal [20].

Corn Gluten Feed

Corn Gluten Feed (CGF) is derived from bran that has been separated from the kernel and mixed with concentrated steep water. This by-product is sold as Wet Corn Gluten Feed (WCGF) or Dry Corn Gluten Feed (DCGF), feed in which the water is removed. Although the nutrient composition of CGF varies depending upon the quality of steep water, as well as the ratio of steep water to corn bran, typical CGF contains 20 percent protein, two percent fat, and seven to ten percent fiber [15, 17, 20]. Corn generates 5.88 lbs of CGF per bushel, and its average market price is about $125 per ton [16, 20].

Corn Gluten Meal

After bran removal, the centrifuge separates the gluten from the starch, and removes the remaining water. CGM typically contains 60 percent protein, two percent fat, and two percent fiber, and is sold primarily to the swine and poultry industries due to its desirable amino acid balance [21, 22]. CGM also functions as a bio-herbicide and bio-pesticide on turf grass fields [23]. One bushel of corn generates 2.55 lbs of CGM, averaging $474 per ton 16, 20]. CGM is the most valuable of all the by-products of wet milling process.

4.2.4.3 Potential Utilization of By-products

Research continues to explore alternative uses for ethanol by-products. One promising possibility is methane generation. Patrick Hirl, Ph.D., of Stanley Consultants, invented a system to generate methane from the by-products of dry milling. The methane replaced all the plant’s natural gas needs and 75 percent of electricity [24]. Hirl estimates that 5.8 tons of whole stillage (all solubles and grains), 2.5 tons of DWG, or one ton of DDGS can generate 11.6 million Btu of biogas, 103 lbs of ammonia (which can be used as fertilizer), and 266 lbs of digested organic matter in the form of compost or topsoil [25]. Hirl estimates the capital cost of the system for a 100 MGY facility at $46 million [25]. NewBio E Systems created a system that utilizes DS to generate methane. An advantage of this system is that DG are still usable as livestock feed [26]. This self-sustaining energy input would remove a source of risk associated with ethanol production, i.e. the unstable price of natural gas.

4.2.5 Ethanol Plant Environmental Issues

4.2.5.1 Emissions

Corn ethanol production provides a variety of vectors for air emissions. The process requires heat sources for drying solid residues and the generation of steam. This heat is most often generated by combustion of liquid natural gas or coal in on-site cogeneration. This cogeneration process can release SO_2, CO, CO_2, and volatile organic compounds (VOC).

Handling and processing of the corn can lead to discharges of particulate matter (PM). This release is not unique to ethanol production; it also results from most grain elevator operations [27]. PM is stimulated by physical handling of the corn and can be contained

by modifying grain handling and construction of physical barriers. Examples of these measures would be reducing the amount of time the corn spends in free fall to minimize kinetic energy transfers to PMs, and sealing containment areas to reduce air currents for PM transport [27]. These advanced measures are supported by the use of filters and more sophisticated trapping technology, although they require careful maintenance. **Error! Reference source not found.** illustrates the distribution of PM sources in the production process for which EPA has data.

Emission Source	Type of Control	Kg/Mg	lb/ton
Grain Receiving	Fabric Filter	0.016	0.033
Grain Handling	None	0.43	0.87
Grain Cleaning	None	0.82	1.6
Grain Cleaning	Cyclone	0.086	0.17
Starch Storage Bin	Fabric Filter	0.0007	0.0014
Starch Bulk Loadout	Fabric Filter	0.00025	0.00049
Gluten Feed Drying			
(Direct Fired Rotary Dryer)	Cyclone	0.13	0.27
(Indirect Fired Rotary Dryer)	Cyclone	0.25	0.49
Starch Drying			
(Flash Dryers)	Wet Scrubber	0.29	0.59
(Spray Dryers)	Fabric Filter	0.08	0.16
Gluten Drying			
(Direct Fired Rotary Dryer)	Cyclone	0.13	0.27
(Indirect Fired Rotary Dryer)	Cyclone	0.25	0.49

Table 1: Filterable Particulate Matter Emissions from a Corn Wet Milling Operation [28]

The production process also generates VOCs and SO_2, but the amounts differ, making quantification difficult. In wet milling processes, the combustion of fuel for the drying process is the largest source of SO_2 [27]. The sulfur generated by the transformation of corn is suspended in the process water and can be removed with alkaline solutions. However, the odor released by the suspended SO_2 necessitates closed systems and ventilation. These measures can isolate and intercept the SO_2 before it is released to the atmosphere [27].

The production of heat for drying is also the greatest source of VOC, although the amounts and impacts of VOC can be abated through drying temperature control. Allowing the drying temperature to exceed 800 degrees Fahrenheit will increase odor and blue haze formation [27]. According to the National Renewable Energy Laboratory (NREL) analysis, the energy requirements of drying consumed 66-69 percent of all energy in dry milling plants. Wet milling plants devote an additional three percent to drying, necessary for the processing of by-products [29]. The same analysis determined that dry milling plants use 36,000–52,360 Btu per gallon, while wet milling plants use 34,000-54,980 Btu per gallon. Wet milling plants are more likely to have cogeneration facilities because of their need for on-site steam production, whereas dry milling plants use electricity for nine to fifteen percent of their energy production [29]. The wet milling cogeneration facilities tend to be coal powered, with only 20 percent of their electrical generation burning liquid natural gas. By way of comparison, dry milling power generation uses 50 percent coal and 50 percent natural gas [29]. The increased use of natural gas and electricity from the power grid suggests dry milling plants are likely to generate less CO_2, SO_2, VOC and PM. However, rising natural gas prices are resulting in increasing interest in use of coal or wood chips as a substitute fuel source [30].

Dry milling plants are increasingly using Combined Heat and Power (CHP) to increase efficiency, adjust for higher fuel costs, and reduce total emissions [30]. CHP meets the need for both heat and electricity. After electricity is generated, the resulting heat can be diverted for steam generation or drying. Deriving joint functions from a single source achieves a reduction to fossil fuel combustion, and thus a reduction in GHG emissions. Table 2 illustrates the advantages of adopting CHP measures on site, in terms of CO_2 reduction and energy consumption per produced gallon of ethanol.

Characteristics	**Natural Gas (No CHP)**	**Natural Gas (CHP Turbine w/ Export)**	**Coal Base (No CHP)**	**Coal CHP (Boiler/Steam Turbine)**	**Biomass Base (No CHP)**	**Biomass CHP (Boiler/Steam Turbine)**
Net Fuel Use (Btu/gal)	40,560	22,738	50,178	45,925	53,540	49,675
Net CO_2 emissions (ton/yr)	132,206	17,265	266,822	251,738	45,169	4,204
Net CO_2 emissions (lbs/gal)	5.29	0.69	10.67	10.07	1.81	0.17

Table 2: Analysis of CO2 emissions for CHP and non-CHP energy use [31]

As indicated by EPA's report on CHP, the combination of on-site cogeneration with biomass power leads to the lowest carbon emissions per gallon of ethanol produced. However, natural gas requires fewer inputs per gallon produced. If rising natural gas costs drive producers to coal-based generation, CO_2 emissions will be higher than the alternatives. However, if producers opt to use biomass fuel sources instead, CO_2 emissions may improve. Regardless of the fuel source, use of CHP systems provides another benefit: proximity to the boiler allows for reduction of total VOC emissions [30].

4.2.5.2 Wastewater

Any production of ethanol from corn starch requires water inputs. The corn must be mixed with water before fermentation can occur, and on-site energy production requires additional water. Older methods of production required an average of 11 gallons of water per gallon of ethanol produced, but technological improvements have lowered that ratio to between 3:1 or 4:1 [32]. Process water is added to corn inputs to create the slurry medium in which fermentation occurs. Following fermentation and extraction of the ethanol, DDG are removed and soluble wastes remain in the process water. These soluble wastes are organic and cannot be discharged into rivers without treatment [6]. Ethanol processing plants employ a variety of methods to process these wastes on-site, including centrifuges, evaporation, and anaerobic digestion [32]. Following this on-site treatment, any remaining wastewater must be sent to public wastewater treatment facilities. However, most new ethanol plants have on-site treatment facilities and discharge no wastewater to the environment or other facilities. The majority of this treatment is a function of the anaerobic digesters, which reduce organic solubles by 85-95 percent [6].

The majority of water consumed in the production process is used for energy production. Steam generation in boilers and cooling systems are the most water-dependent aspects of energy production. There are evaporative losses from these systems, but some of the water can be recycled and re-used, depending on the technology employed [32]. Water is also lost in the exportation of DWG, which are used as feed for livestock [33]. Technology is in development that could significantly reduce the water consumed in cooling towers, and researchers are exploring alternative means of distillation and drying in order to reduce evaporative losses [32].

4.2.6 Ethanol Facilities

As of 2006, there were 116 ethanol production facilities in operation throughout the country [34]. These facilities have an annual production capacity of over 5.4 billion gallons [34]. Additionally, 68 new and expanding production facilities are under construction with an expected increased capacity of 4 billion gallons by the end of 2008 [34]. Indiana is also experiencing an expansion of ethanol capacity and Indiana ethanol production could rise 200 percent by 2009 [35].

Operational ethanol plants	**Year**	**Town/County**	**Corn needed in millions of bushels**	**Estimated production level in million gallons**
Central Indiana Ethanol	2007	Marion/Grant	15	40
Iroquois BioEnergy	2007	Rensselaer/Jasper	15	40
New Energy	1985	South Bend/St. Joseph	37	100
POET Biorefining	2007	Portland/Jay	24	65
The Andersons	2007	Clymers/Cass	40	110
Verasun	2007	Linden/Montgomery	37	100
			168	**455**

Ethanol plants under construction	**Town/County**	**Corn needed in millions of bushels**	**Estimated production level in million gallons**
Altra	Cloverdale/Putnam	22	60
Aventine Renewable Energy	Mt. Vernon/Posey	81	220
Cardinal Ethanol	Harrisville/Randolph	37	100
Indiana Bio-Energy	Bluffton/Wells	37	100
POET Biorefining	Alexandria/Madison	22	60
POET Biorefining	North Manchester/Wabash	24	65
		223	**605**

Proposed ethanol plants which received state incentives	**Town/County**	**Corn needed in millions of bushels**	**Estimated production level in million gallons**
ASAlliances Biofuels LLC	Tipton/Tipton	37	100
Central States Enterprises Inc.	Montpelier/Blackford	40	110
Hartford City Bio-energy, LLC	Harford City/Blackford	33	88
Rush Renewable Energy	Rushville/Rush	22	60
		132	**358**

Table 3: Corn-based ethanol production in Indiana given by existing ethanol plants, plants currently under construction, and those currently proposed [35].

4.2.7 Ethanol Yields

As a starch crop, corn has a lower relative ethanol production yield compared to other feedstocks. Corn yields approximately 313 gallons of ethanol per acre of cropland, while sugarcane produces more than twice the amount, or approximately 652 gallons of ethanol per acre. [36]. Thus, while the United States and Brazil currently produce similar quantities of ethanol, the US devotes twice the cropland to fuel production.

Ethanol has a heat content of 3.5 million Btu per barrel compared to gasoline's 5.25 million Btu per barrel, giving ethanol only 67 percent of the heat content of gasoline [37]. Based on this calculation, US ethanol production in 2006 of 4.85 billion gallons was equivalent to only 3.2 billion gallons of gasoline [36]. Given this disparity, even if all 10.5 billion bushels of corn cultivated in the US in 2006 were devoted to ethanol production, the resultant 18.9 billion gallons of ethanol would displace only 13.4 percent of total US demand [1]. Furthermore, 137 million acres of cropland would be required to harvest enough corn to displace 50 percent of the United States' petroleum imports [1]. Given that US famers have harvested no more than 76 million acres of corn annually in the past 60 years, corn based ethanol is not a potential replacement for US gasoline consumption [1].

4.3 Biodiesel

The military first used the chemical reactions required to make biodiesel during World War II in order to make biodiesel for heavy-duty machinery and glycerin for explosives [38]. In 2005, 1.5 percent of the US soybean harvest produced 256 million liters of biodiesel. This supplied approximately 0.09 percent of total diesel demand in the US that year [39].

4.3.1 Feedstocks

Biodiesel can be made from virtually any oil, including vegetable and seed oils, animal fats, and waste oils. Soy is the most common feedstock used in American biodiesel production. In Indiana, soy is the only feedstock grown in sufficient magnitude to produce large quantities of biodiesel. However, there are other sources that could be utilized to produce biodiesel, such as waste oil or pork by-products [40].

Oil producers prepare soybeans by removing stems, leaves, dirt, and finally, the hull. Production facilities then remove oil by crushing the soybean or through solvent extraction. Next, producers degum the oil by adding water and agitating the mixture at a low heat. The oil is degummed to remove impurities, to create high quality oil for biodiesel production [41]. Finally, producers add citric acid. The by-product, lecithin, is edible and typically sold for use in feed [42].

To ease production, most producers typically refine, bleach, and deodorize (RBD) soybean oil. Refined oil, known as RBD, removes many of the impurities found in production outputs. Bleached oil allows quality control technicians to recognize problems more easily. Deodorized oil prevents odors from making production, distribution, and use disagreeable to workers and consumers. It takes approximately 100 lbs of soybeans and 10 lbs of methanol to produce 100 lbs of biodiesel and 10 lbs of glycerol [42].

Rapeseed is the oilseed that produces canola oil, and is the feedstock of choice in Canada and Europe, where the climate is more favorable for cultivation. Rapeseed produces more oil per acre than soy, but does not grow well in Indiana weather conditions [43]. Other crops, such as oil palm, coconut, and jatropha, also have much higher oil content and a higher oil yield per acre than soy [44]. Another factor that restricts the use of certain feedstocks is the temperature at which the oil gels. Soy has a lower gel point than do many other feedstocks [45]. Additionally, Indiana's cold winters restrict feedstock choices, as certain feedstocks require indoor or heated storage and transportation [46].

4.3.2 Biodiesel Production Process

The production of biodiesel is a relatively simple chemical reaction known as transesterification. In this process, biodiesel is made using heat or pressure in combination with a catalyst (such as sodium hydroxide, sodium methylate, or potassium hydroxide) that transforms oil and methanol into alkyl esters (biodiesel) and glycerin [42]. The production process requires approximately 87 percent oil, 12 percent alcohol, and one percent catalyst [47]. If the oil contains more than four percent fatty acids (as is the case with animal oils or waste oils such as used cooking oils from restaurants), it must be treated and cleaned. Biodiesel must be washed with water to remove excess catalyst, alcohol, and glycerin [42].

In the United States, biodiesel must conform to American Society of Testing Materials (ASTM) standards. As of 2001, ASTM approved a standard allowing up to 20 percent blending of biodiesel [48]. This standard (ASTM D-6751) prescribes several tests for content, flash points, impurities, and other attributes [49]. In recent years, many producers have opted to participate in a program called BQ-9000, which is associated with the National Biodiesel Board and aims to provide quality control measures and promote consumer confidence in biodiesel.

According to the Indiana State Department of Agriculture (ISDA), there are four biodiesel production facilities in Indiana. All of these facilities are located in the northern half of the state and all use soybean oil as their primary input. The facilities have capacities ranging from 5,000,000 gallons per annum to 88,000,000 gallons per annum [35].

4.3.3 Costs of Production

The greatest cost in biodiesel production is the feedstock. According to Pimentel et al. in 2005, the cost of inputs to produce 2204 lbs of soy biodiesel is $1,212.16, with $1,117.42 of that cost the soybeans themselves [50]. At the current point in time, biodiesel production costs are not competitive with conventional diesel. The National Academy of Science stated that the estimated production costs for soybean biodiesel was $0.145 per diesel energy equivalent gallon whereas diesel wholesale prices averaged $0.122 per gallon [39].

Biodiesel production technology has already reached maturity. The transesterification process is already efficient, and researchers do not expect substantial gains in efficiency in the coming years [40]. However, there are several ways that biodiesel production can be made more cost efficient.

One way that producers can lower the costs is to increase production scale. The past several years have seen a trend towards larger producers as it offers several cost advantages [40]. First, producers can put pressure on input and transportation suppliers. Second, producers can lower production costs by producing more with equivalent levels of capital and labor. However, there is a ceiling to these savings, as demand for biodiesel is limited. Without artificial increases in demand or a drastic change in the economics of biodiesel production, these benefits will not materialize [51].

Another potential way that producers can lower costs is by purchasing genetically modified soybeans. Researchers have been working to increase the amount of oil produced per soybean acre, to lower the gelling point, and to reduce future emissions from soy based biodiesel [52].

4.3.4 By-Products and Emissions

Biodiesel production is a low air-emissions process. NREL modeling of emissions and byproducts for the biodiesel conversion process discounts all emissions other than those associated with steam and electrical generation [53]. As demonstrated in the above discussion of air emissions associated with corn ethanol production, the quantity of criteria pollutants associated with steam and electrical generation is dependent on a number of variables including the nature of the source fuel and whether the power and steam are generated via cogeneration or purchased from external sources [30].

Heat is required during the transesterification process to improve efficiency. As such, the use of natural gas or some other source of energy is necessary. Many facilities also refine the fuel and other by-products using steam, which requires the use of an outside source of energy. It is theoretically possible for the facilities to burn glycerol or use a diesel generator to produce the heat required for the production process. However, it is more economically efficient to sell the diesel and glycerol, since using them as a source of energy would require additional expensive machinery [40].

Wastewater is another by-product that biodiesel production facilities emit. Water is used to refine the products of the transesterification process and to transport heat. Efficient facilities minimize their water losses by reusing water as much as possible, through capturing steam and the utilization of other methods [40].

Salt is also a typical by-product of transesterification. While salt potentially has many industrial uses, it is usually not of sufficient purity. Ron Howe, of Integrity Biofuels in Morristown, IN, stated that the Integrity Biofuels production facility sends excess salt to the landfill. The amount of salt generated from transesterification is minimal (about 1 lb for every 100 lbs of biodiesel) [40].

4.4 Cellulosic Ethanol

4.4.1 Basic Cellulosic Biomass Conversion Technologies

Cellulosic biomass is the fibrous, woody portion of a plant that that makes up 75 percent or more of all plant material [54]. Due to the makeup of cellulosic biomass, the entire plant can be used in the production process. Therefore, the yield of sugar per unit of land per year is much higher than corn. Cellulosic biomass can be derived from feedstocks such as corn stover, switchgrass, and short rotation woody crops including willow and poplar. A joint analysis by DOE and USDA shows the US could sustainably produce 1.37 billion dry tons of biomass annually for energy production by the middle of this century and still be able to meet all food, feed, and export demands [55]. As such, corn ethanol will not be the final biofuel infrastructure; it is adequate to be the transition to the inarguably more sustainable and beneficial cellulosic ethanol [55].

There are two conversion processes used to break down cellulosic biomass: thermochemical conversion and biochemical conversion. Both processes are complex due to the fibrous structure of the plant cell walls [59]. Cellulosic biomass is comprised of three primary components: cellulose, hemicellulose, and lignin. The proportions of these components vary within each biomass, and when combined, comprise more than 90 percent of a plant's dry mass [60]. These components make cellulosic biomass more resistant to being broken into simple sugars than traditional first generation biomass feedstocks [36].

Cellulose is a complex carbohydrate made from six-carbon (C-6) sugars, also known as glucose. Cellulose is the most common carbohydrate in all forms of biomass; generally it constitutes 40-55 percent of plant biomass [36]. Hemicellulose is a complex carbohydrate made up of both C-6 and five-carbon (C-5) sugars. Hemicellulose is a major source of carbon comprising between 20 and 40 percent of total biomass [36]. Finally, lignin is a complex polymer that provides the rigidity and structural integrity in plants and plant cell walls and makes up 10 to 25 percent of total plant biomass [54].

4.4.2 Biochemical Conversion Processes

The biochemical conversion of cellulosic biomass to ethanol involves five basic steps: handling, pretreatment, hydrolysis, fermentation, and ethanol recovery [54]. Each step is discussed in detail below.

Biomass handling

The first step in any biomass conversion process is to reduce the size of the raw biomass. This is done through a grinding or chipping process to make ethanol production more efficient [54].

Pretreatment

During the pretreatment phase, the encapsulating layer of hemicellulose and lignin are broken down into simple sugars, allowing access to the cellulose [60]. As a result, the remaining cellulose is more accessible to enzymatic hydrolysis and further processing [59]. The process of removing lignin from biomass is known as *delignification* [61]. Various technologies have been developed for the delignification process and cellulose recovery.

The pretreatment phase is one of the most expensive processing steps with costs as high as $0.30 per gallon of ethanol produced. However, pretreatment shows the greatest potential for efficiency gains and cost reduction through further research and development [62, 63, 64, 65, 66]. Based on the different chemical compositions and structures of cellulosic biomass feedstocks, available pretreatment methods can be tailored for efficiency and effectiveness.

The most common pretreatment process used for corn stover and switchgrass is the diluted acid pretreatment process. However, due to the difference of the proportion of cellulose, hemicellulose, and lignin components contained in the various cellulosic feedstocks, the optimal pretreatment conditions (temperature, pH, acid concentration, etc.) may differ [67].

Cellulosic Hydrolysis

There are two types of cellulosic hydrolysis: acid hydrolysis and enzymatic hydrolysis. Acid hydrolysis breaks down both hemicellulose and cellulose into simple sugars without the use of expensive enzymes [55]. This process is commonly used with first generation starchy feedstocks.

However, acid hydrolysis is not recommended for second generation cellulosic biomass because the acid tends to degrade too large a portion of the hemicellulose sugars before they can be fermented into ethanol, thus reducing yields [54].

Enzymatic hydrolysis (also referred to as enzymatic sacchrification) is more effective for cellulosic biomass than acid hydrolysis and has already replaced the acid hydrolysis process for traditional starch feedstocks in several ethanol facilities in the US [36, 60]. The remainder of this section will focus on the enzymatic hydrolysis process. In this process, enzymes are used to break down the remaining cellulose into its component simple sugars (glucose and mannose) [36]. Since not all of the hemicellulose is broken down in the pretreatment phase, C-5 sugars, including xylose, still remain at the end of the hydrolysis phase [36].

Fermentation
The fermentation process can occur in two stages: C-6 glucose fermentation and C-5 pentose fermentation. In glucose fermentation, yeast or bacteria induce a chemical reaction that converts simple sugars to ethanol. However, the yeast and bacteria used to ferment C-6 sugars cannot easily ferment the C-5 sugars contained in the remaining hemicelluloses [36]. Thus, the C-5 sugar requires customized and genetically engineered bacteria, also called microbes, to enable conversion to ethanol [36, 54]. Currently, there are no organisms that can efficiently convert both C-5 and C-6 sugars into ethanol [55]. However, researchers are using genetic engineering to develop microbes that can do both simultaneously [54]. The Laboratory of Renewable Resources Engineering (LORRE) is working on genetic transformations that will enable both C-6 sugars and C-5 sugars to be fermented into ethanol [68].

Ethanol Recovery
The completed fermentation process produces an ethanol broth. In this step, the ethanol is separated from the mix of water, microbes, and residue, and is purified through distillation [60]. A final dehydration step removes the remaining water from the ethanol in a manner similar to the corn ethanol production process [54, 55].

After distillation and ethanol recovery, undigested lignin residue remains because it cannot be further broken down through fermentation. The lignin residue can be used to produce the electricity required to power the ethanol production process. Burning residual lignin using the thermochemical process discussed in the next section creates more energy than is required for the production process [54]. The demonstrated yield for this process is 60 gallons of ethanol per dry ton of cellulosic biomass. However, projected yields will be around 80 gallons of ethanol per dry ton of cellulosic biomass [55].

4.4.3 Advanced Biochemical Processing

The five steps discussed above complete the basic enzymatic hydrolysis–ethanol fermentation approach (ES/EF-B). This approach is the most common cellulosic ethanol manufacturing technology [55]. Researchers are striving to implement an advanced version of the ES/EF-B approach called Consolidated Bioprocessing (CBP). CBP uses microorganisms that produce all the necessary enzymes to convert both hydrolyze cellulose into sugar and ferment the C-5 and C-6 sugar found in hemicellulose to ethanol [36, 55]. Alternatively, the development of modified enzymes and fermentation organisms will allow for the incorporation of hydrolysis enzyme production, hydrolysis, and fermentation into a single organism [59]. Projections suggest that this process could yield over 100 gallons of ethanol per dry ton of biomass [55]. The CBP process offers the lowest cost in the long run, but is still in the early stages of development [36].

Demonstrated yield in labs and pilot plants is 60 gallons of ethanol per dry ton of cellulosic biomass. However, projected yields will be around 80 gallons of ethanol per dry ton of cellulosic biomass [55].

4.4.4 Thermochemical Conversion Process

There are two main thermochemical pathways for converting biomass into liquid fuel: gasification and pyrolysis. This section will focus on the gasification process since pyrolysis is best suited to provide fuel for stationary electric power rather than transportation fuel [36].

In the gasification process, raw biomass travels into a high temperature gasification vessel, where oxygen levels are kept low to ensure that the resulting gas does not burn [36]. As a result, all three biomass components are converted into syngas, a synthetic gas made up of hydrogen and carbon monoxide [36]. The syngas is then cleaned before it is converted to ethanol or biodiesel using advanced catalytic conversion such as the Fischer-Tropsch (FT) process. This thermochemical process operates on the same engineering principles that turn coal and natural gas into liquid fuel [36, 69].

Gasification and FT thermochemical process advantages include accommodation of various types of plant material, quickness, high theoretical yields, and simple pretreatment [55]. These techniques can theoretically process batches of different feedstocks and can more easily be combined with existing coal gasification facilities. They also provide the benefit of being able to convert high-energy lignin residues into ethanol, a feat enzymes in the biochemical process cannot yet accomplish alone. The use of the thermochemical process is common for SRWCs such as poplar and willow because they contain significantly more lignin than other types of cellulosic biomass [36]. Lastly, gasification and FT synthesis have the potential to produce more fuel per ton of biomass than the biochemical process.

The thermochemical process is not without disadvantage. First, the gasifiers in the thermochemical process are difficult to control and are subject to tar formation and intensive gas clean up, which reduces the ethanol yield [69]. Also, the thermochemical process only yields about 40 gallons per ton of biomass, making it a much less efficient use of biomass than the biochemical process [70].

To maximize economic and energy efficiency, an integrated cellulosic biomass refinery will have the thermochemical and biochemical conversion processes act on the same feedstock. Ideally, the residual lignin left over after the cellulose and hemicellulose portions of a feedstock are processed biochemically, can be thermochemically converted into electricity to power the plant and the conversion process itself, burned for heat, or gasified and converted to FT fuels [59, 69].

4.4.5 Utilization of Byproducts of Cellulosic Ethanol Production

The main by-product of cellulosic ethanol production is lignin. Lignin is a non-fermentable amorphous polymer composed of randomly branched building blocks (phenylpropenyl) connected by carbon-carbon and ether (carbon-oxygen) bonds [71]. The structure of lignin varies widely across plant species and within the same plant family [71]. Currently, lignin is the main by-product of paper mills and is burned to produce heat, steam, and electricity to run the pulping process, which is estimated to be worth $6 per 10^6 Btu [71].

In October of 2007, Holladay et al. of Pacific Northwest National Laboratory published a comprehensive report on lignin utilization prepared for DOE that demonstrates the possibilities of lignin utilization in the short term (three to ten years), medium term (five to 20 years), and long-term (beyond ten years) [71].

The report identified more than fifty opportunities and narrowed them down based on the following five criteria: technological degree of difficulty, market size and value, market risk, building block utility (whether a candidate compound can be a base of a larger group of derivatives), and mixture (whether a candidate is a lignin-based single compound or a complex mixture of lignin and other compounds). Three short-term, three medium-term, and four long-term candidates are summarized below [71].

In the short-term, gasification, pyrolysis, and hydroliquefication are the three most likely feasible opportunities for the utilization of lignin. Syngas can be produced from lignin through a gasification process, and is considered to be a well-established process in other industries such as the steel industry [71]. Syngas can be converted into hydrogen and carbon dioxide with water-gas-shift technology, green gasoline, or green diesel.

Pyrolysis is a process “that can convert dry biomass to a liquid product known as pyrolysis oil or bio-oil.” [71] Pyrolysis oil can replace a fraction of imported petroleum and be converted into green fuels and chemicals; however, certain technological improvements are still needed.

Another opportunity in the short to medium term is hydroliquefication, in which lignin is converted into reformulated gasoline. NREL and the University of Utah together developed processes to convert lignin into three kinds of fuel additives through depolymerization and hydrodeoxygenation [71].

The three medium-term opportunities for lignin utilization are possible through the expansion of current commercial practices such as concrete admixture, animal feed pellets, dye dispersant, road binders, and dust control to produce higher-value products [71]. One of the utilization options is to produce carbon fibers from lignin. If successful, lignin-based carbon fiber can replace some synthetic polymers such as polyacrylonitrile and can be used in domestic passenger vehicles in place of steel panels. The second possible high-value product is polymer modifiers. Currently produced polymer modifiers are used to improve various polymer physical properties, and modifiers that improve performance properties may be possible in the future [71]. The third possible utilization revolves around resins, adhesives, and binders. Bio-based resins and adhesives have great market potential since they can displace formaldehyde, a suspected carcinogen used in many products such as plywood and fertilizer [72].

The four long-term and more challenging opportunities for lignin utilization could potentially take place through the development of conversion technologies required for aromatic chemicals. One of the four goals of this technological development challenge is to produce high-value aromatic chemicals (BTX chemicals: benzene, toluene, and xylene) through aggressive (non-selective) depolymerization (C-C and C-O bond rapture) [71]. The aromatic chemicals that are produced through this process will further expand the opportunity to produce many other chemicals, such as phenol and xylene that can be used in the petrochemical industry, as fuel additives [71]. Past works involving hydroliquefaction suggest a strong possibility that the process can be successful.

The second possible utilization of lignin is to produce other aromatic chemicals, such as aldehydes, catechols, and cresols, through selective depolymerization [71]. The biggest advantage of this process may be that those chemicals "are difficult to make via conventional petrochemical routes." [71] The third opportunity for lignin utilization is to develop new technology that can produce low molecular weight aromatics (e.g. aliphatics) or other chemicals (e.g. acids, diacids, aldehydes, keto acids, etc.) that could be used as fuel additives to syngas, alkylated gasoline, or propane fuels [71]. The fourth option is to develop fermentation routes available today "that use lignin as a nutrition source," but this option requires more research on viable lignin fermentation processes and it is a "higher-risk area of research." [71]

As mentioned previously, these long-term options most likely require a significant amount of time and financial resources for the research and development of new technology; thus, it may not be realistic to vigorously pursue these options. Rather, they are still subjects to be studied at research laboratories or academic institutes.

4.4.6 Environmental Implications

Although there are no commercial cellulosic plants currently operating in the United States, the indication is that existing processing technologies will keep gaseous emissions well within EPA's New Source Performance Standard limits. The sources of gaseous emissions in the cellulosic process are all derived from the heat sources necessary for the creation of steam (in the case of steam explosion pre-treatment), or for the drying of the lignin-rich residue resulting from the fermentation process. This residue, once dried, can be burned as boiler fuel to provide all necessary heat for the cellulosic ethanol production process, with excess capacity for energy cogeneration. The quality of this solid residue obviates the need for any fossil fuels in the production process [73].

	Carbon Flow (C kmol/hr)	**Ratio to Feedstock Carbon Content (C kmol basis)**
Carbon Inlets		
Stover Feedstock	3,144	1.000
Enzymes	25	0.008
Total	3,169	1.008
Carbon Outlets		
Combustion Exhaust	1,497	0.476
Ethanol Product	1,066	0.339
Scrubber Vent	532	0.169
Ash	16	0.005
Gypsum	10	0.003
Aerobic Vent	3	0.001
Loss to Atmosphere	4	0.001
Total	3,129	0.995

Table 4: Carbon inputs and outputs for the cellulosic ethanol production process Carbon is introduced in the forms of feedstock and enzymes, and is released or captured in the proportions provided by the table. [73]

Fermentation of the biomass itself produces no gaseous emissions other than CO_2. Due to the potential for ethanol vapor loss, fermentation occurs within a closed system, so it is possible to capture all CO_2 emissions from fermentation and pursue a variety of means of sequestration [74].

4.4.6.1 Emissions from Cellulosic Boiler Operations

The flue gases resulting from residue combustion are composed primarily of NO_x, SO_x, and CO. Following processing of the flue gas, solid residues retain no further use, and will necessitate disposal (most likely in landfills). Although the flue gas emissions are by nature undesirable, they contain no components that are inherently hazardous [75]. Furthermore, all emissions levels are required to be in compliance with New Source Performance Standards limits set forth by the Clean Air Act [73].

Sulfur is introduced into the ligonocellulosic processing system via hydrogen sulfide created during wastewater treatment, sulfur contained in the original biomass and residues, and the neutralization of sulfuric acid. According to NREL, sulfur is generated at a rate of 0.68 kg per MWhr [73]. All of the sulfur introduced to the combustor is transformed into sulfur dioxide, with one percent of the resultant SO_2 turning into sulfuric acid. Although the amount of sulfur emitted in the combustor is higher than that generated by combustion of unadulterated biomass, it is lower than average coal combustion emission rates. Limestone can be introduced to the system to lower sulfur count, if necessary [73].

Carbon is introduced to the system via biomass and biomass residue. Following consumption, carbon monoxide is produced at a rate of 0.31 kg per MWhr. There are not many opportunities for a negative carbon balance with this kind of production because those parts of the biomass not directly transformed into ethanol (which will eventually combust and release its carbon) are consumed to produce heat and electricity for the production process. The chief opportunity for carbon sequestration is the extraction of carbon from flue gases to deposit in landfills or subterranean carbon sinks. The vast majority of carbon released to the atmosphere is in the form of CO_2 [73].

Table 4 was developed by NREL and details the carbon balance. The majority of released carbon is from the combustion process, followed in quantity by carbon contained in ethanol and scrubber deposits [73].

NO_x is generated at a rate of 0.31 kg per MWhr within the ligonocellulosic processing system, assuming ammonia is used to control NO_X formation. When ammonia is introduced, combustion can also produce N_2O (nitrous oxide), while reducing total NO_x levels. With ammonia introduced, NO_x production is commensurate with that associated with coal combustion. Without ammonia, NO_x levels produced are the same as burning untreated biomass [73].

	Total Flow (kg/hr)	Water Flow (kg/hr)
Process Inlets		
Stover Feedstock	98039	14706
Enzymes	6824	6255
Chemicals & Nutrien	7239	0
Air	310255	3382
Well Water	186649	186649
Inlet Total	609006	210992
Water Consumption/Generation		
Prehydrolysis		-2788
Saccharification		-2736
Combustion		20035
Wastewater Treatment		371
Consumption/Generation Total		14882
Process Outlets		
Ethanol Product	24686	122
Evaporative Losses	195993	156291
Vents to Atmosphere	375443	68051
Solids to Landfill	12718	2194
Outlet Total	608840	226658
Water Difference (inputs+consumption+generation-outputs) = -784		

Table 5: Water inputs and outputs for the cellulosic ethanol production process. Water is introduced via feedstock, enzymes, chemicals and nutrients, air, and well water, and is released or captured in the proportions provided by the table [73].

4.4.6.1 Water Consumption

The hydrolysis process produces wastewater containing complex chemicals that cannot be released into ground water. However, the compounds can be removed through the use of treatment facilities that are now often installed on-site at the production plant. This allows the plants to operate without producing any wastewater that necessitates handling by municipal water treatment plants. This internal purification process of removing the compounds via anaerobic decomposition produces methane, but the methane burned for the creation of steam, the drying of residue, or for assistance in energy cogeneration is not emitted to the atmosphere [6].

Although new plants are intended to be completely closed systems, some water is inevitably lost via consumption in hydrolysis or via evaporation and purposeful venting into the atmosphere. Any water lost is replaced by well water to be used during the hydrolysis process. The following table was produced by NREL and details total water flow.

4.5 Feedstocks

4.5.1 Cornstover

Corn stover is a type of lignon cellulosic biomass. It consists of the stalks, leaves, and cobs remaining above ground after the corn kernels have been harvested [56]. Since no extra investment is required to produce corn stover, it is considered to be one of the most preferred sources of feedstock for Indiana cellulosic ethanol production. Corn stover is converted into ethanol via the biochemical process.

4.5.2 Switchgrass

The Bioenergy Feedstock Development Program examined over 30 herbaceous crops during the 1980s, and selected switchgrass in 1991 as an excellent potential crop for bioenergy in the US because it grows well under a wide range of conditions, prevents land erosion, and can be harvested by conventional farming methods [57, 58].

4.5.3 Short Rotation Woody Crops (SRWCs)

There are many benefits to using SRWCs as biomass feedstocks. Woody biomass possesses a high lignin content, which is considered attractive for gasification and conversion to ethanol or synthetic diesel fuel. SRWCs also produce less ash than agricultural residues, which makes them easier to gasify [36].

4.6 Cellulosic ethanol plants

In 2007, DOE elected to support six cellulosic ethanol plants with $385 million in federal funding [76, 77]. In addition, on January 30, 2008, DOE selected three cellulosic plants in which it will invest over $84 million in the next four years [78]. Table 6 provides additional details about the nine plants. DOE selected various kinds of plants; some process woody biomass, while others process agricultural residues and switchgrass. In addition, some plants will use thermochemical processes to convert biomass to ethanol and the others will use biochemical processes [76, 77, 78]. The knowledge gained from these projects will provide practical and useful information for other commercial-scale cellulosic plants.

Company	Location	Capacity (million gallons of ethanol/year)	Construction Timeline (Start-Complete)	Amount Awarded (Upper Limit)	Technology Process	Feedstock (tons/day)
Abengoa (facility) Bioenergy Biomass of Kansas, LLC of Chesterfield, MO	Colwich, KS	11.4; plus power for facility	late 2008-late 2011	$76 million	Thermochemical; biochemical	corn stover; wheat; straw; milo stubble; switchgrass; other (700)
ALICO, Inc. of LaBelle, FL	LaBelle, FL	13.9; plus 6,255 kilowatts of electric; 8.8 tons hydrogen/day; 50 tons of ammonia/day	2008 - late 2010	$33 million	Thermochemical gasification / ermentation	yard; wood; vegetative wastes (citrus peel); eventually energycane (700)
BlueFire Ethanol, Inc. of Irvine, CA	Southern California	19	mid-2008 - late 2009	$40 million	Concentrated acid hydrolysis	sorted green waste; wood waste from landfills (700)
Broin Companies of Sioux Falls, SD	Emmetsburg, IA	125; 25% cellulosic ethanol	2007 - 30 mo. Later	$80 million	Biochemical integrated into corn dry-mill infrastructure	corn fiber; cobs; stalks (842)
Iogen Biorefinery Partners, LLC, of Arlington, VA	Shelley, Idaho	18	2008 - late 2010	$80 million	Biochemical	wheat straw; barley straw; corn stover; switchgrass; and rice straw (700)
Range Fuels of Broomfield, CO	Soperton, GA	40; plus 9 million gallons of methanol/year	2007 - 2011	$76 million	Thermochemical conversion	wood residues; wood based energy crops (1,200)
ICM Inc.	St. Joseph, MO	N/A	Start 1 year after receiving funds	$30 million	built adjacent to an existing corn-based ethanol plant	Corn fiber; corn stover; switchgrass; sorghum
Lignol Innovations Inc.	Commerce City, CO	N/A	N/A	$30 million	Biochem-organisolve	Hard and soft wood residues
Pacific Ethanol Inc.	Boardman, OR	N/A	N/A	$24.3 million	Using Danish company BioGasol's proprietary conversion	Agricultural and forest product residues

Table 6: A summary of the nine cellulosic ethanol plants supported by the US Department of Energy pilot cellulosic biofuels program [76, 77, 78].

4.7 Current Costs and Targeted Costs in 2012 of Cellulosic Ethanol Production

Although the biomass feedstocks for cellulosic ethanol are relatively inexpensive, the conversion technology is still quite expensive; one of the largest costs associated with cellulosic ethanol production is cost of the enzymes which convert cellulose to sugar [79]. NREL and DOE have contracted with the world's two largest enzyme companies, Genecor International and Novozymes, to reduce the cost of producing these cellulases [80]. The goal is to bring the cost of the enzymes down to about $0.10 per gallon of ethanol produced, a key factor for the cost competitiveness of cellulosic ethanol [60]. Novozymes announced in early 2005 that it had reduced the cost of enzymes to $0.10-$0.20 per gallon of ethanol, far less than the previous costs of approximately $5 per gallon [36].

Process Area	**2005 State of Technology**	**2009 Target**	**2012 Target**
Prehydrolysis/treatment	0.44	0.31	0.25
Enzymes	0.32	0.33	0.10
Saccharification& Fermentation	0.31	0.27	0.10
Distillation & Solids Recovery	0.18	0.17	0.15
Balance of Plant	0.34	0.27	0.22
Processing Total	1.59	1.35	0.82

Table 7: Costs (($/gallon in 2007 $s) associated with biochemical conversion of corn stover to ethanol [79].

Over the past decade, the cost of cellulose per gallon of ethanol has decreased from about $5 to about $0.50; however, this cost is approximately 20 times higher than the cost for enzymes in corn ethanol production [70]. Table 7 and Table 8 demonstrate the current costs and targeted costs for the years 2009 and 2012 for each type of cellulosic conversion technology [79]. Table 7 demonstrates that the largest cost of the corn stover cellulosic production process is pretreatment, but significant cost reductions can be achieved through the development of bioconversion technology such as enzymes and fermentation [79]. Table 8 demonstrates that the largest cost reduction of woody biomass cellulosic ethanol production can be achieved through the development of synthesis gas clean up and conditioning technologies [79].

Process Area	**2005 State of Technology**	**2009 Target**	**2012 Target**
Feed Handling and Drying	0.18	0.17	0.16
Gasification	0.14	0.13	0.13
Synthesis gas Cleanup & Conditioning	0.69	0.62	0.43
Fuels Synthesis	0.08	0.05	-0.03
Product Recovery and Purification	0.05	0.05	0.05
Balance of Plant	0.08	0.10	0.08
Processing Total	1.21	1.11	0.82

Table 8: Costs (($/gallon in 2007$s) associated with thermochemical conversion of hybrid poplar to ethanol [79].

As production facilities continue to improve technology, production costs of cellulosic ethanol will most likely decrease. However, production costs themselves are only one component of total biofuels costs. The harvest and initial transportation of these feedstocks from the field to the production facility, and the distribution of fuel from the facilities are important components of the total cost of biofuel production; these factors can significantly influence the location of biofuel production facilities.

4.8 Indiana Workforce and Employment Impacts

Economic impact analyses of biofuels production must take into account inter-industry relationships within regions. There are a wide range of input-output models which evaluate the potential employment benefits for communities that participate in biofuels production. These modeling systems estimate inter-industry transactions demonstrating the economic impacts of any changes to the economy. Common mechanisms that estimate the economic effects of biofuels production include the Regional Input-Output Modeling System (RIMS II), developed by the US Department of Commerce, and the Minnesota IMPLAN input-output model. An integrated input-output econometric model developed by Regional Economic Modeling, Inc. (REMI) can also estimate economic effects. The different models have varying levels of complexity, with RIMS II being the least complex and REMI being the most complex; the cost of these models increases with their complexity.

An advantage of RIMS II includes the estimation of regional multipliers without conducting expensive surveys. The level of industrial detail for RIMS II minimizes aggregation error and a consistent set of estimating procedures allows for multiplier comparison across areas [81]. Furthermore, empirical analyses show that RIMS II data is accurate within 10 percent of locally developed industry multipliers based on expensive surveys [81]. IMPLAN, similar to RIMS II, is calibrated for a specific region, but unlike RIMS II, it uses computer software and can alter default settings and adjust model specifications before it obtains economic multipliers [81]. While RIMS II and IMPLAN are considered static models, REMI represents a dynamic model or simulation which provides insight to long-term economic impacts. The REMI model is able to stimulate how long-run impacts may differ from short-run impacts due to induced changes in competition for labor, population migration rates, labor or capital substitution, and inflation [82].

When estimating net employment effects, a distinction is made between direct, indirect, and induced employment effects. Indirect employment effects arise from production input purchases made by ethanol plants in the regional economy. Major inputs include corn, natural gas, and electricity, which are only a small fraction of ethanol production inputs [83]. The more purchases the ethanol plant makes from regional suppliers (transportation, maintenance, accounting and financial, business, legal services), the higher the potential local economic impact [83]. Thus, indirect employment effects are jobs created as a result of business-to-business transactions between the ethanol plant and other businesses. Induced employment, in turn, includes additional jobs created from activity associated with spending on household goods and services in the local economy. Direct, indirect, and induced effects give the total effect on employment that is potentially attributed to the biofuels plant [83].

Several studies attempt to estimate the effects of biofuels production; each suggests that there are several potential regional economic benefits that could occur as biofuels production increases. One 2002 study examined the economic benefits to a local community of building and operating a 40 million gallon-per-year (MGY) dry mill ethanol plant. This study estimated job impacts by applying final demand multipliers calculated by the US Bureau of Economic Analysis (BEA). The 2002 study concluded that a 40 MGY ethanol plant will create approximately 41 permanent new jobs as direct employment and 653 additional jobs throughout the economy as a result of new demand for local businesses [84]. Thus the total effect on employment is 694 new jobs. Since the multiplier effect is the ratio obtained by dividing the total value by the direct value, this study implies that there is an effective jobs multiplier of 17, meaning every job in an ethanol plant produces 16 other jobs in the regional economy.

As of 2007, Indiana had six operational ethanol plants with an average capacity of 75 MGY (455 MGY total production capacity) and six more are under construction with a total production level of 605 MGY (average capacity of 100 MGY) [35]. Iowa State University economist David Swenson conducted an analysis concluding that an ethanol plant's direct employment is 35 jobs, indirect – 76.9, induced – 23.5, implying a multiplier effect of 3.87. That means that for every job in the ethanol plant, 2.87 jobs are created in the rest of the economy [83]. According to the Indiana Department of Workforce Development, ten existing and under-construction ethanol plants create an average of 53.7 direct jobs [85].

Several studies also examine the economic benefits of biodiesel production. Bowman estimated the total employment impact is 1,240 jobs, 3,020 jobs, and 10,600 jobs for two, five, and 20 percent blends respectively in Kentucky [86]. Another study conducted by the University of Missouri utilized the IMPLAN model and found a soy diesel plant with annual production of 4.5 MGY in Missouri could create 243 new jobs, 81 of which were direct jobs [86]. Thus, the multiplier effect is three. Similar to Swenson's analysis, the University of Missouri study assumed that there would be no new agricultural production due to biodiesel manufacturing [86].

Purdue University used the IMPLAN model to conduct another study which estimated the potential effects of biofuels production on Indiana employment. An average Indiana biodiesel plant is expected to create 21 direct jobs, and an additional 467 jobs, resulting in a multiplier of 22 [87]. The static IMPLAN model makes projections assuming that all of the necessary resources are available, prices are constant, and demand for inputs as well as outputs will not change. According to Purdue University researchers, increased soybean production revenues come from higher yields, the conversion of non-farmland into soybean acres, or the shift of corn acreage to soybean production. Since the only data available were revenue effects from a switch in corn production to soybeans, researchers adjusted the soybean revenue. Reducing Indiana corn production had a considerable impact on employment effects. Total employment decreased from 467.3 workers down to 133.1 workers [87]. Thus, the multiplier effect including corn adjustments decreases from 22 to six.

The results of different studies and analyses differ depending on the models and assumptions used, but nevertheless all of these studies conclude that ethanol and soy diesel manufacturing are likely to bring positive employment effects in direct, indirect, and induced employment opportunities. As of 2007, biofuels production facilities employed and projected to employ 905 workers in 15 biodiesel and ethanol plants (including those under construction) [85]. The University of Georgia Center for Agribusiness and Economic Development released a study in 2007 concluding that the average earnings for an ethanol plant employee with benefits is $43,348 [88]. This provides Indiana with a net gain in direct employment revenue of $39,229,940.

4.9 Conclusions

Future biofuels production in Indiana will likely incorporate a combination of corn ethanol production, soy biodiesel production, and cellulosic ethanol production from feedstocks such as corn stover and switchgrass. Corn ethanol and soy biodiesel production techniques involve mature production technologies that have already been improved and refined over several decades. Future efficiency gains in these areas are believed to be limited at best. However, continued capacity expansion in both areas and the allocation of larger proportions of the total corn and soy harvest toward biofuels production suggests that both ethanol and biodiesel produced from these feedstocks will continue. Also, the development of “closed-loop” systems may significantly reduce the carbon footprint of biofuels production.

If biofuels are to be considered a serious alternative to gasoline, cellulosic production must be commercialized. Initially the state should focus on cellulosic production using corn stover. Indiana is one of the nation’s largest corn producers and, as such, corn stover is readily available. The creation of ethanol from corn stover requires the use of the biochemical production process. For this technology to be successfully commercialized, continued research and development must be conducted to fine-tune enzymatic hydrolysis and reduce the costs of pretreatment. Enzymatic hydrolysis, the process by which cellulose is broken into simple sugars, depends upon the creation of new enzymes to improve the efficiency of the production process. Through continued investment in research and development, it is believed that cellulosic production can be successful commercialized by 2012. Through the use of tailored incentives toward R&D and the establishment of production facilities, Indiana can become one of the nation’s leaders in cellulosic production. Incentives should be provided for the first commercial cellulosic facility and the first combination facility, in which corn ethanol and cellulosic ethanol are both produced at the same site.

Research should also investigate the possibility for switchgrass ethanol production, in particular with regard to the environmental benefits associated with the feedstock. A transition toward switchgrass as a cellulosic feedstock is believed to be a longer term solution, due to the need to transition cropland toward its production.

Finally, although thermochemical production has been discounted to a large extent due to the timeframe restraints of this research, this production technique may well become viable in the future. In particular, the ability of this technique to take residual lignin, resulting from the biochemical process and convert it into starch. By linking the biochemical and thermochemical processes, a more complete cellulosic market will be possible.

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5. Engine Compatibility

5.1 Introduction

In the United States, spark-ignited internal combustion engines and diesel engines power vehicles on the road today. The traditional combustion engine can run on conventional gasoline or a retrofitted combustion engine, a flex-fuel engine, can use up to 100 percent ethanol as fuel. Currently, almost 700 filling stations nationwide provide E85 blended fuel. Several major car manufacturers are committed to dedicating half of their production to flex-fuel vehicles by 2012, which would inevitably increase the demand for E85 filling stations and in turn ethanol-based biofuels. Compared to traditional combustion engines running on gasoline, current research indicates that the amount of flex-fuel engine pollutant emissions varies across the range of particulates. However, these engines result in decreased fuel efficiency.

The majority of buses and medium to heavy trucks on the road today depend on diesel-powered engines. Currently, manufactures only recommend using between five and twenty percent biodiesel blends because diesel engines running on higher percentage blends have the potential to damage engine components. The widespread usage of biodiesel is dependent on resolving the fuel's negative properties, but current research indicates biodiesel decreases pollutant emissions in most categories.

Biodiesel blended with aviation fuel is a possible alternative for turbine engines, but as with diesel engines on the road, engineers must combat many negative properties of the fuel.

5.2 Spark-Ignited Engines and Ethanol

Spark-ignited internal combustion engines operate by creating an explosion from a mixture of fuel and air inside a confined space called a combustion chamber, or cylinder. This exothermic reaction creates gases at a high temperature and pressure, which expand inside the chamber. The gases then act upon a piston inside the chamber pushing it upward. Each piston is linked to the crankshaft by a connecting rod. When the combustion chambers fire in succession, they turn the crankshaft. The crankshaft converts the piston's motion into rotational energy, which is then transferred through the transmission to turn the wheels of the vehicle [1].

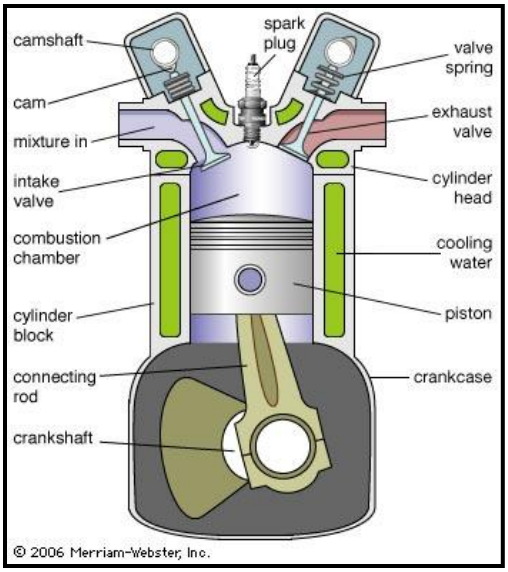


Figure 14: Internal Combustion Engine [2]

5.2.1 History of Spark-Ignited Internal Combustion Engines

Spark-ignited engines designed to burn ethanol have been in widespread use for over 100 years. American inventor Samuel Morey built the first spark-ignited internal combustion engine in the US in 1826. His design relied on a mixture of turpentine and ethanol and could power a car as well as a boat [3]. In 1876, German inventor Nikolaus Otto used ethanol to power a modern internal combustion engine and placed it in the first motorcycle, dubbed the "Otto Cycle." [4] In 1896, American inventor Henry Ford built his first automobile, the Quadricycle, which also relied on ethanol. Ford went on to develop the world's first flex-fuel vehicle, the 1908 Model T, designed to run on either ethanol or gasoline [5]. Since then, ethanol engine technology has improved dramatically [6, 7].

5.2.2 Flex-Fuel Engine Technology

Currently, the US automobile fleet contains over six million flex-fuel vehicles. Nearly 700 filling stations offer E85 fuel, which is a blend of 85 percent ethanol and 15 percent gasoline. Flex-fuel engines are available in a wide range of makes and models. Ford, General Motors, and Chrysler plan to make half of their production flex-fuel capable by 2012 [8]. Modern flex-fuel engines operate similarly regardless of fuel type. The payload and acceleration characteristics of flex-fuel engines are also comparable to their conventionally fueled counterparts. Flex-fuel engines can operate with any blend of ethanol and gasoline.

The engine's fuel system constantly monitors the levels of ethanol and gasoline in the tank allowing the engine to adapt as the mixture changes [9]. Ethanol can be mixed with water, and water vapor presents challenges in the fuel system that gasoline does not. Components made of brass, copper, and aluminum can corrode; therefore, flex-fuel engines cannot utilize these components [10]. Ethanol can also react with many kinds of rubber and cause obstructions in the fuel system. Fluorocarbon rubber, Teflon-lined hoses, and stainless steel fuel tanks are commonly employed in flex-fuel vehicles to counteract this problem [9, 11].

While the conversion of any conventionally fueled vehicle to E85 is technically feasible, only one conversion kit has been approved for use in the US. Flex-Fuel US received EPA certification in November 2007 for its "Flex-Box" conversion kit designed for use in the Ford Crown Victoria [9]. The kit sells for $1,500 plus installation charges and the Chicago Police Department has installed the kits in a 20-car demonstration project [12]. The Crown Victoria kits should be commercially available soon, and kits for other makes and models will enter the market as they complete the EPA certification process.

Flex-fuel vehicles cost slightly more to produce than their conventionally fueled counterparts. The additional cost to the manufacturer is estimated to be as low as $200 per vehicle [13]. Automotive manufacturers are currently offering flex-fuel vehicles at the same price as conventionally fueled models [5, 14]. Automakers are allowed to claim Corporate Average Fuel Economy (CAFE) emissions credits for flex-fuel vehicles so consumers are not directly impacted by the increased cost of production at the present time [15].

5.2.3Future Possibilities for Flex-Fuel Engine Technology

Current flex-fuel engines are constrained because they must use both gasoline and E85 interchangeably. This prevents the optimization of ethanol engine design and limits the fuel's potential. An optimally designed engine can exploit several beneficial characteristics of ethanol such as increased octane, a higher latent heat of vaporization, and improved laminar flame speed [6, 7].

Higher Octane
Ethanol has a higher octane than gasoline and is often employed as a gas additive to increase octane. Most E85 pumps advertise a minimum octane of 100. Fuels with higher octane numbers mean engines running on ethanol can operate at higher compression ratios without pre-ignition [16]. Increasing the compression ratio can improve performance and maximize the benefits from ethanol's higher octane level [6].

Latent Heat of Vaporization
Ethanol has a higher latent heat of vaporization than gasoline and provides a greater charge density [17]. The latent heat of a substance is the amount of heat energy released during a change of phase. Substances change phase when they go from solid to liquid or liquid to gas [18]. Latent heat of vaporization refers to the energy necessary to convert a unit of the substance from liquid to gas if pressure and temperature are constant [19]. The latent heat of vaporization for ethanol is three to five times higher than gasoline, which translates into decreased temperatures in the intake manifold and increased volumetric efficiency [7].

Laminar Flame Speed
When fuel is mixed with air in a combustion chamber and then ignited, a flame front is created around the spark. The flame front spreads outward inside the chamber from the point of ignition. The laminar flame speed is a measure of how fast the flame front moves through the combustion chamber. Ethanol has a higher laminar flame speed than gasoline which permits "leaner" air-fuel mixtures [20]. The stoichiometric air-fuel ratio (AFR) for gasoline is 50 to 65 percent higher than the AFR for ethanol, meaning less air is required for complete combustion with alcohol-based fuels [7].

5.2.4 Problems Associated with Ethanol

Cold Starting Issues
In the past, engines running on alcohol fuels experienced problems with cold starting. Below 11 degrees Celsius, ethanol begins to freeze and the fuel-air mixture is not rich enough to support combustion [21]. Alcohol-based fuels are less volatile than gasoline, which is why they produce fewer evaporative emissions and why cold starting is an issue [6]. When an engine is designed to run specifically on alcohol, it can accommodate the different properties of the fuel. Research suggests that the problems caused by low octane number and vapor pressure can be solved with higher energy ignition systems or higher compression ratios [6]. Ongoing experiments at EPA's National Vehicle and Fuel Emissions Laboratory have demonstrated consistent starting down to zero degrees Celsius [22].

Lower Energy Content
One of the major differences between ethanol and gasoline is energy content. The heating value of alcohol is lower than that of gasoline meaning that it takes more alcohol to achieve the same energy output in an engine [7]. E85 contains 28 percent less energy per gallon than gasoline, and most flex-fuel vehicles experience a 20 to 30 percent reduction in fuel economy when running on

E85 [23, 24, 25]. Research has shown that optimizing an engine for ethanol can mitigate reduced fuel economy; however, such engines are not yet commercially available [5, 22].

5.2.5 Current Work at the EPA

According to research from the EPA's Clean Automotive Technology Program, the reduced efficiency associated with ethanol can be prevented through engine optimization. Brake Thermal Efficiency (BTE) measures how much energy from the fuel is transformed into mechanical work by the engine. Higher BTE numbers imply more efficient engines. Modern gasoline and diesel engines have BTEs around 30 percent and 45 percent respectively [26].

With higher compression ratios and modifications to the combustion chamber, port-injected, spark-ignited ethanol engines can be one-third more efficient than current flex-fuel offerings [7]. EPA test engines have demonstrated up to 42 percent BTE which rivals current diesel technology [22]. Similar research into engine optimization with E85 demonstrates a 20 percent improvement in efficiency over standard gasoline engines [20]. Performance and efficiency of engines optimized for ethanol can exceed conventional gasoline engines and approach the efficiency levels of today's best diesel technology with low emissions [6, 22].

52.6 Combustion Engine Emissions

A 2006 EPA comprehensive assessment of the 2005 Renwable Fuel Standard (RFS) employed various models to estimate the emission levels from the combustion of E10. Comparing results from the MOBILE6.2 modeling tool and various other EPA predictive models, the study determined potential emissions differences between E10 and conventional gasoline. A summary of the results of these models and other studies cited in the 2006 EPA Assessment is provided in Table 9 [27].

Pollutant	Effect Range (% Compared to E0)	Overall Effect	Study	Model(s)
CO	-11 to –19	Reduction		MOBILE6.2
NOx	7.7	Increase		EPA Predictive
VOCs	-7.4	Reduction		EPA Predictive
Toxics	Various	Various		EPA Predictive
PM	-81 to +84	Inconclusive	Colorado DPHE, Alaska, EPA Research Triangle	
Aromatics	-0.63 to -2.39	Reduction	AQIRP	

Table 9: E10 Exhaust Pollutant Emissions Compared to Conventional Gasoline (E0) [27]

Ethanol emissions affect ambient concentrations of pollutants such as carbon monoxide (CO), nitrogen oxides (NOx), particulate matter (PM), and volatile organic compounds (VOC) (as a precursor to ozone). These pollutants are especially important because EPA has categorized them as criteria pollutants which are regulated by the Clean Air Act. The EPA models produced varying results while estimating the effects of E10 use. In general, E10 use led to a decrease in VOC and CO emissions and slight increase in NOx emissions [27]. EPA analyzed three independent studies of the effects of ethanol on PM emissions that produced widely differing results [27]. The first study from the Colorado Department of Public Health and Environment compared E10 and conventional gasoline use in 24 vehicles and found a 36 percent reduction in PM emissions from a cold start using E10, but no significant change in emissions from a regular start. The second study, from the State of Alaska in conjunction with General Motors Corporation, studied ten vehicles fueled with E10 and found considerable variability with effects ranging from an 81 percent reduction to an 84 percent increase in PM emissions. The third study, conducted by EPA researchers, found an average one percent increase in PM emissions with the use of E10, but concluded the study showed "no clear effect of ethanol on PM emissions." [27] EPA's analysis of these studies concluded that data are too limited to determine a quantitative estimate of the effect of E10 on PM emissions [27].

Ethanol emissions may also lead to greater levels of toxic gases and aromatics in the air. Toxic pollutant emissions (formaldehyde, acetaldehyde, benzene, etc.) are important to consider due to the potential for detrimental health effects. People exposed to toxic pollutants at high concentrations or over a long duration may have an increased risk of cancer, damage to the immune system, and neurological, reproductive, developmental, and respiratory health problems [28]. Effects of E10 use on toxic emissions vary widely, showing both increases and decreases in emissions depending on the specific toxic gas; however, the effect on one particular toxic gas is striking. EPA models predict that acetaldehyde emissions increase by 143 percent with E10 use [27]. The implications of this effect will be discussed further in the section on E85.

Pollutant	Effect Range (% Compared to E0)	Overall Effect	Study
CO	No significant estimates	None	AQIRP, CFEIS
NOx	-49 to +4	Inconclusive	AQIRP, CFEIS
NMOG	+33 to +56	Increase	AQIRP, CFEIS
Toxics	+108 (net)	Increase	AQIRP, CFEIS
PM		Theoretical increase	SAE
Aromatics		Theoretical reduction	EPA

Table 10: E85 Exhaust Pollutant Emissions Compared to Conventional Gasoline (E85) [27, 30]

Aromatics are pervasive environmental pollutants formed by incomplete fuel combustion. They have been identified as a potential cause of cancer and are also an important emissions category due to their potential relevance to PM. EPA cites emerging research that indicates aromatics from vehicle emissions contribute to PM formation in the atmosphere [27, 29]. An Auto/Oil Air Quality Improvement Research Program (AQUIRP) test of over 100 vehicles found that E10 use resulted in aromatics emissions reductions of 0.63 percent to 2.39 percent over conventional gasoline use.

For higher concentrations of ethanol such as E85, few data are available largely due to their recent commercial introduction and limited use. The data that exist are summarized in Table 10. In general, E85 studies consider many of the same pollutants as E10 studies; however, E85 emissions may have important effects regarding a pollutant not considered in most E10 studies: non-methane organic gas (NMOG).

A 1993 AQUIRP study and a 2006 EPA Certification and Fuel Economy Information System (CFEIS) study analyzed NOx and CO emissions. AQUIRP found significant decreases in NOx emissions with the use of E85 over conventional gasoline in 1988, while CFEIS showed a four percent increase in NOx emissions [27]. Neither study found significant changes in CO emissions. Less data exist regarding the impact of E85 on PM emissions, although a 2003 Society of Automotive Engineers study showed a negligible increase in PM emissions from E85; however, the study only employed one gas blend and one model year in the test [27].

Both the AQUIRP and CFEIS studies showed that increases in NMOG emissions from E85 use compared to conventional gasoline ranged from 33 to 56 percent [27]. However, most E85 NMOG emissions have lower reactivity than other NMOGs and thus may be less facilitative of ozone formation.

The effects of E85 use on emissions of toxic air pollutants vary widely; however, EPA data indicates an aggregate net increase when all toxic gases are considered [27]. This is largely due to a 2,620 percent increase in acetaldehyde emissions. Other toxic gases decrease with E85 use; specifically, benzene, 1,3-butadiene, ethylbenzene, hexane, styrene, toluene, mylene, p-xylene, o-xylene, and naphthalene are projected to decrease 50 to 80 percent [27]. A study on the effects of E85 use on cancer rates could not determine whether increased toxic gas emissions, especially acetaldehyde, increased cancer risk compared to conventional gasoline [30].

Overall, biofuels' impacts on emissions vary by fuel type. Because of limited data, many of the effects regarding specific pollutants are inconclusive. Generally, ethanol-based fuels seem to lead to a net decrease in aromatics emissions and a potential increase in net toxic emissions, particularly acetaldehyde, which some studies link to negative health effects.

5.3 Diesel Engines

5.3.1 History of the Diesel Engine

The invention of the modern internal combustion engine is largely credited to the work of Rudolf Diesel. Diesel's engine was initially fueled by coal dust and later, by peanut and vegetable oils [31]. Diesel, an early proponent of biofuels, stated in 1911 that "the diesel engine can be fed with vegetable oils," the use of which would "help considerably in the development of agriculture of the countries which use it." [31]

In 1924, the Maschinenfabrick Augsburg-Nuerenburg Company incorporated the diesel engine into a truck and the company exhibited the vehicle at the 1924 Berlin Motor Show [31]. Daimler-Benz, today known as Mercedes Benz, produced the first diesel engine motor car in 1936, the Type 260D [31]. Auto manufacturers began producing diesel engines that could run on fossil fuels during the 1920s, despite the fact that fossil fuels have a lower viscosity than fuels produced with biomass.

5.3.2 The Diesel Engine

The diesel engine is an intermittent-combustion piston-cylinder engine [32]. The majority of diesel engines run on a two-stroke or four-stroke cycle. Diesel engines create energy by burning fuel under compression with a mixture of hot air inside the engine cylinders. Auto-ignition occurs when the air temperature within the cylinder is higher than the ignition temperature of the fuel [32]. At or above the auto-ignition temperature, the fuel spontaneously reacts with oxygen and burns [32].

Diesel engines incorporate a direct-injection system, whereby fuel is injected into the engine's cylinders. In such a system, the combustion process is heterogeneous, meaning the fuel source and air are not premixed. The direct-injection system relies on the rapid vaporization of fuel which is important for successfully igniting the fuel source [32].

The compression ratio is the pre-ignition compression level of the fuel mixture [33]. An engine's compression ratio is determined by the maximum volume of the cylinder with the piston in its lowest position divided by the volume when the piston is at its highest point or fully compressed. A larger compression ratio implies higher air temperature within the engine's cylinders [33]. The air temperature in diesel engines is typically above 526 degrees Celsius (979 degrees Fahrenheit) [32]. Higher compression ratios increase engine efficiency, but may also result in engine knocking [33].

Engine knocking refers to the phenomenon caused when air/fuel pockets explode outside of normal combustion resulting in a knocking sound. Knocking causes reduced engine efficiency and potential engine damage [34]. Direct-injection systems also affect engine efficiency. In modern diesel engines, fuel is injected directly into the engine's cylinders. To promote effective burning, fuel is injected in a cone spray, with fuel radiating from the nozzle [32]. Many of the recent improvements in diesel engine technology are the result of new direct-injection systems. More thorough mixing of the fuel and air significantly improves combustion. Two of the improved methods used to mix fuel and air are known as "air swirls" and "radial movement of the air," otherwise referred to as "squishing [32]."

5.3.3 The US Diesel Market

Table 11 highlights domestic consumption of transportation energy by mode and fuel type in 2005. The information has been limited to purely highway vehicles. All figures are in trillion British Thermal Units (Btu).

	Gasoline	**Diesel**	**Other***	**Total**
Light Vehicles	**16813.5**	**414.1**	**47.5**	**17275.1**
Cars	9080	51.2	9	9140.2
Light Trucks	7697.6	362.9	47.5	8108
Motorcycles	26.9	0	0	26.9
Buses	**6.5**	**167.7**	**16.5**	**190.7**
Transit	0.2	76.3	16.6	93.1
Intercity	0	28.3	0	28.3
School	6.3	63.1	0	69.4
Medium/Heavy Trucks	**460**	**4101.7**	**15.2**	**4576.9**
Highway	**17280**	**4683.5**	**79.2**	**22042.7**

Table 11: US Vehicle Market Energy Consumption, 2005 [35]

Approximately 2.4 percent of US transportation energy is consumed by diesel-fueled light vehicles. Historically, diesel-fueled cars and light trucks comprised only a small portion of the total light-vehicle market. The Alliance of Automobile Manufacturers estimates that there are now 4.8 million diesel-powered cars, SUVs, and trucks in the US [36]. However, demand for diesel-powered vehicles is expected to rise over the next decade. Three automotive manufacturers announced the sale of six new diesel vehicles at the beginning of 2008 and J.D. Power and Associates estimate that diesel vehicles will represent ten percent of the automobile market by 2015 [36].

Diesel vehicles dominate the bus and medium/heavy trucks categories. Approximately 88 percent of bus journeys in 2005 relied on diesel fuel; in the medium/heavy trucking sector, 89 percent of journeys were powered by diesel fuel [35]. Auto manufacturers currently only recommend low blends of biodiesel such as B5 and B20. All biodiesel blends must be created using neat biodiesel that meets American Society of Testing and Materials (ASTM) D6751 standards to prevent invalidating engine warranties. ASTM D6751 was the first national standard for biodiesel fuel within the US, and the standard sets out prescriptions for neat biodiesel blended with gasoline diesel [37]. Table 12 highlights automobile manufacturers' current positions on the use of biodiesel blends.

Company	Audi	BMW	Chrylser LLC		Ford Motor Co	General Motors		Honda	Hyundai	Isuzu	John Deere	Mercedes Benz	Nissan	Volkswagen	Volvo
Biodiesel Blend Approval	TBA	TBA	B20 (Approved Government, Military and Commercial Vehicles)	B5	B5	B20 (Special Equipment Opt. on the 2008 Chevy Silverado and GMC Sierra for approved fleets)	B5	TBA	TBA	B5	B20	B5	TBA	B5	B5

Table 12: Automakers' Support for Biodiesel Blends [38]

5.3.4 Biodiesel's compatibility with diesel engines

The Table 13 below highlights the key characteristics of typical No.2 diesel and neat biodiesel. No.2 diesel is the standard petroleum-based diesel fuel used in motor vehicles, while neat biodiesel refers to 100 percent biodiesel (unblended biodiesel fuel). The two fuels have separate fuel standards, and those for neat biodiesel are more stringent than regular diesel fuel.

Fuel Property	**Diesel**	**Biodiesel**
Fuel Standard	ASTM D975	ASTM D6751
Lower Heating Value, BTU/gal	~129,050	~118,170
Kinematic Viscosity @ 40ºC	1.3 - 4.1	4.0 - 6.0
Specific Gravity kg/l @60oF	0.85	0.88
Density, lb/gal @ 15oc	7.079	7.328
Water and Sediment, vol%	0.05 max	0.05 max
Carbon, wt %	87	77
Hydrogen, wt %	13	12
Oxygen, by dif. Wt %	0	11
Sulfer, wt % *	0.05 max	0.0 to 0.0024
Boiling Point, oC	180 to 340	315 to 350
Flash Point, oC	60 to 80	100 to 170
Cloud Point, oC	-15 to 5	-3 to 12
Pour Point, oC	-35 to -15	-15 to 10
Cetane Number	40 - 55	48 - 65
Lubricity SLBOCLE, grams	2000 - 5000	>7000
Lubricity HFRR, microns	300 - 600	<300

Table 13: No.2 Diesel and B100 Biodiesel Fuel Properties [39]

Fuels derived from vegetable oils, animal fats, partially reacted oils, and other biologically derived fuels that do not meet the specifications set out in the above table, may not be defined as biodiesel [39]. Backyard biodiesel producers are unlikely to meet these high standards, in particular regarding the standards defined for water and sediment volume [39]. There are also accreditation programs for biodiesel producers who meet and exceed the above standards, such as BQ9000 [40].

Biodiesel's octane number is slightly higher than No.2 diesel while both have similar levels of viscosity. One of the major issues surrounding the use of biodiesel in vehicles is the fuel's performance in cold temperatures. As the information in Table 13 suggests, the cloud and pour points of biodiesel occur at higher temperatures than those of regular diesel. These properties may significantly hamper the use of neat biodiesel within the country's northern states during winter.

The cloud point of a fuel is the temperature at which crystals begin to form and its appearance becomes cloudy [39]. Clouding of the fuel can reduce the engine's performance, clog filters, and hamper the functioning of other engine components. The cloud point for the majority of biodiesel falls within the range of -3 degrees Celsius to 12 degrees Celsius (27 degrees Fahrenheit to 54 degrees Fahrenheit).

Test Method	**Cloud Point ASTM D2500**		**Pour Point ASTM D97**		**Cold Filter Plug Point IP 309**	
B100 Fuel	**°F**	**°C**	**°F**	**°C**	**°F**	**°C**
Soy Methyl Ester	38	3	25	-4	28	-2
Canol Methyl Ester	26	-3	25	-4	24	-4
Lard Methyl Ester	56	13	55	13	52	11
Edible Tallow Methyl Ester	66	19	60	16	58	14
Inedible Tallow Methyl Ester	61	16	59	15	50	0
Yellow Grease 1 Methyl Ester	--	--	48	9	52	11
Yellow Grease 2 Methyl Ester	46	8	43	6	34	1

Table 14: Cold temperature properties of Biodiesel fuels [30]

Pour point is defined as the temperature at which the fuel becomes a gel [39]. Upon reaching the pour point, the engine no longer functions correctly, and continued vehicle use can damage both the engine and the fuel system. Biodiesel's cloud and fuel points are affected by the biomass used in the production of the fuel. Table 14 highlights these properties.

The cloud and pour points highlighted in Table 14 refer to neat biodiesel. Two of the most common biomass feedstocks used in biodiesel production, soy and canola (rapeseed), produce some of the highest cloud and pour points of any biodiesel fuel. Many of the cold weather issues surrounding the use of biodiesel can be resolved by blending biodiesel with regular diesel, which improves the cloud and pour points of the fuel. The most common blends are B20 and B5. Other solutions include anti-gel fuel additives and fuel-line heater systems. Research suggests that additives in neat diesel can reduce the pour point by nearly 12 degrees Celsius (54 degrees Fahrenheit), assuming treatment rates of 10,000 parts per million (ppm). However, typical treatment rates for additives are 1,000 ppm, which produce an average pour-point reduction of 3 degrees Celsius [39]. Table 14 also highlights the Cold Filter Plug Point (CFPP) of several biomass biodiesels. CFPP is defined as the temperature at which crystal formation in the fuel can cause test-filter failure [39].

Neat biodiesel is a strong solvent which may cause problems in vehicles that previously combusted diesel or were manufactured before 1993. DOE recommends all engines be cleaned before B100 use, as neat diesel may loosen or dissolve sediments left by regular diesel within the fuel system and engine [39]. B100 can also degrade certain rubber components commonly found in vehicles manufactured before 1993 [39].

All biofuels face problems with microbial contamination. Certain biological organisms can grow on the surface of diesel fuels, including aerobic fungus, bacteria, and yeast hydrocarbon-utilizing microorganisms [39]. DOE recommends use of biocides in both conventional and biodiesel fuels, which prevent the aforementioned contamination [39].

5.3.5 Biodiesel Emissions

Studies of biodiesel emissions primarily examine B20 because it is the most common biofuel blend. Use of the soybean-based variety over conventional diesel fuel is predicted to increase NOx emissions and decrease PM, hydrocarbon (HC), and CO emissions [41]. Toxic gas emissions are predicted to decrease, but results vary considerably with fuel variety. The following Table 15 presents EPA-estimated percentage changes in emissions of B20 over conventional diesel fuel [41]. Soy-based biodiesel shows fairly consistent decreases in all pollutants except NOx.

Pollutant	Effect Range (% Compared to B0)	Overall Effect	Study
PM	-30.8 to +6.0	Decrease	McCormick et al. (2001, 2005), Souligny et al. (2004), Alam et al. (2004), EPA (2002)
HC	-35 to +13.5	Decrease	McCormick et al. (2001, 2005), Souligny et al. (2004), EPA (2002)
CO	-28.1 to +1.0	Decrease	McCormick et al. (2001, 2005), Souligny et al. (2004), EPA (2002)
NOx	-3.0 to +6.0	Increase	McCormick et al. (2001, 2005), Souligny et al. (2004), Alam et al. (2004), EPA (2002)
Toxics		Predicted decrease	

Table 15: B20 Exhaust Pollutant Emissions Compared to Conventional Diesel [27, 41]

A B20 blend minimizes many of the environmental issues related to the use of neat biodiesel. By blending biodiesel, cold weather issues are significantly reduced and drivers are unlikely to notice any detrimental effects from the use of B20, in terms of power, torque, or fuel efficiency [39].

5.4 Turbine Engines

The basic parts of a turbine engine are the inlet, compressor, combustion chamber, turbine, and nozzle (Figure 15). Air flows into the inlet and is compressed. The high-pressure air is forced into the combustion chamber where it is sprayed with fuel and ignited. Energy, in the form of heat, is released past the turbine and through the nozzle providing thrust. The heat flow passing the turbine provides power to rotate the compressor [42].

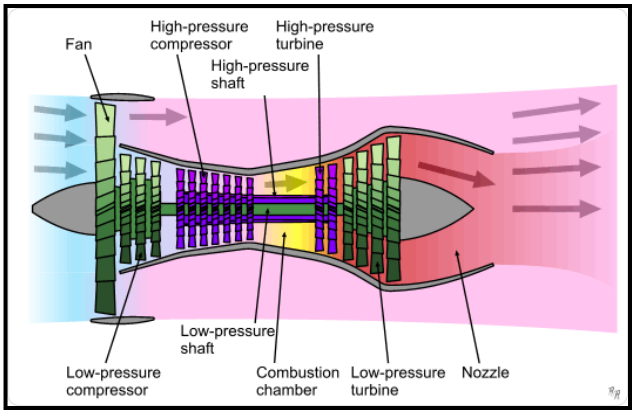


Figure 15: Illustration of Basic Turbofan Engine [44]

The modern western commercial aviation industry uses an updated turbine engine called a turbofan engine (Figure 15). The basic parts of the turbine engine are encased in a covering. The fan draws in air that either enters the inlet or travels outside the casing, bypassing the center. With current technology, 90 percent of the thrust is produced from this “bypass” air driven around the casing at high subsonic speeds. The fan supplements the total thrust by forcing the air directly into the hot turbine exhaust [43].

Combustion occurs when, in the presence of a heat source, fuel reacts with an oxidizer. The oxidizer in this case is air from the atmosphere. Energy is released when the carbon-carbon and carbon-hydrogen bonds in hydrocarbons are broken and new carbon-oxygen and hydrogen-oxygen bonds are formed [45]. Thus, as the number of carbon-carbon and carbon-hydrogen bonds found in the fuel molecule increases, the amount of energy produced during combustion increases. As more energy is produced, the availability of thrust increases driving propulsion.

5.4.1 Aviation Fuels

Aviation fuels are graded on gravimetric and volumetric energy characteristics, thermal stability, characteristics at high and low temperatures, and lubricating capabilities [45, 46, 47. 48]. Current aviation fuels absorb excess heat and act as a hydraulic operating fluid [45]. Besides the combustion energy produced by a fuel, the amount of energy produced as a function of the mass and volume of the aviation fuel is important. Gravimetric energy content is the amount of energy per unit mass of fuel expressed as Megajoules per kilogram (MJ/kg). Each aircraft is certified with a Maximum Take-Off Weight (MTOW), which is the heaviest weight the aircraft can be while still fulfilling all flight safety requirements. Volumetric energy content is the amount of energy per unit volume of fuel which determines the maximum flight range possible with a full load of fuel. Table 16 illustrates how various alternative fuels compare to current aviation fuels along these two measures.

Fuel	**Specific Energy, MJ/kg**	**Density 15°C**	**Energy Density, MJ/l**
FT Synfuel	44.2	0.759	33.6
Jet A/Jet A-1	43.2	0.808	34.9
Liquid Hydrogen	120	0.071	8.4
Liquid Methane	50	0.424	21.2
Methanol	19.9	0.796	15.9
Ethanol	27.2	0.794	21.6
Biodiesel	38.9	0.87	33.9

Table 16: Specific Energy, Density and Energy Density [45]

Petroleum-based hydrocarbon fuels provide a greater amount of energy per mass and volume compared to almost all alternative fuels. Many potential alternative fuels contain oxygen as part of the fuel molecule. The oxygen in the molecule does not contribute any energy during combustion. For example, ethanol contains about 35 percent oxygen by weight whereas conventional jet fuels contain only trace levels of oxygen [49]. The higher oxygen content results in ethanol having a lower gravimetric energy content than conventional jet fuels.

The western commercial aviation industry uses two kerosene-type fuels, Jet A-1 and Jet A, to power jet engines. Jet A is primarily available in the US and Jet A-1 is available internationally. The International Air Transport Association (IATA) maintains the fuel standards at most international airports. Jet A-1 meets the requirements of specifications set by IATA, NATO, and Britain Defense Standard 91-91. In the US, the requirements for commercial aviation jet fuel are defined by the American Society of Testing and Materials (ASTM) regulation D 1655. The fuel supply standards set by IATA and ASTM are almost identical but some IATA standards are slightly more stringent in some areas. For example, the freezing point standard is -40 degrees

Celsius for Jet A and -47 degrees Celsius for Jet A-1. Refineries producing jet fuel must meet rigorous standards for aviation fuel production, but because jet fuel is a mixture of hundreds of chemicals, the specifications do not dictate detailed composition of the fuel. The specifications are performance standards and not composition standards.

Though Jet A and Jet A-1 are primarily kerosene, jet fuel producers must add compounds to supplement qualities of the fuel. The compounds are added in small amounts, usually measuring only in ppm. Common additives add a variety of additional characteristics to the fuel. Anti-knock additives inhibit gasoline from detonating. Anti-oxidants reduce the likelihood of oxidation of the fuel in storage. Corrosion inhibitors decrease the caustic effects of the fuel on ferrous metals found in pipelines and fuel storage tanks. Some corrosion inhibitors also provide lubricating properties for the fuel. Finally, biocide additives help block microbiological growths in the fuel [50].

5.4.2 Alternative Aviation Fuels

The purpose of using alternative fuels in aviation is two-fold. First, the use of alternative fuels should relieve the worldwide demand for petroleum-based aviation fuels. In 2007, alternative fuel accounted for about 30 percent of the airline industry's operating costs, compared with about ten percent in 2002 [51]. Second, the industry is focusing on decreasing its contribution to overall carbon emissions. The industry currently contributes two percent of the total carbon emissions in the world [52]. Due to an expected increase in the number and length of flights, overall emissions are expected to increase significantly over the coming years [53]. In response, the industry has committed to decreasing its total carbon dioxide emissions beyond emissions from burning fuel [54, 55, 56]. Total emissions from the fuel include elements of processing, supply chain distribution, and engine use.

In the aviation industry, the term "alternative fuels" includes biofuels and synthetic fuels (synfuels). In May 2006, the US Air Force Advisory Board (USAF-AB) published the *Report on Technology Options for Improved Air Vehicle Fuel Efficiency* recommending alternative aviation fuel options for the not too distant future [57]. USAF-AB recommended coal-to-liquid (CTL) and gas-to-liquid (GTL) fuels as the "sole viable short term option [57]." In the short term (five–15 years), alternative fuels derived from oil shale, cellulosic-based ethanol blends, and biodiesel are possibilities. Because ethanol has a much lower energy content than conventional jet fuel, ethanol is only viable as a blend in the short term and only if it is widely commercially available. In the long term, biomass and hydrogen fuels look promising for use in aviation [57]. The current unavailability of any alternative aviation biofuels is based on the individual characteristics of each fuel, though several challenges are consistent for all the alternate biofuels. The primary stumbling block for aviation biofuels is their tendency to freeze at normal cruising altitude temperatures. Also, compared to traditional jet fuel, biofuels have poorer thermal stability characteristics. Finally, a pure biofuel does not have stable long-term storage characteristics [47].

Acceptance of alternative fuels is a collaborative process that includes members of the entire commercial aviation industry, from engine and airframe manufacturers, fuel and additive suppliers, to national aviation regulatory agencies, and other interested parties. Following extensive testing in South Africa, GTL-derived synthetic fuel received approval in 1999 from the

South African government for use at the Johannesburg International Airport. To streamline the approval process for alternative fuels, the industry is currently developing a generic approval process for CTL and GTL. Other alternative fuels will be subjected to a full review before approval in the airline industry [58]. The approval process may span years because each engine type will have to be certified for each fuel type [59].

5.4.2.1Biodiesel

The properties for a given biodiesel depend specifically on the feedstock used to produce the fuel. Regardless of the feedstock, the main concern with biodiesel is its low temperature properties (Table 17). Biodiesel manufactured to current standards freezes at current jet aircraft cruise altitudes of 28,000 to 45,000 feet where temperatures are below -30 degrees Celsius. Even blends of biodiesel with Jet A or Jet A-1 have higher freezing points than pure petroleum based jet fuel. Current additives decrease the freezing point by a few degrees Celsius. Any new additives developed would require significant testing prior to approval.

Fuel Property	**Biodiesel (soy)**	**Conventional Jet Fuel**
Flash Point, °C	100	40 - 45
Viscosity 40°C, Cst	4.7	1.2
Sulfur, wt%	< 0.05	0.05 - 0.15
Net Heat of Combustion, MJ/kg	36 – 39	43.2
Relative Density, 15°C	0.87 - 0.89	0.80
Freezing Point, °C	~ 0	< -40
Approximate Carbon Number	C16 - C22	C8 - C16

Table 17: Comparison of biodiesel and conventional jet fuel properties [45]

Non-blended biodiesel also has poor high-thermal stability characteristics. As shown in Table 17, pure biodiesel developed from soybeans has a much higher flashpoint than conventional jet fuel. A 20 percent biodiesel-80 percent Jet A blend has passed thermal stability requirements [47].

5.4.2.2 Ethanol

Several properties of ethanol introduce challenges for developing it into a viable alternative jet fuel. Ethanol is significantly more volatile than jet fuel and boils at 78 degrees Celsius. Ethanol also has a higher heat of vaporization than conventional jet fuels which affects its behavior in the combustion chamber. As a strong solvent, ethanol could damage fuel system materials. A 100 percent ethanol jet fuel will require new storage and distribution systems [45]. In addition to these characteristics, ethanol's energy density (MJ/l) and specific energy (MJ/kg) are almost 40 percent less than conventional jet fuel [59].

For these reasons, some researchers conclude that ethanol is unsuitable as an alternative jet fuel [60].

5.4.3 Current trends in jet engine design

The primary turbofan engine manufacturers are General Electric Aviation, CFM International (50/50 partnership between Snecma and General Electric Company), Rolls-Royce, and Pratt & Whitney. These manufacturers are primarily focusing on improving the efficiency of current engine designs in order to decrease their overall fuel consumption. Table 18 provides information on each manufacturer's advances in engine technology.

The commercial aviation industry has partnered with engine and airframe manufacturers to conduct "demonstration" flights powered with alternative fuels. On February 1, 2008, Airbus flew the A380 with one of the older four Rolls-Royce Trent 900 engines running on a mixture of regular aviation fuel and synthetic fuel processed from natural gas [61]. Later the same month, Virgin Airlines tested a Boeing 747 with one of the four aircraft engines powered by a 20-percent mix of coconut and babassu oil and 80 percent conventional aviation fuel. Virgin did not release the specifics of the General Electric engine used in the test flight [62]. Air New Zealand, partnered with Rolls-Royce and Boeing, plans a 747-400 test flight by early 2009. As with the Virgin Airlines' test, one of the four engines will be powered by a mix of biofuel and conventional aviation fuel [63]. Continental Airlines plans to conduct a biofuels demonstration flight early 2009 using a Boeing Next-Generation 737 equipped with the CFM56-7B engines [64].

Company and website	New engine	Key advances
GE Aviation www.geae.com	Genx	Twin-annular, pre-mixing swirler combustor, high pressure ten-stage compressor, and lightweight composite fan case and fan blades
CFM International www.cfm56.com	CFM56-7B	Successfully ground tested with 30/70 mix of vegetable oil methyl ester and Jet A-1
Rolls-Royce www.rolls-royce.com	Trent 1000	Increased fuel efficiency with 15-20 percent reduction in carbon emissions
Pratt & Whitney www.pw.utc.com	Geared Turbofan	Successfully ground tested with synthetic and jet fuel mix

Table 18: Key advances in jet engine technology by primary manufacturer

In October 2007, a 100 percent biodiesel fueled flight took place. Flying a Czechoslovakian-made L-29 aircraft, the test pilots reached 17,000 feet over Reno, Nevada without any significant drop in engine performance. However, commercial jets regularly cruise at altitudes between 28,000 and 45,000 feet, and the fuels for them will have to resist more adverse conditions. The Motorlet M701 engine on the L-29 Delphin is rated to fly on a variety of fuels including heating oil. The fuel used on the flight was produced from restaurant waste oil. Due to the high aromatic quality of the fuel, soot buildup in the turbine, fuel nozzles, and combustion chamber were found. The chief pilot, who also wrote and conducted the test program, plans on eliminating the buildup by including additives in the fuel. Information on any modifications to the engines was not released [65, 66].

Engine manufacturers created partnerships with other industry leaders to develop biofuels that fuel will act as drop-in alternatives and not require engine modification when mixed with conventional. Potential industry modifications focus on improved fuel efficiency, engine design, aerodynamic improvements, and structural materials of the plane. Engine design improvements include geared turbofan engines with ducted or un-ducted prop fans and inter-cooled, recuperative engines [47].

5.5 Implications for Indiana

The alternative aviation fuel market will not impact Indiana until solutions are found to address the instable characteristics of biofuels. Once biofuels are viable for aviation use, Indiana can enter the market by providing the alternative biofuels to regional airports. A representative from Integrity Biofuels in Morristown, Indiana indicated the company could be ready within the next five to ten years to provide biodiesel to the Indianapolis Airport for jet fuel blending [67]. A reduced cost option offered at the Indianapolis, Chicago, or Cincinnati airports will encourage current stop-over flights to refuel in the Midwest.

5.6 Economic Considerations

This section focuses on the two main ethanol blends – E10 and E85 – that appear to be feasible options within Indiana. The following are considerations expanding upon demand for these biofuels as they relate to vehicle compatibility and availability, as well as other related concerns. In addition, this section includes a brief summary of the outlook for biodiesel as it relates to fuel availability and vehicle use.

5.6.1 E10 Outlook

By far, the most feasible ethanol and gasoline blend is E10, which is compatible with existing gasoline engines [68]. There are some reductions in fuel economy associated with E10 [68]. However, the Government Accountability Office (GAO) reports this reduction to be inconsequential since fueling stations can sell E10 at the same price as regular gasoline, and consumers appear unconcerned by the issue [68].

The Indiana State Department of Agriculture (ISDA) reports the state is projected to meet its goal of one billion gallons of ethanol production annually in 2008 [69]. In 2001, Indiana consumed 8.7 million gallons of gasoline per day [70]. Even if this daily projection were raised to 9 million gallons per day and adjusted to an annual figure, Indiana could more than supply ethanol for a 100 percent E10 scenario within the state. Among other factors, GAO suggests the E10 market is a limiting factor in the growth of E85 use; if the E10 market becomes saturated, E85 use would likely grow [68]. If this is true, there would likely be an increase in demand for flex-fuel vehicles within the state.

5.6.2 E85 Outlook

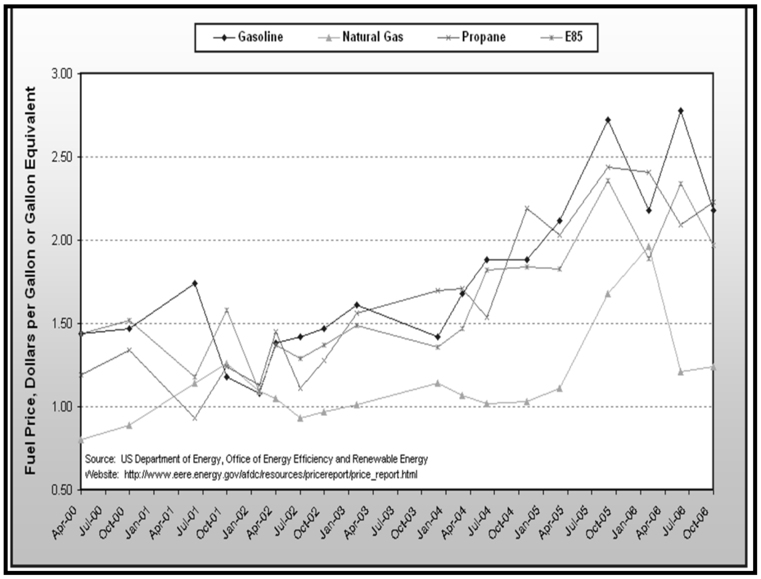
5.6.2.1 Flex-Fuel Vehicle Availability

GAO reports that three percent of transportation vehicles in the US use some form of biofuels [68]. According to the Indiana Bureau of Motor Vehicles, there were 6,062,859 registered cars and trucks in Indiana in 2005 [71]. Based on 2002 data, the Energy Information Administration (EIA) estimates 6,584 of Indiana vehicles are alternative-fuel vehicles, with 1,670 of these vehicles equipped for E85 use [71]. As a rough approximation, three percent of registered cars and trucks in Indiana can use E85 as a fuel source. However, many drivers may own flex-fuel vehicle models without taking advantage of the flexibility in fuel sources the technology provides. A study conducted by the Union of Concerned Scientists found that more than 99 percent of all flex-fuel car owners use regular gasoline as a fuel, largely attributable to the lack of availability of E85 fueling stations in the US [72].

There are more than 4.5 million flex-fuel vehicles in the US, accounting for a mere two percent of vehicles nationally [68]. For manufacturers, the adjustment cost of manufacturing a flex-fuel vehicle ranges from $30-$300 per vehicle, with negligible costs passed on to consumers [68]. Auto manufacturers also receive offset credits for the number of flex-fuel vehicles they produce [72]. This credit is meant to reward manufacturers for the offsets created by anticipated reductions in gasoline consumption in the US from use of flex-fuel vehicles [72].

According to the National Ethanol Vehicle Coalition (NEVC), there were approximately 49 models of flex-fuel vehicles commercially available in the US from 2003 to 2008 [73]. Of these, 33 percent were cars, 27 percent were sport utility vehicles (SUVs), 22 percent were vans, and 18 percent were pick-up trucks [73]. Daimler-Chrysler, General Motors, and Ford agreed to increase manufacturing of flex-fuel vehicles to make up half of their fleets by 2012 [68].

While flex-fuel vehicles are and will continue to be available on the market at affordable prices, one of the main barriers to their intended use is the lack of E85 pumps and distribution infrastructure within the US [68, 72, 74]. According to NEVC, there were 93 E85 refueling stations in Indiana in 2007 [73]. According to Weiss and Gryll, however, stations offering E85 only account for roughly 7 percent of all service stations in the US [72].



Source: US Department of Energy, Office of Energy Efficiency and Renewable Energy
Website: http://www.eere.energy.gov/afdc/resources/pricereport/price_report.html

Figure 16: Midwest Regional Natural Gas, Propane, and E85 Prices Relative to Gasoline 2000-2006 (Dollars per Gallon or per Gallon Gasoline Equivalent) [71]

For comparison, ethanol makes up 40 percent of the transportation fuel utilized in Brazil, and flex-fuel vehicles account for over 70 percent of new auto sales in that country [74]. Throughout the 1980s, the government in Brazil invested heavily in its ethanol infrastructure as a means to increase energy independence [74]. Ethanol did not become popular in Brazil, though, until the government allowed consumers to choose their fuel - gasoline or ethanol – based on market prices [74].

5.6.2.2 Fuel Availability and Consumer Demand

According to data collected by DOE, E85 fuel prices have remained relatively lower than gasoline prices from 2000 to 2006, as evidenced in Table 18 [71]. As of 2006, however, E85 accounted for less than one percent of US ethanol use [68]. GAO attributes this to the prices producers can charge for ethanol blends [68]. Producers sell lower-blend ethanol such as E10 at much higher prices than higher blends, generally having to discount the price of E85 due to the loss of fuel economy [68].

5.6.2.3 Environmental Benefits Associated with Flex-Fuel Vehicles

Indiana ranked sixth amongst states in terms of overall state CO_2 emissions based on 2001 EIA data, with 230.2 million metric tons of CO_2 emissions versus the national average of 111.9 million metric tons per year [71]. According to 2005 data from EIA, Indiana ranked fifth amongst states in terms of its per capita CO_2 emissions [71]. Biofuels may be one possible strategy to lower Indiana's contribution to greenhouse gas emissions.

While there are varying estimates on the extent of environmental benefits associated with biofuels, a study by Hill et al. found the life-cycle reduction of greenhouse gases to be 12 percent for corn-based ethanol and 41 percent for soy-based biodiesel compared to their respective fossil fuels [75]. GAO estimates that E85 is associated with a roughly 20 percent reduction in greenhouse gases compared to fossil-fuels combustion, with cellulosic ethanol generating a purported 70 to 90 percent reduction in greenhouse gases. Interestingly, GAO cites an 85 percent reduction in greenhouse gases for biodiesel relative to regular diesel fuel [68]. While the estimates and methodologies vary, many studies attribute moderate to significant environmental benefits to biofuels based on reduced greenhouse gas emissions.

Attributing a monetary value to environmental benefits is difficult due to lack of price signals, the intangible nature of these benefits, and the cumulative and probabilistic nature of future environmental impacts. Thus, ranking systems are often used to compare intangible benefits and costs between alternatives in these cases. EPA offers an online Green Vehicle Guide with fuel economy standards for domestic automobiles [76]. The guide offers a ranking system for vehicles based on various vehicle emissions. The Air Pollution Score ranks vehicles on a scale from one to ten – with ten being the most environmentally friendly – based on emissions of Clean Air Act criteria pollutants [76]. There is a similar ranking system called the Greenhouse Gas Score created in an analogous manner.

		Fuel Economy Rating: City/Highway (miles per gallon)			***Air Pollution Score: 1-10***			***Greenhous Gas Score: 1-10***		
		Min	Median:	Max	Min	Median:	Max	Min	Median:	Max
SUV	**E**	9/12	10/14	11/14	3	7	7	4	5	6
	G	12/17	14/19	14/19	3	7	7	2	3.5	4
Vans	**E**	9/12	11/17	12/17	6	6	6	4	6	7
	G	12/16	16/23	17/24	6	6	6	2	5	5
Pick-ups	**E**	9/12	9/14	11/14	3	6	7	4	4	6
	G	12/17	14/19	14/19	3	6	7	2	3	4
Cars	**E**	11/16	13/19	14/21	3	6	6	6	7	8
	G	15/23	18/26	19/29	3	6	6	5	6	6

E = Ethanol; G =Gasoline

Table 19: U.S. EPA Green Vehicle Guide Data for 2008 Flex Fuel Vehicles [76]

Using ethanol flex-fuel vehicles as an example, Air Pollution Scores, Greenhouse Gas Scores, and EPA Fuel Economy Ratings were found for all models of flex-fuel vehicles produced in 2008, according to NEVC data. The results are summarized in Table 19, broken down by vehicle class category.

The EPA Green Vehicle Guide does not indicate any reductions in criteria air pollutants emissions for ethanol. The Greenhouse Gas Score shows significant reduction in greenhouse gas emissions from ethanol. For ethanol, the rankings range from four to seven, with pick-ups having the least greenhouse gas benefits across vehicle class categories and cars having the best. When looking at fuel economy differences, gasoline fares better than ethanol. However, from an environmental perspective, ethanol provides greater benefits than gasoline.

5.6.2.4 Other Cost Considerations

Biofuels vehicles have lower fuel economy than their fossil-fuel counterparts. If consumers do not alter their driving behavior, it will take a larger quantity of biofuels to drive the same distance as it would with fossil fuels. DOE created an online Flex-Fuel Vehicle Cost Calculator to compare different models of flex-fuel vehicles [77]. The calculator estimates gallons of gasoline saved per year and the costs associated with driving the same mileage using E85. The results are summarized in Table 20, broken down by vehicle category.

Gas Saved (gallons/year)				
Minimum:	722.69	539.06	707.57	489.14
Median:	**747.07**	**646.37**	**747.07**	**559.62**
Maximum:	847.01	887.57	869.29	667.86
Extra Cost to Drive Same Mileage Using E-85 ($/year)				
Minimum:	$226.37	$283.08	$226.37	$192.19
Median:	**$311.97**	**$369.82**	**$333.80**	**$364.87**
Maximum:	$818.30	$541.33	$818.30	$1,999.04

Assumptions:
Based on 15,000 miles driven per year

Average E85 fuel price $2.29/gallon; average gasoline fuel price $2.72/gal (based on October 2007 Alternative Fuel Price Report)

Based on median fuel economy rating between city and highway driving

Table 20: U.S. Department of Energy Flex Fuel Vehicle Cost Calculator Result for 2008 Flex Fuel Vehicles [77]

A consumer would need to be willing to pay an additional $311.97 to $369.82 per year to drive a flex-fuel vehicle, based on median values across categories. Note, however, that there is some variability in these numbers. For example, driving a Chevrolet Monte Carlo would only cost an additional $192.19 per year to drive, while a Mercury Grand Marquis would cost an additional $1,999.04 per year to drive [68, 77]. GAO also suggests the corrosive nature of higher-blend ethanol fuels may impact long-term engine performance [68]. It is unclear whether consumers would be willing to pay these additional amounts per year.

5.7 Biodiesel Outlook

As discussed in previous sections, biodiesel is compatible with existing diesel engines. However, market forces appear to be the main barrier to biodiesel's widespread use. According to 2006 EIA information, biodiesel comprises a mere 0.6 percent of diesel usage in the US and is projected to remain at this level for the next 15 years [68]. Since soy is the primary feedstock for biodiesel, competition from other soybean uses makes biodiesel more expensive for producers [68]. EIA estimates that low demand for biodiesel is largely due to higher fuel prices from this competition [68]. Biodiesel engines also face performance problems in colder weather, and the fuel may increase risk of fuel-filter blockage [68]. All these considerations contribute to low consumer demand for biodiesel.

5.8 Conclusions

The lack of widespread availability of biofuels in America is the primary restriction to increased biofuels use in ground transportation. Car manufacturers are dedicated to increasing production of flex-fuel vehicles while at the same time keeping the cost to consumers almost equivalent to the cost of traditionally powered vehicles. With car manufacturers increasing production of flex-fuel vehicles, demand for E85 filling stations and in turn, ethanol-based biofuels will increase. Indiana production of ethanol in 2008 is more than sufficient to meet a state 100 percent E10 scenario.

Research results on flex-fuel emissions are contradictory, and a clear picture of emissions is unavailable. Further studies are needed to assess the potential health risks of exposure to ethanol emissions.

Though gasoline-powered vehicles dominate the market today in America, diesel powered vehicles still account for a quarter of the energy consumption by highway vehicles, and demand is expected to increase over the next decade. Currently, car manufacturers only recommend using low blends of biodiesel such as B5 and B20 in diesel engines and use of higher concentrations may invalidate engine warranties. Characteristics of any particular batch of biodiesel are dependent upon the feedstock and the additives required to meet performance standards set by ASTM. Finally, levels of emissions depend on the biodiesel feedstock as well. Overall, particulate matter, hydrocarbons, and carbon dioxide emission decrease, but nitrogen oxide emissions increase with biodiesel use.

Research indicates biodiesel is the most promising alternative jet fuel. Biodiesel’s characteristics closely mirror current jet fuels used in the aviation industry. Similar to the issue of biodiesel in ground transportation, biodiesel’s low temperature characteristics makes it unsuitable for jets flying at normal cruising altitudes. Use of biodiesel in jet engines requires a much lower freezing point than for ground transportation. Generally, ethanol is not considered as a viable alternative jet fuel because of its energy content by mass and volume.

Indiana should consider funding additional research on the environmental impacts of biofuels. Additionally, state-offered rebates for retrofitting fueling stations are useful in correcting the pervasive lack of availability issue.

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6. Logistics

6.1 Introduction

Freight traffic in Indiana consists of four modes: rail, highway, air, and maritime (specifically barge). As much as one-third of all freight traffic neither originates nor terminates within the state [1, 2]. Indiana's geographic location, separating the Eastern states from the Mountain states and other Midwestern states, makes it a likely thoroughfare for through carriers. Recent estimates show that truck traffic on Indiana highways is by far the dominant mode of freight transportation, moving nearly 73 percent of all freight tonnage [1]. The remainder consists of rail transport at 16 percent of freight tonnage, followed by barge at 11 percent, and air at a nominal 0.1 percent [1].[11]

6.2 Current Rail Infrastructure

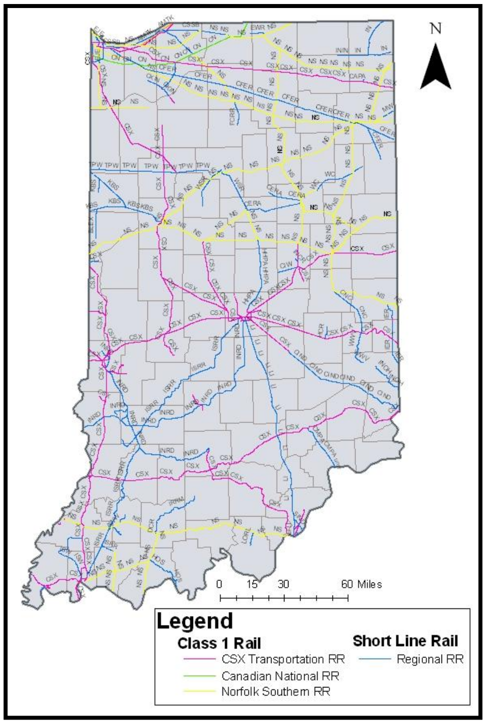

Figure 17: Active Rail in Indiana [3, 4, 5, 6, 7]

For rail traffic originating in Indiana, coal is the most heavily shipped commodity, accounting for 41 percent of total exports and 75 percent of intrastate rail traffic, followed by primary metal products (20 percent) and farm products (17 percent) [2]. Figure 17shows the current rail system for the state. The system consists of four major Class I carriers and 37 regional and short-line railroads [1].[12] The two largest Class I carriers, CSX Transportation, Inc. (CSXT) and Norfolk Southern (NS), maintain 1,929 route-miles and 1,569 route-miles, respectively, in Indiana. CSXT and NS focus primarily on east-west routes connecting major cities such as Chicago, IL, Indianapolis, IN, St. Louis, MO, and Cincinnati, OH, although both carriers do maintain routes which traverse the state north-south [1]. The other Class I carriers each operate a single line: the Canadian Pacific line stretches from Chicago, IL to Louisville, KY, and the Canadian National line passes through northern Indiana between Chicago, IL and Toronto, Ontario [1]. Class I rail accounts for 91 percent of all rail lines in Indiana [2]. In contrast to most short rail lines throughout the Midwest,

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[11] For the purposes of this discussion, air transport will not be addressed as it is not a viable means of moving biofuels feedstock or refined biofuels.

[12] Class I freight are rail systems with annual operating revenues of $346.8 million or more, line-haul are railroads operating at least 350 miles of road and/or earning revenue between $40 million and the Class I threshold, and local or short line railroads smaller than line-haul railroads [9, 10].

short rail lines in the state of Indiana are heavily associated with the movement of coal and metals within and out of the state [2]. The most recent Indiana Department of Transportation (INDOT) *Indiana Rail Plan* indicates that the top three short-line operators, which account for 73 percent of short-line carloads, primarily handle commodities such as coal, metals, and chemicals [2].

While rail is highly dedicated to the coal industry, agricultural transport also benefits from both Class I and regional rail transporters. In Indiana there are over 180 grain elevators, 152 of which are served by the two largest Class I operators. CSXT accesses 75 grain elevators and 14 feed mills while NS accesses 77 grain elevators and 12 processing mills, accounting for around 80 percent of all grain elevators in the state [2]. Nevertheless, short line railroads, comprising 1,269 route-miles, are particularly beneficial for agricultural transport, providing access to Class I railroads in 62 counties, 15 of which are solely serviced by short lines [2]. The majority of agricultural rail shipments, originating in Indiana and totaling over 70,000 carloads, reaches areas in the Southeastern US [1, 2]. Although agricultural transport is a relatively small segment of the rail freight industry, nearly half of all short lines are financially dependent on the shipment of crops, specifically grain, for revenue [2]. Figure 19 illustrates this correlation between grain production and rail lines.

The INDOT *2030 Long Range Transportation Plan* assesses the current state of freight rail in Indiana and forecasts changes in transportation flows. Figure 18, shows the rail traffic density throughout the state in terms of millions of gross ton miles per mile annually (MGTM/M) [2]. Not surprisingly, rail traffic from major metropolitan areas, particularly along the northern routes to and from the Chicago area, shows a higher incidence of congestion. The *Long Range Transportation Plan* also determines which upgrades are necessary to improve the current rail infrastructure and decrease potential congestion due to freight increases. Specifically, the plan suggests increasing the capacity of short-line rail from the current 263,000 lbs to 286,000 lbs gross weight on rail (GWR), as well as building and upgrading bridges [2]. INDOT estimates the cost of the proposed upgrades for the state of at $99.5 million, with one-third of the estimated cost going to upgrade bridges and the remainder to improve track structure [2].

In 2007, Cambridge Systematics, Inc. prepared a *National Rail Freight Infrastructure Capacity and Investment Study* for the Association of American Railroads. The report analyzes the current state of rail infrastructure in the US, forecasts rail use increases and associated travel impacts through 2035 (based on the US Department of Transportation's projected 88 percent increase rail freight demand), and proposes upgrades to mitigate the expected congestion [12]. This study also addresses infrastructure upgrades for Class I as well as short-line rail. For Indiana, the study identifies a potential increase of zero to 30 trains per day by 2035 (from a 2005 baseline) for the east-west Terre Haute-to-Muncie railway and the north-south Fort Wayne-to-Muncie railway; an increase of 30-80 trains per day along the east-west Lafayette-to-Fort Wayne railway and the north-south Evansville railway; as well as a potential increase of 80-200 cars per day along the Chicago-to-Gary, IN railway [12].

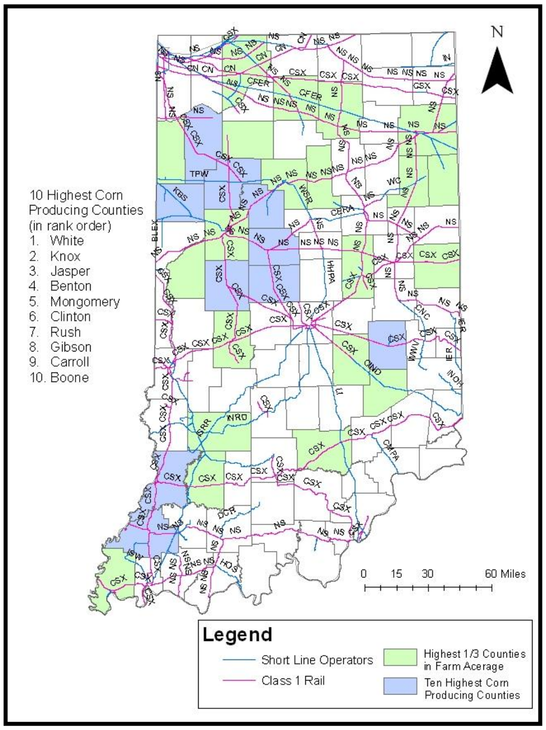

Figure 19: Grain Production and Rail Service [3, 4, 5, 6, 7, 8]

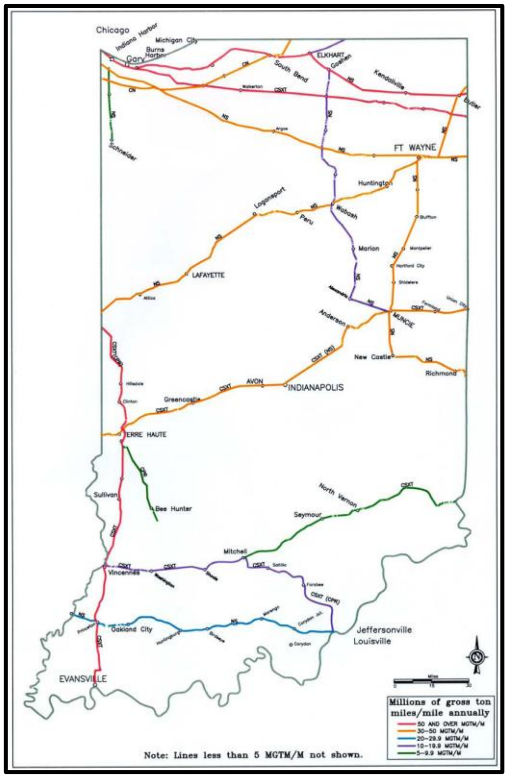

Figure 18: Indiana rail traffic density [11]

6.3 Current Highway Transportation

Truck-based highway transportation is the most common mode of moving freight in Indiana. Figure 20 depicts major highways, state routes, and roadways. Within the state, there are four major east-west interstates: I-80/90 to the north, I-70 and I-74 through the center of the state, and I-64 to the south. Connecting Chicago to Louisville, KY is the north-south I-65; encircling Indianapolis is the outer-belt I-465, and throughout the majority of the state are highways providing access to smaller metropolitan areas and towns. This system of highways and roads is essential for the agricultural industry, which ships 60 percent of Indiana's grain to processing plants or livestock farms using trucks [1].

Freight transportation via highways and roads incurs competition with passenger vehicles. INDOT predicts that from 2000 to 2030 statewide population will increase by 20 percent and travel demand will increase by 52 percent [1]. In order to prepare for the expected increased roadway demand, Indiana has assessed the infrastructural needs of the roadway system in the *Long Range Transportation Plan* and has dedicated funding for added travel lanes, new road construction, new interchange construction, new bridge construction, and freeway upgrades through 2030 [1]. These plans include extending I-69 from Indianapolis to Evansville and constructing the Illiana Expressway in the northwest corner of the state. The plan also surveys freight stakeholders who frequent Indiana's highways and roads in order to outline the strengths and weaknesses of the freight transportation network. The survey finds that freight stakeholders identified Indiana's interstate highways as well maintained and felt that there was little congestion along the roadways; however, these stakeholders found that non-interstate roads were not as well maintained. The survey also notes concern over increased congestion at bottleneck

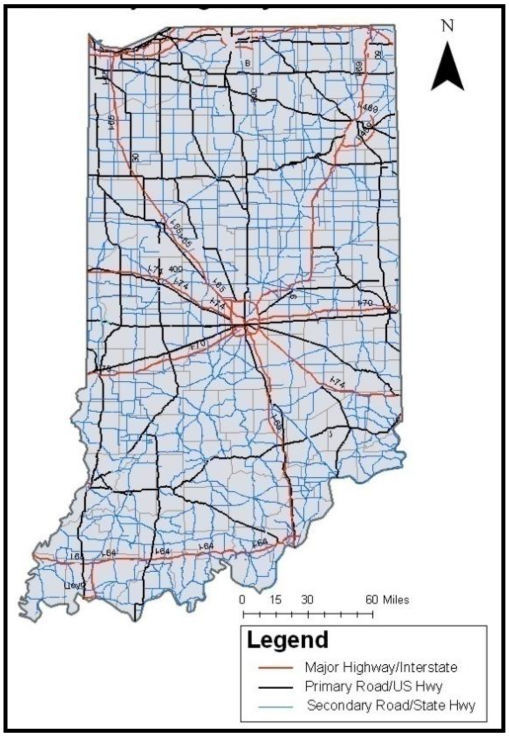

Figure 20: Major Highways and Roadways in Indiana [3, 6, 7, 13]

locations, as well as the Borman Expressway in Northwestern Indiana and the intersection of I-465 and I-69 in Indianapolis [1].

The movement of freight may shift toward truck-based highway transportation and away from barge and rail. INDOT believes that trucking will increase from nearly 73 to 75 percent of freight movement, barge will decrease from 11 to nine percent, and rail freight will decrease from 16 to 15 percent [1]. While INDOT recognizes that the use of biofuels will likely increase, it does not include the potential impact of biofuels on transportation in the forecasts created to determine future transportation trends. Consequently, estimates regarding decreases in rail and barge transport and increases in trucking may be lower than what will occur.

6.4 Current Maritime Transportation

In the extreme north on Lake Michigan and at the southern border along the Wabash and Ohio Rivers, barges transport primarily steel, mining, petroleum, and agricultural commodities [1]. While barge traffic moves 11 percent of freight by weight, less than two percent of freight transport value comes from maritime transport [1]. The movement of commodities by barge is most effective in the warmer months. During the winter, many Indiana ports close due to maintenance needs or because the waterway freezes and becomes impassable [1]. Ultimately, barge transportation is not a practical means of moving feedstocks or refined biofuels within Indiana; this transportation mode is primarily used for interstate commerce and has a very limited range.

6.5 Current Transport of Biofuels

Biofuels occupy a relatively small share of current freight transport in Indiana. Of the state's current capacity of 11.7 billion gallons of ethanol and 455 million gallons of biodiesel, 30 percent of biofuels and biofuels end-products transport by rail, 20 percent by truck, and 50 percent by barge [1]. With the anticipated increase from six to 12 ethanol plants within the next year, the biofuels transportation sector will likely figure more prominently in the freight industry.

6.5 Future Considerations

Within the last year, five ethanol plants came online, increasing the estimated production of corn based ethanol from 102 million gallons to 455 million gallons [14]. The Indiana State Department of Agriculture (ISDA) expects another six plants to be in production by the end of 2008, further increasing production by an additional 605 million gallons [14]. This expected increase in ethanol production will likely change the direction of one of the state's largest exports, corn. A study by Purdue University Extension estimates that in the long term, adjustments for increased ethanol production will decrease exports of corn from 52 percent in 2005 to only 25 percent by 2010 [15]. This decrease in exports will likely coincide with an increase in ethanol production from the current 102 million gallons per year to one billion gallons per year. As of January 2008, ISDA estimates that total corn ethanol production will reach 1.06 billion gallons per year by the end of 2008 [14]. The actual number of ethanol plants to emerge in the near future is uncertain; however, four proposed corn ethanol plants, estimated to produce an additional 358 million gallons per year, have already received state incentives [14].

Additionally the construction of current and expected biofuels production plants near feedstock sources (i.e. farms) is expected to increase the traffic and wear and tear on local roadways to and from biofuels plants. Consequently, there may be a need for an increase in highway maintenance due to greater truck traffic.

An essential factor in the production and distribution of biofuels is the ability of freight transportation corridors to provide a route from the farm to the processing plant, from the processing plant to the product terminal, and on to the final retailer. In order for the network to work, the final retailer must have the capacity to store and distribute the final product. The next section outlines the process behind the multi-step coordinated effort required to move biofuels from the farm to the pump and describes the related economic and environmental considerations associated with the distribution of biofuels within Indiana.

6.7 Transportation of Crops

6.7.1 Transportation of Feedstock from Field to Production Facility

In Indiana, large semi-trucks, railway trains, and barges are the three modes of transportation available to move bulk freight such as biofuels feedstocks. Large semi-trucks and flatbed trucks are the dominant means of crop transportation. Jumbo hopper cars (rail) serve to transport feedstock out of the state and also cover long distances within the state [1]. Since waterborne barge transport is only viable in the northwest and southern corridors, barges are not feasible for mass feedstock transportation throughout the state [1]. Consequently, future transport of feedstock from farms for use at biofuels production plants will primarily take place via trucks and railway trains. Before the feedstock arrives at the production plant, it must be stored in either a grain elevator or on the field for eventual purchase by the plant.

6.7.2 Storage between the Field and the Production Plant

Biofuels production plants do not have the storage capacity to hold feedstocks on site and therefore must purchase and ship feedstocks to the plant on a daily basis [16]. Harvested feedstock storage occurs at either a grain elevator or on the farm. Grain elevators are interim storage facilities for corn and soy feedstocks before purchase or shipment in state or out of state by either truck or railway trains [1]. There are over 180 grain elevators in operation serving farms and distributors throughout the state [2]. Farms located within a 25-mile radius of a grain elevator use trucks to transport the feedstocks to the elevator after harvest [2]. However, farmers bale switchgrass and corn stover cellulosic feedstocks and leave the bales in the field rather than transport the feedstocks to a grain elevator [16]. The storage of corn stover bales occurs, on average, five miles from the field from which it was harvested [17]. Switchgrass, however, remains on or near the field [18].

Production plants purchase feedstocks from either the grain elevator or directly from the farmer and transport the feedstocks to the plant. Ideally, grain elevators or farms are located within a short distance (less than 75 miles) of the plant [15]. However, it is not unlikely for the transportation of soybeans to occur over a distance of up to 150 miles, depending on the popularity of soybean crops around the production plant [19]. Trucks then transport the feedstocks to the production facility from the grain elevator or the farm.

6.7.3 Efficient Feedstock Transportation Considerations

While there are a number of factors influencing the most efficient way to transport feedstocks from the storage facility to the biofuels production plant, the most important element is the weight-to-value ratio (WVR) of the feedstock. The WVR compares the capacity needed to transport a feedstock to the monetary value of that feedstock. It allows production facilities to determine the transportation mode that is most efficient, given hauling capacity and associated costs. WVRs quantify characteristics including the weight of the feedstock, the volume to transport at one time, and the cost of the mode of transportation.

The weights and measurements of corn and soy are quantified in bushels. One bushel is equal to 1.25 cubic feet. The weights and measurements of switchgrass and corn stover are in bales, which are either rectangular or round in shape. The bale size of corn stover ranges from stackers (one half to one ton) and one-ton bales (four feet x four feet x eight feet) for rectangular bales to one-half ton round bales [20]. Switchgrass is baled in round bales weighing roughly half a ton [21].

6.7.4 Trucks

Standard large semi-trucks transport corn and soybeans from the grain elevator to the production plant. One of these trucks has a maximum weight capacity of 26 tons and a volume capacity of 910 bushels [2]. Corn weighs 56 pounds per bushel. Thus, given its weight capacity, a standard semi-truck could transport 1,023 bushels of corn at a time but is limited by its volume capacity to only 910 bushels [22]. Slightly heavier than corn, soybeans weigh 60 pounds per bushel, limiting a standard semi-truck to only 955 bushels at a time [22]. Like corn, the volume capacity of the truck restricts soybean transport to 910 bushels.

A standard flatbed semi-truck transports switchgrass and corn stover bales to the production facility. One of these trucks has a weight capacity of 23 tons and a volume capacity of 52 feet in length, 8.5 feet in width, and seven feet in height [23]. Corn stover bales vary in size (rectangular and round); therefore the quantity that a flatbed semi-truck can transport also varies. If farmers bale corn stover in rectangular bales (four feet x four feet x eight feet), a flatbed truck can transport 23 one-ton bales or 46 half-ton bales of corn stover at one time, taking into account the truck's weight capacity. If corn stover is baled in round bales, 17 one-ton bales can be transported at one time, considering the weight capacity and the standard stacking practice of 12 bales on the bottom and five bales on top [24]. Standard flatbed semi-trucks also transport rectangular bales of switchgrass. A standard bale of switchgrass is three feet in length by four feet in width by eight feet in height [21]. Given the weight of switchgrass, a standard flatbed semi can transport up to 46 bales of switchgrass. However, the volume capacity limits transport to 23 double-stacked rectangular bales of switchgrass.

6.7.5 Rail

Jumbo hopper cars transport all feedstocks by rail. Each jumbo hopper car has a weight capacity of 100 tons and a volume capacity of 3,500 bushels or 100 one-ton bales [2]. The size of a standard jumbo hopper car is 39 to 50 feet in length and 13 to 15.5 feet in height with a volume capacity 4,600 to 3,750 cubic feet [25]. Accordingly, one jumbo hopper can carry 3,936 bushels of corn, 3,674 bushels of soy, 200 bales of switchgrass, or 100 bales of corn. However, the weight capacity of a jumbo hopper car limits the transport of corn and soy to 3,500 bushels per car. The volume capacity of a jumbo hopper car also limits the transport of corn stover and switchgrass to around 40 one-ton bales per rail car or 80 half-ton bales, well under the maximum number of bales given the weight capacity of rail. (See Table 21: Transportation statistics of feasible crops for Indiana.for a summary of feedstock transportation statistics.)

Although the average costs of transporting feedstocks are unavailable, railway train transport is only efficient for transporting feedstocks over a minimum distance of 400 to 500 miles; otherwise, the rail haul of feedstocks is inherently unprofitable due to the low value of the feedstocks [2]. Ideally, the maximum distance for transporting feedstocks from the grain elevator or the field to the biofuels production plant should not exceed 75 miles. As a result, trucks are the only cost-effective option in Indiana for transporting feedstocks from the field to the grain elevator and from the grain elevator or field to the biofuels production plant [15]. If a grain elevator is not located within a 75-mile radius of the plant, or if purchasing from the grain elevator is too expensive, a biofuels production plant can directly obtain corn and soybean feedstocks from the farmer, bypassing the grain elevator storage system as it would for the purchase of corn stover and switchgrass.

	Weight	**Amount Transported per Truck**	**Amount Transported per Rail**
Corn	56 lbs/bushel	910 bushels	3,500 bushels
Soybeans	60 lbs/bushel	910 bushels	3,500 bushels
Corn Stover	~2,000 lbs/bale	23 one ton bales	40 one ton bales
Switchgrass	~1,000 lbs/bale	23 half ton bales	40 half ton bales

Table 21: Transportation statistics of feasible crops for Indiana.

6.7.6 Viable Feedstock Transportation

Trucks are the only cost-effective option for transporting biofuels feedstocks in Indiana due to the fact that rail is not profitable over short distances, including the 75-mile radius limitation for hauling feedstocks to a production plant. Indiana grain exports will continue to rely on rail, but in-state transport will shift to trucks. Trucks can easily access farms and existing biofuels production plants while few rail lines are in close proximity to either. Furthermore, even when using rail transport, trucks still need to transport the feedstock from the field to the railway and from the railway to the production facility. The short distance to either the farm or the grain elevator makes truck transport the most practical option for Indiana. However, as truck traffic expands to meet increasing demand for feedstock transportation to biofuels production plants, negative impacts, such as deteriorating road conditions (particularly on rural roads) and increased ambient pollution, may occur [2].

6.8 Biofuels Distribution

Although production costs are the largest component of retail prices, distribution costs can be significant when transporting biofuels over large distances [26]. According to GAO, DOE lacks a comprehensive strategic plan to coordinate significantly larger volumes of biofuels production with the current distribution infrastructure [27]. DOE's chosen fuel blend strategy for ethanol will greatly influence the nation's distribution infrastructure. The same equipment used to transport and store diesel can be used for biodiesel without any modifications, whereas ethanol requires minor modifications [26].

The current biofuels distribution infrastructure in the US includes rail, truck, and barge. Geographic location, cost efficiencies, and location of terminal storage facilities determine the proper mode of transport. The US has yet to use barge transport as a significant component of its distribution infrastructure due to existing capacity issues [28]. Other countries, such as Brazil and South Africa, distribute large quantities of biofuels through pipelines [29]. For Indiana, rail and truck will likely be the most efficient methods of biofuels transportation.

6.9 Biofuels Transportation Methods

6.9.1 Barge

Indiana has three public ports: one on Lake Michigan at Portage and two on the Ohio River at Jeffersonville and Mount Vernon. Transporting biofuels to distant markets by barge is a possibility for Indiana [15]. Currently, at the Port of Indiana at Mount Vernon, the state's largest ethanol production facility at 220 million gallons per year (GPY), Aventine Renewable Energy is under construction and should come online in 2008 [14]. This facility will be accessible by truck, rail, and river barge. River barges have a 10,000-gallon capacity and—depending on the market location—can cost less than rail transportation [30].

6.9.2 Railroads

Rail transport is typically the most cost effective mode of moving biodiesel and ethanol over medium to long distances of 300 to 2,000 miles [30]. In fact, ethanol shipments by rail nearly tripled from 2001 to 2006, when producers moved 106,000 rail cars [28]. Railroad corporations are now pushing production facilities to transport biofuels via unit trains, which are more efficient with 75 to 95 tank cars [28]. Each tank car has a capacity of 30,000 gallons [28]. These unit train cars are capable of discharging 3,000 gallons per minute (GPM), enabling rail operators to unload 18 cars in four hours, or an entire unit train in one day [30]. This appears to be a faster, more efficient method of transporting ethanol.

In a 2007 GAO report, railroad officials indicate that there is no spare capacity to support higher levels of biofuels transport; however, for Indiana, rail is the best method of exporting biofuels [27]. In 2002, INDOT developed a comprehensive *Indiana State Rail Plan*, which recommends funding track improvements for the state's 1,200 miles of short-line rail, as well as conducting a feasibility study on constructing a short-haul line on the I-65 corridor to divert some truck traffic [2]. Indiana railroads view as unprofitable lines that transport products distances of less than 400 to 500 miles; consequently, trucks will likely become the primary mode of biofuels transport within the state [2]. Coal is the most shipped item on rail followed by grain. Grain export shipments originate on short lines, which then connect to Indiana's Class I rail road lines. Short lines predominately serve rural areas and depend upon grain transport for revenue. They can transport biofuels. Using short lines can greatly reduce truck traffic on country roads and serve as a network for Class I railroad lines.

6.7.3 Tanker Truck

Biodiesel and ethanol distribution via tanker truck is cost effective for deliveries of up to 300 miles [30]. Each truck has a capacity of 7,800 to 8,200 gallons and cost for transport via truck can be as little as a few cents per gallon over short distances [26, 30]. The cost of producing and moving ethanol is the primary limitation to widespread use. As a result, the largest ethanol fuel markets have emerged close to feedstock-growing areas and production facilities [26]. In an interview with Ron Howe of Integrity Biofuels in Morristown, Indiana, he stated that his company ships 70-80 percent of its product to destinations in Indiana, with the remainder going to the Chicago area. Howe also stated that to keep costs low, the company only transports biodiesel distances within 150 miles [19].

Not only do tanker trucks transport biofuels directly from the production facility, but they also upload ethanol at large petroleum product terminals that have received the fuel by rail. These trucks then deliver the fuel to regional terminals that are not equipped for rail delivery or lack the storage capacity for a large quantity delivery [26]. Thus, biofuels production and distribution may cause an increase in truck traffic on state and local roads [15].

6.7.4 Pipeline

Generally, pipeline distribution is the most economical mode of fuel transportation [29]. The use of pipelines for transporting gasoline generates a cost of \$0.03-0.05 per gallon, whereas ethanol, whose main modes of transportation are rail and tanker truck, costs approximately \$0.13-0.15 per gallon [27]. Pipeline distribution of biofuels is operationally prohibitive. The US already has an extensive existing pipeline infrastructure for petroleum, natural gas, diesel, and jet fuel. However, the existing infrastructure is not conducive to biodiesel and ethanol transmission. The infrastructure moves petroleum products from the refineries located on the nation's coasts to its interior [31]. Most ethanol and biodiesel plants are located within the Midwest, and their products must be shipped in the opposite direction of the current pipeline infrastructure to more populated areas.

Because of its chemical properties, the US has not installed pipelines for ethanol transportation and distribution. Ethanol and high-grade alcohols are extremely corrosive on some soft metals such as zinc, aluminum, brass, and lead [32]. Ethanol also has the tendency to attract water and other chemicals left in the pipeline, which reduces its ability to blend at higher concentrations

[33]. Contamination of ethanol by water and other chemicals may damage engines, which then suffer poor performance [32].

Ethanol pipelines in Brazil have been successful, and there is now a project by Petrobras, a state-owned oil company and the nation's largest ethanol producer, to build an approximately 200-mile pipeline [34]. For the past decade, Brazil has been using polyethylene pipelines to transport ethanol [35]. However, as of 2007, no major US pipeline has invested in ethanol transport [31]. In the US, pipelines can be modified in order to support ethanol. This involves using epoxy and other anti-corrosive substances to coat the inside of pipes, and replacing corrosive-susceptible components [31]. The cost of constructing ethanol pipelines is approximately $1 million per mile [27]. However, this may vary dramatically depending on the status of right-of-way. For example, if ethanol pipelines are built along existing pipeline routes, the cost decreases to approximately $500,000 per mile [29]. Nevertheless, to be cost effective in the US, ethanol would have to replace 40 percent of gasoline consumption [29].

Unlike ethanol, biodiesel is not corrosive and does not attract water in pipelines. Since 2006 there have been several B5 biodiesel experimental shipments through existing pipelines. Country Mark Cooperative, an Indiana-based oil refining and marketing company, successfully moved 210,000 gallons of B5 through a 238-mile pipeline network (which usually transports diesel, gas, and heating oil) from their Mount Vernon, IN refinery to their Jolietville, Indiana terminal facility in July 2006 [36]. There is no pipeline transportation of blends higher than B5 due to the risk of the fuel congealing at low temperatures. Yet, there are still concerns that biodiesel transmix,[13] a mixture of biodiesel with another type of fuel, will not meet biodiesel fuel specifications or will contaminate other fuels [36].

6.10 Distribution Considerations

There are many factors to consider in selecting a distribution mode, including the size of the production facility, shipping costs, customer preferences, shipment size, the capability of the producer to use rail or barge transport, and distance to the distribution terminals. Very small production facilities[14] usually transport their product exclusively by truck. For small production facilities, freight rail and trucks are the most cost-effective modes of transportation. Medium-sized production facilities also ship their product mainly by truck and rail. Large production facilities move biofuels economically by truck, rail, and barge [30]. While large production facilities located on navigable waters could transport biofuels via barge, these boats are too slow to get the fuel to market in a timely manner. Moreover, the majority of production facilities (including most of those in Indiana) are not located on navigable waters [28].

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[13] Transmix occurs when different types and grades of fuel are shipped through the same pipeline [36].

[14] Very small production facilities are those that produce less than 10 MGY; small facilities are those that produce 10-25 MGY; medium-sized produce 25-50 MGY; and large produce more than 50 MGY.

6.11 Petroleum Destination Terminals

Before it leaves the facility, producers denature the ethanol by blending 100 percent ethanol with five percent gasoline for transport as E95. Conversely, producers transport biodiesel as B100 (100 percent biodiesel) [26]. Distributors then store and blend the ethanol with gasoline at petroleum product terminals [26]. Petroleum terminals dictate the transportation delivery mode based on both distance from the production facility and its receipt and storage capabilities [30]. Terminals close to a production facility generally receive biodiesel and ethanol by tanker truck. A terminal's receipt capability includes its storage and blending capacity. Large petroleum terminals are accustomed to receiving fuel via pipeline, so some do not have adequate rail infrastructure or train unloading capacity [28].

Facility storage tanks must be large enough to maintain an adequate inventory and receive a minimum shipment size [26]. A 25,000-barrel storage tank costs approximately $500,000 [26]. Additionally, petroleum terminals must install new blending systems or modify existing systems in order to store ethanol and biodiesel; these systems could cost up to $1 million [26]. While some petroleum terminals use the "splash blending" method, where ethanol is mixed with gasoline inside the tanker truck as it is being filled, this method can result in incomplete blending and high product volatility [26].

6.12 Transitioning Gas Stations to Biofuel Retailers

In the US in early 2007, approximately 1,050 public fueling stations offered E85, a high-concentration ethanol blend, and about 325 stations offered biodiesel in 20- to 100-percent concentrations (B20 to B100) [27]. GAO estimates that E85 was available at about 0.6 percent of all fueling stations and that biodiesel from B20 to B100 was offered at about one percent of all diesel stations [27]. In addition to the limited availability of ethanol and biodiesel, the need for specialized storage and dispensing equipment at fueling stations may further hinder the widespread public supply of biofuels [27].

6.13 Ethanol

Many fuel retailers currently blend ethanol with gasoline in order to lower costs, increase the fuel's octane rating, and decrease harmful gasoline emissions [27]. Corn-based ethanol accounts for 98 percent of the ethanol produced in the US [27]. Gasoline-ethanol blends containing 10 percent or less ethanol (E10) are approved for use in all gasoline vehicles and do not require the retailer to modify existing or install new storage and dispensing equipment [26, 28]. Higher concentration blends, such as E85 (85 percent ethanol), can only be used in flex-fuel vehicles (FFVs) and generally cannot be stored and dispensed without equipment modification [26, 38].

E85, the most popular higher blend of ethanol, may require the use of new or modified equipment due to its corrosive nature [27, 38]. High-concentration ethanol blends tend to degrade soft metals such as lead. Terne, a lead-tin alloy, is often used to plate steel gasoline storage tanks [26]. Other materials like natural rubber, polyurethane, polyvinyl chloride (PVC), and some plastics also degrade when in contact with ethanol [26]. Most metal underground storage tanks that meet December 1998 EPA codes and most fiberglass underground storage tanks are suitable for ethanol storage, but those previously used for gasoline must be cleaned before using the tank for an ethanol concentration higher than E10 [32]. Particulates in gasoline tend to settle at the bottom of the tank; adding ethanol—an alcohol—to a dirty tank will place this sludge in suspension, causing problems in the ethanol user's vehicle [32].

Retailers must also ensure that there is no water in the tank and remedy any causes of water buildup in ethanol storage tanks [37]. Ethanol is susceptible to phase separation. If sufficient water accumulates in the storage tank, the ethanol in the blend will absorb the water and separate from the gasoline. This forms two layers in the tank: gasoline on top and ethanol on the bottom. As it is no longer an ethanol blend, this phase separation can cause problems in vehicles' fuel lines [39].

In addition to storage tanks, all fuel dispenser components must consist of ethanol-compatible materials, including filters, dispenser hoses, nozzles, fitting, connectors, adapters, and piping [32].

Costs of converting existing or replacing storage tanks and dispensing equipment vary. A GAO report states that converting existing storage tanks and dispensers to E85 at 64 fueling stations in Illinois from 2005 to 2006 cost an average of $3,354 per station [27]. Other estimates for equipment conversion range from $2,500 to $30,000 [40]. A survey by Underwriters Laboratories, a product safety certification organization that tests products and writes standards for safety, finds that of 45 stations that cleaned existing equipment for use with E85, none took into account manufacturer-recommended retrofits [40]. The report states that these "simplified cases" will likely not meet the Underwriters Laboratories standards for E85 when they are released [40].

Expenses associated with replacing or adding storage tanks and dispensers exceed those of converting existing equipment. One project to install a new E85 storage tank and dispensing equipment at Mammoth Cave National Park in Kentucky in 1998 cost a total of $22,216; the tank alone cost just over $16,000 [32]. This is relatively low, with other estimates ranging from $50,000 to $70,000, and one as high as $200,000 [27, 40]. The Energy Policy Act of 2005 provides assistance for fueling stations in converting or replacing equipment to become E85 compatible. The legislation authorizes a tax credit of 30 percent of the expense of installing E85 distribution equipment, up to $30,000 [41]. Indiana also offers grants of up to $5,000 to defray fueling stations' costs of converting to E85 [42].

6.13.1 Limited Availability at Branded Stations

In addition to the expense associated with modifying or purchasing new storage and dispensing equipment, liability and branding concerns may limit the availability of E85 at fueling stations. A GAO report states that Wal-Mart, BP, and Marathon Petroleum representatives cite the lack of an Underwriter Laboratories-certified E85 dispenser as a greater obstacle to offering E85 at their fueling stations than equipment costs, and these companies have deferred plans to offer E85 until an approved dispenser is available [27].

The same report finds that, while 37 percent of fueling stations are under the brand of five major oil companies (BP America, Chevron Products Company, ConocoPhillips, ExxonMobil, and Shell Oil Products US), only nine percent of stations selling E85 and eight percent of those offering higher biodiesel blends are under one of these brands [27]. None of these major oil companies offers E85 to their stations as a branded product; only in states where it is mandated by law do they offer biodiesel [27]. Because the brand does not have control over the quality of the unbranded product, stations must label the E85 and biodiesel they acquire from other sources differently than branded products and are not allowed to advertise the unbranded biofuels on their marquees [27].

6.14 Biodiesel

Like ethanol, biodiesel may be blended with its petroleum counterpart, diesel, for use in vehicles with diesel engines. Biodiesel may improve engine performance and lubrication, reduce greenhouse gas emissions, and decrease emissions of other common air pollutants [43]. In the US, producers use soybean oil to generate 90 percent of biodiesel [44]. Typical blends of biodiesel are B5 (5 percent biodiesel, 95 percent diesel) and B20 (20 percent biodiesel, 80 percent diesel), though the product can be used in its pure from as B100 [43]. Most diesel engines can run on biodiesel without modification [43]. Biodiesel in lower concentrations does not appear to present any significant material compatibility issues with engines or storage and dispensing equipment [45]. However, some diesel engine companies do not cover biodiesel use in their warranties [46]. Like ethanol, biodiesel in high concentrations such as B100 may cause problems when it comes into contact with certain metals (brass, bronze, copper, lead, tin, and zinc) and other materials (nitrile rubber compounds, polypropylene, polyvinyl, and Tygon) [46]. Vehicles manufactured before 1993 are more likely to contain engine parts incompatible with B100 [45]. Most diesel fuel storage tanks are made from materials that are compatible with biodiesel and require only limited modifications to storage tanks and dispensing equipment [44, 45]. The federal tax credit of up to $30,000 for alternative fuel infrastructure changes at fueling stations (discussed above for ethanol) also applies to biodiesel blends of B20 or above [41].

6.14.1 Potential Policies to Increase Biofuels Distribution by Fueling Stations

As biofuel production and FFV availability increases, ethanol and biodiesel fuels will likely become more accessible to the public. GAO reports that members of Congress have proposed a number of policies to increase the availability of biofuels, such as mandating that major oil companies install at least one E85 dispenser at each of their fueling stations, prohibiting biofuels marketing restrictions on fueling station franchisees, allowing the public to utilize federal fueling stations that offer biofuels, and increasing tax credits to fueling stations that install biofuel infrastructure [27]. The National Governors Association echoes those recommendations and adds that states might “boost the adoption of alternative fuels or vehicles” by, for example, purchasing vehicles for state fleets that can run on biofuels, and by investing in research and demonstration to bring new technologies to market [44].

6.15 Distribution Risks and Benefits

6.15.1 Fire

One major risk associated with biofuels distribution is fire hazard. Both ethanol and biodiesel are volatile substances and receive a three out of four hazard rating by the National Fire Protection Association [47].[15]

Biodiesel fires should be extinguished using foam or dry chemicals as water can splash, spreading the burning liquid [48]. Biofuels leaks should be contained because runoff to sewers and drainage systems could cause fire or explosion hazards [48]. Biodiesel should always be stored in a dry, cool, and well ventilated area.

Ethanol vapors, which have many of the same characteristics as gasoline, are heavier than air; therefore, they travel easily away from the initial release point. There have been some instances where fire has started from ethanol vapors traveling a considerable distance from the release point to an ignition source [48]. Fire suppression of higher ethanol blends such as E85 requires the use of alcohol-resistant foams. However, any ethanol blend under 10 percent can accept the same fire suppression foam technology as used for gasoline and other hydrocarbon fuels [48].

6.15.2 Water Resource Contamination

When motor fuels accidentally spill into environment, they infiltrate groundwater and surface water supplies. Fueling stations, refineries, and major transportation corridors are potential sites of contamination, and these areas become more sensitive as human and wildlife population densities increase. Each type of transportation fuel has a different level of toxicity, and several federal regulations mandate specific handling requirements for different motor fuels. As illustrated below, one of the major benefits of displacing conventional motor fuels such as gasoline and diesel with biofuels is the significant decrease in the health risks associated with the toxic properties of the fuels.

6.15.3 Conventional Fuels Toxicology

Gasoline and diesel fuel are derived from the distillation of petroleum and contain mixtures of hundreds of different hydrocarbon chains. Commercial additives, which improve octane ratings, oxygen content, and other performance measures, further complicate the toxicology of gasoline [49]. Furthermore, the refinery streams used to blend gasoline are all on the Toxic Substances Control Act (TSCA) Chemical Substances Inventory [50]. Additionally, the US regulates gasoline for acute and chronic health effects under the Superfund Amendments and Reauthorization Act (SARA), Sections 311 and 312. Some of the potential additives for gasoline are benzene, ethyl benzene, naphthalene, ethanol, methyl tert-butyl ether (MTBE), tertiary amyl methyl ether (TAME), and ethyl tert-butyl ether (ETBE) [50]. Many of these are highly toxic, and are either known or suspected carcinogens.

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[15] A rating of three is given to materials that are flammable, volatile or explosive at ambient pressures and temperatures

If accidental releases of gasoline go unnoticed or unchecked, the resulting water contamination can pose serious threats to local human and wildlife populations. As with all toxicants, the duration and level of exposure to the chemical constituents of gasoline determine the degree of associated risk. Although gasoline is minimally soluble in water, many of its toxic constituents are more highly soluble, and local environmental conditions dictate the rate of biodegradation and the ultimate fate of the fuel. When gasoline runs off into surface waters, it may be toxic to aquatic organisms; lab tests reveal that LC50s (concentrations lethal to 50 percent of test subjects) range from 1.8 milligrams per liter to 8.3 milligrams per liter for a variety of fish and invertebrates [50].

MTBE is a common gasoline additive which is highly soluble in water, and as its use expanded, concern over leakage from underground storage tanks increased [49]. EPA has classified MTBE as a possible human carcinogen; it also causes acute headache, eye, nose, and throat irritation, cough, nausea, dizziness, and disorientation [49]. As a result, on March 14, 2002, Indiana initiated a partial ban on MTBE in gasoline, allowing no more than 0.5 percent MTBE by volume, with a phase-out date of July 24, 2004 [51]. This created a window of opportunity for ethanol since it is a common substitute for MTBE, but without mandates requiring ethanol use, other more toxic additives such as TAME and ETBE may still replace MTBE. Furthermore, given sufficient levels of ethanol in the subsurface environment, gasoline and water become completely miscible and flow through substrates in a single phase [52]. This can lead to significant increases in BTEX (benzene, toluene, ethylbenzene, and xylene) concentrations in groundwater [52].

While diesel's composition is different from that of gasoline, both fuels contain common ingredients and performance-enhancing chemicals that contribute to the toxicity of the fuel. The US regulates diesel fuel as an acute and chronic health hazard under SARA Sections 311 and 312 [53]. A variety of amines and low-weight polymers are added to stabilize the fuel, prevent corrosion and buildup, and improve the overall cold properties of diesel. Diesel contains varying levels of aldehydes, benzene, 1, 3 butadiene, polyaromatic hydrocarbons (PAH), and nitro-PAH [54]. Benzene poses the most documented threat, and even mixtures containing low levels of benzene merit due caution. The toxic nature of PAHs caused the federal government to begin limiting aromatic content in diesel to below 40 percent in 1993 [54].

While acute exposure to diesel fuel causes severe eye and skin irritation and lung damage if ingested or inhaled, there is little knowledge about chronic exposure to low doses of its constituents, as would be the case with water contamination [53]. Overall, the National Fire Protection Agency (NFPA) gives diesel fuel its lowest ranking for health hazards, but many of its components are known toxins and potential carcinogens, and the substance must be handled accordingly. Diesel is negligibly soluble and volatile and requires similar emergency response measures to those of gasoline [53]. Environmental releases of transportation fossil fuels should be contained and cleaned up immediately, and should be considered a significant threat to human health and the environment.

6.15.4 Biofuels Toxicology

Corn ethanol and biodiesel from soybeans are the primary biofuels produced in Indiana and are intended to displace some gasoline and conventional diesel consumption. While ethanol is a known toxicant, the majority of the research on its health effects regards its presence in alcoholic beverages and not its potential environmental impacts [49].

Although the duration of exposure to ethanol from groundwater contamination could be lengthy if a leaking storage tank went unrepaired, the concentration of ethanol and the total volume consumed would likely be minimal compared to cases of intentional ingestion. Furthermore, ethanol biodegrades more quickly in natural environments than the constituents of gasoline, and it would be unlikely that human exposure to ethanol would be high enough to cause significant harm [52]. Ethanol is completely water soluble, and if it infiltrates groundwater, its plume travels at the same speed and in the same direction as groundwater flow [52]. Although ethanol biodegrades quickly, the process consumes large amounts of oxygen, which can deprive microorganisms of their oxygen requirements and slow the biodegradation of BTEX in gasoline if the two are involved in the same accident [52]. Overall, ethanol is a much simpler substance, biodegrades faster, and poses much less risk to water resources than its petroleum-based counterpart.

While extensive research on alternative uses of ethanol has to some extent precluded serious analysis of its toxic potential in its use as a biofuel, the same is not true for biodiesel. Biodiesel is a relatively new substance, with significantly different chemical properties than its petroleum-derived counterpart. The manufacturing process converts fats and oils into fatty acid methyl esters of varying length [45]. Biodiesel is either consumed neat (100 percent biodiesel) or as a 20 percent additive to conventional diesel. It is a legally registered fuel and fuel additive with the EPA, and is listed under TSCA, but has been found to contain no hazardous materials and is generally regarded as safe to use [45]. Most laws that regulate the toxicity of petroleum-derived fuels do not apply to biodiesel. Biodiesel has received a rating of zero (minimal hazard) for health effects from the Hazardous Material Identification System, and while the oily and flammable nature of the substance merits concern in remediating accidental releases, it is completely insoluble in water and responses to leaks and spills are much less urgent than for conventional diesel [55]. While conventional diesel fuel contains up to 40 percent aromatics, biodiesel contains none, greatly decreasing its toxicity by comparison [56].

Biodiesel can slightly irritate eyes and mucous membranes if inhaled, but vapors are only present if the substance is heated. Skin irritation is not likely, and there are no hazards anticipated from incidental ingestion [45]. In fact, one study sponsored by USDA found that the acute oral LD50 (lethal dose for 50 percent of test subjects) is greater than 17.4 grams per kilogram by body weight, which is nearly ten time less toxic than ordinary table salt (NaCl) [57]. The mutagenic effects from exposure to biodiesel are also substantially lower than those of petroleum-based diesel, and while blends are less mutagenic than conventional diesel, neat biodiesel is by far the safest [56]. Not only is biodiesel insoluble, but it also biodegrades quickly in comparison to petroleum-based diesel. One study found that 95 percent of biodiesel had biodegraded after 28 days, while only 40 percent of conventional diesel had degraded under similar conditions [58].

Overall, research on biofuels, along with general toxicology of their chemical constituents, suggests that petroleum-based transportation fuels are far more toxic than their biofuel alternatives. Biofuels are less toxic in nature and decompose at much faster rates than fossil fuels, leading to the conclusion that the transportation, storage, distribution, and use of biofuels pose much less risk to water resources.

6.16 Conclusions

In establishing BMPs for the harvest of cellulosic feedstocks such as corn stover and switchgrass, policymakers should take shipment needs into consideration. Based on current data, rail transportation of biofuel feedstocks within Indiana will not meet the needs of feedstock producers, nor will it be cost effective. In order to move feedstock efficiently, biofuels producers should employ trucks as the primary mode of transportation. Due to the low economic value of the feedstocks, studies suggest that shipments made in excess of 75 miles will not be economically efficient. To transport refined biofuels over distances of less than 300 miles, tanker trucks are the most cost-effective option. The distribution of refined biofuel by rail is a good alternative, but railway companies require hauling distances of 300-2,000 miles to make rail travel efficient, and infrastructural adjustments are necessary for this to occur. Maintaining and improving Indiana's short-rail lines offers the possibility for export of biofuels and may encourage further investment in the state. For this to be effective, production facilities should located near existing short-rail lines allowing for eventual export via Class I rail. Finally, to ensure the safe transport and storage of biofuels, emergency service individuals and retail operators should train in managing biofuels spills and leaks, and in preventative maintenance of biofuels tankers used for transport and storage tanks. This becomes a greater concern as the quantity of biofuels in transport increases and the number of vehicles running on biofuels grows.

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7. Site Suitability Analysis

7.1 Justification

Corn and crop residues such as corn stover are appealing feedstocks for biofuel production because they are readily available [1]. Furthermore the technology for corn ethanol (hereafter referred to as ethanol) is highly developed [2]. There are currently 12 ethanol plants in production or slated for production within the next year in Indiana [4] (Figure 1). This analysis uses spatial analyst tools to address the question: Where are the most suitable sites to build ethanol production facilities in Indiana?

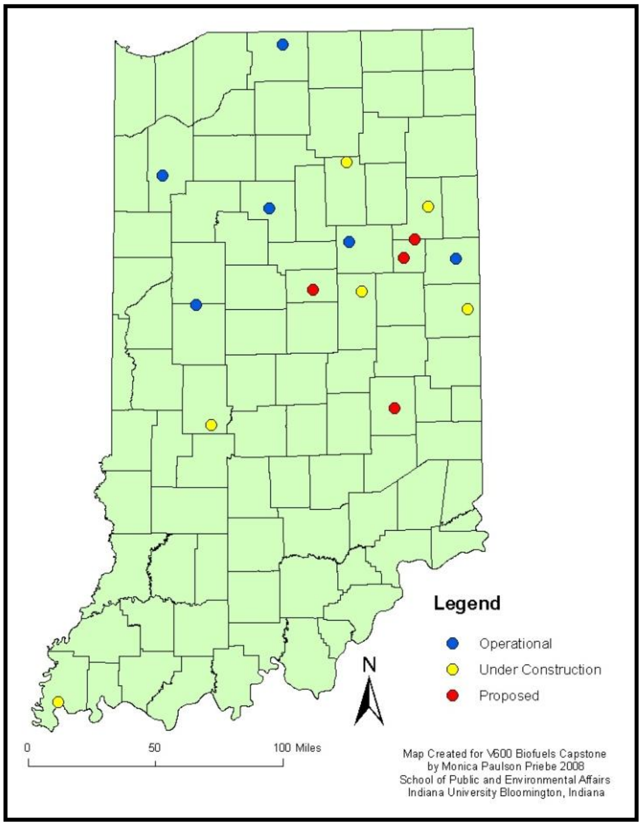


Figure 21: Ethanol facilities funded through state initiatives [3, 4, 5]

Because of resource demands, the distribution of agricultural land across the state, and market saturation careful consideration of future production plant location is important. If sites are not properly selected for these facilities, there could be an inadvertent yet severe impact on land and water resources. There is also the danger that ill-sited plants would no longer be economically efficient after the initial market boom in production facilities settles down. Economically, the constraints imposed on these plants are highly dependent on transportation costs [6]. The farmer can economically transport their crop up to 25 miles [6]. The distance from grain elevators to production facilities is the most significant economic constraint on transportation. Production facilities can get their grain from up to 75 miles away [6]. Further consideration needs to account for current ethanol facilities' locations so as not to saturate the market.

Ecologically, ethanol plants require large volumes of water, on the scale of four gallons to every gallon of ethanol produced [7]. Therefore, surface waters and aquifers will be increasingly tapped to supply a growing water demand. Because groundwater is replenished slowly, facilities would be more sustainable if they were able to use surface water and return the waters to the rivers and lakes. Therefore, plants within pumping distance to surface waters would be preferred.

However facility location along waterways should not be recommended at the extreme environmental costs of building the facility within fragile riparian areas. If the site selection does not account for these water needs, they could threaten the Indiana's freshwater supply. Like all new infrastructure, smart placement is key to the economic and ecological outcomes in the area.

While the push for ethanol has been the main focus for alternative fuels in Indiana [8], relative to other ethanol feedstocks, corn has a low energy balance. Additionally the technology is mature, leaving little room for efficiency gains from production methods [9]. These compelling reasons may lead Indiana to shift focus to cellulosic ethanol production in the near future.

Cellulosic ethanol in Indiana could feasibly be produced from both corn stover and in the future, switch grass. Currently there are no cellulosic plants in Indiana. However there is widespread supply of corn stover which may justify the development of cellulosic ethanol in Indiana. The most suitable sites for cellulosic ethanol production facilities would be largely dependent on similar constraints to current ethanol plants, with the exception that cellulosic plants would not be dependent on grain elevators as farmers are likely to store the bales and sell directly to the production facilities. Therefore, using current trends to predict distances, farmers could travel up to 25 miles to deliver their product [6]. These production facilities would still be dependent on high amounts of water and thus, close proximity to major sources of surface water would be ideal. Availability of roads and slope of the land are also important considerations.

Indiana has a high number of existing ethanol facilities near which cellulosic ethanol could be produced in rotation with grain feedstocks. Therefore, a co-location of corn ethanol and cellulosic ethanol plants may be desired. Once cellulosic production becomes more efficient and profitable, independent cellulosic plants may start to appear across Indiana's landscape.

Once cellulosic production facilities are on line, a shift to the more efficient feedstock, switchgrass, may become appealing. While the cellulosic ethanol process has not yet been perfected, it is projected to be online by 2012 with large opportunities for increased efficiency in production. Therefore, Indiana needs to be planning and effectively locating production facilities taking into consideration economics and the environment.

7.2 Methods

In order to find the most suitable sites in Indiana for corn and cellulosic ethanol production facilities, many factors had to be included in this analysis. Additionally, the most suitable sites for ethanol facilities, because they are largely dependent on location of existing facilities and grain elevators, provided different results than the site suitability analysis for cellulosic ethanol production facilities that do not share this constraint. All analyses were conducted using ArcMap 9.2 [4].

This analysis has a multi-tiered approach. It first focuses on the suitable sites for future and proposed ethanol plants incorporating the following variables: distance to major grain elevator, distance to surface water source, distance to highways, and distance from existing plants. All the following datasets were combined to find developable areas [10, 11, 12, 3]. A Euclidean distance buffer was used which allowed for areas near grain elevators, surface water and highways and far from existing facilities to be ranked higher on a scale of one through ten with ten being the most optimal sites.

Location data was combined with a digital elevation model (DEM) which was converted to slope for the state of Indiana [13]. Protected areas in Indiana, such as parks, as well as highly developed areas and wetlands were excluded from analysis by using a mask over the DEM. Once the slope dataset was masked, the data was reclassified to exclude areas with a slope over 30 percent in the interest of finding more level developable areas. The remaining areas were assessed to find suitable sites for future ethanol facilities using a weighted overlay analysis. The inputs were then weighted, with distance to grain elevators as the most important at 30 percent weight, followed by distance to highways at 25 percent, areas with lower slope at 20 percent, distance to surface water at 13 percent and finally, the distance to current facilities at 12 percent weight.

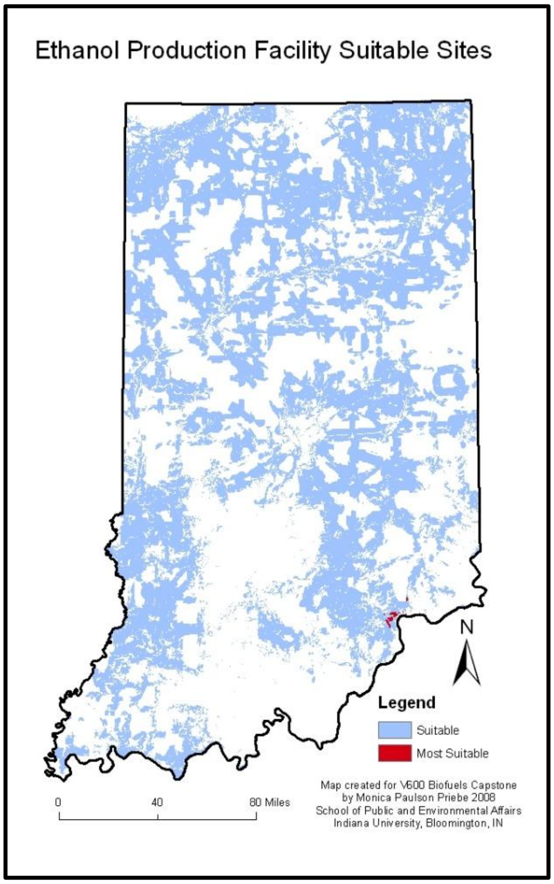
To find the most suitable sites for a future cellulosic ethanol facility location, similar methods of analysis were used excluding the grain elevator and location of current production facility restraints. The variables included were distance to surface water, distance to highways and areas of low slope [11, 12, 13]. These layers were buffered allowing for areas near surface water and highways with low slope to have a higher ranking than the other alternatives. Using a weighted overlay the variables were weighted proportionally to the ethanol facility overlay. The distance to roads was weighted the most at 43 percent, followed by areas of low slope at 35 percent and distance to streams at 22 percent. A map of the suitable sites for cellulosic production was created.

The third tier of analysis used the two outputs from the weighted overlays for ethanol and cellulosic ethanol site suitability analysis and combined them to find areas in which co-location of a corn ethanol and cellulosic ethanol plant could be constructed. From this map, the top three existing sites were selected and buffered with a 25 mile buffer (the likely distance a farmer could transport switchgrass to the production facility). This buffer was overlaid on the current lands used for agriculture [15] and found the area of productive agricultural lands within the 25 mile radius of these facilities. The facility with the highest amount of contributing agricultural land in this area was selected as a possible pilot site for an ethanol-cellulosic ethanol co-production facility.

7.3 Results

Figure 23

While there are suitable lands remaining for ethanol facilities, only one region in the south east corner of Indiana ranks as the most suitable. This is largely, but not completely, due to the number of existing facilities in Indiana.

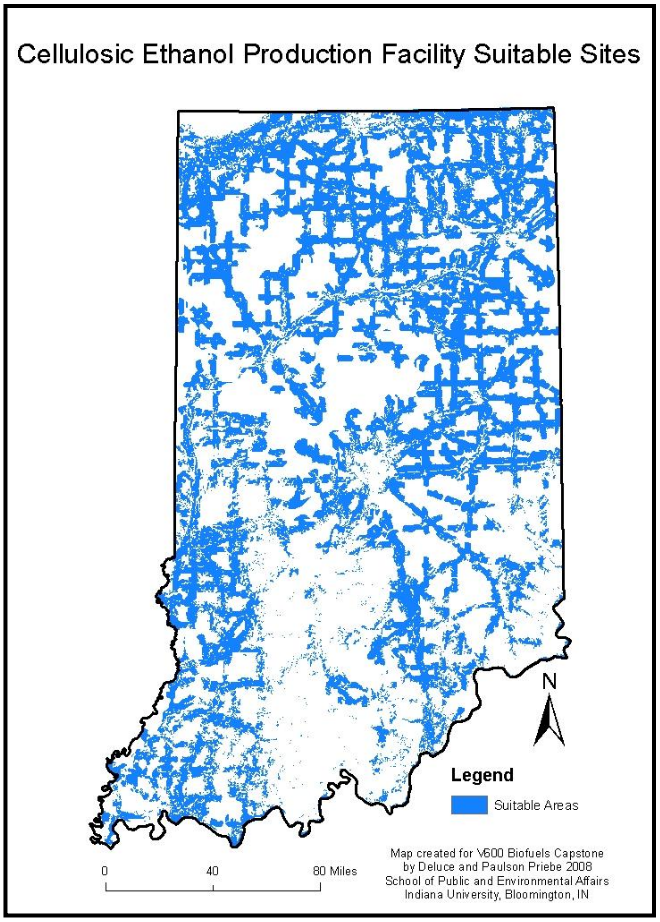


Map created for V600 Biofuels Capstone
by Monica Paulson Priebe 2008
School of Public and Environmental Affairs
Indiana University, Bloomington, IN

Figure 23: Suitable sites in Indiana for ethanol production plant location. Note: there were few areas that were ranked as the highest suitability (marked in red). The rest of the area ranked lower (marked in blue) but is still considered suitable sites.

Figure 22

Switchgrass, which was not limited by current facility location, has more suitable locations



Map created for V600 Biofuels Capstone
by Deluce and Paulson Priebe 2008
School of Public and Environmental Affairs
Indiana University, Bloomington, IN

Figure 22: Suitable sites in Indiana for cellulosic ethanol production plant location. All areas marked in blue were ranked as the highest site suitability. Due to the amount of area included in the top ranking area, the second ranking areas were not included in this analysis

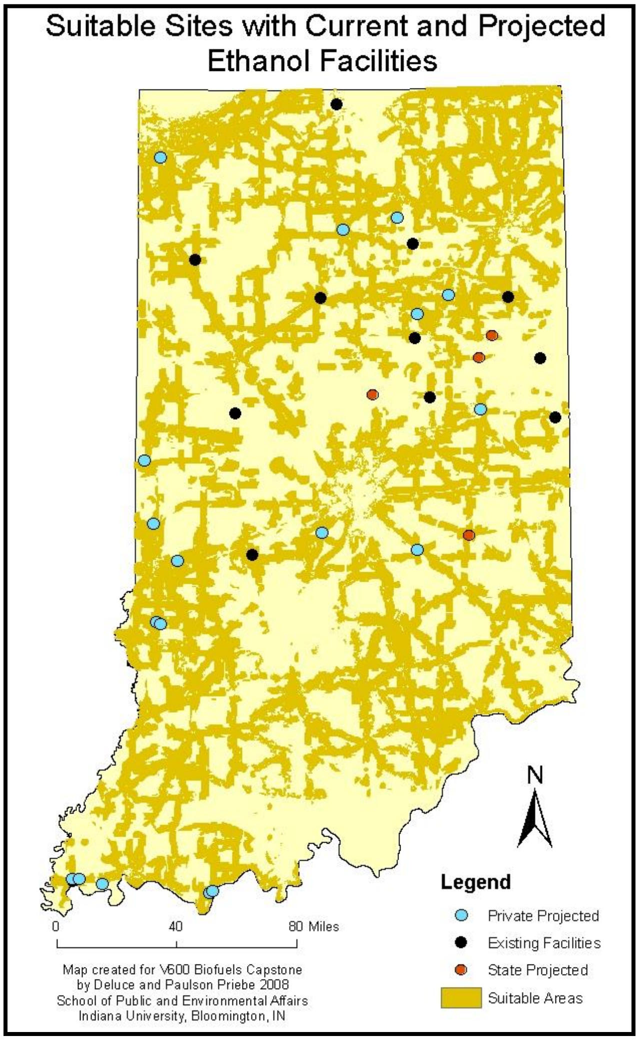


Figure 24: Overlap of suitable areas with current production facilities as well as state and privately funded proposed sites.

Figure 26

It becomes apparent that when state and privately proposed sites are shown with the suitable areas, that many, although not all, match up. This may mean that local conditions are still favorable for production facility construction and operation. However, in some cases it may indicate that the locations proposed may need further analysis.

Figure 25

When the first and second most suitable areas for ethanol production are overlaid with the most suitable sites for cellulosic ethanol, a large area of the state falls within the parameters used in this analysis.

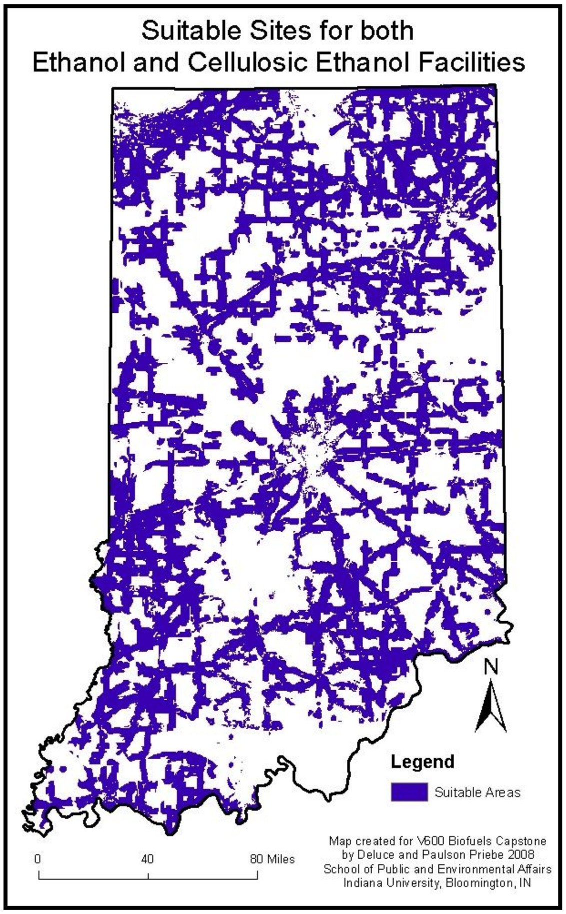


Figure 25: Suitable regions without existing production plants

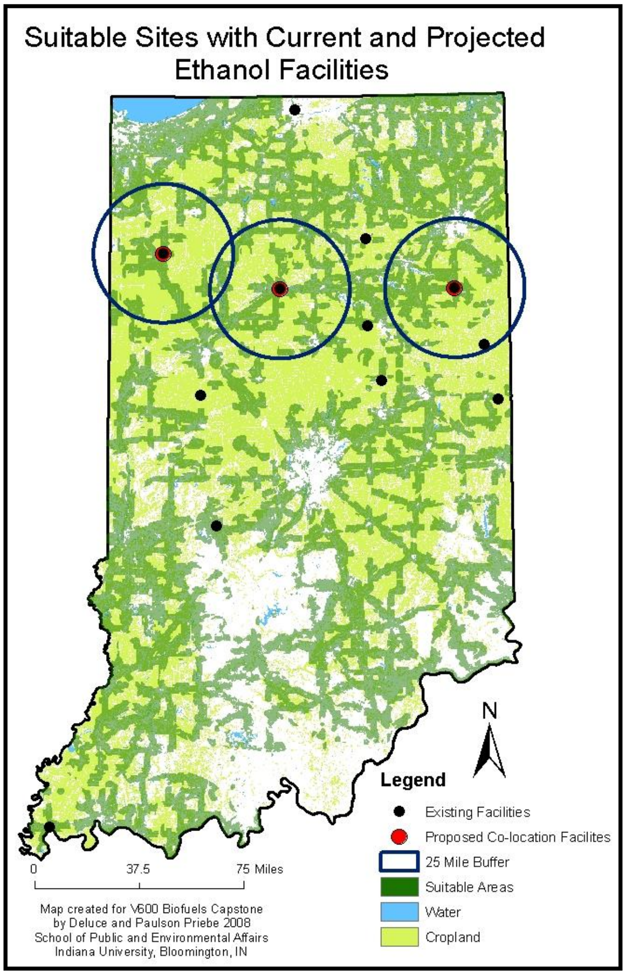


Figure 27: Top three ranked current ethanol facilities for addition of cellulosic ethanol production facility co-location.

Figure 27

All remote analyses however, are subject to error. Spatial GIS analyses results cannot be assumed accurate without on-the-ground verification of results. There may be other conditions at these sites that would restrict construction of these facilities. Other sites less suitable in this analysis may be more suitable when other local conditions are considered. Only current facilities, either in production or in construction, were used in this analysis. This may lead to overlap between the suitable sites for future facilities and the locations of proposed sites. Analysis did not take into account agriculture first; therefore suitable sites were not selected because they have the most contiguous acres of agricultural lands. Area of adjacent agricultural land was taken into account after suitable sites were defined.

Figure 28

For preliminary cellulosic production facilities it may be was to co-locate them with existing ethanol facilities until it becomes more cost effective on a wide-scale. Therefore, when current facilities are assessed, the facilities that fall within the most suitable sites would be the best facilities at which to locate a pilot cellulosic ethanol production facility. When a 25 mile radius was assessed for agricultural land, the site in the middle contained the most. This may be due to the fact that agricultural lands in surrounding states were not assessed in this analysis. According to these results, any of the three sites existing sites would be ideal for a co-located facility.

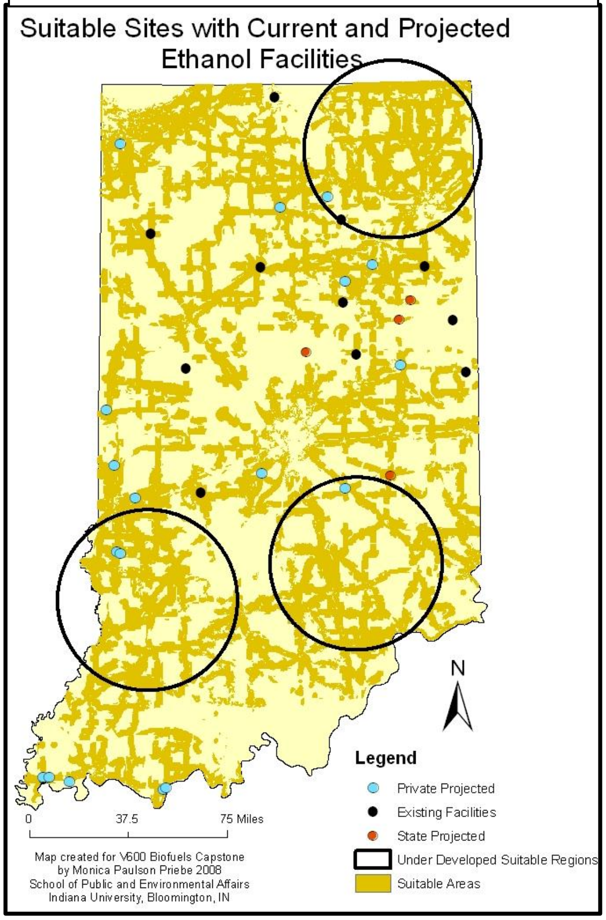


Figure 26: suitable regions without existing production plants.

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8. Energy Balance of Biofuels

8.1 Introduction

The notion of energy balance is a crucial element in the debate over biofuel viability. If the energy availability of a fuel is less than the energy expended during production, the practicality of widespread use diminishes. Energy balances are frequently provided as ratios of usable energy to production energy:

$$ER = \frac{E_f}{E_p}$$

$ER = Energy\ Balance\ Ratio$

$E_f = Energy\ content\ of\ fuel\ (in\ HHV\ or\ LHV)$

$E_p = \ Energy\ employed\ in\ fuel\ production$

If *ER* is greater than one, the energy balance is positive and thus more energy is available in the fuel than is expended in the fuel's production. If *ER* is less than one, the energy balance is negative and less energy is available in the fuel than used in production. Ideally, fuels should have ratios greater than 1 to be considered viable from a pure energy perspective.

An alternate method for considering energy balance is from the perspective of net energy, or total energy available less energy consumed in production:

$$NEV = E_f - (E_p - \ E_c)$$

$NEV = Net\ Energy\ Balance$

$E_f = Energy\ content\ of\ fuel$

$E_p = \ Energy\ employed\ in\ fuel\ production$

$E_c = \ Energy\ credits\ from\ coproducts$

Energy balances are unique for each type of fuel and for the feedstocks used to produce various biofuels. Given the variability of production inputs, these ratios differ spatially and temporally. Spatially the variations are explained largely by the use of different soil types with divergent fertility to produce a given feedstock. Temporally, energy balances are affected by weather conditions that may necessitate greater fertilizer use for feedstock production. The variation in energy contents necessitates an individual analysis of each feedstock under consideration.

This section seeks to explore existing literature and identify the different methods scholars have employed to examine the energy in fuel derived from different feedstocks. A unique situation arises for corn-based ethanol in that suitable data is available to generate Indiana-specific values for the energy balance and net energy for ethanol produced in the state. Insufficient data, however, limits the development of localized energy values for other feedstocks.

8.2 Energy Content of Fuels

All fuels have established amounts of energy available for use, defined above as E_f. Energy content is measured by the amount of heat produced through the combustion of a fuel. Heating values are measured in two forms, high and low. A high, or gross, heat value (HHV) is the amount of heat produced when a set amount of the fuel fully combusts. A low heat value (LHV) removes suppressed heat generated from water vapor from the HHV (note this is the same as E_f in the NEV equation above). For instance, ethanol's HHV is 84,000 Btu per gallon, but its LHV is only 75,700 Btu per gallon once adjusted for latent heat created in water vaporization [1].

Fuel	LHV	HHV		MJ/gallon
Agricultural Residues (low estimate)		4,300	Btu/lb†	
Agricultural Residues (high estimate)		7,300	Btu/lb†	
Biodiesel No. 2		140,000	Btu/gallon‡	126-135
B20 Mix (20/80)		138,000	Btu/gallon‡	
Diesel	130,719	138,714	Btu/gallon*	
Ethanol	75,700	84,000	Btu/gallon†	80-89
Gasoline	116,515	125,000	Btu/gallon*†	132

* Graboski, M. 2002. [3]

‡ North Dakota State University. 2003. [2]

† Oak Ridge National Laboratory. 2008. [1]

Table 22: Energy Content of Select Fuels

Table 22 provides the estimated energy content of various fuels. Gasoline contains 125,000 Btu per gallon at HHV, slightly less than available in various forms of biodiesel [2, 1]. These values are of particular importance in understanding energy balances because different scholars have selectively chosen HHV or LHV to present inflated results for *ER* or *NEV*. The use of HHV necessarily overstates the available energy in a fuel because vaporization is not accounted for; therefore, LHVs are more appropriate for energy balance analysis.

8.3 Analytical Process

Establishing the amount of energy expended during the production of biofuels is a tremendous process and, for the most accurate indication of energy available, must include all primary and secondary input processes. In the literature to be discussed below, the disparity of findings is largely a function of inconsistent use of system boundaries and accompanying assumptions. An ideal primary input boundary for biofuel production includes analysis of (1) feedstock planting, fertilization, and harvest; (2) transportation of feedstock to storage receptacles or processing plants; (3) feedstock-to-fuel conversion processes; and (4) transportation of fuel to storage facilities and/or points of distribution (Table 23). Secondary impacts to consider include inputs such as energy expended for fertilizer and chemical production as well as the output of generated co-products from the fuel conversion process. For example, newer facilities should benefit from more efficient conversion processes whereas older facilities constructed near the beginning of a feedstock's development will have lower conversion rates.

Phase	**Activities**
1. Farming	Feedstock planting Feedstock fertilization Feedstock harvest
2. Transport off farm	Transportation to storage facility Transportation to refining facility
3. Fuel Conversion	Feedstock-to-fuel conversion
4. Fuel Transportation	Transportation of fuel to storage facility Transportation of fuel to distribution site

Table 23: Production Phases to Consider for Energy Balance

8.4 Corn-Based Ethanol Literature Review

Perhaps the most intriguing discussion of biofuel energy balance occurs in the literature related to corn-based ethanol production. At least 15 studies specifically examining the energy required for the production of ethanol have been completed in the past 20 years and found anywhere from incredibly negative net energy values to extremely positive net energy values.

Chambers et al. (1979) published the first major study examining energy balance of corn-based ethanol [4]. Their study highlighted a number of the methodological flaws inherent in examining life-cycle processes, which will become more evident in the subsequent discussion. They concluded that ethanol's energy balance was slightly positive but maintained that when compared to petroleum, the energy benefits were unquestioned since many of ethanol's energy inputs can be supplied by non-petroleum sources, such as coal and natural gas. One decade later, the scholarly examination of energy balances intensified as articles became more frequent. Ho (1989) found a negative *NEV* and an *ER* less than one [5]. In short, Ho's (1989) findings suggested that the energy available from corn-based ethanol was greater than the energy used to produce the fuel [5]. The study relied on corn yields of 90 bushels per acre and early feedstock conversion

Descriptive	US (bu/acre)	Indiana (bu/acre)
Average	104.8	109.4
Median	108.9	112
St. Dev.	13.8	18.8
Maximum	119.8	135
Minimum	81.1	73

Table 24: Characteristics of US and Indiana Corn Yields, 1978-1988 - Authors' calculation using data from NASS 2008 [7]

processes that produced ethanol with 57,000 Btu per gallon. In the end, Ho (1989) found a *NEV* of -3,500 Btu per gall by using the LHV for ethanol [5].

One year later, Marland and Turhollo (1990) published a study that found a positive *ER* and *NEV* but used corn yields of 119 bushels per acre [6]. Marland and Turhollo (1990) calculated *ER* to be 1.25 and *NEV* to be 10,027 Btu per gall [6], drastically different results from Ho (1989) [5]. However, the variation in findings between these two models is largely attributed to two factors: different yield estimates and different heating values. A higher yield indicates more ethanol is produced using the same amount of land and that total energy is more broadly distributed among processes. Ho's (1989) estimates understate known yields for the decade immediately preceding the study, 1978 to 1988, which averaged 105 bushels per acre (Table 24); only two years from the decade had yields less than 90 bushels per acre [5]. The study from Marland and Turhollo (1990) relied on an HHV which overstated a positive *NEV*. If re-calculated based on LHV, their *NEV* would be only 1,766 Btu per gall and their *ER* only 1.15 [6].

One author who has consistently found negative *ER* and *NEV* for corn-based ethanol is Pimentel [8, 9, 10]. Pimentel's first study found a negative *NEV* of 33,517 Btu per gall with an *ER* of 0.74 even with the use of corn yield of 110 bushels per acre [8]. His second study relied on even higher yields but still found a negative *NEV* of 33,562 Btu per gall [9]. In a third study, the yields still increased as the total energy requirements for production decreased; the final result, however, remained negative at -22,119 Btu per gall [10]. Pimentel's studies provide an analysis that is all inclusive of primary and secondary inputs that other scholars (Shapouri et al. 1995; Wang et al. 1999; Wang 2001; Shapouri et al. 2002) argue extend beyond the scope of what a reasonable analysis should include [11, 12, 13, 14]. One highly criticized inclusion from Pimentel [8, 9, 10] is the energy expended in the production of farm equipment and facilities which other scholars tend to omit from their studies.

A number of other studies conducted by scholars linked to the U.S. Department of Agriculture's (USDA) Office of the Chief Economist or organizations tied to the biofuels industry found positive *NEV*s with ratios greater than one. In the six identified agency or industry sanctioned studies from 1995 to 2002, all found positive *NEV*s and *ER*s greater than one [11, 12, 15, 13, 14, 3]. The average corn yield in the studies was 126 bushels per acre, and the range of *NEV*s spanned from a low of 15,114 Btu per gall calculated by Graboski (2002) to a high of 23,769 Btu per gall estimated by Wang (2001) [2, 13]. Two of the studies relied on HHVs (Shapouri et al. 1995; Shapouri et al. 2002) and when adjusted to a LHV result in a mean *NEV* across the five agency or industry studies of 17,444 Btu per gall [11, 14].

Co-product energy crediting is an area of energy balance with even less consensus than system boundary application. A frequent method employed in recent studies is that of Shapouri et al. (2002; 2004) which does apply co-product credits for energy use [14, 16]. Shapouri et al. (2002; 2004) relies on a replacement value estimation technique that sets the credit value equal to the energy required to produce a substitute of specific co-products [14, 16]. Pimentel (2003) utilized an earlier version of Shapouri et al.'s (2004) estimation in his own analysis, but also noted that credits overstated energy use, crediting approximately 19 percent of the total energy [10, 14].

Pimentel (2003) utilized on a nine percent energy credit [10].

To more realistically compare studies to each other, a consistent heating value must be applied. This enables a comparison of like NEVs. After applying a LHV of 75,700 Btu/gall, the specific values for each study alter but none do so significantly enough to alter the authors' conclusions (see Table 1 in Appendix D). Altogether, ten of the studies suggested *NEV*s were positive and five found *NEV*s to be negative for corn-based ethanol.

8.5 Indiana Ethanol Analysis

An Indiana specific ethanol energy balance analysis requires estimates for all facets of the energy balance equation specific to Indiana. This type of analysis has benefits in considering the feasibility of corn-based ethanol production in Indiana because it provides a more localized analysis. Previous studies focused on substantially larger regions or utilized estimates for the entire U.S. that relied on corn yields that deviate from the state of Indiana's historic production levels. For instance, since 1990 Indiana corn yields exceeded U.S. yields in two of every three years and averaged 4.7 bushels per acre higher per year [7]. Since corn yields play a fundamental role in estimating total energy used to produce corn-based ethanol, significant deviations are an area of volatility in *NEV* calculations. Of even greater importance is an ability to isolate the degree to which the volatility of corn yields will affect the overall *NEV* for Indiana. Incorporation of U.S. corn yields may overstate the ability of some regions to perform well based on better soil fertility or weather conditions, particularly in a year where other states realize poor yields due to overuse of marginal lands, drought, tornadoes, or other weather-related conditions. The use of national yields in previous studies normalizes the yields, which fails to take into account the reality that some areas have low yields in a single year while other areas have elevated yields.

Shapouri et al. (1995, 2002, 2004) included Indiana as a component of their analysis and also provided itemized lists of farm inputs for each study which were used as a model for this analysis of Indiana farm inputs (see Table 2 in Appendix D) [11, 14, 16]. Those studies, however, inaccurately portray the current ethanol production situation in Indiana by relying on older data and several faulty assumptions, including one assumption that applied estimates of wet-mill facilities to Indiana despite the fact that no such facilities were operational in Indiana at the time. Other faulty assumptions include

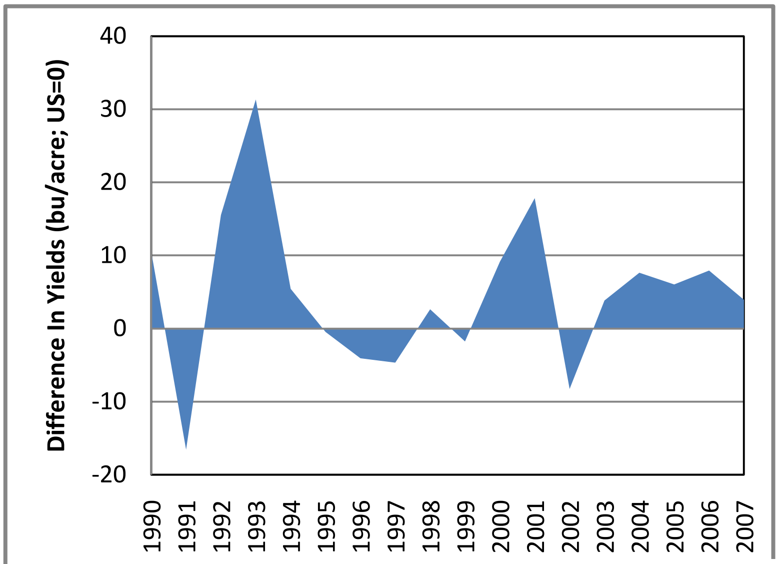

Figure 28: Difference Between Standard Annual US Corn

the use of national estimates for production energy requirements and transportation requirements. Finally, a modest area of error in the calculations conducted by Shapouri et al. (1995, 2002, 2004) results from the use of average corn yields based on total harvested acreage which ignores acreage planted but not harvested due to any of a number of reasons. The error from the use of standard yields results in slightly inflated energy balances [11, 14, 16].

Indiana's current ethanol production sites are listed in Table 25. Indiana is currently producing 457 million gallons of ethanol per year from dry mill facilities [17]. In late 2008, Indiana's first wet-mill plant is expected to enter operation and, along with five other plants, will bring the state's total ethanol production capacity to 1,062 million gallons per year [17, 18]. This analysis will focus on the six existing dry mill facilities to estimate the current energy balance of production in Indiana.

Based on information provided by Hurt (2007), the operational facilities in Indiana have a weighted average corn to ethanol conversion rate of 2.68 [17]. By applying this ratio along with average corn yields from 2004 to 2006 and other data from the same time period, the estimated total energy use for ethanol production in Indiana is 82,642 Btu per gall (see full analysis in Appendix D). Note that this assumes plants becoming operational in 2007 were also contributing to the elevated corn to ethanol conversion rate over the entire time period.

Plant	Capacity MGY	Corn Use (mill. Bu)	DDGs 000s tons	Type	Construction
New Energy Corp	102	36	328	Dry	1984
Iroquois Bio Energy Company	40	14	129	Dry	2007
Andersons Clymers Ethanol	110	39	354	Dry	2007
Central Indiana Ethanol	45	16	145	Dry	2007
VeraSun Energy Corp	100	36	321	Dry	2007
Poet	60	21	193	Dry	2007

Table 25: Existing Ethanol Plants [Hurt, 2007]

Estimates from Shapouri et al. (2004) were applied for co-product credits [16]. When co-product energy credits are factored into the *NEV* using a LHV, the *NEV* for Indiana is estimated to be 7,430 Btu per gall for the 2004 to 2006 period. The positive value is attributed to elevated corn yields in the examined years and more efficient production processes in the newer plants. Without energy credits, however, the *NEV* is estimated to be -5,297 Btu per gall suggesting that slight variations in energy use could throw Indiana production over the zero threshold for energy and render ethanol production energy inefficient.

Unless production patterns in Indiana diverge widely from current estimates, the energy balance for corn-based ethanol produced in Indiana can reservedly be deemed positive, at least for the years examined under a set of narrow assumptions (see Appendix D for full analysis). For instance, variation in corn yields may produce varying results. Figure 29 offers a sensitivity analysis for energy inputs under situations presenting a variety of corn yields (e.g. drought, flooding, etc.). This analysis indicates that once the corn yield reaches 130 bushels per acre, energy expended during farm production of corn per gallon of ethanol will remain below 20,000 Btu per gallon. Further improvements in corn yield do not decrease the energy required for farm production at any significant rate.

The findings of this study, however, are only for data averaged statewide and do not necessarily mean each individual plant operating in the state is doing so with a positive *NEV*. For a plant sited in a low yield county, as is the Poet plant in Jay County, energy balance will yield different results. Note that each plant obtains corn for production in different manners, whether primarily by truck or train, and the corn is shipped from varying locations. These logistical and production-related issues introduce a greater degree of unknown variation in this localized result. Optimally, energy balance research should be conducted using individual ethanol plants as the unit of analysis. Until such time as sufficient data becomes available to provide such a localized and specific analysis, a state-level approach must suffice.

8.6 Cellulosic Ethanol Literature Review

Ethanol production from cellulosic crops requires individual analyses of each crop. Unfortunately, few studies exist for each specific crop considered in the feedstock section of this paper. Instead, what follows is a brief discussion of the available literature related to cellulosic ethanol production, most of which is purely theoretical. Lynd (1996) identified a base case for widespread cellulosic ethanol production energy efficiency and estimated efficiency ratios from 4.4 to 10.4, well above the threshold of 1.0 for a strict balance in energy availability and use in production [19]. Hill et al. identified the efficiency ratio of cellulosic operations as being greater than 4.0 and called it "a major improvement over corn grain ethanol" and biodiesel [20]. A more recent study from Schmer et al. (2007) found a *NEV* for switchgrass in the Great Plains to be 51,971 Btu/gal [21]. Test runs for switchgrass production showed a 0.71 efficiency ratio in the first year of production, but the ratio became greater than one in the second year of production and 14.42 by the fourth year [21]. The most comprehensive of all cellulosic studies to date estimates life-cycle efficiency ratios for different types of cellulosic production processes with all ratios greater than 15; the study, however, assumes high yield sorghum would be the primary feedstock (Granda et al. 2007) [22]. While the authors concede their estimates are likely slight overestimates, the benefits relative to corn-based ethanol in terms of energy appear substantial. Regardless of the feedstock used in ethanol production among the aforementioned studies, the cellulosic approach offers a definitively greater energy

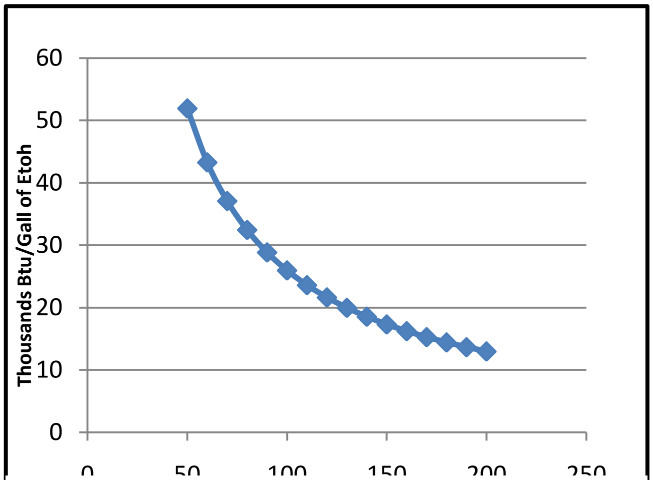

Figure 29: Yield Sensitivity Analysis for Energy Required in Indiana Corn Production

balance than production from corn.

8.7 Biodiesel Literature Review

A small pool of literature has reviewed the energy potential for various feedstocks used to produce biodiesel (Table 26). As with other fuels discussed earlier, these studies depend largely on the established boundaries and the efficiency with which each feedstock is grown and transported for conversion into fuel. The earliest studies on biodiesel examined production from rapeseed and found the feedstock to contain more energy than was expended during production [23, 24]. The National Renewable Energy Laboratory (NREL 1998) concluded 1.2 MJ of energy are required for each MJ of energy contained in soy-based biodiesel [23]. The International Energy Agency, a division of the Organization for Economic Co-operation and Development (OECD), estimates that biodiesel from soybeans yields an ER of 1.4 while from rapeseed the ER is 1.6 [24]. To date, only Pimentel and Patzek (2005) found biodiesel to yield a negative *NEV* but established broad system boundaries that included human labor. Pimentel and Patzek (2005) also noted the low energy balance was a direct function of depressed soybean yields and a high energy conversion process [25]. Hill et al. (2006) found soybean-based biodiesel to yield a *NEV* of 1.93 [20].

Author	**Feedstock**	**Fuel Production Efficiency (gall/ton)**	**Fuel Process energy Efficiency (energy in/out)**
Levy 1993*	Rapeseed	0.306	0.55
ETSU 1996*	Rapeseed	0.283	0.82
Altener 1996*	Rapeseed	0.294	0.48
Levington 2000*	Rapeseed	0.362	0.4
IEA 2004	Rapeseed		1.43
IEA 2004	Soybean		1.6

Table 26: Select Biodiesel Energy Use Studies (* Midpoints substituted for ranges. From IEA 2004 [24].)

8.8 Conclusions

A number of confounding factors significantly affect the energy balance and potential energy gain from each biofuel. Such factors include (1) yield which is dependent on fertilizers, weather, and soil conditions, and (2) the distance from which the feedstock must travel to refining facilities. The largest portion of the entire energy balance equation, however, relies on the efficiency of the production process itself and not on the feedstock development. For this reason, focusing future efforts on improving energy efficiency at the refining level would be the easiest target for improving overall net energy available and energy balances, particularly for corn-based ethanol production.

In Indiana, so long as co-product energy credits are applied, corn-based ethanol production is estimated to be relatively positive. A more accurate analysis would incorporate data available from each production facility now online in Indiana, thus yielding a more precise picture of the actual energy required for the Indiana biofuels industry. As far as cellulosic and biodiesel energy availability, little can be conclusively determined from the available information, particularly for operations specific to Indiana. If the literature accurately portrays the situation in Indiana, however, the energy balance for most cellulosic fuels and biodiesel is positive.

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9. Costs and Benefits of Biofuels

9.1 Introduction

This report presents various economic, social, technological, and environmental considerations associated with biofuels. To place these considerations in a more analytical context for Indiana, analysts evaluated the costs and benefits associated with biofuels. The goal of this analysis is to identify key drivers that influence the net present value (NPV) of different biofuels, and identify the impacts on major stakeholders. Recognizing these drivers helps illustrate key concerns in biofuels policy for the state. The accounting domain is Indiana for the analysis. The time frame assessed is 2008 to 2030 for corn ethanol and soy biodiesel and 2012 to 2030 for cellulosic ethanol. Future biofuels consumption is based on GAO projections of national fuel consumption and a 2006 EPA analysis of current state biofuel consumption (see Appendix E) [1, 2]. Future biofuels production is based on production capacity of current and planned biofuels plants as outlined in a recent ISDA fact sheet [3].

The following sub-sections outline the methods, results, unquantified considerations, and conclusions of analyses of three biofuels: corn ethanol, soy biodiesel, and cellulosic ethanol using corn stover. Analysts present four different scenarios for each fuel type. The first scenario is most indicative of the current situation in Indiana: the presence of substantial federal subsidies and the absence of data on potentially significant environmental impacts. The second scenario presents a case where federal subsidies are removed and environmental costs are still unquantified. The third scenario brings federal subsidies back into the picture and adds a limited number of quantified environmental costs to illustrate the substantial effect on NPV of adding even one environmental cost consideration. Finally, the fourth scenario modifies the third scenario by removing federal subsidies.

9.2 Methods

The accounting domain for analysis is the state of Indiana; therefore, analysts only assessed impacts that occur within Indiana and are directly related to biofuels production and consumption in the state. Stakeholders evaluated Indiana government, gas stations, car manufacturers (regarding E85 only), fuel consumers, agricultural producers, and fuel producers. The baseline for the analysis compares Indiana biofuels production and consumption under the parameters outlined in the introduction to a situation in which no biofuels are produced or consumed in Indiana. It is important to note that the analysis does not directly compare the production and consumption of biofuels as a direct alternative to conventional fuels. The fuel types analyzed are blends of biofuels and fossil fuels.

The time frame of the analysis is 2008 to 2030 for corn ethanol and biodiesel, while the time frame of the analysis for cellulosic ethanol is 2012 to 2030. Current lack of commercial production and quickly evolving technology delay the time frame for cellulosic ethanol.

Analysts derived per-unit and base values for the benefits and costs from many sources. Table 27 lists the original data employed and corresponding sources. It is important to note that data included in this analysis may differ from data provided in other sections of the report. Though data in other sections reflect the broad range of values presented in biofuels research, the data employed here is in a format more suitable for use in a cost-benefit analysis. Analysts converted this data to usable values on a variable basis taking the per-unit values and adjusting for inflation based on the US Department of Labor (DOL) Consumer Price Index – All Urban Consumers [4].

Category	Value / Units	Source
Savings to Consumers of Gasoline	$0.08 / gallon	Rajagopal et al. 2007 [5]
Volumetric Ethanol Excise Tax Credit	$0.51 / gallon	GAO 2007 [1]
Federal Corn Subsidy	$0.28 / bushel	Farm Security and Rural Investment Act of 2002 [6]
Ethanol Production Tax Credit	$2M max for 40-60 million gallons; $3M max for at least 60 million gallons; $20M for at least 20 million gallons of cellulosic	Farm Animal Stewardship Purchasing Act of 2007 [9], Indiana Code 6-3.1-28 [10]
Price of Corn	$3.30 / bushel	Ag Answers 2007 [11]
Plant Cost - Ethanol	$1.90 / gallon of production capacity	Doering 2008 [8]
Production Cost - Ethanol	$0.66 / gallon	Doering 2008 [8]
Sale of By-product - Ethanol	$0.38 / gallon	Doering 2008 [8]
Transportation Cost - Ethanol	$0.054 / gallon	US EPA 2006 [2]
Soil Erosion	$0.59 / pounds / gallon	Sand 2006 [22]
Jobs	675	Abbott 2008 [3]
Opportunity Cost	$3.00 / hour /40 hours week / 52 weeks / year	Krutilla 2008 [14]
Taxes Paid	$43,348 * .034 = $1,473.83	Indiana Department of Revenue 2008 [13]
Taxes to Federal Government	$4,220 + 25% over $30,650 = $7,394.50	IRS 2006 [23]
Federal Biofuel Dispenser Tax Credit	$30,000	GAO 2007 [1]
Minimal Modification	$3,300	GAO 2007[1]
New Dispenser	$13,000	GAO 2007 [1]
New Tank, Piping, etc.	$62,400	GAO 2007 [1]
Retail Sales - Indiana Ethanol	$1.58 / gallon	Alexander 2007 [7]
Retail Sales - Exported to Other States	$1.58 / gallon	Alexander 2007 [7]
Federal Virgin Oil Per Gallon Subsidy	$1.00 / gallon	GAO 2007 [1]
Biodiesel Retailer Tax Credit	$0.01 / gallon	Indiana Code 6-3.1-27-10 [18]
Transportation Cost - Biodiesel	$0.03 - $0.05 / gallon	GAO 2007 [1]
Soybean Price	$4.81 / gallon	Doering 2008 [8]
Production Cost - Biodiesel	$0.47 / gallon	Radich 2004 [19]
Plant Cost - Biodiesel	$1.04 / gallon	Radich 2004 [19]
Retail Sales - Indiana Biodiesel	$1.40 / gallon	Althoff et al. 2003 [15]
Retail Sales - Exported Biodiesel	$1.40 / gallon	Althoff et al. 2003 [15]
Glycerin	$0.25 / pound	Howe 2008 [16]
Plant Cost - Cellulosic Ethanol	$250M for 50 million gallon production capacity	GAO 2007 [1]
Corn Stover	$60 / metric ton	Doering 2008 [8]
Production Cost	$0.80 other costs + $0.40 enzymes = $1.20 / gallon	Doering 2008 [8]
Sale of By-product - Cellulosic Ethanol	$0.10 / gallon	Doering 2008 [8]
Transportation Cost from Field	$35.64 - $41.34 / dry ton	Doering 2008 [8]
Reduced Emissions - E10	-1% Greenhouse gases	GAO 2007 [1]
Reduced Emissions - E85	-20% Greenhouse gases	GAO 2007 [1]
Reduced Emissions - Cellulosic Ethanol	-70-90% Greenhouse gases	GAO 2007 [1]
Reduced Emissions - Biodiesel	-85% Greenhouse gases	GAO 2007 [1]
Adjustment Costs for Cars - E85	$30-$300	GAO 2007 [1]
Dedicated Ethanol Pipeline	$1M / mile	GAO 2007 [1]
Indiana Alternate Fuel Vehicles Tax Credit	15% of investment	Indiana Code 6-3.1-31.9 [25]
Firefighting Foam	$90-$115 / 5 gallons	Blank 2008 [24]
Average Wages for Ethanol Worker	$43,348 / year	Flanders and McKissick 2007 [12]

Table 27: Data Used in Cost-Benefit Analysis with Applicable Sources

Analysts converted all values to January 2008 Dollars, applied low, medium, and high discount factors typical in cost-benefit analysis literature to adjust for the time-cost of money, then multiplied resulting values by the aggregated quantity of fuel and summed to find the net adjusted, discounted value (See Appendix E for additional details on inflation adjustment and discounting). Values employed in the analysis relate to gallons of biofuels in their pure form. The analysis includes costs and benefits associated with different biofuels blends (for example E10 vs. E85) in terms of 100 percent pure gallons of their constituent biofuels.

9.2.1 Corn Ethanol

Benefits of both E10 and E85 blends of corn ethanol considered in the analysis include: savings to consumers, volumetric ethanol excise tax credit, federal corn subsidy, and ethanol exports to other states. Savings to consumers of gasoline represents the reduced cost of conventional gasoline that results when biofuels compete with gasoline in the market. A University of California – Berkley study estimates an inflation-adjusted $0.08 decrease in the 2006 average price of gasoline when ethanol is added to the market [5]. The volumetric ethanol tax credit is provided by the federal government to fuel producers at a value of $0.51 per gallon [1]. The federal government also provides a corn subsidy of $0.28 per bushel of corn to agricultural producers [6]. Since the accounting domain is limited to Indiana, the costs of credits and subsidies to the federal government are outside the boundary of analysis. It follows that tax credits and subsidies provided by the federal government appear as benefits in the analysis rather than as transfers, the common classification for these elements in cost-benefit analyses. For the final quantified benefit of exports of corn ethanol from Indiana, analysts multiplied the price of one gallon of pure ethanol, estimated by Alexander at $1.58 per gallon, by the difference between Indiana ethanol production and consumption estimates employed in this analysis [7].

Transfers employed in the analysis of E10 and E85 blends of corn ethanol include the sale of fuel, the sale of byproducts, the state ethanol production tax credit, agricultural inputs, job creation, and taxes paid. Analysts calculated the sale of ethanol fuel by multiplying the Alexander figure of $1.58 per gallon by estimated Indiana corn ethanol consumption [7]. Analysts include the value as a transfer from fuel producers to consumers, without consideration of the intermediate player - gas stations - in order to simplify the analysis. Doering estimates the value of the sale of byproducts to consumers resulting from the production of corn ethanol as $0.38 per gallon of ethanol produced [8]. This figure represents an average value taking into consideration different potential byproducts that result from the various production processes (for more information on these byproducts, see Section 5). The state ethanol production tax credit is $0.125 per gallon of ethanol produced to a maximum of $2,000,000 per producer for the two current or projected plants producing 40 to 60 million gallons of ethanol per year and $3,000,000 per producer for the 13 plants producing 60 million gallons of ethanol or more [3, 9, 10]. Analysts used a Purdue University estimate of $3.30/bushel for the agricultural inputs [11]. The value of job creation encompasses an estimated 536 jobs created in corn ethanol production facilities [3] multiplied by the average earnings of an ethanol plant employee including benefits, $43,348, then adjusted for federal and state taxes to get the figure $34,479.67 [12]. Recipients of jobs fall under the “Consumer” stakeholder group. Fuel producers pay the corresponding wage cost. Finally, taxes paid are average state taxes paid by job recipients in the "Consumer" stakeholder group to the Indiana government. The state of Indiana personal income tax is 3.4 percent [13].

Costs associated with E10 and E85 blends of corn ethanol include plant construction, the additional capital cost associated with interest payments, fuel production costs, transportation distribution costs, and worker leisure opportunity cost. Analysts employed a plant construction cost estimate of $1.90 per gallon of ethanol produced and adjusted for production capacity and an assumed 25-year useful life of each plant [8]. Analysts assumed fuel producers finance plant construction entirely through borrowing, so employed a capital interest cost of $0.20 per gallon of ethanol produced and again adjusted for production capacity [8]. Production costs of $0.66 per gallon of ethanol produced include the costs associated with the corn ethanol production process, like energy, water, maintenance and others [8]. Transportation distribution costs represent the average freight cost for shipping corn ethanol from the production facilities to the gas stations. EPA estimates this at $0.054 per gallon for the Indiana region [2]. Finally, the worker leisure opportunity cost represents the value of the time given up by workers employed in the production of biofuels. For simplification, analysts assumed that all workers enter the corn ethanol production field from a state of unemployment and assign a time value of $3.00 per hour for 40 hours per week and 50 weeks per year [14]. This is the standard figure employed in cost-benefit literature.

Analysis of E85 blended form of corn ethanol requires additional considerations, including the Federal Biofuel Dispenser Tax Credit as a benefit, and modifying existing equipment and installing new equipment at gas stations as costs. Federal Biofuel Dispenser Tax Credit is $30,000 to each gas station that provides E85. Recognizing that 97 gas stations in Indiana currently provide E85 [1], but having no information on which gas stations plan to offer E85 over the next 22 years, analysts assumed that the number would roughly double to 200 over the time horizon of the analysis (see Appendix E). To provide E85, each gas station faces the additional costs of modifying existing equipment ($3,300), installing new fuel dispensers ($13,000), and installing new tanks and piping ($62,400) [1].

9.2.2 Soy Biodiesel

Both common blends of biodiesel, B2 and B20, exhibit the same benfits, costs, and transfer values. Benefits related to soy biodiesel include the Federal Biofuel Dispenser Tax Credit, Federal Biodiesel Virgin Oil Subsidy, federal soybean subsidy, and soy biodiesel export. The Federal Biofuel Dispenser Tax Credit of $30,000 is equivalent to the tax credit for corn ethanol [1]. Recognizing that 61 stations in Indiana currently provide biodiesel [1], but having no information on which stations plan to offer biodiesel over the next 22 years, analysts assumed that the number would roughly double to 134 over the time horizon of the analysis (see Appendix E)The Federal Biodiesel Virgin Oil Subsidy is $1.00 per gallon of biodiesel produced. The federal government also provides a subsidy of $0.44 per bushel of soybeans to agricultural producers [6]. For the quantified benefit of soy biodiesel exports from Indiana, analysts multiplied the price of one gallon of pure biodiesel, estimated by Althoff et al. at $1.40 per gallon, by the difference between Indiana biodiesel production and consumption estimates employed in this analysis [15].

Transfers include the sale of fuel, sale of byproducts, Indiana Biodiesel Production Tax Credit, Indiana Biodiesel Retailer Tax Credit, job creation, taxes paid, and agricultural inputs. Analysts calculated the sale of biodiesel by multiplying the Althoff et al. figure of $1.40 per gallon by estimated Indiana biodiesel consumption [15]. The major soy biodiesel byproduct, glycerine, sells at $0.25 per pound and the typical biodiesel plant produces 1100 pounds of glycerin an hour [16]. To simplify, analysts included the value as a transfer from fuel producers to consumers, without consideration of the intermediate player, gas stations. The Indiana Biodiesel Production Tax Credit is $1.00 per gallon produced up to a maximum of $3,000,000 [17]. Analysts assumed this subsidy would go to the two biodiesel plants in Indiana that opened in 2007 with capacities of 3,000,000 gallons per year [3]. The state of Indiana provides gas stations with an Indiana Biodiesel Retailer Tax Credit of $0.01 per gallon [18]. Job creation and taxes paid relevant to soy biodiesel employ the same values as corn ethanol job creation, but adjusted for an estimated 134 jobs (see Appendix E) [3]. Analysts assumed soybean oil was the only agricultural input for biodiesel. Analysts employed Doering's estimate of $0.65 per pound, converting pounds to gallons and assuming one gallon of input oil for each gallon of biodiesel produced [8].

Costs associated with soy biodiesel include plant construction, capital interest cost, fuel production costs, transportation distribution cost, and worker leisure opportunity cost. Analysts employed a plant construction cost estimate of $1.04 per gallon of biodiesel produced and adjusted for production capacity and an assumed 25-year useful life of each plant [19]. Analysts assumed fuel producers finance plant construction entirely through borrowing and so employed a capital interest cost of $0.20 per gallon of biodiesel produced adjusting for production capacity [8]. Analysts used production costs of $0.47 per gallon [19]. Regarding transportation distribution costs of biodiesel, trial runs of sending biodiesel through existing pipelines have been successful. Analysts assumed this will be the major distribution method. GAO estimates an average piping cost of $0.04 per gallon. Finally, the methodology for worker leisure opportunity cost was the same as for corn ethanol [1].

9.2.3 Cellulosic Ethanol

Cost, benefit, and transfer figures available for cellulosic ethanol are limited. The benefits analysts employed are the Volumetric Ethanol Excise Tax Credit and cost savings from byproduct use. The federal government provides the same $0.51 per gallon tax credit to cellulosic ethanol producers as to corn ethanol producers. As an indirect benefit, lignin produced in the cellulosic ethanol production process can be used by fuel producers as a heat source with a value of $0.10 per gallon of ethanol produced [8].

Transfers considered in the analysis include the Indiana Ethanol Production Tax Credit, agricultural inputs, and transportation of the feedstock. Indiana provides the same $0.125 per gallon tax credit for cellulosic ethanol producers as corn ethanol producers, with a maximum tax credit for all years of $20,000,000 per producer under 60 million gallon capacity. Because no cellulosic ethanol plants currently operate in Indiana, analysts assumed that ten plants with 50 million gallon capacity each would come into operation over the time frame. Analysts only considered corn stover for cellulosic production. Corn stover costs $60 per ton [8]. The cost of transporting corn stover from the field depends on the distance to the production facility. Analysts assumed production facilities would be sited relatively near corn stover sources to maximize efficiency. Analysts calculated a weighted average transportation cost of $37.23 per dry ton of stover based on cost figures provided by Doering for various distances up to 45 miles. Because the cost of transportation varies with distance, it was assumed that producers would first buy corn stover close to the production facility (see Appendix E) [8].

Costs considered in the analysis include plant construction, capital interest costs, fuel production, and transportation distribution. The GAO estimates plant construction costs at $250,000,000 spread over a 25-year useful life of each plant [1]. Doering estimates capital interest costs for cellulosic ethanol at $0.55 per gallon produced [8]. Analysts employed a fuel production cost of $1.20 per gallon produced, which includes elements used in production like enzymes, energy, water, etc [8]. Transportation costs for cellulosic ethanol is the same as for corn ethanol.

9.3 Results

As mentioned previously, analysts looked at four different biofuels scenarios. The first scenario is most indicative of the current biofuels situation in Indiana: the presence of substantial federal subsidies and the absence of data on potentially significant environmental impacts. The second scenario presents a case where federal subsidies are removed and environmental costs are still unquantified. The third scenario brings federal subsidies back into the picture and adds a limited number of quantified environmental costs to illustrate the substantial effect on NPV of adding even one environmental cost consideration. Finally, the fourth scenario modifies the third scenario by removing federal subsidies. Table 28 provides a summary of each fuel under all four scenarios.

A Kaldor-Hicks Tableau (KHT) illustrating the distributional effects of the first scenario is included for each fuel type below. Analysts chose to present the first scenario, which excludes environmental considerations, because value data for the vast majority of environmental impacts do not exist. Environmental value figures that do exist are presented and analyzed later in this section. The tableaus represent results achieved with a seven percent discount rate, the most conservative for this analysis.

Analysis of Costs and Benefits of Biofuels - Summary Results				
Fuel Type	**Net Present Value**			
r = .03	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Ethanol E10	$ 28,473	$ 14,220	$ 14,680	$ 427
Ethanol E85	$ 28,469	$ 14,216	$ 14,676	$ 421
Biodiesel	$ 2,826	$ 370	$ 2,826	$ 370
Cellulosic Ethanol	$ (3,507)	$ (4,790)	$ (3,507)	$ (4,790)
r = .05				
Ethanol E10	$ 23,530	$ 11,749	$ 12,130	$ 348
Ethanol E85	$ 23,527	$ 11,746	$ 12,126	$ 343
Biodiesel	$ 2,367	$ 319	$ 2,367	$ 319
Cellulosic Ethanol	$ (2,721)	$ (3,716)	$ (2,721)	$ (3,716)
r = .07				
Ethanol E10	$ 19,799	$ 9,884	$ 10,204	$ 289
Ethanol E85	$ 19,796	$ 9,881	$ 10,201	$ 284
Biodiesel	$ 2,019	$ 279	$ 2,019	$ 279
Cellulosic Ethanol	$ (2,131)	$ (2,911)	$ (2,131)	$ (2,911)
	* In millions of dollars			
Scenario 1	No environmental costs included			
Scenario 2	No federal subsidies and no environmental costs included			
Scenario 3	Environmental cost included and federal subsidies included			
Scenario 4	No federal subsidies and environmental cost included			

Table 28: Cost-Benefit Analysis of Biofuels Summary Table with variable discount rates (in millions of 2008 dollars)

9.3.1 Corn Ethanol

A cost-benefit analysis of corn-based ethanol blended into E10 results in a positive NPV ranging from $19.8 to $28.5 billion across discount rates

(Table 28). An analysis of E85 also results in a positive NPV ranging from $19.8 to $28.5 billion across discount rates even accounting for the additional costs and benefits for E85 (Table 28).

Ethanol E10 **Scenario 1**
r = .07

Stakeholders	Indiana Government	Gas Stations	Car Companies	Consumers	Ag Producers	Fuel Producers	Total
Benefits	$ -	$ -	$ -	$ 3,697,933,521	$ 1,889,920,996	$ 29,571,516,811	$ 35,159,371,328
Transfers	$ (30,740,888)	$ -	$ -	$ (9,227,182,795)	$ 19,326,065,109	$ (10,068,141,426)	$ -
Costs	$ -	$ -	$ -	$ (38,788,949)	$ -	$ (15,321,651,792)	$ (15,360,440,741)
Total	$ (30,740,888)	$ -	$ -	$ (5,568,038,223)	$ 21,215,986,105	$ 4,181,723,593	**$ 19,798,930,586**

Table 29: KHT for Corn Ethanol, E10 under Scenario 1 with a seven percent discount rate

Ethanol E85 **Scenario 1**
r = .07

Stakeholders	Indiana Government	Gas Stations	Car Companies	Consumers	Ag Producers	Fuel Producers	Total
Benefits	$ -	$ 1,795,141	$ -	$ -	$ -	$ -	$ 1,795,141
Costs	$ -	$ (4,709,254)	$ -	$ -	$ -	$ -	$ (4,709,254)
Total	$ (30,740,888)	$ (2,914,113)	$ -	$ (5,568,038,223)	$ 21,215,986,105	$ 4,181,723,593	**$ 19,796,016,473**

Table 30: KHT for Corn Ethanol, E85 under Scenario 1 with a seven percent discount rate

9.3.2 Soy Biodiesel

A cost-benefit analysis of soy biodiesel blended into B2 or B20 results in a positive NPV ranging from $2.0 to $2.8 billion, across discount rates (Table 28, listed only as Soy Biodiesel).

Biodiesel B2/B20 **Scenario 1**
r = .07

Stakeholders	Indiana Government	Gas Stations	Consumers	Ag Producers	Fuel Producers	Total
Benefits	$ -	$ 2,344,178	$ -	$ 417,378,647	$ 2,704,298,274	$ 3,124,021,099
Transfers	$ (7,989,364)	$ 4,371,380	$ (765,401,981)	$ 6,265,573,214	$ (5,496,553,249)	$ -
Costs	$ -	$ -	$ (9,697,237)	$ -	$ (1,095,486,469)	$ (1,105,183,706)
Total	$ (7,989,364)	$ 6,715,558	$ (775,099,218)	$ 6,682,951,861	$ (3,887,741,444)	**$ 2,018,837,393**

Table 31: KHT for Soy Biodiesel, B2 and B20 under Scenario 1 with a seven percent discount rate

9.3.3 Cellulosic Ethanol

A lack of data and the relative newness of cellulosic technologies, made the analysis of cellulosic ethanol more limited. Many important values were left out of this analysis, including the proportion of ethanol exports, gasoline cost savings, the sale of the fuel, and job creation. A cost-benefit analysis of data available for cellulosic ethanol blended into E10 resulted in a negative NPV ranging from $2.1 to $3.5 billion across discount rates (Table 28). An analysis of cellulosic E85 should take into account the additional values assessed under corn ethanol E85, but these values could not be determined in relation to cellulosic ethanol because of the lack of data. These unquantified values are discussed below.

Cellulosic Ethanol
E10/E85 **Scenario 1**
r = .07

Stakeholders	Indiana Government	Gas Stations	Car Companies	Consumers	Ag Producers	Fuel Producers	**Total**
Benefits	$ -	$ -	$ -	$ -	$ -	$ 933,376,262	$ 933,376,262
Transfers	$ (79,344,403)	$ -	$ -	$ -	$ 2,489,657,887	$ (2,410,313,484)	$ -
Costs	$ -	$ -	$ -	$ -	$ -	$ (3,064,758,279)	$ (3,064,758,279)
Total	$ (79,344,403)	$ -	$ -	$ -	$ 2,489,657,887	$ (4,541,695,501)	$ (2,131,382,017)

Table 32: KHT for Cellulosic Ethanol, E10 and E85 under Scenario 1 with a seven percent discount rate

9.4 Unquantified Considerations

Because of a lack of data, many important considerations often cited in discussions on biofuels could not be quantified in this analysis. A discussion of these unquantified elements in the context of the quantitative results provides an indication of how they might impact the results if quantified. Analysts considered these impacts in addition to the quantitative results reported above when formulating conclusions. Important considerations include environmental impacts like air pollutant emissions, greenhouse gas emissions, effects on crop prices, increased fire risks, vehicle adjustments, and ethanol pipelines. Also, data on cellulosic ethanol could lead to quantification of missing values identified in the methods section.

Over its life cycle (not including vehicle emissions), E10 is expected to lower emissions of carbon monoxide (CO), volatile organic compounds (VOC), and particulate matter (PM) while increasing a few other emissions like various toxic air pollutants [20]. In contrast, because of the resources used in growing the feedstock and producing the fuel, total life-cycle emissions of CO, VOC, PM, sulfur oxides (SOx), and nitrogen oxides (NOx) are expected to be higher for E85 than those of an energy equivalent amount of conventional petroleum based products [20]. Biodiesel blends, on the other hand, show both reduced vehicle emissions and life-cycle emissions of most of these same pollutants relative to conventional diesel [20]. These emissions could have a quantitative impact on Clean Air Act compliance costs and resulting health effects. The evidence above suggests that adding these impacts to the cost-benefit analysis may positively impact the NPV for soy biodiesel while negatively impacting the NPV for any form of ethanol.

Carbon dioxide (CO_2) emissions are an extremely complicated factor to assess when analyzing these fuels. Existing research is ambiguous; some suggest the life cycle of corn ethanol increases CO_2 emissions while others suggest it reduces them slightly [1, 21]. Soy biodiesel is often projected to have a greater reduction in life-cycle CO_2 emissions than corn ethanol [1, 20]. Cellulosic ethanol theoretically would produce the greatest reduction in life-cycle CO_2 emissions because of the feedstock's CO_2 uptake during growth [1]. CO_2 is a known GHG, and quantifying these emissions over the life cycle of biofuels allows further analysis to gauge impacts on climate change. Many countries and international agreements are already developing carbon markets which will make quantifying these impacts easier.

Chemical and nutrient inputs for agriculture contribute to non-point source pollution, which impairs water quality, aquatic habitat, and ecosystem health. As discussed in the Feedstock

Agriculture section of this report, these problems contribute directly to eutrophication of surface waters and degradation of groundwater. Soil erosion and resulting sedimentation also degrade surface waters, and diminish soil quality. Runoff of agrichemicals and infiltration to groundwater cause serious problems, which may require remedial action. The costs associated with dredging large sediment deposits and treating contaminated well water play into these considerations, but the overall contribution of agricultural practices in Indiana to these problems remains uncertain. Cellulosic feedstocks discussed in this report provide the most optimistic mitigation of these problems.

Since the market does not yet exist, many cellulosic ethanol impacts remain unquantifiable. Some benefits of cellulosic ethanol may include additions to ethanol export, job creation, and environmental benefits like reduced agricultural chemical use. Transfers may include state tax breaks and fuel sales. Costs may include worker opportunity costs, soil erosion from corn stover removal, and soil compaction. Data does not exist on the number of jobs that could be created, the potential amount of cellulosic ethanol that may be added to the market, or even the ethanol price that will result when cellulosic ethanol production begins. These values will only materialize once cellulosic ethanol becomes competitive.

9.5 Discussion and Conclusions

Care should be taken when formulating a comprehensive biofuels policy in Indiana. It was impossible to incorporate all important considerations associated with biofuels into this analysis. Biofuels may have unexpected consequences, such as the costs of equipment and training for emergency responses to ethanol fires. The market for cellulosic ethanol is non-existent, and the provision of E85 is still in its infancy, but the development of these markets will eventually present clearer costs and benefits associated with them.

Necessary infrastructure adjustments and the demand for biofuels also remain highly uncertain. Estimated costs for converting vehicles to flex fuel models that can utilize high ethanol blends are $50-$300 per vehicle, but it is unclear to what extent this will happen [1]. Transportation concerns will also become more important as increased traffic takes its toll on Indiana roads. Future considerations are the expansion of railroads and the possibility of a dedicated ethanol pipeline, but such ideas represent significant costs for the state. One study estimates the cost of such a pipeline at $1,000,000 per mile [1]. In addition, Indiana provides two means of monetary support to gas stations that provide E85: the Indiana Tax Credit for Fueling Stations and the Indiana Gas Station Grant. Information was not available for these investments, but as markets expand for higher ethanol blends, the associated transactions will certainly increase.

Other stakeholders will also face additional considerations outside of the scope of this analysis. Consumers may hesitate to adopt ethanol blends such as E85 as a fuel source because of its lower fuel economy. Agricultural producers have a strong tradition of corn and soybean rotation and may need extra encouragement to gather corn stover or to plant other cellulosic crops. Furthermore, the analysis does not include all potential stakeholders; for instance livestock producers, wheat and other commodity growers, and car manufacturers may be affected by biofuels production and consumption. However, as an overall tool, the calculations presented provide a good conceptual basis for the impacts on a variety of stakeholders and for a number of different biofuels over the next 20 years.

9.5.1 Corn Ethanol

The overall NPV of corn ethanol is positive across all discount rates for two primary reasons: federal subsidies/tax breaks and ethanol exports. Exports are an especially key consideration and could benefit Indiana substantially in the long-term. However, Indiana should consider the impact of future removal of federal corn and ethanol subsidies on the state. Recalling the discussion in the Methods sub-section, federal subsidies appear in the analysis as benefits because they are transfers entering from outside the accounting domain. The NPV of corn ethanol, E10 at a seven percent discount rate decreases from $19,799 million to $9,884 million when federal subsidies are removed (Table 28). Additionally, the state of Indiana is projected to pay over 35 million dollars (NPV) in tax breaks over the next 20 years. Indiana policy makers must decide whether this is sustainable.

Agricultural and fuel producers are the real winners in the corn ethanol analysis, benefiting from tax breaks, subsidies, high crop prices, the sale of byproducts, and high fuel prices. Consumers, on the other hand, show an extremely negative NPV. The negative NPV for consumers is primarily due to the purchase of products like fuel and animal feed (from byproducts). Their negative NPV represents the value they receive from using these goods. Even though the impact of jobs in the analysis is large, ethanol production is a small business compared to other industries and will not create a relatively large number of new jobs in the state.

Additional costs and benefits of E85 primarily affect gas stations through tax credits, grants, and capital modification costs. The impact of the cost of preparing gas stations to provide E85 results in a negative NPV for gas station owners (Note: the profit margin from selling fuel was not included in the analysis). Consequently, if policy makers decide to promote E85 in the state, they should be aware that gas station owners may need greater incentives to add E85 to their stations. Indiana could make efforts to reduce the substantial costs of retrofitting gas stations for E85 use.

The very limited environmental costs available have a huge effect on the NPV of corn ethanol, namely the cost of soil erosion (see Appendix E for more details) [22]. Looking at Table 2, moving from Scenario 1 to 3 in the analysis of corn ethanol, E85 at a seven percent discount level results in a decrease in NPV from $19,796 to $10,201 million. This leads to two conclusions: first, efforts to reduce soil erosion could be a major cost saver in regards to corn ethanol; second, environmental impacts can significantly affect the value of biofuels and warrant extensive additional research.

9.5.2 Soy Biodiesel

As with corn ethanol, the overall NPV of biodiesel is positive primarily due to exports and federal incentives. The NPV of soy biodiesel at a seven percent discount rate decreases from

$2,019 million to $279 million when federal subsidies are removed. Again, Indiana policy makers must be conscious of the effects of removing federal support. Another policy concern is the state will pay 10 to 12 million dollars (NPV) in tax breaks over the next 20 years for biodiesel.

While agricultural producers are substantially benefitting in the biodiesel analyses, fuel producers experience negative net values. If this continues to be the case, fuel producers will no longer be willing to produce soy biodiesel. Redirecting tax credits from gas stations to fuel producers or finding ways to reduce the cost of soybean oil could mitigate the effect on fuel producers. One potential way to reduce the cost of soybean oil is to encourage alternative sources, like waste oil or rapeseed, which may compete with and drive down the price of soybeans.

The negative NPV consumers experience for biodiesel also results from their purchases, but again this is a proxy for their value derived. Gas stations experience positive values with biodiesel compared to corn ethanol because no equipment modifications are required and existing pipelines can be used for biodiesel transportation. Note that the data set employed did not include any figures for environmental impacts of biodiesel. Hence the NPVs in Table 2 do not change for biodiesel when moving from Scenario 1 to Scenario 3.

9.5.3 Cellulosic Ethanol

As mentioned previously, it is difficult to quantify many of the parameters of interest for cellulosic ethanol. Cellulosic ethanol production should lead to greater greenhouse gas emissions reductions. However, collection of corn stover may also lead to greater erosion and soil compaction from harvesting [8]. Substantial research is needed to quantify these and other effects. Incorporating the quantified values into an analysis will significantly clarify the value of cellulosic ethanol.

For cellulosic ethanol to be economically viable, efficiency gains through technological advances must be made in the fuel’s production process. Several considerations make the future of cellulosic ethanol look promising: the replacement of food-based crops with dedicated biomass crops, the effect of removing federal subsidies, and the potential gains in energy balance. In addition, there are less environmental impacts associated with cellulosic sources (aside from corn stover) in comparison with corn and soy. It is difficult to tell whether quantifying these considerations will bring cellulosic ethanol into the positive NPV range, but prospects seem promising. There is huge potential for expanded production if competitive production technology is developed.

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10. Policy Recommendations

10.1 Federal Policy Recommendations

Biofuels policy at the federal level focuses on promoting research, development, and deployment of new technologies for production and distribution, as well as creating incentives for the production and consumption of biofuels. Federal policy is not a coherently coordinated set of initiatives, but rather a patchwork of different agency initiatives created by several statutes passed during the last decade. These initiatives include grants, tax credits, and research initiatives to encourage development of new technologies, bioenergy crop production, and expansion of the biofuels distribution network. This section identifies the major federal agencies that administer programs related to biofuels and explains the key federal initiatives and tax incentives aimed at promoting the production, distribution, and use of cost-competitive biofuels.

10.1.1 Federal Agencies

The Office of Energy Efficiency and Renewable Energy (EERE) is a $1.25 billion agency located within DOE. EERE has jurisdiction over R&D for most renewable energy sources, including solar, wind, geothermal, biomass, and hydroelectric. EERE programs work closely with the US National Laboratories, where a great deal of alternative energy research takes place. The EERE Biomass Program is the center of DOE efforts related to research, development, and demonstration of biofuels technology. The mission of the Biomass Program is "to develop and transform our domestic, renewable, and abundant biomass resources into cost-competitive, high performance biofuels, bioproducts, and biopower through targeted research, development, and delivery leveraged by public and private partnerships [1]." There are three major budgetary components of the program, including:

- Feedstock Infrastructure—to support the development and reduce the cost of biomass resources for energy use
- Platforms R&D—to support the conversion of biomass feedstocks into cost-competitive energy sources
- Utilization of Platform Outputs Research, Development and Delivery—to test the network of technologies for development, production, and distribution of biomass energy sources [2].

IRS has jurisdiction of the administration of the US federal tax code including federal tax credits and exemptions. The Tax Policy subsection below lists and describes biofuels-related tax incentives.

Several offices in USDA also oversee programs related to federal biofuel policy. The Agricultural Research Service (ARS) manages over 1,000 research programs including the Bioenergy and Energy Alternatives National Program [3]. The Office of Rural Development (ORD) oversees the Bio-based Products and Bioenergy Program, which finances development of technologies used to convert biomass into energy, and the Rural Development Business and Cooperative Program offers guaranteed loans to businesses for this purpose [4].

EPA has regulatory oversight for some energy programs, including the Renewable Fuel Standard (RFS). EPA administers the Biodiesel Emissions Analysis Program to research the air pollution effects of various blends of biodiesel [5]. EPA works with DOE to coordinate some federal studies. Other federal studies, such as the Sugar Cane Ethanol Pilot Program established by the Energy Policy Act of 2005 (EPACT), are under the exclusive jurisdiction of EPA [6].

10.1.2 Grants for Research, Development, and Demonstration

The federal government funds the majority of R&D related to biofuels, especially advanced biofuels(renewable fuels other than ethanol derived from corn starch). Funding mechanisms include grants to R&D bodies and public-private ventures that develop new technologies, and financial assistance to local government entities for the purchase of items that further an advantage in the biofuels industry.

EPACT directs DOE to establish a competitive grant pilot program through the Clean Cities Program for the provision of grants to state and local governments that purchase alternative fuel vehicles [7].

The Energy Independence and Security Act of 2007 (EISA) authorized $25,000,000 in biofuels R&D grants for states with low ethanol production and $50,000,000 in grants for cellulosic ethanol and biofuels research [8, 9]. EISA also expands certain R&D provisions of EPACT to include cellulosic and other feedstocks that are less resource and land intensive when converted to fuels. Additionally, the University-Based Research and Development Grant Program authorized $25,000,000 in competitive grants for institutions of higher education to conduct renewable energy R&D [10].

10.1.3 Federal Research and Studies

The federal government conducts a great deal of R&D pertaining to biofuels. These projects can take place in the National Laboratories, the National Academies of Science, and within federal departments like DOE and USDA. The goals of this research are diverse and include studies on biocrop development, the efficiency of production and refinement techniques, best practices for increasing fuel efficiency, increasing the use of certain biobased products, etc.

EPACT directs DOE and USDA to steer R&D efforts towards the development of technologies that facilitate the conversion of cellulosic biomass to biofuels [11]. EISA requires DOE to submit to Congress a report detailing the challenges involved with increasing biodiesel consumption in the US [12]. EISA also requires DOE to study the feasibility of commercial applications that increase the energy efficiency of bio-refinery facilities and develop retrofit technologies that would allow existing bio-refineries to process different forms of biomass, including ligno-cellulosic feedstocks [13]. Another requirement directs DOE to study the effects of various biodiesel blends on the performance and durability of engines [14].

10.1.4 Federal Procurement Policy

Procurement is a very powerful tool the federal government can utilize to shape policy. The Energy Policy Act of 1992 requires federal agencies to purchase alternative-fuel vehicles for the federal fleet. As of 1999, 75 percent of the federal fleet must be alternative-fuel vehicles [15].

10.1.5 Federal Goal Setting

The federal government encourages producers and consumers to invest voluntarily in greater production and consumption of biofuels through goal setting. EPACT established RFS, which set a national goal of producing 7.5 billion gallons of renewable fuels by 2012 [16]. EISA amended EPACT 2005, doubling the 2012 target to 15.2 billion gallons and setting the 2022 target at 36.0 billion gallons. EISA also mandates that 2.0 billion gallons of the target be met with advanced biofuels by 2012, and 21.0 billion gallons by 2022. This act also set targets for cellulosic biofuels and biomass-based biodiesel [17].

10.1.6 Federal Tax Policy and Guaranteed Loan Programs

Federal legislation has established several tax credits for biofuels production. These tax incentives are designed to decrease the consumer cost of biofuels, making them more cost-competitive with traditional fuels. The Small Ethanol Producer Tax Credit (SEPTC) was first introduced in the 1990 Omnibus Budget Reconciliation Act and was strengthened by the JOBS Act and EPACT. Any facility with a production capacity of less than 60 million gallons is eligible for a $0.10 per gallon tax credit for the first 15 million gallons produced annually. This credit is also limited to one credit per owner (owning multiple facilities does not entitle multiple credits) [18].

EPACT establishes the Small Agri-Biodiesel Producer Tax Credit, which offers an income tax credit to producers of agri-biodiesel (biodiesel created exclusively from virgin oils). This small producer credit is also $0.10 per gallon annually for the first 15 million gallons of qualified agri-biodiesel. The same production capacity limitations of the Small Producer Credit apply to this credit [19].

The 2004 JOBS Act created the Volumetric Excise Tax Credit (VEETC) to replace the existing ethanol tax credit. VEETC offers a $0.51 per gallon credit for ethanol mixtures [20].

EPACT also establishes a credit for the installation of alternative fuel stations under which taxpayers can claim up to a 30 percent credit for the cost of installing clean-fuel vehicle refueling equipment. This credit is limited to $30,000 per station [21].

At the time of this report, the 2007 Farm Bill is considering loan guarantees for the construction of biofuels production and refinement facilities. Half of the loan guarantees would cover loans of less than $100 million and half would cover loans up to $250 million [21].

10.2 Indiana Policies and Laws Regarding Biofuels

The state incentive package for Indiana biofuels currently focuses on production and retail tax credits. These types of policies work together with infrastructure grants, government purchase of biofuels, goal setting, promotion and education, and biofuels research. However, the current mix of state policies lacks the ability to move Indiana towards the next phase of cleaner biofuels development.

10.2.1 Production Tax Credits

Ethanol

Indiana provides an ethanol production tax credit to producers of $0.125 per gallon. Of Midwest states offering ethanol production tax credits, Minnesota, Missouri, and South Dakota all offer $0.20 per gallon while Iowa, Illinois, and Ohio all lack a production tax credit [27, 28].

This tax credit applies to both cellulosic and grain ethanol. The total amount of credit per producer varies depending on the amount of ethanol produced.

- For production of 40-60 million gallons of grain ethanol, a maximum credit of $2 million is available.
- For production of 60+ million gallons of grain ethanol, a maximum credit of $3 million is available.
- For production of 20+ million gallons of cellulosic ethanol, a maximum credit of $20 million is available [29].

Biodiesel

The Indiana Biodiesel Production Tax Credit gives $1 per gallon of pure biodiesel produced in Indiana [23]. In order to receive the tax credit, the producer must file an application with the Indiana Economic Development Corporation (IEDC) [23]. The amount of the tax credit cannot exceed $3 million dollars per year, unless approved by the IEDC [24]. Upon IEDC approval, the credit can be extended up to $5 million dollars per year [24].

The state also provides a production tax credit of $0.02 per gallon of blended biodiesel produced in Indiana, and biodiesel producers who use their own fuel do not have to pay the $0.16 per gallon license tax, provided that it is a blend of at least 30 percent [25, 26].

10.2.2 Retailer Tax Credits

Retailers distributing E85 can receive a credit of $0.18 per gallon against the state Gross Retail Tax, up to a maximum of $1 million [29]. Retailers distributing blended biodiesel can receive a credit of $0.01 per gallon; however, this credit is contingent upon annual state funding [30].

10.2.3 Infrastructure Grants

ISDA administers Indiana infrastructure grants and limits them to E85 fueling stations. Individual grants of up to $20,000 are available for new E85 fueling stations or the retrofitting of existing equipment [31]. This is an increase from the previous maximum available grant of $5,000 and is intended to promote E85 pumps along the I-65 corridor [32]. ISDA approves grant applications and allocates a total of $1 million to fueling stations and municipal governments [33].

10.2.4 Government Use

Ethanol

For gasoline-fueled vehicles, government entities are required to use an ethanol blend of at least ten percent whenever possible [34]. Executive Order 05-21 (2005) mandates that state fleet vehicles based in Indianapolis use E85 (if capable) [35].

Political subdivisions (municipal corporations or other special taxing districts) can receive a monthly incentive payment for using E85 in FFVs equal to $33.33 per vehicle. However, the vehicles must have been purchased in the last five years [26].

Biodiesel

Government entities are required to use a blend of at least two percent biodiesel whenever possible [34]. Indiana also sets purchasing requirements for state government and state educational institutions [37]. The purchasing requirements are specified by price preference. For example, if a price preference of ten percent is set, the state is required to purchase biofuels that cost less than ten percent more than the alternative. Indiana sets a price preference of ten percent for purchases by governmental bodies and state educational institutions for fuels that are at least 20 percent biodiesel, or "are primarily esters derived from biological materials, including oilseeds and animal fats, for use in compression and ignition engines [37]."

10.2.5 Goal Setting

While not clearly aimed at changing policy, goals set by Indiana have the power to impact future policies. ISDA completed a strategic plan in 2004 that details ethanol and biodiesel production and use goals through 2025. The plan aims for 300 million gallons of ethanol production by 2010 and 350 million gallons by 2025. The plan also sets goals for ten percent ethanol usage (as a percent of total fuel usage) by 2010 and 20 percent by 2025. Additionally, the plan calls for 100 million gallons of biodiesel production by 2010, and biodiesel usage (as a percent of total fuel usage) of 20 percent by 2025 [38].

Indiana has also signed onto the Energy Security and Climate Stewardship Platform Plan (ESCSPP) with Iowa, Kansas, Michigan, Minnesota, Ohio, South Dakota, and Wisconsin. While the plan sets many goals for the region, it is unclear how large a role Indiana will play in implementing each goal. ESCSPP sets goals to have commercially available cellulosic ethanol by 2012, increase the availability of E85 to 15 percent of stations by 2015, "reduce the amount of fossil fuel that is used in the production of biofuels 50 percent by 2025," and to have "by 2025, at least 50 percent of all transportation fuels consumed by the Midwest [to] be from regionally produced biofuels and other low-carbon transportation fuels [23]."

10.2.6 Promotion and Education

Indiana's biofuels promotion and education is limited to efforts undertaken by ISDA. ISDA is charged with promoting E85 to retailers, auto manufactures, and consumers [39].

10.2.7 Research

The federal government exclusively funds nearly all government research on biofuels. However, the state of Indiana does have limited research and planning efforts underway, including the Environmental Quality Service Council (EQSC), Biomass Feasibility Study Grant Program, Twenty-First Century Research and Technology Fund, and a Strategic Energy Plan for Biofuels.

Indiana established EQSC to conduct studies and produce findings and recommendations concerning the implementation of EPACT's RFS [40]. As of 2008, EQSC has failed to produce any findings or recommendations, but has requested that the Indiana Sustainable Energy Commission (ISEC) be convened to make recommendations on state policies over the next five, ten, 20, 50, and 100 years. Similarly, EQSC also requested that the director of ISDA prepare a comprehensive biofuels plan for the next ten, 20, and 50 years. Thus far, neither of these agencies has produced recommendations for the state [41, 42].

Indiana's Office of Energy and Defense Development (OED) operates the Biomass Feasibility Study Grant Program, which offers $100,000 to qualifying applicants for research related to the conversion of biomass to energy [43]. The Indiana Twenty-First Century Research and Technology Fund provides grants and loans for alternative fuel technologies, provided that they support economic development [44].

In 2006, OED released Indiana's Strategic Energy Plan also known as "Hoosier Homegrown Energy." The plan encourages the growth of Indiana's economic sector through the development of electricity, natural gas, and transportation fuels. Governor Daniels envisions Indiana as "the nation's biofuels capital" and calls for cellulosic ethanol R&D as a way to move beyond grain ethanol [45]. Governor Daniels also encourages investment by the private sector in development of biofuels plants and infrastructure with support from the state through tax incentives, loan guarantees, and regulation [45].

10.3 Indiana's Biofuels Incentives and the Dormant Commerce Clause

As noted above, Indiana has adopted both tax and non-tax incentives to support the state's growing biofuels industry. It is likely that Indiana will continue to offer several of its current incentives into the future, and will create new incentives to encourage new technologies and support emerging trends. However, because Congress has specifically been granted power to regulate interstate commerce, dormant Commerce Clause issues arise when state-created incentives demonstrate favoritism towards in-state actors. This section will provide background information on the development of the dormant Commerce Clause and an analysis of how the dormant Commerce Clause applies to Indiana's current biofuels incentive schemes. Additionally, this section will offer several incentives options to states that may overcome the dormant Commerce Clause hurdle.

10.3.1 The Dormant Commerce Clause: An Introduction

Through the Commerce Clause, the US Constitution grants Congress the power "[t]o regulate Commerce . . . among the several states [46]." In addition to granting Congress the power to regulate interstate commerce, the Commerce Clause also restricts the states' power to regulate if the regulations "place[]an undue burden on interstate commerce [47]." This restrictive doctrine is known as the dormant Commerce Clause (DCC). The Court has explained:

> The [DCC], directly limiting the States' power to discriminate against interstate commerce, prohibits economic protectionism - that is, regulatory measures designed to benefit in-state economic interests by burdening out-of-state competitors. Thus, state statutes that clearly discriminate against interstate commerce are

> routinely struck down . . . unless the discrimination is demonstrably justified by a valid factor unrelated to economic protectionism [48].

If a state regulation or tax discriminates against interstate commerce on its face or by intent based on in-state or out-of-state distinctions, a "strict scrutiny" standard is applied [49]. In such a circumstance, the likelihood of invalidation is great (unless the state is able to present a strong and legitimate state interest that can be advanced in a no less burdensome manner) [49]. If a state is acting under its normal jurisdiction and is not discriminating based on geographic location, but the state action creates a discriminatory burden on interstate commerce, courts apply a balancing test that weighs the state's interest against the burden on commerce [49]. If the state's interest outweighs the burden on commerce, the action will be deemed constitutional [49].

Not only does the DCC prevent states from enforcing direct prohibitions (e.g., taxes, tariffs, or regulations) that discriminate against interstate commerce, it also prevents states from effectuating certain incentives that have discriminatory effects [49]. While the Supreme Court has made clear that states are able to use tax systems and subsidies to encourage economic development, it has also invalidated tax incentives and subsidies with that purpose because the incentives discriminated against out-of-state investments and activities [47]. For example, in *Westinghouse Electric Corporation v. Tully*, the Court held that a New York tax credit for a new type of corporate entity was unconstitutional because New York tied the amount of the credit to the amount of export activity occurring within New York [50]. The result was that if the corporate entities increased export activity within New York, they received larger tax credits [50]. The Court found that New York's efforts to encourage local economic activity discriminated against interstate commerce [50].

The Court has generally analyzed incentives differently, depending on whether the incentives are tax based (e.g., credits, exemptions, or abatements) or non-tax based (e.g., cash grants, loans and financing, etc.).

10.3.1.1 Tax Incentives

The Supreme Court has clearly established that a state is prohibited from creating a discriminatory sales or use tax on out-of-state products to benefit in-state producers or to lure industries into constructing in-state facilities [51]. Additionally, the Court has held that certain state tax incentives are unconstitutional if they discriminate against the free flow of interstate trade. In *New Energy Co. of Indiana v. Limbach*, Ohio created a motor fuel tax credit for each gallon of ethanol sold as part of gasohol [48]. However, the credit only applied if the ethanol was produced in Ohio or in a state providing reciprocal tax credits to ethanol produced in Ohio [48]. The Court explained that the tax credit was "in effect, taxing a product made by [Indiana] manufacturers at a rate higher than the same product made by Ohio manufacturers, without . . . justification for the disparity [48]." The Court held that the Ohio tax scheme facially discriminated against out-of-state producers, and thus, interstate commerce, by differentiating between in-state and out-of-state producers [48].

10.3.1.2 Non-Tax Incentives

Although the Court held in *New Energy Co.* that discriminatory tax credits are unconstitutional, the Court also stated that "direct subsidization of domestic industry does not ordinarily run afoul of [the discriminatory action] prohibition" under the DCC [48]. This "loophole" for direct subsidization results from two factors: (1) the market participant exemption and (2) the general allowance of cash subsidies.

This first factor is the market participant exemption, a Court doctrine that exempts a state from the DCC limitation when the state is deemed a market participant [47]. The exemption was applied in *Hughes v. Alexandria Scrap Corp.*, where the court upheld Maryland's abandoned automobile processing subsidy program, which required less-stringent documentation requirements for in-state processors [52]. The Court explained that Maryland had entered the auto hulk market to increase the price of auto hulks, and that such actions can be distinguished from "[interference] with the natural functioning of the interstate market either through prohibition or through burdensome regulation [52]." As a result, if a state enters the market (e.g., buying or selling goods), it can constitutionally create the same locally beneficial results as it might through a discriminatory—and likely unconstitutional—tax or tax incentive. This exception promotes the idea that states should have a choice in how they allocate their resources when carrying out state business activities and demonstrates recognition of state independence in economic development [47].

The second factor is simply that the Court has thus far refused to consider invalidation of discriminatory cash subsidies to in-state industries [51]. While the Court has noted that it has "never squarely confronted the constitutionality of subsidies," it has mentioned direct payment subsidies in dicta on several occasions [53]. In *New Energy Co.*, the Court mentioned Indiana's cash subsidy program for in-state ethanol producers as an alternative to Ohio's tax credit. Justice Scalia noted that although the Indiana scheme may have been as equally discriminatory as the Ohio scheme, "[t]he Commerce clause does not prohibit all state action designed to give its residents an advantage in the marketplace, but only action of that description *in connection with the State's regulation of interstate commerce* [48]." Additionally, such subsidies were mentioned in *South-Central Timber Development, Inc. v. Wunnicke,* and in *C & A Carbone, Inc. v Town of Clarkston,* although neither case spoke directly to the subsidy [54, 55].

However, a caveat exists in *West Lynn Creamery v. Healy*. In that case, Massachusetts required every milk dealer selling in Massachusetts to pay a "premium payment" into the "Massachusetts Dairy Equalization Fund [53]." The amount paid in was determined by the amount of milk sold in the state. On a monthly basis, the fund's proceeds were distributed to in-state milk producers in shares proportionate to the producers' in-state production of raw milk [53]. While out-of-state producers paid into the fund, they were ineligible to receive producer payments taken out of the fund [53].

The Court held Massachusetts's subsidy to be unconstitutional, stating that "the imposition of a differential burden on any part of the stream of commerce--from wholesaler to retailer to consumer--is invalid, because a burden placed at any point will result in a disadvantage to the out-of-state producer [53]. Although the direct burden (the premium payment) placed on producers appeared to burden equally in-state and out-of-state producers, the combination of the payment with the in-state producer subsidy offset the burden placed on in-state producers. The Court explained that while a "pure subsidy" coming out of the general revenue "poses no burden on interstate commerce" and is an acceptable means of assisting local business, the

Massachusetts payment and subsidy scheme was equal to an "ordinary tariff" on out-of-state producers [53].

10.3.2 Indiana's Current Biofuels Incentives: A Cause for Concern?

As the section on Indiana's policies and laws regarding biofuels describes, Indiana currently has several tax-based incentives directed at the promotion of biofuels. These incentives are primarily focused on in-state production, and due to that focus, raise several red flags when considered in light of the DCC.

The Biodiesel Production Tax Credit, which is equal to $1 per gallon of Indiana-produced biodiesel used to create blended biodiesel, can be applied to state tax liability [56]. State tax liability is a taxpayer's total tax liability that is incurred under the state gross retail and use tax, the adjusted gross income tax, the financial institutions tax, and the insurance premiums tax [56].

Indiana also provides a blended biodiesel production credit for blended-biodiesel producers in the state [25]. The credit is equal to $0.02 per gallon of blended biodiesel produced in Indiana, and may be applied to the state gross retail and use tax, the adjusted gross income tax, the financial institutions tax, and/or the insurance premiums tax [25].

A third production-based tax credit is Indiana's Ethanol Production Tax Credit. This credit, similar to the biodiesel production tax credit, provides a tax credit to ethanol production facilities located in Indiana [57]. The credit is equal to $0.125 per gallon of ethanol produced at an Indiana facility, and it is made available to two types of facilities: (1) those able to produce 40 million gallons of ethanol per year, and (2) pre-existing facilities that increase their capacity by at least 40 million gallons per year [57, 58].

As noted above, incentives based on geographic location have never fared well under the dormant Commerce Clause. The Indiana biodiesel production credit, the blended biodiesel production tax credit, and the ethanol production tax credit are all provided only to in-state biofuels producers. If an out-of-state producer of either biodiesel or ethanol is subject to one or more of the Indiana state taxes noted under the applicable sections of the Indiana Code, providing the biodiesel and ethanol tax credits solely to in-state producers is facially in violation of the DCC. Because the tax credits favor local producers, they all have the potential to overburden out-of-state producers by taxing them at effectively higher rates than the in-state biodiesel and ethanol producers receiving the credit. Much like the tax credit in *New Energy Co.*, the Indiana tax credits, if litigated, would likely be found to "explicitly deprive[] certain products of generally available beneficial tax treatment because they are made in certain other States, and thus on [their] face [the tax incentives] appear[] to violate the cardinal requirement of nondiscrimination [48]."

While Indiana has not appropriated funds for corn-based ethanol or biodiesel production in recent years, a tax credit is still available for in-state cellulosic ethanol production. If cellulosic ethanol production increases in the future and a national or Midwest market emerges, there is no doubt that frequent interstate sales transactions (especially between Indiana and its bordering states) will take place. In such a circumstance, if an out-of-state producer determines that the burden caused by the discriminatory tax credit outweighs the burden imposed by undertaking litigation against Indiana, a lawsuit is likely to result.

10.3.3 Assessing the Future

Indiana's reasoning behind its in-state biodfuels tax credits seems evident. Indiana has entered the race to become a national biofuels leader, and by offering only in-state tax incentives, Indiana hopes to: (a) influence the location decisions of potential biofuels producers (with the ultimate goal of luring potential producers to invest in in-state production facilities), (b) increase the competitiveness of local producers by reducing their tax burden, and therefore, their overall cost, or (c) both [51].

If Indiana is solely attempting to influence producer location decisions, constitutionality aside, the state may want to reconsider the soundness of the "smokestack chasing" approach. Empirical data and business executive surveys demonstrate that location decisions are more frequently based on the state's business climate and other state advantages such as "wages, employee skill levels, availability of raw materials, strength of markets, and regulatory stringency [47]." Alternatively, if two states offer competing subsidies, each subsidy may offset the other, causing producers to make the decision it would have if neither subsidy were offered [51].

However, if all other factors between two states are equal and subsidies are not, it is possible for a subsidy to serve as a "tie-breaker" in location decisions [51]. If that is the case or if the state is attempting to make local production more competitive (or both), the Court, while not providing a direct decision to rely on, seems to have provided states with two ways to maneuver around the DCC. The first is non-coercive tax incentives and the second is non-tax incentives. Additionally, a state can advocate for Congress to enact legislation that allows a state to provide subsidies that interfere with interstate commerce, thus, circumventing the DCC problem.

10.3.3.1 Non-Coercive Tax Incentives

In every case in which the Court has invalidated a tax incentive, the tax incentive has held coercive power. This means that the tax incentive had the ability to force an entity to pay a higher effective tax to the taxing state unless the entity located the respective operation/transaction in-state [59]. Essentially, in the invalidated cases, the state was saying:

> You are already subject to our taxing power because you engage in taxable activity in this state. If you would like to reduce your tax burdens, you may do so by directing additional business activity into this state. Should you decline our invitation, we will continue to exert our taxing power over you as before, and your tax bill might even go up [59].

Although many tax incentives hold coercive power, there are some that do not. These include tax incentives "framed not as exemptions from or reductions of *existing* state tax liability but rather as exemptions from or reductions of *additional* state tax liability to which the taxpayer would be subjected only if the taxpayer were to engage in the targeted activity in the state [59]." An example of such an incentive would be a real property tax exemption for new construction. When offering a non-coercive tax incentive, the state essentially says: "Come to our state and we will not saddle you with any additional property tax burdens. Moreover, should you choose not to accept our invitation, nothing will happen to your tax bill - at least nothing that depends on our taxing regime [59].” By utilizing non-coercive tax incentives rather than coercive tax incentives, states such as Indiana may be able to achieve the same goals while potentially avoiding DCC constitutionality issues.

10.3.3.2 Non-Tax Incentives

An additional way to sidestep DCC problems may be to avoid utilizing a tax scheme all together. Rather, a state can provide non-tax incentives to business entities it favors, such as biofuels producers. As earlier noted, non-tax subsidies such as “direct payment subsidies, funded out of the general treasury, supply of infrastructure, provision of low-interest loans, assistance in job-training or recruitment, and granting of land, are largely immunized from dormant Commerce Clause scrutiny [51].” By focusing on non-tax incentives, a state can still encourage local economic development and favor certain businesses or industries, but it significantly reduces its chances of being held in violation of the DCC. Additionally, by focusing on non-tax incentives, a state may be able to further develop some of the other factors businesses consider when making location decisions, such as labor force training or the provision of land located near biofuels crops of choice.

10.3.3.3. Congressional Action

Congressional consent is another safeguard for states wishing to implement subsidies that burden interstate commerce. Through a grant of authority, Congress can allow discriminatory subsidies, such as tax credits, to stand, despite their violation of the DCC. For example, EPACT explicitly authorizes tax incentives for coal mined in a state if the state utilizes clean coal technologies, stating such incentives shall “be considered a reasonable regulation of commerce; and . . . not be considered to impose an undue burden on interstate commerce or to otherwise impair, restrain, or discriminate, against interstate commerce [60].” If Indiana is able to secure congressional consent for in-state cellulosic ethanol production tax incentives, Indiana will no longer be in danger of being held in violation of the DCC.

10.3.3.4 Conclusions

State-offered incentives can provide Indiana with a means to encourage growth and development in biodiesel and ethanol; however, Indiana needs to consider incentive design implications to ensure that the incentives will withstand DCC scrutiny. While the courts do not take issue with in-state promotion of economic development, they will quickly invalidate any tax, regulation, or incentive that burdens interstate commerce by discriminating against out-of-state entities. By carefully designing incentive schemes to avoid DCC restrictions, or by securing Congress’s approval, Indiana can provide the biofuels incentives necessary to “Fuel Indiana’s Future.”

10.4 Federal Recommendations

10.4.1 R&D Push for Widespread Commercialization of Corn Stover Cellulosic Ethanol

Rationale Behind Proposal

Corn stover is Indiana's best cellulosic biofuels option for the foreseeable future. Indiana is one of the nation's top corn producers; therefore, utilizing the by-product from current harvesting techniques is both preferable and efficient. However, as stated earlier, corn stover cellulosic ethanol is not yet available for widespread commercial production. Therefore, it is important to infuse the R&D community with funding, so it can further refine the corn stover cellulosic ethanol process.

Proposal

Indiana's Washington delegation should introduce legislation that encourages increased short-term (two to three years) funding for corn stover cellulosic commercialization so that the process can become a significant contributor to the US energy portfolio over the next 20 years. Indiana senators and representatives should lobby for funding in one of two ways:

- Specifically draft legislation that provides funding incentives for private entrepreneurial entities that conduct corn stover commercialization R&D.
- Create federal-state pilot programs that build corn stover cellulosic ethanol facilities that fine-tune the enzyme, production, and transportation processes so that corn stover cellulosic ethanol can become a cost-effective energy option for Indiana in the immediate future.

10.4.2 Conservation Reserve Program Modifications

Rationale Behind Proposal

As crop prices have risen, fueled by increased demand for corn and other bioenergy crops, many farmers have incentive to remove lands from CRP and place them into agricultural production. Some interest groups have proposed allowing farmers to leave CRP contracts early in order to grow bioenergy crops such as corn.

Proposal

The federal government should not encourage the removal of land from conservation programs. Many of these lands are marginal for crop growth or contain sensitive ecosystems and wildlife populations. Instead, federal efforts should focus on high-energy yield crops, such as switchgrass, that represent the future of the biofuels market and preclude further CRP encroachment.

There are several proposals to create such a reserve program. At this time, the House version of the 2007 Farm Bill includes a Biomass Energy Reserve Program (BER) [61]. This program would establish a biomass energy reserve "to encourage production of dedicated energy crops in a sustainable manner that protects the soil, air, water, and wildlife of the United States…" (renewable fuels other than ethanol derived from corn starch) [61]. The program offers financial support and technical assistance to landowners who wish to produce crops for the bioenergy industry. Though the bill language identifies sustainability as a priority, it does not specify land and crop eligibility requirements.

The National Wildlife Federation's Biofuels Innovation Program proposal (BIP) is similar to BER and identifies the specific land and crop types that are eligible under the program. BIP would allow up to five million acres of land to be placed under the control of the Natural Resources Conservation Service (NRCS) in order to establish a base of support for advanced biomass energy production. Farmers would submit a proposal that identifies the characteristics and amount of land to be enrolled under the program, as well as the type and mix of crops. Farmers will be eligible for a range of incentives including reimbursement for costs related to converting the land and incentive payments for growing certain crops. BIP prioritizes those proposals having the greatest benefits to the environment, bioenergy crop production, and crop diversification.

10.4.3 Use Energy Frontier Research Centers to Advance Cellulosic Biofuels

Rationale Behind Proposal

The newly modified RFS calls for the production of 36 billion gallons of biofuels annually by 2022 [62]. Congress expects that 21 billion gallons of this amount will consist of *advanced* biofuels (renewable fuels other than ethanol derived from corn starch), of which 16 billion gallons will be derived from cellulosic biofuels [62, 63]. Moreover, these biofuels must satisfy greenhouse emissions standards based on lifecycle studies which consider *all* emissions resulting from fuel production, from field to tank, including emissions from changes in land use [63]. As a result, the Office of the Biomass Program (OBP) within Department of Energy (DOE) is striving to make the production of cellulosic ethanol cost competitive by 2012, a goal which has been endorsed by Governor Daniels [64, 65].

Meeting EISA goals will require the joint efforts of federal and state governments, industrial and agricultural communities, and finance and business entrepreneurs. Coordination of multidisciplinary scientific and engineering expertise from academia and the National Laboratories will be critical to building a strong technology foundation. Programs within DOE are therefore entering partnerships with industry, academia and the National Laboratories in order to leverage their resources [8, 9, 66, 67, 68].

Proposal

DOE's Office of Basic Energy Sciences (BES) recently announced that it plans to establish Energy Frontier Research Centers (EFRCs) "to accelerate the rate of scientific breakthroughs needed to create advanced energy technologies for the 21st century [69]." BES expects that an annual $2-5 million will be available during an initial five-year period, after which, $100 million will be available for multiple EFRC awards starting in 2009. BES will issue a Funding Opportunity Announcement (FOA) during FY2008 to request applications [69].

The research program of an EFRC applicant must have several "distinguishing attributes." An example of a "research focus area" which would meet BES expectations is how biological feed stocks are converted into portable fuels, specifically research into the cause of current "bottlenecks" in cellulosic biofuels production [69].

10.4.4 Biodiesel from Alternative Forms of Biomass

Rationale Behind Proposal

Like ethanol, biodiesel production enjoys government subsidies and tax credits that make it price competitive with petroleum-based diesel. Nevertheless, there are only a few alternatives for the diesel fuel and, consequently, only a relatively small market exists for biomass-derived biodiesel from oil seed crops such as soybeans or rapeseed, or from waste oils.

Moreover, biodiesel from these feedstocks has significant drawbacks. Soy crops need relatively high amounts of insecticides and fertilizers while producing, per acre, only one-sixth the amount of biofuel produced from corn ethanol (See Section 4.3). Biodiesel from soy and rapeseed may cause engine problems with blends higher than 20 percent. Waste oil may contain impurities that create emissions which are detrimental to the environment. As a result, it remains unlikely that biodiesel from these feedstocks will substantially displace the use of conventional biodiesel [70].

However, just as cellulosic ethanol represents a more promising long-term alternative to gasoline than corn-based ethanol, newer technologies are emerging that can produce clean low-sulfur synthetic diesel fuels from alternative forms of biomass and other organic materials. One of the more promising technologies can utilize a wide variety of organic wastes as feedstocks [70].

Proposal

Because drivers are unlikely to notice any detrimental impact, Indiana should encourage use of B20 in all vehicles throughout the state. However, Indiana should provide funding and incentives towards research and investment in technology for converting biomass and organic wastes into high-quality, environmentally sound, and economically lucrative diesel fuels which are compatible with existing vehicle technologies and can be readily integrated into existing distribution infrastructure.

10.4.5 Closing CAFE Standards Loopholes for E-85 Vehicles

Rationale Behind Proposal

The federal government's CAFE program currently provides credits to auto manufacturers for producing dual-fuel vehicles that run on conventional gasoline as well as unconventional fuels such as ethanol. The purpose of these incentives is to support the use of alternative fuels that decrease carbon emissions. In reality, however, there is little consumer demand for these vehicles; the vehicle engines are less efficient than conventional engines, and many consumers never use alternative fuels in them [71].

Proposal

Because there is insufficient demand for alternative fuels, the result of the CAFE dual fuel credit is lower overall fuel economy for vehicle fleets [72]. The Government Accountability Office has recommended in several reports to Congress that CAFE be eliminated. The federal government should not offer incentives for the production of dual-fuel vehicles at this time. This "dual-fuel loophole" should be closed until there is sufficient demand for alternative fuels.

10.4.6 Funding for Comprehensive Environmental Assessments at University Research Centers and Institutes

Rationale Behind Proposal

Beneficial and detrimental environmental effects are among the most important qualitative factors that must be considered in Indiana's assessment of biofuels. However, few studies have been conducted to quantify or comprehensively analyze the environmental impacts of biofuels. Major areas of uncertainty include, but are not limited to, the following;

- The pollution impacts of cellulosic ethanol production facilities (e.g., emissions, effluent discharges, etc.)
- Indiana's carbon inventory and how land use changes resulting from biofuels production affect state carbon storage and emissions
- The extent and value of CO_2 emission reductions from biofuels engines compared to their fossil fuel counterparts
- The invasive potential of biofuels crops
- The extent to which various biofuels blends (including E10 and E85) would provide environmental benefits

Proposal

Federal funding should be directed to university research centers and institutes to model, measure, valuate, and comprehensively analyze the environmental impacts of biofuels in Indiana within a time period of five years. By obtaining and analyzing these data, economic analyses of biofuels in Indiana will provide more realistic and reliable results that can be used to inform long-term biofuels investment and policy decisions.

10.5 State Recommendations

10.5.1 Statewide Financial Incentives for Corn Stover Cellulosic Ethanol

Rationale Behind Proposal

The market for corn stover ethanol is only emerging, and if Indiana desires to be a national leader in this sector, the state must create an economically favorable landscape for entrepreneurial businesses. Since Indiana has comparative advantages in geography and climate, it should provide financial incentives to lure corn stover cellulosic ethanol producers to the state. The goal is to promote corn stover ethanol as an integral part of the state's energy portfolio. Since the state believes that corn ethanol and biodiesel are ready to compete in a market without special incentives, incentives for corn stover cellulosic ethanol may be allotted from currently funded fuel initiatives.

Proposal
Although cellulosic ethanol from corn stover is not yet cost effective on a large scale, Indiana should legislate proactively by 2009 to ensure the state is prepared to support this technology. Indiana's General Assembly should therefore, pass the following measures:

- Subsidize property tax exemptions for the first corn stover and the first combination corn stover/switchgrass cellulosic ethanol plants built in Indiana. Localities, driven by potential job creation, will vigorously compete for the new plants, and private entrepreneurial companies will be able to select optimal locations for their facilities.
- Encourage the growth of corn stover cellulosic ethanol production by transferring all remaining production credit incentives from biodiesel to corn stover initiatives. Additionally, the General Assembly should appropriate additional production credit funding opportunities for corn stover cellulosic ethanol (above and beyond the transferred funds), thus signaling that corn stover ethanol is clearly in the best interests of Indiana's long-term future.

10.5.2 Standardized Safety Procedures for Ethanol and Biodiesel Infrastructure and Distribution

Rationale Behind Proposal
Ethanol and biodiesel are volatile substances that are flammable or explosive at ambient pressures and temperatures [73]. Ethanol vapors travel easily through the air and biodiesel vapors travel easily through water. Both have the potential to cause fires and explosions. A biodiesel fire requires the use of foam or dry chemicals, and higher ethanol blends such as E85 require the use of alcohol-resistant foams [74].

Best management practices (BMPs) that include safety procedures and emergency response plans can help reduce the incidence of fires or explosions. BMPs regarding storage, containment areas, and safety precautions are needed to ensure these volatile substances will not cause harm. The state should develop safety material, formulate emergency procedures, designate emergency program teams, and coordinate emergency response. Indiana has no mandate for best management safety procedures concerning ethanol and biodiesel facilities, distribution infrastructure (such as terminals and tankers), or distribution facilities (i.e., gasoline stations).

Proposal
The state of Indiana should mandate BMPs in all ethanol and biodiesel production facilities, distribution infrastructure, and distribution facilities. The BMPs should focus on accident prevention and safety techniques. BMPs will help to reduce the likelihood of fires and explosions and ensure personnel and infrastructure are properly equipped and trained to handle an emergency situation.

10.5.3 Best Management Practices Outreach and Implementation on Indiana's Farmland

Rationale Behind Proposal
Indiana's ground and surface waters will be detrimentally affected by changing land use patterns associated with increased biofuels production. Potential negative consequences include

increased sedimentation, increased nutrient loading from fertilizer usage, and greater water toxicity resulting from increased pesticide, herbicide, and fungicide inputs (See Section 4.5.6). To mitigate the detrimental effects of land use change, Indiana farmers must utilize BMPs such as integrated pest management, riparian buffer zones, winter cover crops, no-till farming, diversified agricultural landscapes, and nutrient management (See Section 4.5.6). Such practices must not only be promoted by state officials. Indiana farmers should also receive training on how to implement and sustain BMPs.

Proposal

Indiana should develop an outreach, education, and implementation program for BMPs on its agricultural acreage. This program should be undertaken by a state organization that already has a well-developed presence in the agriculture industry and a working relationship with Indiana farmers. Potential organizations include the Purdue University Cooperative Extension Service or Indiana's Soil and Water Conservation Districts. If additional incentive is required, the state can provide performance subsidies to farmers utilizing BMPs that result in short-term economic losses (e.g., lower yields, increased inputs, etc.). By establishing BMPs throughout Indiana, the detrimental effects of sedimentation, increased chemical inputs, and poor soil quality will be significantly reduced and the long-term health of Indiana's farmland will be maintained.

10.5.4 Switchgrass Buffer Strips Bordering Riparian Zones on Indiana Croplands

Rationale Behind Proposal

The growth of cellulosic feedstocks (such as perennial grass) results in significant water quality benefits over corn ethanol production. By encouraging production of cellulosic crops on marginal lands—such as those immediately adjacent to riparian zones—Indiana will receive substantial water quality benefits, and the state will have a supply of feedstocks to accommodate cellulosic production facilities once the technology becomes commercially viable.

Proposal

Indiana should mandate that a certain portion of riparian cropland acreage near Indiana waters (e.g., 30 ft. from the ordinary high water mark) be taken or left out of crop production. Additionally, a supplemental program should be developed that allows farmers with land falling under the mandate to enroll in a program, similar to CRP, that pays farmers rent for planting portions of the mandated acreage in punctuated switchgrass strips. A state department or organization such as ISDA should establish program specifications best able to preserve stream bank integrity, protect riparian biodiversity, allow wildlife access to water supplies, and promote the growth and harvesting of cellulosic feedstocks in Indiana.

10.5.5 E10 Retailer Tax Credit of $0.02 per Gallon Against the State Gross Retail Tax

Rationale Behind Proposal

E10 should be encouraged in Indiana because it is a blended fuel that all vehicles can use, in contrast to E85. E10 can be sold at the retail level without retrofitting or installing new infrastructure. E10 only requires that fuel storage tanks be cleaned, and this can be done at minimal cost. The current producer incentive for E85 is a credit of $0.18 per gallon against the State Gross Retail Tax [29].

Proposal
This proposal seeks to increase the amount of E10 sold within the state of Indiana. By providing retailers a credit against the state gross retail tax, retailers will be encouraged to clean tanks and increase the availability of E10.

This incentive is favorable to an E10 *mandate* because it gives retailers flexibility. Retail mandates implemented in Hawaii, Minnesota, Missouri, Montana, and Oregon offer limited exemptions for retailers and unreasonably force the market towards E10. By offering E10 incentives, retailers may choose on an individual basis whether or not it is economically efficient to offer E10.

ISDA estimates that the state will produce more than one billion gallons of ethanol after construction of the six new plants is complete. This is more than enough ethanol for the entire state of Indiana to offer E10, and still retain export capability.

10.6 Creating an Atmosphere in Support of Biofuels

Successful policy entrepreneurs realize that “windows of opportunity” play an important role in determining which policy issues become a priority for the public (first) and lawmakers (in response to public demand). Public, private, and nonprofit parties with a vested interest in Indiana biofuels proliferation therefore face two options: 1) wait for a window of opportunity to present itself, or 2) take an active role in *creating* the window of opportunity. Since it is impossible to predict the former, stakeholders should take action and persuade the public that biofuels proliferation is a top priority for the state. Creating a favorable political landscape for biofuels proliferation is a multi-stage process. To realize maximum success, the Governor’s Office should wholeheartedly adopt the following coalition building and marketing plan that promotes biofuels proliferation as one of the most important statewide issues by 2009.

10.6.1 Building a Reputable Coalition

There are currently dozens of public, private, and non-profit organizations within Indiana that have a vested interest in the proliferation of biofuels. With the exception of the Biofuels Indiana Initiative (a six-organization coalition with little influence), there have been no significant attempts to build a public-private biofuels coalition that would be able to effectively disseminate information to consumers, lawmakers, farmers, and producers. Therefore, the Governor’s Office should initiate the formation of the Hoosier Homegrown Energy Coalition.

The Hoosier Homegrown Energy Coalition will serve as the organization that disseminates a unified message regarding the proliferation of biofuels. The Coalition will be a public-private partnership that unites Indiana’s stakeholders in order to create a successful biofuels industry with supportive consumers, lawmakers, farmers, and producers. The Coalition will be responsible for the creation and implementation of a six-month marketing campaign (to be discussed in greater detail in Appendix F that will provide the support needed for Indiana biofuels proliferation in the immediate future.

It is important that the Coalition be comprised of individuals from government, private industry, non-profit organizations, and academia. The goal of the Coalition is to bring together ideas from a variety of stakeholders to ensure that Indiana biofuels have a successful future. Ideally, the Coalition will be limited to 20 member organizations to facilitate effective communication of all members' ideas and goals. Potential members should include representatives from the following organizations:

- Indiana Office of Energy and Defense Development
- Indiana Department of Agriculture
- Indiana Department of Natural Resources
- Indiana Department of Environmental Management
- Indiana Governor's Office
- Indiana Chamber of Commerce
- South Shore Clean Cities Coalition
- Central Indiana Clean Cities Organization
- Richard G. Lugar Center for Renewable Energy
- Purdue University Department of Agricultural Economics
- Indiana University School of Public and Environmental Affairs
- Agribusiness Council of Indiana
- Indiana Corn Growers Association
- Indiana Soy Bean Alliance

In addition to the above stakeholders, there should be one or two representatives from the Indiana automobile manufacturing industry (i.e. General Motors and/or Toyota) to address FFV issues and other automobile technologies related to biofuels. Finally, a representative of an Indiana biofuels plant and a representative from a farmer cooperative are essential if the Coalition hopes to achieve maximum effectiveness.

The Coalition will meet quarterly to discuss biofuels proliferation issues within the state. However, it may be necessary to meet monthly immediately following the Coalition's formation in order to jumpstart the six-month marketing campaign. The Coalition's first order of business should be the acquisition of a marketing consultant to serve as the moderator during meetings and (more importantly) as the overseer of the Coalition's marketing campaign. The Marketing Consultant's office will serve as the central meeting location for the Coalition and will ideally be located in Indianapolis or the surrounding area. One individual from each of the representative organizations will be required to attend all Coalition meetings. Each representative will serve as the liaison between his/her organization and the Coalition, and each individual will ideally serve at least a one-year term with the Coalition so as to maintain consistency.

A total of three committees will manage each of the three audience-specific marketing messages focused on consumers, lawmakers, and farmers/producers. These committees will each meet one time between each Coalition quarterly meeting and will ensure the delivery of each audience-specific message. The combined efforts of the committees and the overall Coalition will ensure a unified message for the biofuels proliferation movement.

The Hoosier Homegrown Energy Coalition represents the first step in a process that will ultimately achieve Governor Daniels' goal of transforming Indiana into "the nation's biofuels capital [45]." The Coalition will provide the oversight and leadership needed to ensure that Indiana bolsters its economy and job creation efforts through the proliferation of the biofuels industry.

10.6.2 Making Biofuels Proliferation a Public Priority

Alternative energy issues are increasingly important to the public, but it is still unknown if or when they will trump other public policy issues (such as property, sales, or income taxes) as a top priority. Biofuels stakeholders clearly recognize this reality as most of the organizations contained within the proposed Coalition have attempted to promote the importance of biofuels to consumers using one or more communications mediums. However, these well-intentioned (but disaggregate) attempts often projected a vague and conflicting biofuels agenda to the public. The successful formation of the Coalition is an important first step in adding credibility and coherence to the biofuels proliferation movement, but the six-month biofuels marketing campaign (Appendix F) will ultimately ensure citizen and lawmaker interest in passing innovative biofuels legislation during the 2009 legislative session.

The six-month marketing campaign provides the Coalition with a plan that, if fully implemented, will generate maximum success for the biofuels movement. However, budgetary realities will likely be a relevant consideration for organizations within the Coalition—particularly public entities. The marketing consultant overseeing the entire campaign must prioritize so as to create the most cost-efficient and effective marketing plan possible.

Regardless of cost constraints, the Coalition should adhere to the six-month marketing timeframe that begins in mid-October (when bills are first eligible for filing by state legislators) and ends in mid-March (the conclusion of the legislative session). Concentrated advertising in the early stages of the marketing campaign will ensure public and government biofuels interest when bills are written. The Coalition will then continue to build support for the passage of biofuels bills after they have been submitted (although public attention will automatically increase once the bill is introduced on the General Assembly floor). A culminating rally at the Capitol that includes all supporters of biofuels legislation will emphatically demonstrate to lawmakers that there is a high electoral demand for passage of biofuels legislation.

10.6.3 The Messages behind the Marketing Campaign

Different parties respond to messages in different ways, and the Hoosier Homegrown Energy Coalition should therefore utilize carefully tailored messages when disseminating biofuels information to particular audiences. An overall message will also appear on all Coalition publications to ensure that the organization remains cohesive and readily identifiable to all Hoosiers. The following is a breakdown of the specific messages that will be repeated throughout the marketing campaign:

- Hoosiers Homegrown Energy Coalition
    - Organizational Message (always appears under the Coalition's name)
        - "Fueling Indiana's Future."

- Audience-specific Messages (message choice depends upon the intended audience)
  - Consumer-specific
    - "Home is where the fuel is. Indiana Biofuels: Good for your family. Good for your finances. Good for your future."
  - Lawmaker-specific
    - "An opportunity to stand out. Indiana Biofuels: Leading the US into an age of energy security and economic prosperity."
  - Farmer/Producer-specific
    - "Investing in America's energy future. Indiana Biofuels: Promoting smart business practices through the advancement of renewable energy resources."

Note: To better understand how specific messages are utilized within the six-month marketing campaign, consult the "Biofuels Marketing Campaign" located in Appendix F

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Appendix A: Feedstock Agriculture

Region	Name of Natural Region	Description
1	Lake Michigan	Entirely aquatic, Indiana's portion of Lake Michigan
2	Northwestern Morainal	Previously Glaciated Area formed by Wisconsinan Ice sheet. Knob and kettle to rolling hills topography. Poor agricultural lands with well drained calcareous. Home to the eastern deciduous forest, tallgrass prairie, northern forest and wetlands.
3	Grand Prairie	Glaciated plain of unconsolidated deposits of sediments including sands, lacustrine sediments, outwash plain sediments and till from the WisconsinanGlaciation. Soils are within silty clay loam variations. Historically the dominate ecosystem in this area was tallgrass prairie.
4	Northern Lakes	Glaciated by Wisconsinan ice sheet this region is identified by numerous freshwater glacial lakes. The area is covered with thick and complex deposit of glacial materials. Soils range from loamy to neutral clayey to sandy loams. The natural communities include bogs, fens, marshes, prairies, sedge marshes, swamps and deciduous forests.
5	Central Till Plain	Largest natural region in Indiana. Formally forested plain of Wisconsinan till in central Indiana. Forms major divide between communities with strong northern affinities and communities with strong southern affinities. Characterized by three sections: Entrenched Valley Section, Tipton Till Section and Bluffton Till Plain. Soils range from thick loess to loamy to clayey respectively. Predominant ecosystem was mixed forest communities.
6	Black Swamp	Western part of large lacustrine plain that was once covered by ancient glacial melt water lake. Naturally poorly drained deep clay and silt loam soils. This ecosystem used to be dominated by swamp forest but is largely non-existent today due to extensive drainage for agriculture expansion.
7	Southwestern Lowlands	Most of this region was glaciated by the Illinoian ice sheet. It is characterized by low relief and aggraded valleys. Area is nearly level, undissected with poorly drained soils. Mostly forests with some barren areas and prairie where the ice sheets did not cover.

8	Southern Bottomlands	Half of this region was once glaciated; however this had little effect on these low-lying bottomlands along rivers and larger streams in southern Indiana. Soils are mostly silt loams and dominant ecosystems previously included swamp, pond, slough, marsh and prairie. Much of this has been converted to agriculture lands.
9	Shawnee Hills	Not glaciated, this area is the only contiguous belt of rugged hills. Sandstone forms distinct cliffs. Consists of well drained silt loam soils. The dominant plant community is upland forest with patches of limestone glades and barrens.
10	Highland Rim	Unglaciated except for relatively unmodified glaciated areas along edges. Karst topography with well drained silty loams derived from loess and weathered limestone. Dominant natural communities pre-settlement were forest, glades and barrens.
11	Bluegrass	Similar to the Kentucky bluegrass region. This entire region was covered by pre-Wisconsinan ice sheets. The northern boundary is where the southern edge of the Wisconsinan ice sheet ended. This area, while glaciated, only has a thin layer of till with bedrock outcroppings. Soils are silt loams. This region was originally forested.

Source: [1]

Appendix B: Feedstock Agriculture

Although some reports have suggested Miscanthus may not be viable in Indiana's climate, a project at the University of Illinois in Champaign Urbana (UIUC) has demonstrated markedly positive results under similar conditions. As a C4 photosynthesizing species, Miscanthus is a superiorly efficient convertor of sunlight to biomass, and rare for temperate climates [2]. UIUC'sMiscanthus plots have yielded up to three times more biomass than Switchgrass, in several different parts of the state. Despite initial concerns that Midwestern climates might suffer temperatures cold enough to kill Miscanthus crops over winter, UIUC's crops have survived temperatures as low as -10 ^{o}F without loss [3]. Remaining concerns could hinge on the necessity of cellulosic ethanol production to derive fuel from Miscanthus, and its current lack of production plants in Indiana.

Many objections to industrial production of Miscanthus can stem from the difficulty of its propagation. The most suitable species for biofuel purposes, Giant Miscanthus, is a hybrid of two distinct species of Miscanthus (*M. sinensis* and *M. sacchariflorus*) and is sterile, incapable of normal reproduction. Although this alleviates concerns of invasive species potential, it does complicate wide-spread adoption of the crop. Currently, the optimal planting process is to divide rhizomes (underground storage organs) and individually plant them. It is theoretically possible to replicate Miscanthus via tissue culture and rooted cuttings from adult plants, but these methods have a high failure rate in the field environment [3]. At the time of writing, there are no commercial means of planting Miscanthus rhizomes; they must be manually inserted individually. Europeans have had some success with modifying existing farm equipment for mechanized planting, but the resources do not currently exist in the United States. However, the potential of Miscanthus may justify American research and development of such equipment. Miscanthus can be harvested with conventional forage/herbage harvesters [2]. After initial planting, the established plants will naturally spread out underground and form dense coverage. With the exception of replacing any rhizomes that fail following the initial planting, Miscanthus does not require periodic replanting, and adult plants can serve as a source of rhizomes for establishing future crops [3].

Once Miscanthus is planted, it might require irrigation during dry periods, as there is a correlation between water availability and crop yield. However, UIUC's research indicates typical Illinois summer conditions are sufficiently moist to produce high yields, suggesting that native Indiana conditions should likewise suffice. UIUC's research indicates maximum yields can be expected within three years of initial planting, but could be delayed by an additional two to three years in inferior soil. Miscanthus is capable of fixing its own Nitrogen; UIUC's research shows no significant yield increase from application of Nitrogen fertilizer, which reduces potential economic and ecological costs. However, European practice is to apply Nitrogen, Phosphorous and Potassium following the second year of establishment (40-100kg ha^{-1} of N and K, 10-20 kg ha^{-1} of P, depending on yield and soil conditions [2].
Although the freshly planted Miscanthus may require herbicidal weed treatment in its first year, it is sufficiently established by the second year to suppress weeds without assistance. The Nitrogen fixation and nutrient reclamation services provided by Miscanthus yield additional

ecological and economic benefits in soil replenishment.Miscanthus also requires minimal efforts before its land can be converted back to conventional crops, as opposed to trees and short rotation woody crops [2].

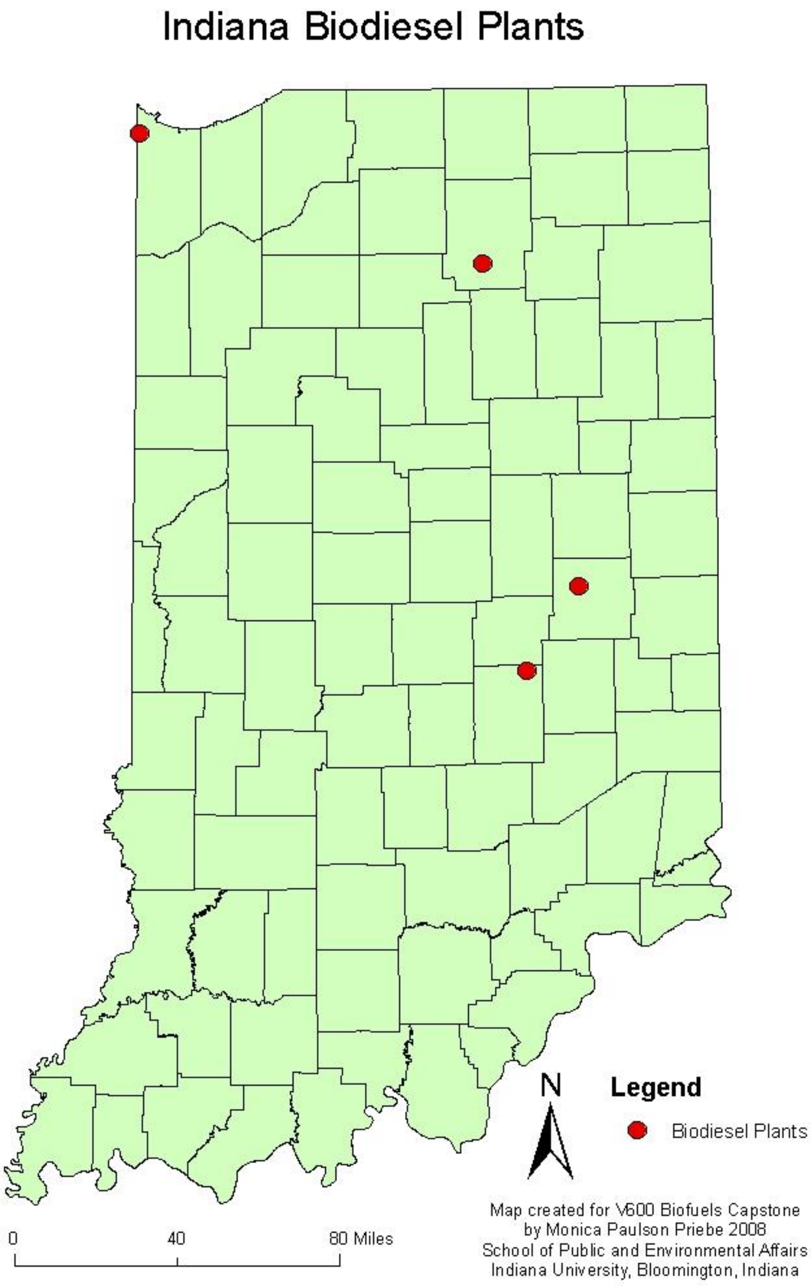
UIUC's project found it preferable to plant approximately 4,850 rhizomes per acre in the first year, although it is to be expected that some rhizomes fail and require replanting in the second or third years. Once established, Miscanthus is harvested in the beginning of winter, when the plants have withdrawn minerals and moisture to their root systems. This not only prepares them for the coming spring, it minimizes impurities in the processing and combustion of fuel. As an additional benefit, harvesting later in the year obviates the need for costly heating and drying of the material, positively affecting Miscanthus' net energy balance. The majority of the fuel potential comes from the stems of the grass, which can reach twelve feet of height in one growing season.

UIUC's unfertilized plots yielded biomass averages of 9.8 tons per acre in Northern Illinois, 15.5 tons per acre in Central Illinois and 15.8 tons per acre in Southern Illinois (averaged over a three year period from 2004-2006). By way of comparison, UIUC's data for unfertilized Switchgrass planted in 2002 shows 2.2 tons per acre in Northern Illinois, 5.2 tons per acre in Central Illinois, and 2.7 tons per acre in Southern Illinois (Table 1) [3]. According to information from UIUC, Miscanthus vastly outperforms corn, yielding 168% of corn's biomass per hectare. With an annual yield of 2,960 gallons of ethanol per hectare, Miscanthus would require only 9.3% of America's harvested cropland in order to provide an annual quantity of 35 billion gallons of ethanol. To achieve that quantity of ethanol, corn would require 14.8% of harvested cropland [4].

Table 1: All Numerical values represent tons of biomass produced per acre in a single growing season.

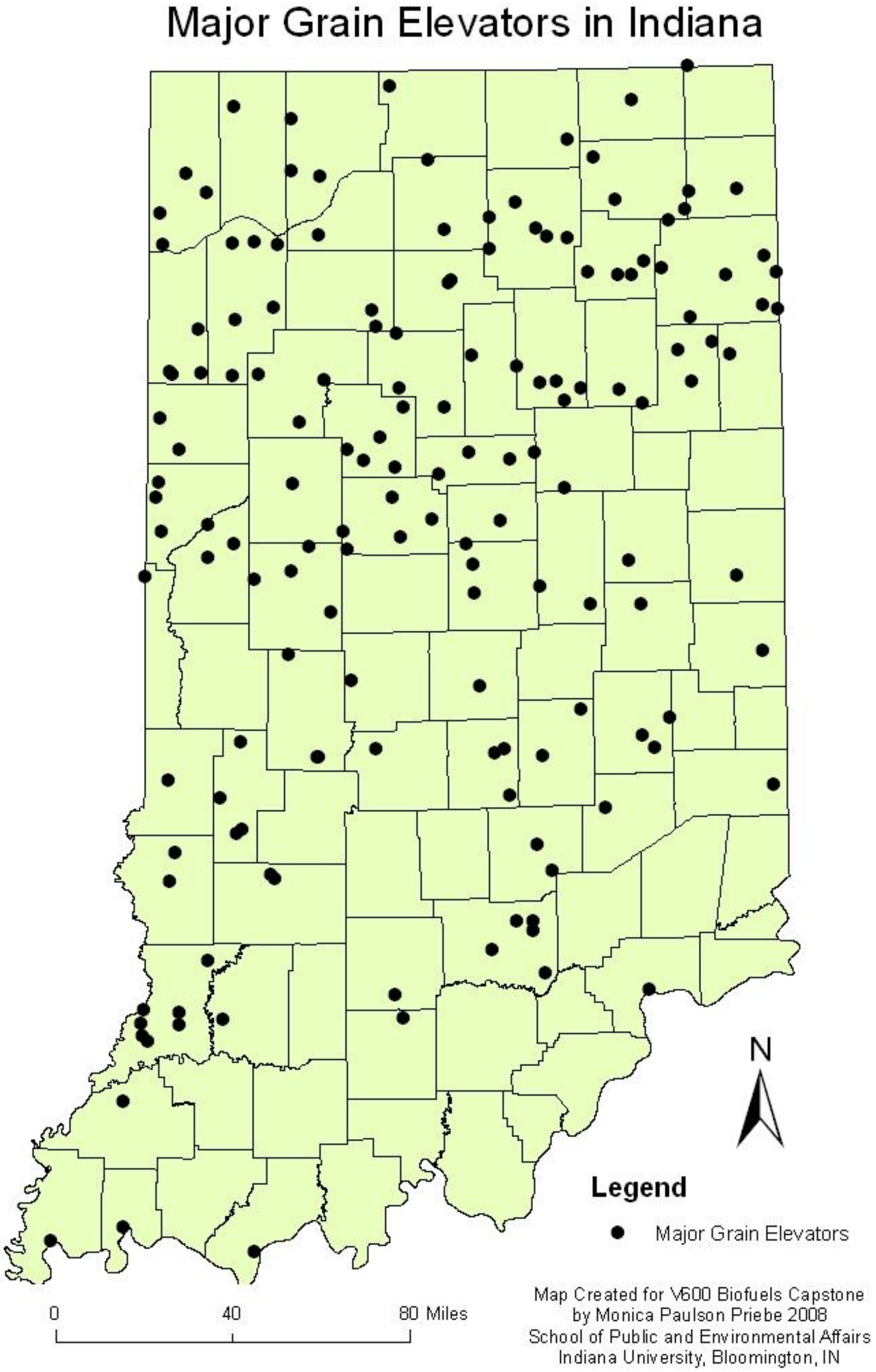
Region	Miscanthus	Switchgrass
Northern Illinois	9.8	2.2
Central Illinois	15.5	5.2
Southern Illinois	15.8	2.7

Appendix C: Additional site suitability considerations


Indiana Biodiesel Plants

Map created for V600 Biofuels Capstone
by Monica Paulson Priebe 2008
School of Public and Environmental Affairs
Indiana University, Bloomington, Indiana

Source: [5, 6, 7]


Major Grain Elevators in Indiana
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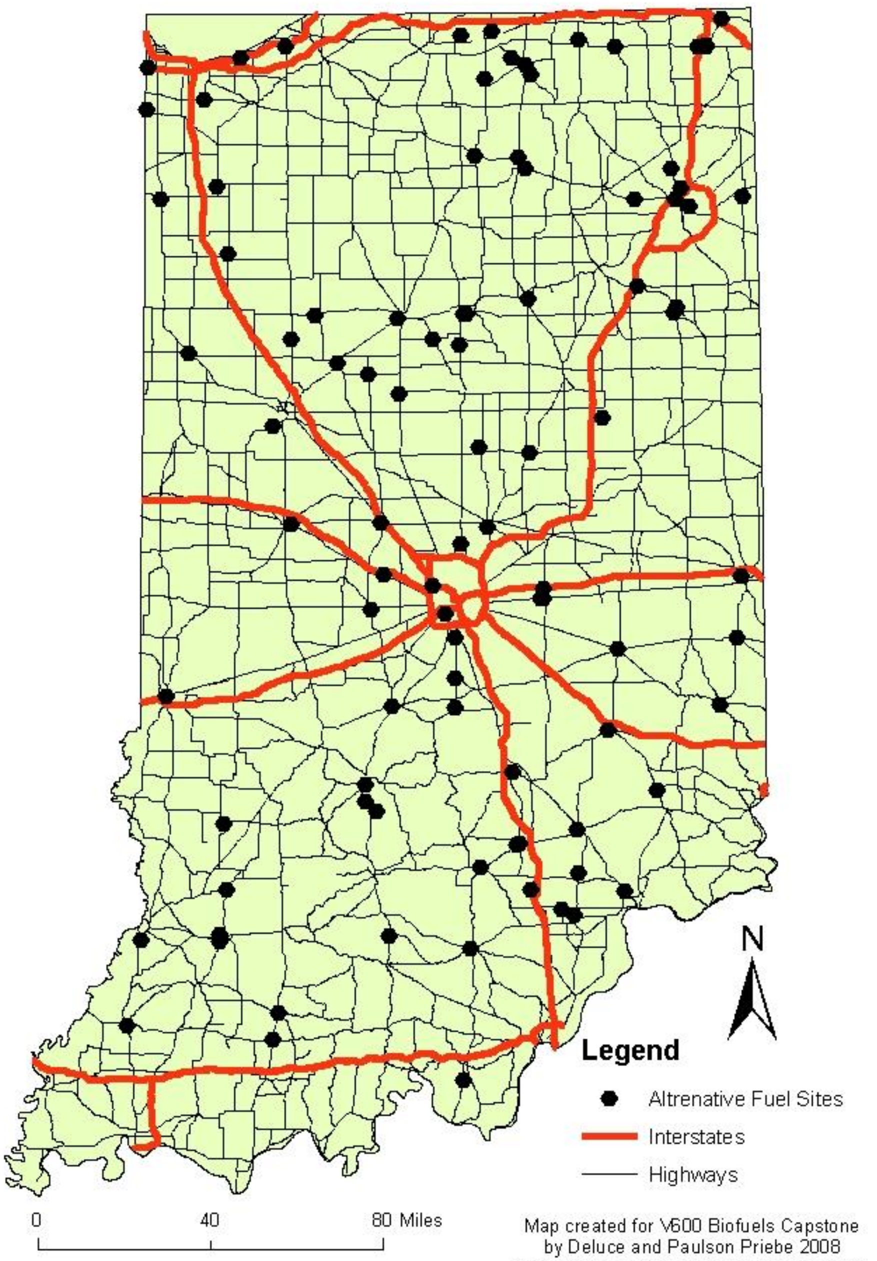
Map Created for V600 Biofuels Capstone
by Monica Paulson Priebe 2008
School of Public and Environmental Affairs
Indiana University, Bloomington, IN

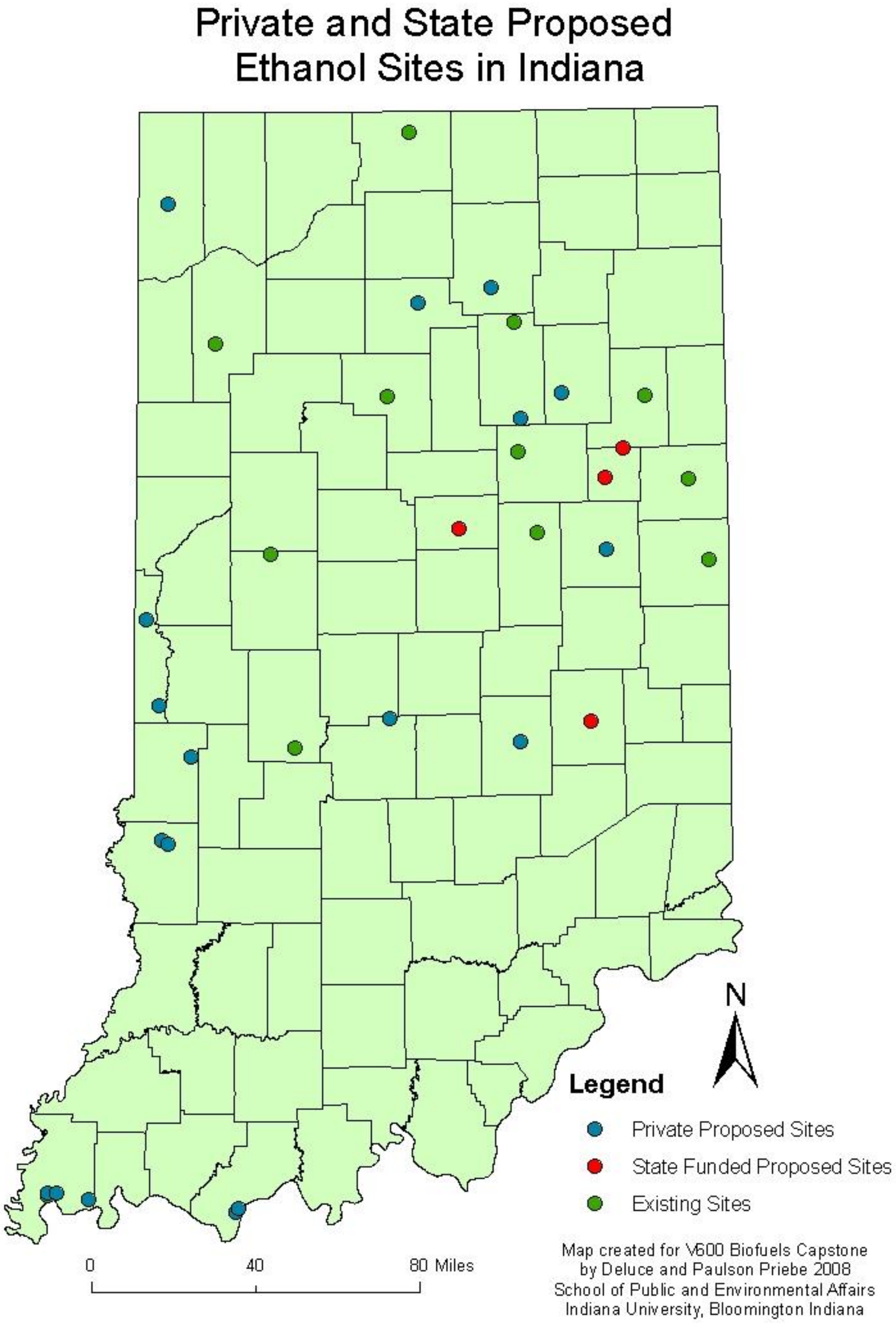
Source: [6, 7, 8]



Alternative Fuel Site in Indiana

Map created for V600 Biofuels Capstone
by Deluce and Paulson Priebe 2008
School of Public and Environmental Affiars
Indiana University, Bloomington Indiana

Source: [7, 9, 10]



Source: [5, 7, 11, 6]

Appendix D: Energy Balance Appendix

Table 1. Energy Balance Studies for Corn Ethanol (adjusted LHVs for all studies).

Year	Author	Corn Yield (bu/acre)+	Corn ethanol conversion rate (gal/bu)	Ethanol conversion process (Btu/gal)	Total Energy use (Btu/gal)	Coproducts energy credits (Btu/gal)	Calc. NEV (Btu/gal)	Calc. EB
1989	Ho [12]	90	NR	57000	90000	10000	-4300	0.95
1990	Marland and Turhollow [13]	119	2.50	50105	73934	8127	9893	1.13
1991	Pimentel [14]	110	2.50	73687	131017	21500	-33817	0.74
1992	Morris and Ahmed (Industry Avg)[15]	120	2.56	49380	75811	24950	24839	1.33
1992	Morris and Ahmed (Industry Best)[15]	120	2.56	36232	57979	32693	50414	1.87
1992	Keeney and DeLuca [16]	119	2.56	48470	91196	8078	-7418	0.92
1995	Lorenz and Morris [17]	120	2.55	53956	81909	27579	21370	1.26
1995	Shapouri et al. [18]	122	2.53	53277	82824	15056	7932	1.10
1999	Wang et al. [19]	125	2.55	40850	68450	14950	22200	1.32
1999	Argi. And Agri-Food Canada [20]	116	2.69	50415	68450	14055	21305	1.31
2001	Pimentel [21]	127	2.50	75118	131062	21500	-33862	0.74
2001	Wang [22]	125	2.58	39067	66564	14333	23469	1.35
2002	Shapouri et al. [23]	125	2.66	51779	77228	14372	12844	1.17
2002	Graboski (baseline 2000) [24]	140	2.65	55049	77497	14829	13032	1.17
2002	Graboski (2002 new plants) [24]	140	2.73	47937	70551	12880	18029	1.26
2002	Graboski (2002 industry) [24]	140	2.68	52513	75020	14134	14814	1.20
2002	Graboski (2012 projection) [24]	154	2.80	45768	64479	10062	21283	1.33
2003	Pimentel [25]	137	2.60	54171	99119	0	-23419	0.76
2004	Shapouri et al. [26]	139	2.66	49733	72052	26250	29898	1.41
2008	**v600 Calculations - INDIANA**	**155.7**	**2.68**	**50002**	**82642**	**14372**	**7430**	**1.09**

** Original citations from Graboski 2002,Shapouri et al. 2002, or original authors; total energy use confirmed in primary sources*

+ Note that all yields are standard yields except for this study which uses a planted yield calculation.

Indiana Energy Balance Analysis for Corn-Based Ethanol Production

The Indiana-specific energy balance estimates use the four phrase process outlined in the text: farming, feedstock transportation, fuel conversion, and fuel transportation. Energy estimates were created for each phase to the best degree possible, many of which rely on data from Shapouri et al. (2002) as discussed below [23].

The time frame for this analysis is 2004 to 2006 for which corn production and acreage data was obtained from the USDA (NASS 2008) [27]. Statewide standard average yields of corn based on harvested acreage amounted to 159.6 bushels per acre. The average yield based on the total planted acreage from 2004 to 2006 was slightly lower at 155.7 bushels per acre.

Phase I: Farming

Farm inputs include all processes outlined by Shapouri et al. (2002) with updates where possible from USDA Farm Census data (see Table 2 below) [23, 27].

Table 2. Farm Inputs for Indiana Corn Production

Input	Unit	IN	Source
Seed	Kernels/acre	28,281	Shapouri 2004est
Fertilizer:			
.Nitrogen	Pounds/acre	147	USDA 2008
.Potash	Pounds/acre	124	USDA 2008
.Phosphate	Pounds/acre	77	USDA 2008
.Lime	Pounds/acre	20	Shapouri 2002 est
Energy:			
.Diesel	Gallons/acre	4.6	Shapouri 2002 est
.Gasoline	Gallons/acre	2.1	Shapouri 2002 est
.LPG	Gallons/acre	3.2	Shapouri 2002 est
.Electricity	kWh/acre	28.3	Shapouri 2002 est
.Natural Gas	Cubic ft/acre	144.2	Shapouri 2002 est
Custom Work	Dol./acre	7.8	Shapouri 2002 est
Chemicals	Dol./acre	3.19	Shapouri 2002 est
Custom Drying	Dol./acre	2	Shapouri 2002 est

These estimates are then converted to a Btu per bushel of corn estimate using the following formula:

$$E_I = \frac{I * E_r}{Y}$$

$$E_I = TotalInputEnergy \left(\frac{Btu}{bu}\right)$$

$$I = InputTotal\ (variousunits)$$

$$\beta = HeatFactor\ (Shapourietal. 2002)$$

$$Y = PlantedYield$$

The above equation yields results as presented in Table 3.

Table 3. Farm Inputs for Indiana Corn Production (Btu/bu)

Input	**β**	**Est. E_I Btu/bu**
Seed	.841	718
.Nitrogen	24500	23,133
.Potash	4000	3,186
.Phosphate	4175	2,065
.Lime	620	80
.Diesel	137202	4,054
.Gasoline	125073	1,687
.LPG	91538	1,881
.Electricity	12356	2,264
.Natural Gas	1021	946
Custom work	28500	1,428
Chemicals	150000	3,156
Total energy per bushel		**44,597**
		Btu/gall
Total energy per gallon		16,668

The total energy as Btu per Bushel is then converted to Btu per gallon of ethanol using a weighted conversion factor of 2.68 calculated from Hurt (2007) [28].

Phase II: Corn Transportation

The transportation of corn energy estimates assume corn is transported from the farm to either a storage facility or a plant at an average of 25 miles OR taken directly to a plant at an average of 75 miles. These estimates dismiss the use of trains to transport corn to ethanol facilities since active ethanol plants in Indiana are sited in areas with high production of corn. Using truck size estimates from Lee (2007) and Benson and Bullen (2007) and fuel efficiency estimates from Fuel

Charger (2008), average energy per gallon of ethanol was calculated (see Tables 4 and 5) [29, 30, 31].

Note that corn transport estimates used in this analysis are 1,000 Btu/gall less than provided in Shapouri et al. (2002), a likely source of error in the estimation techniques incorporated into this study [23].

Table 4. Corn Transportation to Granaries

PART I		
Average distance to plant	25	miles
Average truck haul	547	bushels
Est. MPG	5	mi/gall fuel
Total needed bushels per year	163000000	Bu/yr
Total truck loads	297989	loads/yr
Total truck load miles	7449725.777	miles/yr
Total gallons of fuel	1489945.2	gall/yr
Energy per gallon of diesel fuel	139000	Btu/gall
Total energy for transport	207,102,376,600	Btu TOTAL
Average energy per bushel	1270.566728	Btu/bu of corn
Average energy per gallon Etoh	**474.9**	**Btu/gall Etoh**

Table 5. Corn Transportation to Refineries

PART II		
Average distance to plant	75	miles
Average truck haul	875	bushels
Est. MPG	5.5	mi/gall fuel
Total needed bushels per year	163000000	bu/yr
Total truck loads	186285.7	loads/yr
Total Truck load miles	13971428.6	miles/yr
Total gallons of fuel	2540259.7	gall/yr
Energy per gallon of diesel fuel	139000	Btu/gall
Total energy for transport	353,096,103,896	Btu TOTAL
Average energy per bushel	2166.2	Btu/bu of corn
Average energy Per gallon Etoh	**809.64**	**Btu/gall Etoh**

Table 6. Total of Corn Transportation to Granaries and Refineries

Total		
Total average energy per gallon	**1284.52**	**Btu/gall Etoh**

Phase III: Production

Estimates for production originate from a survey conducted by the USDA and reprinted in Graboski 2002 [24]. Unlike the estimates provided in Shapouri et al. (2002), only dry mill facilities are included in this analysis (see Table 7) [23]. The available results included one plant, presumably a smaller facility, with reported low thermal and electrical use. This plant was dropped from the facility average shifting the average thermal energy use from 37,410 Btu per gal to 38,804 Btu per gal and electrical use from 1.11 kwh per gal to 1.10 kwh per gal. Electrical use was converted by its HHV (8,625 Btu per kwh) and added to thermal energy's HHV for an estimated production energy use of 50,001 Btu per gal of ethanol produced. Except for removal of the low producing plant in the analysis, this is precisely the method utilized by Graboski (2002) [24].

Note that reliance on the survey may provide poor estimates of production energy. The survey was originally conducted in 2001 and does not include newer production facilities, as are most of the facilities in Indiana. However, the potential for overestimation is partially offset by potential survey error from respondents who may have underreported total energy use in the initial survey.

Table 7. Dry Mill Energy Requirements

	Graboski 2002 [24]	This study
Averagethermal energy use (Btu/gal)	39,031	40,485
Averageelectrical use (Kwh/gal)	1.11	1.10
Total estimated energy (Btu/gal)	48,539	50,002

Phase IV: Ethanol Transportation

Similar to corn transportation, energy use per gallon of ethanol transported was calculated (see Table 8). An average trucked distance of 100 miles was assumed for transportation of ethanol to retail distribution sites using the fuel efficiency and loading estimates from Phase II-Part 2.

Table 8. Ethanol Transportation to Distribution Sites

Distance	100	miles
Haul	8000	gallons
Total EtOH	457,000,000	gall/yr
Truck loads	57,125	loads
Truck miles	5,712,500	mi
Total diesel fuel	1,038,636	gall/yr
Energy PG	139,000	Btu/gall fuel
Average energy per gallon Etoh	**315.9**	**Btu/gallon Etoh**

Total Energy

Estimates from previous tables are summarized in Table 7. Also included are co-product energy credits extracted directly from Shapouri et al. (2002) [23]. No attempt to re-estimate co-products was made for this analysis; however, this estimate does fall within a mid-range of credits applied in previous studies (see Table 1).

Table 10summarizes the key values integrated into the energy balance equation for Indiana.

Table 9. Energy Requirements for Corn-Based Ethanol Production in Indiana (Btu/gal)

Phase	**Btu/gal**	**Source**
I. Corn production	16,668.3	Table 3
II. Corn transport	1,284.52	Table 4
III. Ethanol conversion	50,001.7	BBI International Survey (2001) of Ethanol Plants from appendix of Graboski 2002 [24]
IV. Ethanol transport	315.9	Table 6
Co-products	14,372.0	Shapouri et al 2002 [23]
TOTAL	**82,642.4**	

Table 10. Key Values for Indiana NEV

Planted corn yield (bu/acre)	155.6889
Corn ethanol conversion rate (gal/bu)	2.675562
Ethanol conversion process (Btu/gal)	50001.66
Total energy use (Btu/gal)	82642.38
Adjusted NEV (Btu/gal)	7429.618
Adjusted EB	1.089901

Appendix E: Technical Appendix for Cost-Benefit Analysis

<u>Methodology</u>

As mentioned in the Analysis of Costs and Benefits of Biofuels section, the accounting domain for this analysis is the state of Indiana. Only those impacts that occur within the state of Indiana have been included. The baseline for this analysis is a “no biofuels” alternative, a world where biofuels are not being produced or consumed in Indiana. Only those values that are a direct result of biofuel production and consumption in Indiana and its consequences have been included in the analysis.

The time frame for the analysis is from 2008-2030 for ethanol and biodiesel and 2012-2030 for cellulosic ethanol.

Transfer, cost, and benefit values were calculated on a variable basis, taking the per unit value and adjusting for inflation based on the Consumer Price Index – All Urban Consumers (United States Department of Labor [32]. All values have been adjusted for inflation by converting to January 2008 Dollars.

Adjusting for Inflation

To adjust for inflation, it is necessary to take the current January 2008 CPI index value and divide it by the prevailing index value when the value was produced.

For example, to convert 2007 Dollars to January 2008 Dollars:

Inflation adjustment factor = (January 2008 CPI / 2007 annual average CPI)
Inflation adjustment factor = (211.080/207.342)

The values were then multiplied by chosen discount factors to adjust for the time-cost of money.

Discounting

The discount rates used in this analysis are three percent, five percent, and seven percent. The discount factors were calculated using the following equation:

Discount factor = 1/ (1 + discount rate) ^ year

For example, to calculate the discount factor for a five percent discount rate:

Discount factor = 1/ (1.05) ^ year

The final values were then multiplied by the appropriate dollar amounts and summed over all years to find the total inflation adjusted, discounted value.

Table 1.<u>**Demand Schedules for the United States and Indiana**</u>

GAO Gasoline Projections for United States Consumption

Year	Barrels	Gallons
2004	4,800,000,000	201,600,000,000
2030	6,800,000,000	285,600,000,000

Gasoline Consumption

Year	Consumption in United States	Consumption in Indiana	Percentage
2004	201,600,000,000	3,059,000,000	1.52%
2005	204,830,769,231	3,113,427,692	1.52%
2006	208,061,538,462	3,162,535,385	1.52%
2007	211,292,307,693	3,211,643,077	1.52%
2008	214,523,076,924	3,260,750,769	1.52%
2009	217,753,846,155	3,309,858,462	1.52%
2010	220,984,615,386	3,358,966,154	1.52%
2011	224,215,384,617	3,408,073,846	1.52%
2012	227,446,153,848	3,457,181,538	1.52%
2013	230,676,923,079	3,506,289,231	1.52%
2014	233,907,692,310	3,555,396,923	1.52%
2015	237,138,461,541	3,604,504,615	1.52%
2016	240,369,230,772	3,653,612,308	1.52%
2017	243,600,000,003	3,702,720,000	1.52%
2018	246,830,769,234	3,751,827,692	1.52%
2019	250,061,538,465	3,800,935,385	1.52%
2020	253,292,307,696	3,850,043,077	1.52%
2021	256,523,076,927	3,899,150,769	1.52%
2022	259,753,846,158	3,948,258,462	1.52%
2023	262,984,615,389	3,997,366,154	1.52%
2024	266,215,384,620	4,046,473,846	1.52%
2025	269,446,153,851	4,095,581,539	1.52%
2026	272,676,923,082	4,144,689,231	1.52%
2027	275,907,692,313	4,193,796,923	1.52%
2028	279,138,461,544	4,242,904,615	1.52%
2029	282,369,230,775	4,292,012,308	1.52%
2030	285,600,000,000	4,341,120,000	1.52%

Gasoline consumption in the United States was based on Government Accountability Office (GAO) projections [33]. One barrel is equal to 42 gallons and so these estimates were converted from barrels to gallons by multiplying by 42.

U.S. gasoline consumption 2004 = 4,800,000,000 barrels * 42 gallons = 201,600,000,000 gallons

U.S. gasoline consumption 2030 = 6,800,000,000 barrels * 42 gallons = 285,600,000,000 gallons

United States gasoline consumption was assumed to grow linearly between projection years.

Total Gasoline consumption in Indiana was 3,059,000,000 gallons in 2004 [34].

In order to project future Indiana gasoline consumption, it was necessary to find Indiana's percentage of national gasoline consumption.

Indiana gasoline consumption in 2004 / U.S. gasoline consumption in 2004:
3,059,000,000 / 201,600,000,000 = 1.52%

It was assumed that Indiana's future gasoline consumption would be stable as a percentage of total gasoline consumption and has been projected by multiplying the forecasted United States consumption by 0.0152.

Table 2. Corn Ethanol Consumption

Year	Consumption in Indiana	Production in Indiana	Bushels Needed to Produce
2008	157,820,337	1,060,000,000	392,592,593
2009	160,197,150	1,060,000,000	392,592,593
2010	162,573,962	1,060,000,000	392,592,593
2011	164,950,774	1,060,000,000	392,592,593
2012	167,327,586	1,060,000,000	392,592,593
2013	169,704,399	1,418,000,000	525,185,185
2014	172,081,211	1,418,000,000	525,185,185
2015	174,458,023	1,418,000,000	525,185,185
2016	176,834,836	1,418,000,000	525,185,185
2017	179,211,648	1,418,000,000	525,185,185
2018	181,588,460	1,418,000,000	525,185,185
2019	183,965,273	1,418,000,000	525,185,185
2020	186,342,085	1,418,000,000	525,185,185
2021	188,718,897	1,418,000,000	525,185,185
2022	191,095,710	1,418,000,000	525,185,185
2023	193,472,522	1,418,000,000	525,185,185
2024	195,849,334	1,418,000,000	525,185,185
2025	198,226,146	1,418,000,000	525,185,185
2026	200,602,959	1,418,000,000	525,185,185
2027	202,979,771	1,418,000,000	525,185,185
2028	205,356,583	1,418,000,000	525,185,185
2029	207,733,396	1,418,000,000	525,185,185
2030	210,110,208	1,418,000,000	525,185,185

Consumption of ethanol in Indiana in 2004 was 4.84 percent of U.S. gasoline consumption in 2004 [43]. Future Indiana ethanol consumption is projected linearly at 4.84 percent of total U.S. gasoline consumption.

Corn Ethanol Production

Ethanol production in Indiana is based on ethanol production facilities currently operating and planned production facilities estimated to be in operation in 2013 [35]. The bushels needed to produce value was projected by taking the total production of ethanol within the state of Indiana and dividing by 2.7, assuming that one bushel of corn yields 2.7 gallons of ethanol.

Table 3. GAO biodiesel projections for United States consumption

Year	Gallons
2006	287,000,000
2012	308,000,000
2030	395,000,000

Table 4. Soy Biodiesel Consumption

Year	Consumption (Gallons)	Consumption in Indiana	Production in Indiana	Bushels needed to produce
2006	287,000,000	31,888,889	10,000,000	6,711,409
2007	290,500,000	32,277,778	108,000,000	72,483,221
2008	294,000,000	32,666,667	108,000,000	72,483,221
2009	297,500,000	33,055,556	108,000,000	72,483,221
2010	301,000,000	33,444,444	108,000,000	72,483,221
2011	304,500,000	33,833,333	108,000,000	72,483,221
2012	308,000,000	34,222,222	108,000,000	72,483,221
2013	312,833,333	34,759,259	108,000,000	72,483,221
2014	317,666,667	35,296,296	108,000,000	72,483,221
2015	322,500,000	35,833,333	108,000,000	72,483,221
2016	327,333,333	36,370,370	108,000,000	72,483,221
2017	332,166,667	36,907,407	108,000,000	72,483,221
2018	337,000,000	37,444,444	108,000,000	72,483,221
2019	341,833,333	37,981,481	108,000,000	72,483,221
2020	346,666,667	38,518,519	108,000,000	72,483,221
2021	351,500,000	39,055,556	108,000,000	72,483,221
2022	356,333,333	39,592,593	108,000,000	72,483,221
2023	361,166,667	40,129,630	108,000,000	72,483,221
2024	366,000,000	40,666,667	108,000,000	72,483,221
2025	370,833,333	41,203,704	108,000,000	72,483,221
2026	375,666,667	41,740,741	108,000,000	72,483,221
2027	380,500,000	42,277,778	108,000,000	72,483,221
2028	385,333,333	42,814,815	108,000,000	72,483,221
2029	390,166,667	43,351,852	108,000,000	72,483,221
2030	395,000,000	43,888,889	108,000,000	72,483,221

Biodiesel consumption in the United States is based on GAO projections [33]. It was assumed that demand would grow linearly between projection years.

Reliable estimates of biodiesel consumption in Indiana are not available. It was assumed that the majority of biodiesel consumption occurs in the Midwest close to the feedstock. As a result, biodiesel consumption in Indiana is estimated as one ninth of total biodiesel consumption in the United States.

Soy Biodiesel Production

Production in Indiana is based on production facilities currently operating [35]. The bushels needed to produce value was projected by taking the total production of biodiesel within the state of Indiana and dividing by 1.49, assuming that one bushel of soybeans yields 1.49 gallons of biodiesel.

Table 5. Cellulosic Ethanol Production

Year	Production in Indiana	Number of Plants	Tons of Corn Stover Needed to Produce
2012	50,000,000	1	833,333
2013	50,000,000	1	833,333
2014	50,000,000	1	833,333
2015	50,000,000	1	833,333
2016	100,000,000	2	1,666,667
2017	100,000,000	2	1,666,667
2018	100,000,000	2	1,666,667
2019	100,000,000	2	1,666,667
2020	200,000,000	4	3,333,333
2021	200,000,000	4	3,333,333
2022	200,000,000	4	3,333,333
2023	200,000,000	4	3,333,333
2024	300,000,000	6	5,000,000
2025	300,000,000	6	5,000,000
2026	300,000,000	6	5,000,000
2027	300,000,000	6	5,000,000
2028	500,000,000	10	8,333,333
2029	500,000,000	10	8,333,333
2030	500,000,000	10	8,333,333

Cellulosic ethanol is a developing technology and no plants are currently operating in Indiana. The first plant is assumed to become operational in 2012, with a production capacity of 50 million gallons per year. The growth in the number of plants is presented in Table 5. All plants are assumed to have a production capacity of 50 million gallons per year. The tons of corn stover needed to produce value was calculated by taking the total projected cellulosic ethanol production within the state of Indiana and dividing by 60, assuming that one ton of corn stover yields 60 gallons of ethanol [36].

Calculations

Due to the large number of calculations involved and the fact that all of the calculations follow the same format, Table 6 illustrates basic process used to produce all of the calculations. Detailed calculations are available from the authors upon request.

Table 6. Sample Template of Calculations

Savings to Consumers of Gasoline

Year	Value	Year	Discount Factor	Total Adjusted Discounted Value	Total Value
2008	$ 0.08	0	1	$ 0.08	$ 273,126,695.39
2009	$ 0.08	1	0.970873786	$ 0.08	$ 269,165,096.34
2010	$ 0.08	2	0.942595909	$ 0.08	$ 265,202,566.76
2011	$ 0.08	3	0.915141659	$ 0.08	$ 261,242,521.62
2012	$ 0.08	4	0.888487048	$ 0.07	$ 257,288,177.75
2013	$ 0.08	5	0.862608784	$ 0.07	$ 253,342,562.50
2014	$ 0.08	6	0.837484257	$ 0.07	$ 249,408,522.00
2015	$ 0.08	7	0.813091511	$ 0.07	$ 245,488,729.21
2016	$ 0.08	8	0.789409234	$ 0.07	$ 241,585,691.56
2017	$ 0.08	9	0.766416732	$ 0.06	$ 237,701,758.32
2018	$ 0.08	10	0.744093915	$ 0.06	$ 233,839,127.70
2019	$ 0.08	11	0.722421277	$ 0.06	$ 229,999,853.66
2020	$ 0.08	12	0.70137988	$ 0.06	$ 226,185,852.42
2021	$ 0.08	13	0.68095134	$ 0.06	$ 222,398,908.79
2022	$ 0.08	14	0.661117806	$ 0.06	$ 218,640,682.14
2023	$ 0.08	15	0.641861947	$ 0.05	$ 214,912,712.24
2024	$ 0.08	16	0.623166939	$ 0.05	$ 211,216,424.81
2025	$ 0.08	17	0.605016446	$ 0.05	$ 207,553,136.83
2026	$ 0.08	18	0.587394608	$ 0.05	$ 203,924,061.70
2027	$ 0.08	19	0.570286027	$ 0.05	$ 200,330,314.15
2028	$ 0.08	20	0.553675754	$ 0.05	$ 196,772,914.92
2029	$ 0.08	21	0.537549276	$ 0.05	$ 193,252,795.35
2030	$ 0.08	22	0.521892501	$ 0.04	$ 189,770,801.68
Total					$ 5,302,349,907.83

Each value is calculated using the same formula:

Sum of (value * inflation adjustment factor * discount factor * quantity) for all years

Following is the conversion process and formula for each value reported in the cost-benefit analysis:

Ethanol E10

Benefits

Savings to consumers of gasoline:

Price of gasoline in the absence of ethanol supply: $2.61 per gallon [37].

Average retail gasoline price for 2006: $2.53 per gallon [37].

Price of gasoline in the absence of ethanol supply – average retail gasoline price for 2006 = savings to consumers of gasoline

$2.61 / gallon - $2.53 / gallon = $0.08 / gallon

$0.08 / gallon * inflation adjustment factor * discount factor * number of gallons of gasoline consumed

Volumetric ethanol excise tax credit [33]:

$0.51 / gallon * inflation adjustment factor * discount factor * number of gallons of ethanol produced

Direct Federal Payment Corn Subsidy[38]:

$0.28/ bushel * inflation adjustment factor * discount factor * number of bushels used to make ethanol

Ethanol exported outside Indiana [39]:
$1.58 / gallon * inflation adjustment factor * discount factor * (number of gallons of ethanol produced in Indiana – number of gallons of ethanol consumed in Indiana)

Transfers

Sale of Fuel [39]:

$1.58 / gallon * inflation adjustment factor * discount factor * number of gallons of ethanol consumed

Sale of By-product [36]:

$0.38 / gallon * inflation adjustment factor * discount factor * number of gallons of ethanol produced

Ethanol production tax credit [40, 41]:

The tax credit is $0.125 / gallon of ethanol produced. The maximum tax credit for all years is $2,000,000 per producer for a plant producing 40 to 60 million gallons of ethanol per year and $3,000,000 per producer for a plant producing 60 million gallons of ethanol or more. The below calculation was used until each cellulosic production facility received the appropriate maximum nominal payment. These payments were adjusted into real dollars. The New Energy ethanol plant in South Bend was excluded from the calculation because it entered production well before the tax credit was initiated [35].

$2,000,000 * inflation adjustment factor * discount factor * 2 ethanol production facilities

$3,000,000 * inflation adjustment factor * discount factor * 13 production facilities

Agricultural Input (Corn) [42]:

$3.30 / bushel * inflation adjustment factor * discount factor * number of bushels needed to make the quantity of ethanol produced

Job creation [35]:

Employment is estimated at 536 jobs for all ethanol production facilities in the state of Indiana. This value was derived by taking the number of jobs estimated to be created in the state of Indiana for all biofuel production, 670, and dividing it by the 20 current and planned ethanol and biodiesel production facilities [35]. This number was then multiplied by the 16 current and planned ethanol production facilities, which yields 536 jobs [35]. The average earnings of an ethanol plant employee, with benefits, is $43,348 [43]. The wages have been adjusted for tax payments [44, 45].

Federal taxes paid are a loss to the accounting domain.

Federal income tax payment = $4,220 + 25% over $30,650 = $7,394.50 [45].

Salary – federal taxes – state of Indiana taxes = Adjusted income

$43,348 - $7,394.50 -$1,473.83 = $34,479.67

$34,479.67 / year * inflation adjustment factor * discount factor * 536 jobs

Taxes paid [44]:

The state of Indiana personal income tax is 3.4 percent.

Taxes paid = $43,348 * 0.034 = $1,473.83

$1,473.83 * discount factor * 536 jobs

Costs

Plant construction cost [36]:

The plant construction cost is variable and is based on production capacity. The cost of the plant is spread out over the useful life of the plant, which is assumed to be twenty-five years. The plant cost does not include the cost of borrowed capital, which is included in the capital cost value.

(($1.90 / gallon) / 25 years) * discount factor * production capacity

All of the values for each plant currently operating in Indiana and planned facilities are then summed to produce a total value.

Capital cost [36]:

An additional capital cost considered is the interest paid on a loan. It is assumed all of the plants are financed through borrowing and that an interest payment must be captured in the producer's cost. Otto Doering estimates that ethanol producers have a capital interest cost of $0.20 / gallon [36].

$0.20 / gallon * discount factor * production capacity

Production cost [36]:

Based on Otto Doering's "Economic Perspectives on Producing Liquids Fuels from Plant Feedstocks" [36]:

Other costs: $0.62 / gallon

Enzymes: $0.04 / gallon

Production cost = other costs + enzymes

Production cost = $0.62 + $0.04 = $0.66

$0.66 / gallon * inflation adjustment factor * discount factor * number of gallons of ethanol produced

Transportation distribution cost [34]:

$0.054 / gallon * inflation adjustment factor * discount factor * number of gallons of ethanol produced

Worker leisure opportunity cost [46]:

The worker leisure opportunity cost uses a value of $3, which is standard in the literature.

($3 * 40 hours / week * 50 weeks / year) * discount factor * 536 jobs

Soil erosion [47]:
The soil loss is estimated in the following way:

soil loss = 21 lbs. / gallon

topsoil = $0.028 / lb.

topsoil = $0.59 / gallon

$0.59 / gallon * inflation adjustment factor * discount factor * number of gallons of ethanol produced

Qualitative

Reduced Emissions [33]:

-1% greenhouse gases

Ethanol E85

Benefits

Federal biofuel dispenser tax credit [33]:

The federal biofuel dispenser tax credit was calculated in the following way:

Currently, there are 97 gas stations in Indiana that offer E85. It was assumed that this number would roughly double to 200 stations due to increased demand for E85 by consumers and the increased production of ethanol within the state. It was assumed that this increase would occur gradually from 2014 to 2018. Finally, it was assumed that all stations currently offering E85 had claimed the tax credit.

Table 7. Assumed Increase in New Stations Offering E85 by Year

Year	Number of new stations
2014	13
2015	20
2016	20
2017	25
2018	25

$30,000 / station * inflation adjustment factor * discount factor * number of new stations offering E85

Costs

Minimal modification [33]:

$3,300 / station * inflation adjustment factor * discount factor * number of new stations offering E85

New dispenser [33]:

$13,000 / station * inflation adjustment factor * discount factor * number of new stations offering E85

New tank, piping, etc. [33]:

$62,400 / station * inflation adjustment factor * discount factor * number of new stations offering E85

Qualitative

Reduced emissions [33]:

-20% greenhouse gases

Firefighting foam [48]:

$90-$115 / 5 gallons

Adjustment cost for cars [33]:

$30 - $300 / car

Indiana Alternate Fuel Vehicles Tax Credit [49]:

15% of qualifying investment

Dedicated Ethanol Pipeline [33]:

$1,000,000 / mile

Indiana Tax Credit for Fueling Stations [50]:

$0.18 / gallon, with a maximum of $1,000,000 for all retailers

Indiana Gas Station Grant [51]:

$5,000 / retailer, with a maximum of $1,000,000 for all retailers

Biodiesel

Benefits

Federal biodiesel virgin oil subsidy [33]:

$1.00 / gallon * inflation adjustment factor * discount factor * number of gallons of biodiesel produced

Federal biodiesel dispenser tax credit [33]:

Currently, there are 61 gas stations in Indiana that offer biodiesel. It was assumed that this number would roughly double to 134 stations due to increased demand for biodiesel by consumers and the increased production of biodiesel within the state. It was assumed that this increase would occur gradually from 2008 to 2012. Finally, it was assumed that all stations currently offering biodiesel had claimed the tax credit.

Table 8. Assumed Increase in New Stations Offering Biodiesel by Year

Year	Number of new stations
2008	14
2009	29
2010	15
2011	15
2012	14

$30,000 / station * inflation adjustment factor * discount factor * number of new stations offering biodiesel

Direct federal payment soybean subsidy [38]:

$0.44/ bushel * inflation adjustment factor * discount factor * number of bushels used to make biodiesel

Export of biodiesel to other states [53]:

Iowa State University estimates a tax exclusive price of biodiesel of $1.30 - $1.50 / gallon [53]. The value used in this analysis is simply the median value of this range.

$1.40 / gallon * inflation adjustment factor * discount factor * (number of gallons of biodiesel produced – number of gallons of biodiesel consumed in Indiana)

Transfers

Biodiesel production tax credit:

All biodiesel producers in the state of Indiana are entitled to a subsidy from the state of Indiana equal to $1.00 per gallon produced, subject to a maximum of $3 million [53]. It was assumed that all plants opening prior to 2007 had claimed the tax credit. Two plants opened in 2007 and will be eligible for the tax credit in 2008 [35]. These plants each have a capacity in excess of three million gallons a year and will exhaust the tax credit in 2008.

Biodiesel retailer tax credit: (Indiana Code 6-3.1-27-10).
$0.01 / gallon * inflation adjustment factor * discount factor * number of gallons of biodiesel produced

Taxes paid [44]:

The state of Indiana personal income tax is 3.4 percent.

Taxes paid = $43,348 * 0.034 = $1,473.83

$1,473.83 * discount factor * 134 jobs

Job creation [35]:

Employment is estimated at 134 jobs for all biodiesel production facilities in the state of Indiana. This value was derived by taking the number of jobs estimated to be created in the state of Indiana for all biofuel production, 670, and dividing it by the 20 current and planned ethanol and biodiesel production facilities [35]. This number was then multiplied by the 4 current biodiesel production facilities, which yields 134 jobs [35]. The average earnings of an ethanol plant employee, with benefits, is $43,348 [43]. The wages have been adjusted for tax payments[44, 45]

Federal taxes paid are a loss to the accounting domain.

Federal income tax payment = $4,220 + 25% over $30,650 = $7,394.50 [45].

Salary – federal taxes – state of Indiana taxes = Adjusted income

$43,348 - $7,394.50 -$1,473.83 = $34,479.67

$34,479.67 / year * inflation adjustment factor * discount factor * 134 jobs

Sale of fuel [52]:

$1.40 / gallon * inflation adjustment factor * discount factor * number of gallons of biodiesel consumed in Indiana

Agricultural input (soybean oil) [36]:

The soybean input value was calculated in the following way:

$0.65 / pound

7.4 pounds = 1 gallon

$0.65 * 7.4 = $4.81 / gallon

$4.81 * discount factor * number of gallons of biodiesel produced

Sale of Glycerin by-product [55]:

The typical biodiesel plant produces 1100 pounds of glycerin an hour.

($0.25 / pound * 1100 pounds an hour * 24 hours / day * 7 days / week * 50 weeks / year) * discount factor * number of plants producing biodiesel

Costs

Plant construction cost [56]:

The plant construction cost is variable and is based on production capacity. The cost of the plant is spread out over the useful life of the plant, which we assume to be twenty-five years. The plant cost does not include the cost of borrowed capital, which is included separately in the capital cost value.

(($1.04 / gallon) / 25 years) * inflation adjustment factor * discount factor * number of gallons of biodiesel produced

All of the values for each plant currently operating in Indiana are then summed to produce a total value.

Capital cost [36]:

The capital cost is interest paid on a loan. It is assumed that all of the plants are financed through borrowing and that an interest payment must be captured in the producer's cost. Otto Doering estimates that ethanol producers have a capital cost of $0.20 / gallon [36]. It is assumed that biodiesel producers make the same interest payment as ethanol producers.

$0.20 / gallon * discount factor * production capacity

Production cost [56]:

$0.47 / gallon * inflation adjustment factor * discount factor * number of gallons of biodiesel produced

Transportation distribution cost [36]:

Trial runs of biodiesel through existing pipelines have been successful and so it was assumed that biodiesel would be distributed through existing pipelines. The transportation cost for these pipelines ranges from $0.03 to $0.05 / gallon. This range was averaged, yielding a value of $0.04 / gallon.

$0.04 / gallon * inflation adjustment factor * discount factor * number of gallons of biodiesel produced

Worker leisure opportunity cost [46]:

The worker leisure opportunity cost uses a value of $3, which is standard in the literature.

($3 * 40 hours / week * 50 weeks / year) * discount factor * 134 jobs

Biodiesel B20

Qualitative

Reduced emissions [36]:
-78% greenhouse gases

Cellulosic ethanol E10

Benefits

Volumetric ethanol excise tax credit [36]:

$0.51 / gallon * inflation adjustment factor * discount factor * number of gallons of cellulosic ethanol produced

Use of by-products in production process:

Cellulosic ethanol produced from corn stover yields lignin as a by-product that can be used to generate heat in the production process. Otto Doering estimates the value of this benefit at $0.10 per gallon [36].

$0.10 / gallon * inflation adjustment factor * discount factor * number of gallons of ethanol produced

Transfers

Ethanol production tax credit [40, 41]:

The maximum tax credit for all years is $20,000,000 per producer. The below calculation was used until each cellulosic production facility received the maximum nominal payment. These payments were adjusted into real dollars.

($0.125 / gallon * 50 million gallon production capacity) * inflation adjustment factor * discount factor * number of production facilities

Agricultural input (corn stover) [36]:

$60 / dry ton of corn stover * inflation adjustment factor * discount factor * number of tons of corn stover needed to make quantity of cellulosic ethanol produced

Transportation from field [36]:

The cost of transporting corn stover from the field depends on the distance. The value used in the calculation was based on estimates from Otto Doering [36]. Because the cost of transportation varies with distance, it was assumed that producers would first buy corn stover close to the production facility. This is reflected in the weighted value calculated in Table 9.

Table 9. Weighted Value Calculation for Cost of Transportation

Distance	Percetage	Cost	Weighted Cost
5 miles	30%	$ 35.64	$ 10.69
15 miles	30%	$ 36.09	$ 10.83
25 miles	20%	$ 38.34	$ 7.67
35 miles	15%	$ 39.84	$ 5.98
45 miles	5%	$ 41.34	$ 2.07
		Total	$ 37.23

(($37.23 / dry ton) / 60 gallons / dry ton) * inflation adjustment factor * discount factor * number of gallons of cellulosic ethanol produced

Costs

Plant construction cost [33]:

The plant construction cost is assumed to be $250,000,000 [33]. The cost of the plant is spread out over the useful life of the plant, which we assume to be twenty-five years. The plant cost does not include the cost of borrowed capital, which is included separately in the capital cost value.

($250,000,000 / 25 years) * inflation adjustment factor * discount factor * number of production facilities

Capital cost [36]:

The capital cost is interest paid on a loan. It is assumed that all of the plants are financed through borrowing and that an interest payment must be captured in the producer's cost. Otto Doering estimates that cellulosic ethanol producers would have a capital cost of $0.55 / gallon [36].

$0.55 / gallon * discount factor * production capacity

Production cost [36]:

The production cost is based on Otto Doering estimates.

Production cost = other costs + enzymes

Other costs = $0.80 / gallon

Enzymes = $0.40 / gallon

Production cost = $0.80 + $0.40 = $1.20 / gallon

$1.20 / gallon * inflation adjustment factor * discount factor * number of gallons of cellulosic ethanol produced

Transportation distribution cost [34]:

$0.054 / gallon * inflation adjustment factor * discount factor * number of gallons of cellulosic ethanol produced

Qualitative

Reduced emissions [33]:

-70 to -90 % greenhouse gases

<u>Cellulosic Ethanol E85</u>

Qualitative

Firefighting foam [48]:

$90-$115 / 5 gallons

Adjustment cost for cars [33]:

$30 - $300 / car

Indiana Alternate Fuel Vehicles Tax Credit [49]:

15% of qualifying investment

Dedicated Ethanol Pipeline [33]:
$1,000,000 / mile

Appendix F: Hoosier Homegrown Energy Coalition

Introduction

The following campaign outline provides the Hoosier Homegrown Energy Coalition with a marketing plan that ensures biofuels proliferation as a top priority at the Capitol in 2009. The Coalition must realize that other energy interests (i.e. clean coal technology) also desire to become a top priority among lawmakers and the public. However, the biofuels marketing campaign will create a level of organizational unity and message coherence unmatched by other organizations, thus opening the requisite window of opportunity at the Capitol, resulting in the successful biofuels proliferation throughout the state.

The campaign outlined in this manual is six months in duration and will require active involvement and financial support from all organizations within the Hoosier Homegrown Energy Coalition. While it may be cost prohibitive to implement every aspect of the biofuels marketing plan, it is nonetheless important to realize the following: 1) a concentrated, six-month marketing effort will achieve a degree of legislative progress that individual organizations would be unable to realize individually; and 2) political realties are such that it is possible for biofuels to otherwise remain a ‘backburner’ issue in Indiana for the foreseeable future.

Multiple communications mediums will be utilized to raise awareness (first) and more importantly, interest in biofuels proliferation. Television, radio, print sources, and the Internet all offer various communicative advantages and ensure that the campaign targets a wide range of population demographics. This campaign outline provides a brief overview, desired objective, specific message, and target audience for each medium. The specific design of each advertisement is beyond the scope of this document. The Coalition should therefore identify and hire a consultant that will oversee all marketing efforts and provide the detail that is ultimately required.

In addition to advertising through multiple mediums, the Coalition will also utilize audience-specific messages to ensure maximum success among different demographics. The Coalition will always include the message “Fueling Indiana’s Future” for consistency purposes, but will differentiate more specific portions of the message depending upon the intended audience (consumers, producers/farmers, or lawmakers). The following is a breakdown of those specific messages:

- Hoosier Homegrown Energy Coalition
    - Organizational Message (always appears under the Coalition’s name)
        - “Fueling Indiana’s Future.”

- Audience-specific Messages (message choice depends upon the intended audience)
    - Consumer-specific
        - "Home is where the fuel is. Indiana Biofuels: Good for your family. Good for your finances. Good for your future."
    - Lawmaker-specific
        - "An opportunity to stand out. Indiana Biofuels: Leading the US into an age of energy security and economic prosperity."
    - Farmer/Producer-specific
        - "Investing in America's energy future. Indiana Biofuels: Promoting smart business practices through the advancement of renewable energy resources."

The remainder of this document divides the marketing campaign into three phases (October, November-February, and March) and provides a skeleton outline for the marketing activity that should occur within each time frame. The organizations that are interested in Indiana biofuels proliferation must realize that it is necessary to *make* the biofuels issue important at the Capitol in 2009. By adhering to and expanding on this campaign outline, the Hoosier Homegrown Energy Coalition will ultimately achieve success for each of its member organizations that would not have been possible without collective action and a unified message.

Phase I – The Introduction

(October)

Press Conference

- WHAT: Press conference hosted by the Governor or Lieutenant Governor that introduces the Coalition and the importance of biofuels for the future of Indiana.
- OBJECTIVE: Organize an event that will be covered by print and television media and signal the beginning of the biofuels marketing campaign.
- SPECIFIC MESSAGE: Focus on the overall message of the Coalition: "Fueling Indiana's Future."
- INTENDED AUDIENCE: Morning/evening news viewers and newspaper readers.

Television

- WHAT: Begin with advertisements that introduce the Coalition and the member organizations. Ideally, the Governor will be featured to enhance credibility. The ads should be more "personal interest" in design in lieu of specific biofuels facts.
- OBJECTIVE: Ensure that all Indiana residents are familiar with the Hoosier Homegrown Energy Coalition member organizations (Promote understanding that the Coalition is a public-private initiative that deserves the trust and support of all Hoosiers).

- SPECIFIC MESSAGE: “Home is where the fuel is. Indiana Biofuels: Good for your family. Good for your finances. Good for your future.”
- INTENDED AUDIENCE: Families (run ads during evening sitcoms) and news viewers (run ads during the evening news hour).

Radio

- WHAT: Focus on talk-show stations that cater to politically active individuals. Be sure progressive and conservative radio shows are covered equitably.
- OBJECTIVE: Focus on why biofuels are important for Indiana’s future, while again stressing that a Coalition is behind the biofuels initiative.
- SPECIFIC MESSAGE: “Home is where the fuel is. Indiana Biofuels: Good for your family. Good for your finances. Good for your future.”
- INTENDED AUDIENCE: Middle-aged, middle-upper class, politically motivated individuals.

Print

- WHAT: Public ads in major papers (print and online) in Indianapolis, Fort Wayne, Evansville and South Bend (so as to cover all geographic regions of the state). The ads should be simple in design and clearly display the Coalition’s logo, slogan, and message.
- OBJECTIVE: Increase familiarity with the Coalition’s overall message and goals (do not provide specific facts about biofuels but instead lead interested individuals to information disseminated through other mediums).
- SPECIFIC MESSAGE: “Home is where the fuel is. Indiana Biofuels: Good for your family. Good for your finances. Good for your future.”
- INTENDED AUDIENCE: Middle-aged, working and middle-upper class, socially interested individuals.

- WHAT: Ads in the Farmer’s Almanac and seed/farm equipment catalogs that are read by Indiana farmers.
- OBJECTIVE: Increase familiarity with the Coalition’s overall message and be sure that farmers know their interests are being represented by the Coalition.
- SPECIFIC MESSAGE: “Investing in America’s energy future. Indiana Biofuels: Promoting smart business practices through the advancement of renewable energy resources.”
- INTENDED AUDIENCE: Indiana farmers and other potential producers of biofuelsfeedstocks.

- WHAT: Mailings/brochures to state politicians and Indiana's federal representatives. Send materials to central offices and send Coalition representatives to every member's office to personally distribute biofuels information.
- OBJECTIVE: 1.) Ensure the candidates realize that biofuels will be the most publicized issue during the upcoming legislative session; and 2.) Ensure the candidates realize the Coalition represents a wide array of voters throughout the state (and that voters will be responsive to the Coalition's final assessment of the upcoming legislative session).
- SPECIFIC MESSAGE: "An opportunity to stand out. Indiana Biofuels: Leading the U.S. into an age of energy security and economic prosperity."
- INTENDED AUDIENCE: All Indiana General Assembly members and Indiana's House/Senate delegation to the U.S. Congress.

Internet

- WHAT: Hoosiers Homegrown Energy Coalition webpage that provides information and legislative updates to interested citizens. The webpage will be integral throughout the six-month campaign and should therefore remain up-to-date at all times and provide links to contact local legislators.
- OBJECTIVE: Maintain a source of up-to-date information that allows interested farmers/producers, consumers, and lawmakers to learn more about biofuels and the current state of biofuels legislation during the 2009 session.
- SPECIFIC MESSAGE: All three audience-specific messages will be included within segments of the webpage.
- INTENDED AUDIENCE: Farmers/producers, consumers, and lawmakers that are interested in learning more about Indiana biofuels and legislative progress (the webpage is a secondary source of information – individuals will likely hear about the Coalition from another source before going online).

Phase II – The Crescendo

(November – February)

Note: Increase the frequency of advertisements during January-February and push the March 1st Celebration Rally at the Capitol.

Town Hall Meetings

- WHAT: Ten-city tour (with a mix of both urban and rural locations) by the Coalition's marketing consultant to inform citizens about biofuels and their future in Indiana's economy. These meetings will be a significant contributor to stakeholder mobilization and information-dissemination efforts.

- OBJECTIVE: Educate and mobilize a grassroots effort by consumers and farmers/producers in important rural and urban constituencies.
- SPECIFIC MESSAGE: "Home is where the fuel is. Indiana Biofuels: Good for your family. Good for your finances. Good for your future." AND "Investing in America's energy future. Indiana Biofuels: Promoting smart business practices through the advancement of renewable energy resources."
- INTENDED AUDIENCE: Consumers and farmers/producers

Television

- WHAT: Run 'dichotomous choice' ads that explain that there are multiple energy options currently available, but that citizens should choose biofuels whenever possible so as to ensure the best future for Indiana.
- OBJECTIVE: Recognize that biofuels are currently similar in price to other energy alternatives and they will soon be the best option in Indiana (consumers should support biofuels proliferation in the short term to prosper in the long term).
- SPECIFIC MESSAGE: "Home is where the fuel is. Indiana Biofuels: Good for your family. Good for your finances. Good for your future."
- INTENDED AUDIENCE: Families (run ads during evening sitcoms) and news viewers (run ads during the evening news hour).

Radio

- WHAT: Run "dichotomous choice" ads that explain that there are multiple energy options currently available, but that farmers/producers should choose biofuels whenever possible so as to ensure the best future for Indiana (and themselves). Run the ads on local farm programs.
- OBJECTIVE: Convince farmers/producers that the demand for biofuels will continue to rapidly increase.
- SPECIFIC MESSAGE: "Investing in America's energy future. Indiana Biofuels: Promoting smart business practices through the advancement of renewable energy resources."
- INTENDED AUDIENCE: Indiana farmers and other potential producers of biofuelsfeedstocks.

- WHAT: Interview the Coalition's marketing consultant on news talk shows throughout Indiana. Speak with as many talk show hosts as possible about the Coalition's objectives.
- OBJECTIVE: Provide more in-depth information about biofuels and their importance for Indiana's future.

- SPECIFIC MESSAGE: “Home is where the fuel is. Indiana Biofuels: Good for your family. Good for your finances. Good for your future.”
- INTENDED AUDIENCE: Middle-aged, middle-upper class, politically motivated individuals.

Print

- WHAT: Bus ads in all major Indiana cities with public transportation.
- OBJECTIVE: Increase familiarity with the Coalition’s logo and basic messages. Clearly direct interested individuals to the Coalition’s website for additional information about biofuels and future mobilization efforts.
- SPECIFIC MESSAGE: “Home is where the fuel is. Indiana Biofuels: Good for your family. Good for your finances. Good for your future.”
- INTENDED AUDIENCE: Middle to upper class urban citizens that see the bus ads while commuting to and from work.

- WHAT: Billboard ads on all major trucking highway segments located between Indiana cities.
- OBJECTIVE: Increase familiarity with the Coalition’s logo and basic messages. Clearly direct interested individuals to the Coalition’s website for additional information about biofuels and future mobilization efforts.
- SPECIFIC MESSAGE: 50% of ads: “Home is where the fuel is. Indiana Biofuels: Good for your family. Good for your finances. Good for your future.” 50% of ads: “Investing in America’s energy future. Indiana Biofuels: Promoting smart business practices through the advancement of renewable energy resources.”
- INTENDED AUDIENCE: Rural citizens, commuters between cities, and truckers that are potential distributors of biofuels.

Phase III – The Exclamation Point

(March)

March 1st Biofuels Celebration Rally at the Capitol

- WHAT: A gathering of all biofuels stakeholders (consumers, farmers/producers, and lawmakers) and the Hoosier Homegrown Energy Coalition at the steps of the Capitol to celebrate the successful culmination of the biofuels marketing campaign and (hopefully) the passage of biofuels legislation during the 2009 session. Media members will also be invited en masse.

- OBJECTIVE: The event will provide incentive for legislators to pass biofuelslegislation for two reasons: 1.) All legislators that supported biofuels legislation will receive a significant amount of positive media coverage due to the rally (and that will surely aid in future re-election campaigns); and 2.) If biofuels legislation is not passed by March 1st, the rally will instead become an event that laments legislative inaction and provides an opportunity for negative media coverage directed toward the General Assembly.
- SPECIFIC MESSAGE: The new biofuels legislation, endorsed by the broad-based Hoosier Homegrown Energy Coalition, will surely "Fuel Indiana's Future." Broadcast public appreciation to stakeholders and lawmakers that supported the biofuels proliferation movement.
- INTENDED AUDIENCE: Indiana consumers, farmers/producers, and lawmakers. The rally should have broad-based appeal that informs as many Hoosiers (and potential voters) as possible about the success of the Coalition's biofuels proliferation initiative.

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