Producing Liquid Fuels from Coal

Prospects and Policy Issues

James T. Bartis, Frank Camm, David S. Ortiz

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1200 South Hayes Street, Arlington, VA 22202-5050
4570 Fifth Avenue, Suite 600, Pittsburgh, PA 15213-2665
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Summary

During 2007 and 2008, world petroleum prices reached record highs, even after adjusting for inflation. Concerns about current and potentially higher future petroleum costs for imported oil have renewed interest in finding ways to use unconventional fossil-based energy resources to displace petroleum-derived gasoline and diesel fuels. If successful, this course of action would lower prices and reduce transfers of wealth from U.S. oil consumers to foreign oil producers, resulting in economic gains and potential national-security benefits.

Oil shale, tar sands, biomass, and coal can all be used to produce liquid fuels. Of these, coal appears to show the greatest promise, considering both production potential and commercial readiness. It is the world's most abundant fossil fuel. Global, proven recoverable reserves are estimated at one trillion tons (World Energy Council, 2004), which represent nearly three times the energy of the proven reserves of petroleum.

The technology for converting coal to liquid fuels already exists. Commercial coal-to-liquids (CTL) production has been under way in South Africa since the 1950s. Moreover, CTL production appears to be economically feasible at crude oil prices well below the prices seen in 2007 and 2008. However, without effective measures to manage greenhouse-gas emissions, the production and use of coal-derived liquids to displace petroleum-derived transportation fuels could roughly double the rate at which carbon dioxide is released into the atmosphere. In the absence of an effective national program to limit greenhouse-gas emissions, it is unclear whether the federal government would support the development of a CTL industry capable of producing millions of barrels per day (bpd) of liquid fuels.

Research Goals and Methodology

This study analyzed the costs, benefits, and risks of developing a U.S. CTL industry that is capable of producing liquid fuels on a strategically significant scale. Our research approach consisted of the following basic steps:

- To understand commercial development prospects, we examined what is known and not known regarding the economic and technical viability and the environmental performance of commercial-scale CTL production plants.
- To quantify benefits and understand how the large-scale introduction of unconventional fuel sources might affect both the world price of oil and the well-being of oil consumers and producers, we developed a model of the global oil market designed to allow us to compare policy alternatives in the face of inherent uncertainties about how various aspects of the market might behave in the future.
- To investigate how integrated packages of public policy instruments could encourage investment in unconventional-fuel production plants, we reviewed fundamental aspects of contract design and developed a financial model to determine how those incentive packages might affect (1) the rate of return to investors and (2) the net present value of cash flows between such plants and the government.

Finally, our study consistently took into account two overarching policy goals: reducing dependence on imported oil and decreasing greenhouse-gas emissions.

Principal Findings

U.S. Coal Resources Can Support a Domestic Coal-to-Liquids Industry Far into the Future

The United States leads the world with recoverable coal reserves estimated at approximately 270 billion tons. These reserves are broadly distributed, with at least 16 states having sufficient reserves to support commercial CTL production plants (see pp. 9–12). In 2006, the United States mined a record 1.16 billion tons of coal, nearly all of which was used to produce electric power. Dedicating only 15 percent of recoverable coal reserves to CTL production would yield roughly 100 billion barrels of liquid transportation fuels, enough to sustain three million bpd of CTL production for more than 90 years (see pp. 12–13).

Technology for Producing Coal-to-Liquids Fuels Has Advanced in Recent Years

In the United States, interest in CTL fuels has concentrated on two production approaches that begin with coal gasification: the Fischer-Tropsch (FT) and methanol-to-gasoline (MTG) liquefaction methods. The FT method was invented in Germany during the 1920s and is in commercial practice in South Africa. The Mobil Research and Development Corporation invented the MTG approach in the early 1970s. Both approaches involve preparing and feeding coal to a pressurized gasifier to produce *synthesis gas*—the important constituents of which are hydrogen and carbon monoxide. After deep cleaning, processing, and removal of carbon dioxide, the synthesis gas is sent to a catalytic reactor, where it is converted to liquid hydrocarbons. The principal products of an FT CTL plant are exceptionally high-quality diesel and jet fuels that can be sent directly to local fuel distributors (see pp. 20–22). In an MTG CTL plant, the synthesis gas is first converted to methanol. The methanol is then converted to a mix of hydrocarbons that are very similar to those found in raw gasoline. Between 90 and 100 percent of the final liquid yield of an MTG CTL plant is a zero-sulfur automotive gasoline that can be distributed directly from the plant. (See pp. 25–26.)

A favorable attribute of both approaches is that the synthesis gas can be produced from a variety of feeds, including natural gas, biomass, and coal. Although no FT CTL plants have been built in more than 20 years, the FT approach has advanced through the recent and ongoing construction of large commercial plants designed to produce liquids from natural gas that cannot be pipelined to nearby markets (see p. 19). Although no commercial MTG CTL plant has ever been built, we judge the process as ready for initial commercial operations, based on ten years of large-scale operating experience, starting in 1985, when the process was commercially applied to produce gasoline from natural-gas deposits in New Zealand (see pp. 24–25).

Technology for Controlling Carbon Dioxide Emissions Is Advancing

If the entire fuel cycle is taken into account—i.e., oil well or coal mine through production to end use—we estimate that greenhouse-gas emissions from a CTL plant would be about twice those associated with fuels produced from conventional crude oils. Slightly higher values would result from less efficient CTL plants or by comparing with light crude oils. And slightly lower values would result from more energy-efficient CTL plant designs or by comparing with the heavier crude oils that are taking an increasing role in worldwide oil production. Technological advances aimed at significantly improving the energy efficiency and costs of CTL production might be able to reduce plant-site greenhouse-gas emissions by one-fifth—not enough to match those of conventional petroleum (see pp. 31–32). To avoid conflict with growing national and international priorities to reduce global greenhouse-gas emissions, the large-scale development of a CTL industry requires management of plant-site carbon dioxide emissions.

Capturing the carbon dioxide that would be otherwise emitted from a CTL plant is straightforward and relatively inexpensive. CTL plants already remove carbon dioxide from the synthesis gas, so capture simply involves dehydrating and compressing the carbon dioxide so that it is ready for pipeline transport. If 90 percent of plant-site emissions were to be fully captured and then stored, the production and use of fuels produced in early CTL plants should not cause any significant increase or decrease in greenhouse-gas emissions as compared to fuels derived from conventional light crude oils. For nearly full capture of plant-site carbon dioxide emissions, we estimate that product costs would increase by less than $5.00 per barrel. (See pp. 32–33.)

There are two principal methods for disposing of the captured carbon dioxide. The first is to use the captured carbon dioxide to enhance oil recovery in partially depleted oil reservoirs using a well-known method called carbon dioxide flooding. The advantage of this method is that at least two barrels of additional conventional petroleum will be produced for each barrel of CTL fuel. Moreover, CTL plant operators might be able to sell their captured carbon dioxide at a profit above their costs of capture and transport. This enhanced oil recovery method is limited to the first 0.5 million bpd to one million bpd of CTL production capacity built within a few hundred miles of appropriate oil reservoirs. A pioneer field test and demonstration of carbon dioxide sequestration through enhanced oil recovery has been under way since 2000 at the Weyburn oil field in Saskatchewan. (See pp. 34–36.)

The second method is to sequester carbon dioxide in various types of geologic formations. The latter approach is broadly viewed as the critical technology that will allow continued coal use for power generation while reducing greenhouse-gas emissions. Two major demonstrations of carbon dioxide sequestration in geological formations are under way outside the United States. Results to date have been promising (see p. 36). However, the development of a commercial sequestration capability within the United States requires addressing important knowledge gaps associated with site selection and preparation, predicting long-term retention, and monitoring and modeling the fate of the sequestered carbon dioxide. There are also important legal and public acceptance issues that must be addressed. Toward this end, U.S. Department of Energy plans to conduct at least eight moderate- to large-scale demonstrations over the next five years. (See pp. 74–75.)

A Combination of Coal and Biomass to Produce Liquid Fuels May Be a Preferred Solution

Biomass can be converted to a synthesis gas that FT reactors can use to produce fuels identical to those derived from coal or natural gas. The biomass-to-liquids (BTL) approach results in low total-fuel-cycle release of greenhouse gases because the emissions at the plant are balanced by the carbon dioxide absorbed from the atmosphere during the growth cycles of the biomass crops.

A promising direction for alternative-fuel production would be an integrated FT or MTG plant designed to accept both biomass and coal. A coal- and biomass-to-liquids (CBTL) approach can ameliorate problems created by the use of biomass alone—i.e., the logistics of biomass delivery that limit production levels and the annual climate variations that can cause major fluctuations in the quantity of biomass available to a BTL-only plant. A CBTL plant can be substantially larger than a BTL plant, and its large-scale economies would enable it to operate at a significantly lower cost. The marginal benefits of adding a coal feedstock to a biomass feedstock may more than offset the marginal costs associated with sequestering the increased carbon dioxide emissions that result. (See pp. 37–38.)

Given information that is currently available and considering the entire fuel cycle, we conclude that CBTL fuels can be produced *and used* at greenhouse-gas emission levels that are well below those associated with the production and use of conventional petroleum fuels. For example, with 90-percent sequestration of plant-site emissions, we estimate that a 55/45 coal/dry biomass mix (based on energy input) will result in CBTL fuel production with zero net greenhouse-gas emissions considering the full fuel cycle from coal mining and biomass cultivation to end use. Likewise, a 75/25 coal/dry biomass mix would yield roughly a 55- to 65-percent reduction in greenhouse-gas emissions, as compared to conventional petroleum fuels. (See pp. 39–40.)

Developing a Coal-to-Liquids Industry in the United States Will Be Expensive, but Significant Production Is Possible by 2030

CTL plants are capital intensive. For moderate to large CTL plants, we estimate capital investment costs of $100,000 to $125,000 (in January 2007 dollars) per barrel of product. Considering operating and coal costs, we estimate that, for CTL fuels to be competitive, the selling price for crude oil (using a West Texas Intermediate benchmark) must be between $55 and $65 per barrel. These prices include the costs of capturing about 90 percent of carbon dioxide emissions but do not assume any income or outlays associated with sequestering that carbon dioxide. Our cost estimates are highly uncertain, since they are based on low-definition engineering designs. Also, our estimates apply only to the first generation of CTL plants built in the United States. We expect the cost of building and operating new plants to drop significantly once early commercial plants begin production and experience-based learning is under way. (See pp. 42–45.)

Considering the importance of experience-based learning, the need to avoid cost-factor escalation, and the time required to bring carbon capture and sequestration to full commercial viability, we estimate that, by 2020, the production level of CTL fuels can be no more than 500,000 bpd. Post-2020 capacity buildup could be rapid, with U.S.-based CTL production potentially in the range of three million bpd by 2030. (See pp. 46–48)

Coal-to-Liquids Development Offers Strategic National Benefits

The United States now consumes about 20 million barrels of liquid fuels per day. This level of use is projected to rise slightly over the next 25 years. If a domestic CTL industry is developed and operates on a profitable basis, the United States would benefit from the economic profits generated by that industry. CTL production would benefit oil consumers by reducing the world price of oil, and this reduction in world oil prices would yield national security benefits. Having a domestic CTL industry in place would also increase the resiliency of the petroleum supply chain in the United States and provide enhanced employment opportunities, especially in states holding large reserves of coal. To examine these benefits, we assumed a hypothetical domestic CTL production rate of three million bpd by 2030.

Economic Profits. If a large CTL industry develops by 2030, we anticipate that post-production learning will result in significantly lower CTL production costs. At world crude oil prices of between $60 and $100 per barrel (2007 dollars), direct economic profits of between $20 billion and $70 billion per year are likely. Through various taxes, a portion of these profits, between $7 billion and $25 billion per year, would go to federal, state, and local governments and thereby broadly benefit the public. (See p. 60.)

Reduced World Oil Prices. Lower world oil prices will likely be the result of any increase in liquid-fuel production, either domestically or abroad, from unconventional resources. Based on examining a broad range of potential responses by the Organization of the Petroleum Exporting Countries (OPEC), we anticipate that world oil prices will drop by between 0.6 and 1.6 percent for each million barrels of unconventional-fuel production that would not otherwise be on the market. Further, this price decrease should be close to linear for unconventional-fuel additions of up to ten million bpd. Unconventional-fuel additions in this range are possible, but only by considering potential 2030 production levels from domestic oil shale and biofuel resources as well as both domestic and international production of coal-derived liquid fuels. Looking only at coal-derived liquids, it is possible that total world production could reach about six million bpd by 2030. (See p. 62.)

By reducing oil prices, consumer and business users of oil in the United States (and elsewhere) would benefit. From a national perspective, reduced profits to domestic petroleum producers would offset a portion of these benefits. Considering both oil users and producers, we estimate a net national benefit at between $2 billion and $8 billion per year for each million barrels per day of unconventional-fuel production (see pp. 63–65). Or equivalently, by lowering world oil prices, each barrel of CTL benefits the overall economy by between $6 and $24. The estimate of these benefits reflects our judgment that long-term oil prices will range between $60 and $100 per barrel with a range of market responses to the added supplies of liquid fuels. These benefits accrue to the nation as a whole, as opposed to the individual firms investing in CTL production. These analytic results support our finding that, to counter efforts of certain foreign oil suppliers to control prices by restraining production, the United States should be willing to spend $6 to $24 per barrel more than market prices for substitutes that reduce oil demand. (See pp. 65–66.)

National Security Benefits. The national security benefits of having a domestic CTL industry in place flow primarily from the anticipated reduction in world oil prices and thereby a reduction in revenues to oil-exporting countries. To the extent that this reduction in prices and revenues helps to limit behavior counter to U.S. national interests, there would be a benefit beyond the economic gain in reduced oil prices just noted. However, a three million bpd domestic industry would yield between a 3- and 8-percent reduction in the revenues of oil exporters. This small change in revenue would unlikely change the political dynamics in oil-producing nations unfriendly to the United States. With regard to enhancing national security, the principal contribution of CTL production would be its role in a portfolio of measures to increase liquid-fuel supplies and reduce oil demand. For example, global unconventional-fuel production of ten million bpd by 2030 could reduce OPEC annual revenues by up to a few hundred billion dollars. (See pp. 66–67.)

Environmental Impacts of a Large-Scale Coal-to-Liquids Industry Will Need to Be Addressed

Under current federal and state environmental, reclamation, and safety laws and regulations, the land, air, water, and ecological impacts of coal mining are mitigated to varying degrees. However, residual impacts of mining activities can still adversely change the landscape, the local ecology, and water quality. CTL development at a scale of three million bpd by 2030 would require about 550 million tons of coal production annually. Depending on whether and how greenhouse-gas emissions are controlled during this period, the net change in coal production between now and 2030 resulting from a gradual buildup of demand from a CTL industry could range from minimal up to an increase of about 50 percent above current levels. If large-scale development of a CTL industry is accompanied by a significant net increase in coal production or a significant change in extraction technologies, a review of the legislation and regulations governing mine safety, environmental protection, and reclamation may be appropriate. Such a review would assess the potential environmental and safety impacts of increased mining activity and evaluate options for reducing such impacts. More immediately, there is a clear need for research directed at mitigating the known and anticipated environmental impacts and reducing the work hazards associated with coal mining. (See pp. 78–79.)

Because of advances in environmental control technologies, CTL plant operations should not pose significant threats to air and water quality. There will be some locations where CTL development will be limited or prohibited, but, given the geographic diversity of the domestic coal resource base, large-scale development is unlikely to be impaired by a lack of suitable plant sites. (See pp. 76–78.)

It is difficult to predict how future, more technically mature CTL plants would manage water supply and consumption, especially in arid regions of Montana and Wyoming that hold enormous coal resources. Although design options are available to reduce water use in CTL plants, water consumption may be a limiting factor in locating multiple CTL plants in arid areas. (See pp. 79–81.)

Uncertainties Are Impeding Private Investment

Although numerous private firms have expressed considerable interest in CTL development in the United States, actual investment levels appear to be very limited. Discussions with proponents of CTL development indicate that three major uncertainties are impeding private investments:

- uncertainty about CTL production costs
- uncertainty regarding how and whether to control greenhouse-gas emissions
- uncertainty regarding the future course of world crude oil prices.

Of these three factors, the greatest impediment appears to be the uncertainty regarding future world oil prices. If investors would be confident that average long-term crude prices would remain consistently above $100 per barrel, no government policy would be required to support the emergence of a successful commercial CTL industry. But with the possibility that oil prices could fall significantly in the near to medium term, the financial risk surrounding initial CTL investments is appreciable. Given the extremely large capital investment required for even a moderate-size CTL plant, very few firms have the financial resources to take on this risk. (See p. 82.)

To Spur Early Coal-to-Liquids Production Experience, Government Incentives Should Target Prevailing Uncertainties

The firms most capable of overseeing the design, construction, and operation of CTL plants are the major petrochemical companies, which have the technical capabilities and the financial and management experience necessary for investing in multibillion-dollar megaprojects. They are also best suited to exploit the learning that would accompany early production experience. Yet none has announced interest in building first-of-a-kind CTL plants in the United States. (See p. 81.)

How can the federal government encourage the early participation of these and other capable companies in the CTL enterprise? The answer lies in the creation of incentive packages that cost-effectively transfer a portion of investment risks to the federal government.

We found that a balanced package of a price floor, an investment incentive, and an income-sharing agreement is well suited to do this. The investment incentive, such as a tax credit, is a cost-effective way to raise the private, after-tax internal rate of return in any future. A price floor provides protection in futures in which oil prices are especially low. And an income-sharing agreement compensates the government for its costs and risk assumption by providing payments to the government in futures in which oil prices turn out to be high (see pp. 92–96). Because the most desirable form of a balanced package depends on expectations about project costs, the government should wait to finalize its design until it has the best information on project costs that is available without actually initiating the project. Specifically, an incentive agreement should not be finalized until both government and investors have the benefit of improved project-cost and performance information that would be provided at the completion of a front-end engineering design. (See pp. 96–97.)

Loan guarantees can strongly encourage private investment. However, they encourage investors to pursue early CTL production experience only by shifting real default risk from private lenders to the government. By their very nature, the more powerful their effect on private participation, the higher the expected cost of these loan guarantees to the government. In addition, loan guarantees encourage private investors to seek higher debt shares that increase the risk of default and thus increase the government's expected cost for providing the guarantee. The government should take great care in employing loan guarantees to promote early CTL production experience. It should fully recognize both the costs that such guarantees could impose on taxpayers and the extent to which government oversight of guaranteed loans can be effective in limiting those costs. (See pp. 98–100.)

Overall Prospects

The prospects for developing an economically viable CTL industry in the United States are promising, although important uncertainties exist. Both FT and MTG CTL technologies are ready for initial commercial applications in the United States; production costs appear competitive at world oil prices well below current levels; and proven coal reserves in the United States are adequate to support a large CTL industry operating over the next 100 years.

Opportunities to control greenhouse-gas emissions from CTL plants are currently limited to enhanced oil recovery. But the prospects for successful development of large-scale geologic sequestration are promising, as is the development of technology that would allow the combined use of coal and biomass in production plants based on either the FT or MTG approaches. Within a few years, CTL plants could begin to alleviate growing global dependence on price-controlled conventional petroleum at greenhouse-gas emission levels comparable to those associated with conventional-petroleum products. Within a few more years, we anticipate that approaches would be available that allow the combined use of coal and biomass to produce liquid fuels so that total-fuel-cycle greenhouse-gas emission levels are significantly below those associated with conventional petroleum. (See pp. 46–48.) Most importantly, the low cost of capturing carbon dioxide at CTL plants implies that any measure that will induce reductions in greenhouse-gas emissions from coal-fired power plants will also be more than adequate to promote deep removal at CTL or CBTL plants (see p. 74).

Key Recommendations

With regard to the development of coal-derived liquids or other unconventional-fuel sources, the government could place itself anywhere along a continuum of policy positions. At one extreme is the hands-off position, which favors the free operation of the market and private decisionmaking unfettered by government interference. Support would be available for long-term research and development directed at significantly improving the economic and environmental performance of CTL production but not for near-term technology development or demonstration activities. (See pp. 106–107.)

At the other extreme, the government could choose specific alternatives to conventional oil production today and initiate large-scale federal support of these alternatives to ensure successful development of a new industry that can displace conventional oil production in the world market over the long term. (See pp. 107–109.)

Our research supports a policy strategy that falls between these extremes. This *insurance-policy* approach recognizes prevailing uncertainties and emphasizes future capabilities. The five elements of the insurance strategy are as follows:

- Cost-share a few site-specific front-end engineering design studies of CTL and dual-feedstock production plants to establish costs, risks, potential economic performance, and environmental impacts. (See p. 109.)
- Use federal incentives to ensure early commercial production experience with a limited number of first-of-a-kind CTL or dual-feedstock plants to establish performance and provide a foundation for post-production learning. (See p. 110.)
- Conduct multiple large-scale, long-term demonstrations of the sequestration of carbon dioxide generated at electricity-generation or CTL production plants (or both) at a scale and duration beyond that currently planned for in the U.S. Department of Energy's Regional Carbon Sequestration Partnerships. (See p. 111.)
- Undertake the research, development, and testing required to establish the technical viability of using a combination of biomass and coal for liquid production. (See p. 112.)
- Broaden and expand the federal portfolio directed at long-term, high-payoff research relevant to transportation fuel production. (See p. 112.)

The principal value of federal efforts to implement an insurance strategy is to accelerate CTL commercial development above what it would otherwise be. A five-year acceleration of development of a strategically significant CTL industry in the United States could result in national economic benefits with a present value of about $100 billion. (See p. 117.)

Air Force Options for Coal-to-Liquids Industrial Development

Should the Air Force choose to play an active role in promoting the development of a domestic CTL industry, it should do so recognizing that the primary potential benefits of success would accrue more to the nation as a whole than to the Air Force as an institution. (See p. 113.)

The U.S. Air Force's 2016 goal of being prepared to acquire alternative fuel blends to meet 50 percent of its domestic aviation fuel requirements is consistent with an overall federal insurance-policy strategy. The amount of FT CTL capacity required to meet the potential fuel purchases associated with the U.S. Air Force goal (50,000–80,000 bpd) falls within the overall production requirements of an insurance strategy, namely, obtaining early production experience from a limited number of CTL plants. (See p. 106.)

The U.S. Air Force might consider using fuel purchase contracts to promote early CTL production experience. To be more cost-effective, such contracts should be part of a broader federal package of investment incentives, such as investment tax credits, accelerated depreciation, and loan guarantees. These additional instruments could allow lower price floors and lessen the probability of out-year government purchases at above-market prices. (See pp. 92–93.)

Another option that the U.S. Air Force and the U.S. Department of Defense (DoD) might consider is to use DoD's contracting authority to establish a guaranteed or fixed price over a significant portion of the operating life of a CTL plant. Such agreements are rarely observed in contracts between private parties. Our findings indicate that a long-term price guarantee should be avoided because it is among the least cost-effective approaches available to the federal government. (See p. 114.)

Currently, DoD contracts are limited by law (10 USC 2306b) to a duration of no more than five years, with options for an additional five years, and a total amount of less than $500 million, unless specifically authorized otherwise by Congress. As such, DoD's ability to provide incentives for private investments in early CTL plants is severely limited. New legislative authority is needed if DoD and the U.S. Air Force wish to overcome the limitations imposed on contract duration and size. (See p. 114.)