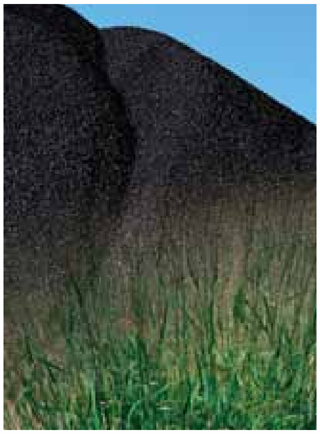
THE NATIONAL ACADEMIES
REPORT IN BRIEF

Liquid Transportation Fuels from Coal and Biomass

Technological Status, Costs, and Environmental Impacts

Americans rely heavily on imported petroleum-based fuels for transportation. However, concerns about tightening global supplies of oil, the need for supply diversity, and increasing evidence linking carbon dioxide emissions to climate change, have driven a search for alternatives to petroleum-based fuels. This report, one in a series of five reports from the National Academies' America's Energy Future initiative, assesses the potential for producing liquid fuels from coal and biomass (plants and waste), including considerations of technical readiness, costs, and environmental impacts. The report concludes that liquid fuels produced from coal and biomass could become an important part of a U.S. energy strategy.

The United States transportation sector relies almost exclusively on oil, using about 14 million barrels of oil per day to fuel all U.S. transportation needs, 9 million of which are used in light-duty vehicles (e.g., cars, sport utility vehicles) Americans drive every day. Domestic energy sources (e.g., coal, nuclear) can supply all U.S. electricity needs, but the United States is unable to supply sufficient oil to satisfy its transportation demands, and currently imports about 60 percent of the petroleum it uses.



Reliance on oil raises two issues. The first is energy security. Global demand for oil continues to rise, while at the same time, fears have arisen that oil production could peak in the next 10-20 years and then drop off. The second issue is that greenhouse-gas emissions that result from burning petroleum products account for one-third of total carbon dioxide emissions in the United States and are an important contributor to global climate change.

The nation can increase energy security and potentially reduce greenhouse-gas emissions by developing replacements for gasoline and diesel made from oil. This report concludes that liquid fuels made from biomass (plant matter and wastes) and coal hold promise. They are deployable over the next 10-25 years, could become cost-competitive with petroleum, and will reduce reliance on oil. Their greenhouse gas emissions could be similar to or lower than those of petroleum-based fuels. However, even with abundant supplies of biomass and coal, the technologies needed to convert them into liquid fuels and to capture and store carbon dioxide from the conversion process, still need to be demonstrated at commercial scale.

Supply of Biomass

To date, the primary biofuels in the United States have been ethanol from corn grain and biodiesel from soybean, which accounted for less than 3 percent of U.S. transportation-fuel consumption in 2007. These fuels have raised several issues. Diverting corn and soybean crops to biofuel production induces competition between food, feed, and fuel. In addition, growing such crops requires a lot of fossil fuels (e.g., fertilizer and farm vehicles), making the reductions in greenhouse-gas emissions compared with petroleum-based gasoline small at best.

The next generation of biofuels is expected to be made from cellulosic biomass—residues from agricultural and forestry practices, crops grown only for conversion to fuel (dedicated energy crops), and municipal solid wastes—which offer substantial reductions in greenhouse-gas emissions relative to petroleum-based fuels. The report concludes that approximately 550 million tons per year of cellulosic biomass could be produced by 2020 without any major impact on food production or the environment (see Table 1).

To attain the panel's projected sustainable supply of cellulosic biomass, incentives would have to be provided to farmers and developers to use a systems approach for growing and collecting the biomass and converting it to biofuel—an approach that addresses soil, water, and air quality; carbon sequestration; wildlife habitat; and rural development in a comprehensive manner.

Supply of Coal

The United States probably has sufficient coal resources to meet the nation's needs for well over 100 years at current rates of consumption. Making liquid fuels from coal would result in an expansion of the coal-mining industry. For example, a 50,000-barrels/day plant will use about 7 million tons of coal per year, and 100 such plants would use about 700 million tons of coal per year, which is a 70 percent increase in coal consumption. That would require major increases in coal-mining and transportation infrastructure for moving coal to the conversion plants and moving fuels to the market. Increased mining has numerous environmental effects that will need to be dealt with in an environmentally acceptable way. A key question is the availability of sufficient coal in the United States to support such increased use while supporting the coal-based power industry.

Table 1. Estimated Cellulosic Feedstock that Could Potentially Be Produced for Biofuel

Fuel Product	Current Technologies	Available by 2020
	(millions of tons)	
Corn stover	76	112
Wheat and grass straw	15	18
Hay	15	18
Dedicated fuel crops	104	164
Woody biomass	110	124
Animal manure	6	12
Municipal solid waste	90	100
Total	**416**	**548**

Challenges in Converting Biomass and Coal to Liquid Fuel

Even with abundant quantities of biomass and coal, a commercially deployable set of conversion technologies needs to be developed or demonstrated immediately and driven to commercial readiness. There are two key conversion technologies: (1) biochemical conversion, which uses enzymes to break down starch, cellulose,[1] or hemicellulose[2] from biomass into sugars that are converted into ethanol, and (2) thermochemical conversion, which uses heat and steam to convert biomass and/or coal into syngas from which liquid fuels are synthesized.

Biochemical Conversion

Cellulosic feedstocks are not yet part of our energy portfolio because converting them into ethanol is more complicated than converting corn grain or soybean, and, as of 2008, no commercial-scale cellulosic conversion plants were yet operational. Over the next decade, process improvements in cellulosic-ethanol technology are expected to come from evolutionary developments gained through demonstration and commercial experience and from future scientific developments. Economics are also expected to improve as scale of production expands to optimal size.

An expanded transport and distribution infrastructure will also be needed because ethanol is too corrosive to be transported in pipelines used for petroleum. Studies should be conducted to identify the infrastructure needed to accommodate increasing volumes of ethanol and integrating these volumes into the fuel system. Research on converting biomass to fuels more compatible with the

[1] A complex carbohydrate, $(C_6H_{10}O_5)n$, that forms cell walls of most plants.

[2] A matrix of polysaccharides present in almost all plant cell walls with cellulose.

current distribution infrastructure could yield new technologies in the next 10-15 years.

If all conversion and distribution infrastructure is in place, 550 million dry tons of biomass/yr could be used to produce up to 2 million bbls/day (30 billion gallons/yr) of ethanol. Of course, producing the supply depends on the availability of cellulosic-ethanol plants. If the rate at which plants are built exceeds that experienced with corn-grain-ethanol plants by 100 percent, cellulosic ethanol could be added to the fuel portfolio at up to 0.5 million barrels of gasoline equivalent per day by 2020. By 2035, up to 1.7 million barrels per day (gasoline equivalent) could be produced, representing about 15% of oil use in U.S. transportation.

Thermochemical Conversion

Technologies for converting coal through thermochemical conversion are commercially deployable today, but at life-cycle greenhouse-gas emissions about twice those of petroleum-based fuels. The ability to capture the carbon dioxide released during coal conversion processes and store it deep underground (geologic storage of carbon dioxide) is key to producing liquid fuels from coal with life-cycle greenhouse-gas emissions comparable to gasoline and diesel. However, geologic storage of carbon dioxide has yet to be adequately demonstrated on a large scale in the United States.

Liquid fuels produced from biomass are more expensive than those from coal because of the higher costs of biomass feedstocks, but they can have carbon dioxide life-cycle emissions close to zero without carbon dioxide storage or highly negative with effective carbon dioxide storage. To make such fuels competitive, the economic incentive of reduced carbon dioxide emissions has to be sufficiently high, for example, through policies that put a price on carbon dioxide emissions.

Thermochemical conversion of biomass and coal together to produce liquid fuels offers promise as a future U.S. strategy, because it allows a larger scale of operation than would be possible with biomass only and reduces capital costs per unit of capacity. It also extends the potential impact of limited biomass supply. Overall carbon dioxide life-cycle emissions are lower than those from coal alone because the emissions from coal are countered by carbon dioxide uptake by biomass during its growth. Without carbon dioxide storage, life-cycle carbon dioxide emissions from coal-and-biomass-to-liquid conversion plants are similar to that of gasoline and diesel; with carbon dioxide storage, life-cycle emissions are close to zero. If 550 million tons of biomass are combined with coal (60 percent coal and 40 percent biomass on an energy basis), 4 million barrels per day (60 billion gallons/yr) of gasoline equivalent could feasibly be produced, which is about 30 percent of the amount of fuel used in U.S. transportation today.

To make coal and biomass liquid fuels commercially deployable by 2020 while meeting goals for reducing carbon dioxide emissions, a program of aggressive support of first-mover commercial coal-to-liquid and coal-and-biomass-liquid fuel plants with integrated geologic carbon dioxide storage would have to be undertaken immediately and proven viable by 2015. Coal-and-biomass-to-liquid plants would probably be sited in regions near coal and biomass supplies, so buildout rates will be lower than those of cellulosic-ethanol plants discussed above.

The report estimates that at a 20 percent per year growth rate from 2020 until 2035, 2.5 million barrels of gasoline equivalent (about 20 percent of oil use for U.S. transportation) would be produced per day in combined coal biomass plants. That would consume about 300 million dry tons of biomass—less than the projected biomass availability—and about 250 million tons of coal per year.

Costs, Barriers, and Deployment

Production of alternative liquid transportation fuels from coal and biomass with technology commercially deployable by 2020 can play an important role in reducing U.S. oil consumption and carbon dioxide emissions. The various options have different greenhouse-gas impacts, and the choice will most likely depend on U.S. carbon policy. The report estimates costs of cellulosic ethanol, coal-to-liquid fuels with and without geologic carbon dioxide storage, and coal-and-biomass-to-liquid fuels with and without geologic carbon dioxide storage using a consistent set of assumptions (see Table 2). Although the estimates do not represent predictions of prices, they allow comparisons of fuel costs relative to each other. The costs of cellulosic ethanol and coal-and-biomass-to-liquid fuels with carbon dioxide storage become more attractive if a carbon dioxide emission price of $50/tonne is included.

Reaching the supplies of 1.7 million barrels of cellulosic ethanol per day, 2.5 million barrels of liquid fuels from coal plus biomass per day, or 3 million barrels of coal-to-liquid fuels per day (or some combination of the above) will require the permitting and construction of tens to hundreds of conversion plants and the associated fuel transport and delivery infrastructure. It will take more than a decade beyond 2020 for these fuels to penetrate the U.S. market at these levels. In addition, if investors foresee crude-oil price fluctuations, especially towards levels below these alternatives, investments may be foregone or delayed unless some form of protection against such fluctuations is put in place.

Table 2 Estimated Costs[1] of Fuel Products with and without a CO_2 Equivalent Price of $50/tonne[a]

Fuel Product	Cost without CO_2 Equivalent Price	Cost with CO_2 Equivalent Price of $50/tonne
	($/bbl gasoline equivalent)	
Gasoline at crude-oil price of $60/bbl	75	95
Gasoline at crude-oil price of $100/bbl	115	135
Cellulosic ethanol	115	105
Biomass-to-liquid fuels without carbon capture and storage	140	130
Biomass-to-liquid fuels with carbon capture and storage	150	115
Coal-to-liquid fuels without carbon capture and storage	65	110
Coal-to-liquid fuels with carbon capture and storage	70	90
Coal-and-biomass-to-liquid fuels without carbon capture and storage	95	120
Coal-and-biomass-to-liquid fuels with carbon capture and storage	110	100

[1] These costs are estimates intended as a basis for comparing gasoline with the different alternative liquid fuels.
[a] Numbers in table are rounded to nearest $5.

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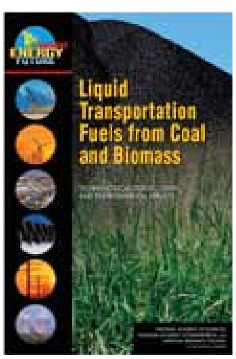
This report brief was prepared by the National Research Council based on the panel's report. The National Academies appointed the above panel of experts, who volunteered their time for this activity. The committee's report is peer-reviewed and signed off by both the committee members and the National Academies.

EXPERT CONSENSUS REPORT



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America's Energy Future: Opportunities, Risks, and Tradeoffs

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