from "Overview and Summary of America's Energy Future: Technology and Transformation", NAS-NRC Report, 2010

ALTERNATIVE LIQUID TRANSPORTATION FUELS

The U.S. transportation sector consumes oil at a rate of about 14 million barrels per day (bbl/d), 9 million of which are used in light-duty vehicles. Total U.S. oil consumption is 20 million bbl/d, about 12 million of which are imported. Although petroleum will continue to be an indispensable transportation fuel for several decades, substantial longer-term options could start to make significant contributions between 2030 and 2035. By producing alternative liquid transportation fuels from domestic resources, the United States could reduce its dependence on imported oil, increase energy security, and reduce greenhouse gas emissions.

Fuels from Coal and Biomass

Coal and biomass are two abundant resources with substantial potential for production of alternative liquid transportation fuels. U.S. recoverable reserves of coal are more than 200 times the 1 billion metric tons currently produced annually, and additional identified resources are much larger. Biomass can be produced continuously, but the natural resources required to support production can limit the amount produced at any given time. Conversion technologies must reach commercial readiness before industry can transform these resources to liquid transportation fuels.

Biomass Supply

Biomass for fuels must be sustainably produced to avoid excessively burdening the ecosystems that support its growth. Because corn grain is used for food, feed, and fiber production and also requires large amounts of fertilizer, the AEF Committee considered corn grain ethanol to be a transition fuel to cellulosic ethanol (using nonfood feedstocks) and other biomass-based liquid fuels (biobutanol and algal biodiesel).

Using today's technology and agricultural practices, farmers could potentially produce about 365 million dry metric tons of cellulosic biomass sustainably per year from dedicated energy crops, agricultural and forestry residues, and municipal solid waste. Production from dedicated fuel crops grown on idle agricultural land in the Conservation Reserve Program would have a minimal impact on U.S. food, feed, and fiber production and the environment. By 2020, the production of biomass could reach 500 million dry metric tons annually.

It is likely that producers will need incentives to grow biofeedstocks that do not compete with other crops and to avoid land-use practices that cause significant net greenhouse gas emissions. To ensure a sustainable biomass supply requires a systematic assessment of the resource base that addresses environmental, public, and economic concerns.

Conversion Technologies

Biochemical conversion and thermochemical conversion can be used to produce liquid fuels from biomass and coal.

Biochemical Conversion

The biochemical conversion of starch from grains to ethanol has already been used commercially. Although production of grain-based ethanol motivated the initial construction of infrastructure, advanced cellulosic biofuels have a much greater potential to reduce oil use and limit CO_2 emissions (Figure 8), and they have a minimal impact on the food supply. Biochemical processes to convert cellulosic biomass into ethanol are in the early stages of commercial development. Improvements in the technologies are expected to reduce the nonfeedstock costs of cellulosic ethanol by about 25 percent by 2020, and 40 percent by 2035.

Because ethanol cannot be transported in oil pipelines, an expanded infrastructure would be required for cellulosic ethanol to reach its full potential. Studies are needed to identify the ethanol infrastructure required and to address the challenges of distributing and integrating this fuel into the U.S. transportation system. Biochemical conversion technologies for creating fuels more compatible with the current distribution infrastructure might also be developed over the next 10–15 years.

With all the necessary conversion and distribution infrastructure in place, 500 million dry metric tons of biomass could be used to produce up to 30 billion gallons of gasoline-equivalent fuels per year (or 2 million bbl/d). However, the actual supply is unlikely to meet this full potential soon. When the production of corn grain ethanol was commercialized, U.S. production capacity grew by 25 percent annually over a 6-year period. Assuming that cellulosic ethanol plants are built at a rate twice that of corn grain ethanol plants, up to 0.5 million bbl/d of gasoline-equivalent cellulosic ethanol could be produced by 2020. By 2035, up to 1.7 million bbl/d could be produced—an amount equal to about 20 percent of

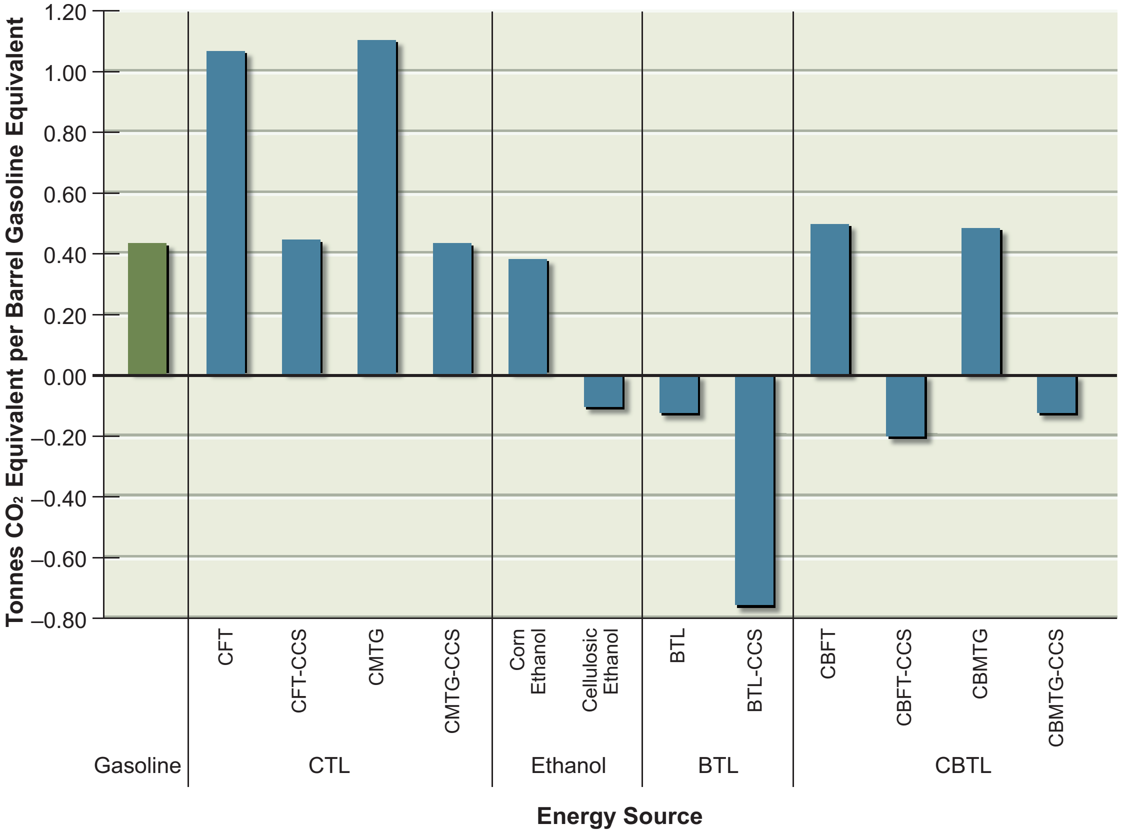

FIGURE 8 *Estimated net life-cycle greenhouse gas emissions for the production, transportation, and use of alternative liquid transportation fuels. An estimate of negative CO_2-equivalent emissions indicates removal of CO_2 from the atmosphere on a net life-cycle basis. The precise value of CO_2 emissions from CBTL depends on the ratio of biomass to coal used. BTL, biomass-to-liquid fuel; CBFT, coal-and-biomass-to-liquid fuel, Fischer Tropsch; CBMTG, coal-and-biomass-to-liquid fuel, methanol-to-gasoline; CBTL, coal-and-biomass-to-liquid fuel; CCS, carbon capture and storage; CFT, coal-to-liquid fuel, Fischer-Tropsch; CMTG, coal-to-liquid fuel, methanol-to-gasoline; CTL, coal-to-liquid fuel.*

the 9 million bbl/d (140 billion gallons per day) of the fuel currently used in light-duty vehicles.

Thermochemical Conversion

Technologies that convert coal into transportation fuels could be used on a commercial level today, but life-cycle emissions of greenhouse gas would be more than twice the CO_2 emissions associated with petroleum-based fuels (see Figure 8).

Fully commercializing this technology requires the use of CCS, which has not been adequately demonstrated on a large scale in the United States. But if CCS is adequately demonstrated, the geologic storage of CO_2 would have a relatively small impact on engineering costs and the efficiency of coal-to-liquid plants.

Liquid fuels produced from thermochemical plants using only biomass feedstocks are more costly than fuels produced from coal. But they can have life-cycle CO_2 emissions that are close to zero without geologic CO_2 storage or that are highly negative with geologic CO_2 storage. However, there must be a significant economic incentive for reducing CO_2 emissions to make such fuels cost competitive.

Co-feeding biomass and coal to produce liquid fuels allows for a larger scale of operation and lower capital costs than would be possible with biomass alone. If 500 million dry metric tons of biomass are combined with coal (60 percent coal and 40 percent biomass on an energy basis), production of 60 billion gallons of gasoline-equivalent fuels per year (4 million bbl/d) would be feasible. That amount represents about 45 percent of the current volume of liquid fuel consumed by light-duty vehicles in the United States. Moreover, co-fed biomass and coal involves fewer life-cycle CO_2 emissions than does coal-to-liquids alone, because the CO_2 emissions associated with coal are countered by the CO_2 uptake by biomass during its growth. Without geologic CO_2 storage, combined coal-and-biomass-to-liquid fuels have life-cycle CO_2 emissions similar to those of gasoline. With geologic CO_2 storage, these fuels have close to zero life-cycle CO_2 emissions.

Whether thermochemical conversion involves coal alone or a combination of coal and biomass, the viability of CO_2 geologic storage is critical to its commercial implementation. If CCS demonstrations are initiated immediately and geologic CO_2 storage is proven viable and safe by 2015, the first commercial thermochemical conversion plants could be operational by 2020.

Given the vast amounts of coal in the United States, the actual supply of coal-to-liquid fuel will be limited by its market penetration rather than by the availability of coal. In 20 years, if two to three coal-to-liquid plants are built each year, up to 3 million bbl/d of gasoline equivalent could be produced annually from about 525 million metric tons of coal. However, this would require a 50 percent increase in coal production, along with the accompanying social, environmental, and economic costs.

Because coal-and-biomass-to-liquid fuel conversion plants are much smaller than those that convert coal and will probably be sited in regions close to coal and biomass supplies, build-out rates will be lower. The AEF Committee estimates that at a 20 percent growth rate, combined coal-and-biomass plants could produce 2.5 million bbl/d of gasoline equivalent by 2035. This production would consume about 270 million dry metric tons (300 million dry tons) of biomass per year—tapping less than the total projected biomass availability—and about 225 million metric tons of coal.

Alternative Liquid Fuels from Coal and Biomass—Costs, Barriers, and Deployment

Using a consistent set of assumptions, the AEF Committee estimated the costs of cellulosic ethanol, coal-to-liquid fuels with and without CO_2 storage, and coal-and-biomass-to-liquid fuels with and without CO_2 storage (Figure 9). These estimates are not predictions of future prices, but they allow comparisons of fuel costs relative to each other. Coal-to-liquid fuels with CCS can be produced at a cost of $70/bbl of gasoline equivalent and are competitive with $75/bbl gasoline. In contrast, fuels produced from biomass without geologic CO_2 storage cost

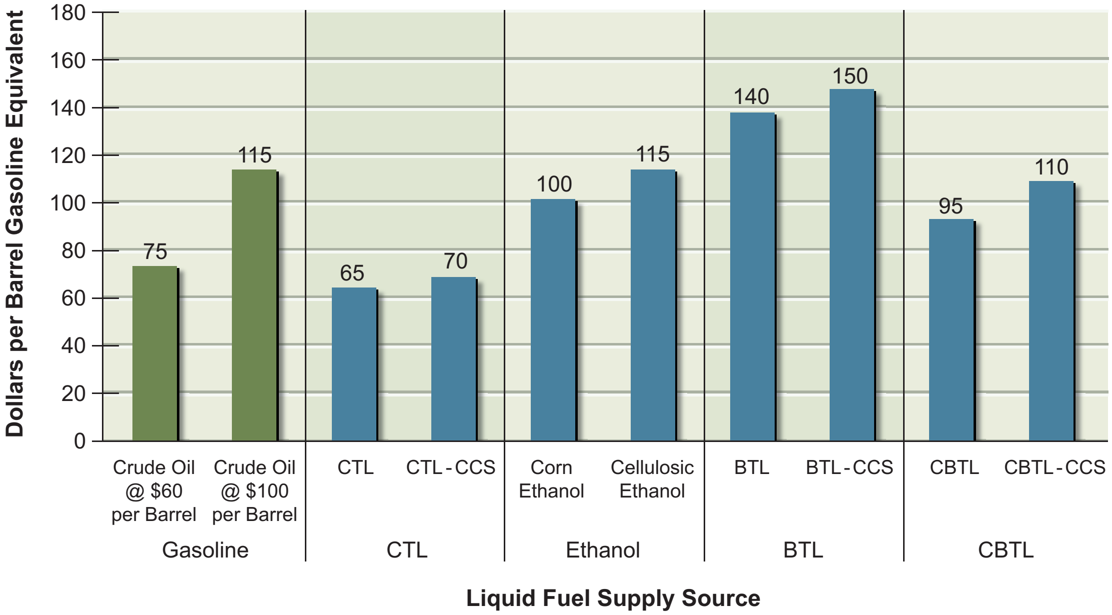

FIGURE 9 *Predicted future prices for a number of liquid fuel feedstocks. Estimated costs are in 2007 dollars and are rounded to the nearest $5. CTL, coal-to-liquid feedstocks; BTL, biomass-to-liquid feedstocks; CBTL, coal-and-biomass-to-liquid feedstocks; CCS, carbon capture and storage.*

$140/bbl for biomass-to-liquid fuels produced by thermochemical conversion. Cellulosic ethanol produced by biochemical conversion costs $115/bbl of gasoline equivalent. The costs of coal-and-biomass-to-liquid fuels with CCS and cellulosic ethanol become more attractive if the price includes a CO_2 price of $50 per metric ton.

Realizing the potential production of each of these fuels will require the permitting and construction of tens to hundreds of conversion plants with the associated transportation and delivery infrastructure. Given the magnitude of U.S. petroleum consumption and its expected growth, a business-as-usual approach for deploying these technologies will be insufficient to significantly reduce oil consumption. The development and demonstration of technology, construction of plant, and implementation of infrastructure require 10–20 years. In addition, investments in alternative fuels must be protected against fluctuations in crude oil prices.

Because geologic CO_2 storage is key to several of these technologies, commercial demonstrations of coal-to-liquid and coal-and-biomass-to-liquid fuel technologies integrated with CCS need to proceed immediately if the United States is to deploy commercial plants by 2020. Moreover, detailed scenarios for biofuel and coal-to-liquid fuel market-penetration rates must be developed to ensure the full utilization of feedstock. In addition, current government and industry programs must be evaluated to determine whether emerging conversion technologies are capable of reducing U.S. oil consumption and CO_2 emissions over the next decade.

Other Transportation Fuels

Technologies for producing transportation fuels from natural gas have been deployed or will be ready for deployment by 2020. But only if large supplies of natural gas are available at acceptable costs will the United States be likely to use natural gas as a feedstock for transportation fuel.

Hydrogen has considerable potential, as discussed in previous National Research Council reports.[17] Hydrogen fuel-cell vehicles could yield large and sustained reductions in U.S. oil consumption and greenhouse gas emissions, but it will take several decades to realize these potential long-term benefits.

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[17]See, for example, National Research Council, *Transitions to Alternative Transportation Technologies: A Focus on Hydrogen,* The National Academies Press, Washington, D.C., 2008.