# The Environmental Impacts of Biofuels in New York State

Draft Executive Summary
Report 08-07
July 2008

New York State
Energy Research and
Development Authority

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- Conducting a multifaceted energy and environmental research and development program to meet New York State's diverse economic needs.
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- Making energy more affordable for residential and low-income households.
- Helping industries, schools, hospitals, municipalities, not-for-profits, and the residential sector, including low-income residents, implement energy-efficiency measures.
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Prepared for the

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## NOTICE



The full report: NYSERDA Report 08-07 "The Environmental Impacts of Biofuels in New York State" will be available for download at: http://www.nyserda.org/publications/default.asp

## DRAFT EXECUTIVE SUMMARY

## INTRODUCTION

### Statement of Purpose

This executive summary encapsulates a literature review and meta analysis of the environmental impacts of biofuels, along with an analysis of the energy and economic aspects of the biofuels industry, within and relative to New York State.

Due to concerns about environmental and human health, climate change, and energy security, unprecedented levels of resources are being devoted, on a global scale, to the development of transportation fuels from biomass. To assess the potential impacts and sustainability of biofuels production and use in New York State, this executive summary reviews the most robust life-cycle analyses for the main biofuels pathways of interest to the State, including ethanol from corn and cellulosic feedstocks; biodiesel from soybeans and waste grease; biobutanol; and renewable diesel. Opportunity feedstocks for the State are assessed, as are emerging technologies and applications. Finally, this executive summary describes the status of the biofuels industry in New York State, suggests approaches to setting sustainability goals relative to state policy objectives, and presents conclusions. Wherever possible, methodological issues, such as comparability problems between different life-cycle analyses (LCAs), are identified, as are the many areas needing further research.

As a condensation of a much larger document, this executive summary necessarily omits many supporting details, nuances of discussion, and references[1]. For a full review of the research findings, the reader is encouraged to refer to the full report.

### Fuel Production Pathways & Technologies

The term "pathway" refers to the entire life cycle of biofuels production and use. A biofuel LCA contains five major stages:

1. Feedstock Production
2. Feedstock Transportation
3. Biorefinery (Fuel Processing)
4. Fuel Blending & Distribution
5. Fuel Combustion

For each of the biofuels examined the most significant LCA consequences occur in the first, third, and fifth stages. A pathway is therefore defined as any unique combination of feedstock type and production methodology (LCA Stage 1), fuel processing technology (LCA 3), and combustion circumstance (LCA 5).

### A Note on Biofuels and the Nitrogen Cycle

One significant effect of biofuel production and use is the potential release of reactive nitrogen (N) to the environment, which can damage human and environmental health and increase the rate of global warming. For this reason, significant emphasis has been placed in this report on understanding and evaluating the life-cycle nitrogen emissions, primarily nitrogen oxides ($NO_x$), nitrous oxide ($N_2O$) and N fertilizer runoff, associated with specific biofuel production and use pathways.

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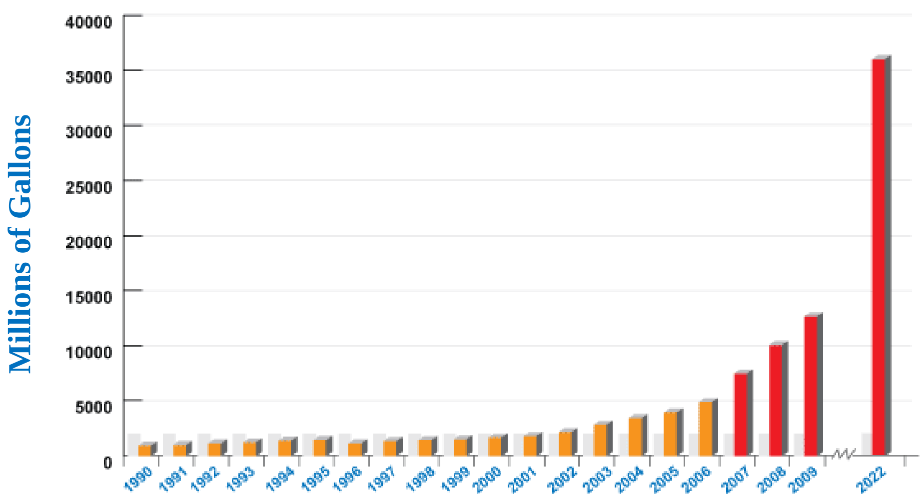
[1] See the Reference section at the end of the executive summary for a listing of the references used in the full report.

## INDUSTRY OVERVIEW

### Ethanol

The growth of U.S. ethanol production and consumption has been dramatic in recent years, driven by favorable federal policies, high oil prices, low agricultural feedstock prices, and profits for ethanol producers. Capacity has risen from 1.7 billion gallons to 4.3 billion gallons, while consumption has expanded from 1.6 billion gallons to 4.9 billion gallons from 2000 to 2006. While large increases in plant capacity continue—capacity is now over 13 billion gallons including facilities under construction—there could be several years of increasing uncertainty surrounding ethanol markets.

**Figure ES-1: U.S. Ethanol Production**




**Source: Network for New Energy Choices, based in part on Renewable Fuels Association statistics and H.R.6 (passed in the Senate on June 21, 2007).**

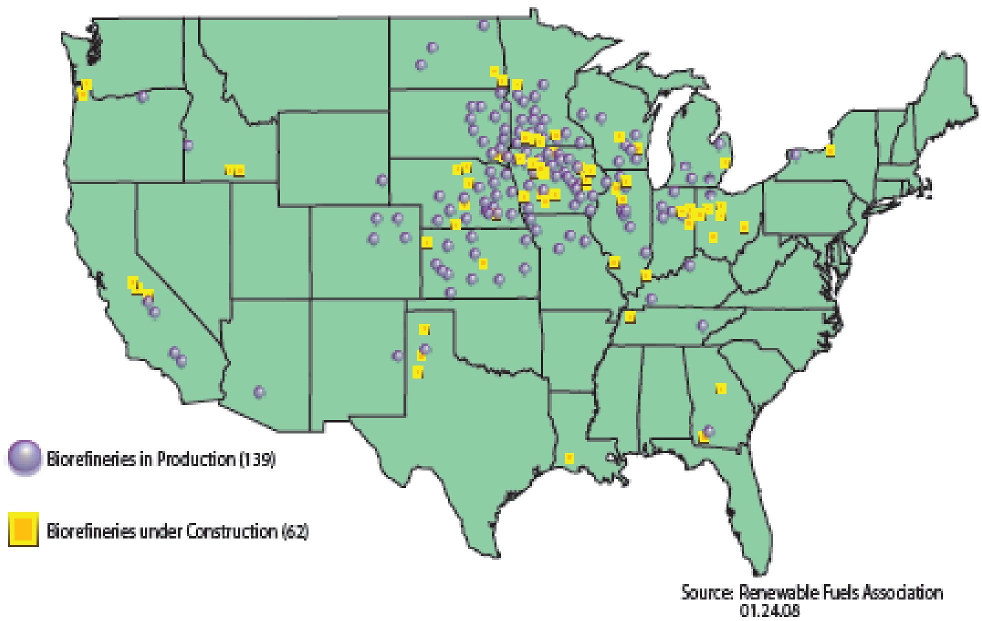
Over the next several years demand will continue to increase. The Energy Independence and Security Act of 2007 set new requirements for 2008 through 2022.[2] The Act increases required use of renewable fuels beginning in 2008 but caps ethanol supply from corn at 15 billion gallons; the rest will need to come from non-food "cellulosic" sources, such as switchgrass and wood chips. There is also a practical "blending cap" of about 15 billion gallons, the level at which ethanol production would saturate projected gasoline usage at

[2] The Renewable Fuel Standard (RFS), found in Title II, Subtitle A of the Energy Independence and Security Act of 2007, amends the previous RFS signed into law in 2005. The new bill increases and extends the RFS, which requires minimum annual use of renewable fuel in U.S. transportation. The higher standard seeks to reduce foreign oil dependence and greenhouse gas emissions while strengthening economic opportunity. The amended RFS instructs the EPA to promulgate regulations guaranteeing that designated amounts of renewable fuel are sold or introduced into U.S. commerce and applies to refiners, blenders, and importers. The previous standard was 5.4 billion gallons for 2008, increasing to 7.5 billion gallons by 2012. The new RFS starts at 9.0 billion gallons in 2008 and rises to 36 billion gallons by 2022. Furthermore, beginning in 2016, only advanced biofuels (cellulosic ethanol and other biofuels derived from feedstock other than corn starch that achieve a 50% greenhouse gas emission reduction) can be used to meet the increased RFS target. The emissions reduction requirement may be adjusted to a lower percentage (but not below 40%) if it is determined that the requirement is not feasible for advanced biofuels. Cellulosic biofuels must achieve a 60% emissions reduction requirement, but this too may be adjusted to not less than 50% if the Administrator determines that the reduction is not feasible. Renewable fuels produced from new biorefineries must reduce the life cycle of greenhouse gas emissions relative to the life cycle from gasoline and diesel emissions by at least 20%. In addition, fuels manufactured from biorefineries that displace more than 80% of the fossil-derived processing fuels used to operate the facility will qualify for cash awards.

an E10[3] blend level.  Demand growth beyond that point will require acceptance of higher blends such as E20 and/or substantial turnover of the automobile fleet to flexible fuel vehicles capable of using E85.

In the United States, ethanol from fermentation of corn grain (henceforth corn ethanol) accounts for over 95% of production.  Fuel production plants have been heavily concentrated in leading Midwest corn production states, a fact that may contribute to short-term supply limits associated with congestion in the distribution infrastructure.  Additional supply-side limits might emerge from more stringent siting requirements, as increasing attention is focused on the environmental impacts of ethanol production, including both the water demands from shrinking aquifers and other stresses inherent in moving increased acreage to corn, the only visible short-term means to support continued rapid supply growth.

**Figure ES-2:  U.S. Ethanol Biorefinery Locations**




Ethanol production is currently evolving in two distinct manners: marginal advances for corn ethanol production and the slower, but potentially more transformative, shift to second-generation ethanol production via the use of cellulosic feedstocks.

Marginal advances for corn ethanol include improved production processes, which will continue to boost the yield beyond the approximately 2.8 gallons per bushel currently achieved by plants with the newest technology, and closed loop integration strategies, such as co-location with livestock operations, power-plants and demand centers, which offer opportunities to improve the process-energy costs of production and other economic characteristics.

The shift to the use of cellulosic feedstocks carries the prospect for improved energy balance and environmental benefits as compared to the first generation corn ethanol industry of today.  Cellulosic ethanol is also expected to result in lower costs of production and multi-fold increases in supply.  However, this depends upon projected, but unproven, shifts in the cost of production and underlying technological breakthroughs such as improved and alternate production processes.  The speed with which cellulosic

[3] Blends of gasoline and ethanol are characterized by the maximum allowed percent of ethanol in the gasoline. Thus, E10 is 10% ethanol and E85 ranges from 70% to 85% ethanol.  The actual ethanol content percentage will always be slightly smaller than this standard nomenclature suggests since ethanol has a small component of gasoline added as a denaturant before it ever leaves the ethanol plant.

ethanol can begin to be produced in commercial quantities remains uncertain and appears closely tied to federal policies and shifting costs of production.

**Ethanol in New York State**

New York has traditionally been a “corn-deficit” state. Much of New York’s substantial corn crop is consumed by the State’s dairy industry, leaving no surplus for ethanol production. To date, New York has not been substantially affected by the corn ethanol economy in a direct manner, but there have been indirect impacts. Corn grain acreage increased by a projected 13% in 2007, and corn silage acreage increased by eight percent. In addition, the large increase in corn prices has affected both corn producers and livestock producers, who must buy corn for feed.

When seeking an enhanced role for New York within the existing corn ethanol paradigm, several strategies warrant further inquiry. First, co-location of ethanol plants with dairy operations offers two fundamental advantages: (1) process heat required for the plant could be obtained via biogas production from animal manure, rather than from fossil fuels; and (2) the main co-product, dried distillers grains with solubles (DDGS), could be fed to dairy animals. If DDGS can be used locally in this way, the significant energy and expense of drying it for transport can be avoided. Another co-location strategy, previously examined in depth by National Renewable Energy Laboratory (NREL) and co-funded by the NYSERDA near Dresden, New York, involved the co-location of an ethanol plant with a coal-fired electric plant. Using biomass for process heat could also greatly reduce greenhouse gas (GHG) emissions (See Figure ES-5).

Additional assessment is needed to determine the cost savings that might be obtained from building ethanol plants near demand centers or plants with good transport connections to New York’s metropolitan corridor. To date, the costs of shipping grain have been avoided by producing ethanol near corn supplies. Increasingly, infrastructure adjustment problems have placed upward pressure on the costs of shipping ethanol from plants to blending and distribution points. Plants located in New York face higher feedstock import costs, but gain some benefits of lowered fuel shipping costs to regional blending and distribution points. Preliminary evidence suggests that smaller ethanol plants suffer little or no scale disadvantages as compared to the largest plants being built near corn production centers.

The most compelling long-term opportunity for New York is to identify cellulosic feedstock advantages. Currently, feedstock costs represent approximately 55% of the variable costs of ethanol production. The cellulosic feedstocks most readily available in significant amounts are crop residues (mostly corn stover) and mixed species grasses from idle croplands and a portion of hay and pasture lands. There is a need to quantify the amounts of such feedstocks that can be sustainably harvested without interfering with existing agricultural enterprises. Wood waste from the state’s forests, urban centers, and mills could also be a suitable feedstock; studies suggest that this resource is large but needs to be better quantified. New York has very large areas of forest that would benefit from timber stand improvement harvests. Such harvests remove low-value cull wood (a modest portion of the biomass) and leave high-value timber species, thus improving future economic returns and retaining benefits for wildlife habitat, ongoing carbon sequestration, and other important ecosystem services. New York also has a climate and some lands suitable for dedicated perennial bioenergy crops, including grasses and short rotation woody crops such as coppiced willow or poplar. Further research on the wide range of potential cellulosic feedstocks could position New York to gain a larger benefit from second-generation ethanol production.

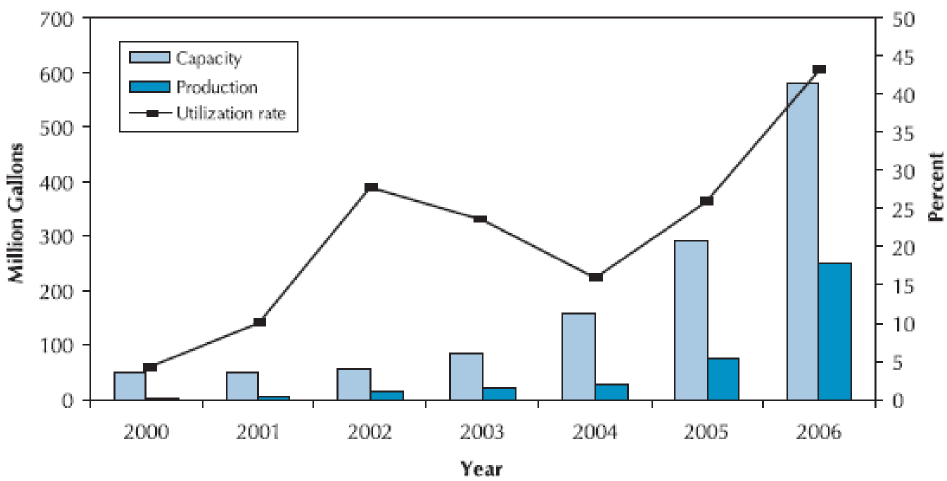
An important part of any New York biofuels strategy is the identification of available land resources, especially idle or underused agricultural land, for expansion into feedstock production. Recent work has identified approximately 1.3 million such acres in the state. Note that the effects of land use change on GHG emissions should be considered in any LCA of bioenergy options (see Land Use Change section).

**Biodiesel**

The expansion of the biodiesel industry shares many similarities to the expansion of the ethanol industry:

- It depends upon favorable federal policies, particularly the Renewable Fuels Standard, and the Excise Tax Credit breaks.
- It has experienced significant, rapid growth from one-half million gallons of production in 1999 to 225 million gallons in 2006, with considerable growth in 2007. As of late 2007, capacity from 165 plants is nearly 1.85 billion gallons a year, resulting in significant production overcapacity.
- It has benefited from high petroleum and diesel fuel prices.
- Until very recently, the industry benefited from favorable soybean feedstock prices and supply conditions (soybeans are the source of more than 70% of the current biodiesel feedstock supply and more than 70% of the variable costs of soy-biodiesel production).
- It has found underused and low cost waste grease resources.

**Figure ES-3: Biodiesel Production Graph (2000 to 2006)**

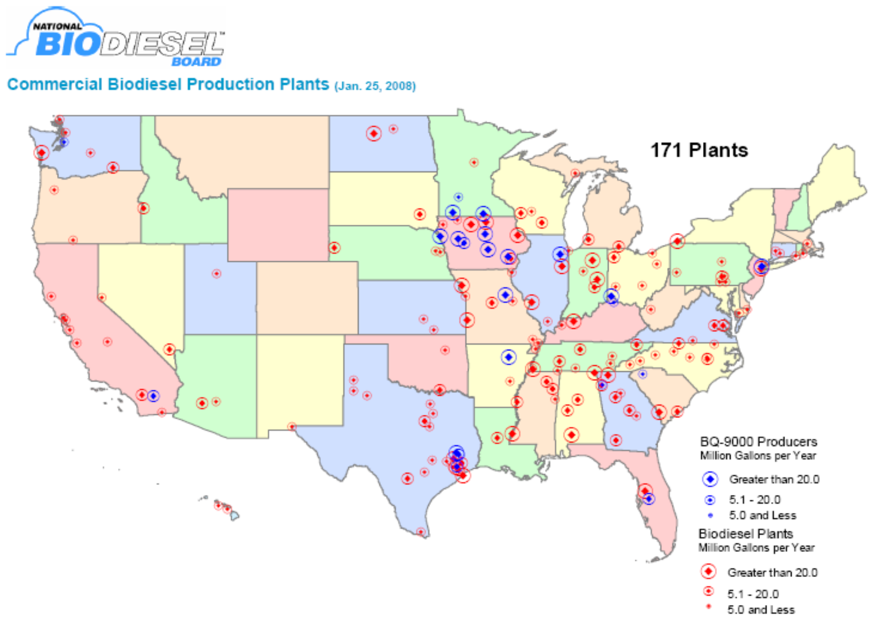



*Source:* National Biodiesel Board.
*Note:* Capacity given is on September 1 of each year.

Despite its rapid growth, the biodiesel industry is dwarfed by the ethanol industry. Biodiesel production in 2006 was less than a quarter of a billion gallons and represents less than 0.5% of the petro-diesel market, while ethanol is now equal to approximately 4% of the gasoline market.

Biodiesel producers are less dependent upon their primary agricultural feedstock, soybeans (70% and dropping), than ethanol producers are upon corn (over 95% and probably relatively unchanging for a few years). Production is distributed more widely and in smaller economic units than is the case with ethanol. There is substantial biodiesel overcapacity, while the ethanol industry is producing at near full capacity. Biodiesel also has better net energy characteristics than corn ethanol, reduces greenhouse gas emissions more effectively, and reduces most other emissions relative to petrol-diesel.

**Figure ES-4: Commercial Biodiesel Production Plants (2008)**




Other significant developments for biodiesel include the emergence of favorable policy and tax support for renewable diesel, a fuel distinct from biodiesel, and the possibility that biodiesel demand could be locally stimulated for at least two markets outside of the mainline transportation fuels marketplace as a substitute for heating fuel oils, and as the energy source for distributed and back-up power generation. To an even greater degree than the corn ethanol industry, the petro-diesel replacement industry (biodiesel and renewable diesel) remains closely tied to federal policies and shifting costs of production.

**Biodiesel in New York.** Despite its advantages, economic considerations, such as New York's lack of soybean crushing capacity to produce oil, suggest that the profitability of conventional soybean biodiesel plants should be examined prior to the commitment of public or private resources.

## SELECTED RESULTS

### <u>Corn Ethanol: Net Environmental Impacts</u>

The United States is now the world's second-largest producer of ethanol, behind Brazil. Ethanol production in the United States has climbed to 6 billion gallons/year, nearly all of it from corn; ethanol production now accounts for nearly 18% of total U.S. corn use.

Corn has many advantages as a biofuel feedstock in the United States, not the least of which are numerous national and state policy incentives and a mature industry. However, there is ongoing controversy in the literature about the GHG benefits of corn ethanol. In particular, recent literature indicates that the direct and indirect effects of land use change can be large enough to make corn ethanol a net emitter of GHG for decades or centuries (see Land Use Change section).

Current corn growing practices include the intensive applications of nitrogen fertilizer, resulting in reactive nitrogen pollution. Reactive nitrogen is highly mobile in the environment. It can enter ground or surface water, change chemical form, and be volatilized. A single molecule can contribute to a series of environmental impacts as it moves through the atmosphere, deposits to forests, leaches into lakes and streams, and ultimately makes its way to coastal waters. These impacts include global warming, acid rain, eutrophication, photochemical smog, and nitrogen pollution. In the past century, humans have increased the environmental cycling of reactive nitrogen more than 10-fold; three-quarters of this is due to fertilizer production and use and biological nitrogen fixation by crops.

Corn ethanol's contribution to global warming is due primarily to $N_2O$ emissions from fertilizer application to farm soils. $N_2O$ has a global warming potential (GWP) 296 times greater than that of $CO_2$, the primary greenhouse gas. Even though the growing corn takes up the $CO_2$ released when ethanol is combusted, its fertilizer requirements result in significant $N_2O$ emissions from croplands. This is why, although GHG emissions from corn ethanol are generally less than those from gasoline, corn ethanol is still a net emitter of GHGs.[4]

**Nitrogen is a key driver of environmental effects in New York State**

Many areas of the state already suffer from excess reactive nitrogen:

1. Portions of the State's coastal waters, and downstream water bodies, notably the Chesapeake Bay;
2. Groundwater in some portions of New York; and
3. Air in urban areas, where the heat island effect[5] intensifies $NO_x$-related ground-level ozone[6] production – a serious human health hazard.

Nutrient management in agriculture has received increased attention during recent decades. Opportunities exist to reduce nutrient losses from agriculture, losses that may decrease air, surface water and groundwater quality. Bioenergy options should use agricultural best management practices, such as cover crops, reduced tillage operations, precision fertilizer application, crop buffers, etc., to minimize nutrient losses. In addition, it would be productive to search for "win-win" situations in which bioenergy crops could be used to help mitigate existing problems of excessive nutrients, such as phosphorus, that occur in some portions of New York. Further research in New York would be useful to compare the GHG and other environmental benefits of increased corn production on existing agricultural lands as compared to converting other lands to corn production.

Corn ethanol production and use also results in heightened emissions of some criteria pollutants and airborne toxics, notably fine particles ($PM_{2.5}$), acetaldehyde and formaldehyde. In addition to its air and water impacts, corn ethanol production and use has less easily quantifiable impacts on land and ecosystems. As with most farming systems, corn cropping can reduce habitat, biodiversity, and ecosystems services. Corn ethanol is land-intensive as well as fertilizer-intensive, and it requires higher quality land than cellulosic feedstocks such as switchgrass or willow. Use of the corn stover for cellulosic ethanol production can improve the overall yield; however, stover removal should be managed carefully to avoid soil erosion, which depletes soil carbon stocks and impairs water quality. Reduced tillage practices can reduce erosion and permit sustainable harvest of corn stover. The processing of corn into ethanol also requires significant quantities of water – three to six liters per liter of ethanol produced.

**How does corn ethanol compare to gasoline?**

Life-cycle $NO_x$ emissions from corn ethanol production and use are roughly double that of reformulated gasoline (RFG). This assumes a highly efficient ethanol production process that features advanced gas turbine combined-cycle (GTCC) technology as a crucial efficiency-enhancing and emissions-reducing factor.

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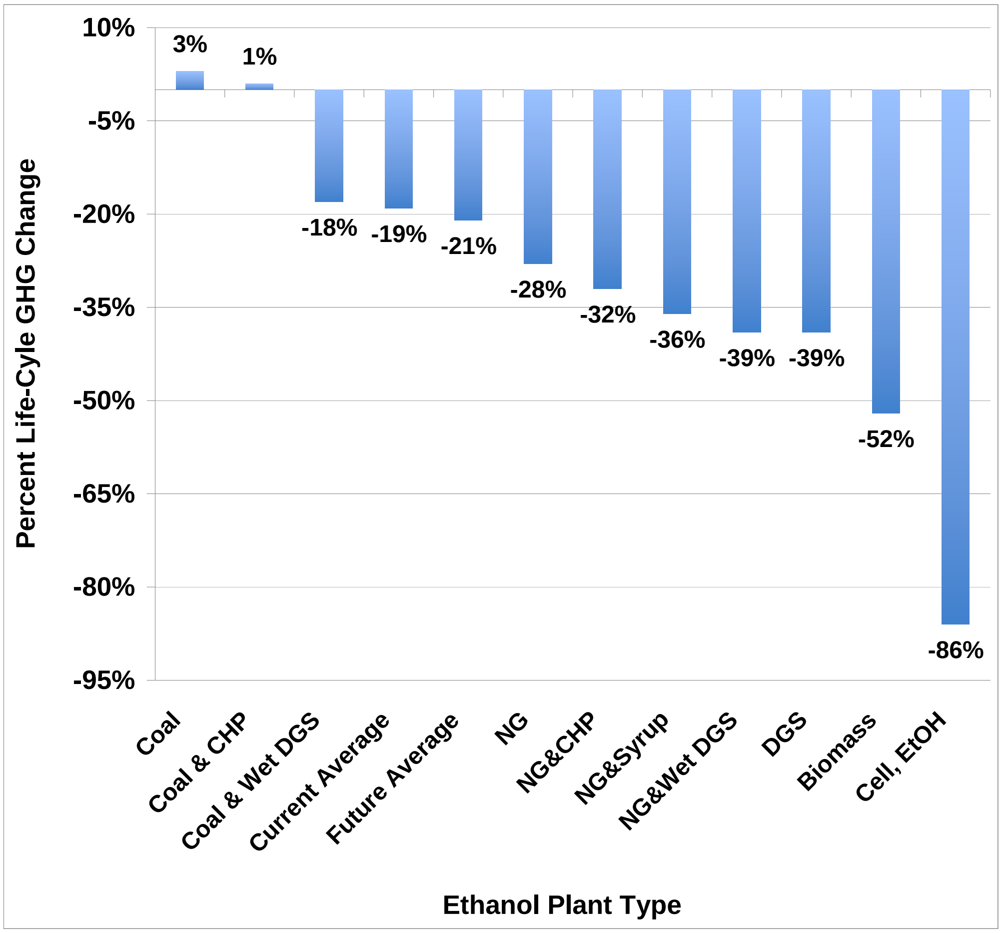
[4] Estimates of GHG releases from corn ethanol are based on IPCC estimates of the amount of $N_2O$ released per hectare of cropland. These IPCC estimates have recently been challenged by researchers who argue that $N_2O$ releases from cropland may be twice as large as previously believed. If this proves true, corn ethanol would offer no GHG benefit relative to gasoline.

[5] A "dome" of elevated temperatures over an urban area caused by structural and pavement heat fluxes, and pollutant emissions (U.S. EPA).

[6] The U.S. EPA just increased the stringency of the National Ambient Air Quality Standards (NAAQS) for ozone and photochemical oxidants due to the deleterious effects of ozone on human health.

The life-cycle GHG impact of corn ethanol, relative to gasoline, depends to a large extent on the type of fuel used to power the ethanol production process. Results range from a 3% increase if coal is used as the process fuel, to a 52% reduction if woodchips are used. If coal and biomass are not considered, the range is smaller, from a 12% to 39% reduction. Figure ES-5 illustrates the extent to which the process fuel determines net GHG emissions.

**Figure ES 5: Life-cycle GHG changes (%) compared to gasoline for each ethanol plant type.**




**Note 'DGS' is the same as DDGS. All cases are corn ethanol plants except cellulosic ethanol, which is fed with switchgrass. Source: Wang, Wu and Huo (2007)**

In the chart above, plant processing types are defined as follows:

**Coal**: New corn ethanol plant fuelled with a coal-fired boiler.
**Coal & CHP**: Coal fuelled corn ethanol plant with addition of combined heat and power (CHP) system for added energy efficiency.
**Coal & Wet DGS:** Coal fuelled corn ethanol plant with transport of wet DGS to nearby animal feedlots, to avoid need for drying of DGS.
**Current Average**: Average of current operational corn ethanol plants, assuming 80% are dry milling and 20% wet milling plants.
**Future Average**: A 2010 corn ethanol scenario, using projected average results assuming 87.5% dry milling, 12.5% wet milling.
**NG**: New corn ethanol plant fuelled with natural gas.
**NG & CHP**: Natural gas (NG) fuelled corn ethanol plant with CHP system for added energy efficiency.

**NG & Syrup**: NG-fuelled corn ethanol plant producing corn syrup (or DDGS) as a co-product which is then burned to provide a portion of the steam required for plant operation.
**NG & Wet DGS**: NG-fuelled corn ethanol plant with wet DGS transport to nearby animal feedlots, to avoid need for DGS drying.
**DGS**: Corn ethanol dry-milling plant that burns co-product DGS in order to supply all steam needed for plant operation.
**Biomass**: Corn ethanol plant fuelled with wood chip-derived syngas from gasifier (could also use corn stover as the fuel).
**Cellulosic Ethanol (Cell. EtOH)**: Switchgrass ethanol plant using lignin to generate steam for plant operation.

It should be noted that Figure ES-5 is from a single study using the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model. These results assume the use of high-quality, high-yield croplands (such as those already in use) to grow corn. Other published estimates of GHG vary more widely, and some estimates show much greater GHG emissions than gasoline. This is particularly true if corn production is expanded by converting idle or marginal land currently in permanent pasture or hay, or converting land in permanent herbaceous cover, such as forests (see Land Use Change section).

## Human Health Impacts

To assess the likely effects of ethanol use on human health, it is important not only to look at levels of toxic emissions, such as carbon monoxide (CO), particulate matter (PM) and toxic chemicals, but also at where in the life cycle of the fuel these emissions occur. "Upstream" emissions are those that take place primarily at the farm or processing facility; "downstream" or tailpipe emissions are primarily from fuel combustion in vehicles. Downstream emissions are often considered more serious threats to human health, as they take place in urban and residential environments where the exposure is to a larger population and in areas that are more densely populated. An exposure assessment in context with risk is therefore recommended. Sparsely populated rural areas, where possible increases in $NO_x$ and potential increases in ozone formation might result in adverse health impacts regionally, could benefit from modeling studies. Other "upstream" impacts include exposure to microbial contaminants and endotoxins from biofuel transportation, handling and processing. Odor issues in farm regions also need to be assessed.

**TABLE ES-1: Net toxic emissions of corn ethanol (as E85) compared to gasoline**

| Toxin | Health Impact | Net Relative to Gasoline | Where Emitted in Fuel Life Cycle |
|---|---|---|---|
| CO | Toxin, cardiovascular disease | slight increase | Tailpipe |
| PM | Causes cardiovascular disease | 247% | Upstream |
| Acetaldehyde | Toxin, irritant, possible carcinogen | 1946% | Tailpipe, farm and atmospheric |
| Formaldehyde | Toxin, allergen, carcinogen | 240% | Tailpipe, farm and atmospheric |
| Benzene | Toxin, carcinogen | -80% | Tailpipe |
| Butadiene | Toxin, irritant, carcinogen | -15% | Tailpipe |

**Source: Winebrake et al. 2000**

It is important to note that the chemicals in Table ES-1 can vary greatly in their degree and type of toxicity. Normalizing for cancer toxicity based on EPA estimated Cancer Unit Risk Estimate (CURE) values, production and use of corn-derived E85 emits about 5% more carcinogens over the fuel cycle than gasoline, but nearly 50% less urban (tailpipe) carcinogens. Although human cancer impacts from toxics may be less for corn ethanol than for gasoline, the above data are based on a limited emissions test database for E85 and an older flexible-fuel vehicle (FFV) fleet. In addition, non-cancer human health impacts, such as asthma and heart disease, are not represented by CURE values. Therefore, the numbers do not tell the whole story. Furthermore, the location of emissions, such as evaporative emissions, may have much to do with the degree to which human health impacts result.

To establish the relative effects between alternative fuels and gasoline on human health, reduced or increased emissions of the following compounds need to be identified:

1) Compounds with known direct adverse health (cancer or non-cancer) outcomes, which are present in exhaust and evaporative emissions of gasoline fuel vehicles;

2) Compounds that can contribute to photochemical smog;

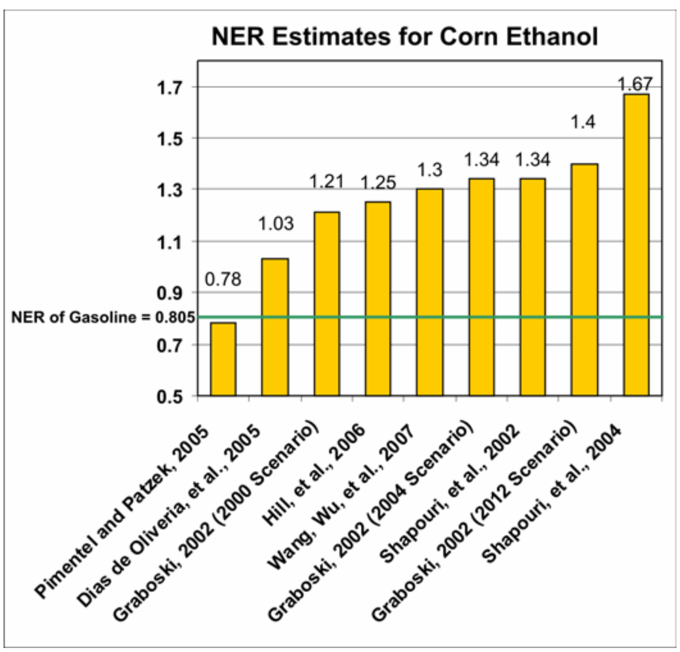
3) Compounds emitted from alternative fuels but not current gasoline fuels that may contribute to adverse health outcomes.

Fewer good studies have been conducted on biodiesel than ethanol, and the ethanol studies that do exist are mostly based on corn ethanol. Polynuclear aromatic hydrocarbon (PAH) emissions are certainly lower in biodiesel than in petrol diesel. However, more studies are needed to confirm and quantify the data for this known carcinogen that is present in conventional diesel.

**Net Energy Ratio**

The net energy ratio (NER) is the ratio of the net energy content of a fuel divided by the non-renewable energy required to produce and deliver the fuel. As ethanol is a gasoline replacement, it is important to compare NER values for ethanol to that of gasoline (0.805). Based on the studies reviewed, the NER of corn ethanol ranges from 0.78 to 1.67 relative to gasoline.

**Figure ES-6: NER Estimates for Corn Ethanol**




**Note: Dias de Oliveria, et al. (2005) reported the NER of corn ethanol as 1.03 in the worst-case scenario, and 1.12 in the best-case scenario.**

There has been criticism of the earlier results of Pimentel (2005) and Patzek (2004) as having been based on outdated data, assumptions, and methods. Among other researchers, there is broad consensus that corn ethanol's NER is greater than one.

**Alternate Ethanol Feedstocks**

There is broad agreement that U.S. ethanol manufacturers need to transition as soon as possible from corn to cellulosic feedstocks. Such a transition will aid in meeting ethanol production goals, improve the environmental performance and sustainability of ethanol, and help to avoid impacts on food prices. A variety of cellulosic feedstocks are being investigated, including crop residues such as corn stover; dedicated crops, such as grasses and woods; and waste products, such as urban wood waste, mill residues, and wood from forestry culling . A number of cellulosic ethanol plants are planned or under construction in the United States, with at least one pilot plant online. However, there is no broad agreement as to the best feedstock and processing technology.

The range of GHG emissions reductions from cellulosic ethanol, relative to gasoline, is 82% to 115%. This range includes various feedstocks, processes and process fuels. A summary is presented in Table ES-2.

**Table ES-2: Summary of GHG reduction estimates for Cellulosic Ethanol versus gasoline**

| Metric(Unit) | Feedstock(s) | Fuel Blend | Gross Value | % reduction as compared to gasoline |
|---|---|---|---|---|
| g $CO_2$eq/mmbtu | Forest residues, Corn stover | E100 | 30,000-75,000 [b] | 85-89 |
| g $CO_2$eq/mmbtu | Corn/biomass [c] | E100 | 9023 [d] | 90.9 |
| g $CO_2$ eq/mmbtu | Switchgrass | Not reported | 15,000[e] | 86 |
| g CO2eq/MJ (g $CO_2$eq/mmBtu) | Switchgrass/Corn Stover | Not reported | 14(14,770)[f] | 86 |
| g CO2eq/MJ (g $CO_2$eq/mmBtu) | Switchgrass | E100 | 11(11,605)[g] | 88 |
| g $CO_2$eq/gge[h] | Switchgrass | E100 | Not reported | 82-87 |
| g $CO_2$eq/km | Corn stover | E85, E100 | 200.23, 254.13 | 83, 106[j] |
| g $CO_2$eq/km | Corn stover, Switchgrass | E85 | 87, 107 | 57 to 65 |
| g $CO_2$eq/mile | Switchgrass | E90 | 308.5 | 44 |
| g $CO_2$eq/$m^2$/yr | Reed canary grass, Hybrid poplar, Switchgrass | Not reported | 100, 145, 155[i] | 85, 117, 114[j] |
| mg $CO_2$eq/ha | Corn and Corn stover | E10 | 320-442 | Not reported |
| kg $CO_2$eq/ha | Low impact high diversity native grasses | Not reported | Net Sink[k] | Not reported |

**Notes:**

***Various researchers have reported LCA results in different units. The results are included here to give the reader a wide range of perspectives, although they may not be directly comparable with one another.***

a: The comparison to gasoline is either reported or uses the assumed GHG emissions of gasoline by the researcher.

b: These are approximate values estimated from a figure.

c: The displacement index is based on corn ethanol using biomass as process energy. See text for more details of this assumption.

d: The EPA (2007) reports Well-to-Pump emissions and End Point Combustion Emissions separately. These values are a sum of the two.

e: 15,000 g $CO_2$eq/mmBtu is an approximate value estimated from a figure.

f: The values in parenthesis are original Pace team unit conversions of MJ to mmBtu.

g: The values in parenthesis are original Pace team unit conversions of MJ to mmBtu.

h: gge stands for gallons gasoline equivalent.

i: These are approximate values estimated from a figure.

j: Values over 100% indicate these perennial crops sequester more carbon than their use as ethanol feedstocks releases.

k: Tilman (2006) reports that low- intensity high-diversity native grasses are a net GHG sink reducing emissions by 6,164 kg $CO_2$ eq/ha.

Compared with corn, cellulosic feedstocks promise to reduce risks of surface water eutrophication, ground water nitrate and nitrite contamination, and pesticide contamination from agrochemical runoff and leaching. However, this does not necessarily mean that life-cycle $NO_x$ emissions would be substantially reduced. There is a great deal of uncertainty regarding the amount of nitrogen input required for cellulosic crops. Non-farmed feedstocks can incur other environmental costs. For example, forestry residues may require no fertilizer, but they incur substantial energy and GHG costs due to harvest, transport, and size reduction of the wood. Additionally, cellulosic feedstocks are harder to process than starches such as corn, requiring energy- and input-intensive biological and physical degradation steps. Because cellulosic ethanol remains largely at the pilot stage, studies typically make many assumptions, and results can vary widely. While the literature suggests that the risks are lower and more manageable for cellulosic crops, these risks do require attention if significant benefits are to be realized. Therefore, sustainability standards and compliance measures will be needed.

**Corn Stover**

The case of corn stover (stalks, cobs and husks) is unique in that it is a crop residue associated with corn, the predominant ethanol feedstock. Because it is a crop residue, growing it does not require extra nitrogen fertilizer beyond what would have been applied to grow the corn. However, harvesting, transporting, and processing corn stover does create additional environmental impacts, depending on the technology and processes used. In addition, removing too much stover from the field can increase the risk of erosion. Sustainable stover removal rates depend on soil attributes, climate, farming practices, and other variables. Reduced tillage practices can decrease erosion potential, allowing more stover to be harvested sustainably. Note that New York is unusual relative to other states in that about half the state's corn is harvested for silage, meaning the stover is already removed as part of the crop.

Life-cycle $NO_x$ air emission results for corn stover ethanol are quite mixed due to varying assumptions regarding cropping practices, farm inputs, harvest techniques, and the energy inputs to the fuel production process. Estimates vary from a 40% increase to an order of magnitude increase relative to gasoline. One study predicts that $NO_x$ emissions from corn stover ethanol could decline over time until they are equal to those of RFG in a 2030 scenario.[7] This is based on the assumption that by 2030, stover will be pretreated with biochemical and/or thermochemical processes and then converted to fuel using GTCC technology.

Results for other air emissions also show high variability. For volatile organic compounds (VOCs), stover E85 results range from a 17% increase relative to RFG, to a 36% decrease relative to conventional gasoline. $PM_{10}$ results range from nearly twice the emissions of the reference fuel, in a 2012 scenario, to slightly lower than the reference fuel in a technologically advanced 2030 scenario. Life-cycle CO results show slight increases. As with GHG emissions, more study will be needed to reconcile such divergent findings.

**Waste wood**

New York has significant waste wood resources including forestry cull wood, urban waste wood, and mill residues. The vast majority of urban waste wood and mill residue is either disposed of in landfills or used to produce mulch and related products. The portion currently destined for landfills could be diverted to fuel production with no negative impacts on the mulch industry; if transportation of wood wastes is assumed to be minimal (most studies assume feedstocks would be generated within 50 miles of the processing facility), diverting wood waste from landfills and/or mulching could even confer emissions benefits. Life-cycle analyses of waste wood used for electrical production have concluded that the major benefit, in terms of GHG emissions, is in averted methane emissions from landfills and mulching.[8] There

[7] A scenario is determined by the group conducting the modeling, based on their assumptions of certain technologies and processes being in place by the year cited. It is one of the inputs of a LCA model.

[8] It is assumed that if the residue feedstock were not burned for energy generation, it would be allowed to decompose and release methane, which has a high GWP. This assumption may be more or less accurate depending on the degree to which landfill gas is captured, and the degree to which mill waste and other wood residues are replaced by alternative products in mulch production.

is a need for similar studies of waste wood use in biofuels production. New studies of the potential resource in New York from forestry residues should also be undertaken.

Culling wood from the state's forests could increase the value of the standing timber, maintain carbon sequestration, and likely maintain other ecosystem services, since most of the biomass is not removed. However, good forest management practices must be used in order to avoid adverse impacts on forest, soil, or water quality. Intensive short-rotation forestry that removes most of the biomass in sensitive watersheds can cause increased leaching of nitrate and other nutrients from soil to nearby surface waters, causing surface water acidification and reduced soil productivity. These impacts are likely to be most significant in nutrient-poor soils and in areas that have received decades of acid deposition and have therefore already experienced considerable nutrient loss. Many forests in the Adirondack and Catskill regions of New York would be sensitive to these types of effects.

In a 2030 scenario, one study found life-cycle $NO_x$ emissions for woody residue-based E85 to be midway between corn stover and corn grain, with VOC emissions equivalent to corn stover. CO emissions were found to be equivalent to corn and slightly higher than RFG or stover. $PM_{10}$ results are equivalent to RFG.

### Grasses and woody crops

Dedicated cellulosic ethanol crops include short rotation woody crops (SRWC), such as hybrid poplar and willow, and perennial grasses, such as switchgrass, reed canary grass, and miscanthus. Both can be cultivated on unused and marginal cropland, land that has returned to pasture, and land in the Conservation Reserve Program (CRP). Because they are perennial crops, they generally pose fewer environmental risks in the feedstock production stage than do annual crops. They require less tillage and significantly fewer applications of fertilizers. As with other cellulosic feedstocks, the potential water impacts are unknown, depending largely on not-yet-commercialized pretreatment processes. Recent literature suggests, however, that conversion of wild lands to perennial energy crops can cause GHG emissions greater than those from gasoline for many years or decades (see Land Use Change section).

Grasses require significantly less nitrogen fertilizer than corn, and may offer higher yields per acre[9] and have a more favorable energy balance. For E85 containing ethanol from switchgrass, the available life-cycle studies indicate that total $NO_x$ emissions should be about 36% greater than gasoline reference fuels. These studies project highly efficient fuel production processes. PM results vary from no difference to 20% reductions for switchgrass-derived E85 relative to RFG, using a highly efficient GTCC fuel production process. Life-cycle VOCs are calculated to decrease from 7% to 36%, while results for CO show nearly no difference between switchgrass and gasoline.

There are few data available for life-cycle air emissions from SRWC. Results for SRWC E10 show a $NO_x$ emissions increase of about 9% relative to conventional gasoline, but results for a 10% blend are likely to be significantly lower than for an 85% blend.

### New York Biomass Feedstock Availability

New York State has significant biomass resources, the availability of which is partly a function of price. Figure ES-7 provides a profile of biomass feedstock availability in New York State in dry tons (estimated at $8 per dry ton for most feedstocks) in 1995 U.S. dollars. In this figure, the distribution of feedstocks within the state is not considered; it is assumed that feedstocks are available within 50 miles of a user facility. Some opportunity costs have not been considered, and sustainability has not been thoroughly analyzed.

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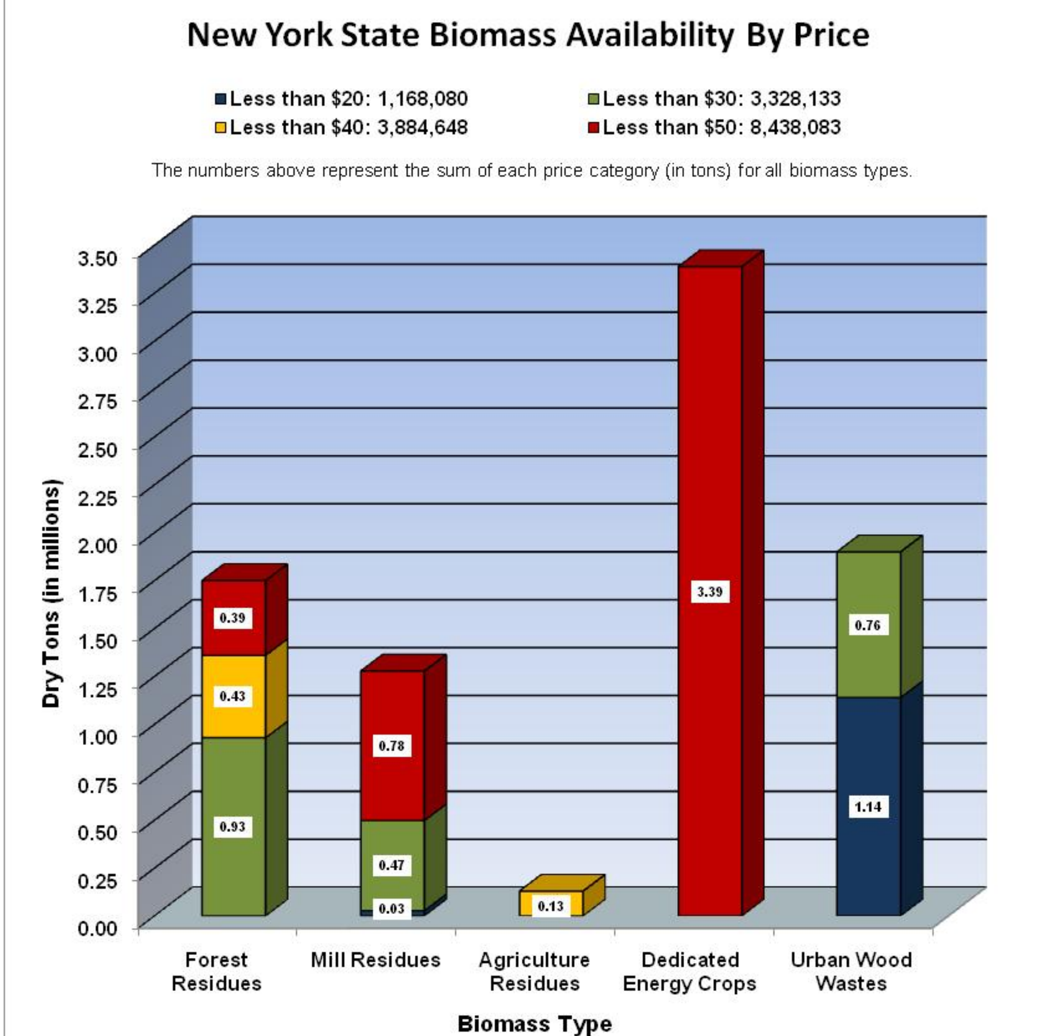
[9] This depends on what scenarios are being compared. Some researchers estimate corn yields on marginal land to be almost as high as grass yields. Since about half of the corn biomass is stover, total corn/corn stover yields could be much higher than perennial grass yields.

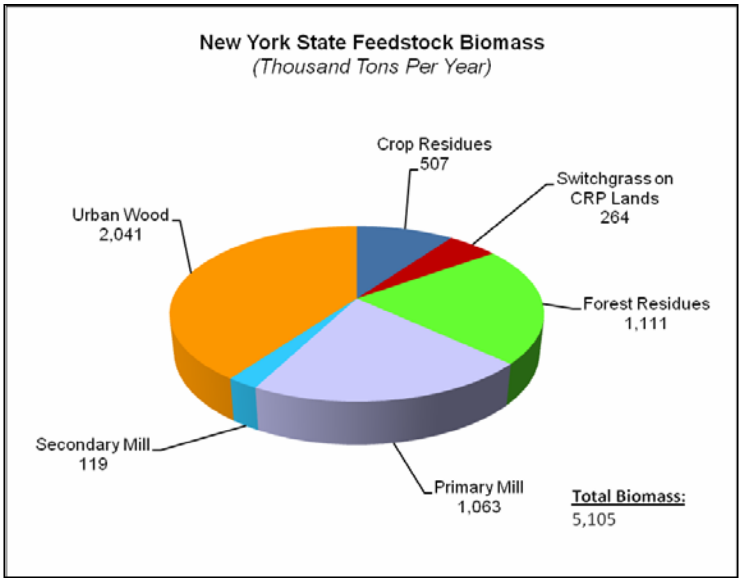
**Figure ES-7: New York State Biomass Availability by Price**




The graph above displays biomass feedstock availability in New York State, estimated in dry tons, per delivered price in 1995 dollars. These estimates are based on an assumed transportation cost of $8/dry ton for most feedstocks. The distribution of feedstocks within the state is not considered; it is assumed that feedstocks are available within 50 miles of a user facility.

**Source: Walsh et al, 2000**

**Figure ES-8: New York State Biomass Availability**




**Source: A Geographic Perspective on the Current Biomass Resource Availability in the United States (Milbrandt, 2005), available at [http://www.nrel.gov/docs/fy06osti/39181.pdf](http://www.nrel.gov/docs/fy06osti/39181.pdf).**

Figure ES-8 shows the technical availability of NYS biomass feedstocks, based on a geographic information system (GIS) study. Inputs to this study included population, climate, forested land, socio-economic drivers, the location and number of livestock, and related data.

**Sugar cane ethanol**

Sugar cane is the feedstock for ethanol in Brazil. Sugar cane ethanol production is significantly different from grain or cellulosic ethanol production for a number of reasons. Sugar cane is a perennial plant and has a much higher yield per area than other ethanol crops. In addition, processing sugar into fuel is simpler than processing grains or cellulose into fuel because there is no hydrolysis step. Sugar ethanol production facilities can be smaller than grain or cellulose ethanol plants because the fermentation process is very rapid, and in many cases, the mills burn bagasse (the fiber portion of the cane that remains after sugar extraction) to generate heat and electricity, so that fossil fuel inputs to the process are minimal. This avoided fossil fuel energy use results in significant reductions in GHG emissions. However, the transportation impacts for importing the feedstock must be considered.

A Canadian study calculates the life-cycle GHG emissions from sugar cane ethanol as 5.7% less than from conventional gasoline, and 5.2% less than from RFG. This study notes that results for sugar cane ethanol were increased 20% - 25% due to transportation impacts alone. In addition, significant GHG impacts were ascribed to land use changes and the production of lime. Unfortunately, the few studies extant on life-cycle impacts of sugar cane-derived ethanol do not give any results for criteria pollutants, toxics, or impacts to ecosystems.

**Soy Biodiesel: Environmental Impacts**

The second largest biofuel produced in the United States is biodiesel, mostly from soybeans. Unlike corn, soybeans are nitrogen-fixing plants, which means they can convert atmospheric $N_2$ to reactive nitrogen, and therefore need little or no additional nitrogen fertilizer. Soybeans also require less energy to grow than corn, thus avoiding some of the $NO_x$ emissions from farm equipment. However, soybean cultivation still contributes to the total amount of reactive nitrogen in a watershed. On an acreage basis, corn production in the U.S. Corn Belt releases more $NO_3$, $NH_3$, $NO_x$, and $N_2O$ to the environment than does soybean production. However, because soybean yields are so much lower per acre than corn,[10] on a yield basis, soybean production causes greater $NO_3$ runoff than corn production.

Modeling results indicate that over its life cycle, soy biodiesel emits 41% to 68% fewer GHGs, on a $CO_2$ equivalent basis, than petroleum diesel. However, as with corn ethanol, benefits are likely to decrease if crops are grown on marginal lands. One researcher calculated that producing soy biodiesel on previously undisturbed land would result in a 53% *increase* in GHG emissions relative to a low-sulfur diesel baseline. In this study, emissions were mainly due to land use change and cultivation, especially $CO_2$ emissions due to cultivation of land assumed to be previously uncultivated (time discounting was applied, but the time horizon was not clearly specified)

There are few good studies on biodiesel, and many of the studies that have been done predate the ultra-low-sulfur diesel (ULSD) standard. The impact of the ULSD standard is not only to reduce sulfur emissions, which contribute to acid rain, but also to allow the use of advanced emissions control systems that can reduce tailpipe emissions of $NO_x$ and PM.

Soy biodiesel, in the form of B20 (20% biodiesel mixed with 80% petroleum diesel), appears to emit more $NO_x$ than does petroleum diesel. A Canadian study found that it would release 33% more $NO_x$ over the entire fuel cycle, and 123% more from upstream emissions (farm and fuel production) alone. A second Canadian study found that 75% of the life-cycle $NO_x$ emissions from soy biodiesel are from upstream processes. This is significant because only downstream (tailpipe) $NO_x$ is subject to EPA regulations and can be controlled by the implementation of fuel standards and emissions control devices. Upstream $NO_x$ emissions, in this case largely from farm processes, are largely unregulated and can be extremely difficult to control.

With regard to other air pollutants, the use of soy biodiesel slightly reduces CO emissions relative to petroleum diesel, by about 7% to 11% over the total fuel cycle. However, most CO emissions occur at the tailpipe, where they are regulated by EPA standards and can be captured by emissions control devices. Differences in VOC and hydrocarbon emissions between B20 and petroleum diesel are uncertain. However, with regard to PM, B20 increases emissions upstream by 90%. A slight decrease at the tailpipe is likely moot in light of new fuel standards and auto emissions technology. Emissions of speciated airborne toxics from biodiesel production and use are uncertain.

Currently, demand for ethanol in the United States is causing many farmers to switch from a corn/soy rotation to pure corn production, decreasing the supply of soybeans and stimulating the development of soybean cultivation in other parts of the world. This can cause direct and indirect effects on land use, ecosystem services, and biodiversity. For example, increased soybean production in Brazil may increase demand on finite land resources and contribute to the conversion of land from savannahs and rain forests to cropland, resulting in elevated GHG emissions and reduced carbon sinks (see Land Use Change section).

**Net Energy Estimates**

As with corn ethanol, there is a range of estimates regarding the NER of soy biodiesel. Although less influenced by process energy inputs than ethanol, biodiesel's NER can vary widely depending on how co-product allocations are calculated. One study found that soy biodiesel's NER could vary from 1.16 to 3.38 solely based on alternative co-product allocation calculations. As in the case of ethanol, Pimentel and Patzek (2005) report the most unfavorable findings, an 8% net loss of energy. However, among other researchers, there is a broad consensus that soy biodiesel's NER is positive, and probably better than corn ethanol's.

[10] Soybean biodiesel yields are 350 – 550 liters/hectare; corn ethanol yields are 3,100 – 3,900.

**Alternate Biodiesel Feedstocks**

Biodiesel can be made from dozens of different oilseed crops, including rapeseed/Canola and oil palm, using the same basic process.[11] Biodiesel can also be made from certain types of algae, which are extremely high yielding and have the potential to be grown in artificial environments near power plants, where they can absorb waste $CO_2$. Finally, biodiesel can be made from waste products such as tallow and yellow grease (used cooking oil).

As biodiesel feedstocks, Canola and rapeseed have environmental impacts very similar to soybeans, with the important difference that they are not legumes, and therefore require much more nitrogen fertilizer, resulting in increased energy inputs and reactive nitrogen emissions. They are not widely grown in the United States, which is a net importer of Canola oil. Relative to Canadian petroleum diesel (300 ppm sulfur), Canola production and use as B20 emits 38% more $NO_x$ over its life cycle, nearly three-quarters of it in the upstream farm and fuel processing stages. Emissions of CO decrease by 13%, and VOCs decrease by 8% relative to petroleum diesel, but upstream PM is increased by 72%.

Palm oil has attracted a lot of interest due to its high yield (5,600 liters/hectare), which makes it the lowest-cost biodiesel feedstock in commercial production. Currently, in some locations poor cultivation practices are depleting soil quality, and the rapid expansion of oil palm plantations is being accomplished by burning forests and peat bogs, resulting in air pollution, habitat destruction, loss of biodiversity, and significant GHG releases that have been estimated to overwhelm any benefit from biodiesel use for decades or centuries to come. European countries have curtailed imports of oil palm imports until cultivation practices are improved, and efforts are underway in several countries to introduce practices that protect soil quality and avoid carbon releases from tropical deforestation. However, monitoring of cropping practices to ensure sustainability could prove very difficult. Additionally, assessment of palm oil biodiesel's environmental impacts must include the impacts of long-distance transport to the U.S.

A Canadian study indicated that palm oil B100 would emit about 70% fewer GHGs on a $CO_2$-equivalent basis than petroleum diesel (0.001% S) on a g/km basis. This is about the same result this study found for soy (-66%) and Canola (-74%). Calculated on a volumetric basis, B20 from palm oil would emit 13% more NOx, 8% less CO, 10% fewer VOCs (ozone weighted), and 25% more particulate matter than petroleum diesel over its life cycle. This study included the transportation impacts of importing palm oil 12,000 km by ship and assumed a mixture of legume intercropping for the first five years of tree stand growth, with added nitrogen fertilizer inputs in the following 20 years. Because there is little reliable information on the energy inputs needed for the oil extraction process, the Canadian study assumes a relatively inefficient process.

Oil palm plantations are undergoing a process of modernization by adopting more efficient production practices and replacing older tree stands with higher-yielding varieties. At the same time, new, cold-tolerant varieties are being developed to expand the region in which oil palm can be commercially grown (current production is primarily in Malaysia and Indonesia, but the crop can also be grown in some regions of Africa and South America). The impact these changes will have on the environmental profile of palm oil is not known.

Algae promises even higher oil yields than oil palm, with the added advantage that it may be able to be grown in translucent plastic tubes, using few land resources and allowing it to be "fed" with captured $CO_2$ emissions from fossil fuel electricity generation. This represents a significant advance over algae cultivation in ponds. However, these techniques are commercially unproven, and little information is available regarding potential environmental impacts.

[11] Unlike ethanol, the properties of biodiesel can vary somewhat depending on the feedstock. For example, the cold filter plugging point (CFPP) of palm oil biodiesel is between 11 and 15 degrees Celsius (52 and 59 degrees Fahrenheit). Even at blend levels of B20 or lower, this can cause fuel injector clogging under cold conditions, meaning the fuel requires further processing to winterize it before it can be sold year round in cold climates.

Yellow grease, essentially used cooking oil, is the second most commonly used biodiesel feedstock in the United States, but it accounts for only about 1% of biodiesel production. Since it is a waste product, it can be used for biodiesel production with few direct environmental impacts from feedstock production.[12] Life-cycle GHG emissions for yellow grease are about 65% lower than for petroleum diesel and about 20% lower than for soy biodiesel. Based on a Canadian study, yellow grease B20[13] emits 5.5% less upstream $NO_x$ than Canadian diesel (300 ppm sulfur), 12% less upstream CO (and 10% less CO from vehicle operation, but this is subject to regulatory controls), 14% less ozone-weighted VOCs, and 6.6% less PM.

**Biodiesel Coproducts**

Unlike ethanol fuel production processes, which can benefit significantly from energy-efficiency improvements such as GTCC technology, biodiesel oil extraction and fuel production processes are already quite efficient. One study found that for biodiesel, the largest impact on results is due to different co-product assumptions. For example, most biodiesel production processes produce glycerine that contains water, salt and other impurities, and must be purified in order to compete with the pure glycerine made by other processes. However, some biodiesel processes can produce pure glycerine. This obviates the need for an additional glycerine purification step, essentially doubling the glycerine energy and emissions credit.

Questions of coproduct allocation—how to count the environmental impacts of coproducts, and the significance of indirect impacts caused by coproduct substitutions—will be important to answer as biodiesel development goes forward.

**Biodiesel for Home Heating**

Few studies have examined emissions from biodiesel blended with No. 2 heating oil for use in home furnaces. Limited results indicate that a 20% blend does not require equipment modification and offers some advantages, including decreases in PM emissions of approximately 13%; decreases in CO emissions of up to 10%; and decreases in $NO_x$ emissions from 10% to 20%. Reductions of approximately 14% in particle-bound sulfate emissions have also been observed, which is in-line with an observed 20% reduction in stack $SO_2$ emissions relative to the base fuel. This significant reduction in PM sulfate has positive implications for environmental and human health.

One potential advantage of biodiesel for home heating use is that for continuous combustion applications, such as boilers and turbines, fuels can be used that do not meet ASTM specifications, meaning the cost of producing B20 for home heating applications could be significantly reduced. The upstream environmental impacts of producing a fuel to less exacting specifications have not been investigated.

**Biobutanol**

As an automotive fuel, butanol has a number of advantages over ethanol, including lower vapor pressure resulting in fewer evaporative emissions, the ability to be distributed via pipeline as opposed to truck or train, and a higher energy density (meaning a gasoline/butanol blend would impose a lesser mileage penalty than a gasoline/ethanol blend). Because biobutanol can be produced using the same feedstocks as ethanol, and with a very similar production process, most studies assume it would be produced in existing ethanol production facilities.

[12] Since yellow grease is currently used to produce other products, such as animal feed and cosmetics, indirect impacts could result if significant portions of this resource were diverted to biofuel production, necessitating that an alternative animal feed and cosmetic feedstock be found.
[13] This study treats yellow grease separately from tallow. Tallow is defined as recycled animal and poultry byproducts, and used cooking oil, while yellow grease is defined as used cooking oil only.

Despite its advantages as a fuel, biobutanol will not become a viable alternative to ethanol unless yields are dramatically improved. Biobutanol is produced by a bacteriological process, which historically has only yielded 1% to 1.4% butanol concentration, along with a number of coproducts. For this reason, biobutanol was replaced by petroleum-based butanol during the 1950s. In recent years, considerable work has been done to try to improve biobutanol yields through an improved process or the genetic manipulation of bacteria. However, until this work yields commercial results, the process energy required to produce biobutanol in any quantity will result in an overwhelmingly poor environmental profile.

Few studies are available on the environmental effects of biobutanol. One such study finds that Bu10 compares unfavorably to both E10 and RFG on greenhouse gas emissions, and emits 167% more $NO_x$ than gasoline. A "future" biobutanol scenario, in which energy used in fuel production is assumed to decrease by 25% from current rates, and the yield is assumed to consist of pure butanol (plus DDGs), fares no better in the comparison. This is because what the future scenario gains from the assumed higher yields and lower energy inputs, it loses when byproduct credits are subtracted from the model.

**Renewable diesel**

Renewable diesel is different from biodiesel, and the terms are not interchangeable. It is being advanced commercially by large corporate sponsors such as the ConocoPhillips/Tyson Foods partnership, which projects 175 million gallons a year from its first commercial scale plant, to be located in Texas.

Renewable diesel production pathways can accommodate feedstocks such as fatty waste animal processing by-products. This offers a possible advantage in an industry that is potentially supply-constrained. Renewable diesel pathways can also in some cases allow the use of existing oil industry refineries, avoiding significant capital expenses associated with new biodiesel refineries. The fuel is chemically more similar to petro-diesel than biodiesel and is expected to be distributed through the existing petro-diesel infrastructure. Renewable diesel also benefits from the same federal incentives offered to biodiesel.

Renewable diesel bears close attention. The potential for very fast growth may exist, and policy measures designed to encourage diesel substitutes will need to consider the implications of this option.

**Land Use Change**

Land use changes for biofuels production—for example, converting pasture or forests to croplands—can have enormous impacts on estimates of net GHG emissions. Recent publications show that including such effects results in emissions estimates that are often much greater than those from equivalent fossil fuels use for decades or centuries. However, the degree of impact depends greatly on the type of land undergoing changes, and how that land is managed. Accounting only for direct effects and using best management practices such as reduced tillage, large-scale land use change can still result in net GHG emissions for more than 50 years. Indirect effects can be even greater than direct effects, especially when they involve clearing forests for agriculture. Because biofuels feedstocks such as corn and soybean are global commodities, strategic analyses of bioenergy options for NYS should not ignore potential indirect effects of land use change on global GHG emissions.

There are substantial uncertainties in the effects of land use change on GHG emissions from soils due to the paucity of data on the fate of carbon in eroded soils. Additional uncertainty stems from the fact that only a few LCAs of biofuel pathways have included thorough analysis of land use change. More research should be performed to address findings from the literature. A careful assessment of the potential effects of different bioenergy pathways on land use and the resultant impacts on GHG emissions would fill an important information gap for New York State.

**Sustainability**

It is vital that biofuels be developed in a way that is sustainable.  Although there is no consensus to date on a precise set of sustainability goals and measures, substantial agreement can be found.  For example, sustainable biofuels should have a positive energy balance; be carbon-neutral or –negative; and be socially responsible.

The elements of sustainability should be analyzed using an integrated approach, and the analysis should be spatially explicit and conducted at multiple spatial scales.  It will be important for New York to consider not only national and international sustainability goals as they are developed, but also specific ways in which those goals will apply to the State and interact with existing laws and policies, both within the State, such as the Renewable Portfolio Standard (RPS) and regionally, the Regional Greenhouse Gas Initiative (RGGI).

**Conclusions**

- There are many biofuel production pathways using different feedstocks, conversion technologies and sources of process energy. The dominant biofuels are ethanol, a gasoline replacement fuel; and biodiesel, a petroleum diesel replacement fuel.
- The dominant ethanol pathway in the U.S. at present is corn ethanol, using natural gas for process energy.
    - New York State is a net importer of corn.
    - Corn ethanol most likely emits more life-cycle GHGs than gasoline; requires intensive nitrogen fertilization, resulting in high levels of reactive nitrogen pollution from farms; and results in high levels of some criteria pollutants and airborne toxics, notably fine particles ($PM_{2.5}$), acetaldehyde, and formaldehyde.
- Cellulosic ethanol, which could be produced from perennials such as grasses and woody crops, or from waste and cull wood, is in the pilot stage.
    - Perennials generally pose fewer environmental risks in the feedstock production stage than do annual crops.  New York has substantial land currently in pasture or hay, a portion of which could be used to produce perennial energy crops.
    - Waste feedstocks typically pose the fewest environmental risks.  New York has substantial forest cull and waste wood resources, which could give the state a competitive advantage in producing waste wood-based cellulosic ethanol.
    - Cellulosic feedstocks require a longer, more energy- and input-intensive conversion process to produce ethanol (than corn).  The energy balance and emissions profile of cellulosic ethanol will depend in part on how these technical challenges are resolved.
- The dominant biodiesel pathway in the U.S. is soy biodiesel.
    - Soy biodiesel has better net energy characteristics than corn-ethanol, reduces greenhouse gas emissions more effectively, and reduces most other tailpipe emissions relative to petrol-diesel. However, as with corn-ethanol, benefits are likely to decrease if crops are grown on marginal lands.
    - Soybean cultivation contributes to total amount of reactive nitrogen in a watershed. On an energy yield basis, soybean production may cause greater $NO_3$ runoff than corn production.
- As with ethanol, waste biodiesel feedstocks, such as yellow grease, typically pose the fewest environmental risks. Although yellow grease biodiesel currently represents a small fraction of the

market, New York has significant yellow grease resources, which could give the state a competitive advantage.

- Biodiesel can be blended with #2 heating oil for use in home furnaces. The few studies that have examined emissions from such use indicate reduced emissions of PM, CO, $NO_x$, and particle-bound sulfate.

- The impact of land use change on GHG emissions is only beginning to be understood; substantial uncertainties exist, partly because only a few analyses of biofuel pathways have included thorough analysis of land use changes. Careful assessment of the potential effects of different bioenergy pathways on land use, and the resulting impact on GHG emissions, would fill an important information gap for New York State.

- To ensure biofuel production is carried out on a sustainable basis, future regional standards for feedstock cultivation and processing need to be explored.

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# The Environmental Impacts of Biofuels in New York State

Draft Executive Summary 08-07

State of New York
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