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Liquid Fuels from Coal, Natural Gas, and Biomass: Background and Policy

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Liquid Fuels from Coal, Natural Gas, and Biomass: Background and Policy

Summary

As the price of gasoline approaches the 1981 record high (adjusted for inflation), liquid transportation fuels synthesized from coal, natural gas, and biomass are proposed as one solution to reducing dependency on imported petroleum and strained refinery capacity. The technology to do so developed from processes that directly and indirectly convert coal into liquid fuel. Congress now faces decisions on whether, and to what extent, it should support such a solution.

Lacking domestic petroleum resources, but abundant in coal, Germany built synthetic fuel plants during World War II that employed the Bergius coal hydrogenation process (direct liquefaction), and Fischer-Tropsch synthesis (indirect). The United States attempted to capitalize on the German experience after World War II. Despite considerable investment in synthetic fuel research and development, the United States cut support for commercialization when crude oil prices dropped and supplies stabilized in the mid-1980s. Since then, several synthetic fuels plants have been constructed around the world that convert coal, natural gas, or biomass to liquid fuels using the Fischer-Tropsch process. Several private ventures in the United States are now studying the feasibility of constructing Fischer-Tropsch synthetic fuel plants based on coal, natural gas, and biomass.

Proposals to expand the use of coal to synthesize transportation fuels have generated much opposition, particularly because the carbon dioxide (CO_2) produced in the Fischer-Tropsch process is a greenhouse gas associated with global warming. Also, opponents claim that coal-based synthesis, in particular, is inefficient and thus prohibitively expensive. Proponents counter that Fischer-Tropsch technology provides a means of capturing carbon dioxide for geological sequestration (though a promising solution, sequestration remains unproven on an industrial scale) and that it appears economically viable in a sustained crude oil price range above $40 to $45 per barrel.

Fischer-Tropsch synthesis is well suited to producing middle-distillate range fuels like diesel and jet. The diesel produced is superior to conventionally refined diesel in terms of higher cetane-number and low sulfur content. Overall, middle distillate fuels represent a limited portion of U.S. refinery production, which is primarily driven by the demand for gasoline. A synthetic fuels industry (whether coal, natural gas, or biomass based) that would rival or supplant petroleum refining would require a major shift in transportation fuel demand. Coal-to-liquids would also compete for the same resources needed for electric power generation, and the rail capacity currently supporting their demand.

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Introduction

High crude oil and gasoline prices, as well as strained refining capacity, have stimulated congressional and private sector interest in producing synthetic fuels from alternative resources. Current conditions almost reprise the era of the 1970s, when energy security concerns generated by oil embargoes stimulated federal spending in synthetic fuels. Despite considerable investment, federal support was withdrawn after supply concerns eased in the 1980s. The currently favored approach to producing synthetic fuels — the Fischer-Tropsch process — uses carbon monoxide and hydrogen from combustion of fossil or organically derived feedstocks. The process and has been commercially demonstrated internationally and in pilot plant demonstration in the United States. Jet fuel from a gas-to-liquids pilot plant has already been certified for use by the United States Air Force, at least one coal-to-liquids enterprise is in the planning phase, and others are being studied.

As an abundant resource in the United States, coal has long been exploited as a solid fossil fuel. As oil and natural gas supplanted coal throughout the last two centuries, technologies developed to convert coal into other fuels. Proponents of expanding the use of coal, such as the Coal-to-Liquids Coalition, argue that the United States should alleviate its dependence on imported petroleum and strained refinery capacity by converting coal to transportation fuels. Opponents, such as the Natural Resource Defense Council, argue that "considerable economic, social, and environmental drawbacks of coal-derived oil preclude it from being a sound option to move America beyond oil."[1]

Fischer-Tropsch synthesis, particularly coal based, poses several challenges. It is criticized as inefficient and thus costly. The byproduct of synthesis is carbon dioxide, a greenhouse gas associated with global warming. The use of coal and natural gas as feedstocks would compete with electric power generation — over 50% of domestic electricity generation is coal based — and gas is widely used as fuel for peak generating plants and domestic heating. The fuels produced, primarily diesel and jet, would not substitute widely for the preferred transportation fuel in the United States — gasoline. Similarly, using biomass as feedstock would compete with cellulosic ethanol production, as it is now envisioned.

Some of Fischer-Tropsch technology's comparative merits and drawbacks are presented in **Table 1**.

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[1] NRDC, *Why Liquid Coal Is Not a Viable Option to Move America Beyond Oil*, February 2007, [http://www.nrdc.org/globalwarming/solutions].

Table 1. Comparative Merits and Drawbacks of Fischer-Tropsch

Abundant coal reserves available as feedstock.	↔	Competition for coal in electric power generation.
Coal-to-liquids generates significant CO_2.	↔	CO_2 separation during synthesis gas production makes capture feasible.
Produces ultra-low sulfur, high cetane diesel.	↔	Produces low-octane gasoline.
Low efficiency in converting coal to liquid.	↔	Waste heat available for electricity co-generation.
May have lower operating expenses than direct coal liquefaction.	↔	Conceptually more complex than direct liquefaction approach and higher in capital investment cost.
Deep geologic sequestration offers solution for CO_2 emissions.	↔	CO_2 sequestration not yet demonstrated on a large industrial scale.
Gas-to-liquids offers reduced CO_2 generation.	↔	Competition with domestic natural gas use.
Biomass-to-liquids offers zero carbon footprint.	↔	Competition with biomass for cellulosic ethanol production.

This report begins with a review of the synthetic fuels technology, which evolved from direct and indirect conversion of coal to liquid fuels. Attention is given to Fischer-Tropsch synthesis, as this represents the currently favored and commercially demonstrated technology. Past and currently operating synthetic fuel plants are described with comparisons of their relative efficiency. Finally, policy history and policy considerations are presented, along with bills recently introduced in Congress pertaining to coal-to-liquids research and industrial development.

Synthetic Fuel Technology

Synthetic fuels can be traced to the mid-19th century processes of making coal oil, coal gas, and the later manufacture of town gas. Coal oil was introduced as a substitute for more costly illuminating fuels, particularly premium whale oil. Originally sold under the trade name of kerosene, coal oil was in turn replaced by a similarly named, but cleaner burning, crude oil distillate. Coal gas also served as an early illuminating fuel, but burned with a yellow flame of poor quality. A process for improving coal gas was devised by passing it over a water bath. This was improved on further by passing steam through incandescent beds of charred coal (coke) to produce "water gas," a mixture of carbon monoxide (CO) and hydrogen (H_2) gases. Water gas, more commonly known as "town gas," produced a hotter, cleaner burning blue flame than coal gas. Town gas illumination eventually gave way to electric lighting, but it continued as an industrial heating fuel into the 1950s, when natural gas became more widely available.

Petroleum was considered a scarce commodity in the early 20th century, more suited to making illuminating fuel. Gasoline was considered too volatile a petroleum distillate and did not find widespread use until transportation modes shifted from horse and buggy to the automobile. With the growth of the automobile and aircraft industries, the demand for gasoline and thus petroleum increased. In Germany, researchers looked to coal for a petroleum substitute. The carbon monoxide and hydrogen produced in manufacturing town gas provided an essential first step in synthesizing liquid fuel from coal. The two processes developed, direct and indirect coal-to-liquids conversion, provided complementary means of producing a range of fuels and chemicals. Each offered advantages and disadvantages.

Bergius Direct Liquefaction

In the early 20th century, German researcher Friedrich Bergius developed a process to directly liquefy coal under high temperature and pressure (coal begins to dissolve above 250 degrees centigrade), and then "crack" the coal molecules into smaller molecules using hydrogen.[2] Bergius termed the process "coal hydrogenation," which was later referred to as "direct liquefaction." Coal also served as the source of hydrogen. (In modern refining, hydrogen is manufactured from methane gas (CH_4) decomposed by a process termed "steam reforming." Modern refineries rely extensively on hydrogen for hydrocracking and hydrotreating.)

Fischer-Tropsch Synthesis

As Bergius was perfecting direct liquefaction, German scientists Franz Fischer and Hans Tropsch were developing a means of indirectly converting coal into a liquid fuel. In 1926, Fischer and Tropsch reported a process to synthesize hydrocarbons using an iron or cobalt catalyst to react hydrogen (H_2) with carbon monoxide (CO) under lower temperatures and pressures than Bergius' process.

Essentially, Fischer-Tropsch (F-T) synthesizes straight molecular chains of carbon and hydrogen, whereas Bergius breaks heavier-weight hydrocarbons into lighter-weight, shorter-length molecules. Both processes involve hydrogen. Fischer-Tropsch synthesis, however, relies on carbon monoxide's potential for exchanging oxygen with hydrogen in the presence of a catalyst. As in the manufacture of water gas, coal is burned to produce the carbon monoxide and steam reacting with hot coal disassociates to produce hydrogen, as shown in the following "water gas shift" equations:[3]

$$C + H_2O \rightarrow CO + H_2 \text{ and } CO + H_2O \rightarrow CO_2 + H_2$$

The CO_2 byproduct of these reactions can be scrubbed from the "syngas" stream before it is introduced to the synthesis reactor. This provides the opportunity to capture CO_2 for sequestration as discussed below.

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[2] A.C. Feldner, Department of Commerce Bureau of Mines, *Recent Developments in the Production of Motor Fuel from Coal*, Information Circular No. 6075, 1928.

[3] Robert Bernard Anderson, *Fischer-Tropsch Synthesis*, Academic Press Inc., 1984.

In the following simplification, Fischer-Tropsch synthesis occurs through two simultaneous reactions promoted by the contact of CO and H_2 with a catalyst:

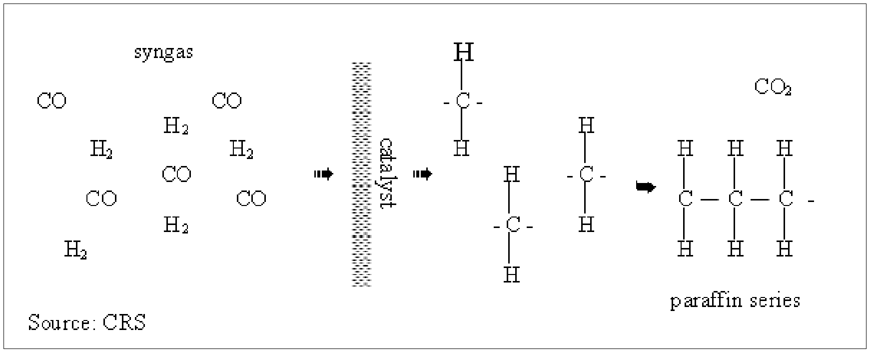
$$2H_2 + CO \rightarrow -CH_2- + H_2O \text{ and } CO + H_2O \rightarrow CO_2 + H_2$$

which can be simplified as:

$$2CO + H_2 \rightarrow -CH_2- + CO_2.$$

As shown conceptually in **Figure 1**, CO and H_2 (syngas) react on the catalyst surface to form $-CH_2-$ that links up to build longer-chain hydrocarbons. As discussed later, these hydrocarbons substitute for conventional middle-distillate fuels.

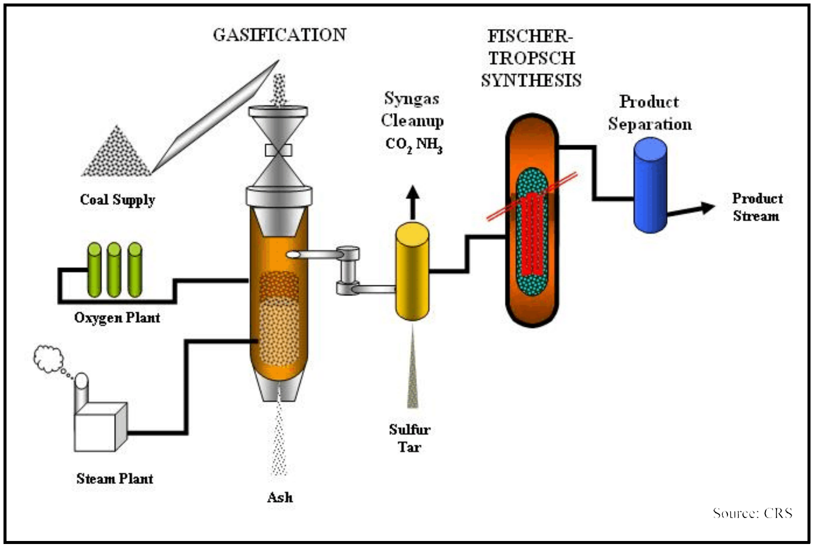
Figure 1. Fischer-Tropsch Synthesis



Source: CRS

A conceptual Fischer-Tropsch plant is shown in **Figure 2**. The slate of products synthesized can be adjusted by varying the temperature, pressure, and duration of reaction. F-T synthesis ideally produces straight-chain hydrocarbons in the paraffin series (also referred to as alkanes).

Figure 2. Conceptual Fischer-Tropsch Plant



Source: CRS

Paraffins are characterized as having carbon atoms attached by single bonds, and remaining bonds saturated with hydrogen. The paraffin series ranges from the methane (CH_4 — the principle component of natural gas) through the gasoline boiling range of C5-C10, the middle-distillate range fuels of C11-C18 (kerosene, jet, and diesel), and longer chain waxes.[4]

Comparing Fischer-Tropsch Products to Conventional Petroleum Distillates

Conventionally refined gasoline, diesel, and jet fuels are complex mixtures of hydrocarbons that include paraffins, naphthenes, and aromatics (which give diesel fuel its unique odor).[5] F-T synthesized fuels, by comparison, are composed primarily of paraffins.

Refining begins in the atmospheric distillation tower, where the "straight-run" petroleum fractions in the boiling ranges of gasoline, naphtha, kerosene, diesel and jet fuel condense and separate. Heavier fractions are cracked with catalysts and hydrogen to produce more gasoline range (C5+) blending stock, and low-octane paraffins are converted into high-octane aromatics (octane is discussed below). Other processes such as alkylation produce branched chain hydrocarbons in the gasoline range. Diesel and jet fuel are formulated by blending straight-run cut distillates with cracked stock (heavier fractions) to meet standardized specifications developed by the American Society for Testing and Materials (ASTM International) and the Environmental Protection Agency (EPA). These include octane and cetane number, sulfur content, and exhaust emissions.

The fuel specifications most familiar to motorists are "octane" and "cetane" numbers. In the case of gasoline, the octane-rating refers to the property of resisting spontaneous ignition. In contrast, diesel fuel is rated by its relative ease of ignition under compression (a desired property). This may seem a paradox — gasoline should resist ignition and diesel should ignite easily. As gasoline is more volatile than diesel, it is desirable that it not ignite before the spark plug fires.

Octane

Higher octane-number fuels better resist engine "knock" — the sound caused by fuel prematurely igniting during compression. In early gasoline research, the least knock resulted from using iso-octane, which arbitrarily received a rating of 100.[6] Iso-octane refers to a branched "isomer" in the paraffin series having eight carbons

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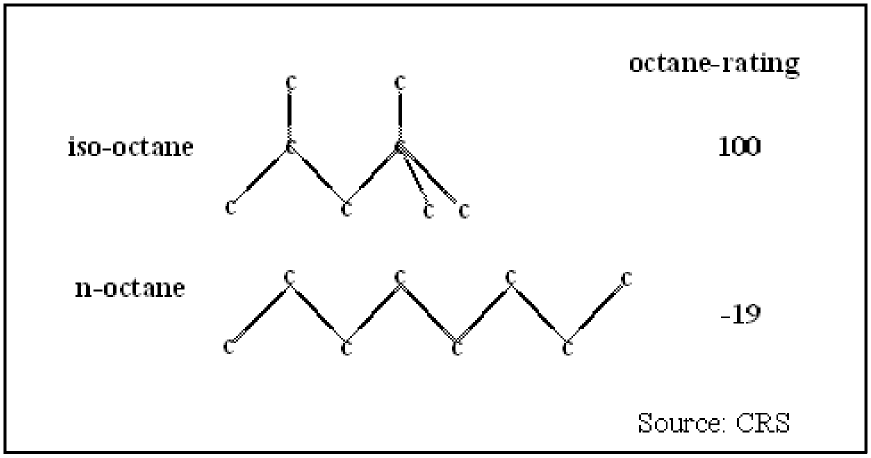
[4] The length of the carbon chain is abbreviated. For example a paraffin consisting of six carbons would be written as C6.

[5] James H. Gary and Glenn E. Handwerk, *Refining Petroleum — Technology and Economics, 4th Ed.*, Marcel Dekker, Inc., 2001.

[6] John M. Hunt, *Petroleum Geochemistry and Geology*, W. H. Freeman and Co., 1979. p. 51 .

(C_8H_{18}).[7] The straight-chain isomer in this series, n-octane, has a rating -19. These isomers of paraffin are shown in **Figure 3**. Fischer-Tropsch synthesis produces primarily straight-chain paraffins, thus any gasoline produced is low in octane rating.

Figure 3. Iso-octane vs N-octane



Source: CRS

Modern formulated gasolines range in octane from 87 to 93, achieved by blending various petroleum distillates, reforming gasoline-range hydrocarbons, and adding oxygenates such as MTBE or ethanol to boost octane-number. Branched paraffin series like iso-octane can not be directly produced in Fischer-Tropsch synthesis. Consequently, when Fisher-Tropsch synthesis has been used to produce gasoline, it has been blended with conventionally refined petroleum to achieve the desired octane-number.

Cetane

The standard for diesel fuel rates the ease of which auto-ignition occurs during compression in the engine cylinder, thus eliminating the need for a spark plug. The number 100 was assigned to "cetane," the more common name for n-hexadecane. Cetane's chemical formula is often written as $C_{16}H_{34}$ to represent a straight-chain hydrocarbon in the paraffin series. It consists of 16 carbon atoms with three hydrogen atoms bonded to the two end carbons, and two hydrogens bonded to each of the middle carbons. In other words, the benchmark for rating diesel fuel is a paraffin — the hydrocarbon the Fischer-Tropsch synthesis is best suited to making.

Diesel fuel cetane-numbers range from 40 to 45, and as high as 55 in Europe, where high-speed diesel engines are prevalent in light-duty passenger vehicles. The cetane-number for F-T synthesized diesel can be as high as 70. In tests conducted by the National Renewable Energy Laboratory (NREL) Fischer-Tropsch diesel fuel had

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[7] Or more correctly 2,2,4-trimethylpentane.

a cetane-number greater than 74.[8] The diesel fuel was supplied by Shell Oil Company's gas-to-liquids plant in Bintulu, Malaysia.

Sulfur

As now regulated by the EPA (40 C.F.R. 80.520) diesel fuel must contain less than 15 parts-per-million (ppm) sulfur — referred to as ultra-low-sulfur diesel (ULSD). Conventionally refined aviation jet fuel may have a sulfur content as high as 3,000 ppm. However, as it has been used in blending winter diesel fuel to lower the gel point, it has had a practical limit of 500 ppm (the previous EPA limit for diesel). It is uncertain whether EPA may promulgate future rules on jet fuel sulfur content, thus limiting its use in blending winter ULSD. Fischer-Tropsch diesel fuel contains virtually no sulfur, as it must be removed before the synthesis reaction to avoid poisoning the catalysts used in the reactor. Despite its detrimental environmental effects, sulfur contributes to the "lubricity" of fuel. Under reduced sulfur, engines wear out sooner. Fuel can be blended with additives to make up for the loss of sulfur lubricity and engines can be manufactured from tougher materials, as has been the case in the EPA mandated transition from low-sulfur diesel (500 ppm) to ultra-low-sulfur diesel (15 ppm).

Exhaust Emissions

Diesel engines characteristically emit lower amounts of carbon monoxide (CO) and carbon dioxide (CO_2) than gasoline engines, but they emit higher amounts of nitrogen oxides (NOx) and particulate matter (PM). NOx is the primary cause of ground-level ozone pollution (smog) and presents a greater problem, technically, to reduce in diesel engines than PM. The CO, NOx, and PM emissions for gasoline and diesel engines are regulated by the 1990 Clean Air Act amendments (42 U.S.C. 7401-7671q). In emissions testing performed by the National Renewable Energy Laboratory (NREL), trucks using "neat" Fischer-Tropsch diesel fuel emitted about 12% lower NOx and 24% lower PM compared to trucks using conventionally refined diesel fuel (meeting California No. 2 diesel standards).[9]

Synthetic Fuel Plants

The following discussion summarizes industrial progress in synthetic fuels. As a means of comparing plant efficiencies (where possible), the energy in Btu contained in the feedstock (coal, gas, biomass) consumed is compared to the energy in the product produced.[10] Greenhouse gas emissions, primarily carbon dioxide, are also

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[8] P. Norton, K. Vertin and B. Bailey (NREL); N. N. Clark and D. W. Lyons (West Virginia Univ.); S. Goguen and J. Eberhardt (U.S. DOE); *Emissions from Trucks Using Fischer-Tropsch Diesel Fuel*; Society of Automotive Engineers Technical Paper Series 982526; 1998.

[9] P. Norton, et al., op. cit.

[10] The energy term Btu refers to British Thermal Unit, which describes the unit of heat

(continued...)

discussed as they may present regulatory challenges for future Fischer-Tropsch plants.

Germany's Synthetic Fuel Program

As part of continency planning for petroleum supply shortages, Germany built a number of coal-based synthetic fuel plants, which operated through World War II. Germany operated 12 coal hydrogenation plants to produce aviation gasoline (primarily), motor gasoline, diesel, heating oils, and lubricants. Peak production of 21.5 million barrels was reached in 1944.[11] According to the interrogation of a scientist who had worked on Germany's synthetic fuel program, roughly 6.7 to 7.7 metric tons of coal were required to produce one metric ton (approximately 7 barrels) of liquid product — roughly one barrel per ton of coal. [12]

Germany also built synthetic fuel plants based on Fischer-Tropsch synthesis leading up to World War II, and had completed nine by the war's end. Production was geared to low-octane motor fuel, diesel, lubricating oil, miscellaneous chemicals, and soap. Fischer-Tropsch output was low in comparison to hydrogenation at approximately 450,000 barrels annually, with the best plant capable of producing no more than 3,000 barrels per day. The plants were also about 20% more costly to operate than the hydrogenation plants, with 50% of the cost in synthesis gas production. Low-grade coal (bituminous and lignite) was used as a feedstock. From 7.1 to 8.9 metric tons of coal were required to produce one metric ton of liquid product — slightly less than one barrel per ton.

U.S. Synthetic Fuel Program

Concerns for oil supplies during World War II also prompted U.S. interest in synthetic fuels. The U.S. Synthetic Liquid Fuels Act of 1944 authorized construction and operation of plants producing synthetic liquid fuel from coal, oil shale, and agricultural and forestry products.[13] After WWII, the United States tried to capitalize on German technology and experience by sponsoring a number of research, development, and demonstration projects. The Bureau of Mines received funding for an 11-year demonstration plant program that ended in 1955. Work on Fischer-Tropsch synthesis was carried out in a pilot-scale plant at the Bureau's Morgantown, West Virginia, Laboratory. Research improved on the German fixed-bed synthesis reactor with the development of a fluidized-bed reactor.

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[10] (...continued)
energy required to raise 1 pound of water by 1 degree Fahrenheit.

[11] Anthony N. Stranges (Texas A&M University), *Germany's Synthetic Fuel Industry 1927-1945,* AIChE Spring National Meeting, 2003.

[12] *Synthetic Oil Production in Germany — Interrogation of Dr. Butefisch* available through the Fischer-Tropsch Archive, [http://www.fischer-tropsch.org/].

[13] 30 U.S.C. Secs. 321 to 325 authorized $30 million over five years for "the construction and operation of demonstration plants to produce synthetic liquid fuels from coal, oil shales, agricultural and forestry products, and other substances, in order to aid the prosecution of the war, to conserve and increase the oil resources of the Nation, and for other purposes."

During the 1960s, the Department of the Interior's Office of Coal Research sponsored research to directly liquefy Eastern coal, expending approximately $45.7 million (unadjusted for inflation) between 1961 and 1969.[14] Under the 1970s era DOE Synthetic Fuels program, two coal liquefaction projects were planned. Approximately $1,666 million (unadjusted for inflation) was spent between 1975 and 1984 on research, development, and demonstration.[15] Several processes were evaluated — noncatalytic solvent extraction, catalytic processing, and donor solvent processing — and various coals were tested.[16] In privately sponsored development, the Gulf Oil Company reported yielding three barrels of low sulfur fuel oil per ton of Eastern high-sulfur coal using its catalytic coal to liquids process. Exxon reportedly achieved a comparable yield with its donor solvent process. Accordingly, Gulf was achieving a 62% thermal conversion efficiency (see Appendix for calculations).

Efforts to move coal liquefaction beyond the demonstration phase stalled, despite federal and private funding commitments. Project cost overruns of several times the initial $700 million estimate led DOE to cancel work. Several other factors during in the 1980s also contributed to cancellation. The dramatic drop in crude oil prices, the development of new oil fields, and reduced consumption from conservation efforts all contributed to making synthetic fuels economically uncompetitive. Refineries also began converting heavy heating oil into higher value transportation fuel.

Though U.S. interest in making coal-based transportation fuel was abandoned by the mid-1980s, South Africa continued in its efforts to develop Fischer-Tropsch synthesis on a commercial scale. Several other commercial scale efforts have since succeeded in adapting Fischer-Tropsch synthesis to natural gas, where abundant supplies make it economically feasible to do so. Renewed U.S. interest in the technology includes both coal and natural gas. Consequently, the balance of this report will focus on Fischer-Tropsch.

Sasol Coal-to-Liquids Plants

The lack of petroleum resources but abundant coal resources led the Republic of South Africa to investigate establishing an oil-from-coal industry in 1927. After WWII, South Africa's government adopted German technology to build a coal-to-liquid synthetic fuel plant. The South African Coal Oil and Gas Corporation (now known as Sasol) was founded as a state owned company in 1950 to synthesize fuel from coal based on German and U.S. developed Fischer-Tropsch technology (see Bureau of Mines above). Sasol was privatized in 1979.

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[14] Linda B. Cohen and Roger C. Noll, "Synthetic Fuels from Coal," in *The Technology Pork Barrel*, The Brookings Institution, 1991.

[15] Paul F. Rothberg, CRS Report IB77105, Coal Gasification and Liquefaction, February 1, 1984.

[16] Martin A. Elliot, Ed., *Chemistry of Coal Utilization, 2nd Supplementary Volume*, John Wiley & Sons, 1981.

Sasol One started operation in 1955 at Sasolburg, South Africa. It employed two technologies. One unit used a fixed-bed catalyst similar to a German process operated during WWII, provided by the German firm Argbeit-Gemeinshaft Lurgi und Ruhrchemie (Arge).[17] It operated in the temperature range of 220-240°C at a pressure of 925 bar. Production was optimized for long-chain linear paraffins. A second unit used a fluid bed catalyst system developed by the U.S. firm M.W. Kellogg. Technical difficulties prevented its operation until 1957. Its higher operating temperature range of 310-340°C made it better suited to producing gasoline-range hydrocarbons. In 1970, Sasol One produced approximately 297,000 tons of liquid annually (1.9 million barrels of fuel oil equivalent), while consuming approximately 3.96 million tons of coal. This equated a yield of approximately ½ barrel per ton coal.

A second and third plant were built in Secunda, South Africa. Sasol Two was completed in 1980 at a cost of $3,200 million and Sasol Three in 1984 at a cost of $2,520 million.[18] (Costs reflect value of U.S. dollar at the time, unadjusted for inflation.) The Secunda complex is dedicated to producing liquid fuels and chemicals.

The Secunda complex originally operated 80 Lurgi fixed-bed dry-bottom gasifiers to make synthesis gas, and 16 circulating fluid bed reactors (rated at 7,500 barrels per day each). These processes gave it a capacity of 120,000 barrels per day. In 2000, Sasol replaced the fluid-bed reactors with 8 Sasol Advanced Synthol (SAS) reactors (rated at 20,000 barrels per day). The SAS reactors use a fluidized, iron-based catalyst that operates in the 300-350°C temperature range.

With the new SAS reactors, the Secunda complex production increased to 150,000 barrels per day of products in the C1-C20 range (automotive fuels and light olefin used as feedstock for chemical manufacturing).[19] In 2001, Secunda also supplied 14.3 million gigaJoules (135.54 million therms) of methane rich gas to South Africa's gas distribution network.[20]

In 2006, Secunda consumed approximately 41.8 million metric tons of low rank sub-bituminous coal supplied by Sasol Mining (the equivalent of 126,000 U.S. short

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[17] National Academy of Sciences/National Research Council, *Chemistry of Coal Utilization*, pp. 2112-2113, John Wiley & Sons, 1981.

[18] Costs reflect value of U.S. dollar at the time, unadjusted for inflation. Sasol *Coal-to-Liquids Development*, presentation to the gasification technologies Council Conference, October 2005.

[19] Thi Chang, *Oil & Gas Journal*, "South African Company Commercializes New F-T Process, January 10, 2000.

[20] A gigajoule (GJ) is a standard measure used for the heating value of fuel gas supplied to South African customers. A joule is an international unit of energy defined as the energy produced from one watt flowing for one second. Giga denotes a measure of a billion (10^9). 1 GJ = 0.96 million cubic feet (mcf) of gas, under standard temperature and pressure conditions. 1 Therm = 100,000 Btu. Department of Minerals and Energy, Republic of South Africa, *Gas Infra-Structure Plan*, April 19, 2005, [http://www.dme.gov.za/pdfs/energy/gas/gas_infrastructure_plan.pdf].

tons per day).[21] At that rate of consumption, Secunda yields approximately 1.2 barrels per ton of coal, making it approximately 27% efficient in converting the coal's heat content (Btus) to liquid products. (Refer to the Appendix for calculation of the value). This does not include the heat value of the methane-rich gas that Secunda also produces, which would increase efficiency.

Sasol Sasolburg and Secunda, combined, produce 30 million metric tons of CO_2 annually. Sasol uses the Benfield process to absorb and capture 90-98% of CO_2 produced.[22] Sasol reports producing 3.04 metric tons of CO_2 per metric ton of overall product,[23] the equivalent of 0.82 metric tons elemental carbon per ton liquid.[24] This is approximately equivalent to emitting 0.48 U.S. tons of CO_2 per barrel of product produced.[25]

By the end of 1979, production costs were estimated at approximately $30 per barrel, while world spot prices for crude oil were $10 per barrel higher.[26] Until 2000, Sasol had been receiving a tariff protection when the world market oil price fell below $21.40 per barrel.[27] Crude oil prices had remained below the tariff protection level in the years 1986 through 1996, except for a brief period during the 1991 Persian Gulf War. The tariff protection lapsed in 2000. South Africa also put a sliding price scale in place to make imported refined products more costly than Sasol's, up to crude oil prices of $45 per barrel.

Shell Bintulu Gas-to-Liquids Plant

In 1993, Shell International Gas Limited began operating the first-of-its-kind full-scale commercial gas-to-liquids plant, built alongside its liquefied natural gas (LNG) plant at Bintulu in Sarawak (Malaysia).[28] Shell's Middle Distillate System (SMDS) technology was developed using natural gas as a feedstock for Fischer-Tropsch synthesis to produce middle distillates.

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[21] Platts, Coal-to-Liquids Technology, December 19, 2006 [http://www.platts.com/Coal/Resources/News%20Features/ctl/sasol.xml].

[22] The Benfield process uses a hot potassium carbonate solution that is diethanolamine promoted. A. Engelbrecht, A. Golding, S. Hietkamp, and B. Scholes, *The Potential for Sequestration of Carbon Dioxide in South Africa,* March 12, 2004, South Africa Department of Minerals and Energy.

[23] Sasol, *Highlights Sasol Sustainable Development Report 2006.*

[24] To convert CO_2 gas to elemental C, multiply CO_2 by 12/44. EPA Office of Transportation and Air Quality, *Metrics for Expressing Greenhouse Gas Emissions: Carbon Equivalents and Carbon Dioxide Equivalents*, EPA420-F-05-022, February 2005.

[25] 1 metric ton product ≈ 7 barrels.

[26] Sasol Ltd, *Hoovers*, [http://www.hoovers.com].

[27] "S. Africa to cut price protection for synfuel," *Oil & Gas Journal,* December 25, 1995.

[28] Shell Gas & Power External Affairs, *Gas to Liquids: Shell Middle Distillate Synthesis Process and Products*, August 2002.

The Bintulu plant produces 12,500 barrels per day of product (50% middle distillates, and 50% speciality products such as detergent feedstocks and waxes), while consuming 100-120 million cubic feet per day of natural gas produced from the South China Sea. This makes it approximately 54% efficient in converting the energy content of natural gas to liquid products. (Refer to the Appendix for calculation of the value.)

Shell states that the SMDS fuels produced have virtually no aromatic and sulfur components, and when blended with conventional diesel give significant reductions in regulated emissions (NOx, SOx, HC, CO, and particulates). SMDS diesel can also be used as a "neat" fuel in diesel engines with minor modifications.

Oryx Gas-to-Liquids Plant

The Oryx Gas-to-Liquids (GTL) plant at Ras Laffan Industrial City, north of the Qatar capital Doha, represents a joint venture between state-owned Qatar Petroleum (51%) and Sasol Ltd. (49%).[29] Built at a cost of $950 million, operations commenced in June 2006, after 2½ years of construction. The plant uses Sasol's Fischer-Tropsch based Slurry Phase Distillate low temperature process.

Oryx is designed to produce 34,000 barrels per day of liquids (24,000 barrels diesel, 9,000 barrels naphtha, and 1,000 barrels liquefied petroleum gas). Qatar's Persian Gulf North Gas Field is expected to provide approximately 330 million cubic feet per day of "lean" gas as feedstock. This makes Oryx approximately 52% efficient. (Refer to the Appendix for calculation of the value.)

Sasol Chevron — the London-based joint venture between Sasol and Chevron Corporation — will market the Oryx GTL diesel initially in Europe and then elsewhere. The joint venture plans to expand Oryx plant capacity to about 100,000 barrels per day and is considering plans to build an integrated GTL plant with a capacity of about 130,000 barrels per day.

Syntroleum Catoosa Demonstration Facility

Syntroleum Corporation (Tulsa, Oklahoma) operates a 3-barrel-per-day Fischer-Tropsch pilot plant, used primarily to evaluate catalyst systems, and a 70-barrel-per-day demonstration plant used to produce products and evaluate technology. Syntroleum has received $31.6 million in federal government contracts since 1998 to evaluate Fischer-Tropsch technology for the Departments of Defense, Energy, and Transportation. The U.S. Air Force purchased 100,000 gallons of jet fuel synthesized from natural gas from Syntroleum in 2006, for testing in a B-52 Stratofortress.[30] The Air Force recently certified the fuel as a substitute for conventionally refined JP-8 in

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[29] Qatar Petroleum, *Oryx GTL Inauguration - A Key Step in Qatar's Bid to Become the GTL Capital of the World* [http://www.qp.com.qa/qp.nsf/8c264276b952633c432571290026c60e/4cebdaa21d0dc4264325718600180400?OpenDocument#].

[30] Syntroleum, *Department of Defense-Assured Fuels Initiative Slides* [http://www.syntroleum.com/B52TestDay.aspx].

its B52 fleet, and will be evaluating its suitability in other aircraft and as a substitute diesel fuel.

Choren Industries

Choren Industries (a partnership of Daimler AG, Volkswagen, and Shell) is finishing construction of its Beta biomass-to-liquid plant in Freiberg, Germany. The initial production goal is 15,000 metric tons (735,000 barrels) per year of diesel. Choren plans are to expand capacity to 200,000 metric tons (1,400,000 barrels) per year with its Zeta-plant (equivalent to 3,800 barrels per day). The German Energy Agency assumes that biomass-to-liquids is 42% efficient in energy conversion.[31]

National Energy Technology Laboratory Study

The National Energy Technology Laboratory (NETL) has examined the technical and economic feasibility of a commercial scale coal-to-liquids facility using Illinois basin coal.[32] With a production goal of 50,000 barrels per day (diesel and naphtha) and consumption rate of 24,533 tons of coal per day, the plant would yield slightly more than 2 barrels per ton of coal. This would making it approximately 40.5% efficient. (Refer to the Appendix for calculation of the value.) This efficiency would not include 125 megawatts of electric power that would be generated from waste heat.

The plant is expected to produce 560 million cubic feet (32,032 tons) of CO_2 per day, which would equate to 0.64 tons of CO_2 per barrel.[33]

NETL estimates construction costs of approximately $4.5 billion.

Baard Energy Coal-to-Liquids Plant

Baard Energy, L.L.C., through its project company Ohio River Clean Fuels, L.L.C., is planning to build a 35,000 barrel per day coal-to-liquids plant in Wellsville, Ohio. Baard's plans call for converting coal and biomass to synthesis gas, and using Fischer-Tropsch synthesis to produce diesel, jet, and naphtha hydrocarbons. The plant would also generate 250 to 300 megawatts of electricity daily. Baard expects that up to 85% of the CO_2 produced by the plant could be captured. Baard cites an Idaho National Laboratory study of the project that attributes use of Fischer-Tropsch diesel fuel with a 46% reduction in CO_2 emissions over conventionally refined diesel fuel.[34]

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[31] Deutsche Energie-Anentur GmbH, *Biomass to Liquid - BtL, Implementation Report*, December 2006.

[32] U.S. DOE National Energy Technology Laboratory, *Baseline Technical and Economic Assessment of a Commercial Scale Fischer-Tropsch Liquids Facility* (DOE/NETL-2007/1260), April 9, 2007.

[33] 1 standard cubic foot (SCF) CO_2 = 0.1144 pounds.

[34] Richard D. Boardman, *Plant Modeling & Emissions Comparative Analysis Approach* —
(continued...)

Comparing Efficiencies

For comparison purposes, yield and thermal conversion efficiency of the various plants discussed above are presented in **Table 2**. Yield in barrels per ton pertains to liquid fuels from coal. Thermal conversion efficiency is a term adopted in this report to compare the heating value of the feedstock to the product. It does not imply an economic comparison; that is, that one technology requiring lower Btu than another is necessarily economically superior. An economic comparison would also weigh the capital cost of construction, operation and maintenance costs, the price of fuel, and the intrinsic value of environment and national security, which is beyond the scope of this report.

Table 2. Comparative Efficiencies of Processes Converting Coal, Gas, and Biomass to Liquid Fuels

	Germany WWII		**Gulf DL**	**Sasol F-T CTL**	**Shell F-T GTL**	**Oryx F-T GTL**	**Choren F-T BML**	**NETL F-T CTL**
	DL	**F-T CTL**						
Yield barrels/ton	1	1	3	1.2	n.a.	n.a.	n.a.	2
Thermal conversion efficiency %	—[a]	—[a]	62	27[b]	54	52	42	40.5

Note: DL: direct liquefaction; F-T CTL: Fischer-Tropsch coal-to-liquids; F-T GTL: gas to liquids, F-T BML: biomass-to-liquids.

a. insufficient information on coal heating value to determine thermal conversion efficiency
b. does not credit methane-rich gas production

Comparison might be made with the efficiency of producing other energy resources, such as petroleum, tar sands, or oil shale. The giant oil fields of North America, now depleted, produced from 50 to 1,000 barrels per acre-foot (43,560 ft^3).[35] The NETL study expects to yield approximately 2 barrels per ton of Illinois bituminous coal — the equivalent of 3,806 barrels per acre-foot.[36] In further

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[34] (...continued)
Coal/Biomass Gasification with Fischer-Tropsch Diesel Production, Idaho National Laboratory, May 2007. A full technical report is scheduled to be delivered by Baard Energy and the Idaho National Laboratory at the 24th Annual International Pittsburgh Coal Conference in Johannesburg, South Africa, September 10-14, 2007.

[35] American Association of Petroleum Geologists, *Geology of Giant Petroleum Fields*, 1970.

[36] Assumes in place density of 1,903 tons per acre-foot for bituminous coal. From James G.
(continued...)

comparison, Canada's mined oil sands yield ½ barrel per ton.[37] Oil shales of the western United States could be expected to produce no more than 2/3 barrel per ton.[38]

A further comparison might be made to refining oil and generating electricity. The 5,555.3 million barrels of crude oil refined in 2005 (the equivalent of 32,221.3 trillion Btu)[39] consumed approximately 2,862.5 trillion Btu (fuel oil, still gas, petroleum coke, natural gas, coal, purchased electricity and steam).[40] (For analysis, refer to the Appendix.) Thus, on average, U.S. refineries consumed roughly 9% of the equivalent energy contained in the crude petroleum refined, making them 91% efficient. (ExxonMobile estimates, however, that its refineries require from 10%-20% of the energy in a barrel of crude oil to convert the remaining barrel into products.)[41] Coal-fired electric power plants, by comparison, average about 33% efficiency.[42]

It is emphasized that these comparisons are illustrative and do not of themselves indicate overall economic or environmental advantages.

Greenhouse Gas — CO_2

Carbon dioxide sequestration may offer a viable solution if CO_2 emissions were to be regulated. Sequestration depends on the ability to capture CO_2 after combustion, and then pump it into deep underground reservoirs. (See CRS Report RL33801, *Direct Carbon Sequestration: Capturing and Storing* CO_2.) Though considerable reservoir capacity exists in the United States, the pipeline infrastructure to facilitate sequestration would be needed on an industrial scale. (See CRS Report RL33971, *Pipelines for Carbon Sequestration: Emerging Policy Issues*.)

Legislation has been introduced in Congress to reduce and stabilize greenhouse gas emission. For example, H.R. 3221 — *New Directions for Energy Independence, National Security, and Consumer Protection Act* — includes provisions aimed at reducing the growth in carbon emissions. (See CRS Report RL233831, *Energy Efficiency and Renewable Energy Legislation in the 110th Congress.*) Carbon dioxide production associated with Fischer-Tropsch coal-to-liquids remains the primary objection by many in Congress to offering or approving legislation that promotes its development.

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[36] (...continued)
Speight, *The Chemistry and Technology of Coal*, Table 9.3 Expressions of the In-Place Density of Coal, CRC Press, 1994.

[37] Government of Alberta, Oil Sand Facts [http://www.energy.gov.ab.ca/1876.asp].

[38] CRS Report RL33359, *Oil Shale: History, Incentives, and Policy*, by Anthony Andrews.

[39] U.S. DOE EIA Petroleum Navigator, Refinery Net Input, [http://www.eia.doe.gov/].

[40] U.S. DOE EIA, Petroleum Navigator, Fuel Consumed at Refineries, [http://www.eia.doe.gov/].

[41] Lori Ryerkerk, Beaumont Refinery Manager, Texas Industrial Energy Management Forum, April 7, 2005.

[42] President's Council of Advisors on Science and Technology, *Report on Energy Efficiency — Findings and Recommendations*, February 20, 2003.

Of 42 states that have conducted greenhouse gas inventories, at least 30 states have either completed or are in the process of preparing climate change action plans and 12 states have set statewide greenhouse gas targets. A small, but growing, number of states have implemented or are creating mandatory emission reduction programs. (See CRS Report RL33812, *Climate Change: Action by States To Address Greenhouse Gas Emissions*.)

A recent U.S. Supreme Court decision compels the EPA to consider regulating CO_2 emissions from mobile sources under the Clean Air Act.[43] Whether EPA would be compelled to extend rulemaking to stationary sources, such as coal burning power plants or coal-to-liquids plants, for example, is uncertain. EPA has estimated the percentage change in lifecycle greenhouse gas emissions, relative to petroleum-based fuels that would be displaced by alternative and renewable fuels, including coal-, gas-, and biomass-to-liquids.[44] The analysis is based on work performed by the DOE Argonne National Laboratory using the *Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation* (GREET) model. The fuels are compared on an energy equivalent basis. The assumptions made about Fischer-Tropsch coal-to-liquids include a plant efficiency of 52.4%, and that 85% of the carbon (exclusive of the fuel product) is captured. As shown in **Figure 4**, the impact on greenhouse gas emissions (GHG) from coal-to-liquids fuel with carbon capture and sequestration (CC&S) would represent an increase 3.7% over petroleum-based fuels; without capture and sequestration a 118.8% increase. Gas-to-liquids would increase greenhouse gas emissions by 8.6% (EPA does not state whether this factors in CC&S).

A direct comparison might be made with CO_2 emissions from refineries. In 2005, U.S. refineries emitted 277.6 million metric tons (306.11 million U.S. tons) of CO_2[45] to produce 5,686 million barrels of petroleum products in 2005[46] — or approximately 0.05 tons CO_2 per barrel. Sasol, considered the largest single global source of CO_2,[47] emits approximately 0.48 U.S. tons per barrel of product.[48] The NETL study plant would emit 0.64 tons of CO_2 per barrel.

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[43] Massachusetts et al. v. Environmental Protection Agency et al. Certiorari to the United States Court of Appeals for the District of Columbia Circuit No. 05-1120. Argued November 29, 2006; decided April 2, 2007.

[44] EPA Office of Transportation and Air Quality, *Greenhouse Gas Impacts of Expanded Renewable and Alternative Fuels Use* (EPA420-F-07-035), April 2007.

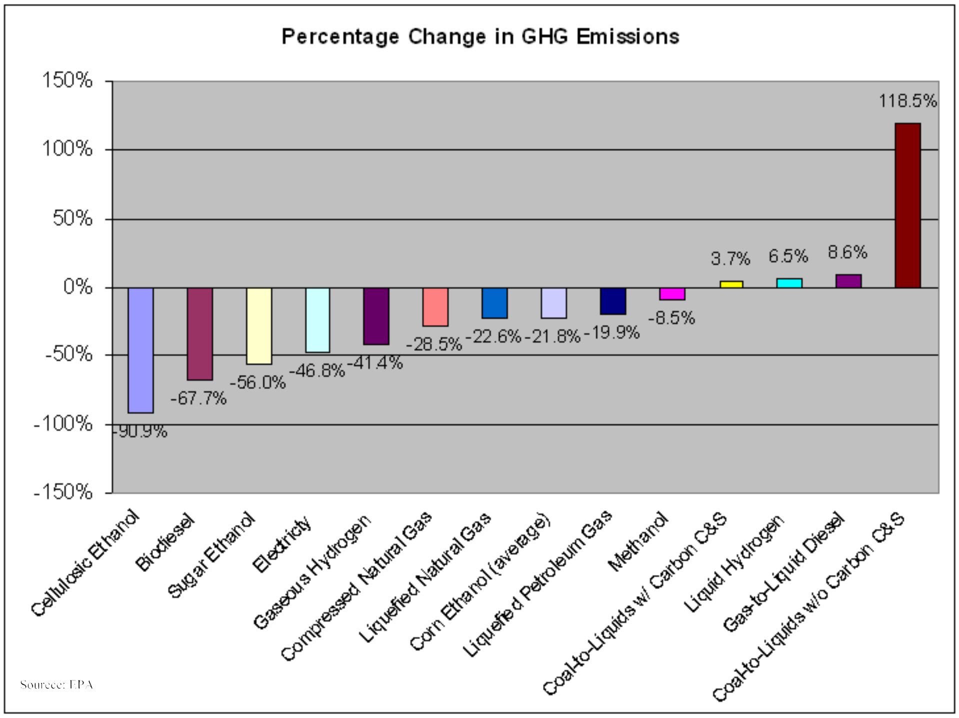
[45] Mark Schipper, U.S. DOE EIA, *Energy-Related Carbon Dioxide Emissions in U.S. Manufacturing* (DOE/EIA-0573), 2005.

[46] U.S. DOE EIA, Refinery Net Production (annual-thousand barrels) [http://tonto.eia.doe.gov/dnav/pet/pet_pnp_refp2_dc_nus_mbbl_a.htm].

[47] John Yeld, Cape Argus (Cape Town), *South Africa: Sasol Plant Named as Top Culprit in Emissions* [http://allafrica.com/stories/200708080651.html].

[48] 1 metric ton product ≈ 7 barrels.

Figure 4. Greenhouse Gas Impacts of Expanded Renewable and Alternative Fuels Use.



Sourece: EPA

Policy History

Congress first promoted synthetic fuel from coal through the U.S. Synthetic Liquid Fuels Act of 1944.[49] Intended to aid the prosecution of World War II and conserve and increase national oil resources, the act authorized the Secretary of the Interior to construct, maintain, and operate plants producing synthetic liquid fuel from coal, oil shale, and agricultural and forestry products.[50] The Bureau of Mines received funding for an 11-year demonstration plant program that was largely completed by 1955.

During the Korean War, Section 303 of the Defense Production Act of 1950 (Ch. 932, 64 Stat. 978) authorized the President to have liquid fuels processed and refined for government use or resale, and to make improvements to government- or privately-owned facilities engaged in processing and refining liquid fuels when it would aid the national defense.[51] During the 1970s, the Department of Energy

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[49] 30 U.S.C. Secs. 321 to 325.

[50] 30 U.S.C. Sections 321 to 325 authorized $30 million over five years for the construction and operation of demonstration plants to produce synthetic liquid fuels from coal, oil shales, agricultural and forestry products, and other substances.

[51] Ch. 932, 64 Stat. 798 (Title III Expansion of Production Capacity and Supply) intended to develop and maintain whatever military and economic strength necessary to support collective action through the United Nations. The act authorized the diversion of certain (continued...)

(DOE) directed a synthetic fuels program toward commercializing coal liquefaction, coal gasification, and oil shale technologies. In 1980, Congress amended Section 305 of the Defense Production Act (P.L. 96-294, Energy Security Act) to authorize the President's purchase of synthetic fuels for national defense. President Carter then directed the Secretary of Defense to determine the quantity and quality of synthetic fuel needed to meet national defense needs for procurement.[52] Congress further amended the Defense Production Act to financially assist synthetic fuel production from coal, oil shale, tar sands, and heavy oils by establishing the U.S. Synthetic Fuels Corporation (P.L. 96-294, the United States Synthetic Fuels Corporation Act of 1980).[53] The stated goal of the act was reaching a daily synthetic fuels production capacity of 500,000 barrels of oil equivalent by 1987, and 2 million by 1992.

Within a few years, the House began considering a bill (H.R. 935, Synthetic Fuels Fiscal Responsibility Act of 1985) to abolish the Synthetic Fuels Corporation. The Energy and Commerce Committee debate of the bill (H.Rept. 99-196) linked abolishing the Corporation to reducing the federal deficit and viewed purchasing oil for the Strategic Petroleum Reserve as a far more cost effective defense against another oil embargo than subsidizing synthetic fuels. Congressional criticism also focused on conflicts of interest among the Corporation board members, high salaries for staff, lack of interest on the part of private industry, and the possibility of huge subsidies going to profitable oil companies.[54] The minority view noted that as late as 1983, the Department of Defense had certified that synthetic fuel was needed to meet national defense needs. Language rescinding most of the Synthetic Fuels Corporation funding was included in the FY1986 continuing appropriations resolution (H.J.Res. 465, P.L. 99-190).

Though direct federal support for synthetic fuel ended, production continued to receive indirect benefits. Section 45K (Credit for Producing Fuel From a Nonconventional Source) of the Internal Revenue Code defines a qualified fuel for the purpose of tax credit to include "liquid, gaseous, or solid synthetic fuels produced from coal (including lignite), including such fuels when used as feedstocks." The Energy Information Administration reports on production of "coal synfuels," but limits the definition to coal-based solid fuels that have been processed by a coal synfuel plant and coal-based fuels such as briquettes, pellets, or extrusions, formed from fresh or recycled coal and binding materials.[55]

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[51] (...continued)
materials and facilities from civilian to military use when expansion of production facilities beyond the levels needed to meet civilian demand was required.

[52] The American Presidency Project, Executive Order 12242 Synthetic Fuels, [http://www.presidency.ucsb.edu/ws/index.php?pid=45171], signed September 30, 1980, was later revoked by President Reagan's Executive Order 12346, February 8, 1982.

[53] Title I, Part B of the Energy Security Act of 1980.

[54] *CQ Almanac*, "Congress Dismantles Synthetic Fuels Program," 1985.

[55] Energy Information Administration Frequently Asked Questions - Coal [http://tonto.eia.doe.gov/ask/coal_faqs. asp#coal_synfuel].

The Energy Policy Act of 2005 (P.L. 109-58) includes new provisions for unconventional fuels and loan guarantees for facilities using Fischer-Tropsch to produce fuels. Section 369 amends 10 U.S.C. 141 (Miscellaneous Procurement Provisions) by inserting Section 2398a for procurement of fuel derived from coal, oil shale, and tar sands.[56] This directs the Secretary of Defense to develop a strategy to use fuel produced from coal (among other strategic unconventional fuels) to help meet the fuel requirements of the Defense Department when the Secretary determines that doing so is in the national interest. Section 417 (Department of Energy Transportation Fuels from Illinois Basin Coal) directs the Energy Department to evaluate production of Fischer-Tropsch transportation fuels from Illinois basin coal. Section 1703 (c) (1)(D) (Eligible Projects) authorizes the Energy Secretary to make loan guarantees to facilities that generate hydrogen-rich and carbon monoxide-rich product streams from the gasification of coal or coal waste and use the streams to produce ultra clean premium fuels through the Fischer- Tropsch process. Section 1703(c)(4) (Liquefaction Project) authorizes funds awarded under the clean coal power initiative in subtitle A of Title IV for coal-to-oil liquefaction projects to finance the cost of loan guarantees. The Defense Secretary has not acted on procuring coal-based fuel under Section 369, Section 417 remains unfunded by both Congress and the President's budget request, and the Energy Secretary has not awarded loan guarantees under Section 1703.

Policy Considerations

In the past, the precipitous drop in crude oil price and increased supply played key roles in suspending federally funded coal-based synthetic fuel programs.[57] Direct coal liquefaction was considered economically unviable and fraught with technical problems. Critics of refineries charged at that time that they were inefficient, polluting, and produced dirty fuels — much the same criticism leveled at coal-to-liquids. Meanwhile, U.S. refineries began an intense period of recapitalization in response to Clean Air Act amendments and applied much of the same technology considered too costly for direct liquefaction. For some time afterwards, refineries remained the loss-leader in vertically integrated petroleum operations. Unprofitable refining was necessary for petroleum producers in order to maintain their market access.

Proponents of coal-to-liquids point to Sasol as evidence that the Fischer-Tropsch technology is viable. However, the South Africa government protected Sasol while crude oil prices remained low. During that same economic period, Canada continued to support the development of its oil sands resources. Thus, criticism that U.S. energy policy decisions were shortsighted in abandoning synthetic fuel efforts contrast with the reality that the refining industry transformed itself under the same economic circumstances without government support.

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[56] Energy Policy Act of 2005, P.L. 109-58, Title III, Subtitle F, Sec. 369. Oil Shale, Tar Sands, and Other Strategic Unconventional Fuels; (q) Procurement of Unconventional Fuels by the Department of Defense.

[57] See section on U.S. Synthetic Fuels Program and the Synthetic Fuels Corporation in CRS Report RL33359, *Oil Shale: History, Incentives, and Policy,* by Anthony Andrews.

Constructing a first or even second Fischer-Tropsch synthetic facility (regardless of feedstock is coal, gas or biomass) is likely to encounter permitting as well as economic barriers. (See CRS Report RL32666, *The Gas to Liquids Industry and Natural Gas Markets*.) Advocates of developing a synthetic fuels industry argue for a variety of incentives they view necessary in helping help bridge barriers to entry; such as: loan guarantees, streamlined permitting, infrastructure improvements, and long-term contracts for purchasing coal-, gas-, or biomass- to-liquid fuels. Some might argue that offering loan guarantees for such an industry would be a misplaced incentive given the current high prices of crude oil and refined gasoline. Others might argue that the petroleum industry's reluctance to increase refining capacity justifies federal intervention. The Energy Policy Act of 2005 already includes the provisions of Section 391, *Refinery Revitalization*, for streamlining the application and permit process among federal agencies for new refineries, which arguably could be applied to Fischer-Tropsch plants.

Proposed increases in average fuel economy standards, such as the provisions offered in S.Amdt. 1792 to H.R. 6 — *To provide for corporate average fuel economy (CAFE) standards* (introduced June 20, 2007) — would likely have some stimulus on a fledgling Fischer-Tropsch industry. Automobile manufacturers might achieve the proposed standards through increased production of diesel passenger vehicles, which at the same time consume less fuel and emit lower CO_2 than gasoline engines (partially offsetting the CO_2 emitted in producing such fuels). In that case the demand for diesel fuel might increase. U.S. refineries would be pressed to adjust their product slate toward more diesel production, and distributors would be pressed to import more diesel fuel. However, refineries may be limited to adjusting their product slates to no more than 10% to 20% diesel without making capital investments. The increased U.S. demand for imported diesel would compete with European demand, where the preference for diesel vehicles is already increasing. Either case could place upward pressure on prices and thus stimulate private investment.

Carbon dioxide's contribution to global warming represents the primary drawback to Fischer-Tropsch, particularly when using coal feedstock. Carbon capture and sequestration offers a promising solution. However, sceptics of the solution may go unchallenged without an industrial scale demonstration. Private interests may forestall investment in synthetic fuels over the uncertainty of future carbon emission regulations, particularly if rules are not applied evenly to existing emission sources. Policy makers may face few options in contending with the broad issue of reducing carbon emissions from existing fossil fuel users.

Legislation in the 110th Congress

A number of bills promoting coal-to-liquid fuels have been introduced in the 110th Congress. These include:

- H.R. 370, *Coal-to-Liquid Fuel Promotion Act of 2007*, would provide a loan guarantee program, authorize the Defense Secretary to enter contracts with companies for long term procurement of CTL fuel, and research the environmental effects of F-T fuels.

- H.R. 2208, *Coal Liquid Fuels Act*, would provide standby loans for CTL projects.

- H.R. 6, *Renewable Fuels, Consumer Protection, and Energy Efficiency Act of 2007*, as passed by the Senate, would include fuel derived from coal in the definition of a refined petroleum product, include the manufacture of transportation fuels from coal as an industrial source of carbon dioxide (for the purpose of carbon capture and sequestration). S.Amdt. 1781 (*To Provide for Corporate Average Fuel Economy (CAFE) Standards*) to H.R. 6 would include coal-to-liquid fuel in a coal innovative direct loan program, provide for a study of maintaining coal-to-liquid products in the Strategic Petroleum Reserve, provide for a report on emissions of coal-to-liquid products used as transportation fuels, and provide for a clean coal-derived fuel feasibility study.

- S. 133, *American Fuels Act of 2007*, would define alternative diesel fuel to include CTL that provides for sequestration of carbon emissions and amend the 10 U.S.C. Section 2922d definition of a "covered fuel" to include fuel produced from coal and authorize the Defense Secretary to enter into contracts with companies for the production of covered fuels.

- S. 155, *Coal-to-Liquid Fuel Promotion Act of 2007*, would provide loan guarantees for large scale CTL facilities producing more than 10,000 barrels per day, authorize the Defense Secretary to enter into contracts with companies that operate CTL facilities near military installations, authorize research into the environmental effects of F-T fuels, and provide tax credit for investing in qualified CTL projects.

- S. 1443, *Clean, Affordable, and Domestic Fuels for Energy Security Act of 2007*, would mandate regulations and emission standards for coal-derived fuels, provide loan guarantees for coal-derived fuel facilities, and establish research centers for coal-derived fuel.

Appendix

Gulf Oil Company Direct Coal Liquefaction Efficiency

Feedstock:

Pittsburgh coal @ 14,040 Btu/pound x 2,000 pounds/ton = 28,080,000 Btu per ton[a]

Product:

distillate fuel oil = 5,825,000 Btu per barrel[b]

Calculation:

(3.0 barrels x 5,825,000 Btu/barrel) ÷ 28,080,000 Btu/ton = 62%.

Sources:

a. *Marks' Standard Handbook for Mechanical Engineers* 10th Ed, Sec. 7, "Fuels and Furnaces," McGraw Hill, 1996.

b. Energy Information Administration, *Monthly Energy Review, Appendix A Thermal Conversion Factors*, 2007.

Sasol Secunda Complex Coal-to-Liquids Efficiency

Feedstock:

sub-bituminous coal: 41,800,000 metric tons/yr x 1 year/365 days x 2204 lbs/m-ton x 11,482 Btu/lb[a] = 2,898,094,549,041 Btu

Products:

liquid fuels: 150,000 barrels/day x 42 gal/bbl/ 123,600 Btu/gal[b] = 778,680,000,000 Btu

Calculation:

Product (778,680,000,000)/ Feedstock (2,898,094,549,041 = 27%

Sources:

a. Sasol coal ranges from 10,000 to 11,482 Btu/lb in calorific value, with fixed carbon ranging from 49.4% to 57.7%. Methane rich gas: 33.9 megaJoules/cubic meter) (910 Btu/ft^3) compared to natural gas: 37 to 40 MJ/m3 of (1,027 Btu/ft^3). Republic of South Africa, Department: Minerals and Energy, Operating and Developing Coal Mines in the Republic of South Africa 2005, Table 1, [http://www.dme.gov.za/pdfs/minerals/d2_2005.pdf].

b. assumed for diesel, no further information is available. Department of Minerals and Energy, Republic of South Africa, Gas Infra-Structure Plan, April 19, 2005, [http://www.dme.gov.za /pdfs/energy/gas/gas_infrastructure_plan.pdf].

Shell Bintulu Gas-to-Liquids Efficiency

Feedtsock:

natural gas: 20,000,000ft^3/day x 1,027 Btu/ft^3 = 123,240,000,000 Btu

Products:

middle distillate: 6,250 bbl/day x 42 gal/bbl x 123,600 Btu/gal[a] = 445,000,000 Btu

detergent feedstocks and waxes:

6,250 bbl/day x 5,537,000 Btu/bbl[b] =	34,606,250,000 Btu
product total =	67,051,250,000 Btu

Calculation:

Product (67,051,250,000)/Feedstock (123,240,000,000) = 54%

Sources:
a. Norton et al.
b. assumed based on EIA

Oryx Gas-to-Liquids Efficiency

Feedstock:

“lean” gas: 330,000,000 ft^3 /day x 1,027 Btu/ft^3 [a] = 338,910,000,000 Btu

Products:

diesel: 24,000 bbl/day x 42 gal/bbl x 123,600 Btu/gal[b] = 124,588,800,000 Btu
naphtha: 9,000 bbl/day x 5,248,000 Btu/bbl[a] = 47,232,000,000 Btu
liquified petroleum gas: 1,000 bbl/day x 4,000,000 Btu/bbl[a] = 4,000,000,000 Btu
product total = 175,820,800,000 Btu

Calculation:

Product (175,820,800,000)/ Feedstock (338,910,000,000) = 52%

Sources:
a. assumed based on EIA
b. Norton et al.

NETL Coal-to-Liquids Efficiency

Feedstock:

Illinois No. 6 coal: 24,533 tons/day x 13,126 Btu/lb. x 2000 lb./ton = 644,040,316,000 Btu

Products:

diesel: 27,819 bbl/day x 42 gal/bbl/ 123,600 Btu/gal = 144,413,992,800 Btu
naphtha: 22,173 bbl/day x 5,248,000 Btu/bbl = 116,363,904,000 Btu
product total = 260,777,896,800 Btu

Calculation:

Product (260,777,896,800) / Feedstock (644,040,316,000) = 40.5%

Table A1. Energy Consumed by Refining in 2005

	Volume by Unit	Heat Content	Energy (million BTU)
Crude Oil Refined	5,555 million barrels	5.825 million Btu/barrel	32,221,264,446
Fuels Consumed			
Liquefied Petroleum Gases	4.17 million barrels	4.000 million Btu/barrel	16,680,000
Distillate Fuel Oil	0.76 million barrels	5.825 million Btu/barrel	4,427,000
Residual Fuel Oil	2.21 million barrels	6.287 million Btu/barrel	13,894,270
Still Gas	238.24 million barrels	6.000 million Btu/barrel	1,429,440,000
Petroleum Coke	89.65 million barrels	6.024 million Btu/barrel	540,051,600
Other Petroleum Products	5.33 million barrels	5.825 million Btu/barrel	31,047,250
Natural Gas	682,919 million cubic feet	1,027 Btu/cubic foot	701,357,813
Coal	41,000 short tons	20.4 million Btu/ton	836,400
Purchased Electricity	36,594 million kilowatt hours	3,412 Btu/kilowatt-hour	124,858,728
Purchased Steam	63,591million pounds	1,000 Btu/pound	63,591,000
		TOTAL ENERGY CONSUMED IN REFINING	2,926,184,061
		FUELS CONSUMED ÷ CRUDE OIL REFINED =	9.08%

Sources: U.S. DOE EIA, Petroleum Navigator, Fuel Consumed at [http://tonto.eia.doe.gov/dnav/pet/pet_pnp_top.asp] (Refineriespet_pnp_capfuel_dcu_nus_a.xls); U.S. DOE EIA, Thermal Conversion Factor Source Document [http://www.eia.doe.gov/emeu/mer/pdf/pages/sec12_a_doc.pdf].