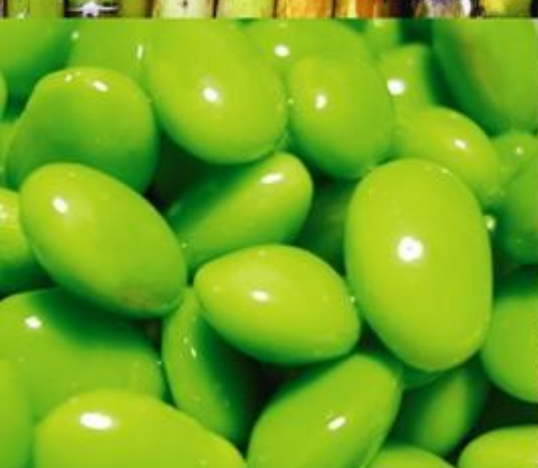



The Potential Role of Biofuels in New Jersey to Reduce Carbon Emissions from Electricity Generation

Columbia University
for the New Jersey Department of Environmental Protection



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Executive Summary

In response to the international scientific consensus on the growing impact of climate change, the State of New Jersey has undertaken proactive measures to reduce its carbon emissions. In addition to instituting a Renewable Portfolio Standard and adopting aggressive emission reduction targets pursuant to Governor Corzine's Executive Order 54 and the State's new Global Warming Response Act, it has joined the Regional Greenhouse Gas Initiative (RGGI), a cooperative effort by ten Northeast and Mid-Atlantic States to implement a regional cap-and-trade program for carbon dioxide emissions from power plants in the region. As a component of this initiative, New Jersey recognizes that substituting sustainably-produced biofuels for fossil fuels in its electricity generation sector can potentially help the State meet its stringent emission reduction targets.

This report assesses the role that biofuels can play in New Jersey for the State's Department of Environmental Protection (NJDEP). The centerpiece of the study lies with its lifecycle emissions models developed for three biofuel feedstocks: food waste, waste grease, and soybean oil. Using existing lifecycle emissions models as our basis, we designed models to calculate net carbon emissions using a comprehensive assessment over the lifetime of a feedstock. In addition, we reviewed the current policies and initiatives aimed at reducing greenhouse gas emissions in the State, examined the availability of various feedstocks for producing biofuels, and determined New Jersey's biofuel production and combustion capacity. Finally, RGGI stipulates that all feedstocks used in biofuel production be harvested sustainably. In response, we have developed sustainable harvesting guidelines to help the NJDEP and other regulatory agencies assess the eligibility of first generation biofuel feedstocks.

The results of our models indicate that the three biofuel feedstocks analyzed, when used for electricity generation offer carbon savings in comparison to fossil fuels. Of the models, anaerobic digestion of food waste offers the greatest carbon savings, followed by waste grease, and finally soybean oil. Despite the significance of these results, we believe that is it also essential to consider the environmental, economic, and social ramifications that could result from the use of each feedstock, as well as its production and combustion potential in New Jersey. Our analysis suggests that second generation feedstocks (such as food waste and waste grease) offer substantial advantages over first generation feedstocks. In addition to higher carbon savings, using second generation feedstocks circumvents problems associated with land use conversion and competition with food supply. It also reduces landfill volume and provides a market for an otherwise discarded or low-value product. We recognize, however, that first generation feedstocks are likely to remain an attractive option for biofuel production in the near future while innovative technologies are being developed to efficiently utilize second generation feedstocks, and therefore strongly recommend that a robust oversight system ensures sustainable production and harvesting of these biofuel crops.

Finally, it is important to note that this report only considers technologies for biofuel production and combustion that are currently commercially viable. We suggest that the NJDEP conduct further research on other feedstocks and remain attentive to emerging technologies in order to identify the most appropriate and effective options for helping the State achieve its emission reduction goals.

Introduction

The international scientific community has reached a consensus that human-induced global climate change will lead to widespread economic and social disruptions in future decades if we do not take immediate steps to mitigate its causes.[1] Emissions from the combustion of fossil fuels significantly contribute to climate change by increasing the buildup of greenhouse gases in the atmosphere. Concern over the negative impacts of global warming, coupled with increasing unease about our nation's dependence on foreign oil has prompted interest in the renewable energy sector and the development of alternatives to fossil fuels.

Given the current lack of federal mandates to reduce greenhouse gas (GHG) emissions in the United States, some states and regions have passed their own legislation to address the issue. New Jersey has been particularly proactive by developing policies to reduce industrial emissions and promote the use of renewable fuels. Along with nine other states, New Jersey joined the Regional Greenhouse Gas Initiative (RGGI) with the goal of regulating carbon dioxide (CO_2) emissions from power plants. RGGI establishes statewide emissions budgets or "caps" and requires energy producers to buy and hold carbon allowances in proportion to their emissions of CO_2.[2] As the agreement moves toward implementation in 2009, there is new interest in quantifying carbon emissions from alternative fuels that could be substituted in place of fossil fuels and potentially offset some of the carbon dioxide emissions produced in electricity generation.

Biofuels Overview

One such alternative that has been widely developed in recent years is biofuel, fuel sources derived from recently living organisms or their metabolic by-products.[3] The source material, or feedstock, required for the production of a biofuel can be broken into two general categories: first generation and second generation. A **first generation** feedstock is one grown with the specific intent of becoming a biofuel.[4] Corn, soybeans, canola, sugar cane, sugar beets, and palm are all examples of crops grown as biofuel feedstocks. A **second generation** feedstock is one that has an economic use before being converted into fuel.[5] Used cooking oil, grease from wastewater treatment, food waste, paper wastes, wood, and animal wastes are all second generation feedstocks.

Controversy in the scientific and policy arenas persists over the benefits from using biofuels as a replacement for fossil fuels. Two recent articles in the leading scientific journal *Science* have independently asserted that clearing new land for first generation biofuel cultivation causes a net release of carbon that can be comparable to or even higher than carbon emissions from fossil fuel combustion.[6,7] Clearing land for agriculture can increase the net carbon footprint by releasing stored fossil soil carbon and by eliminating the carbon sink function of the once intact ecosystem.[8] At the same time, a wise land management plan that prioritizes long-term soil quality and erosion control within the agriculture system can regain some of the lost carbon.

Another contentious issue with first generation biofuel feedstocks is that a rapid conversion of land (currently dedicated to food crops) geared towards biofuel production threatens the stability of the entire food supply and drives food prices upwards.[9] As global

demand for first generation feedstocks rapidly increases, these articles stress the importance of examining the potential negative repercussions on the environment and existing economic and political systems. Both articles, however, highlight the fact that utilizing waste products to generate biofuels eliminates the land conversion issues, and may be a more viable option for achieving significant carbon emission reductions.[10,11] Biofuels generated from such second generation feedstocks can create additional environmental and social benefits by diverting a portion of the waste stream from landfill sites or incineration facilities and converting it to a useable energy source. Given the growing concerns over the relative greenhouse gas emissions associated with first and second generation biofuel feedstocks, we were careful to address these issues in our study.

Report Focus and Goals

We designed this report to serve as a resource for the New Jersey Department of Environmental Protection (NJDEP) and other RGGI regulatory agencies in determining how biofuels might apply to RGGI guidelines. We created lifecycle emissions models for food waste, waste grease, and soybean oil that quantify carbon emissions from their use in electricity generation. This information can guide RGGI carbon credit allocations for utility producers using the feedstocks analyzed in this report, and provide clarity to decision-makers in terms of the effectiveness of biofuel technologies for reducing greenhouse gas emissions.

In addition, we developed sustainable harvesting guidelines for first generation crops (see Appendix 1). The guidelines are intended to assist state regulatory agencies in deciding whether a biofuel meets the baseline determinants of sustainable production as required under RGGI.[12] Given the detrimental land use changes and food supply disruptions associated with first generation biofuel feedstocks, our research focuses primarily on the potential of using second generation products as a fuel source.

We analyzed each biofuel feedstock for its production potential in New Jersey as well as the environmental, economic, and social ramifications that could result from its use. We also considered small alternative electricity generators (less than 25 MW) that are not regulated by RGGI but can help New Jersey meet its renewable energy goals. This report provides a comprehensive assessment of the viability of biofuels in New Jersey and their potential to contribute to the State's emission reduction targets.

New Jersey Energy Goals and Accompanying Legislation

The State of New Jersey has promulgated various regulations and incentives intended to support the use of renewable energy while simultaneously working to increase energy efficiency, reduce electricity demand, and promote renewable technology.[13] These include the adoption of a Renewable Portfolio Standard, Executive Order No.54, and the Global Warming Response Act.

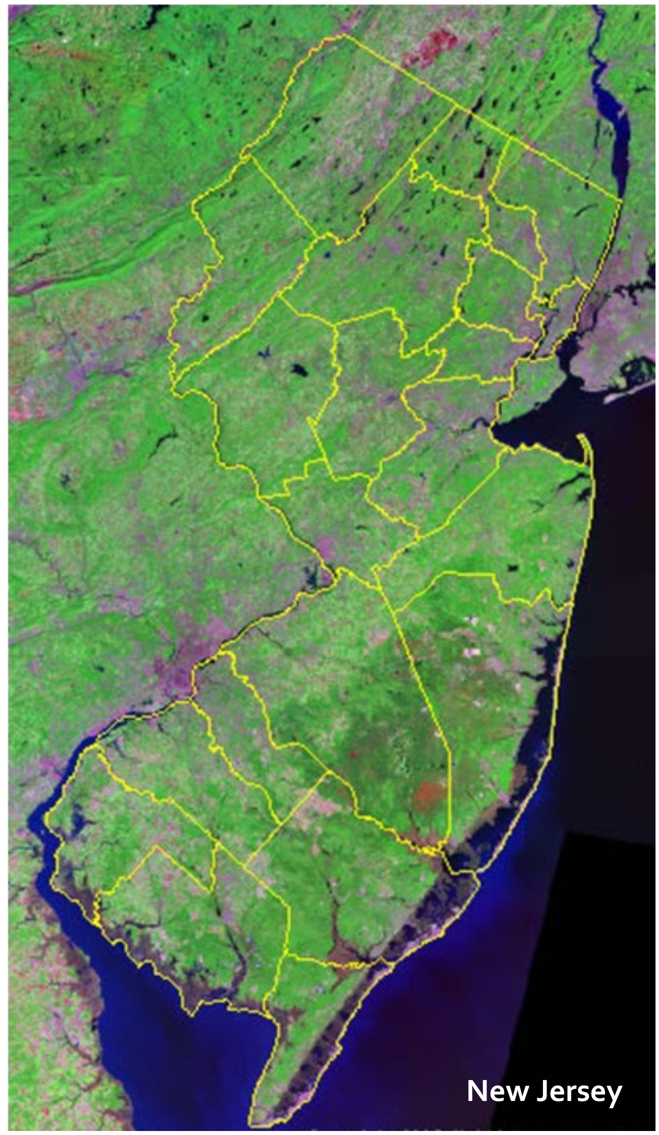
New Jersey Renewable Portfolio Standard

In April 2006, the New Jersey Board of Public Utilities updated their statewide Renewable Portfolio Standard (RPS), a regulatory mandate that requires utility operators to use specified percentages of renewable technologies as part of their electricity generation portfolios. The goal for New Jersey utilities' renewable electricity generation is 22.5% of total energy production by 2021.[14]

The RPS establishes two classes of renewable energy: Class I and Class II. "**Class I Renewables**" include wind, solar-electric generation, fuel cells powered by renewable fuels, geothermal technologies, wave and tidal action, methane gas from landfills, anaerobic digestion of food waste or sewage sludge at a biomass facility, and other biomass resources provided that the biomass is cultivated and harvested in a sustainable manner. "**Class II Renewables**" include hydropower facilities generating 30 MW or less, electricity from resource-recovery facilities in New Jersey, and resource-recovery facilities outside New Jersey that meet certain conditions.[15] Table 1 shows the renewable requirements for each renewable class.

Class	Percentage of Total Energy
Class I	20.00%
Class II	2.50%
Total	22.50%

Table 1: Renewable Portfolio Standard Requirements by 2021



Executive Order Number 54 and the Global Warming Response Act

On February 13, 2007, New Jersey Governor Jon Corzine issued Executive Order No. 54 calling for strict greenhouse gas emissions reductions.[16] Five months later, on July 6, 2007, Governor Corzine signed the New Jersey Global Warming Response Act (GWRA).[17] The greenhouse gas reductions mandated by GWRA echo those called for in the Executive Order. According to the law, New Jersey must reduce greenhouse gas emissions to 1990 levels by 2020 and to 20% of 2006 levels by 2050.[18]

Regional Greenhouse Gas Initiative

Overview

New Jersey joined the Regional Greenhouse Gas Initiative (RGGI) to further its commitment to mitigating climate change. RGGI is a cooperative effort by ten Northeast and Mid-Atlantic States to design and participate in a regional cap-and-trade program covering carbon dioxide emissions from power plants in the region with a capacity of 25 MW or more.[19]

Biofuel Combustion and RGGI Credits

RGGI policy dictates that electricity-generating facilities of 25 MW or more are not liable for CO2 emissions attributable to the burning of eligible biomass.[20] Few facilities operate on 100% biofuel feedstocks and instead co-fire biofuels with other fossil fuels. For example, a facility may operate on 80% fossil fuels and 20% biofuels. Under RGGI, this facility would only need enough carbon allowances to account for the emissions associated with the fossil fuels. Thus, decision-makers need to have quantitative data on the effectiveness of biofuel technologies for reducing greenhouse gas emissions. The RGGI Model Rule provides calculation methods for determining fossil fuel versus solid biofuel emissions, yet calculation methods for emissions from the lifecycles of liquid biofuels are relatively unknown. Thus, we created lifecycle emissions models for different biofuel types to quantify offset carbon.

Baseline Criteria for Sustainable Harvesting

The RGGI Model Rule requires that all biomass feedstocks "available on a renewable or recurring basis (excluding old-growth timber)" must be "sustainably harvested" in order to be considered "eligible biomass" for RGGI credits.[21] The Model Rule does not define "sustainably harvested," however, and instead leaves the task of determining sustainability to the states. As such, we created guidelines for assessing sustainable agricultural production to assist state regulatory agencies in making such determinations (see Appendix 1).

New Jersey Biofuels Potential

New Jersey Biofuels Potential

After reviewing current policies and initiatives aimed at reducing greenhouse gas emissions in New Jersey, we assessed the availability of various feedstocks for producing biofuels. Additionally, we examined the feasibility of currently available technologies and potential future alternatives, and determined the biofuel production and combustion capacity in the State.

Biofuel Feedstock Production in New Jersey

First Generation Biofuels

This section focuses exclusively on the biofuel feedstock potential generated within New Jersey rather than on imports of first generation biofuel feedstocks from across state lines since we wanted to assess the home-grown potential for biofuel production in the State. In New Jersey, the number of farms decreased by 2% between 1997 and 2007. Of the remaining 9,800 farms, the latest U.S. Department of Agriculture (USDA) Agriculture Census notes that approximately 790,000 acres (17% of total land area) are under cultivation.[22] The climate in New Jersey is generally adequate for crop production with average temperatures ranging from the upper-60s to mid-70s degrees Fahrenheit during the growing season (typically May through September) and constant precipitation throughout the year averaging approximately 45 in/year.[23]

The major first generation crops grown in New Jersey are corn and soybeans; both have similar acreage distribution patterns. Figures 1 and 2 show total acres planted and yield per acre of corn and soybeans divided by region. The regions are comprised as follows:

- **Northern Region**: Hunterdon, Morris, Somerset, Sussex, and Warren Counties
- **Central Region**: Burlington, Mercer, Middlesex, Monmouth, and Ocean Counties
- **Southern Region**: Atlantic, Cumberland, Gloucester, and Salem Counties.

These figures exclude various counties depending on crop type and year.[24]

Figure 1 shows that the Northern Region dominates corn production in New Jersey planting nearly as many acres as the two other regions combined. Yield levels are similar in the Northern and Central Regions, while the Southern Region shows lower production rates. Overall, the state produced 8,256,000 bushels of corn (for grain) totaling over $27 million in 2006.[25] Figure 2 shows that soybeans, on the other hand, are grown primarily in the Central and Southern Regions with the Southern Region again producing at a lower rate. In 2006, New Jersey produced 3,010,000 bushels of soybeans worth about $17,759,000.[26] The soybean to biodiesel path was chosen for analysis because biodiesel fuel, unlike ethanol, could be readily combusted to generate electricity at a number of RGGI facilities.

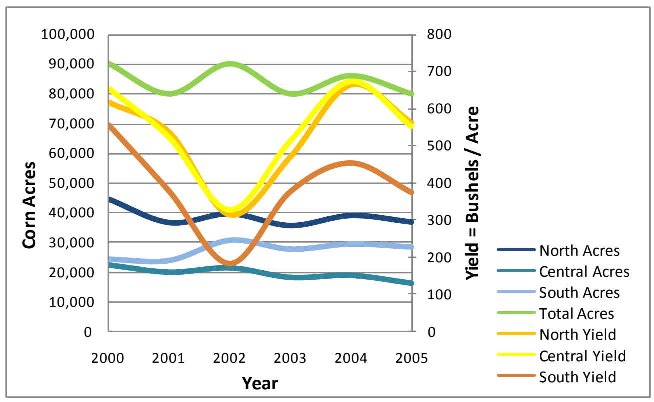


Figure 1: Corn Production in Acres Planted and Yield per Acre (Bushels/Acre)

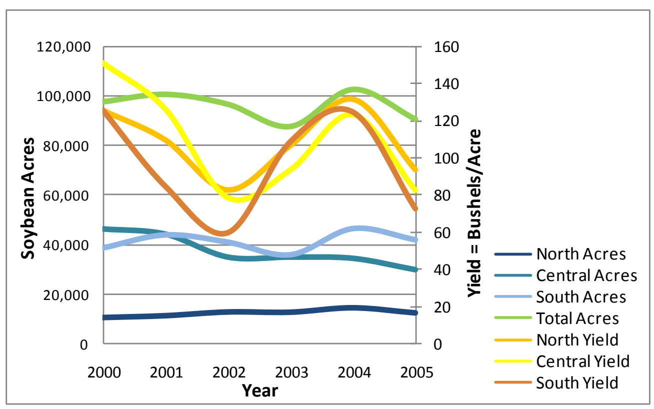


Figure 2: Soybean Production in Acres Planted and Yield per Acre (Bushels/Acre)

Second Generation Biofuels

Greases and Fats

Attaining estimates for second generation feedstocks is more complicated than those for first generation feedstocks. There are no comprehensive records to provide exact figures on how much waste greases and fats could be collected for biodiesel production in New Jersey. However, it is possible to generate some reasonable estimates. Waste greases include yellow grease and brown grease (also called trap grease). Yellow grease is collected primarily from deep fryers of restaurants; brown grease is collected from grease traps of restaurants as well as the wastewater stream and has a higher free fatty acid content than yellow grease making it more difficult to process. The National Renewable Energy Laboratory (NREL) recently estimated that on average, Americans generate 9 lbs. of yellow grease and 13 lbs. of brown grease/year/person, or approximately 1.16 and 1.69 gallons/year/person respectively.[27]

Assuming a 98% biodiesel yield from yellow grease and a 50% yield from brown grease, the yield for biodiesel could approximate 15 pounds/year/person.[28] In metropolitan areas, 2 million gallons of waste grease could be collected for every one million people. The population of New Jersey is approaching 9 million people; this figure combined with a conservative estimate of 30% capture of grease per resident provides a potential yield of over 4 million gallons of grease for biodiesel production. Other estimates approximate the available amount of grease at between 9 and 10 million gal/year.[29]

Currently, there are several grease haulers in New Jersey that are paid to collect both yellow and brown waste greases including Darling International Inc. which renders the yellow grease onsite.[30] Yellow grease is used as an additive in livestock-feed and oleochemicals which are used to manufacture soaps, lubricants, paints, varnishes and other end products. As the biofuel industry grows, it will compete for yellow grease with these feed and chemical production industries. Although haulers also collect brown grease, it has fewer commercial applications and is generally sent to incineration facilities or landfills. In recent years, however, some regional companies have developed technologies to process distressed and low quality brown waste greases into biodiesel.[31]

It is also difficult to determine available amounts of tallow and other animal fats. One study from the New York State Energy Research and Development Authority (NYSERDA) estimated that New York, New Jersey, and Pennsylvania together could approach 30 million gallons of biodiesel produced. The majority of this would come from Pennsylvania.[32]

When all grease and fats are combined, estimates vary but it is certainly feasible for the State of New Jersey alone to produce at least 10 - 15 million gallons of grease and fat per year for biodiesel production.

Municipal Solid Waste

An additional second generation feedstock is municipal solid waste (MSW). In 2003, New Jersey residents generated 19.8 million tons of solid waste. Of this total, slightly over half was recycled, 20% went to New Jersey landfills, 19% was sent out of the state, and 8% went to resource recovery facilities.[33] With these recycling rates, biofuel production from MSW could divert significant amounts of this waste from landfills, both in-state and across state lines. Food waste is of particular interest because of its potential to reduce carbon emissions. In New Jersey, food waste represents 7.4% of the total MSW stream, approximately 1.6 million tons. Currently, just 14% of food waste is being recycled leaving significant potential to enhance collection rates.[34]

Biofuel Production Technologies

After determining which feedstocks are feasible in New Jersey, it is important to analyze the various biofuel production processes. The most commercially available biofuels in the U.S. are biodiesel and ethanol, although the production and use of biogas is becoming increasingly common.

New Jersey has a considerable number of power plants currently fit to combust biodiesel and biogas, making the potential for these fuels to help the State address its emission reductions goals considerable. On the other hand, virtually no power plants use ethanol to generate electricity and since it cannot be co-fired in the power industry's existing diesel generators, it is currently less useful for reducing emissions in this sector. Table 2 illustrates the different technologies that New Jersey should consider when developing its biodiesel and biogas production capabilities. Some of the relevant biodiesel, biogas and ethanol production technologies are described below.

Biodiesel

The most commonly used feedstocks to produce biodiesel in the U.S. are soybean oil and yellow grease.[35] Other feedstocks include rapeseed, common in Europe, palm and coconut oil, found in Southeast Asia, and jatropha, native to Central America but now grown in a variety of tropical and subtropical regions. Technology for converting these inputs into fuel is both sound and commercially viable. Fuel producers usually employ either batch or continuous processing methods. Batch processing is the simplest of these. It requires a simple structure, limited technical expertise and less capital than other production methods. However, batch systems have a limited capacity and are better suited for smaller-scale production. The continuous production system is an alternative method and, typically has greater capacity. This method is more complex and capital intensive. It requires constant operation, staffing, technical expertise and frequent maintenance, but is the most practical for mass-production of biodiesel.[36]

Biogas

New Jersey's power industry has a large capacity to fire biogas for electricity. The State also produces substantial quantities of sewage, wastewater, and other organic wastes and manure which are usually sent to landfills where they decompose, releasing great volumes of greenhouse gases and losing considerable energy content. Anaerobic digestion (AD) technology provides a tool for reducing this inefficiency. AD systems are typically constructed on farms and at municipal waste facilities to treat organic wastes, mitigate the emission of landfill gases, and yield valuable fertilizers.[37] Scales of AD systems vary widely. Some are continuous/plug-flow/mixed systems where new waste is pumped into a horizontal tank, displacing old waste. These are better suited for production on a large scale because they require staffing, technical expertise and are capital intensive. In smaller covered lagoon systems, waste is simply stored in a pool-like basin, left to undergo microbial digestion. These require less capital and are generally simpler to maintain.[38] AD systems also produce biogas which may be combusted as fuel in existing natural gas firing power plants. It may be both environmentally and economically beneficial to co-site anaerobic digesters with existing power plants in the coming years.

Ethanol and Other Technologies

For the purpose of New Jersey's emissions reductions goals, ethanol is not as useful as biodiesel or biogas because it takes so much energy, and thus carbon, to produce. In the near term, ethanol will likely continue to be used primarily as an automotive fuel. Nonetheless, it is an abundant biofuel in the U.S., mass-produced in steadily increasing amounts for the past three decades. Wet and dry milling are the most common technologies used to produce ethanol. These methods differ primarily in their initial treatment of the feedstock. In typical wet milling, corn kernels are decomposed in a mixture of water and acid. This yields separated starch, germ, fiber and protein—all of which are processed further. In dry milling, the corn kernels are simply grinded without chemical pretreatment which yields granules which are processed further. Although wet milling produces several valuable co-products and can be quite lucrative, it is becoming obsolete due to inefficiency and capital intensity. For the past decade or so, technology has shifted production towards the dry milling process, which requires less capital and gains higher yields of ethanol per input.[39]

Other promising biofuel technologies include cellulosic technology which potentially uses waste to produce ethanol, reducing waste volume and lowering the price of ethanol. However, currently there are technical, economic, and commercial barriers to its use. Also, in the future, gasification technology may make it possible to decontaminate commercial and industrial wastes, producing fuel in the process.[40]

Technology	Relevance to RGGI Goals	Primary Input	Fuel Output	Technology Profile
Batch Biofuel Production	High	Soybean Oil and Yellow Grease	Biodiesel	• Technology is sound • Less capital intensive • Suited for smaller plants • Does not require constant operation • Flexibility to use multiple feedstocks
Continuous Biofuel Production	High	Soybean Oil and Yellow Grease	Biodiesel	• Technology is sound • Capital intensive • Suited for larger plants • Requires constant operation/staffing • Requires more uniform feedstock • More efficient in mass production
Batch/Lagoon Anaerobic Digestion	Moderate	MSW, Wastewater and Manure	Biogas	• Technology is sound • Less capital intensive • Suited for smaller plants • Less efficient for mass production • Lower operation and maintenance costs • Low failure rates
Continuous/Mixed Anaerobic Digestion	Moderate	MSW, Wastewater and Manure	Biogas	• Technology is sound • Capital intensive • Suited for larger plants • Requires constnat operation/staffing • Suited for mass production • High failure rates in past • Requires high level of technical expertise
Wet Mill Biofuel Production	Low	Corn and Sugar	Ethanol	• Technology is sound • Capital intensive • Yields many valuable co-products (7) • Biofuel production is not usually primary goal • Lower ethanol yield per input • Becoming obsolete for ethanol production
Dry Mill Biofuel Production	Low	Corn and Sugar	Ethanol	• Technology is sound • Less capital intensive • Suited for various capacities • Yields few valuable co-products (3) • Biofuel production is primary goal • Gain higher yields of ethanol per input
Cellulose Conversion	Low	Cellulosic Materials	Ethanol	• Technology being developed • Not commercially available • Cheapest feedstocks • Would reduce cost of ethanol substantially • More inclusive feedstocks • Would reduce waste streams
Biomass Gasification	Low	Carbonaceous Materials	Syngas	• Technology being developed • Mostly small-scale applications have been attempted • High failure rate thus far • Potential for more efficient, clean production of fuel

Table 2: Technologies Relevant to New Jersey's Greenhouse Gas Reduction Goals[41-44]

Biofuel Production and Combustion Capacity in New Jersey

Biofuel Production

In the fall of 2007, *Biodiesel Magazine* reported that New Jersey has the fifth largest potential capacity of U.S. states for producing biodiesel at 134 million gallons per year (MMgy).[45] This amount of biodiesel could be used to power approximately 131,719 homes per year (assuming the average U.S. home uses approximately 10,000 kWh of electricity per year).[46] New Jersey's existing facilities can produce up to 74 MMgy of biodiesel, and there are plans for new plants that will enable an additional 60 MMgy in production capacity.[47] Currently, there are two operating biodiesel facilities in New Jersey: Eastern Biofuels, LLC located in Newark[48] uses soybean oil to produce biodiesel, and Fuel: Bio Holdings, LLC located in Elizabeth[49] produces biodiesel from varied inputs.[50] Renewable Power and Light PLC is planning for a 60 MMgy production facility that will produce biodiesel. The company is also converting an older gas-fired power plant in Elmwood Park into a biodiesel-only electricity generating facility rated at 65 MW,[51] and has successfully tested another 85 MW biodiesel-powered facility in Massena, New York.[52]

Green Diesel, LLC of Summit and Garden State Biodiesel, Inc. of Harrisonville[53] have recently developed plans for two additional production facilities, of 46 and 30 MMgy capacities respectively, that will use soybean oil, yellow grease, and animal fat feedstocks to produce biodiesel.[54] Although it remains unknown when (and if) all of the planned and under-construction facilities will commence biodiesel processing, New Jersey could soon be positioned to produce up to 210 MMgy of biodiesel if the total production potential is taken into consideration.

Electricity Generating Units Capable of Co-Firing Biodiesel

Table 1 in Appendix 2 lists the power plants in New Jersey that have the ability to co-fire biodiesel without making major modifications to existing facilities. These plants are currently using kerosene, distillate oil, and residual oil as primary fuels, and would not require major adjustments to make use of biodiesel. First, they would need to stabilize the temperature of the biodiesel storage tanks to prevent coagulation or crystallization of the fuel under cold conditions. Second, the fuel storage tanks need to be completely cleaned before the biodiesel blend is added. Once these adjustments are made to the power plant and its equipment, the blended biodiesel fuel would be handled and used much like regular diesel fuels .

Some plants have a higher total generation capacity than their diesel-fired generation capacity, which means that they are using more than one fuel to generate electricity. As RGGI regulates power plants of 25 MW total capacity and greater, it is critical to note each plant's total generation capacity. There are 16 power plants with 25 MW total capacities or greater that are currently fit to co-fire biodiesel. Regarding these plants, it is important to be aware of the diesel-fired generation capacity in order to estimate the actual amount of power that may be generated with biodiesel.

The total potential capacity of diesel-firing generators in New Jersey is estimated to be 2,883 MW (see Table 1, Appendix 2). Realistically, only a fraction of this would be sustained with biodiesel because it is unlikely that power plants will use 100% biodiesel fuel (B100); B20 (biodiesel blend of 20% biodiesel with 80% petroleum diesel) is more common. Additionally, generator-unit warranties and biodiesel price considerations would affect biodiesel blending.

Electricity Generating Units Capable of Co-Firing Biogas From Anaerobic Digesters

Table 2 in Appendix 2 lists power plants that are currently fit to co-fire biogas. Many of New Jersey's power plants that previously combusted primarily diesel fuels have been converted to operate with natural gas in order to lower emissions.[55] In total, the state's gas-firing generators have an estimated capacity of about 11,000 MW. With many generators able to use natural gas, landfill gas, and other biogas, there is ample reason to examine the feasibility of constructing ADs on-site at power facilities.

In the past, uncertainty regarding the economic viability of AD operation has deterred applications. As federal and state regulations encourage emission-reduction projects and renewable fuel use, the economic viability of AD operation will increase. Profits and cost-avoidance that power plants might realize through capturing and using biogas are dependent on commercial electricity rates, digester types, and other site-specific factors. In New Jersey there are existing loan, rebate, and grant programs which may assist power plants in constructing and operating anaerobic digesters.[56] These and additional programs could serve to offset prohibitively high upfront capital costs.

Small Scale Alternatives to Reduce GHGs in New Jersey

In addition to RGGI compliance, New Jersey is generally interested in reducing its greenhouse gas emissions. Although RGGI rules only apply to projects that produce 25 MW of power, there are several types of small-scale energy systems that can help reduce emissions. We have analyzed three examples of small scale energy systems:

- anaerobic digestion on farms,
- anaerobic digestion at wastewater treatment plants,
- and the combustion of recovered landfill gas.

Anaerobic Digestion on Farms

In 2007, the EPA released an update on anaerobic digesters at livestock facilities that generate electricity from manure. Of 111 digesters in the U.S., there are currently none in New Jersey. Surrounding areas, particularly New York State and the Midwest have several.[57]

Haubenschild Farm

One useful example is the 800-cow Haubenschild Farm in Princeton, Minnesota. The Haubenschild family commissioned the digester in 1999 at a cost of $355,000. At this facility, manure is collected and then stored in a 350,000 gallon in-ground cement tank. From there, the manure is heated in pipes inside the digester to create biogas that is used to run a 130 kW generator and a 5 kW fuel cell.[58] Assuming the generator and fuel cell each run approximately 12 hours/day, a total of about 55 homes could be powered each year (assuming the average U.S. home uses approximately 10,000 kWh of electricity per year).[59]

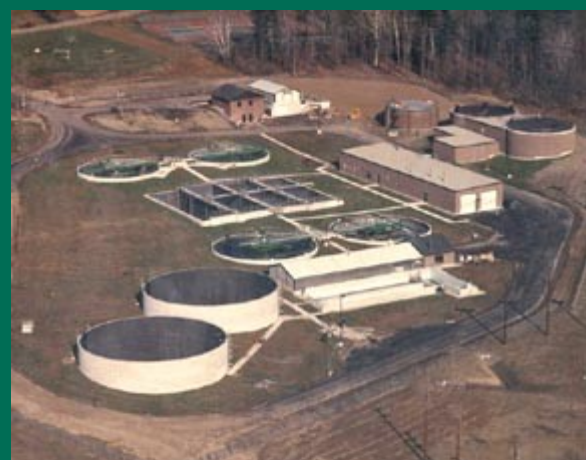
Facilities like the Haubenschild Farm are effective at producing electricity on a small scale even though RGGI does not regulate them.

Wastewater Treatment Facilities

Wastewater treatment facilities also have the potential to utilize waste products to generate electricity. These facilities use anaerobic digesters to produce biogas that is then used to produce electricity or is burned directly to provide heat. The EPA estimates that over 500 such systems operate in the U.S. with the potential to produce as much as 340 MW of electricity.[60]

Essex Junction Wastewater Treatment Plant

This plant in Essex Junction, Vermont is a wastewater treatment plant that generates electricity from methane gas. It uses an anaerobic digester to stabilize the sludge, which generates a methane gas byproduct. In 2003, Essex Junction installed 2-30kW microturbines designed to run off the methane gas. On average, the facility produces 30,300 cubic feet of methane gas per day, which allows each microturbine to run around the clock. The project cost $303,000 to build and will be completely paid for within 7 years. Its energy savings each year are equivalent to $37,000.[61]



New Jersey Potential

The Rahway Valley Sewerage Authority in Rahway, New Jersey, has a multiphase wastewater treatment project currently in development that should be complete by September 2008. The project will expand and upgrade the wastewater treatment plant for nine towns. The wastewater treatment facility will combine methane from sludge digestion with natural gas to power four generators that will provide 6.2 MW of electricity. The project also includes a cogeneration plant. The entire upfront cost is $248 million.[62] The electricity savings and sludge disposal cost reductions are estimated to be to approximately $1.2 million a year.[63]

Landfill-Gas Energy Generation

According to the EPA, landfills are the largest producer of human-related methane gas. Decomposing trash produces landfill gas which is equal parts CO_2 and methane (which is about 21 times more potent than CO_2 as a greenhouse gas).[64] If the gas is not captured it is released into the atmosphere where it contributes to local air pollution and climate change. It is extremely advantageous to capture this gas to produce energy. The EPA estimates that 445 facilities are using landfill gas for energy and that 535 landfills have the potential to use the gas for energy.[65]

Monmouth County and GFS Energy, LLC

Monmouth County was one of the first counties in New Jersey to begin capturing methane gas from its landfill and use it to produce electricity. In 1995, Monmouth leased landfill space to GFS Energy, LLC who operated an electricity facility using landfill gas. GFS Energy paid the county $250,000 a year to operate this facility until 2006. In 2006, the County and GFS Energy renegotiated their contract and GFS began utilizing all methane gas captured at the landfill, excluding the amount needed to run the facility. Each month, Monmouth County receives a royalty based on GFS Energy's revenues with the minimum royalty of $50,000 each month. The County also uses the gas to run the facility. In December 2007, the county began operating a $3 million generator for its own uses. The County was eligible for an $800,000 rebate from New Jersey's Clean Energy Program, therefore the project's net cost was $2.2 million. They anticipate a savings of $1.2 million each year.[66]

	Landfill	MW
1	Edgeboro Landfill	16.6
2	Ocean County Landfill	14.4
3	Monmouth County Landfill	10
4	Burlington Landfill	7.3
5	ILR Landfill	6.7
6	Edison Township SLF	6.6
7	Atlantic County Utilities Authority Landfill	5.4
8	Cumberland County Landfill	4.8
9	Balefill Landfill Gas Utilization Project	3.8
10	Warren County District Landfill	3.8
11	Pennsauken Sanitary Landfill	2.8
12	Kinsley Landfill	2.4
13	Kingsland Landfill	1.9
14	Hamm Landfill	1.2
15	Cape May Landfill	0.3
16	HMDC Kearny Landfill 1C	n/a
17	Salem County - Under Construction	
	Total	**88**

Table 3: New Jersey Landfill Gas Operations [67]

Note: *Capacity (MW) was aggregated in cases of separate operations at the same landfills.*

New Jersey Potential

As shown in Table 3, there are 16 landfills utilizing landfill gas in New Jersey that are capable of producing a total of 88 MW of energy (averaging 5.5 MW/facility).

In addition, there are two facilities under construction in Cumberland and Salem Counties and eight facilities with potential to utilize landfill gas.[68] If these new facilities also average 5.5 MW/facility, then New Jersey has the potential to harness as much as 55 MW of additional energy.

New Jersey Biofuels Potential

Lifecycle Emissions Models

To assess the net impact of one biofuel feedstock over another, it is necessary to understand the true environmental footprint of the feedstock. We have evaluated existing lifecycle emissions models that calculate the fossil emissions from producing biofuel from a variety of feedstocks and used them to create our own models. The result is a set of models NJDEP can use when calculating offset credits, specifically for electric generation facilities subject to RGGI rules.

We examined both first generation (soybean oil) and second generation (food waste and waste grease) biofuel feedstocks. We selected food waste due to the extensive generation of waste in New Jersey, and the lack of any useful application. However, this feedstock represents some challenges in terms of downstream operations such as collecting and separating waste. The second model examines waste grease, such as used cooking oil and tallow (animal byproducts), which we selected since we feel that there is significant potential in terms of availability and benefits of using this feedstock. Finally, we chose to model soybean oil, one of the most common sources of biodiesel, since we wanted to examine the results for a first generation crop in comparison to second generation feedstocks.

Methodology

Each model was designed to create a complete assessment of all carbon dioxide emissions generated from a unit of biofuel produced from each of the three feedstocks. This allows us to compare the amount of carbon dioxide emissions or reductions between scenarios, and create a sensitivity analysis for each. The models were constructed in the following manner:

1. We examined all steps involved in processing the feedstock and creating the fuel, identifying the main stages of each cycle and determining all associated fossil emissions.
2. We determined which energy inputs and outputs are critical for each of the phases in every model, accounting for the co-products or other waste created from each stage.
3. We researched existing studies and published reports that approximate the different variables needed. These reports provide either a specific amount of energy used for a process studied, (for example the specific amount of electricity used to generate a kg of biodiesel in a biofuel plant), or estimate values that can be extrapolated to the scenario created in the model, (for example the material composition of a vehicle to estimate the composition of the hauling trucks).
4. Since we gathered information from a variety of different types of studies and sources, we converted all emissions and co-products into comparable units.
5. We calculated CO_2 emissions generated at each stage of the lifecycle, and conducted basic sensitivity analyses to determine which variables had the greatest overall impact on the model results.

General Assumptions

Each lifecycle accounts for the fossil energy consumed in all processes, the capacity of the transportation vehicles to relocate the waste or fuel, the materials and energy involved in creating these transportation vehicles, the distances between rendering facilities to power plants, and the energy required for power generation.

One of the largest assumptions made in the transportation process phase in these models involves the carbon intensity of producing the trucks. This includes waste-hauling trucks in the case of the food waste model, grease collection tankers in the grease model, and soybean haulers and soybean oil tankers in the soybean oil model. Based on a paper published by the Massachusetts Institute of Technology (MIT),[69] along with data from Ward's Automotive Guide,[70] that estimate the composition of the average American passenger vehicle by type of material, these models assume that a waste-hauling truck, or a grease collection vehicle would have a similar material profile. It is also important to note that these models do not consider the carbon dioxide emissions associated with the production of the diesel fuel used to run the trucks, or of the fossil fuel sources used for normal electricity production in the New Jersey grid.

The models also make some assumptions about co-credits. A co-product credit is a percentage of the fossil CO_2 emissions which are attributed to a useful byproduct of the biofuel production process. This amount is subtracted from the total fossil CO_2 emissions associated with the biofuel. For example, in producing biodiesel one of the most common co-products is glycerin, which is typically used to make soap or cosmetic products. Since the glycerin is a useful product, total emissions of the lifecycle can effectively be reduced by 10% for every step in the process up until the point at which the glycerin was produced.[71]

All three models have been tailored specifically for the state of New Jersey, though with minor modifications they could be easily reconfigured for use in other areas. At the same time, all of the variables listed in the final model sheet can be altered to fit different scenarios, and results of the calculations will change based on those inputs. The most significant assumptions made in this model are related to the amounts of electricity, wastewater, co-products, and waste heat produced per unit of input in the process of making any biofuel. Any changes to these values (either because of more accurate data or technological/process improvements) will significantly alter the final model results. Appendix 3 has a step-by-step deconstruction of every assumption and calculation used in our models.

Food Waste Model

This model analyzes the carbon dioxide emissions from collecting municipal food waste, processing it into methane-based biogas using anaerobic digestion technology, and then combusting it to produce electricity. Figure 3 represents the flow chart of the basic stages included in this process.

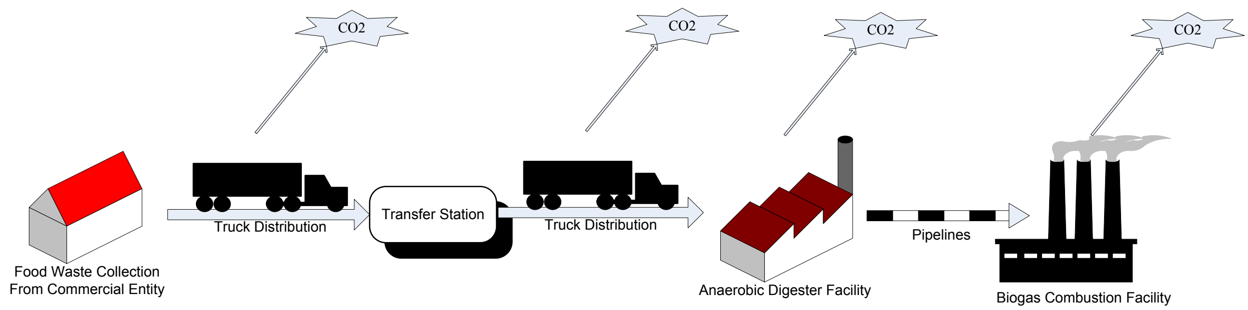


Figure 3: Food Waste Model Lifecycle Flow Chart

Major Assumptions

Source Collection

- Food waste inputs are taken from the point when they became waste products. Any energy or carbon inputs associated with their production should be attributed to the process of intended use (namely consumption).
- Food waste will be source-separated from the general waste stream before collection.
- Food waste will only be collected from large commercial entities such as restaurants and grocery stores.
- Waste from residential sources is ignored due to the difficulties associated with mandating separation and collection. Residential separation is not impossible, but simply unlikely given the current political and cultural climate.

Transportation

- There are two stages of transportation: from collection to transfer stations where it is aggregated and from the transfer station to the anaerobic digestion facility.
- The determined distances were chosen with a realistic perspective of where these digesters might be located.

Anaerobic Digestion

- Many small-scale digesters would be constructed at the sites of electric generation facilities that would be suitable for co-firing biogas.
- Ethanol plants and anaerobic digesters of similar cost have similar types of material inputs, and these inputs produce similar amounts of greenhouse gas emissions. By utilizing data from studies of ethanol production plants which estimated the carbon dioxide emissions associated with capital construction costs and size of various plants, we were able to estimate carbon dioxide emissions produced as a result of the construction of an anaerobic digester.

Electricity Generation

- The model assumes electricity generation will occur on-site, at the pre-existing facilities; therefore, the greenhouse emissions resulting from the construction of the generating facility have not been taken into consideration.
- Current generation occurs with single-cycle turbine driven technology, and significant improvements to efficiency could be gained if combined-cycle technology is considered.

Wastewater and Co-production

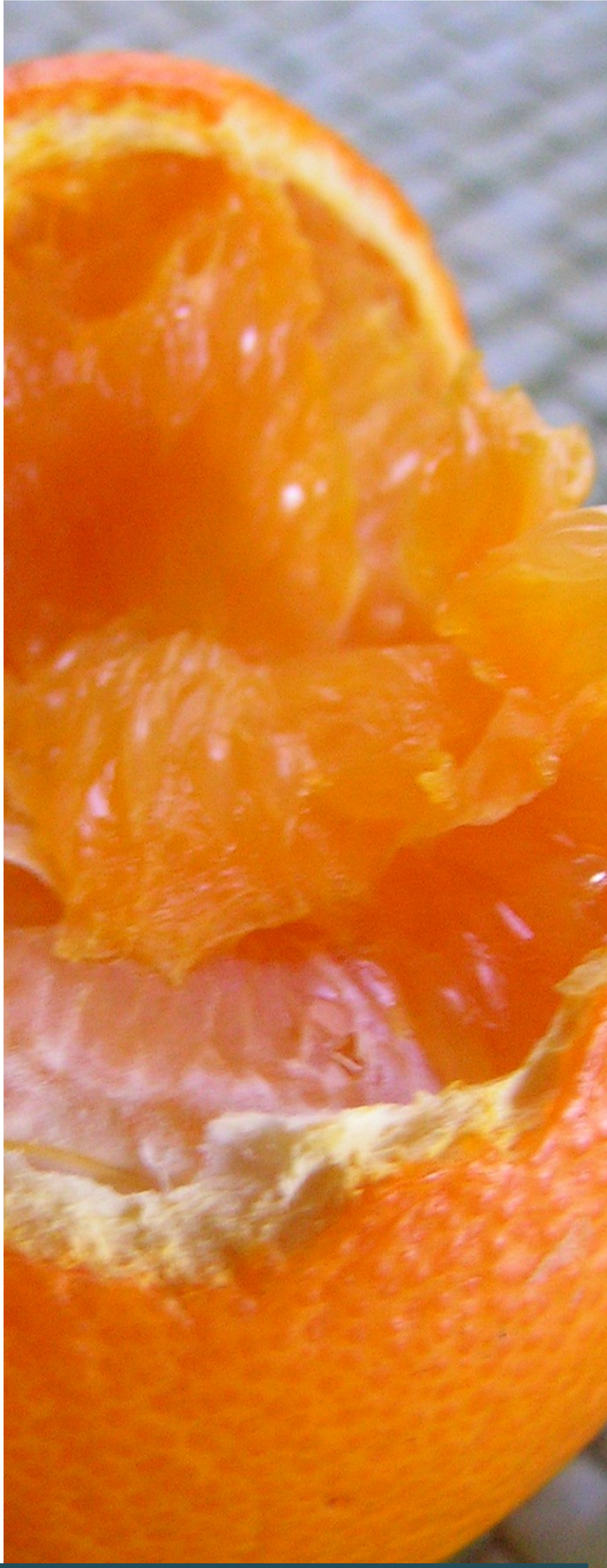
- Any wastewater produced in the anaerobic digestion process will be treated in a conventional wastewater treatment plant.
- This model includes a variable for the co-product credit associated with the economically useful byproducts of the anaerobic digestion process. An assumed value of 10% is used to attribute carbon dioxide emissions and offsets generated in the food waste lifecycle to these byproducts. This is a fairly conservative estimate compared with other co-product credit estimates in biofuel production scenarios.[72]

Results

Totaling the CO_2 equivalent emissions for each stage of the lifecycle, applying the co-product credit of 10%, and applying the credit for emissions saved through diversion of waste from landfills produces a figure of **-0.9296 kg of fossil CO_2 equivalent emissions per kWh of electricity generated from an anaerobic digester.** This equates to approximately -153.38 kg of fossil CO_2 equivalent emissions per metric ton of food waste used. See Appendix 3 for detailed calculations.

Given the best assumptions and data available, the results of the model suggest that any food waste diverted from landfills and used to produce electricity using anaerobic technology are actually net greenhouse gas negative. This is due to the extremely significant savings in emissions from landfills, and would remain the case even assuming a 90% average methane capture rate for the entire State. Though emissions associated with plant construction are likely to rise with the incorporation of more accurate data, collection/transportation of the food waste (and possibly the biogas) are likely to remain the largest contributors to greenhouse-gas emissions.

While the scale of anaerobic digestion projects will be constrained by the limited supply of the feedstock and the capital costs associated with construction, this technology has potential to reduce the fossil carbon footprint of the State of New Jersey.



Waste Grease Model

This model calculates the carbon dioxide emissions from collecting waste greases (yellow grease and tallow) from existing restaurants and commercial entities, processing them into biodiesel using rendering and methyl esterification technology, and then combusting them to produce electricity. Figure 4 represents the flow chart of the basic stages included in this process.

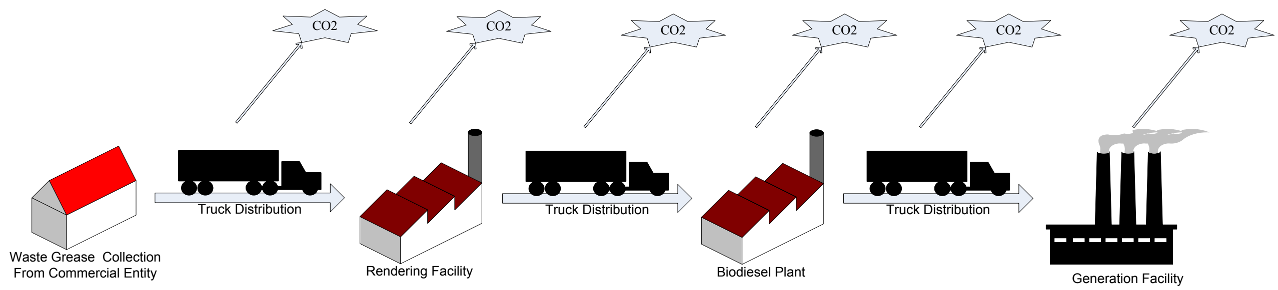


Figure 4: Waste Grease Model Lifecycle Flow Chart

Major Assumptions

Source Collection

- Only waste greases currently being disposed of are considered as inputs, and they enter the biodiesel lifecycle at the point when they became waste products.
- The collection of waste greases is assumed to occur in a manner and scale similar to current methods (private collection and hauling).
- Because waste greases currently being collected and utilized as positive economic goods are not considered, we need not account for displaced economic activities.

Transportation

- The emissions produced by the actual transportation of waste grease and biodiesel have been tailored to a specific production scenario. The distances between an actual rendering plant, biodiesel production facility, and cogeneration power station have been used instead of average distances, thus allowing the model and its results to be more specifically tailored to different scenarios.
- In our opinion, the chosen distance scenario still reflects a fairly realistic average distance scenario.

Rendering and Refining Process

- Carbon dioxide emissions associated with the construction of rendering, refining, and electricity generation facilities have not been considered in this model, largely because the majority of all infrastructure needed to complete this process is currently in place, though increases in production beyond certain volumes will require new facilities.
- The model is only geared to yellow grease and tallow, since they have approximately equivalent energy inputs for rendering. The model could be modified slightly to work for brown grease by adjusting the numbers for rendering energy and wastewater associated with the rendering cycle.

Wastewater and Co-production

- Any wastewater produced in the rendering facility or the biodiesel production plant is treated in a conventional wastewater treatment plant.
- A co-product credit of 10% is associated with the generation of glycerin from the biodiesel production process. This glycerin byproduct represents approximately 10% of the mass-balance in the biodiesel refining process.[73]

Mass Loss

- The rendering of waste grease into usable oil involves a loss of mass as contaminants and water are removed. We have calculated that an average mass-loss for yellow grease and tallow is about 11%, meaning that approximately 1.11 units of grease are needed to produce 1 unit of usable oil. Therefore, the fossil CO_2 emissions of each stage of the lifecycle model up to and including rendering will need to be increased by 11% to account for the added amounts of waste grease needed to produce an equivalent amount of biodiesel.

Results

The estimated number of kg of biodiesel needed to produce 1 kWh of electricity, multiplied by the final number of kg of CO_2 equivalent emissions generated per kg of biodiesel produced by the model result is **0.0619 kg of fossil CO_2 equivalent emissions per kWh of electricity generated from waste-grease derived biodiesel.** This can be compared to the -0.9296 kg produced per kWh generated using biogas from anaerobic digesters, and the 0.5723 kg produced per kWh through current generation of electricity in the New Jersey grid.[74]

The value given above for electricity currently produced in the New Jersey grid only represents the direct fossil emissions from the combustion of fossil fuels, not the associated emissions generated through the production, processing, or transportation of the fuel sources.

Soybean Oil Model

This model looks at processing the soybean feedstock using methyl esterification technology for biodiesel production to be used for electric cogeneration facilities in New Jersey. It is further designed to estimate the amount of greenhouse gas emissions produced from the cultivation of the soybeans. Figure 5 shows the diagram of the lifecycle analyzed.

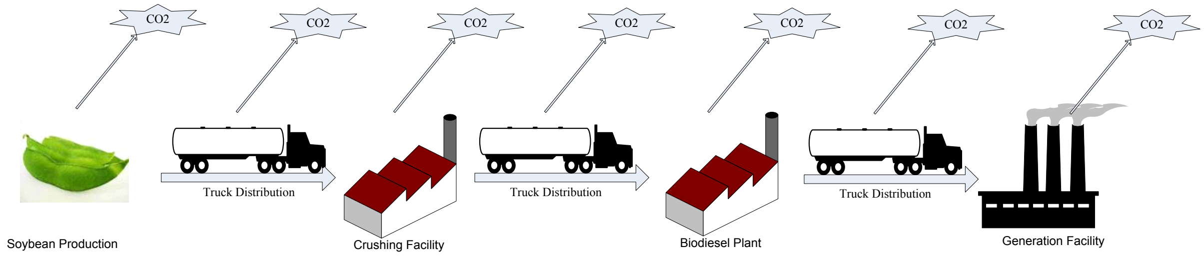


Figure 5: Soybean Oil Model Lifecycle Flow Chart

Major Assumptions

Cultivation

- Soybean planting season in the U.S. takes place in May and June and harvesting occurs from September to November.
- No existing soybean cultivation will be allocated to biodiesel production. Instead, additional cultivated land area will be needed to increase soybean yields. This assumption was made in order to avoid the uncertainty related to soybean's role as a food stock.
- Fossil fuel input values for construction of farm machinery is considered by accounting for the amount of energy input per liter of biodiesel produced.[75]
- Inputs to the soybean production process are divided into two categories: the inputs for **fossil fuel energy** including diesel, gasoline, natural gas, propane and electricity; and the **primary energy** inputs including nitrogen fertilizer, phosphate fertilizer, potash fertilizer, and agrochemicals, (including pesticides, herbicides, etc).

Crushing and Biodiesel Production

- Once harvested, soybeans must be crushed and pressed to obtain the oil.
- Data for the carbon emissions associated with soybean crushing and processing were obtained from the NREL study of lifecycle inputs to soybean biodiesel production.[76] These numbers include values for natural gas use, steam production, electricity, and hexane production.

Transportation

- Transportation distances are based on a specific farm in Southampton, New Jersey, the nearest available crushing facility in Salisbury, Maryland, and an existing biodiesel plant located in Berlin, Maryland. We also assume that the resulting biodiesel fuel will be co-fired at an existing cogeneration power plant located in Vineland, New Jersey.
- New transportation vehicles will be required to haul soybean oil from the farm to the processing facilities, and new vehicles will be required to transport biodiesel to the cogeneration plant.
- An average liquid tanker truck weighs approximately 10 short tons, or 20,000 lbs.[77] For the purposes of this vehicle construction segment, we also assume that the vehicle transporting processed soybean oil from the crushing facility to the biodiesel plant, and the vehicle transporting refined biodiesel to the power generation facility, have the same profile.

Co-product Credit

- The production of biodiesel renders two main co-products: a 25% credit to the production of soybean meal which is mainly used as an animal feedstock and a 10% credit associated with the generation of glycerin.

Results

Results from the soybean analysis show that aggregating the CO_2 equivalent emissions for each stage of the lifecycle and applying the co-product credits produces a final number of **0.3309 kg of fossil CO_2 equivalent emissions per kWh of electricity generated from soybean derived biodiesel**.

Our analysis shows that soybean production accounted for by far the largest percentage of emissions (66%), followed by biodiesel production (13%), soybean crushing

(11%), transportation distance (9.615%), vehicle construction (0.4%), and wastewater treatment (0.006%). We vetted these results against other studies in our literature to obtain a general comparison of how each stage of the lifecycle stages contributes to the overall emissions profile of the feedstock. This high-level comparison confirmed our results. The NREL study shows that agriculture and crushing make up roughly 47% of fossil fuel requirements while the processing of soybean oil into biodiesel requires approximately 49%. Since the NREL study did not account for the energy inputs related to the production of farm machinery, removing that number from our calculations would produce similar results.

Another major assumption we made is that the current biodiesel production plants (either in New Jersey or nearby) have the excess capacity to process additional soybean or waste grease inputs efficiently and effectively. In reality, if New Jersey does take policy action towards embracing biomass-based energy sources, specifically biodiesel, it will likely need to invest in new infrastructure. This would increase the carbon footprint of the biodiesel plant stage of the lifecycle considerably.

This model does not take into consideration sustainable farming guidelines. Therefore, because the production segment is such a large contributor to the overall carbon emissions, soybean could become a more attractive first generation feedstock by focusing on reducing the carbon footprint of the fertilizer inputs or the crushing energy inputs. In addition, soybean production may be more economical and sustainable in other parts of the country where conditions such as climate, weather, soils, etc. are more conducive to growth. This model looks specifically at production of the crop in New Jersey. In reality, New Jersey may choose to purchase soybeans or soybean oil from out of state. In this case, the additional input or transportation pathway must be modeled.

A paper published by Hill et al. conducted a thorough study of the lifecycle emissions of biodiesel from soybean, comparing it to ethanol from corn grain.[78] Utilizing some similar assumptions in our model (such as machinery composed entirely of steel for simpler carbon accounting), their conclusions served as a benchmark to verify our results for associated CO_2 emissions. However, there were some major differences between the two studies. We felt that the Hill study's inclusion of CO_2 emissions from the households of farming families was outside the realistic scope of consideration, and that assuming the use of hybrid or specialized seed was equally unnecessary. With the aim of providing slightly conservative estimates of carbon savings, our study also used a much lower number for the co-product credit associated with soybean meal than did the Hill paper. Still, the results of the two analyses were fairly similar, with the Hill paper concluding that fossil carbon emissions would be reduced by approximately 40% through the production and use of soybean biodiesel, and our results showing a slightly higher reduction of about 42%.

Sensitivity Analysis

A basic sensitivity analysis has been conducted for every model to quantitatively determine the variables contributing most directly to the results, and also to qualitatively establish the range of possible variation for different assumptions. These analyses have been conducted for the current assumptions given in the most-likely-scenario models, and reflect the extent to which a 100% change in the value for any variable will affect the final value produced. For example, a 100% change in the value for vehicle weight will change the final number for kg of CO_2 equivalent produced per kWh generated by 1.2%. In this manner we can roughly conclude which variables have the largest effects on our final results. All detailed results for the sensitivity analysis are included in each model section in Appendix 3.

Canola

Although time and resource constraints have prevented us from assembling a comprehensive model for the fossil carbon dioxide emissions associated with the production of biodiesel from canola (a particular type of rapeseed), a detailed literature review of the subject allows us to draw some general conclusions.

As a first generation feedstock produced using conventional agricultural methods, a lifecycle pathway diagram for canola would be very similar to one for soybeans, with a few minor modifications. One unique property of canola seed is that by weight, it yields twice the amount of oil as soybeans. The oil yield (in liters) per kilogram of grain/seed is 0.44 for canola and 0.2 for soybeans.[79] Assuming similar inputs per acre, this would correspond to per unit fossil carbon dioxide emissions for feedstock production of approximately one half those of soybeans.

However, canola requires one very significant on-farm input which soybean does not: nitrogen fertilizer. Current research suggests that on average, canola requires 100 pounds of nitrogen input per acre. This is highly significant, since scientific literature suggests that nitrogen inputs may be the largest single contributor to greenhouse gas emissions when considering conventional agriculture.[80] Therefore, because nitrogen fertilizer is energy intensive to produce, the input energy required to produce 1 gallon of biodiesel from canola is 2,300 Btu per gallon of biodiesel greater than biodiesel from soybean.[81]

Carbon dioxide emissions associated with biodiesel production, wastewater treatment, and the allocation of co-product credits would be similar to those determined for the soybean model. One additional point to consider is the fact that canola is currently produced mainly in the Northern-Central U.S. and in Southern-Central Canada. Depending on the ability to cultivate it closer to New Jersey, significant transportation costs/energy inputs may need to be considered.

Comparative Results

Table 4 illustrates the final conclusions of each model in comparison, along with standard CO_2 emissions from electricity generated in the New Jersey grid. As expected, biodiesel produced from waste grease is less carbon intensive than fuel produced from first generation feedstocks because there is essentially no production process for waste grease to consider. The most important point to note is that according to our results, each of these biofuel production processes is less CO_2 intensive than producing electricity with conventional fossil fuels.

CO_2 Equivalent Emissions from all Models	
Fossil Fuels	0.5723 kg / kWh produced
Soybean Oil	0.3309 kg / kWh produced
Waste Grease	0.0619 kg / kWh produced
Food Waste	- 0.9296 kg / kWh produced

Table 4: General Results from all Models

Figure 6 summarizes the different inputs that compose the total CO_2 equivalent emissions associated with generating one kWh with each type of fuel source. The summary of inputs for the food waste, waste grease, and soybean oil models are color-coded (refer to the legend to identify each input for a fuel). CO_2 equivalent emissions are all inputs with a positive value. Each of the three biofuel models also show a net negative value which are CO_2 equivalent emissions savings such as co-products and landfill savings. An important note is that fossil fuel emissions represent only direct emissions from combustion and do not represent the sum total of energy inputs from fossil fuel production.

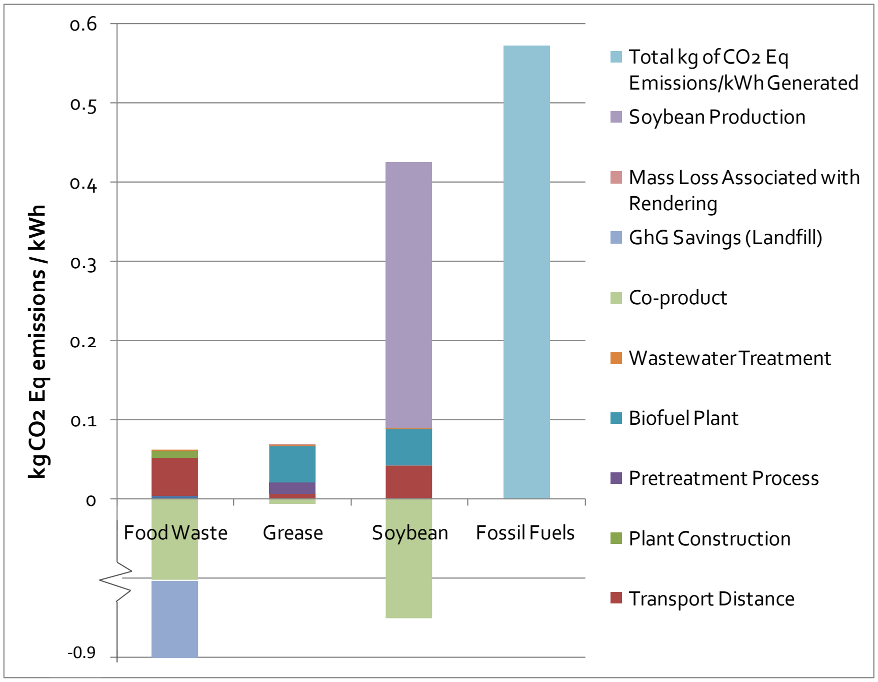


Figure 6: Total kg of CO_2 Equivalent Emissions per kWh Generated by Feedstock Divided by Lifecycle Section

Finally, Figure 7 shows the net positive and negative CO_2 equivalent emissions for each fuel source (these numbers are the same as in Table 4). One caveat regarding these summarized numbers is that the CO_2 equivalent emissions for each biofuel do not take into account emissions associated with the construction of a biofuel production facility. If the emissions for facility construction were taken into account, the CO_2 equivalent emissions for the three listed feedstocks would be closer to the value of CO_2 equivalent emissions associated with fossil fuels.

It must be noted that the fossil fuel number shown in this figure does not include the total associated carbon dioxide emissions since there was no lifecycle calculation completed for fossil fuels. A full lifecycle calculation for fossil fuels would take into account factors such as infrastructure and transportation vehicles, which would likely increase the fossil fuel carbon dioxide emissions amount significantly.

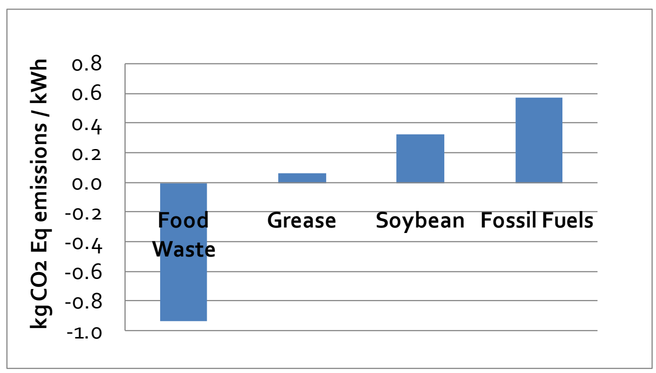


Figure 7: Total kg of CO_2 Equivalent Emissions per kWh Generated by Feedstock

Model Limitations and Future Steps

These models provide NJDEP with the basic tools to help them determine and quantify the emission reductions achieved by different initiatives throughout the State of New Jersey. It is important to note, however, that there are several limitations to these models. For example, they do not consider the carbon dioxide emissions associated with the production of the diesel fuel used to run the trucks or of the fossil fuel sources used for normal electricity production in the New Jersey grid. Modifications to those two assumptions could be the next step to broadening the scope of the study.

As mentioned in the results, the amount of emissions attributed to fossil fuels (0.5723 kg produced per kWh) considers only the actual emissions at the plant, and does not take into account emissions over a complete lifecycle of the feedstock as do our constructed models that capture the carbon dioxide emissions generated throughout the entire production, transport, and processing chain. It is reasonable to conclude that a more robust assessment of the total carbon impact of fossil fuels, taking into account all associated processes, would yield a higher number of net carbon dioxide emissions than the number representing strictly on-plant emissions. This consideration renders the substitution of biofuels for fossil fuels even more promising to reducing the carbon dioxide emissions from electricity generation.

It is also important to note that we have assumed that electricity generation will occur at existing facilities. The greenhouse emissions resulting from the construction of additional generating facilities have not been established yet, and will need to be included in future studies. It is also assumed that current generation occurs with single-cycle steam driven technology, but there is potential for significant efficiency improvements if combined-cycle technology is considered.

Finally, future analysis should include a scenario in which wastewater could be treated and released directly from the sites of anaerobic digesters, grease renderers, and biodiesel production facilities. This would require significantly less energy compared to diverting the water to conventional treatment facilities, since the wastewater generated in these processes would require fairly low amounts of treatment compared to normal municipal wastewater. However, due to the minimal contributions of CO_2 equivalent emissions from wastewater treatment in all the models, the overall impact on model results would likely be negligible.

Lifecycle Emissions Models

Food Waste

While the use of food waste for electricity generation has several environmental and economic benefits, substantial challenges regarding its available volume and required infrastructure are an impediment to its widespread application in New Jersey. Using food waste as a feedstock greatly reduces the greenhouse gas emissions of electricity generation facilities when compared to fossil fuels. There have been some successful pilot projects for food waste. The University of California at Davis operates the largest food waste digester in the country and has the potential to digest up to 3 tons of food waste per day (see UC Davis case study). Food waste represents a component of existing mixed solid waste, but is not currently available as a separated feedstock.

Therefore, any program design that considers food waste as a potential fuel source would need to address the major issues of feedstock supply and municipal solid waste sorting. In addition, the high capital costs for construction and maintenance of these facilities can be a prohibitive factor. Currently, limitations on production and processing capabilities for food waste render it a less viable alternative to fossil fuels for electricity generation.

CO_2 equivalent emissions of fossil fuel electricity generation: 0.5723 kg/kWh
CO_2 equivalent emissions of food waste electricity generation: -0.9296 kg/kWh
Net emissions reduction: 1.5019 kg/kWh

Benefits

- Has negative greenhouse gas emissions and the greatest reduction potential of the three models;
- High potential for reduction of RGGI carbon allowances;
- Utilizes an existing waste product that would otherwise be sent to landfills;
- Beyond the carbon reduction as a biofuel feedstock, diverting food waste from landfills reduces landfill methane release;
- Currently no competing applications for food waste;
- Stable generation of food waste.

Challenges

- New Jersey lacks a sufficient sorted supply of food waste because existing waste is commingled with solid waste;
- Collection of food waste requires additional hauling and transportation from disparate locations;
- High capital cost of construction and maintenance of food waste digesters;
- Not directly applicable to RGGI objectives because most digesters operate under 25 MW capacity;
- Potentially unpopular among New Jersey residents and businesses that may not want to handle trash and rotting food.

Recommendations

- Encourage construction of small anaerobic digesters at RGGI compliant facilities;
- Consider projects to encourage separation of food from other trash, including pilot projects in major New Jersey cities;
- When developing food waste to energy infrastructure, site processing facilities in a centralized location to limit transportation distance and related emissions;
- Begin a public relations/education campaign to dispel concerns regarding trash and food waste;
- Consider tax incentives for utilities that install food waste digesters.

Case Study: UC Davis Food Waste[82]

On October 24, 2006, the Biogas Energy Project at the University of California at Davis (UC Davis) began converting food waste into biogas for electricity generation using an anaerobic digester. The digester is capable of processing 3 tons of food waste, yard waste, and manure each day. Each ton of waste produces enough energy to power 10 homes for one day. Dr. Ruihong Zhang, a professor of Biological and Agricultural Engineering at UC Davis launched this project as the culmination of her research on anaerobic digestion, which proved that small-scale laboratory experiments could convert food waste into methane and hydrogen gas. In order to adapt a digester to meet her research needs, Dr. Zhang worked with Onsite Power Systems who invested a total of $2 million in the project. In California, over 5 million tons of food waste are sent to landfills each year. Thus, this technology has the potential to divert a significant portion of the waste stream away from landfills.

Potential for New Jersey to Adopt a Similar Program

New Jersey faces one major obstacle in adopting a food waste to energy program: food waste is not widely available as a separated feedstock. Food waste would need to be separated from other municipal solid waste. It would be most feasible to start at restaurants, hotels, and casinos where food waste represents a large percentage of total waste. Once sufficient feedstock is secured, the next step would be to build appropriately-sized anaerobic digesters at the sites of existing gas-burning generation units.

Waste Grease

Waste grease has several positive environmental effects when used for electricity generation. Aside from producing fewer emissions upon combustion, it is a renewable source of energy made from vegetable oil, frying oils, and tallow. Using waste grease diverts this otherwise polluting substance from landfills, incinerators and sewers. Because the grease has a prior use, it does not require new land to be cultivated, nor is there a conflict of interest between food and feedstock production.

The viability of waste grease for electricity production, however, is limited by current collection and processing methods. In addition, there is already a market for yellow grease that could compete for the grease needed to generate biodiesel. Programs and policies designed to promote the generation and use of biodiesel from waste grease might focus on a comprehensive availability assessment, structuring a collection scheme, and encouraging the recycling of waste grease. The City of San Francisco, California, recently launched SFGreasecycle, a program to collect waste greases from restaurants and residents and convert it to fuel for the City's transportation fleet. This program can be used as a guide for the NJDEP when developing a similar program for New Jersey (see SFGreasecycle case study).

CO_2 equivalent emissions from fossil fuel electricity generation: 0.5723 kg/kWh
CO_2 equivalent emissions from waste grease electricity generation: 0.0619 kg/kWh
Net emissions reduction: 0.5104 kg/kWh

Benefits

- Fossil carbon reduction potential is significant;
- Does not compete with the production of food as compared to first generation biofuel feedstocks;
- Utilizes a waste product that would likely be sent to landfills or illegally dumped;
- Potential to increase collection of waste grease thereby decreasing the build up of grease in wastewater pipes; saves municipalities a significant amount of money from avoiding costly clean-up projects associated with clogged sewage and water lines;
- Potential to provide more jobs as the scale of waste grease hauling increases;
- Minimal modification costs to electricity generators already firing liquid fossil fuels;
- Stable supply of yellow grease from the local restaurant industry, brown grease from water treatment plants/restaurants and tallow from slaughterhouses;

Challenges

- Lack of comprehensive data on total availability;
- Implementing a program to collect yellow grease may be costly and interfere with existing uses;
- May require investment in a new fleet of grease collection vehicles and training new staff;
- Technological limitations for commercially processing brown grease into biodiesel.

Recommendations

- Incentivize grease recycling in the commercial and residential sectors;
- Consider initiating a program that contracts with local haulers to collect additional waste grease for power plants;
- Outfit garbage trucks or recycling trucks to also collect grease;
- Provide research and development grants/tax credits to encourage the processing of brown grease and tallow to take advantage of underutilized waste grease feedstocks.

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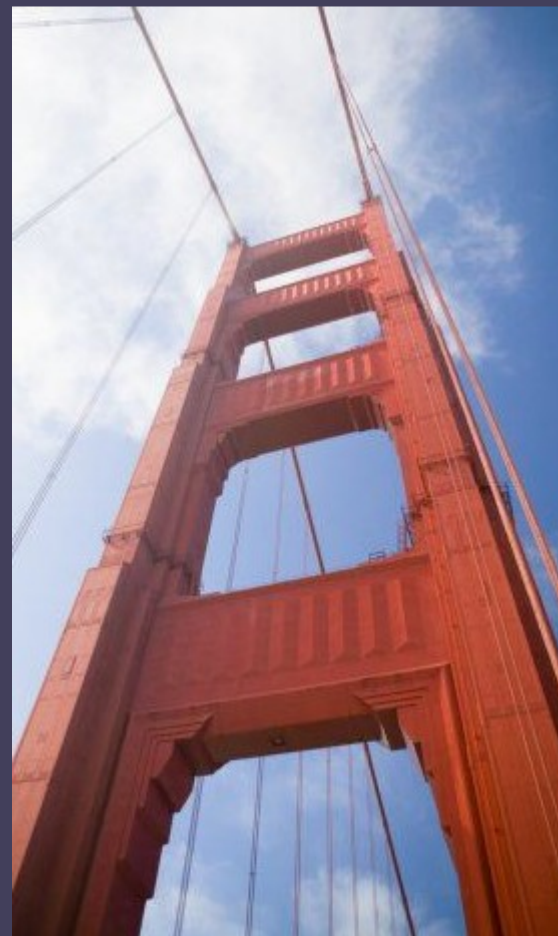
Case Study: SFGreasecycle[83-87]



In November 2007, the City of San Francisco launched SFGreasecycle, a citywide program to collect used cooking grease and convert it to fuel for the City's transportation fleet. This program is the first of its kind in the U.S.

Every year, San Francisco spends $3.5 million to address sewer overflow problems attributable to grease. Restaurant grease that escapes or is illegally dumped into wastewater hardens and collects on pipe walls, restricting the flow of water and causing backup and overflow of sewage. The City's Public Utilities Commission (PUC) recognized this problem and established the SFGreasecycle program for used yellow grease, which involves 1) getting the city's 1,600 vehicles running on biodiesel (B20), 2) securing the feedstock, and 3) using the grease in the City's transportation vehicles.

In May 2006, San Francisco Mayor Gavin Newsom took the first step to achieving SFGreasecycle's goals by issuing Executive Directive 06-02: Biodiesel for Municipal Fleets, reaffirming the City's dedication to using alternative fuels and setting goals for using biodiesel. The Directive stated that all departments should be using at least 25% B20 by March 31, 2007, and 100% B20 by December 31, 2007. The next step, securing the feedstock, is achieved as the City collects, (at no charge), grease from participating restaurants and processes it into biodiesel. Finally, the cycle is completed when the grease is used in the City's fleet. The PUC estimates that it can generate 1.5 million gallons of biofuel each year from the City's waste grease.

When the program started, there were 59 participating restaurants—this number has grown to 161 in only a few months. Since the program started, independent haulers have been forced to lower their prices to compete with the free services offered by the city. The City has also extended this program to residential drop-off events. The program costs $1.3 million per year, but the PUC considers this a small price to pay when the cost of clogged drains amounts to $3.5 million a year.

Potential for New Jersey to Adopt a Similar Program

San Francisco's program could potentially be adapted to help New Jersey achieve its emission reduction goals. For New Jersey, it is not economically feasible to begin hauling waste grease at no cost to customers. Instead, the State could enter into contracts with existing waste grease haulers wherein the state pays a discounted rate for hauling, while restaurants pay nothing. As costs to restaurants go down, more restaurants are likely to enter the program thereby increasing the supply of grease. The state could utilize existing biodiesel processing facilities and perhaps create incentives for retrofitting plants to use biodiesel for electricity generation.

Soybean Oil

First generation biofuels are relatively carbon intensive when compared with food waste and waste grease. First generation crops maintain carbon uptake throughout the growing cycle but there is also fossil carbon released during the harvesting, transporting and processing stages of the biofuel process. However, first generation biofuel production is already occurring in New Jersey and is likely to increase in upcoming years especially given available government incentives (see Appendix 4). We must work within this existing framework and support the use of first generation biofuels only when farmers strictly adhere to sustainable harvesting guidelines.

CO_2 equivalent emissions of fossil fuel electricity generation: 0.5723 kg/kWh
CO_2 equivalent emissions of soybean oil electricity generation: 0.3309 kg/kWh
Net emissions reduction: 0.2414 kg/kWh

Benefits

- Net carbon savings as compared to fossil fuels;
- Minimal capital cost because of existing infrastructure for processing first generation biofuels and electricity generation from biofuels;
- Potential for reduction from RGGI carbon allowances if the feedstock is sustainably harvested;
- Provides a secondary/alternative market for farmers potentially reducing the fluctuation in commodity prices.

Challenges

- May pose threats to natural areas and land held in conservation programs as agricultural land becomes more profitable;
- May increase capital costs to farmers as farmers rearrange cropping patterns;
- Diverts food from consumption and leads to unstable food prices;
- Questions of sustainability – maintaining food supply versus boosting overall production.

Recommendations

- If RGGI allowance reductions are to be granted to facilities using first generation crops, it is important that they adhere to strict sustainable harvesting guidelines;
- The NJDEP should take an active role in supporting the maintenance of fallow and conservation land through financial incentives to keep some land out of agricultural production;
- When using first generation crops for biofuels, the NJDEP should encourage the use of non-food crops as opposed to food crops.

Feedstock Scenario Analyses: The Bottom Line

Model	Emissions Reduction Potential	RGGI Allowance Reduction Potential	Feedstock Status	Viability
Food Waste	Highest emissions reductions of three models	Greatest RGGI allowance reduction potential	Feedstock currently unavailable in sufficient volume	Not currently viable due to high capital costs and supply constraints
Waste Grease	Second highest emission reduction potential of three models	Greater RGGI allowance reduction potential than soybeans	Existing feedstock, but exact quantities unknown	Currently viable with yellow grease; viable technology not currently available for brown grease
Soybean Oil	Lowest emissions reduction of three models	Lowest RGGI allowance reduction potential	Existing feedstock source	Currently used and viable

Conclusion

Climate change challenges governments at all levels to develop innovative policy solutions. New Jersey has embraced that challenge by joining RGGI and adopting ambitious yet achievable greenhouse gas reduction requirements. As New Jersey attempts to meet its targets, it is clear that biofuels can play a role. Although our analyses show that there are no straightforward answers to implementing biofuels for electricity generation, we recommend that NJDEP continue to identify and apply sound, balanced approaches to realize the benefits that this alternative energy source presents.

We have provided individual assessments of the viability of the three feedstocks (food waste, waste grease, and soybean oil) modeled for electricity generation in New Jersey. Because of the issues of food security and land use change, we are hesitant to support first generation crops as biofuel feedstocks without strict adherence to sustainable harvesting guidelines. The potential benefits of utilizing second generation feedstocks can ultimately be greater than those of first generation feedstocks. The amount of available feedstock and the existing processing capabilities can make second generation feedstocks viable for New Jersey in the near future. Taking advantage of available sources of waste grease in particular could be an effective strategy for New Jersey in meeting its emission reduction goals. Finally, due to the dynamic nature of this subject, and the growing concern to find optimal solutions to reduce greenhouse gas emissions, we recommend that the NJDEP continue to invest in research of new feedstocks and technologies as they emerge Despite the role that economic market drivers play in facilitating increased use of biofuels, innovative energy policy is an essential component of any framework supporting alternatives to fossil fuel use.


Appendix 1
Sustainable Harvesting Guidelines

Introduction

With oil prices at historic highs and some effects of climate change already apparent, the call for sustainability is becoming louder. The Earth must support an ever-growing human population, increasing the strain on the natural resources we use to produce food, shelter, and energy. Under current growth rates, we are expected to add close to 3 billion people by 2050 to the current population of over 6.6 billion people.[88,89]

With the rise in population comes the associated increase in resource use. To meet the growing food demand, it is expected that we will convert one billion hectares of land to agriculture, a size larger than the United States.[90] Most of the highest quality lands are already cultivated, which means that future expansion will occur in more marginal lands where degradation of soils and surrounding water sources is likely.[91] It is estimated that agricultural water use will increase by nearly two times its current rate.[92] Additionally, increased agriculture brings the likelihood of greater fertilizer use and thus the potential for greater eutrophication and pesticide bioaccumulation.[93] Increasing the intensity of agriculture will also have profound effects on an already altered nutrient cycling system. Replacing lost nutrients from harvest with synthetic inputs can alter existing soil composition and can lead to increased atmospheric emission and nitrate leaching.[94]

To meet future needs, ecosystem services must be accounted for and protected. The implementation of more sustainable practices in every country in the world, regardless of development status will help alleviate these problems. However, what makes a system, particularly an agricultural system, sustainable is a rather contentious issue. Richard Harwood of Michigan State University offers some basic tenets:

1. agriculture must continuously increase productivity and efficiency,
2. biological processes must be controlled through increasingly natural processes (rather than with pesticides),
3. and on-farm nutrient cycles must be much more closed.[95]

Unfortunately, these points are rather ambiguous and quantitative measures are still lacking primarily because of disagreement over what exactly should be measured. Richard Noorgard of the University of California at Berkeley sums up competing interests well:

> *"environmentalists want environmental systems sustained. Consumers want consumption sustained. Workers want jobs sustained. Capitalists and socialists want their 'isms' while aristocrats, autocrats, bureaucrats and technocrats have their 'cracies.' All are threatened…with the term meaning something different for everyone, the quest for sustainable development is off to a cacophonous start."*[96]

Despite these challenges, there are effective tools that can be used to improve the long term sustainability of farming. Farmers will play an increasingly critical role as stewards of the land, and although they will have complex issues to face, many of the most pressing problems have been identified and there are viable solutions to address them.

The onus is on today's farmers, scientists and policy makers to devise systems that will meet the needs of a growing future population while maintaining current standards. David Tilman of the University of Minnesota notes that the next fifty years are likely to be the final period of rapid global expansion requiring, "…increased crop yields, increased efficiency of nitrogen, phosphorus and water use, ecologically based management practices, judicious use of pesticides and antibiotics…"[97] The sustainable harvesting guidelines that follow strive to balance the economic, environmental and sociopolitical pillars of sustainability.[98]

Goals and Intentions

The Regional Greenhouse Gas Initiative (RGGI) Model Rule[99] requires that electricity generators use biomass feedstocks that have been produced and harvested sustainably in order to receive credits, but what constitutes "eligible biomass" remains undefined under the RGGI rules. These guidelines are designed to assess the degree to which a first generation biofuel feedstock has been produced and harvested sustainably.

They include the following:

- a self-assessment tool for farmers,
- an explanation of the importance of each facet of the on-farm activities addressed,
- and recommendations for how stringently the regulatory agency should interpret the assessments in terms of defining whether a producer is employing sustainable harvesting practices or not.

The guidelines, specifically the self-assessment tool, are intended to be used by farmers and practitioners to assess the sustainability of their on-farm activities through simple and inexpensive measures that many farmers already employ. Farmers understand the importance of sustainable practices and will continue to be vital in encouraging sustainability in agriculture. These guidelines are designed to serve as a tool to help them assess their participation in the sustainable production of biofuels. By integrating a holistic approach, the aim of the guidelines is to promote awareness of human action upon the environment and the tradeoffs present in the process of crop production. Through assessment of soils, water use and quality, pesticide and fertilizer use, the goal is not to impede or inhibit production, but simply to ensure that the agriculture of today is able to continue long into the future and meet the needs of a growing population and economy.

The following summaries provide explanations of the importance of each facet of the on-farm activities addressed in the self-assessment tool.

Pest Management

In agriculture, a "pest" is any organism that hinders the viability of the crop.[100] While chemical pesticides can effectively control pests, the overuse of such chemicals is problematic for a number of reasons, the most immediate and common being the impact of the chemicals on the surrounding environment, such as pollution of local groundwater supplies from agricultural runoff. Other issues include the effect of these chemicals on the health and safety of workers and people living in nearby areas and pesticide resistance. In addition, applications can kill beneficial species in addition to the target pest species. On a larger level, the production of pesticides is chemical and energy intensive, and certain application techniques, such as aerial spraying, can drift into surrounding areas.[101] For these reasons, it is desirable to minimize chemical use and promote a more sustainable long-term agricultural system.

Integrated Pest Management (IPM) promotes a stable crop production while minimizing the risk of pesticides on humans, animals and the environment. It encompasses a multitude of strategies to control pests naturally, and when chemical use is necessary, to minimize the impact of such use. It does not require that all chemicals are outlawed and only organic farming is done, but rather, seeks to use more benign methods whenever possible.[102] Under our sustainable harvesting guidelines, it is important that farmers develop a pest prevention plan and document its implementation.

Some strategies of IPM include using natural predators, trapping devices, and biological pesticides. For example, biological and microbial pesticides (fungi, viruses, and bacteria) either target specific pests or compete with disease causing bacteria. Pheromones can disrupt normal mating behavior or lure pests into traps, and natural compounds such as fine clays or baking soda can prevent fungal growth. Also, crop rotation can eliminate the need for chemical pesticides by disrupting normal pest behavior.[103] In some cases, chemical pesticides may be applied, but it is imperative that their use is justified, and the least hazardous chemical is chosen.

Fertilizer / Nutrient Use

Tailoring fertilizer type and application rate to specific crops can help achieve optimal growth. Additionally, the soil composition and pH determines the effectiveness of the applied fertilizers.[104] While most fertilizers can be synthetically manufactured, there are important benefits to using organic inputs whenever possible. Organic fertilizer can be produced on-farm from a composting process, utilizing either animal or plant wastes. This practice not only saves the farmer money, but also promotes environmental sustainability by eliminating the energy required for fertilizer production (an energy intensive process), the negative externalities of mining nutrients such as phosphorus that are in limited supply, and the transport of the fertilizer from factory to farm.[105] A robust fertilizer plan considers the crop specificity as well as the ability of the soil to absorb and retain the inputs, and employ on-farm produced compost as a fertilizer whenever possible.

Fertilizers are best utilized by the plants when applied in the appropriate amounts, as under or over-application can limit their effectiveness. It is also crucial that the soil is able to readily absorb the applied amounts. Some of the most significant negative environmental effects of fertilizer use are the impact they have on the surrounding environment, such as waterways and lakes. A major global issue in the Gulf of Mexico in the U.S. is eutrophication, which occurs when nitrogen runoff from farms infiltrates waterways and causes algal blooms. An erosion control plan that limits runoff and strategies to improve soil health and fertility such as cover cropping can improve the ability of the soil to absorb applied fertilizer and retain them, thus reducing the negative impacts on the external environment.[106] The long-term fertility of the soil can be preserved by integrating a well-managed fertilizer plan with an overall sustainable farming strategy.

Crop Rotation Practices

Crop rotation is the practice by which a succeeding crop varies in species or variety from the previous crop. The rotation series can be within a single year (a winter cover crop and a summer harvest crop) or on a multi-year rotational period such as an entire year of barley followed by a year of wheat. The established benefits to operating a rotational crop system as opposed to a monocropping approach include increased crop yields (due to the enhanced soil fertility of multiple crops) as well as heightened disease resistance and reduction of soil erosion.[107] The choice of plant varieties that are integrated into the rotational system largely determines the extent of benefits. For example, legumes fix nitrogen in the soil, providing more nitrogen for the next variety planted on the same plot of land. Similarly, using multiple varieties in a cover crop planting, as opposed to a single variety, can confer even greater benefits such as control of invasive species, enhanced soil fertility, and increased resilience of the overall system.[108]

Because a well-executed polycropped farming system helps preserve soil fertility and reduce erosion, water usage, and the need for fertilizers and pesticides, it should be required practice for a farm producing biofuel feedstocks to be considered sustainably harvested under RGGI. While additional planning and management is also necessary to design, implement, and maintain a successful crop rotation program, the benefits far outweigh the costs, and the alternative strategy of monocropping is largely considered insufficient in ensuring long-term soil fertility and erosion control. There are numerous resources available to assist farmers in designing a rotational system, such as county and university cooperative extensions.

Water Use and Pollution Management

Water management is one of the key components for sustainability in agriculture because it is the single largest user of freshwater resources, using an average of 70% of global surface water supplies.[109] Given rising concern over global water shortages, and the fact that much of the world has little or no access to clean water, the diversion of water to agriculture is of great consequence. Therefore, it is essential for the agricultural sector to have a clear understanding of how its irrigation systems work, their capacity, and how best to control the use of water in order to conserve without compromising crop yields. There are excellent resources like ATTRA, the National Sustainable Agriculture Information Service, which provide information such as how to calculate appropriate water use.[110] The sustainable guidelines address appropriate water use in an attempt to optimize the potential for long term sustainability.

Appropriate water use is not only important for preserving valuable freshwater resources, but also limiting water pollution from agricultural chemical runoff and soil erosion. Water quality degradation can result in serious environmental and public health impacts, disruption of ecosystem function, and biodiversity loss. Agricultural practices often result in the discharge of pollutants and sediment to nearby water sources or water logging of irrigated land. The use of pesticides and fertilizers increases the likelihood of water pollution and therefore must be minimized as much as possible and carefully managed, monitored, and recorded. In addition to ecosystem benefits, costs are also minimized for farmers through appropriate water, fertilizer, and pesticide use. The sustainable harvesting guidelines address the optimal use of on-farm inputs as well as ways in which runoff, discharge, and sedimentation can be minimized or prevented.

Soil Management

There is a basic irony involved in meeting the food demands for a growing population. As population increases, there is an increase in demand, which requires an increase in production to meet the need. Yet, as the population increases, so too does the demand for land, which is in direct competition for food production. Farmers face many pressures including suburban sprawl onto formerly productive land. So farmers are often faced with having to produce more food on the same amount of land or less, which can threaten soil health.

Magdoff et al. assert that the foundation of sustainable agriculture is adequate management of soil organic material (SOM) – living organisms and residues in various stages of decomposition.[111] On the surface SOM protects soils from erosion and rain compaction while in the subsurface it stores vital nutrients such as nitrogen and carbon and maintains soil structure and tilth.[112] Because SOM serves various soil functions, definitive limits have not yet been established and any such attempts are based on consensus reports from soil inventories.[113] Thus, the questions addressing SOM and other nutrients in the sustainability guidelines represent more qualitative properties of soil with a healthy SOM content. Upon this base then, other qualities such as soil structure and water holding capacity are assessed in a similar fashion.

Soil quality changes rather quickly and is a direct function of stewardship.[114] Crops rely on nutrients to grow, nutrients are provided from the soil and, subsequently, soils take time and proper management to replenish nutrient supplies. In truth, not all soils are created equal in terms of production potential but the good news is that under proper care, degraded soils can be repaired. The key is finding the right balance of several critical elements. John W. Doran of the University of Nebraska-Lincoln notes that "the assessment of soil quality, health, and direction of change over time are the primary indicators of sustainable land management,"[115] and the ability to effectively diagnose and correct soil deficiencies is essential.

Forestry Management

The Forest Stewardship Council (FSC) has outlined both national and regional guidelines for forestry management in the United States which allow for a certification process of forests across the country. The national standards provide a baseline for forestry management practices for all forests nationwide, while the set of nine regional standards provide a framework for taking into account the environmental, economic, and social differences in the forested regions of the U.S.[116] These standards detail a wide range of practices from minimizing environmental impact, to avoiding biodiversity loss, to respecting the rights of indigenous people in the regions, to improving methods of monitoring and assessment. The FSC promotes sustainable forestry practices by providing these guidelines and a certification process for sustainable forestry. Implementing sustainable forestry management ensures the long-term existence of forest resources as well as the stability of cultures that depend on them.

Recommendations

Recommendations for the Regulatory Agency

Best practices in developing comprehensive guidelines for sustainable agriculture vary greatly depending on variables such as location, climate, soil type, land use history, and the specificities of the crop plant. Strategies to promote soil fertility in a corn crop on a 20-year old plot of flat land, for example, might vary greatly from what practices ensure long-term soil health on a hilly, newly developed berry farm. There are, however, some commonalities and general requirements requisite for a sustainable agricultural system. The regulatory agencies should assess the appropriateness of these requirements in meeting their own goals for ensuring the long-term health of agricultural lands.

Recommended Requirements by Topic

Pest Management

- An established IPM plan demonstrates a commitment to using biological controls or other environmentally benign practices whenever possible.
- For each pesticide used, there should be a comprehensive record that includes its application history, rate, method, and target pest and crop type.
- The farmer has made a good-faith effort whenever possible to lessen the negative effects of pesticides by using a less hazardous chemical, by adopting application methods that minimize environmental damage, and/or by implementing IPM strategies.

Fertilizer/Nutrient Use

- A nutrient management plan that provides a detailed application history of all fertilizers used.
- A regular system of soil testing for pH and nutrient levels that serves to ensure the effectiveness of the nutrient management plan.
- Use of organic fertilizers and/or compost produced on-farm from farm wastes is given preferential consideration as a practice promoting long-term sustainability.

Crop Rotation Practices

- A sustainable designation should ensure that a system of crop rotation is occurring on all lands in question.
- A system of crop rotation that includes either a cycle of a non-harvested crop that is planted to enhance soil fertility (and ultimately is tilled back into the soil), intercropping, or cover cropping is preferred.

Water Use and Pollution Management

- A documented irrigation plan that demonstrates efforts to reduce runoff, groundwater contamination (if applicable due to the presence of wells) and excessive use.
- Comprehensive water use records that show a stable level of water use (under normal climatic conditions).

Soil Management

- A long-term erosion control plan for all agricultural lands.
- Adoption of practices that promote topsoil conservation, and an assessment of their effectiveness.
- Results of regularly conducted "Soil Health Tests" should score mostly in the medium to high categories.

Forestry Management

- For forest products to be considered "sustainably harvested" under RGGI, the producer should be certified by the U.S. Forest Stewardship Council (USFSC).

Considerations for the Future

Climate Change

There is a consensus in the scientific community that global climate change will affect the Northeastern region profoundly. Some of the predicted climatic changes are increased flooding, storm surges, rising sea levels, and warmer overall conditions, though there is great uncertainty in the severity and onset of such perturbations.[117] Because farmers must adapt to climatic conditions, the regulatory agency should incorporate flexibility in assessing whether a farmer is practicing sustainable methods, particularly regarding directly relevant issues such as water usage. It is important to note that the questions included in the self-assessment tool assume climate regularity, and therefore may need to be modified to account for climatic variability.

It is crucial for farmers to take a proactive approach in developing adaptation strategies to climate change. While some agricultural practices can release stored carbon from the soil, a sustainable approach aims to build a healthy soil structure that can function as a significant carbon sink.[118] Similar to the place-specificity of best practices for sustainable agriculture, mitigation strategies vary depending upon the characteristics of the land. A comprehensive, robust farm management plan that promotes soil fertility is an essential first step in building a healthy agricultural system that is minimally vulnerable to changing climatic conditions.[119]

Land Use Changes

In these guidelines, the assumption was made to consider only land that is currently in agricultural production when assessing sustainability. However, as we look to the future, it is difficult to predict with certainty what land use changes might occur in the RGGI states if first generation biofuel crops become more economically attractive. There is the possibility that land currently producing food will be converted to produce biofuels, which has implications for food prices and availability in the region. Questions of soil nutrient levels and depletion rates, and long-term soil health must be maximized, particularly if farmers intensify their production. Also, it is probable that land currently not in agricultural production will be transformed for agricultural output if demand for biofuel feedstocks is high. This scenario, as highlighted in a recent article in *Science* by Searchinger et al., can drastically increase the carbon footprint of biofuels, due to the carbon released from land clearing.[120]

Pest Management

Note: *Pest refers to insects, plant diseases, fungi, rodents and weeds.*

Do you have an Integrated Pest Management (IPM) plan in place including scouting and economic thresholds to manage pests and reduce pest management environmental risk?

☐ YES ☐ NO

Do you have a record of the percentage of acreage where an IPM plan is in place?

☐ YES ☐ NO

Do you use pesticides?
Note: *Pesticide refers to herbicides, insecticides, fungicides, miticides, and rodenticides.*

☐ YES ☐ NO

Do you have at least two years of written records or documentation that support your current system of pest control activities?
Note: *Records should include the target pest, crop type and type of pesticide used, dates and application rates or the cultural or biological control method used and dates implemented, including spot treatments.*

☐ YES ☐ NO

When you apply pesticides, do you follow a schedule or a written plan to conduct pest control activities?
Note: *A schedule or written plan provides recommendations on the chemical (pesticides), biological (beneficial insects, controlled grazing), or cultural (brush management, burning), control of pests (insects, weeds, plant diseases or rodents). It outlines the use, amount, form, timing and application of the control method to obtain optimum yields while minimizing the risk of surface and groundwater pollution.*

☐ YES ☐ NO ☐ N/A

List the pesticides you currently use, or have used in the last 12 months:
Trade Name:
Common Name:
Type:
Chemical Family:
Application Method:

Are the chemicals you use specific to the target pest; do they have minimal effects on non-target species?

☐ YES ☐ NO ☐ N/A

Are the workers on your farm properly trained to apply pesticides?

☐ YES ☐ NO ☐ N/A

Do the workers on your farm have proper safety equipment?

☐ YES ☐ NO ☐ N/A

Do you have a comprehensive plan in place for safe storage and disposal of pesticides?

☐ YES ☐ NO ☐ N/A

Fertilizer/Nutrient Use

Note: *The term nutrient includes organic and inorganic forms from all sources, such as commercial, animal waste, sludge, compost or agricultural by-products.*

Where nutrients are applied, is the schedule and rate based on a nutrient management plan that provides recommendations or procedures to determine the amount, form, placement and timing of plant nutrients to obtain optimum yields while minimizing the risk of surface and ground water pollution?

☐ YES ☐ NO ☐ N/A

The plan should address all sources of nutrients utilized. The procedure used to determine nutrient recommendations should be based on one or more of the following:

- Realistic crop yield goal
- Soil test results
- Previous crop credits
- Leguminous crop credits
- Manure application history, and/or
- Leaf tissue analysis (if appropriate).

☐ YES ☐ NO

Do you have at least two years of written records or documentation that support your current system of fertilization activities?
Note: *Records should include crop type, projected yields, soil analysis, dates and application rates of all nutrients used.*

☐ YES ☐ NO

Do you produce any fertilizers on your farm (compost for example)?

☐ YES ☐ NO

If not, have you considered this practice?

☐ YES ☐ NO

If applicable, what types of roadblocks do you face in creating a functional compost pile (describe)?

If you produce on-farm compost, approximately what percent of the fertilizers you use is made on-farm compared to those purchased ?

Do you use any organic fertilizers?

☐ YES ☐ NO

How often do you test your soil for pH and nutrient level?

Do you use fertilizers specific to each crop?

☐ YES ☐ NO

Crop Rotation Practices

Do you plant the same land area with more than one crop?

☐ YES ☐ NO

If so, how often do you rotate crops (for example, every year, every 2 years)?

Are all of the crops for harvest, or do you plant crops that are unharvested and/or tilled into the soil ?

☐ All for harvest ☐ Some are unharvested and/or tilled into soil

Which of the following crops do you plant for the purpose of enhancing soil fertility (check all that apply)?

☐ Grasses

☐ Legumes

☐ Small grains

☐ Other (describe):

☐ None

Which of the following do you include in your crop rotation (check all that apply)?

☐ No-till, strip-till, direct seeding, or mulch-till

☐ Perennial grass or hay in rotation

☐ Add organic soil amendments such as manure or compost

☐ Grow cover and green manure crops

☐ Other (describe):

☐ None

Water Use and Pollution Management

Are your crops primarily rain-fed or dependant upon irrigation?

If you irrigate, do you adjust rates according to climatic factors such as rainfall and temperature to minimize water use?

☐ YES ☐ NO ☐ N/A

Do you have any records of standard water use such as gallons/acre?

☐ YES ☐ NO

If so, is your water use increasing?

☐ YES ☐ NO

Are there mitigating factors? If yes, please explain:

☐ YES ☐ NO

When applying pesticides or manure, do you maintain a reasonable setback distance between the application area and intermittent streams/ditches, perennial streams, surface water, surface water inlets and/or sink holes?

☐ YES ☐ NO

Do you apply irrigation water at rates that minimize water loss due to surface runoff, evaporation or deep percolation?

☐ YES ☐ NO

Which of the following measures have you taken to safeguard groundwater from contamination by properly protecting active or abandoned wells (check all that apply)?

☐ Install sanitary well caps, tightly secured with a screened vent

☐ Use pitless adaptors (special pipe fitting that connects a water line to a well casing and provides a sanitary and frostproof seal)

☐ Prevent surface runoff from reaching the area immediately surrounding the well

☐ Other (describe):

☐ None

Soil Management

Which of the following techniques do you use to control erosion (check all that apply)?

☐ Crop rotation

☐ Cover cropping

☐ Perennial cover

☐ Polyacrylamide (PAM)

☐ Residue management

☐ Irrigation water management

☐ Contouring

☐ Buffers

☐ Other (describe):

☐ None

Which of the following measures do you take to control soil compaction (check all that apply)?

☐ Avoiding tillage when soils are wet

☐ Utilizing permanent access roads

☐ Reducing tillage operations

☐ Growing deep rooted cover crops

☐ Other (describe):

☐ None

Soil Health Test

How often do you perform the soil health tests listed below?

Sensory Properties			
Indicator	**Ranking**		
	Low	*Medium*	*High*
Feel	☐ Soil is mucky, greasy, or sticky	☐ Soil is smooth or grainy and compresses when squeezed	☐ Soil is loose, fluffy, and opens up after being squeezed
Soil Organisms	☐ Little or no insects, worms, fungi, or soil life	☐ Small variety of insects, worms, fungi, or soil life	☐ Many insects, worms, fungi, soil full of variety of organisms
Decomposition	☐ Residues and manures do not break down in soil	☐ Slow rotting of residues and manures	☐ Rapid rotting of residue and manures
Earthworms	☐ Little or no signs of worm activity in a shovelful of top soil	☐ Few worm holes or castings in shovelful of topsoil	☐ Worm holes and castings are numerous in shovelful of topsoil
Crop Vigor/Appearance	☐ Stunted growth, uneven stand, discoloration, low yields	☐ Some uneven or stunted growth, slight discoloration, signs of stress	☐ Healthy, vigorous, and uniform stand

Water Capacity and Erosion			
Indicator	**Ranking**		
	Low	*Medium*	*High*
Wind or Water Erosion	☐ Obvious soil deposition, large, joined gullies, obvious soil drifting	☐ Some deposition, few gullies, some colored runoff, some evidence of soil drifting	☐ No visible soil movement, no gullies, clear or no runoff, no obvious soil drifting
Water Holding Capacity	☐ Plant stress immediately following rain or irrigation, soil has limited capacity to hold water, soil requires frequent irrigation	☐ Crops are not first to suffer from dry spell, soil requires average irrigation	☐ Soil holds water well for long time, deep topsoil for water storage, crops do well in dry spells, soil requires less than average irrigation
Water Infiltration	☐ Water on surface for long period of time after rain or irrigation	☐ Water drains slowly after rain or irrigation, some ponding	☐ No ponding after heavy rain or irrigation, water moves steadily through soil
Drainage	☐ Excessive wet spots in field, ponding, root disease	☐ Some wet spots in field and profile, some root disease	☐ Water is evenly drained through field and soil profile, no evidence of root disease

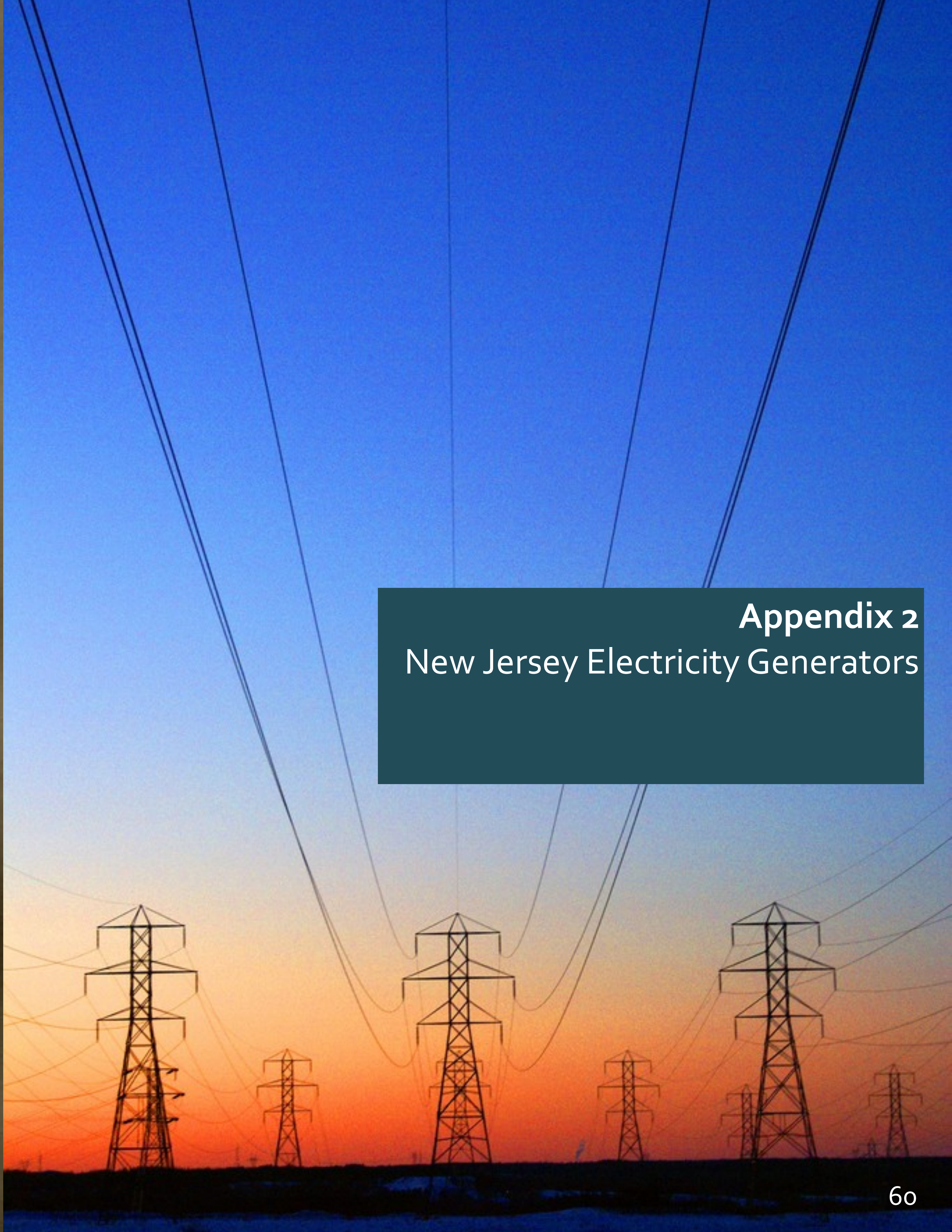
Soil Structure, Tillage and Quality						
Indicator	**Ranking**					
	Low		*Medium*		*High*	
Compaction	☐	Hard layers, tight soil, restricted root penetration, obvious hardpan, roots turned awkwardly	☐	Firm soil, slightly restricted root penetration, moderate shovel resistance and penetration of wire flag beyond tillage layer	☐	Loose soil, unrestricted root penetration, no hardpan, mostly vertical root plant growth, wire flag easily inserted
Workability	☐	Many passes and energy expended for good seedbed, soil difficult to work	☐	Soil works reasonably well with moderate expense of energy	☐	Till easily and requires little power to pull implements
Soil Tilth/Structure	☐	Soil clods difficult to break, crusting, tillage creates large clods, soil falls apart in hands, very powdery	☐	Moderate porosity, some crusting, small clods, soil breaks apart between fingers with medium pressure	☐	Porous, soil crumbles easily under light pressure
Tillage Ease	☐	Plow scours hard and soil never works down	☐	Soil grabs plow, is difficult to work, and needs extra passes	☐	Plow field in higher gear and soil flows and falls apart and is mellow
Surface Cover	☐	Soil surface is clean, bare, and residue is removed or buried following harvest	☐	Surface has little residue, mostly buried	☐	Surface is littered, lots of mulch left on top or cover crop used
Aeration	☐	Soil is tight, closed, almost no pores	☐	Soil is dense and has few pores	☐	Soil is open, porous and breathes
Topsoil Depth	☐	Subsoil is exposed or very near surface	☐	Topsoil is shallow	☐	Topsoil is deep
Plant Roots	☐	Poor growth/structure, brown or mushy roots	☐	Some fine roots, mostly healthy	☐	Vigorous and healthy root system, good color
Root Mass	☐	Very few roots, mostly horizontal	☐	More roots, some vertical, some horizontal	☐	Many vertical and horizontal roots, deep roots
pH	☐	Hard to correct for desired crop	☐	Easily correctable	☐	Proper pH for crop
Nutrient Holding Capacity	☐	Soil tests dropping into "low" category	☐	Little or slow downward trend	☐	Soil tests trending up in relation to fertilizer applied and crop harvested but not into "very high" category

Forestry Management

Are your forestry practices currently certified by the U.S. Forest Stewardship Council (FSC)?

☐ YES ☐ NO

Self-assessment questions are based on citations 121—125.



Appendix 2
New Jersey Electricity Generators

Plant Name	Total Plant Capacity (MW)	Capacity of Diesel Firing Generators at Plant (MW)	Primary Diesel Firing Generator Fuel
PSEG Salem Generating Station	2,381.8	41.8	Kerosene
PSEG Linden Generating Station	2,108.3	519.4	Residual oil
PSEG Burlington Generating Station	819.0	352.9	Kerosene
PSEG Mercer Generating Station	768.0	115.2	Kerosene
Gilbert	608.0	608.0	Distillate oil
PSEG Kearny Generating Station	552.5	294.0	Residual oil
PSEG Sewaren Generating Station	546.2	115.2	Kerosene
B L England	483.0	184.0	Residual oil
Sayreville	462.0	106.0	Distillate oil
Werner	212.0	212.0	Distillate oil
Middle Station	79.6	79.6	Kerosene
Howard Down	70.5	45.5	Residual oil
Cedar Station	67.2	67.2	Kerosene
Missouri Avenue	55.8	18.6	Kerosene
PSEG Bayonne Generating Station	42.2	42.2	Kerosene
West Station	27.0	27.0	Distillate oil
Merck Rahway Power Plant	19.8	19.8	Distillate oil
PSEG National Park Generating Station	18.5	18.5	Kerosene
Trigen Trenton Energy	12.0	6.0	Distillate oil
Bayville Central Facility	6.9	6.9	Distillate oil
Lowe Paper Simkins Industries	3.0	3.0	Residual oil
Total Capacity	**9,343.3**	**2,882.8**	

Table 1: New Jersey Electricity Generators Capable of Co-Firing Biodiesel, (shaded region represents power plants with capacity under 25 MW)[126]

Plant Name	Total Plant Capacity (MW)	Capacity of Gas Firing Generators at Plant (MW)	Primary Gas Firing Generator Fuel
PSEG Linden Generating Station	2,108.3	1588.9	Natural Gas
Bergen	1,362.0	1362.0	Natural Gas
Linden Cogen Plant	1,034.9	1034.9	Natural Gas
AES Red Oak LLC	955.0	955.0	Natural Gas
PSEG Essex Generating Station	595.2	595.2	Natural Gas
PSEG Kearny Generating Station	846.9	552.9	Natural Gas
PSEG Edison Generating Station	501.6	501.6	Natural Gas
PSEG Hudson Generating Station	1,114.4	454.7	Natural Gas
PSEG Sewaren Generating Station	546.2	431.0	Natural Gas
Sayreville Cogeneration Facility	430.2	430.2	Natural Gas
Ocean Peaking Power LP	383.0	383.0	Natural Gas
PSEG Burlington Generating Station	594.9	242.0	Natural Gas
Lakewood Cogen LP	238.5	238.5	Natural Gas
Eagle Point Cogeneration	225.0	225.0	Natural Gas
Bayonne Cogen Plant	191.6	191.6	Natural Gas
Glenn Gardner	159.6	159.6	Natural Gas
Camden Cogen LP	157.0	157.0	Natural Gas
Newark Bay Cogeneration Project	156.0	156.0	Natural Gas
Parlin Power Plant	139.0	139.0	Natural Gas
Pedricktown Cogen Plant	134.5	132.5	Natural Gas
Sherman Avenue	112.8	112.8	Natural Gas
Sayreville	212.0	106.0	Natural Gas
Deepwater	173.7	100.2	Natural Gas
Cumberland	99.4	99.4	Natural Gas
Carlls Corner	83.8	83.8	Natural Gas
Prime Energy LP	83.0	83.0	Natural Gas
Forked River	76.8	76.8	Natural Gas
Micketon Station	71.2	71.2	Natural Gas
Newark Power Plant	64.6	64.6	Natural Gas
Paulsboro Refinery	57.0	57.0	Natural Gas
Roche Vitamins	40.5	40.5	Natural Gas
Kenilworth Energy Facility	28.8	28.8	Natural Gas
Sunoco Eagle Point Refinery	22.5	22.5	Other Gas
Edgeboro Landfill	16.6	16.6	Landfill Gas

Table 2: New Jersey Electricity Generators Capable of Co-Firing Biogas[127]

Note: *Table 2 continues on page 63*

Plant name	Total Plant Capacity (MW)	Capacity of Gas Firing Generators at Plant (MW)	Primary Gas Firing Generator Fuel
Ocean County Landfill	14.4	14.4	Landfill Gas
Anheuser Busch Newark Brewery	13.0	13.0	Natural Gas
Hoffmann LaRoche	10.6	10.6	Natural Gas
Bristol Myers Squibb	10.5	10.5	Natural Gas
University of Medicine Dentistry NJ	10.5	10.5	Natural Gas
Masterfoods USA	10.2	10.2	Natural Gas
Monmouth County Landfill	10.0	10.0	Landfill Gas
O'Brien Biogas IV LLC	9.9	9.9	Landfill Gas
KMS Crossroads	9.2	9.2	Natural Gas
Schering Cogen Facility	8.1	8.1	Natural Gas
Burlington Landfill	7.3	7.3	Landfill Gas
ILR Landfill	6.7	6.7	Landfill Gas
Edison Township SLF	6.6	6.6	Landfill Gas
Trigen Trenton Energy	6.0	6.0	Natural Gas
Atlantic County Utilities Authority Lan	5.4	5.4	Landfill Gas
Aventis Pharmaceuticals	5.0	5.0	Natural Gas
Cumberland County Landfill	4.8	4.8	Landfill Gas
Pharmacia	4.8	4.8	Natural Gas
Hunterdon Cogen Facility	4.1	4.1	Natural Gas
Balefill Landfill Gas Utilization Project	3.8	3.8	Landfill Gas
Warren County District Landfill	3.8	3.8	Landfill Gas
Pennsauken Sanitary Landfill	2.8	2.8	Landfill Gas
Kinsley Landfill	2.4	2.4	Landfill Gas
Freehold Ashbury Park Press	2.2	2.2	Natural Gas
FiberMark Technical Specialty	2.3	2.0	Natural Gas
Kingsland Landfill	1.9	1.9	Landfill Gas
HMDC Kingsland Landfill	1.8	1.8	Landfill Gas
Rowan University	1.5	1.5	Natural Gas
Asbury Park Press	1.4	1.4	Natural Gas
Hamm Landfill	1.2	1.2	Landfill Gas
Lafayette Energy Partners LP	1.2	1.2	Landfill Gas
Bayville Central Facility	6.9	0.9	Other biomass gas
Cape May Landfill	0.3	0.3	Landfill Gas
HMDC Kearny Landfill 1C	n/a	n/a	Landfill Gas
Total Capacity in New Jersey	**13,207.1**	**11,078.1**	

Table 2 (continued): New Jersey Electricity Generators Capable of Co-Firing Biogas
Note: *Capacity (MW) was aggregated in cases of separate operations at the same landfills*

Appendix 3
Lifecycle Emissions Models

Introduction

The following sections outline in detail the assumptions, calculations and methods used in our three lifecycle emissions models (food waste, waste grease, and soybean oil).

These models were designed to estimate the amount of greenhouse gas emissions produced in the process of collecting or generating feedstock sources for producing biofuels and combusting them to produce electricity. The models have been tailored specifically for the State of New Jersey, though with minor modifications they could be effectively reconfigured for use in other areas.

Food Waste Model

This model estimates the amount of emissions produced in the process of collecting food waste, processing it into methane-based biogas using anaerobic digestion technology, and then combusting it to produce electricity.

In constructing the food waste model, we assumed that the lifecycle of the food waste inputs would originate at the point in time when they became waste products. Any energy or carbon inputs associated with their production should be attributed to the process of intended use (namely consumption). After interviewing various experts in the waste collection and separation fields, we determined that food waste separation from the general waste stream would be prohibitively costly, energy intensive, and time consuming. Therefore, this model assumes that food waste will be source -separated from the general waste stream before collection. We also assumed that food waste will only be collected from large commercial entities (restaurants and grocery stores for instance), similar to the manner in which waste oil/ grease is currently collected, and that waste from residential sources will be ignored due to the difficulties associated with mandating separation and collection. This is not to say that residential separation is impossible, simply unlikely given the current political and cultural climate.

This model includes two separate stages of transportation. Given transportation and collection costs, it is much more realistic to assume that waste would be collected and aggregated at localized transfer stations (similar to municipal solid waste) before being transported to an anaerobic digestion (AD) facility. It also assumes that the biogas produced by the digester will be combusted to produce electricity on-site; however, this version takes a more realistic view of where these digesters will be located. Given the dispersed nature of the feedstock, and high transportation costs, it seems much more likely to assume that many small-scale digesters would be constructed at the sites of electric generation facilities that would be suitable for co-firing biogas.

One of the largest assumptions made in the transportation process phase of the model deals with the carbon intensity of producing waste-hauling trucks. We were not able to find reliable data on the composition of a waste-hauling truck by material type. Therefore, we used a paper published by the Massachusetts Institute of Technology (MIT),[128] along with data from Ward's Automotive Guide[129] to estimate the composition of the average American passenger vehicle by type of material, and assumed that a waste-hauling truck would have a similar material profile.

It is also important to note that this model does not consider the carbon dioxide emissions associated with the production of either the diesel fuel used to run the trucks, or the fossil fuel sources used for normal electricity production in the New Jersey grid.

Of all the information used to construct this model, verifiable data about the carbon dioxide emissions produced as a result of the construction of an anaerobic digester were the most difficult to find. Extensive research provided data on the capital costs and size of various anaerobic digesters, but no information about the composition of those facilities by material type. Therefore, we used data from studies of ethanol production plants, which estimated the carbon dioxide emissions associated with capital construction. We assumed that ethanol plants and anaerobic digesters of similar cost would have similar types of material inputs, and that these inputs would produce similar amounts of greenhouse emissions.

Currently, the model assumes that the digesters will be located on the sites of natural gas-fired electricity generation facilities, and that these facilities are pre-existing. Therefore, the greenhouse gas emissions resulting from the construction of the generating facility have not been taken into consideration. We also assumed that current generation occurs with single-cycle turbine driven technology, and significant improvements to efficiency could be gained if combined-cycle technology was considered.

The amount of greenhouse emissions saved by diverting food waste from landfills has been one of the most interesting aspects of this model. Data on the amounts of methane produced from landfilled food waste is fairly reliable, and the NJDEP has provided us with excellent data on the average percentage of landfill gas that is being recovered in New Jersey. Our conclusions suggest that diversion of food waste from landfills actually prevents greater amounts of CO_2 equivalent fossil emissions from entering the atmosphere than are generated during the entire anaerobic digestion lifecycle.

This model also assumes that any wastewater produced in the anaerobic digestion process will be treated in a conventional wastewater treatment plant. Since the wastewater generated by the digester would require fairly little treatment compared to normal municipal wastewater, it might be logical to assume that the water could be treated and released directly from the site of the digester using much less energy than if it was diverted to conventional wastewater treatment.

This model also includes a variable for the co-product credit associated with the economically useful byproducts of the anaerobic digestion process. An assumed value of 10% is used to attribute carbon dioxide emissions and offsets generated in the food waste lifecycle to these byproducts. This is a fairly conservative estimate compared with other co-product credit estimates in biofuel production scenarios.[130]

Finally, the most significant assumption made in this model is related to the amounts of electricity, wastewater, co-products, and waste heat produced per unit of waste input in the anaerobic digestion process. Data from research conducted at Columbia University in 2004 was used throughout this model, and so a variable for these assumptions has been included.[131] However, it must be noted that because of the frequency with which these numbers are used, any changes to them (either because of more accurate data or technological/process improvements in the anaerobic digestion process) will significantly alter the final model results.

As mentioned earlier, the following sections detail the individual steps and calculations used in constructing the model. All of the variables listed in the final model can be altered to fit different scenarios, and results of the calculations will change based on those inputs.

Given the best assumptions and data available, the results of the model suggest that any food waste diverted from landfills and used to produce electricity using anaerobic technology are actually net greenhouse gas negative. This is due to the significant savings in emissions from landfills, and would remain the case even assuming a 90% average methane capture rate for the landfills receiving the waste. Though emissions associated with plant construction are likely to rise with the incorporation of more accurate data, collection/transportation of the food waste (and possibly the biogas) are likely to remain the largest contributors to greenhouse-gas emissions. While the scale of anaerobic digestion projects will be constrained by the limited nature of the feedstock, and the capital costs associated with construction, it is important to note that this technology has the potential to greatly reduce the fossil carbon footprint of the State of New Jersey.

According to preliminary results and calculations, the process of producing a kWh of electricity generated using biogas from anaerobic digesters generates approximately **-0.9296 kg produced per kWh generated using biogas from anaerobic digesters.** This can be compared to the 0.0618 kg produced per kWh generated using waste grease derived biodiesel and the 0.5723 kg produced per kWh through current generation of electricity in the New Jersey grid.

Vehicle Construction

Variables	Units	Assumed value
Vehicle weight	Short tons	10
Average life of truck	Years	13
Average load capacity	Short tons	21
Number of loads hauled per year	#/yr	520
Electricity produced for sale by plant	kWh/metric ton of waste	165
Kilograms CO_2 Eq/kWh generated		**0.003932**

Transport Distance

Variables	Units	Assumed value
Average distance to plant	miles	83.59
Fuel economy of garbage truck	miles/gallon	2.8
% of distance traveled by garbage truck	% of total distance	25%
Fuel economy of tractor-trailer	miles/gallon	6.5
% of distance traveled by tractor-trailer	% of total distance	75%
Kilograms CO_2 Eq/kWh generated		**0.048176**

Plant Construction

Variables	Units	Assumed value
Average life of plant	Years	15
% of lifetime plant is operational	%	90%
Carbon intensity of construction per MW	kg CO_2 Eq	1,148,850.00
Kilograms CO_2 Eq/kWh generated		**0.009715**

Wastewater Treatment

Variables	Units	Assumed value
Gallons treated at plant	gallons/day	9,000,000
Electricity usage of plant	kWh/month	200,000
Gallons produced from AD	gallons/kilowatts produced	0.698
Carbon intensity of NJ electricity gen	lbs of CO_2 emissions/kWh	1.262
Kilograms CO_2 Eq/kWh generated		**0.000296**

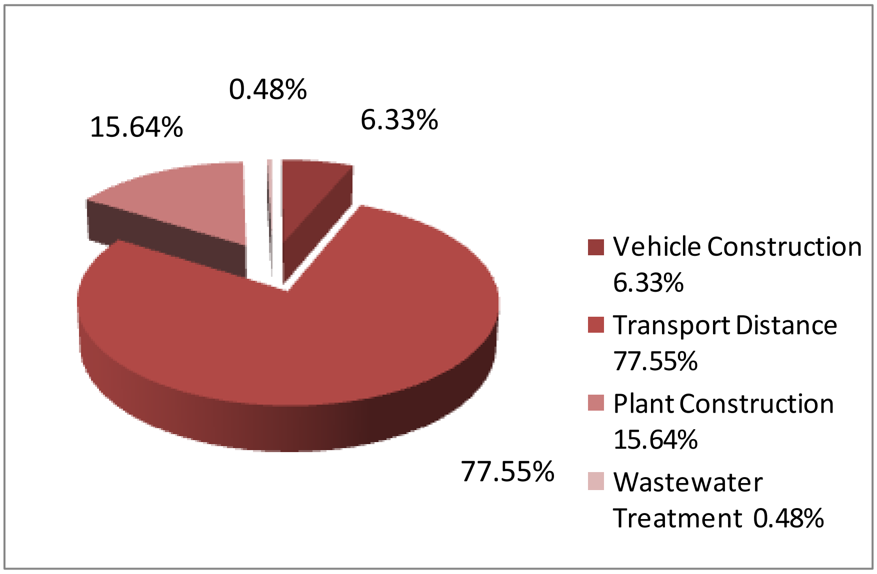
GhG Savings from Landfill Diversion

Variables	Units	Assumed value
Amount of food waste generated	Short tons	1,595,142.59
Capture rate	% waste diverted to AD from landfil	32.25%
GhG emissions factor	Mt CO_2 Eq/short ton of waste	0.78
Landfill gas capture rate	%	78%
Total GhG savings from available waste	**Mt CO_2 Eq**	**84,304.33**
Kilograms CO_2 Eq/kWh generated		**1.095**

Coproduct Credit

Variables	Units	Assumed value
Total CO_2 Eq emissions allocated to coproduct	**%**	10%

CO_2 Emissions per Model Segment



SUMMARY TABLE OF RESULTS	
Vehicle Construction	0.003932
Transport Distance	0.0482
Plant Construction	0.009715
Wastewater Treatment	0.0002959
GhG Savings (Landfill)	1.095
Coproduct	10%
TOTAL kg of CO_2 EQ Emissions/kWh Gnerated	-0.92962754
TOTAL kg of CO2 EQ Emissions/Metric Ton of Food Waste	-153.388544

Fossil Greenhouse Gas Emissions From Producing Garbage Trucks and Trailers

Studies published by MIT[132] and data from Ward's Automotive Guide[133] have established that the average car is made up of the following general materials: plastic, aluminum, copper, zinc, lead, other ferrous, iron, carbon steel, among others. Based on the percentage of pounds of these components we have estimated the amount of each material for the trucks, having assumed that the average waste collection vehicle and tractor-trailer are made up similar percentages of materials.

Using data from the GREET Model, we have determined the kg of CO_2 emitted per pound of material used in vehicle manufacture.[134]

According to our calculations, there are approximately 2.0891 kg of CO_2 emissions per pound of vehicle weight.

Garbage Trucks:

An average garbage truck (which can vary substantially) might weigh 10 tons, or 20,000 pounds.[135]

This means that the average garbage truck would generate about 41,782 kg of fossil carbon dioxide emissions to build.

2.0891 kg/pound * 20,000 pounds = 41,782 kg

The average life of a garbage truck is assumed to be 13 years.[136]

Assuming that the truck runs five days a week (5 days * 52 weeks/year) it would run 260 day per year, and make two trips per day. We also assume an average load of approximately 21 tons or 42,000 pounds or 19,050.5 kg.

Assuming 41,782 kg of fossil CO_2 emissions associated with construction, divided by 13 years of useful life = 3,214 kg, divided by 260 days per year = 12.36 kg, divided by two trips per day = 6.18 kg, divided by 19,050.5 kg of waste hauled in one trip = $3.244e^{-4}$ kg of fossil CO_2 emissions per kg of waste transported.

1,000 kg of waste = 165 kWh of electricity.[137]

> ($3.244e^{-4}$ kg of emissions per kg of waste * 1,000 kg of waste) / 165 kWh = 0.001966 kg of fossil CO_2 emissions per kWh of electricity generated from anaerobic digester.

Tractor Trailers:

Our research indicates that while the average garbage truck and tractor trailer have very similar overall weight and load capacities,[138] the most significant difference is in their respective fuel economies. While garbage trucks (which make more frequent stops and idle while doing so) can only get about 2.8 mpg, large tractor trailers normally attain about 6.5 mpg.[139]

After speaking with the managers of various solid waste districts in New Jersey, we discovered that most waste is initially collected and transported to a transfer station via garbage truck, and then transferred to a tractor trailer for shipment to the final destination. Assuming that approximately one tractor-trailer will be needed for every garbage truck, we can simply multiply the figure above by two to find the total kg of fossil CO_2 emissions per kWh of electricity generated (associated with the construction of all transportation vehicles).

Fossil Greenhouse Gas Emissions From Transportation

Carbon dioxide emissions from a gallon of diesel = 2,778 grams * 0.99 (oxidation factor) * 44/12 (molecular weight of carbon dioxide/molecular weight of carbon) = 10,084 grams/gallon = 10.1 kg/gallon = 22.2 pounds/gallon.[140]

Garbage trucks get approximately 2.8 mpg,[141] while tractor-trailers get approximately 6.5 mpg.

The maximum average distance to an anaerobic digester from any location in the State of New Jersey assumed in model is 83.59 miles. While the actual distance is likely to be less than this, we have aired on the conservative side of this calculation.

We assume that the waste will be transported ¼ of this distance in a garbage truck, and the remaining ¾ in a tractor-trailer. Thus, the weighted average fuel economy for an entire trip would be

(0.25*2.8 mpg) + (0.75*6.5 mpg) = 5.575 mpg

83.59 miles / 5.575 miles per gallon = 14.99 gallons

14.99 gallons of diesel * 10.1 kg of CO_2 emissions per gallon = 151.43 kg of CO_2

Assuming an average load of 19,050.5 kg of waste per trip, each kg of waste has $7.948e^{-4}$ kg of fossil CO_2 emissions associated with transportation.

> 151.43 kg of CO_2 per trip / 19,050.5 kg of waste per trip = $7.948e^{-4}$ kg of CO_2 per kg of waste

1,000 kg of waste = 165 kWh of electricity.[142]

($7.948e^{-4}$ kg of CO_2 per kg of waste * 1,000 kg of waste) / 165 kWh = 0.0048176 kg of fossil CO_2 emissions per kWh of electricity generated from anaerobic digestion (associated with transportation).

Fossil Greenhouse Gas Emissions From Constructing The Plant

The EBAMM Model assumes that there are 8.8 g of fossil CO_2 emissions for every liter of ethanol produced, which can be attributed to the construction of an ethanol plant.[143] 1 U.S. gallon = 3.7854118 liter, so there would be 33.3 g of CO_2 emissions per gallon of ethanol.

Conventional industry estimates, provided by the University of Iowa, are that the average ethanol plant has capital costs equal to $1.25 per gallon of ethanol that it is rated to produce per year. The average plant also has an average lifetime of 15 years.[144] Thus, we could assume and approximate that a 57.5 million gallon/year plant, producing 862.5 million gallons over its lifetime, with 33.3g of CO_2 associated per gallon, would have a fossil CO_2 intensity of 28,721,250 kg or 28,721 metric tons (Mt) of CO_2.

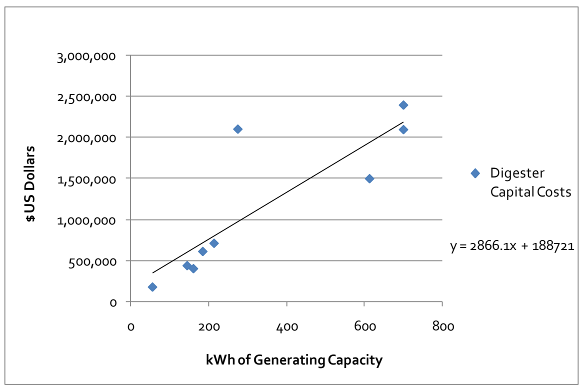


Figure 1: Digester Capital Costs Related to Generation Capacity[145-147]

57.5 million gallons/year * 15 years * 33.3g of CO_2 per gallon = 28,721,250 kg of CO_2

Such a plant would cost $71.875 million to build.

57.5 million gallon/year * $1.25 per gallon of ethanol produced per year = $71.875 million

The cost function for existing anaerobic digesters below shows that the approximate cost of a digester (less than 1 MW) is equal to:

Total Digester Cost = ($2,866.1 * # of kWh capacity) + $188,721

Assuming that an ethanol plant and anaerobic digester of equal costs will have approximately the same construction inputs and therefore carbon intensity, we could conclude, for instance, that a 25 MW digester would have a carbon footprint of 28,721,250 kg of CO_2, or 1,148,850 kg of CO_2 per MW installed.

Assuming that the digester has a similar lifetime to the plant (15 years), that is 76,590 kg of CO_2 per MW installed per year.

28,721,250 kg of CO_2 in 15 years / 15 years / 25 MW = 76,590 kg of CO_2 per MW installed per year

Assuming that the plant will be operational 90% of the time (8,760 hours * 0.9 = 7,884) there will be 9.72 kg of CO_2 emissions per MW installed per hour.

76,590 kg of CO_2 per year / 7,884 operational hours per year = 9.72 kg of CO_2 per hour

9.72 kg of CO_2 per hour per MW / 1,000 kWh per MWh = 0.009714 kg CO_2 per kWh of electricity generated.

Fossil Greenhouse Gas Emissions From Wastewater Treatment

The average wastewater treatment plant in New York, according to the New York State Energy Research and Development Authority (NYSERDA), processes 9 million gallons per day and uses approximately 200,000 kWh per month.[148] We assume that New Jersey treatment plants are similar to those in New York.

This means that in the average day of a 30 day month, a plant uses 6,666 kWh of electricity and processes 9 million gallons.

It takes 1 kWh of electricity to process 1,350 gallons of wastewater.

9 million gallons per day / 6,666 kWh per day = 1,350 gallons per kWh

1 gallon of water weighs 8.33 pounds or 3.78 kg

That means that it takes 1 kWh of electricity to process 5,103 kg of wastewater.

1,350 gallons per kWh * 3.78 kg per gallon = 5,103 kg of wastewater per kWh

2.64 kg of wastewater is produced from an anaerobic digester per kWh of electricity delivered to the grid.[149]

It takes $5.171e^{-4}$ kWh of electricity from the New Jersey grid to process the 2.64kg of wastewater produced from an anaerobic digester, or the equivalent of 1 kWh of electricity delivered to the grid from an anaerobic digester.

1 kWh of electricity to process 5103 kg of wastewater = $1.959\ e^{-4}$ kWh per kg of wastewater

$1.959\ e^{-4}$ kWh required per kg of wastewater * 2.64kg of wastewater produced from generating 1 kWh of anaerobic electricity = $5.171e^{-4}$ kWh needed to process wastewater generated per kWh electricity generated from the digester.

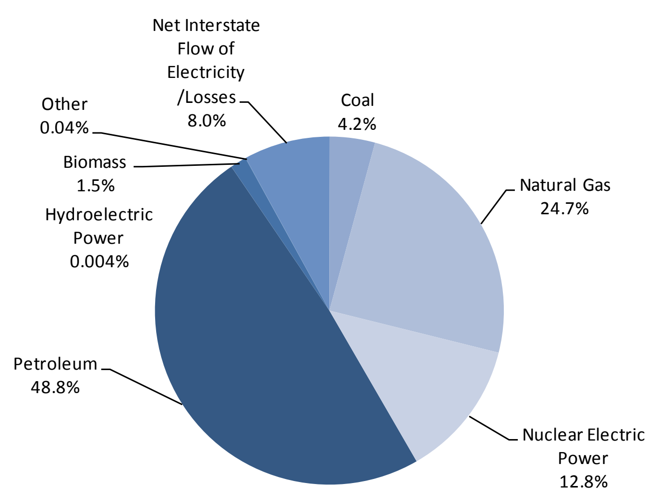


Figure 2: New Jersey 2002 Total Energy Used by Fuel Source (total 2,519.9 trillion Btu)[150]

NJDEP has used a value of approximately 1.2617 pounds of fossil CO_2 emissions resulting from 1kWh of electricity generation in New Jersey, and thus we will use this value.[151]

1 pound = 0.45359 kg

So there is 0.5723 kg of fossil CO_2 emissions resulting from 1 kWh of electricity generation in New Jersey

1.2617 lbs per kWh*0.45359 kg per pound = 0.5723 kg per kWh

$5.171e^{-4}$ kWh of electricity from the New Jersey grid per kWh generated from the digester * 0.5723 kg of fossil CO_2 emissions resulting from 1kWh of electricity generation in New Jersey = $2.959e^{-4}$ kg of fossil CO_2 emissions from wastewater treatment per kWh of electricity generated from a food waste anaerobic digester.

Greenhouse Gas Savings From Diverting Food Waste from Landfill to Anaerobic Digestion

It is assumed that 1,595,142.59 short tons of food waste were generated in New Jersey in 2005. Of that, 86.2% went to landfills.[152]

Therefore, the total amount of potential food waste available for anaerobic digestion is 1,375,012.91 short tons = 1,595,142.59 short tons * 0.862

Of this amount, we found that approximately 50% of food waste is generated by commercial sources like restaurants, groceries, schools, and business cafeterias, and the balance is residential.[153-155] Considering the difficulty in capturing the residential stream, we are assuming the commercial to be the only viable source (1,375,012 short tons * 0.5 = 687,506 short tons). Assuming a 75% capture rate of this stream:

687,506 * 0.75 = 514,433.49 short tons of food waste for anaerobic digestion. This quantity is equivalent to 466,591.17 metric tons.

According to the EPA's Waste Reduction Model (WARM), 0.78 Mt CO_2 Eq is generated per 1 short ton of food waste deposited into a landfill.[156] Thus, if 514,433.49 short tons of food waste were placed in a landfill, 401,258.12 Mt CO_2 Eq would be emitted.

514,433.49 short tons * 0.78 Mt CO_2 Eq per short ton = 401,258.12 Mt CO_2 Eq

Approximately 50% of emissions from food waste are comprised of CO_2 and the other 50% are methane (CH_4). We have discounted out the CO_2 because these emissions would be produced if the food waste was allowed to naturally decompose in the environment, and because the CO_2 can be reabsorbed by plants as part of the carbon lifecycle, while methane cannot. Considering CO_2 has a global warming potential of 1 and CH_4 has a potential of 21,[157] we calculated the weighted average of the CO_2 and CH_4 emissions in terms of CO_2 Eq or global warming potential. We calculated that removing all emissions of CO_2 would reduce the total CO_2 Eq emissions by 4.5%.

401,258.12 Mt CO_2 Eq * 0.955 = 383,201.50 Mt CO_2 Eq

We next calculated the total kWh of electricity that can be produced from all commercially available food waste that could theoretically be collected in New Jersey.

466,591.17 metric tons * 165 kWh per metric ton = 76,987,543.24 kWh

Next, we calculated the amount of greenhouse gas emissions savings: 383,201.50 Mt CO_2 Eq / 76,987,543.24 kWh = 0.00497 Mt CO_2 Eq per kWh generated. We then proceeded to convert this into kg CO_2 Eq by multiplying by 1,000.

0.00497 Mt CO_2 Eq per kWh generated * 1,000 kg/metric ton = 4.97 kg CO_2 Eq saved per kWh generated.

This number was then reduced based on the estimated average percentage of landfill gas captured at active landfills of 78% provided by NJDEP.[158]

4.97 kg CO_2 Eq saved per kWh generated * (1 – 0.78) = 1.0934 kg CO_2 Eq saved per kWh generated

The results of the analysis for the food waste anaerobic model indicate, as expected, that most of the variables contributing to the transportation stage have the largest influence on the final carbon intensity of the entire process. We have also performed a qualitative analysis of each variable and determined how confident we are in the inherent assumptions. For instance, the confidence in the variable for the average distance to the plant is fairly low because it is based on the number of anaerobic digesters constructed in the state, and the value could change dramatically. The same is true for the carbon intensity of each MW of capacity installed in a newly constructed anaerobic digester. The values for this number were based on the assumption that construction materials for ethanol plants and anaerobic digesters were roughly similar. Considering Low and Medium levels of confidence for values, which contribute to approximately 35% of the variation in the overall model, it would be fair to assume that the final number produced by the model could vary by as much as 35%.

Sensitivity Analysis: Food Waste Model

Variables	Contribution to Final Result	Confidence
Vehicle Weight	1.20%	High
Average Life of Truck	1.20%	High
Number of Loads Hauled per Year	1.20%	High
Kg of CO_2 per lb of Vehicle Weight	1.20%	Medium
Average Load Capacity	25.38%	High
Average Distance to Plant	24.18%	Low
Fuel Economy of a Garbage Truck	1.56%	High
% of Distance Traveled by Garbage Truck	4.68%	High
Fuel Economy of Tractor Trailer	18.70%	High
% of Distance Traveled by Tractor Trailer	4.68%	High
Average Life of Plant	5.30%	Medium
% of Lifetime Plant is Operational	5.30%	High
Carbon Intensity per MW Installed	5.30%	Low
kWh to Treat One Gallon of Wastewater	0.10%	High
Gallons Wastewater produced from AD	0.10%	High
Carbon Intensity of New Jersey Electricity Generation	0.10%	High

The size of the emissions reduction from landfill diversion is approximately 1,762.8% (17.628 times) as large as all of the fossil CO_2 emissions from the whole AD process. The sensitivity value for landfill methane capture was not included in the overall emissions results because the current sensitivity analysis was conducted to approximate the percentage of each variable's contribution to overall fossil CO_2 emissions, not necessarily reductions.

Conclusion

Totaling the CO_2 equivalent emissions for each stage of the lifecycle, applying the co-product credit of 10%, and applying the credit for emissions saved through diversion of waste from landfills produces a figure of -0.9296 kg of fossil CO_2 equivalent emissions per kWh of electricity generated from an anaerobic digester. This equates to approximately -153.38 of fossil CO_2 equivalent emissions per metric ton of food waste used.

By comparison, we know that 1.314 pounds of CO_2 is emitted for every kWh generated using natural gas. This equates to 0.5947 kg of CO_2.[159]

1.314 pounds of CO_2 * 0.45259 kg per pound = 0.5947 kg of CO_2

It should be noted that this figure only represents the direct fossil emissions from the combustion of natural gas. It does not represent the associated emissions generated through the production, processing, or transportation of this fuel.

Waste Grease Model

This model has been designed to estimate the amount of greenhouse gas emissions produced in the process of collecting waste grease (yellow grease and tallow), processing it into biodiesel using rendering and methyl esterification technology, and then combusting it to produce electricity.

In constructing the waste grease model, it was assumed that the lifecycle of the various waste grease inputs would originate at the point in time when they became waste products. Any energy or carbon inputs associated with their production should be attributed to the process of intended use (namely consumption). We also assumed that the collection of waste greases would occur in a manner similar to current methods (private collection and hauling), but that the scale would simply be increased. Waste greases which are currently being collected and utilized as positive economic goods would not be considered, and therefore displaced economic activities do not need consideration. Only waste greases currently being disposed of are considered as possible feedstocks in this model.

While carbon dioxide emissions associated with the construction of transportation vehicles use an average vehicle size/ production scenario, the emissions produced by the actual transportation of waste grease and biodiesel has been tailored to a specific production scenario. The location of an actual rendering plant, biodiesel production facility, and cogeneration power station, and the distances between these sites have been used instead of average distances. This will allow the model and its results to be more specifically tailored to different scenarios.

One of the largest assumptions made in the transportation process phase in the model deals with the carbon intensity of producing waste-hauling trucks. We were not able to find reliable data on the composition of a truck by material type. Therefore, we mainly used papers published by MIT which estimated the composition of the average American passenger vehicle by type of material, and assumed that a waste-hauling truck would have a similar material profile. It is also important to note that this model does not consider the carbon dioxide emissions associated with the production of the diesel fuel used to run the trucks, or of the fossil fuel sources used for normal electricity production in the New Jersey grid. These are both points of possible improvement for subsequent versions of this model.

It is also important to note that carbon dioxide emissions associated with the construction of rendering, refining, and electricity generation facilities have not been considered in this model. This is largely because the majority of all infrastructure needed to complete this process is currently in place, though increases in production beyond certain volumes would certainly require new facilities.

As mentioned earlier, the following sections detail the individual steps and calculations used in constructing the model, and roughly correspond to sections in the final model Excel sheet. Most of the sections in this document also have corresponding sheets of Excel data or calculations. All of the variables listed in the final model sheet can be altered to fit different scenarios, and results of the calculations will change based on those inputs

According to preliminary results and calculations, the process of producing a kWh of electricity from waste grease-derived biodiesel generates approximately 0.0618 kg of fossil CO_2 emissions. This can be compared to the -0.9296 kg produced per kWh generated using biogas from anaerobic digesters from our food waste model, and the 0.5723 kg produced per kWh through current generation of electricity in the New Jersey grid.

Vehicle Construction

Variables	Units	Assumed value
Vehicle weight	Short tons	10
Average life of truck	Years	13
Average load capacity	Gallons	3130
Number of loads hauled per year	#/yr	520
Kilograms CO_2 Eq/kg of biodiesel produced		**1.793E-03**

Transport Distance

Variables	Units	Assumed value
Average distance from commercial entities to rendering facilities (Stage 1)	miles	10
Distance from rendering facility to biodiesel plant (Stage 2)	miles	3.7
Distance from biodiesel plant to generation facility (Stage 3)	miles	98.9
Fuel economy of vehicle (Stage 1)	miles/gallon	2.8
Fuel Economy of Vehicle (Stage 2 + 3)	**miles/gallon**	6.5
Kilograms CO_2 Eq/kg biodiesel produced transported		**1.890E-02**

Pretreatment Process

Variables	Units	Assumed value
Amount of energy used to run plant	kWh/metric ton oil or tallow	88
Carbon intensity of NJ electricity gen	lbs of CO_2 emissions/kWh	1.2617
Kilograms CO_2 Eq/kg treated		**5.036E-02**

Biofuel Plant

Variables	Units	Assumed value
Energy inputs (Electricity)	g fossil CO_2 / kg biodiesel	18.29
Energy inputs (Steam)	g fossil CO_2 / kg biodiesel	82.97
Chemical inputs (methanol)	g fossil CO_2 / kg biodiesel	35.865
Chemical inputs (Sodium Hydroxide (NaOH))	g fossil CO_2 / kg biodiesel	2.1042
Chemical inputs (Sodium Methoxide (CH_3OH))	g fossil CO_2 / kg biodiesel	23.2311
Co-products (glycerol)	kg/kg of biodiesel produced	10%
Wastewater	L /kg biodiesel	0.36
Kilograms CO_2 Eq/kg biodiesel produced		**1.625E-01**

Generation Facility

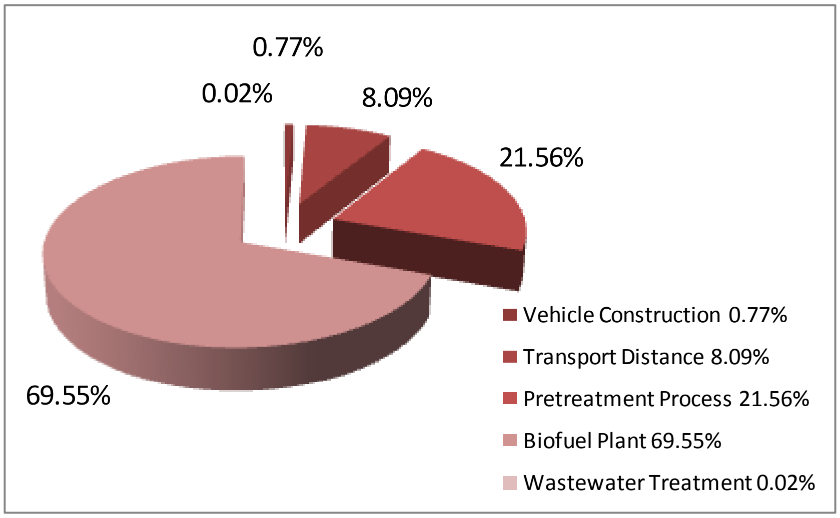
Variables	Units	Assumed value
Net Heating Value	Btu / gallon of biodiesel	118,296
U.S. Average Btu to kWh Electric Generation conversion ratio	Btu / kWh produced	10,280
Kilograms CO_2 Eq/KwH generated		

Wastewater Treatment

Variables	Units	Assumed value
Gallons treated at plant	gallons/day	9,000,000
Electricity usage of plant	kWh/month	200,000
kWh needed to treat one gallon of wastewater	kWh/gallon	0.000740741
Wastewater produced from pretreatment	% of waste grease comprised of water	10%
Wastewater produced from biodiesel generation	liters/ kg of waste grease	0.360
Carbon intensity of NJ electricity gen	lbs of CO_2 emissions/KwH	1.2617
Kilograms CO_2 Eq/kg of biodiesel produced		**5.235E-05**

Mass Loss Associated w/ Rendering		
Variables	Units	Assumed value
Units of waste grease required per unit of biodiesel	%	111%
Added intensity of Stage 1 of transportation (vehicle production)	kg CO_2 / kg of biodiesel produced	6.574E-05
Added intensity of Stage 1 of transportation (distance)	kg CO_2 / kg of biodiesel produced	2.978E-04
Added intensity of Rendering/Pretreatment Process	kg CO_2 / kg of biodiesel produced	5.540E-03
Kilograms CO2 Eq/kg of biodiesel produced		5.903E-03

CO_2 Emissions per Model Segment



SUMMARY TABLE OF RESULTS	
Vehicle Construction	1.793E-03
Transport Distance	1.890E-02
Pretreatment Process	5.036E-02
Biofuel Plant	1.625E-01
Wastewater Treatment	5.235E-05
Mass Loss Associated with Rendering	5.903E-03
Coproduct Credit	10%
kg CO2 EQ Emissions/kg of biodiesel	0.215524
kg CO2 EQ Emissions/kWh generated	0.061879

Greenhouse Gas Emissions From Producing Tanker Trucks

Studies published by MIT[160] and data from Ward's Automotive Guide[161] have established that the average car is made up of the following general materials: plastic, aluminum, copper, zinc, lead, other ferrous, iron, carbon steel, among others. Based on the percentage of pounds of these components we have estimated the amount of each material for the trucks, having assumed that the average waste collection vehicle and tractor-trailer are made up of similar percentages of materials.

Using data from the GREET Model, we have determined the kg of CO_2 emitted per pound of material used in vehicle manufacture.[162]

According to our calculations, there are approximately 2.0891 kg of CO_2 emissions per pound of vehicle weight.

We assume that the average liquid tanker truck weighs approximately 10 tons, or 20,000 pounds.[163]

This means that the average truck would require about 41,782 kg of fossil carbon dioxide emissions to build.

2.0891 kg/pound * 20,000 pounds = 41,782 kg

The average life of a truck is assumed to be 13 years.[164] (This is the average usable life given for a garbage truck, but we assume that the usable life is similar for a tanker truck of approximately equal size).

Assuming that the truck runs five days a week (5 days * 52 weeks/year) it would run 260 days per year, and make two trips per day. We also calculated an average load of approximately 3,130 gallons.

Since biodiesel weighs approximately 7.3 pounds per gallon[165] (and refined oil and waste grease weigh about the same) the average load of a tanker truck would weigh 22,849 pounds or 10,341.22 kg.

3,130 gallons * 7.3 pounds per gallon * 0.45259 kg per pound = 10,341.22 kg per load

Assuming 41,782 kg of CO_2 emissions associated with construction, divided by 13 years of useful life = 3,214 kg, divided by 260 days per year = 12.36 kg, divided by two trips per day = 6.18 kg, divided by 10,341.22 kg of waste hauled in one trip = $5.98e^{-4}$ kg of fossil CO_2 emissions per kg of waste grease transported.

Since there are three stages in the transportation process (from waste source to rendering facility, from rendering facility to biodiesel plant, and from biodiesel plant to generation facility), we assume that there will be three tanker trucks needed for efficient transportation. Therefore, the figure above is multiplied by three, for a final number of 1.793^{-3} kg of fossil CO_2 emissions per kg of waste grease transported (associated with the construction of transportation vehicles).

Fossil Greenhouse Gas Emissions From Transportation

Carbon dioxide emissions from a gallon of diesel = 2,778 grams * 0.99 (oxidation factor) * 44/12 (molecular weight of carbon dioxide/molecular weight of carbon) = 10,084 grams/gallon = 10.1 kg/gallon = 22.2 pounds/gallon.[166]

We assume that tanker trucks in the first stage of transportation (from waste sources to rendering facility) will have fuel economies similar to those of garbage trucks (2.8 mpg), since they weigh approximately the same and will make similar numbers of stops.[167] Similarly, we assume that tanker trucks in the second and third stages of transportation have fuel economies similar to those of tractor trailers (6.5 mpg).[168]

In this specific scenario we are considering a waste grease collection area centered around the metropolitan area of Newark, and a rendering facility (Darling International) located in Newark.[169] The average distance from any commercial entity to Darling is assumed to be 10 miles. Furthermore, this scenario considers the FuelBio plant as the refining facility, also located in Newark. The distance from Darling International to FuelBio is 3.7 miles.

Finally, the biodiesel will be shipped to the cogeneration plant in Vineland, Atlantic County, New Jersey.[170] The exact is distance 98.9 miles. All distances were calculated using Google Maps as of April 3, 2008.

To calculate the total fuel used for the entire transportation process, the distance of the first stage was divided by 2.8 mpg, while the distances of the second and third stages were divided by 6.5 mpg. These figures were then added together for a total of 19.35 gallons.

(10 miles / 2.8 miles per gallon) + ((98.9 miles + 3.7 miles) / 6.5 miles per gallon) = 19.35 gallons

19.35 gallons of diesel * 10.1 kg of CO_2 emissions per gallon = 195.49 kg of CO_2

Assuming an average load of 3,130 gallons of grease or biodiesel, each gallon has 0.06245 kg of fossil CO_2 emissions associated with transportation.

195.49 kg of CO_2 per total trip / 10,341.22 kg of waste hauled in one trip = 0.0189 kg of CO_2 per kg of waste transported.

<u>Fossil Greenhouse Gas Emissions from Rendering Process</u>

The average amount of electricity used for rendering a metric ton of yellow grease or tallow is 88 kWh/metric ton.[171] (This number would need to be increased slightly for brown/trap grease).

To convert from metric ton to kilograms, we have (88 kWh /metric ton) / (1,000 kg/ metric ton) = 0.088 kWh/kg of grease.

According to the NJDEP, 1 kWh of electricity generated in New Jersey produces 1.2617 pounds of CO_2 equivalent emissions.[172] To convert this to kg of CO_2 equivalent, (1.2617 pound CO_2/kWh)*(0.45359 kg/pound) = 0.57kg CO_2/kWh

(0.088 kWh/kg of grease)*(0.5722 kg CO_2/kWh) = 0.0504 kg CO_2/kg of grease processed.

<u>Fossil Greenhouse Gas Emissions from Biodiesel Production / Refining</u>

According to one study produced by the National Renewable Energy Laboratory (NREL), producing one metric ton of biodiesel requires 28.9 kWh of electricity from the grid and 329,793.50 kcal of steam.[173] The same study finds that producing each kilogram of biodiesel also requires 0.024 kg of Sodium Methoxide (CH_3ONa), 0.0023 kg of Sodium Hydroxide (NaOH), and 0.096 kg of Methanol (CH_3OH).[174]

Looking at the electricity input first, 28.9 kWh per metric ton of biodiesel produced is the equivalent of 0.0289 kWh per kg of biodiesel. Since each kWh of electricity produced for the New Jersey Grid has 1.2617 pounds of CO_2 equivalent emissions associated with it, each kg of biodiesel produced will have 0.03646 pounds of CO_2 emissions.

0.0289 kWh per kg of biodiesel * 1.2617 pounds of CO_2 equivalent emissions per kWh = 0.03646 pounds of CO_2 per kg biodiesel

0.03646 pounds of CO_2 per kg biodiesel *0.45359 kg per pound = 0.016539 kg of CO_2 emissions per kg of biodiesel * 1,000 grams per kilogram = 16.53 grams of CO_2 emissions per kilogram of biodiesel produced.

We also came across another study produced by the U.S. Department of Energy and the Department of Agriculture, which lists the grams of fossil CO_2 emissions associated each different input of the biodiesel production process (standardized to one kilogram of biodiesel produced). According to this study, steam production = 82.96g, electricity generation = 18.26g, Methanol production = 35.86g, Sodium Methoxide production = 23.23g, and Sodium Hydroxide production = 2.1g.[175] Given the fact that this study's number for electricity generation was so close to our own calculated value, we feel very confident in utilizing the rest of these given values in this model. Thus, there is approximately 0.1625 kg of CO_2 emissions per kg of biodiesel produced.

(82.97g + 18.29g + 35.86g + 23.23g + 2.1g) / (1,000 g / kg) = 0.1625 kg of CO_2 emissions per kg of biodiesel produced

Fossil Greenhouse Gas Emissions From Wastewater Treatment

The average wastewater treatment plant in New York, according to NYSERDA, processes 9 million gallons per day and uses approximately 200,000 kWh per month.[176] We assume that New Jersey treatment plants are similar to those in New York.

This means that in the average day of a 30 day month, a plant uses 6,666 kWh of electricity and processes 9 million gallons.

6,666 kWh per day / 9 million gallons per day = 0.000740741 kWh/ gallon of wastewater treated.

For the pretreatment/rendering stage of the process, the amount of wastewater produced is largely dependent on the percentage of water mixed in with the waste grease at the time of collection. Yellow grease tends to have the lowest amount of water, followed by tallow, and finally brown grease. Assuming that the majority of the feedstock will be comprised of yellow grease and tallow, we estimate that the waste grease will have an average water content of approximately 11%.[177] First, this means that about 0.111 kg of wastewater will be generated for every kg of processed oil produced (the mass balance between processed oil and biodiesel is approximately 1 to 1).[178]

(0.111kg of wastewater per kg of biodiesel produced * 0.2642 gallons per kilogram of water = 0.02932 gallons of wastewater generated per kg of biodiesel produced)

Second, this means that approximately 1.11 kg of waste grease would be needed to produce 1kg of treated oil, from which 1 kg of biodiesel could be produced. This means that the first stage of the transportation process, along with the energy input for rendering, will be 11% more intensive than previously calculated. A multiplier to this effect has been included at the end of the model.

Additionally there are 0.36 liters of wastewater generated per kilogram of biodiesel produced in the biodiesel refining process.[179]

0.36 liters per kg of biodiesel * 0.26147 gallons per liter = 0.09412 gallons of wastewater generated per kg of biodiesel produced.

This number added to the amount from the pretreatment/rendering process yields a number of

0.09412 gallons of wastewater + 0.02932 gallons of wastewater = 0.1234 gallons of wastewater generated per kg of biodiesel produced

0.1234 gallons of wastewater generated per kg of biodiesel produced * 0.000740741 kWh per gallon of wastewater treated = $9.14e^{-5}$ kWh per kg of biodiesel produced

1.2617 pounds of CO_2 per kWh * 0.45359 kg per pound = 0.57229 kg of CO_2 emissions per kWh

0.57229 kg of CO_2 emissions per kWh * $9.14e^{-5}$ kWh per kg of biodiesel produced = $5.23e^{-5}$ kg of fossil CO_2 emissions associated with the treatment of wastewater as a result of the production of 1 kg of biodiesel.

Mass Loss Associated with Rendering:

The rendering of waste grease into usable oil involves a loss of mass as contaminants and water are removed. We have calculated that an average mass-loss for yellow grease and tallow is about 11%, meaning that approximately 1.11 units of grease are needed to produce 1 unit of usable oil. Therefore, the fossil CO_2 emissions of each stage of the lifecycle model up to and including rendering will need to be increased by 11% to account for the added amounts of waste grease needed to produce an equivalent amount of biodiesel

Co-Product Credit:

A co-product credit of 10% is associated with the generation of glycerin from the biodiesel production process. First, this number is similar to other co-product credits allocated in similar lifecycle models.[180] Secondly, the glycerin byproduct represents approximately 10% of the mass-balance in the biodiesel refining process.[181]

Electricity Generation:

It must be noted that biodiesel has an energy content of 118,296 Btu per gallon, compared to conventional No. 2 Diesel fuel, which has an energy content of 129,500 Btu per gallon (a difference of 11%). Practically, this means that when comparing the carbon emission output of waste-grease biodiesel compared to conventional diesel, that the biodiesel emission profile must be increased by 11%.

It was also calculated that in 1994, the average heat content (Btu) required per unit of electricity output (kWh) for all fossil fuel electricity generation facilities in the U.S. was 10,280 Btu / kWh produced.[182] This means that

> 10,280 Btu per kWh produced / 118,296 Btu per gallon = 0.0869 gallons of biodiesel needed to produce 1 kWh of electricity
>
> 0.0869 gallons of biodiesel needed to produce 1 kWh of electricity * 7.3 pounds per gallon * 0.45259 kg per pound = 0.28711 kg of biodiesel needed to produce 1 kWh of electricity

(0.2155 kg of CO_2 Eq. emissions generated per kg of biodiesel produced) * (0.28711 kg of biodiesel needed to produce 1 kWh of electricity) = **0.0618 kg of fossil CO_2 Eq. emissions per kWh** of electricity generated from waste-grease derived biodiesel.

Sensitivity Analysis: Waste Grease Model

Variables	Contribution to Final Result	Confidence
Vehicle Weight	0.20%	High
Average Life of Truck	0.20%	High
Number of Loads Hauled per Year	0.20%	High
Kg of CO_2 per lb of Vehicle Weight	0.20%	Medium
Average Load Capacity	2.74%	High
Fuel Economy of Vehicle (Stage 1)	0.48%	High
Commercial Entities to Rendering (Stage 1)	0.48%	Low
Rendering to Biodiesel Plant (Stage 2)	0.08%	Medium
Biodiesel Plant to Generation Facility (Stage 3)	2.08%	Medium
Fuel Economy of Vehicle (Stage 2+3)	2.16%	High
Amount of Energy used for Pretreatment	10.50%	Medium
Carbon Intensity of New Jersey Electricity	10.54%	High
Energy Inputs (Electricity)	7.77%	High
Energy Inputs (Steam)	35.70%	High
Chemical Inputs (Methanol)	15.40%	High
Chemical Inputs (Sodium Hydroxide)	0.70%	High
Chemical Inputs (Sodium Methoxide)	10.50%	High
kWh to Treat One Gallon of Wastewater	0.03%	High
Wastewater produced from Pretreatment	0.01%	Medium
Wastewater Produced from Biodiesel Production	0.02%	High

The results of the analysis for the waste grease model show that the rendering and biodiesel production processes are by far the largest contributors to carbon intensity in the overall model. To the best of our knowledge, biodiesel production plants currently produce their steam using industrial boilers, and draw their electricity directly from the local power grid. If these two processes could be integrated using combined-cycle turbine technology, significant carbon/energy savings could be achieved. Considering the qualitative evaluation of variables, the largest uncertainties lie in the transportation and rendering stages of the model. Though we considered a transportation scenario using actual existing facilities, the distances would clearly be altered if different facilities had been selected.

Also, the number and location of additional commercial entities is fairly unclear, so estimations for the distances between these locations and rendering facilities is likely to be rough at best. The values for energy used and wastewater produced at the rendering facility are also somewhat variable, because both are directly related to the amount of water and other non-grease materials contained within the waste grease. The different types of greases (yellow, brown, tallow) all have different proportions of these excess materials, and so the percentages at which they are combined can have a large effect on overall carbon intensity. Considering Low and Medium levels of confidence for values which contribute to approximately 12.9% of the variation in the overall model, it would be fair to assume that the final number produced by the model could vary by as much as 12.9%.

Conclusion

The final result of this model is that there is 0.0619 kg of fossil CO_2 Eq. emissions per kWh of electricity generated from waste-grease derived biodiesel. This value is compared to 0.5947 kg of fossil CO_2 emitted for every kWh generated using natural gas and to 0.5723 kg, which is the average fossil CO_2 emissions from the production of 1 kWh of electricity in the State of New Jersey.

Soybean Oil Model

This model has been designed to estimate the amount of greenhouse gas emissions produced in the cultivating and processing of soybeans for biodiesel production, specifically for use by electric cogeneration facilities in New Jersey. The model provides an emissions profile for the carbon intensity of the soybean production stage to the processing of biodiesel using methyl esterification technology, through to combustion to produce electricity. The model has been tailored specifically for the State of New Jersey, though with minor modifications it could be effectively tailored for use in other areas. The following document is a step-by-step detailed explanation of all assumptions and calculations used in the model.

In designing the model, it was assumed that no existing soybean cultivation would be allocated to biodiesel production, and additional cultivated land area would be needed to increase soybean yields. This assumption is made to avoid the uncertainty related to soybean's role as a food stock, and the possible economic impacts associated to their reallocated use as a biodiesel input. Due to the increase in land used for soybean cultivation, additional farm machinery and on-farm inputs will be required. This is in contrast to our assumptions regarding biodiesel production / refining infrastructure. It is assumed that soybean crushing will occur at the nearest available facility, in Salisbury, Maryland,[183] and processing of soybean oil into biodiesel will take place at an existing biodiesel plant located in Berlin, Maryland.[184] This is based on the assumption that additional biodiesel production capacity and infrastructure are available within the region. Similarly, we assume the resulting biodiesel fuel will be co-fired at an existing cogeneration power plant located in Vineland, New Jersey.

It is important to note that new transportation vehicles will be required to haul soybean oil from the farm to the processing facilities, and new vehicles will also be required to transport biodiesel to the cogeneration plant. Though the current model is based on the carbon dioxide emissions associated with the production of an average vehicle, the model can also be modified to represent detailed vehicle specifications. The model also treats fuel economy and transportation distance in this way, providing realistic average scenarios, but allowing for more detailed inputs that will further increase the accuracy and specificity of the model.

One of the largest assumptions made in the transportation process phase in the model deals with the carbon intensity of producing a soybean or oil hauling truck. We were not able to find reliable data on the composition of such trucks by material type. Therefore, we mainly used papers published by MIT, which estimated the composition of the average American passenger vehicle by type of material, and assumed that a soybean-hauling truck would have a similar material profile. It is also important to note that this model does not directly consider the carbon dioxide emissions associated with the production of the diesel fuel used to run the trucks, or the fossil fuel sources used for normal electricity production in the New Jersey grid. However, our research did uncover a life-cycle-analysis for the production of petroleum diesel, the results of which have been included in an individual section of this report. These numbers could certainly be incorporated or compared to the final results of this model, in order to enhance the understanding of actual carbon intensity associated with fossil fuel production.

The production of biodiesel renders two main co-products that we calculate and include in the model. These products are soybean meal, which is mainly used as an animal feedstock, and glycerin, which is typically used to make soap or cosmetic products. Keeping consistent with studies we have seen, we have allocated a percentage of the total fossil carbon dioxide emissions in the lifecycle to each of the co-products. It must also be noted that only a percentage of the carbon dioxide emissions produced up to the point in the lifecycle where the co-product was produced will be allocated to the co-product. For instance, soy-meal receives a 25% co-product credit in this model, but that will only take into consideration the emissions produced in the production of soybeans, the transportation to the crushing facility, and the crushing process, which separates the soy-meal from the usable oil. We assume in the model, based on our literature review, that soy-meal will be allocated a 25% credit, and glycerin will receive a 10% credit.

As mentioned earlier, the following sections detail the individual steps and calculations used in constructing the model, and roughly correspond to sections in the final model Excel sheet. Most of the sections in this document also have corresponding sheets of Excel data or calculations. All of the variables listed in the final model sheet can be altered to fit different scenarios, and results of the calculations will change based on those inputs.

According to preliminary results and calculations, the process of producing a kWh of electricity from soybean derived biodiesel generates approximately 0.33090 kg of fossil CO_2 emissions. This can be compared to 0.0618 kg of fossil CO_2 emissions from waste-grease, -0.9296 kg produced per kWh generated using biogas from anaerobic digesters, and the 0.5723 kg produced per kWh through current generation of electricity in the New Jersey grid.

Soybean Production and Processing

Variables	Units	Assumed value
Primary energy inputs to agriculture	g fossil CO2 / kg soybeans	49.14
Fossil fuel energy inputs to agriculture	g fossil CO2 / kg soybeans	133.72
Construction of farm equipment and machinery	MJ / liter of biodiesel	1.414
Kilograms CO2 Eq/kg oil		**1.170275**
Kilograms CO2 Eq/kg oil (considering co-products)		**0.760679**

Vehicle Construction I

Variables	Units	Assumed value
Vehicle weight	Short tons	10
Average life of truck	Years	13
Average load capacity	Short tons	21
Number of loads hauled per year	#/yr	520
Kilograms CO2 Eq/kg oil		**0.001622**
Kilograms CO2 Eq/kg oil (considering co-products)		**0.001054**

Transport Distance I

Variables	Units	Assumed value
Avg distance - farm to soybean crushing facility	miles	158
Fuel economy of vehicle	miles/gallon	6.5
Kilograms CO2 Eq/kg oil transported		**0.06443**
Kilograms CO2 Eq/kg oil (considering co-products)		**0.04188**

Soybean Crushing and Processing

Variables	Units	Assumed value
Soybean crushing and processing	g fossil CO2 / kg soybean oil	200.32
Kilograms CO2 Eq/kg oil		**0.200320**
Kilograms CO2 Eq/kg oil (considering co-products)		**0.130208**

Vehicle Construction II

Variables	Units	Assumed value
Vehicle weight	Short tons	10
Average life of truck	Years	13
Average load capacity	Gallons	3130
Number of loads hauled per year	#/yr	520
Kilograms CO2 Eq/kg oil		**0.000598**
Kilograms CO2 Eq/kg oil (considering co-products)		**0.000538**

Transport Distance II

Variables	Units	Assumed value
Avg distance - soy crushing facility to biodiesel plant	miles	22.8
Fuel economy of vehicle	miles/gallon	6.5
Kilograms CO_2 Eq/kg oil transported		**0.003426**
Kilograms CO_2 Eq/kg oil (considering co-products)		**0.003083**

Biodiesel Plant

Variables	Units	Assumed value
Energy inputs (Electricity)	g fossil CO_2 / kg biodiesel	18.26
Energy inputs (Steam)	g fossil CO_2 / kg biodiesel	82.97
Chemical inputs (methanol)	g fossil CO_2 / kg biodiesel	35.860
Chemical inputs (Sodium Hydroxide (NaOH))	g fossil CO_2 / kg biodiesel	2.1040
Chemical inputs (Sodium Methoxide (CH_3OH))	g fossil CO_2 / kg biodiesel	23.23
Co-products (glycerol)	kg/kg of biodiesel produced	0.100
Waste water	L /kg biodiesel	0.38
Kilograms CO_2 Eq/kilogram produced		**0.162423**
Kilograms CO_2 Eq/kg oil (considering co-products)		**0.146181**

Wastewater Treatment

Variables	Units	Assumed value
Gallons treated at plant	gallons/day	9,000,000
Electricity usage of plant	kWh/month	200,000
kWh needed to treat one gallon of wastewater	kWh/gallon treated	0.000740741
Gallons produced from biodiesel generation	L /kg biodiesel	0.380
Carbon intensity of NJ electricity gen	lbs of CO_2 emissions/KwH	1.2617
Kilograms CO_2 Eq/kg biodiesel produced		**0.00001285**
Kilograms CO_2 Eq/kg oil (considering co-products)		**0.00001156**

Vehicle Construction III

Variables	Units	Assumed value
Vehicle weight	Short tons	10
Average life of truck	Years	13
Average load capacity	Gallons	3130
Number of loads hauled per year	#/yr	520
Kilograms CO_2 Eq/kg biodiesel		**0.0005977**
Kilograms CO_2 Eq/kg oil (considering co-products)		**0.0005379**

Transport Distance III

Variables	Units	Assumed value
Avg distance -biodiesel plant to power plant	miles	153
Fuel economy of vehicle	miles/gallon	6.5
Kilograms CO_2 Eq/kg biodiesel transported		**0.075955**
Kilograms CO_2 Eq/kg oil (considering co-products)		**0.068359**

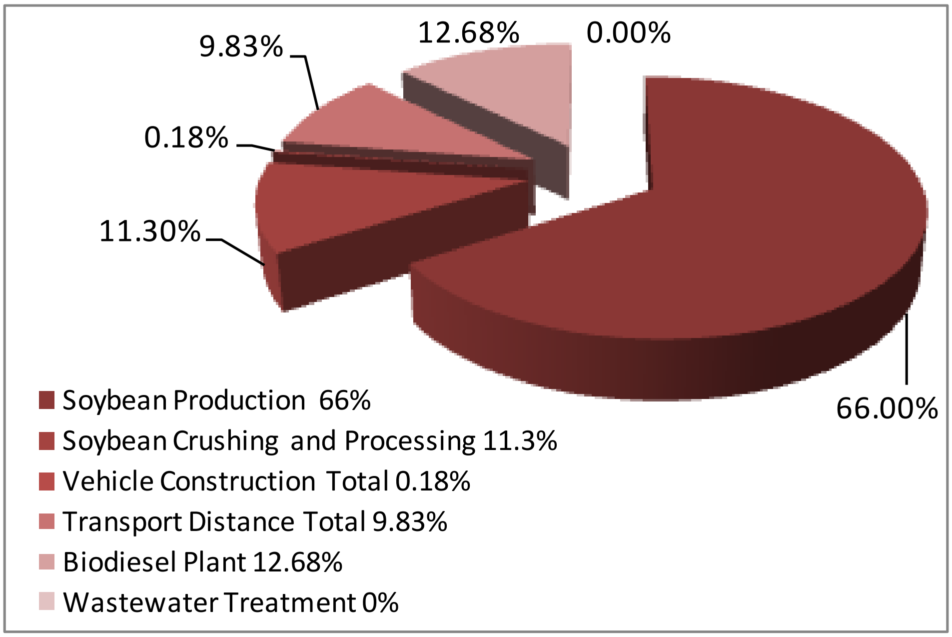
Co-product Credits

Variables	Units	Assumed value
Co-product Credit for Soymeal	**%**	25%
Co-product Credit for Glycerol		10%

Generation Facility

Variables	Units	Assumed value
Net Heating Value	Btu / gallon of biodiesel	118,296
U.S. Average Btu to kWh Electric Generation conversion ratio	Btu / kWh produced	10,280

CO_2 Emissions per Model Segment



SUMMARY TABLE OF RESULTS	
Soybean Production	0.760679
Soybean Crushing and Processing	0.130208
Vehicle Construction Total	0.0021
Transport Distance Total	0.1133
Biodiesel Plant	0.1461806
Wastewater Treatment	0.000011563
TOTAL CO2 EQ EMISSIONS kg/kg biodiesel	1.152535
TOTAL CO2 EQ EMISSIONS kg/ kWh	0.330906

Soybean Cultivation and Processing

Carbon equivalent emissions for soybean cultivation and processing are based on material data produced in the 1998 study conducted by the National Renewable Energy Laboratory (NREL) on the lifecycle of petroleum diesel and soybean biodiesel.[185] The study provides both net energy balances and associated fossil CO_2 emissions for the production of soybeans for use in biodiesel production.

We used data which is given in units of grams of fossil CO_2 emitted per kg of soybeans produced. The various inputs to the soybean production process can be roughly divided into two categories, fossil fuel energy inputs and primary energy inputs. The inputs for fossil fuel energy include diesel (84.68 g/kg), gasoline (42.02 g/kg), natural gas (.00497 g/kg), propane (2.61 g/kg), and electricity (4.41 g/kg). The primary energy inputs include nitrogen fertilizer (17.93 g/kg), phosphate fertilizer (11.99 g/kg), potash fertilizer (7.58 g/kg), and agrochemicals, including pesticides, herbicides, etc. (11.64 g/kg). All of the inputs for the two categories were summed to produce the final values inputted to the model.

Fossil Fuel Energy Inputs = 84.68 g/kg + 42.02 g/kg + 0.00497 g/kg + 2.61 g/kg + 4.41 g/kg = 133.72 g fossil CO_2 emissions / kg of soybeans produced

Primary Energy Inputs = 17.93 g/kg + 11.99 g/kg + 7.58 g/kg + 11.64 g/kg = 49.14 g fossil CO_2 emissions / kg of soybeans produced

In order to convert these values to units of kg fossil CO_2 emissions / kg of biodiesel produced, we first had to divide the final number by 1000 g/kg, and then multiply by 5 kg of soybeans / kg of biodiesel produced (a number given in the NREL study).[186]

Fossil Fuel Energy Inputs: (133.72 g fossil CO_2 emissions / kg of soybeans produced) / (1,000 g / kg) * (5 kg of soybeans / kg of biodiesel produced) = 0.668 kg fossil CO_2 emissions / kg of biodiesel produced

Primary Energy Inputs: (49.14 g fossil CO_2 emissions / kg of soybeans produced) / (1,000 g / kg) * (5 kg of soybeans / kg of biodiesel produced) = 0.2457 kg fossil CO_2 emissions / kg of biodiesel produced

One input not included in the NREL study was a value for the energy input / CO_2 emissions associated with the construction of farm machinery. However, another study conducted by Hill et al., which investigated the net-energy-balance and associated CO_2 emissions from soybean-biodiesel production did calculate the energy input values for farm machinery. These values are given as 1.414 MJ of energy input per liter of biodiesel produced (associated with the construction / production of all farm machinery).[187] In order to convert this value to kg of fossil CO_2 emissions per kg of biodiesel produced, several steps are necessary. First, the units of MJ per liter must be converted to units of kWh per liter, and then into kg of fossil CO_2 per liter. The MJ to kWh is a straight unit conversion of where 1 MJ = 0.2777 kWh, and we know from previous conversations with the NJDEP that 1 kWh of electricity in the New Jersey grid produces 0.5723 kg of fossil CO_2 emissions.[188] The next step is to convert liters of biodiesel into kg of biodiesel. This is accomplished using straight conversion values of 3.78 liters per gallon, 7.3 lbs per gallon of biodiesel,[189] and 2.2 lbs per kg.

(1.414 MJ of energy input / liter of biodiesel produced) * (0.2777 kWh / MJ) = 0.3927 kWh / liter of biodiesel

(0.3927 kWh / liter of biodiesel) * (0.5723 kg of fossil CO_2 / kWh of electricity in New Jersey) = 0.2247 kg of fossil CO_2 / liter of biodiesel

(0.2247 kg of fossil CO_2 / liter of biodiesel) * (3.78 liters / gallon) = 0.8494 kg of fossil CO_2 / gallon of biodiesel

(0.8494 kg of fossil CO_2 / gallon of biodiesel) / (7.3 lbs / gallon) = 0.1164 kg of fossil CO_2 / lb of biodiesel

(0.1164 kg of fossil CO_2 / lb of biodiesel) * (2.2 lb / kg) = 0.2561 kg of fossil CO_2 / kg of biodiesel

We feel that these numbers are fairly accurate given the assumptions in the Hill et al. paper, especially considering that we were able to replicate our results for associated CO_2 emissions through a secondary calculation. Given the listed weights of the different machinery, and assuming (as the Hill study did) that all machinery is completely composed of carbon steel, we were able to use the numbers listed in the GREET model for kg of fossil CO_2 emitted per lb of steel to recalculate the kg of fossil CO_2 emitted per lb of biodiesel. The resulting value was within 85% of our number of 0.2561 kg of fossil CO_2 / kg of biodiesel. We believe this difference is acceptable, and can be associated with very slight differences in carbon-accounting methodology.

Thus, the final value for kg of fossil CO_2 per kg of biodiesel associated with soybean production can be found by summing the values for fossil fuel energy inputs, primary energy inputs, and the construction of farm machinery.

(0.668 kg fossil CO_2 emissions / kg of biodiesel produced) + (0.2457 kg fossil CO_2 emissions / kg of biodiesel produced) + (0.2561 kg of fossil CO_2 / kg of biodiesel produced) = 1.1698 kg of fossil CO_2 / kg of biodiesel produced

It should be noted that the final number produced in the model spreadsheet is slightly higher, due to rounding errors associated with the calculations above.

Vehicle Construction
Studies published by MIT[190] and data from Ward's Automotive Guide[191] show the average car is made up of a number of general materials in pounds (percentages have been added for materials being considered).

Using data from the GREET Model we have determined the kg of CO_2 emitted per pound of material used in vehicle manufacture.[192]

According to our calculations, there are approximately 2.0891 kg of CO_2 emissions per pound of vehicle weight.

We assume that an average liquid tanker truck weighs approximately 10 short tons, or 20,000 lbs.[193] For the purposes of this vehicle construction segment, we also assume that the vehicle transporting processed soybean oil from the crushing facility to the biodiesel plant, and the vehicle transporting refined biodiesel to the power generation facility both have the same profile.

This means that the average truck would require about 41,782 kg of fossil CO_2 emissions to build.

2.0891 kg/pound * 20,000 pounds = 41,782 kg fossil CO_2 emissions

The average life of a truck is assumed to be 13 years (this is the average usable life given for a garbage truck, but we assume that the usable life is similar for a truck transporting oil and biodiesel of approximately equal size).[194]

The soybean growing season in the U.S. typically runs September to November. Assuming that the truck runs five days a week (5 days * 52 weeks/year) it would run 260 days per year, and make two trips per day for a total of 520 trips a year. We also calculated an average load of approximately 3,130 gallons.

We assume a gallon of soybean oil weighs approximately the same as a gallon of biodiesel (based on mass-balance calculations). According to the EPA this is approximately 7.3 pounds per gallon.

(3,130 gallons of soybean oil/truck load) * (7.3 pounds per gallon) = 22,849 lbs * 0.45259 kg per pound = 10,341.22 kg of soybean oil per load.

Assuming 41,782 kg of fossil CO_2 emissions associated with construction, divided by 13 years of useful life = 3214 kg, divided by 520 trips per year = 6.18 kg, divided by 10,341.22 kg of waste hauled in one trip = 0.0005976 kg of fossil CO_2 emissions per kg of soybean transported.

The first transportation phase of the lifecycle consists of transporting the soybeans from the farm to the soybean crushing facility. We assume that this vehicle will be of a similar type to the vehicle transporting solid food waste in the food waste model, and therefore the numbers from that model were used. For step-by-step calculations of fossil CO_2 emissions associated with this vehicle, please see the vehicle construction section of the food waste model.

Transport Distance
Carbon dioxide emissions from a gallon of diesel = 2,778 grams * 0.99 (oxidation factor) * 44/12 (molecular weight of carbon dioxide/molecular weight of carbon) = 10,084 grams/gallon = 10.1 kg/gallon = 22.2 pounds/gallon.

We assume that trucks and liquid tankers will have fuel economies similar to those of tractor trailers (6.5 mpg) given the weight being hauled and the limited number of stops.[195]

In this specific scenario, we assume the soybean farm is located in Southampton, Burlington County, New Jersey's largest and most agriculture-intensive county, which is approximately 158 miles away from the nearest soybean crushing facility, located in Salisbury, Maryland and operated by Perdue Farms LLC.

To calculate the total fuel used for this transportation segment, the distance was divided by the fuel economy in miles per gallon

158 miles / 6.5 mpg = 24.31 gallons of diesel.

24.31 gallons of diesel * 10.1 kg of CO_2 emissions per gallon = 245.53 kg of CO_2

Assuming an average load of 19,051 kg of soybeans:

245.53 kg of CO_2 per total trip / 19,051 kg of soybeans in one trip = **0.01288 kg of CO_2 per kg of soybean transported.**

Again, the second transport phase of the lifecycle consists of transporting the refined soybean oil from the crushing facility to the biodiesel plant, located in Berlin, Maryland and operated by Maryland Biodiesel Inc.[196] The only variables to change were the construction assumptions for the liquid tanker truck (in which only the load profile changes), and the distance of 22.8 miles. For the third transportation phase the liquid tanker construction profile is also used, along with a distance of 153 miles from the biodiesel production plant in Berlin, Maryland to the co-generation power facility located in Vineland, New Jersey.

Soybean Crushing and Processing

Data for the carbon dioxide emissions associated with soybean crushing and processing were obtained from the NREL study of lifecycle inputs to soybean biodiesel production.[197] The total value was reported as 200.328 g of fossil CO_2 emissions per kg of soybean oil produced. This number included values for natural gas use, steam production, electricity, and hexane production. Converting this number into a value for the total kg of fossil CO_2 emissions per kg of biodiesel is fairly simple. It is only necessary to convert g of fossil CO_2 into kg by dividing by 1,000. Since 1 kg of soybean oil is used to create 1 kg of biodiesel, no further calculations / conversions are necessary.

(200.328 g of fossil CO_2 emissions per kg of soybean oil produced) / (1,000 g / kg) = 0.200328 kg of fossil CO_2 emissions per kg of biodiesel produced

Biodiesel Production / Refining

According to the NREL study, producing 1 metric ton of biodiesel requires 28.9 kWh of electricity from the grid and 329,793.50 kcal of steam.[198] The same study finds that producing each kilogram of biodiesel also requires 0.024 kg of Sodium Methoxide (CH_3ONa), 0.0023 kg of Sodium Hydroxide (NaOH), and 0.096 kg of Methanol (CH_3OH).[199]

Looking at the electricity input first, 28.9 kWh per metric ton of biodiesel produced is the equivalent of 0.0289 kWh per kg of biodiesel. Since each kWh of electricity produced for the New Jersey Grid has 1.2617 pounds of CO_2 equivalent emissions associated with it, each kg of biodiesel produced will have 0.03646 pounds of CO_2 emissions.

(0.0289 kWh per kg of biodiesel * 1.2617 pounds of CO_2 equivalent emissions per kWh = 0.03646 pounds of CO_2 per kg biodiesel)

0.03646 pounds of CO_2 per kg biodiesel * 0.45359 kg per pound = 0.016539 kg of CO_2 emissions per kg of biodiesel * 1,000 grams per kilogram = 16.53 grams of CO_2 emissions per kilogram of biodiesel produced.

We also looked at another study produced by the U.S. Department of Energy and the Department of Agriculture, which lists the grams of fossil CO_2 emissions associated each different input of the biodiesel production process (standardized to 1 kilogram of biodiesel produced). According to this study, steam production = 82.96g, electricity generation = 18.26g, Methanol production = 35.86g, Sodium Methoxide production = 23.23g, and Sodium Hydroxide production = 2.1g.[200] Given the fact that this study's number for electricity generation was so close to our own calculated value, we feel very confident in utilizing the rest of these given values in this model. Thus, we approximate 0.1624 kg of CO_2 emissions per kg of biodiesel produced.

(82.96g + 18.26g + 35.86g + 23.23g + 2.1g) / (1,000 g / kg) = 0.1624 kg of CO_2 emissions per kg of biodiesel produced.

Wastewater Treatment

The average wastewater treatment plant in New York, according to NYSERDA, processes 9 million gallons per day and uses approximately 200,000 kWh per month.[201] We assume that New Jersey treatment plants are similar to those in New York.

This means that in the average day of a 30 day month, a plant uses 6,666 kWh of electricity to process 9 million gallons.

6,666 kWh per day / 9 million gallons per day = 0.000740741 kWh/ gallon of wastewater treated.

Additionally there are 0.38 liters of wastewater generated per kilogram of biodiesel produced in the biodiesel refining process.[202]

0.38 liters per kg of biodiesel * 0.26147 liters per gallon = 0.09935 gallons of wastewater generated per kg of biodiesel produced.

> (0.09935 gallons of wastewater generated per kg of biodiesel produced) * (0.000740741 kWh per gallon of wastewater treated) = 0.00007359 kWh per kg of biodiesel produced
>
> 1.2617 pounds of CO_2 per kWh * 0.45359 kg per pound = 0.57229 kg of CO_2 emissions per kWh
>
> 0.57229 kg of CO_2 emissions per kWh * 0.00007359 kWh per kg of biodiesel produced = 0.000042115 kg of fossil CO_2 emissions associated with the treatment of wastewater as a result of the production of 1 kg of biodiesel

0.000042115 kg of fossil CO_2 emissions * 2.204 pounds/kg = 0.00009282 kg of CO_2 emissions per pound of biodiesel, divided by 7.3 pounds/gallon = 0.00001271 kg of fossil CO_2 emissions / gallon of biodiesel.

Co-product credit

A co-product credit of 10% is associated with the generation of glycerin from the biodiesel production process. First, this number is similar to other co-product credits allocated in similar lifecycle models.[203] Secondly, the glycerin byproduct represents approximately 10% of the mass-balance in the biodiesel refining process.[204] This credit is effectively reduces the fossil CO_2 emissions associated with the biodiesel by 10% for every step in the lifecycle process up until the point at which the glycerin was produced. In addition we allocate 25% credit to the production of soybean meal, which is used as animal feed. We feel that this number is probably errs on the conservative side, since soybean meal represents approximately 80% of the mass balance of soybeans, one pound of soybean meal currently has a price almost double that for one pound of soybean oil on the Chicago Mercantile Exchange,[205] and other studies also allocate much higher values.[206]

Final CO_2 Emissions Conversion

As mentioned in the waste grease model, biodiesel has an energy content of 118,296 Btu per gallon, compared to conventional No. 2 Diesel fuel, which has an energy content of 129,500 Btu per gallon (a difference of 11%). Practically, this means that when comparing the carbon emission output of soybean biodiesel compared to conventional diesel in kWh, that the biodiesel emission profile must be increased by 11%.

It was also calculated that in 1994, the average heat content (Btu) required per unit of electricity output (kWh) for all fossil fuel electricity generation facilities in the U.S. was 10,280 Btu / kWh produced. This means that 10,280 Btu per kWh produced / 118,296 Btu per gallon = 0.0869 gallons of biodiesel needed to produce 1 kWh of electricity
0.0869 gallons of biodiesel needed to produce 1 kWh of electricity * 7.3 pounds per gallon * 0.45259 kg per pound = 0.28711 kg of biodiesel needed to produce 1 kWh of electricity

This number, multiplied by the final number produced by the model (1.15253 kg of CO_2 Eq. emissions generated per kg of biodiesel produced) * (0.28711 kg of biodiesel needed to produce 1 kWh of electricity) = 0.33090 kg of fossil CO_2 Eq. emissions per kWh of electricity generated from soybean derived biodiesel.

Sensitivity Analysis: Soybean Oil Model

Variables	Contribution to Final Result	Confidence
Primary Energy Inputs to Agriculture	13.86%	High
Fossil Fuel Energy Inputs to Agriculture	37.62%	High
Construction of Farm Machinery	14.52%	Medium
Vehicle Weight (total)	0.10%	High
Average Life of Truck (total)	0.10%	High
Number of Loads Hauled per Year (total)	0.10%	High
Kg of CO_2 per lb of Vehicle Weight (total)	0.10%	Medium
Farm to Crushing Facility (Stage 1)	1.20%	Medium
Fuel Economy of Vehicle (Stage 1)	1.20%	High
Average Load Capacity (Stage 1)	1.20%	High
Soybean Crushing and Processing	11.00%	High
Crushing Facility to Biodiesel Plant (Stage 2)	0.01%	Medium
Fuel Economy of Vehicle (Stage 2)	0.01%	High
Average Load Capacity (Stage 2)	0.01%	High
Energy Inputs (Electricity)	1.43%	High
Energy Inputs (Steam)	6.63%	High
Chemical Inputs (Methanol)	2.86%	High
Chemical Inputs (Sodium Hydroxide)	0.13%	High
Chemical Inputs (Sodium Methoxide)	1.95%	High
kWh to Treat One Gallon of Wastewater	0.00%	High
Wastewater Produced from Biodiesel Production	0.00%	High
Carbon Intensity of New Jersey Electricity	0.00%	High
Biodiesel Plant to Power Plant (Stage 3)	2.00%	Medium
Fuel Economy of Vehicle (Stage 3)	2.00%	High
Average Load Capacity (Stage 3)	2.00%	High

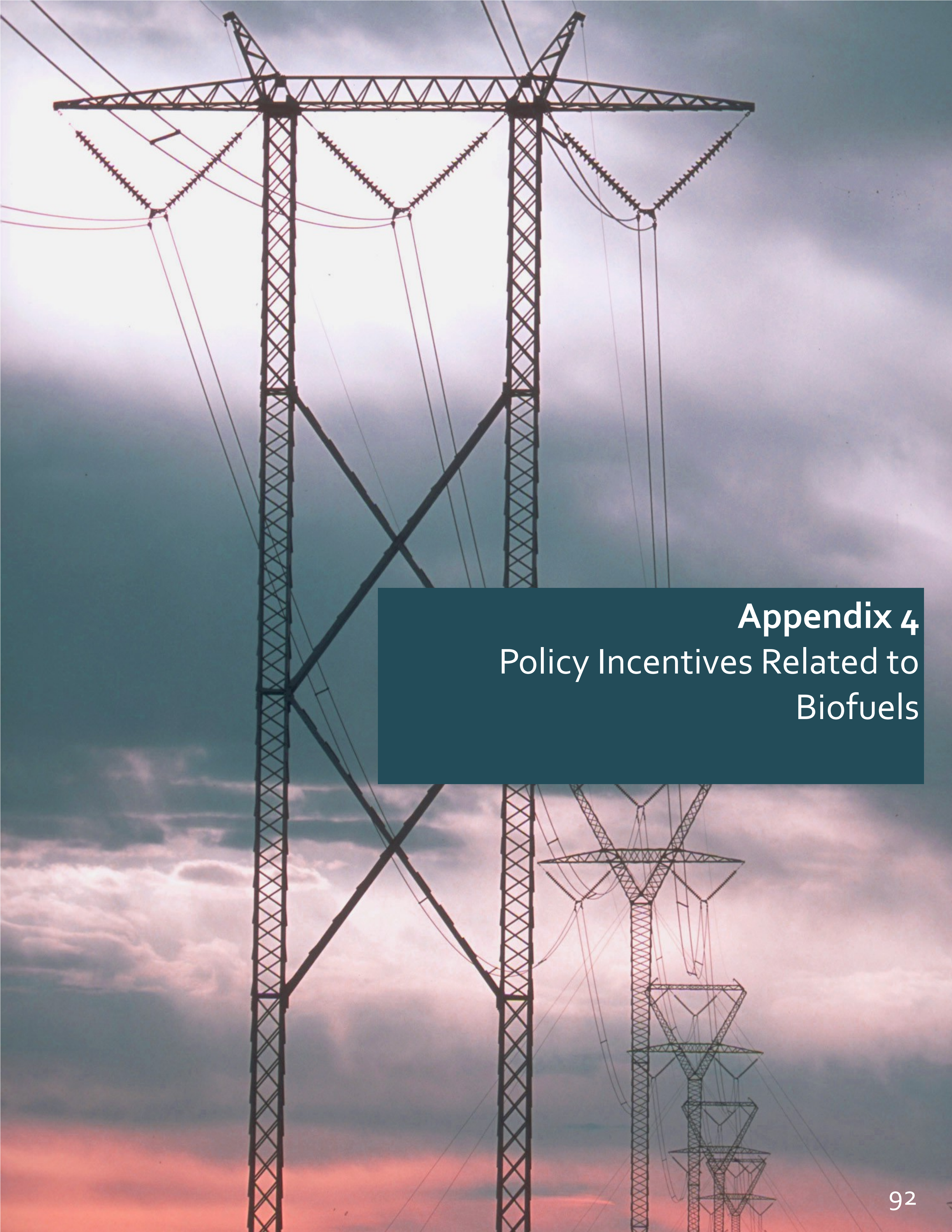
The results of the analysis for the soybean model show that production of the soybean feedstock is by far the most carbon intensive throughout the entire lifecycle. This does not necessarily say that vehicle construction and transportation use any less energy than in other models, just that these amounts are relatively small in comparison to the total amounts of energy used for feedstock production. The largest areas of uncertainty in this model are again, the actual transportation distances between various facilities, and the exact inputs needed for farm machinery production (simply due to the calculations performed and the assumptions regarding composition of machines). Though the study of soybean production inputs used average values for many different states in the U.S., actual values would vary around that average depending on the exact location of production. Considering Low and Medium levels of confidence for values which contribute to approximately 17.825% of the variation in the overall model, it would be fair to assume that the final number produced by the model could easily vary by as much as 17.825%.

Conclusion

Results from the soybean analysis show that aggregating the CO_2 equivalent emissions for each stage of the lifecycle and applying the co-product credits produces a final number of 0.3309 kg of fossil CO_2 equivalent emissions per kWh of electricity generated from soybean derived biodiesel. Our analysis shows that soybean production accounted for by far the largest percentage of emissions (66%), followed by Biodiesel Production (13%), Soybean Crushing (11%), Transportation Distance (9.615%), Vehicle Construction (0.4%), and Wastewater Treatment (0.006%). We vetted these results against other studies in our literature to obtain a general comparison of how each stage of the lifecycle stages contributes to the overall emissions profile of the feedstock. This high-level comparison confirmed our results. The NREL study shows that agriculture and crushing make up roughly 47% of fossil fuel requirements while the processing of soybean oil into biodiesel requires approximately 49%. Since that study didn't account for the energy inputs related to the production of farm machinery, removing that number from our calculations would produce similar results.

This model does not take into consideration sustainable farming guidelines. Therefore, because the production segment is such a large contributor to the overall carbon emissions, soybean oil could become a more attractive first generation feedstock by focusing on reducing the carbon footprint of the fertilizer inputs or the crushing energy inputs. In addition, soybean production may be more economical and sustainable in other parts of the country where conditions such as climate, weather, soils, etc. are more conducive to growth. This model looks specifically at production of the crop in New Jersey. In reality, New Jersey may choose to purchase soybeans or soybean oil from out of state. In this case, the additional input or transportation pathway must be modeled.

Given the assumptions in the Hill et al. paper, we believe that our final numbers are fairly accurate especially considering that we were able to replicate our results for associated CO_2 emissions through a secondary calculation. Given the listed weights of the different machinery, and assuming (as the Hill study did) that all machinery is completely composed of carbon steel, we were able to use the numbers listed in the GREET model for kg of fossil CO_2 emitted per lb of steel to recalculate the kg of fossil CO_2 emitted per lb of biodiesel. The resulting value was within 85% of our number of 0.2561 kg of fossil CO_2 / kg of biodiesel. We believe this difference is acceptable, and can be associated with very slight differences in carbon-accounting methodology.



Appendix 4
Policy Incentives Related to Biofuels

RGGI incentives					
Administrator	Program	Description	Jurisdiction	Type	Amount Available
IRS	Small Ethanol Producer Credit	Ethanol producers with less than 60 million gallons/year may claim a credit on the first 15 million gallons produced in a year	Federal	Tax Credit	$0.10/gallon
IRS	Biodiesel Tax Credit	Producers of biodiesel blends may claim a tax credit for agri-biodiesel (from virgin agricultural products) or biodiesel from recycled products	Federal	Tax Credit	$0.50/gallon (recycled products) $1.00/gallon (virgin products)
IRS	Small Agri-Biodiesel Producer Credit	Agri-biodiesel producers with less than 60 million gallons per year may claim a credit on the first 15 million gallons produced in a year	Federal	Tax Credit	$0.10/gallon
USDA	Business and Industry	Loan guarantees for various agricultural	Federal	Guaranteed Loan	80% loans < $5 mil 70% loans < $10 mil 60% loans > $10 mil
USDA	Rural Business Enterprise Grants	Grants to finance and facilitate development of small rural business enterprises	Federal	Grant	no maximum grant amount
DOE	Biomass Research and Development Initiative	Grants for biomass research, development, and demonstration projects	Federal	Grant	$12 million total
DOE	DOE Loan Guarantee Program	Loan guarantees for energy projects that reduce air pollutant and greenhouse gas emissions, including biofuels projects	Federal	Loan Guarantee	$4 billion total
NJ Commerce and Economic Growth Commission	Sustainable Development Loan Fund	Low interest loan to companies wishing to improve the environmental quality of operations	State	Loan	$250,000/loan
NJ Board of Public Utilities	Renewable Energy Business Venture Assistance Program	Grants to assist renewable energy companies in bringing products/technologies to market	State	Grant	$500,000/grant

Non - RGGI Incentives					
Administrator	Program	Description	Jurisdiction	Type	Amount Available
USDA	Renewable Energy Systems and Energy Efficiency Improvements	Grants and loans for development of renewable energy projects and energy efficiency improvements	Federal	Grant/Loan	Grants: 25% - $250,000-$500,000 Loans: 50% - $10 million
USDA	Value-Added Producer Grants	Grants to producers for development of value-added agricultural activities, including biofuel production	Federal	Grant/Loan	$100,000-$300,000/grant
NJ Board of Public Utilities	On-site Renewable Energy Rebate Program	Rebate to reduce cost of renewable generation system	State	Rebate	Up to $5/watt for up to 1000Kw
NJ Board of Public Utilities	Renewable Energy Project Grants	Grants for development of renewable energy facilities larger than 1 MW	State	Grant	20% of development costs

Table 1: Policy Incentives Related to Biofuels (New Jersey and Federal)[207-211]

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