Fuel Cycle Evaluations of Biomass - Ethanol and Reformulated Gasoline

OVERVIEW

Ethanol's Clear Future

The use of ethanol from biomass can substantially reduce U.S. crude oil imports, reduce the threat of global warming, and decrease sulfur dioxide emissions. These are the significant findings of the most recent, comprehensive analysis of ethanol production conducted by the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL).

The use of ethanol from biomass can substantially reduce U.S. crude oil imports, reduce the threat of global warming, and decrease sulfur dioxide emissions.

Ethanol is available and used as a transportation fuel in the United States today. However, today's ethanol is usually made from corn and used only in blends (10% ethanol mixed with 90% gasoline) to increase the oxygen content of gasoline. Such oxygenated blends have helped to improve the air quality in several of our nation's traffic-congested cities—but pure, or *neat,* ethanol from biomass can do even more to improve our environment.

Promising new technological developments make it likely that, before 2000, a commercial industry will be established that converts biomass wastes and *non-food* agricultural crops—*energy crops* like trees and grasses—into ethanol. Advances in automobile engine design will enable consumers to purchase specially designed cars that use neat ethanol. Best of all, these cars will allow consumers to enjoy performance and fuel economy that is actually better than the gasoline-fueled vehicles of today.

- The biomass-to-ethanol fuel cycle generates 4.07 British thermal units (Btus) for every 1 Btu of fossil energy consumed. In comparison, the production of reformulated gasoline (RFG) generates only 0.79 Btus of fuel energy for every 1 Btu of fossil energy consumed.
- Net carbon dioxide emissions for ethanol are 90% less than for RFG.
- Net sulfur dioxide emissions for ethanol are 70% less than for RFG.

Examine the Ramifications of Manufacturing

The development of alternative fuels like ethanol requires innovative technologies. DOE's optimism for the widespread use of ethanol is based on an extensive research and development (R&D) program. The program has developed and demonstrated technologies that enable ethanol producers to cost-effectively extract sugar from fibrous materials found in woody plants, grasses, and many wastes—sugar that cannot be extracted using traditional methods. This is significant because ethanol is an alcohol made by fermenting sugar using processes similar to those used to produce beer and whiskey.

To predict the costs and benefits of new ethanol technologies objectively, we must evaluate them as part of the entire manufacturing process.

Without this new technology, ethanol fuel producers must use plants that contain high levels of starch, such as corn and other food grains which can be processed using conventional methods.

It's easy to foresee that technologies like these could revolutionize the ethanol industry. In fact, *R&D* magazine selected one new ethanol process as one of the 100 most significant technological achievements of 1993. However, to predict the costs and benefits of new ethanol technologies objectively, we must evaluate them as part of the entire manufacturing process.

Think of an assembly line that includes all of the activities required to transform biomass into usable fuels—activities like planting, growing, harvesting, and transporting energy crops as well as converting, distributing, and actually using the final fuel product. Each of the individual operations that comprise the manufacturing process have environmental, economic, and energy resource ramifications, which must be considered before the merits of ethanol can be impartially compared to those of other transportation fuels. Therefore, we must thoroughly understand the entire manufacturing process.

In DOE's study, analysts conducted a comprehensive study of the manufacturing processes for two fuels. They researched and described how a likely 2010 ethanol industry will operate and compared it to the well-established RFG industry, because DOE studies project that RFG will be the primary fuel used in the United States by 2000. The primary goal was to identify and describe each of the hundreds of steps that comprise the ethanol and RFG manufacturing processes. In addition, the analysts identified and estimated the inputs, outputs, and emissions attributable to each activity.

Each of the individual activities that comprise the manufacturing process have ramifications, which must be considered before the merits of ethanol can be impartially compared to those of other transportation fuels.

Examples of inputs include electricity, water, fuels to operate farming and industrial equipment, chemicals, and energy feedstocks—raw materials like crude oil and energy crops that are converted into transportation fuels. Examples of outputs include consumer products like transportation fuels, fuel additives, chemicals, and electricity. Emissions include solid waste, waste water, and air pollutants like carbon dioxide, carbon monoxide, and sulfur dioxide.

Both fuel manufacturing processes produce multiple consumer products, so the analysts estimated the quantities of inputs, outputs, and emissions in proportion to the resulting products. For example, not all of the air pollutants released when crude oil is produced can be attributed to gasoline. Only 58% of the yield from the average oil well is crude oil—42% is natural gas. Furthermore, only 30% of each barrel of crude oil is used to produce gasoline. Therefore, gasoline is responsible for only 17.4% (58% x 30%) of air pollutants generated during crude oil production.

In researching both manufacturing processes, the analysts excluded pre-operational activities like oil exploration and construction of industrial facilities, distribution networks, ethanol conversion plants, refineries, and oil pipelines. Post-operational activities like waste disposal and dismantling of obsolete or abandoned industrial facilities were also excluded.

Although the ethanol and RFG manufacturing processes are very different and very complex, the analysts found that both can be summarized and discussed as a five-stage process:

Feedstock Production—Activities required to produce raw materials like crude oil and energy crops.

Feedstock Transport—Endeavors required to transport raw materials to the refinery or ethanol conversion plant, as applicable.

Fuel Production—Processes required for refining or converting raw materials into fuel.

Fuel Transport—Elements required to distribute transportation fuels to consumers.

Fuel End Use—Consumption of transportation fuels by light-duty passenger vehicles.

Fuel Cycle Data

Inputs	Outputs	Emissions
Feedstocks	Fuels	Air
Crude oil	Gasoline	CO_2
Biomass	Ethanol	CO
Fuels	Coproducts	NO_x
Diesel	Refined products	VOC
MTBE	Electricity	SO_2
Natural gas		Particulates
Chemicals		Toxics
Fertilizer		Waste water
Pesticides		Solid waste
Catalysts		
Water		
Labor		
Electricity		

The 2010 Fuel Industry

In 2010, the cars and trucks we drive will be more fuel efficient and will comply with stricter clean air requirements, such as those outlined in the Clean Air Act Amendments (CAAA) of 1990. Based on engine efficiency projections for 2010, cars specifically designed to use ethanol will travel 28.25 miles per gallon (12 kilometers per liter) and gasoline-fueled cars will travel 35.6 miles per gallon (15.1 kilometers per liter) on average. But how will the fuels we purchase be produced?

Even with advances in petroleum production technologies and changes in crude oil characteristics, DOE anticipates that the 2010 RFG industry will remain about the same as it is today. RFG will be produced from a mix of domestic and imported crude oils. An increasing amount of RFG will be oxygenated with ethanol and ethyl tertiary butyl ether (ETBE), which is made from ethanol. However, DOE expects that most RFG will be oxygenated with 15% methyl tertiary butyl ether (MTBE), which is usually made from natural gas. RFG is required in many of the nation's traffic-congested cities, to help them comply with the clean air standards established by the CAAA.

The 2010 ethanol industry will be far more localized than the RFG industry.

Domestic crude oil is pumped and stored near the well, then transported by pipeline, barge, ocean tanker, rail, or truck to storage tanks, at the refinery. Imported oil is normally transported to the United States by ocean tanker, transferred to port storage tanks and then transported by pipeline to a nearby refinery. At the refinery, crude oil is converted into numerous products like diesel, kerosene, jet fuel, lubricating oil, butane, benzene, and, of course, gasoline. Compounds like ethanol, ETBE, and MTBE are mixed with gasoline to form RFG, which is sent to bulk terminals by pipeline, barge, rail, or truck, and then distributed to retail outlets by tanker truck.

The petroleum industry's network of refineries, pipelines, and other industrial facilities enables many manufacturing activities to be highly centralized. For example, much of the MTBE mixed into gasoline used in the Northeast is produced on the Texas Gulf Coast.

In contrast, the 2010 ethanol industry will be far more localized than the RFG industry, largely because of the cost of transporting energy crops to processing plants. Energy crops appropriate to the individual region will be grown and harvested within 100 miles of the ethanol conversion facilities. Harvested crops will be transported to the conversion plant using the area's most cost-effective transportation network—possibilities include barge, rail, and truck. The ethanol conversion facility will convert 80% of the energy crops into ethanol and 20% into electricity, with part of the latter being sold to the local electric utility. The ethanol will be mixed with 5% gasoline and distributed to consumers within a 200-mile radius using existing gasoline transportation and storage facilities that have been modified for ethanol service.

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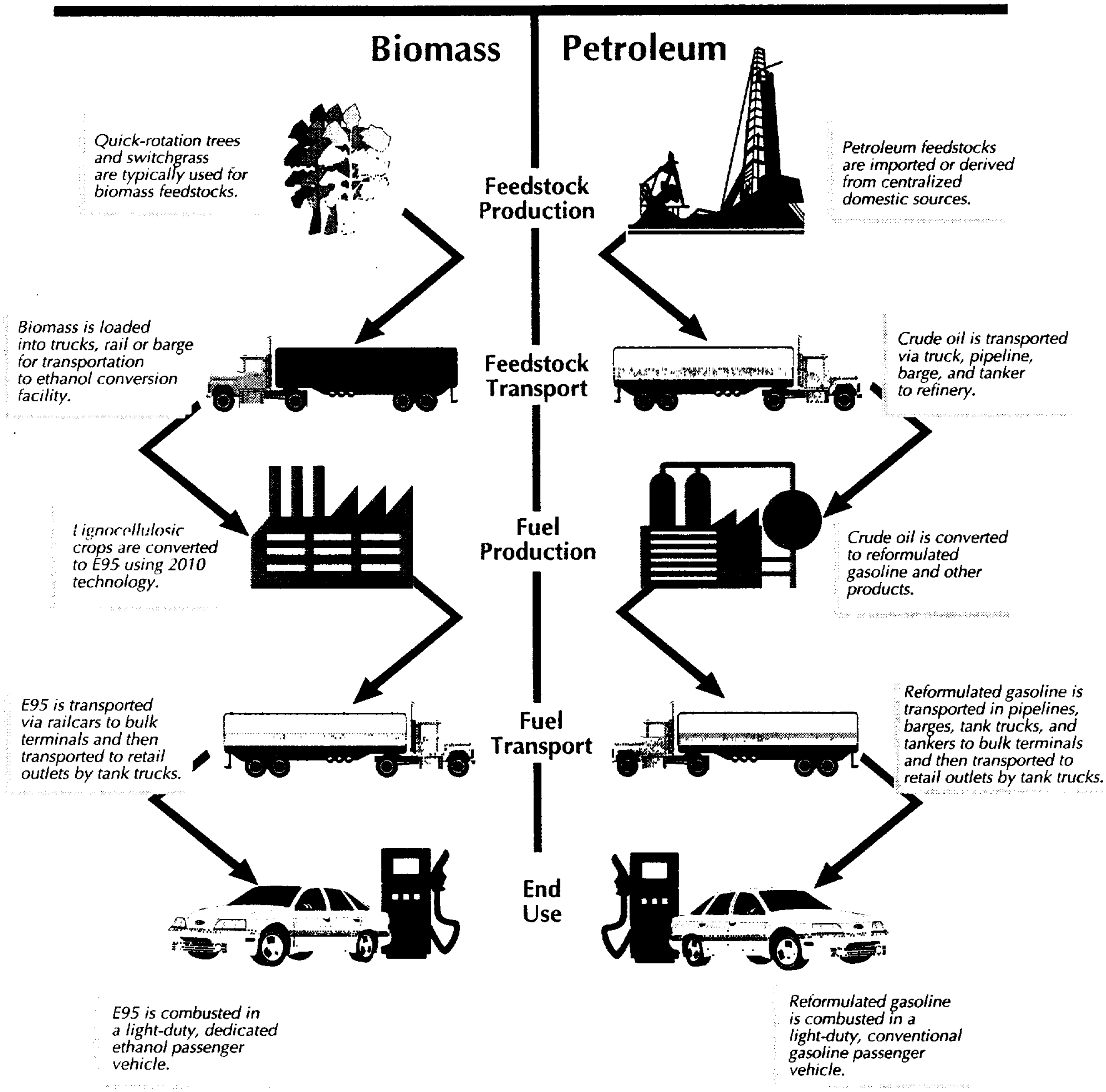
DOE's description of the 2010 fuel industry has significant implications. For example, it's evident that the ethanol industry could generate local jobs and boost the agricultural economy. The real value of the analysis, however, is that analysts can use this clearer understanding of the RFG and ethanol manufacturing processes to compare the merits of both fuels head-to-head—for example, to evaluate the merits of both fuels with regard to air emissions and energy efficiency.

Fuel Manufacturing Processes
Not including construction, exploration, and decommissioning



A frequently mentioned benefit of ethanol is that each tank of the fuel consumed replaces gasoline that would have been used instead. But you may be surprised to learn that a considerable amount of fossil fuel savings are hidden within the ethanol manufacturing process. Because typical tank-to-tank comparisons do not take into account the fossil fuels consumed to produce transportation fuels, the analysts used their understanding of the ethanol and RFG manufacturing processes to compare how efficiently each used 1 Btu of fossil fuel energy.

You may be surprised to learn that a considerable amount of fossil fuel savings are hidden within the ethanol manufacturing process.

Results indicate that the ethanol process is a far more energy-efficient consumer of fossil fuels, which include not only petroleum products, but also coal and natural gas. The ethanol process generates 4.07 Btus of fuel energy for every 1 Btu of fossil fuel energy consumed. In comparison, the RFG process generates only 0.79 Btus of fuel energy for every 1 Btu of fossil fuel energy consumed.

To understand why fossil fuel energy shrinks in the RFG manufacturing process, keep in mind that crude oil—a fossil fuel—is the RFG feedstock. Even if 1 Btu of fossil fuel energy *could be* converted directly into RFG *without consuming any fossil fuels at all*, each Btu of fossil fuel energy would generate only 1 Btu of fuel energy. Because many of the activities in the RFG manufacturing process require fossil fuels, process improvements can only narrow the gap between actual Btus created and the one-to-one maximum theoretically possible.

Ethanol is not constrained by the 1-Btu maximum because fossil fuels aren't an ethanol feedstock. In fact, for ethanol to compete with RFG, the ethanol manufacturing process must be as efficient as possible and limit the use of fossil fuels. For example, the ethanol conversion process used in the study's scenarios burns crop by-products to generate electricity. In fact, enough electricity is produced that the excess can be sold to the local electric utility. In comparison, petroleum refining must purchase power from the local electric utility. Most U.S. electric utilities generate electricity with power plants that burn fossil fuels such as coal—and that trend is increasing.

Fossil fuels are an important national resource. Because the increased use *and production* of ethanol will displace fossil fuels that would be used otherwise, it can play an important role in stretching the nation's limited supply of fossil fuels *and* improving the environment.

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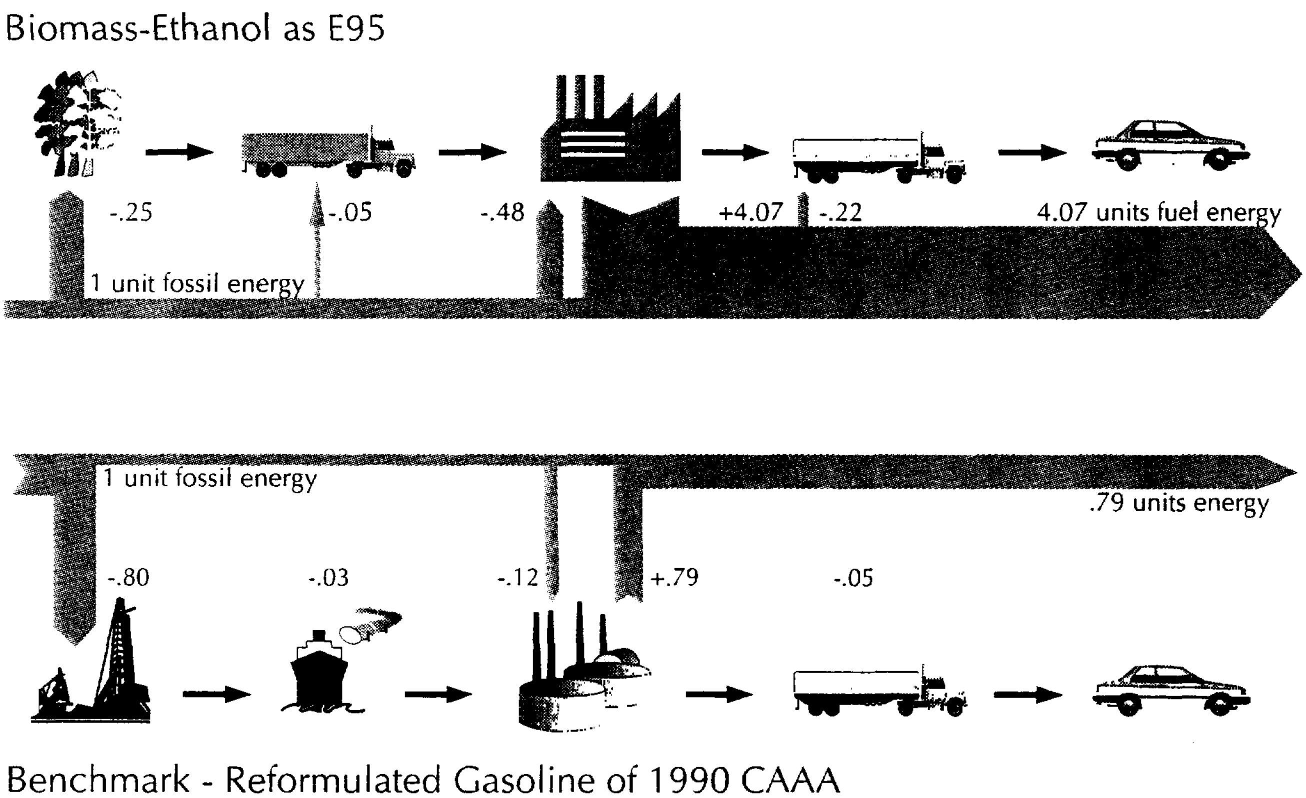
Fossil Energy Inputs and Fuel Energy Outputs



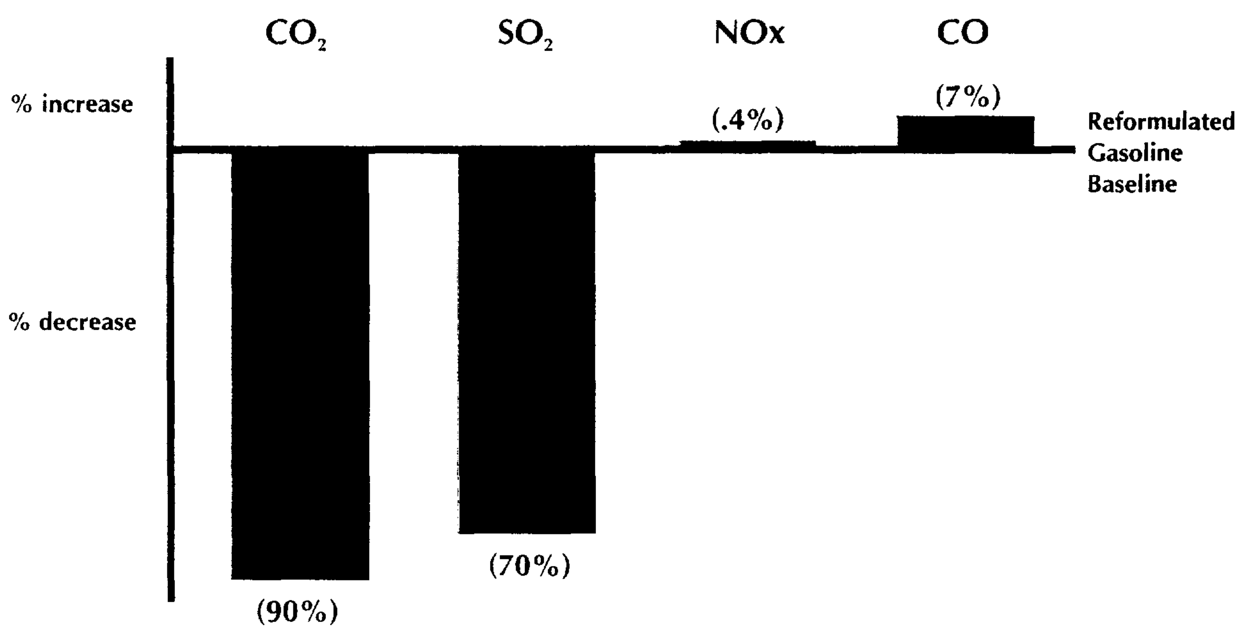
The Tail Pipe Dream

If ethanol *is* a pipe dream, it is a tail pipe dream. It reduces many types of air pollutants and is especially efficient at reducing carbon dioxide, which is the greenhouse gas considered most responsible for global climate change. Carbon dioxide is reduced because the energy crops that are converted into ethanol absorb carbon dioxide during their growth through a process called photosynthesis. Theoretically, the carbon dioxide released when the ethanol is used should equal the amount absorbed by the plants grown to produce the fuel. In reality, however, the ethanol manufacturing process does include other sources of carbon dioxide emissions, like the diesel tractors used in energy crop farming and harvesting.

The DOE-sponsored analysts used their knowledge of the ethanol and RFG manufacturing processes to evaluate emissions theories. Air emissions generated and consumed by the 2010 ethanol industry in five locations nationwide were estimated and compared to the expected results for the 2010 RFG industry.

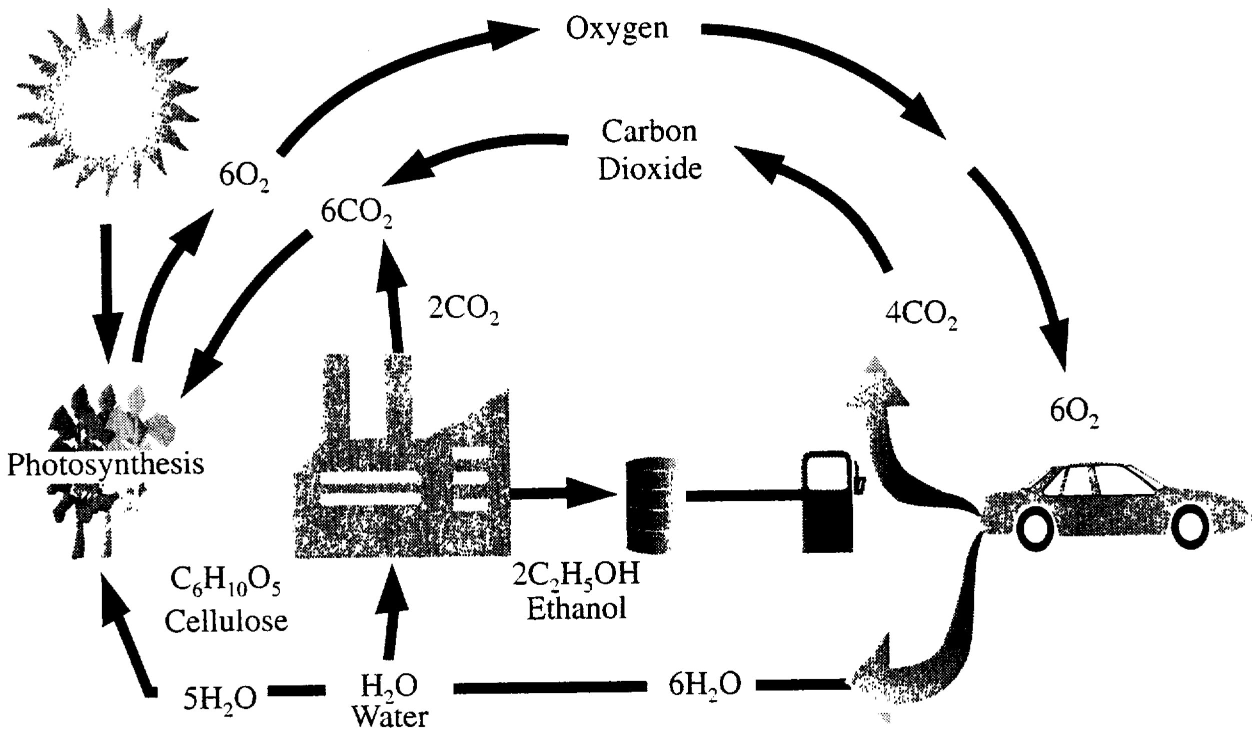
The results indicate that net carbon dioxide emissions (that is, carbon dioxide released less carbon dioxide absorbed) for ethanol over the five-stage fuel manufacturing process would be 90% less than for RFG. Results are equally impressive for sulfur dioxide, which is a leading agent responsible for acid rain. Results indicate that production and use of ethanol would curtail sulfur dioxide emissions at least 70% more than RFG. The analysts also found that ethanol and RFG would produce comparable levels of oxides of nitrogen, another global warming agent.

Air Emission Benefits of Ethanol



Source: Tyson, S., Fuel Cycle Evaluations of Biomass-Ethanol and Reformulated Gasoline, Volume I, prepared for the U.S. Department of Energy by the National Renewable Energy Laboratory (NREL/TP-463-4950), November 1993.

Biomass-to-Ethanol Air Emissions Advantage



For More Information about this Topic

The conclusions about air emissions and fossil fuel energy consumption in this DOE-sponsored study are just two examples of how a comprehensive understanding of the ethanol manufacturing process enables analysts to provide conclusive, substantiated predictions about the environmental and energy efficiency benefits that this alternative fuel could offer. This information should help anyone who wants to make informed decisions about alternative energy policies and options.

NOTE:

The ethanol referred to in this study is produced from lignocellulosic material-trees, grasses and organic wastes-called biomass. Corn ethanol is not described in this report. Information regarding corn ethanol can be found in "Farmers Fueling America; A Special Report on Ethanol," Farm Journal Custom Publishing Co.,, 1991; High Plains Corporation, Wichita, Kansas, Keeney, D. R., and Deluca, T. H., "Biomass as an Energy Source of the Midwest U.S., "American Journal of Alternative Agriculture, draft copy, in press, 1992, "Annual Report on Fuel Ethanol," Solar Energy Research Institute, Golden, CO, 1990, "Agriculture Chemical Usage; 1991 Field Crops Summary," U.S. Department of Agriculture, ERS, Washington, D.C., 1992.

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NOTES

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