# Biomass as a Source of Renewable Energy and its Impact on the Air Quality

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**Abstract**

Biomass is a great source of renewable liquid fuel. Cellulosic Ethanol is generally blended in gasoline to reduce emissions, increase octane, and extend gasoline stocks. Concerns over climate change have raised interest in developing fuels with lower fuel-cycle greenhouse-gas emissions. Cellulosic Ethanol can provide significant environmental benefits, can be produced sustainably from renewable sources, and lends itself to local and regional production. Emerging technologies that produce ethanol from agricultural waste, forest residue, municipal solid waste, and energy crops have the potential to dramatically improve the benefits of Cellulosic fuel ethanol. Their use could significantly decrease the energy required to produce the fuel, as well as decreasing associated greenhouse gases.

## Introduction

Ethanol is a liquid transportation fuel made from renewable resources or plant biomasses such as agricultural wastes, corn, grain, grasses, sugar cane, straw, wood based waste such as newsprint, woodchips, and manufacturing waste materials. Ethanol is a clean burning fuel that lowers overall Green House Gas Emissions. This is achieved as the biomass absorbs the Carbon Dioxide as it grows. Ethanol contains a high percentage of oxygen (35%) producing more complete fuel combustion, can be blended with petroleum and integrates into existing fuel delivery systems and provides an alternative form of energy by reducing reliance on fossil fuels. New Flexible Fuel Vehicles currently available, operate on E85 ethanol based fuels with a content of 85% ethanol and 15 % petroleum. Brazil is the largest producer of ethanol. The Brazilian government has mandated for 25% ethanol content in gasoline. Forty percent of all vehicles in Brazil utilize E85 or similar. In the United States of America, there are 72 ethanol plants with a capacity to produce 10.8 bL/year of high grade ethanol. The Cleaner Air Act 1990 has driven industry growth. Amongst other initiatives, the Act bans the use of MTBE and other toxins and carcinogenic additives into transport fuels. Fuel spills containing these additives have resulted in significant ground water contamination issues in recent years. In many States, ethanol use in transport fuel is mandated at 10%. During the past two years in California's major fuel companies have switched to ethanol. This switch has come 12 months prior to the 2004 deadline for the phase out of the MTBE additives. Ethanol will be a major source of hydrogen in fuel cells for the proposed $ 1.2 billion Freedom Fuel Program for encouraging the use of hydrogen as fuel.

## Cellulosic Ethanol

Newer manufacturing processes allow ethanol to be made from cellulosic feedstocks, also called biomass feedstocks. Cellulosic ethanol is currently the subject of intensive scientific research. While not yet widely commercialized, cellulosic ethanol has some great advantages compared to corn-based ethanol, and is often viewed as the future of the U.S. ethanol industry. Cellulose is the main component in the cell walls of plants, and is the main structural or stiffening material in plants. Cellulosic materials that can be made into ethanol are generally classified under four headings: agricultural waste, forest residue, municipal solid waste, and energy crops. Agricultural waste includes wheat straw, corn stover (leaves, stalks and cobs), rice straw, and bagasse (sugar cane waste). Forestry residue includes wood and logging residues, rotten and dead wood, and small trees. Municipal solid waste contains paper, wood, and other organic materials that can be converted into ethanol. Energy crops, grown specifically for fuel, include fast-growing trees and shrubs, such as hybrid poplars, willows, and grasses such as switchgrass. Besides being potentially less expensive than corn ethanol, cellulosic ethanol has many other advantages: The same plant materials that are being used for feedstocks can often be burned to fuel the ethanol plant, avoiding the fuel expenses (usually natural gas) and the consumption of fossil fuels required by conventional grain ethanol plants. A 1999 study by Argonne National Laboratory found that substituting cellulosic ethanol for gasoline would result in a net greenhouse gas reduction of 86 percent, compared to a 35 percent reduction in greenhouse gases by substituting corn ethanol for gasoline. (Wang et al., 1999) Cellulosic feedstock prices should be more stable and less volatile than corn prices. Cellulosic ethanol plants can dispose of a wide variety of organic wastes.

A few small-scale cellulosic ethanol plants are under construction or operating in the U.S. and Canada, using sugar cane residue, municipal solid wastes, rice straw, and timber residue as feedstocks. Cellulosic materials are generally less expensive than corn but also harder to convert to sugar. Chemically, cellulose is a long chain of tightly bound sugar molecules. The conversion of cellulose to sugar is generally accomplished by using sulfuric acid, through either *dilute acid hydrolysis* or *concentrated acid hydrolysis.* Many researchers today are most enthusiastic about a process called *enzymatic hydrolysis,* where an enzyme called *cellulase* is used, instead of sulfuric acid, to convert cellulose to sugar. In processes known as *thermal gasification* and *pyrolysis,* cellulosic material is heated to extremely high temperatures (up to 2200° F), creating a gas or oil that can be converted into ethanol using microorganisms or a catalytic reactor. Ethanol has also been made from methane, which can be captured from landfills or anaerobic digesters. According to a 2004 U.S. Department of Energy (USDOE) report, “The production of ethanol from corn is a mature technology that is not likely to see significant reductions in production costs.” (DiPardo, 2004) On the other hand, many are optimistic that the cost of producing cellulosic ethanol will eventually drop far below the cost of producing corn-based ethanol. Until recently, the cellulase enzymes used for enzymatic hydrolysis were prohibitively expensive, costing five or six dollars per gallon of ethanol. In 2005, two companies Novozymes Biotech and Genencor International reported achieving costs as low as 10 to 20 cents per gallon of ethanol, in laboratory trials funded by USDOE and the National Renewable Energy Laboratory.

## Uses and Advantages

The benefits of cellulosic Ethanol is that it emits nearly 60% less greenhouse gases than reformulated gasoline, relies on non-food and waste resources. In the U.S. today, ethanol has two main uses. It is often used as an "extender," adding volume to conventional gasoline. Since ethanol contains 35 percent oxygen. This oxygen acts as oxygenating agent during combustion in the IC engine, thus preventing formation of carbon monoxide and reducing air emissions. Gasoline with ethanol as anti-knocking agent enables high-compression engines to run more smoothly, without "knocking" increasing the life of the engine. Ethanol can be blended with diesel fuel, creating an experimental fuel called E-diesel. Ethanol is currently the most cost-effective renewable source of hydrogen, making it a strong candidate for use in fuel cells. Ethanol has been used as a transportation fuel in the U.S. since about 1908. Henry Ford designed the Model T to run on either gasoline or ethanol, and ethanol continued to be widely available as an automobile fuel through the 1930s. (DiPardo, 2004).

Over 30 percent of all gasoline sold in the U.S. is blended with ethanol, and ethanol comprises about two percent of the gasoline consumed in the U.S. (Renewable Fuels Association) Many states require gasoline to contain ethanol. Minnesota, New York, and Connecticut currently require gasoline to include a 10 percent ethanol blend, known as E10. *Flexible fuel vehicles* can accept a range of fuel mixtures including gasoline and E85, a blend of 85 percent ethanol and 15 percent gasoline. Flexible fuel vehicles cost at most a few hundred dollars more to manufacture than standard vehicles. A sensor automatically detects the fuel mixture and adjusts the timing of spark plugs and fuel injectors so the fuel burns cleanly.

Recent simulations of cellulosic ethanol production by National Renewable Energy Laboratory (NREL) indicated an ethanol yield of 76 gal per dry ton of hardwood biomass for ethanol plants that will be in operation around the year 2005. Such ethanol plants consume 2,719 Btu of diesel fuel and generate 1.73 kilowatt hours (kWh) of electricity per gallon of ethanol produced. For cellulosic ethanol plants operating in 2010, the simulations indicated an ethanol yield of 98 gal per dry ton of hardwood biomass. The plants will consume 2,719 Btu of diesel fuel and generate 0.56 kWh of electricity per gallon of ethanol produced. Table 4 presents the assumptions used in our analysis.

## Benefits of Cellulosic Ethanol

cellulosic ethanol achieves great GHG emissions and energy benefits. Under the near-future case, for E85, woody cellulosic ethanol reduces petroleum use by 70%, GHG emissions by 102%, and fossil energy consumption by 79%. The greater- than-100% reduction for GHG emissions is caused by GHG emissions offsets in electric power generation. The offsets are from the displacement (reduction) of utility-generated electric power that results from the sale of excess electric power generated by the woody biomass cellulosic ethanol technology. The specified herbaceous cellulosic ethanol production technology is estimated to reduce petroleum use by 71%, GHG emissions by 68%, and fossil energy consumption by 70%. Under the future case, energy and GHG emissions benefits of woody cellulosic ethanol, though still substantial, are less than those for the near-future case because of the substantial reductions in electricity credits for future cellulosic ethanol plants (see Table 5). Energy and emissions benefits of herbaceous cellulosic ethanol are similar for the near-future and the future cases. Thus, improvements in ethanol yields in cellulosic ethanol plants over time, because they are accompanied by reduced electricity credits, do not result in greater emissions and energy benefits. However, the technological improvements will certainly help the economics of producing cellulosic ethanol.

Ethanol has many attractive features. It is biodegradable, made from renewable sources, and offers a home-grown alternative to limited supply of oil. (USDOE, 2004) Substituting ethanol for fossil fuels also reduces tailpipe emissions of carbon dioxide, and many studies have shown a in the U.S. since 1979 and at higher levels since the early 1990s, when the 1990 Clean Air Act Amendments began requiring gasoline to be *reformulated* in parts of the country with poor air quality. Reformulated gasoline was required to have high oxygen content and low levels of smog-forming compounds and other air pollutants.

## Air Quality

One often-cited benefit of ethanol use is improvement in air quality. Through 2005, ethanol was primarily used in gasoline to meet a minimum oxygenate requirement for Reformulated Gasoline (RFG) program. RFG is used to reduce vehicle emissions in areas that are in severe or extreme non-attainment of National Ambient Air Quality Standards (NAAQS) for ground level ozone. Ten metropolitan areas, including New York, Los Angeles, Chicago, Philadelphia, and Houston, are covered by this requirement, and many other areas with less severe ozone problems have opted into the program, as well. In these areas, RFG is used year-round. EPA states that RFG has led to significant improvements in air quality, including a 17% reduction in volatile organic compound (VOC) emissions from vehicles, and a 30% reduction in emissions of toxic air pollutants. Furthermore, according to EPA, "ambient monitoring data from the first year (1995) of the RFG program also showed strong signs that RFG is working. For example, detection of benzene declined dramatically, with a median reduction of 38% from the previous year." However, the benefits of oxygenates in RFG have been questioned. Although oxygenates lead to lower emissions of carbon monoxide (CO), in some cases they may lead to higher emissions of nitrogen oxides ($NO_X$) and VOCs. Since all three contribute to the formation of ozone, the National Research Council concluded that while RFG certainly leads to improved air quality, the oxygenate requirement in RFG may have little overall impact on ozone formation. In fact, in some areas, the use of low-level blends of ethanol (10% or less) may actually lead to increased ozone formation due to atmospheric conditions in that specific area. Some argue that the main benefit of oxygenates is that they displace other, more dangerous compounds found in gasoline such as benzene. Furthermore, high gasoline prices have also raised questions about the cost-effectiveness of the RFG program.

The air quality benefits from purer forms of ethanol can be substantial. Compared to gasoline, use of E85 can result in a significant reduction in ozone-forming vehicle emissions in urban areas. And while the use of ethanol also leads to increased emissions of acetaldehyde, a toxic air pollutant, as defined by the Clean Air Act, these emissions can be controlled through the use of advanced catalytic converters. However, as was stated above, purer forms of ethanol have not been widely used. Directly related to fossil energy consumption is the question of greenhouse gas emissions. Proponents of ethanol argue that over the entire fuel cycle it has the potential to reduce greenhouse gas emissions from automobiles relative to gasoline, therefore reducing the risk of possible global warming.

Because ethanol contains carbon, combustion of the fuel necessarily results in emissions of carbon dioxide ($CO_2$), the primary greenhouse gas. Further, greenhouse gases are emitted through the production and use of nitrogen-based fertilizers, as well as the operation of farm equipment and vehicles to transport feedstocks and finished products. However, since photosynthesis (the process by which plants convert light into chemical energy) requires absorption of $CO_2$, the growth cycle of the feedstock crop can serve to some extent as a “sink” to absorb some fuel-cycle greenhouse emissions. Because of the limited use of fertilizers, fossil energy consumption and thus greenhouse gas emissions is significantly reduced with ethanol production from cellulosic feedstocks. The Argonne study concludes that with advances in technology, cellulosic E10 could reduce greenhouse gas emissions by 7% to 10% relative to gasoline, while cellulosic E85 could reduce greenhouse gas emissions by 67% to 89%. The study of energy consumption and greenhouse gas emissions found a similar potential for greenhouse gas reductions.

The use of ethanol as a transportation fuel has many undisputed air quality benefits. Adding ethanol to gasoline has been shown to reduce tailpipe emissions of many toxic air pollutants, including particulate matter, benzene, and carbon monoxide. Many studies show, however, that ethanol slightly raises the volatility of gasoline, causing increased emissions of hydrocarbons and nitrogen oxide (NOx), which can contribute to smog formation. Ethanol’s *energy balance* is sometimes defined as the difference between the amount of energy stored in a gallon of ethanol and the amount of energy needed to grow, produce, and distribute that gallon of ethanol. While the topic has been hotly debated for years, the current prevailing opinion is that ethanol has a net positive energy balance.

## Conclusion

The energy problems confronting us are so profound that they will likely require dramatic changes in our way of life within the next decade or two. It is unrealistic to hope that ethanol will replace petroleum or that it will allow us to continue using energy as we have for the past seventy-five years. The first and most urgent priority of any sensible national energy strategy will be efficiency and conservation, reducing our energy usage to more sustainable levels. Nonetheless, Cellulosic ethanol is probably our most promising biofuel option right now from the standpoint of reducing our reliance on oil and making the transition to a more sustainable transportation system. Ethanol has many clear tailpipe emission benefits and is generally far more environmentally benign than the gasoline. Two concerns about ethanol have received more attention than all the others combined: the high cost/incentives issue and the energy balance issue. These concerns are over-emphasized. The more important questions about ethanol concern its possible impacts on air, water, and soils. As the cost of cellulosic ethanol continues to drop, the ethanol industry will start to look far different from what it is today.

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Minnesota Department of Agriculture's Ethanol Page www.mda.state.mn.us/Ethanol

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