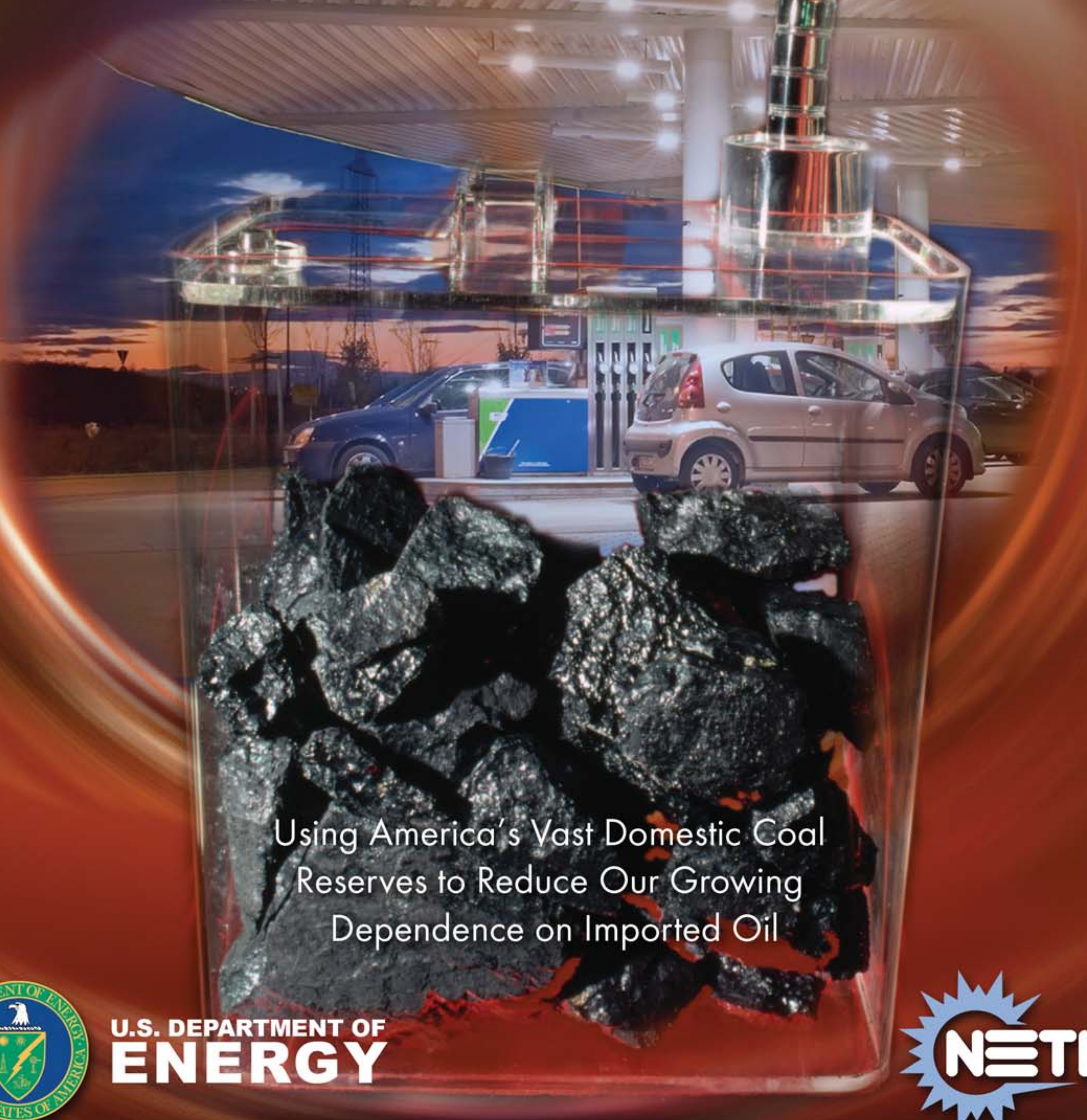
U.S. Department of Energy

Office of Fossil Energy • National Energy Technology Laboratory

# COAL-TO-LIQUIDS TECHNOLOGY

## CLEAN LIQUID FUELS FROM COAL



Using America's Vast Domestic Coal Reserves to Reduce Our Growing Dependence on Imported Oil

U.S. DEPARTMENT OF ENERGY

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# COAL-TO-LIQUIDS TECHNOLOGY

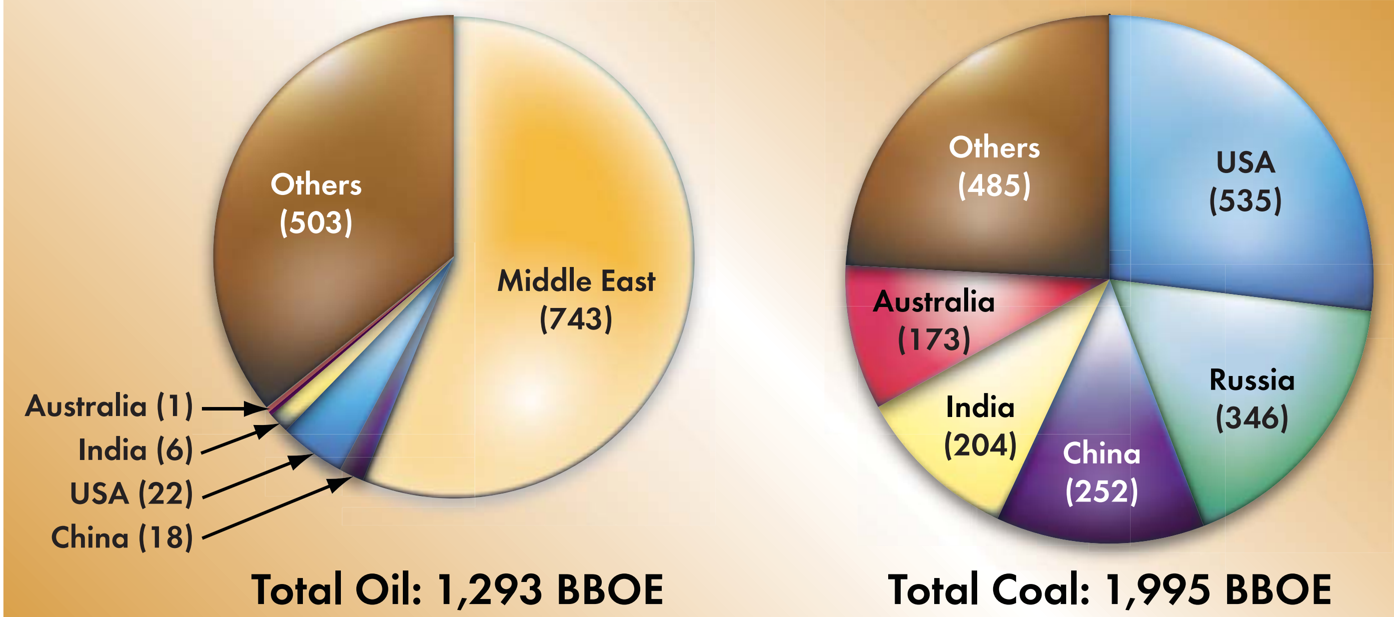
## COAL — NOT AN ORDINARY ROCK

Coal is a solid fossil fuel with a high carbon content but a low hydrogen content, typically no more than 5–6 percent of the total weight of coal. On a molecular level, it consists of long chains of mostly aromatic hydrocarbon structures. It is mostly associated with the generation of electric power or as a feedstock in the production of steel. However, this versatile, solid rock can be broken down into simple molecules and put back together into many different, useful forms.

Technologies exist today to break down coal into the simple molecules of carbon monoxide and hydrogen, and then to combine these molecules to form many useful products such as liquid transportation fuels, natural gas, and chemical feedstocks that are used to produce common household products such as tape and film. Today, these products are manufactured using fuels and chemicals produced from petroleum and natural gas. However, the United States has the opportunity to more fully utilize its abundant coal resource as a flexible feedstock to produce liquid fuels and chemicals that address the country's energy and economic needs through Coal-to-Liquids (CTL) technology.

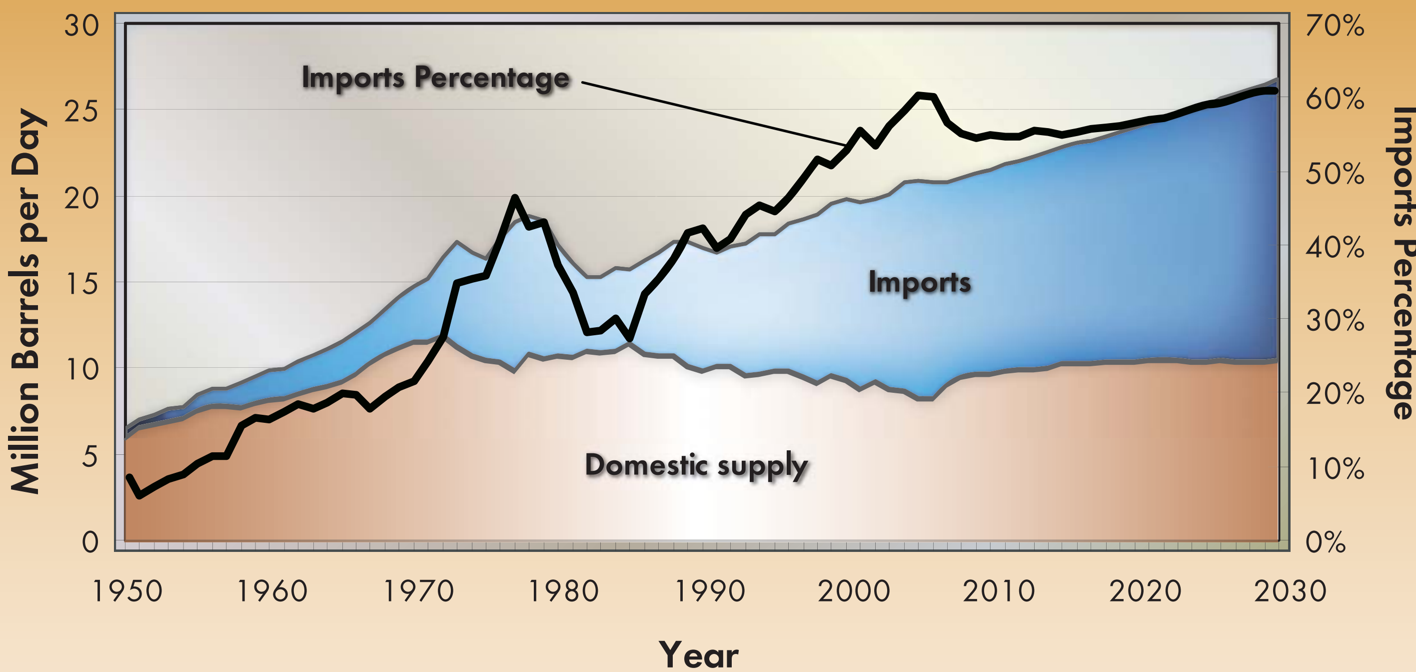
*The United States has an abundance of coal — approximately a 250-year supply at today's production rates.*

**Figure 1: World Oil and Coal Reserves — Billion Barrels Oil Equivalent (BBOE)***




**Source: EIA, International Energy Annual 2005 (1 ton coal is equivalent to 2 BBOE) and Oil and Gas Journal, January 2006*

**Figure 2: Domestic Liquid Fuels Supply and Imports — 1950–2030***




**Source: Energy Information Administration (EIA), Annual Energy Review 2006, July 2007, and Annual Energy Outlook 2007, February 2007.*
*Notes: Domestic supply includes crude oil production, lease condensate, natural gas plant liquids, refinery process gain, ethanol, liquids produced from natural gas and coal, and other supplies such as other hydrocarbons, ethers, and biodiesel.*

## DEPENDENCE ON FOREIGN OIL — A CONTINUING AND GROWING CONCERN

America's economic well-being is heavily dependent upon the availability of secure and affordable transportation fuels such as gasoline, diesel fuel, and jet fuel. The United States is becoming increasingly reliant on imported oil, some of which comes from potentially unstable regions of the world, while at the same time our domestic crude oil production has decreased (Figure 1). There also is growing global competition for petroleum as China and India continue their economic expansion. Finally, global energy delivery supply lines are getting longer, and exposure of these important lines to acts of terrorism will become more difficult to manage with time.

Acknowledging these factors, there is a growing consensus on the need to reduce U.S. dependence on imported oil, and to consider a portfolio approach of producing gasoline, diesel, and jet fuel from coal; utilizing oil shale; increasing domestic production of oil, gas, and biofuels; and increasing vehicle fuel economy.

The United States has an abundance of coal — approximately a 250-year supply at today's production rates. Figure 2 shows the relative magnitude of the domestic coal supplies in the United States compared to worldwide oil and coal reserves. Although the Middle East has the majority of proven oil reserves, the United States, Russia, China, India, and Australia control the largest coal reserves.

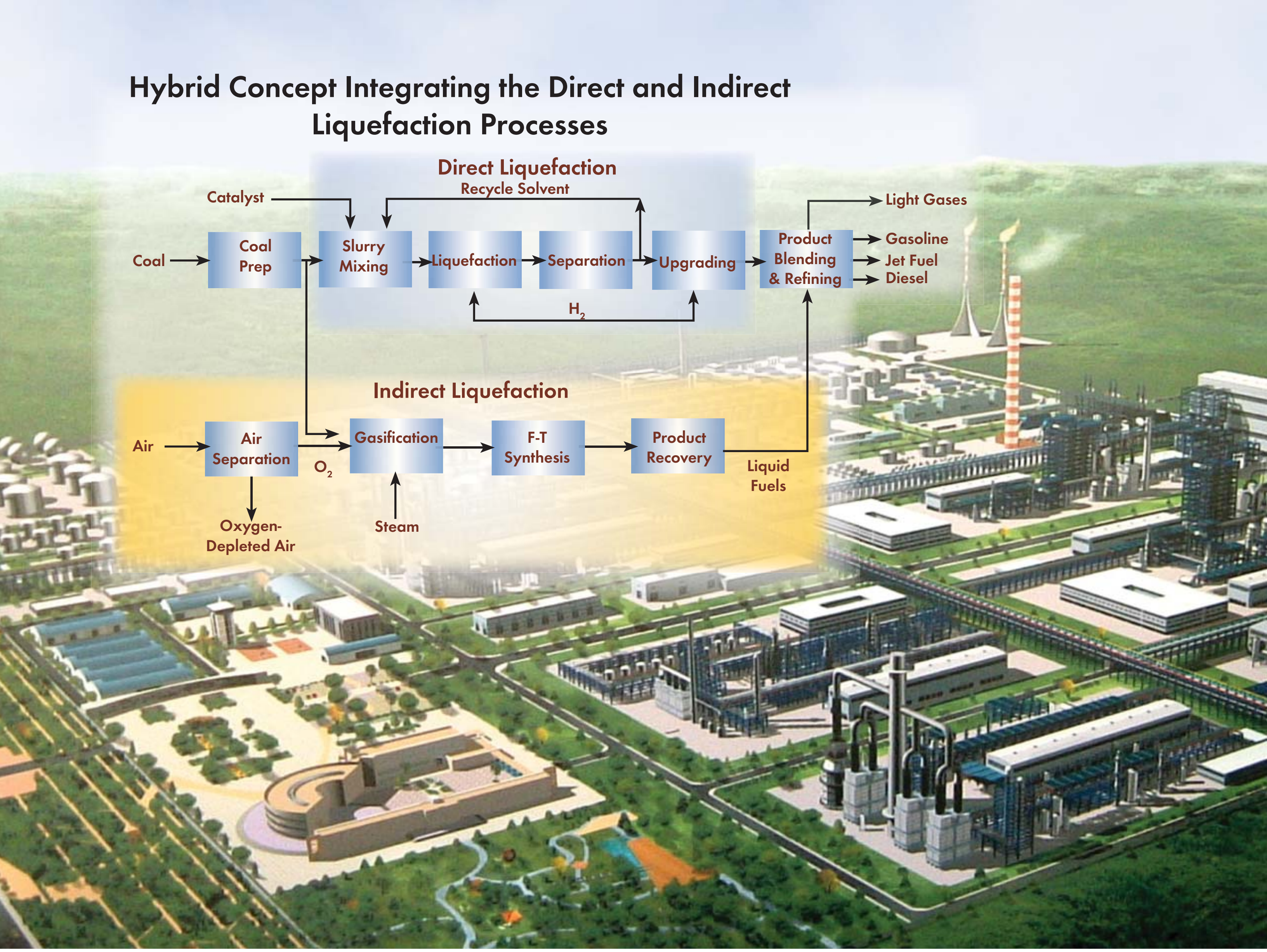
## CTL TECHNOLOGY BASICS

Approximately two barrels of clean diesel, gasoline, and jet fuel can be produced from a ton of coal. There are three processes that can produce these fuels from coal:

- **Indirect liquefaction,** which breaks down the coal into simple molecules that are then combined to form liquid fuels;
- **Direct liquefaction,** which breaks down coal to the correct molecule size to form liquid fuels; and
- **Hybrid concept,** which incorporates technologies from both direct and indirect liquefaction processes.

Additionally, all three processes can efficiently integrate carbon capture and storage technologies to mitigate global warming concerns.

In the indirect liquefaction process, coal first is gasified with oxygen and steam to produce synthesis gas — a mixture of carbon monoxide, hydrogen, and other compounds that is cleaned of impurities. The cleaned synthesis gas is sent to a water-gas shift reactor where the ratio of carbon monoxide-to-hydrogen is adjusted and optimized. The shifted gas then is fed to the Fischer-Tropsch (F-T) reactors where the gas is converted to liquid fuels. The liquid fuels have a high cetane value (a measure of diesel fuel quality), and contain zero sulfur and essentially zero aromatic compounds. The process yields mostly diesel and jet fuels, which can be




used in vehicles and airplanes, or blended into petroleum-derived diesel and jet fuels and subsequently used. Typically, carbon dioxide is captured during the water-gas shift and F-T reactions, making the process "carbon capture ready" and very amenable to carbon sequestration.

An alternative to the indirect liquefaction process is direct liquefaction, which converts coal at high temperature and pressure, in the presence of hydrogen and catalyst, to liquid fuels. This process results in more of, and a higher octane gasoline (measure of gasoline quality) compared to the indirect process. However, in order to meet current fuel quality requirements, some additional processing in a traditional oil refinery may be required.

Finally, a hybrid process concept combines technologies from both the indirect and direct liquefaction processes.

There are two key features of this hybrid process: 1) the hydrogen required for the direct process can be manufactured in the indirect process; and 2) the hybrid process yields both a high-quality diesel fuel from the indirect process and a high-quality gasoline from the direct process.

## BENEFITS OF CTL TECHNOLOGY

- Reduce growing dependence on imported crude oil by using ample domestic coal reserves
- CTL technology has been demonstrated for more than 50 years
- CTL fuels can be zero-sulfur, zero-aromatic fuels, and can be used in existing engines
- CTL fuels can be distributed using the existing crude oil and product infrastructure
- Aside from liquid transportation fuels, CTL plants also can produce power and chemical feedstocks in "poly-generation" plants
- CTL plants and hydrogen from coal plants share many of the same technologies; therefore if a transition to a hydrogen economy occurs, investment in CTL plants will not result in stranded investments since the plants can be converted to produce hydrogen
- Unique jet fuel qualities are of particular interest to the United States Air Force
- CTL fuels can be competitive with crude oil at $50/bbl

Artist Conception of the Shenhua Direct Coal Liquefaction Plant in China.

- Efficient integration of clean coal technologies and carbon capture and storage technology minimize environmental concerns

## FOCUS ON ENVIRONMENTAL ISSUES AND GREENHOUSE GASES

Coal liquefaction processes are designed to be responsive to environmental concerns, including global warming. The design of an indirect liquefaction plant provides a logical and cost-effective mechanism for carbon dioxide separation that can readily be used in a carbon capture and storage scheme. CTL technology also capitalizes on the decades of achievements of the DOE Clean Coal Program including gasification technology advancements, oxygen production and separation, state-of-the-art effluent gas treatment and emissions controls, novel hydrogen production technologies, and the latest carbon dioxide capture and storage developments.

CTL processes can also benefit from the environmental advantages of co-firing biomass with coal, thus further minimizing carbon dioxide emissions. Since biomass resources such as switchgrass, hybrid poplar, and corn stover (the remaining parts of corn left in the field such as the stalks and leaves) are considered renewable resources and produce no net $CO_2$ emissions, supplementing coal with some biomass allows the CTL facility to take advantage of the biomass $CO_2$ emissions benefit.

## EVOLUTION OF CTL TECHNOLOGY

Coal liquefaction technology has its roots in Germany where direct liquefaction was developed by Fredrich Bergius in 1917, and indirect liquefaction was developed by Franz Fischer and Hans Tropsch in 1923. The process they developed is more commonly known today as the Fischer-Tropsch process.

CTL technology was originally utilized to assure fuel supplies during World War II. This process was costly and eventually abandoned after the war ended. The only other, and currently thriving, significant application of CTL technology is in South Africa, where more than 150,000 bpd of CTL fuels and chemicals are produced in vintage 1980s technology plants. The U.S. Department of Energy (DOE) had a successful CTL program in the 1980s coinciding with the spike in petroleum prices, but interest in the program subsided by the early 1990s as oil prices retreated. The DOE program during that time successfully developed several technologies to the demonstration-scale phase in partnership with industry. Until recently, high investment costs have limited further application of this technology.

Currently, China plans to make significant investments in CTL technology to enhance their energy security. Also, India is pursuing engineering studies for implementation of CTL technology. Both China and India have sizeable coal reserves, second only to the United States.

## TECHNOLOGY ADVANCEMENTS

In the 1980s and 1990s, DOE research, development, and demonstration (RD&D) activities successfully developed several coal pilot scale liquefaction technologies and more recently, several companies have begun to initiate commercial-scale CTL activities in the United States and around the world. Of note, the People's Republic of China is aggressively pursuing CTL commercialization and is implementing technology developed under the DOE RD&D Program from the 1980s and 1990s.

In response to the concerns over climate change, there is growing emphasis on implementing carbon capture and storage technology and on co-feeding coal and biomass feedstocks to reduce the carbon footprint of CTL plants as noted below:

- DOE has an aggressive program on carbon sequestration which continues to make advancements in the safe, permanent, and secure storage of carbon dioxide from large central plants. As announced in October of 2007, DOE co-funded a $318 million new world class $CO_2$ sequestration program initiative aimed at demonstrating the technical viability of the $CO_2$ storage technologies and assuring environmental safeguards on an industrial scale.
- Co-feeding of coal and biomass to produce liquid fuels is a relatively new concept. DOE-sponsored R&D programs will play a key role in progressing this co-feeding concept in light of the limited data available on the processing of coal and biomass mixtures and technical and economic issues. Key issues include development of feedstock preparation and pre-treatment technologies needed for various coal and biomass feedstock types and feed mixture percentages of each and characterization of the solid, liquid, and gaseous products from the gasifier.

*CTL processes can also benefit from the environmental advantages of co-firing biomass with coal, thus further minimizing carbon dioxide emissions.*

## EXPANDED GOVERNMENT ROLE

Reliable and affordable energy is central to the United States' continued economic and national security. The role of the federal government is to help the nation meet its energy, scientific, environmental, and national security goals. This is achieved by developing and deploying new energy technologies to reduce dependence on foreign energy sources, in an environmentally responsive manner; ensuring U.S. competitiveness in the global marketplace; and encouraging entrepreneurship and innovation.

Expanded government efforts in coal liquefaction can support this overall role, and are focused on four key areas: technology, operability, financing, and education. Combined, these government efforts should result in economically acceptable solutions that will provide important and environmentally sound alternatives for the nation's growing liquid fuel needs while maintaining U.S. technology leadership.

The United States Air Force has taken an active role in pursuing development and utilization of CTL fuels, having certified its B-52H Stratofortress aircraft on a 50/50 blend of JP-8 and F-T fuel. The Air Force plans to test and certify every airframe to operate on the blend by early 2011. Additionally, the Air Force has a goal of purchasing 50 percent of its fuel supply in 2016 from domestic synthetic fuel sources such as CTL.

Another effort underway is a joint government-industry activity known as the Commercial Aviation Alternative Fuels Initiative (CAAFI). CAAFI participants include:

- **Government:** DOE, Department of Defense, Federal Aviation Administration, Department of Commerce, National Aeronautics and Space Administration
- **Industry:** Coal, biofuels, Air Transport Association, Aerospace Industries Association, Airports Council International-North America
- **Universities** and think tanks

CAAFI is pursuing alternative fuels for the purpose of securing a stable fuel supply, reducing environmental impacts, improving aircraft operations, and furthering research and analysis. CAAFI is structured into four panels — research, environmental, economics and business, and certification and qualification — which focus on achieving this purpose.

## Possible Federal Government Roles

**From a *technology* point of view:** Supporting R&D to resolve the following issues regarding CTL technology: update process technology for latest gasification developments, assure processing flexibility to accommodate selected biomass feedstocks, conduct economic studies and analyses to determine most attractive process designs, and determine how best to integrate carbon capture and storage concepts.

**From an *operability* point of view:** Advance construction of first-of-a-kind pioneer plants to demonstrate the overall technical feasibility and operability, and establish economic, technical, and environmental baselines to better define the technology.

**From a *financing* point of view:** Develop and implement the preferred financial incentive package including investment credits, tax breaks, low cost financing alternatives, and loan guarantees to reduce financial risk and encourage industry investment.

**From an *educational* point of view:** Foster education and proactive communication programs to inform the public about CTL technologies, their products, and benefits, and address any concerns.

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