

From Coal and Biomass to Synthetic Fuel

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The U.S. Air Force is aiming for 50 percent of its fuel to be synthetic by 2016, and it must also drastically reduce carbon dioxide emissions. A novel process could make both these goals a reality.

Energy availability and affordability are crucial to the national security of most countries, and the United States is no exception. The perennial instability in the Middle East, the wars in Iraq and Afghanistan, the increased demand for oil in Asia, and the effects of natural disasters like Hurricane Katrina have combined to drive oil prices into the prohibitive range for U.S. citizens, businesses, and government agencies. A new level of fear over the uncertainty of oil supplies has penetrated everyday life, and many believe that the government's ability to ensure the people's safety is at stake.

The task of ensuring the nation's security falls to the U.S. Department of Defense (DOD), which must have assured and affordable energy sources to fulfill that mission. The DOD is the largest single energy consumer in the United States; but at less than 1.5 percent of the total U.S. oil mar-

ket, it is more of a participant than a market driver.

As the sidebar "Energy Spending and Reduction Goals" describes, the DOD has ambitious plans for future energy allocations and reductions. A promising way to meet these goals is to produce synthetic fuel oil through the Fischer-Tropsch (FT) chemical process, which converts natural gas or coal into liquid fuel. The two German scientists for which the process is named created FT in 1923, and Germany later used it in World War II to produce fuel oil from coal. The process is still viable, but as of December 2007, South Africa was the only country with commercially operational FT plants. These plants alone produce more than 150,000 barrels per day (BPD) of gasoline, diesel, and jet fuels for cars, trucks, and airplanes.

Recognizing FT's potential, the U.S. Air Force (USAF) began investigating the

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- Coal and biomass co-conversion has a double benefit in reducing carbon dioxide: no carbon input penalty from the biomass and the ability to capture and sequester carbon during conversion.
- In all cases, the coal-and-biomass-to-liquids plants could produce the desired carbon dioxide level by co-gasifying coal with a relatively modest amount of biomass.
- Studies project that enough biomass will be available to support the production of 100,000 barrels per day of fuel, which means that biomass availability should not be a constraining factor.
- An aggressive timeline for ramping up a coal and biomass to liquids industry would require government incentives for alternative fuel use, but it could meet the U.S. Air Force's fuel production and emission-reduction targets.

Energy Spending and Reduction Goals

In fiscal year 2006, the U.S. Department of Defense (DOD) spent more than \$20 billion on energy. Liquid fuels for aircraft, ships, tanks, and other vehicles accounted for about 75 percent of its energy consumption. With DOD's current consumption about 350,000 barrels of oil a day, a \$10 per barrel price increase translates to an additional \$1.3 billion on its fuel bill.

In fall 2005, then Secretary of Defense Donald Rumsfeld established the Energy Security Task Force to explore near- and long-term options for reducing DOD's energy use. The task force recommended increasing platform efficiency, establishing an alternative fuels program, and accelerating initiatives to make military installations more energy efficient.

At 200,000 barrels of fuel per day, the U.S. Air Force (USAF) is the largest energy consumer within the DOD. In 2001, USAF established the Assured Fuels Initiative to reduce U.S. dependence on foreign oil through the development of innovative practices and the pursuit of new technologies. In partnership with other federal agencies, USAF is conducting or funding the research and development necessary to evaluate, demonstrate, and certify a clean, secure, and environmentally responsible fuel for aircraft operations.

process, and in 2006, successfully tested a 50-50 blend of conventional jet fuel and FT synthetic fuel derived from natural gas. The following year, it tested the blend again in a B-2 bomber in both warm and cold weather. In both cases, the synthetic fuel blend performed on par with conventional petroleum-based military aviation fuel. Tests in other aircraft are planned through 2011, and tests will expand to include the B-1 bomber and C-17 cargo jet.

Because scientists can create the synthetic fuel from numerous natural resources, such as coal, natural gas, shale, tar sands, and renewables, USAF began working with the U.S. Department of Energy's National Energy Technology Laboratory (NETL) to examine the feasibility of producing 100,000 BPD of jet fuel from coal and biomass with a net carbon footprint 20 percent below that of fuels produced from conventional petroleum. NETL, in turn, tasked Noblis to develop plant designs that

could meet these USAF targets for alternative fuel production.

Co-conversion requirements

An existing process, coal to liquids (CTL), can produce high-quality, zero-sulfur fuels from coal by gasifying the coal and then passing the clean coal-derived gas—essentially carbon monoxide and hydrogen—over FT catalysts. However, because significant energy is used in conversion and the carbon content of the coal feedstock is high, the carbon dioxide (CO₂) emissions, on a well-to-wheels basis, are more than double those from petroleum. The sidebar “Emissions Comparison” describes how Noblis measured these emissions. When coupled with carbon capture and sequestration during fuel production, CTL can only roughly match existing CO₂ emissions from petroleum. If, however, biomass is added to coal and the two are used together as feedstock, it is possible to meet USAF's goals of assured fuel security and a smaller carbon footprint.

This coal and biomass to liquids (CBTL) process has several advantages over CTL. As Figure 1 illustrates, the carbon in the biomass is not counted as a carbon input penalty because through photosynthesis the biomass has recently removed this carbon

from the atmosphere. Moreover, during conversion, part of this biomass carbon is captured and sequestered within the CBTL facility. Thus, a double benefit accrues—no carbon input penalty and the ability to capture and sequester the carbon within the biomass during conversion.

Plant design

Executing the CBTL process would first require that a plant be able to co-gasify mixtures of coal and biomass to produce a clean synthesis gas. It must then send that gas to FT units that would produce clean synthetic diesel, jet, and naphtha liquid fuels.

An appropriately designed plant must have the right mixture of coal and biomass. To comply with the USAF target, the mixture must produce these synthetic fuels with a net carbon footprint (or net CO₂ emissions) 20 percent lower than when producing these fuels from petroleum.

Biomass and coal types

USAF requested three biomass types—woody biomass (such as poplar trees) switch grass, and corn stover—all of which are relatively abundant and not a food source for humans. For the coal part of co-conversion, the choice was Illinois #6 bituminous coal in all three designs.

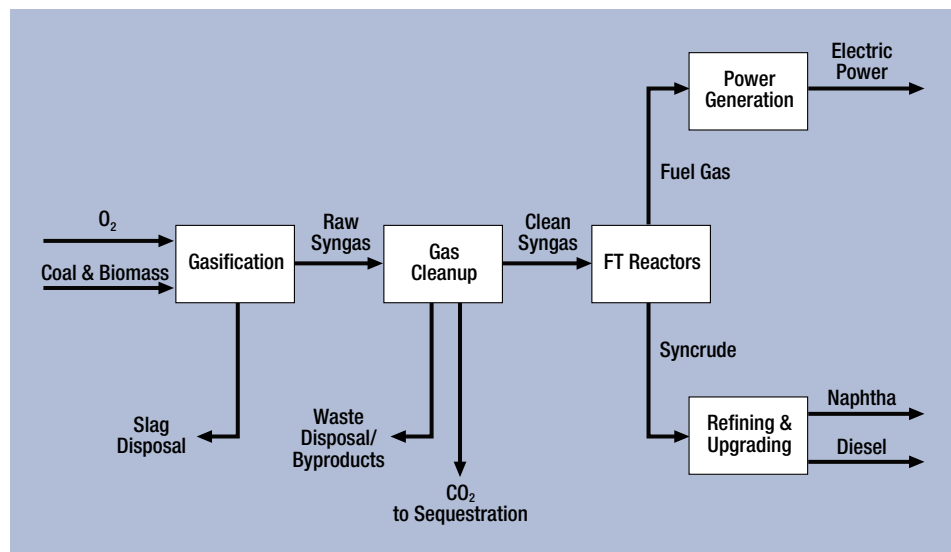


Figure 1. How the coal and biomass to liquid fuel (CBTL) process works. Coal and biomass are gasified in entrained flow gasifiers (Gasification) and the raw synthesis gas is cleaned of impurities (Gas Cleanup). The clean synthesis gas is then sent to one or more FT reactors, where the hydrocarbon fuels are produced.

Emissions Comparison

To compare CO₂ emissions from petroleum-derived and Fischer-Tropsch diesel, Noblis looked at the major CO₂ sources from biomass and coal production and transportation to the coal to liquids (CTL) facility. Sources included the carbon emissions associated with biomass production (planting, fertilization, harvesting, processing and transportation) and coal mining and transport as well as the CO₂ emissions from transporting the diesel product and from fuel combustion. Most of these emissions, apart from fuel combustion, came from the energy used in each processing step.

The well-to-wheels life-cycle analysis was somewhat limited in that it omitted the CO₂ emissions from building the CTL facility. Because of the controversy surrounding this issue, the analysis also omitted any credits for soil carbon that the biomass stores. Finally, only CO₂ emissions were included, not those of other greenhouse gas emissions like methane and nitrous oxide.

To estimate CO₂ emissions associated with feedstock and product production, transport, and processing, Noblis analysts used the Argonne National Laboratory's Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) version 1.7. GREET, an open-source model sponsored by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy, has been used to evaluate various fuel and vehicle systems for government and industry and is widely accepted as a tool for estimating well-to-wheels greenhouse gas emissions from fuels.

Noblis then prepared a conceptual process design for a CBTL facility that could co-feed coal and the particular biomass type into a gasifier to produce a synthetic gas suitable for FT synthesis. The conceptual design estimated the performance, size, and cost of the major pieces of equipment and provided the basis for arriving at the CO₂ emissions associated with FT diesel fuel synthesis.

Conceptual plant designs

All the conceptual CBTL plant designs were based on the process configuration in Figure 1. The plants studied were 7,500 BPD diesel plants located in southern Illinois. The 7,500 BPD capacity was based

on a preliminary and highly approximate estimate of the required biomass. Choosing this as the reference plant size does not imply that it is either the maximum or optimal size for a CBTL plant. Indeed, enough biomass could be available for plants at least as large as 30,000 BPD.

For each conceptual plant, Noblis estimated the amount of biomass that would have to be co-fed with coal to attain the target 20 percent reduction in CO₂ emissions. In these plant configurations, about 88 percent of the CO₂ emissions from the conversion of coal to FT fuels are captured and compressed to 2,200 pounds per square inch. After compression, the CO₂ is piped from the CBTL plant boundary to a site for sequestering.

Table 1 shows the percentage of biomass co-fed with coal (on both a weight and an energy basis) that is needed to attain the CO₂ emissions target in producing FT diesel. In all cases, the plants could produce the desired CO₂ level by co-gasifying coal with a relatively modest amount of biomass.

Economics and feasibility

As part of this study, Noblis conducted economic analyses for the coal-only (CTL) and CBTL plants to estimate the capital and operating costs of these plants and thereby the required selling price of the liquid fuels. Table 2 shows the product's required selling price for CTL and CBTL plants with each of the three biomass types.

Overall, this analysis found that the percentage of biomass required is relatively low and within the range of the limited gasification demonstration test data available for coal biomass that is co-fed to pressurized gasifiers. For this reason, Noblis believes that the proposed CBTL process is feasible.

Nonetheless, the amount of actual field data available on gasification of biomass in pressurized entrained flow gasifiers is so limited that considerable research, design, and development will be needed to determine the pretreatment necessary and arrive at the optimal system that will enable the reliable feeding of these biomass types to high-pressure gasification systems. Biomass gasification using high-temperature and pressure-entrained flow gasifiers

Table 1. Biomass needed to achieve a 20 percent reduction in CO₂ emissions.

Biomass Type	Weight (Percent)	Energy (Percent)
Woody	10 to 15	7 to 10
Switch grass	12 to 18	7 to 10
Corn stover	12 to 18	7 to 11

Table 2. Required selling price of fuels (per barrel) in the CTL and CBTL plants and crude oil equivalent price (also per barrel).

Plant Type	Required Selling Price	Crude Oil Equivalent
Coal-only (CTL)	\$71	\$55 to 60
CBTL with woody biomass	\$76	\$58 to \$62
CBTL with switch grass	\$75	\$58 to \$63
CBTL with corn stover	\$75	\$58 to \$63

Table 3. Biomass yields needed for a CBTL facility producing 7,500 barrels per day of FT diesel and land area required to produce the yield.

Biomass Type	Yield (dry tons per acre)	Land Required (sq. mi.)
Woody	5 to 6	1,440
Switch grass	5 to 6	1,440
Corn stover	2	920

would be preferable to eliminate tar and methane formation from the biomass. Also the CBTL plants would be simpler and less costly if they could use the same gasifier to process both coal and biomass. Separate feed systems for coal and biomass could have a potential advantage: If the biomass feed system has problems, the plant can keep the gasifier operational using coal.

Resource assessment

Noblis in cooperation with two of its subcontractors also conducted a limited resource assessment to determine if sufficient biomass can be harvested and transported to a CBTL facility that was large enough to be economically practical. Results indicate that plants producing about 7,500 BPD of FT diesel would require a sustainable annual biomass supply of 1,000 tons per day. Thus, for plants of that size, biomass

availability would not be a major limiting factor. Table 3 shows the yields for each biomass type and the land area required to produce them.

The land required to grow enough woody and switch grass biomass is higher because the study assumes that only 8 percent of the land is available for producing energy crops. Corn stover requires fewer square miles because as much as 31 percent of the land is likely to be available. The study also assumes that half the crop is left on the land for soil conditioning.

All three biomass types showed nearly equivalent performance in the CBTL process, but harvesting and processing costs varies. Because biomass is far less dense than coal, CBTL plants will probably be located closer to crop-growing areas to reduce biomass transportation costs. Figure 2 shows the expected distribution of biomass crops. Coal can readily be transported economically over long distances.

Various studies have looked at the amount of biomass that might be available for energy production. A joint 2005 study by the U.S. Department of Energy and U.S. Department of Agriculture¹ suggests that an annual biomass supply of 1.3 billion dry tons is technically feasible, including forestry and forest product residues, agriculture residues, urban wastes, and dedicated energy crops. Approximately 256 million dry tons of this 1.3 billion is corn stover and 377 million is energy crops, such as switch grass and poplars. A 1999 study by Oak Ridge National Laboratory² suggests that more than 500 million dry tons of biomass could be available in the United States at delivered prices between \$55 and \$65 per dry ton (in 2006 dollars). More than 330 million of that will be agricultural residues or energy crops (switch grass, poplars, or other).

More recently, a study by the University of Tennessee³ analyzed two scenarios in which biomass plays a more significant role in the nation's total energy future. This study projects that, by 2025, 1 to 1.3 billion dry tons of biomass will be available nationwide. Figure 2 shows one scenario of the quantity and location of new crop residues and dedicated energy crops, such as switch grass and poplars, that could be available by 2025.

Around 2015, the greatest concentration of crop residues and dedicated energy

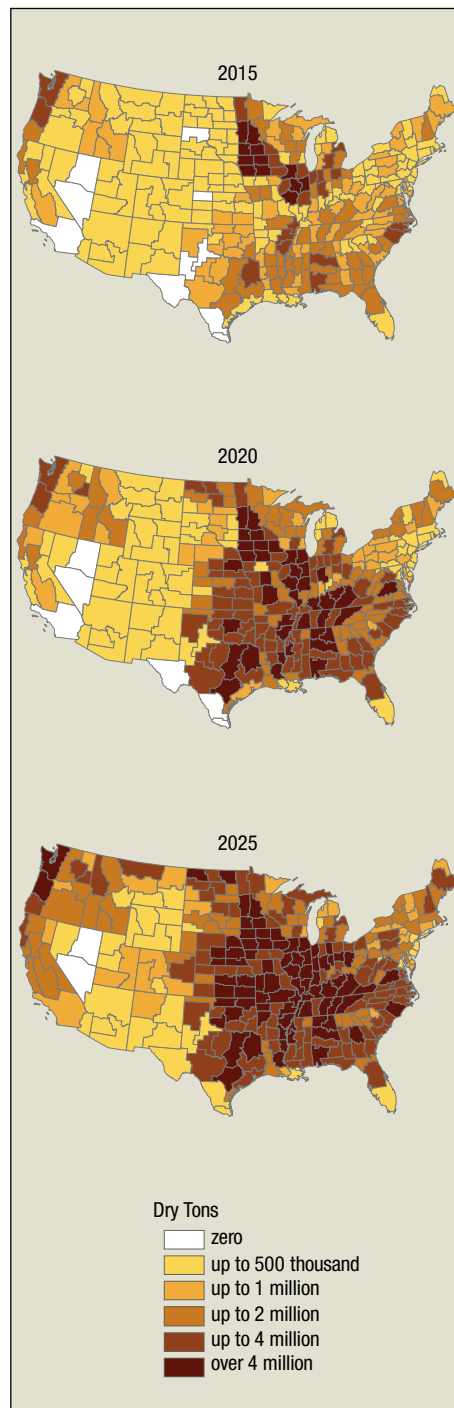


Figure 2. Expected distribution of new biomass energy crops from 2015 to 2025. Initially, biomass production would have to rely on existing crop residues, but by 2015, crop residues and dedicated energy crops should be widely available throughout the United States with the highest concentrations in the central, eastern, and southeastern regions. Source: B.C. English, et al., *25% Renewable Energy for the United States by 2025: Agricultural and Economic Impacts*, Univ. of Tenn., Agricultural Economics, Nov. 2006.

crops should be in Illinois, Iowa, and other Midwestern states, a region that is also close to the Illinois coal basins. Thus, it is likely that the central United States will be the site of first adoption for CBTL plants.

From these studies, it appears that a significant amount of biomass feedstock might be available—enough to support the production of 100,000 BPD of fuel. Thus, biomass availability should not be a constraining factor.

Cost exclusions

Except for one sensitivity case, the economic analysis excluded all additional cost for sequestering or storing the CO₂. In the sensitivity case, Noblis added \$4.60 per metric ton for CO₂ transporting, sequestering, and monitoring. This increased the required selling price of the FT fuels by about two percent compared to cases with no costs for those functions. However, if the CO₂ could be sold for enhanced oil recovery operations, it would have a positive value and represent a credit in the economic analysis.

Industry ramp-up scenarios

Figure 3 shows four hypothetical timelines for the buildup of a CBTL industry that could supply 100,000 BPD of FT diesel. Figure 4 shows a breakdown for the most aggressive scenario, the only one that meets the USAF production target by 2016.

Conservative

The conservative timeline in Figure 3 assumes that one developer will enter the market and begin the permitting and design process in 2008. Two years are allotted for this phase followed by four years of construction. The plant begins producing in 2014 with a 50 percent maximum capacity factor for the first year and 90 percent maximum for the second year, followed by sustained operations at the rated plant capacity.

After a full year of operation, work begins on the second-generation plant of double the original capacity. This plant should require only one year for design and permitting and only three years for construction. The scenario assumes that a second developer will enter the market when the

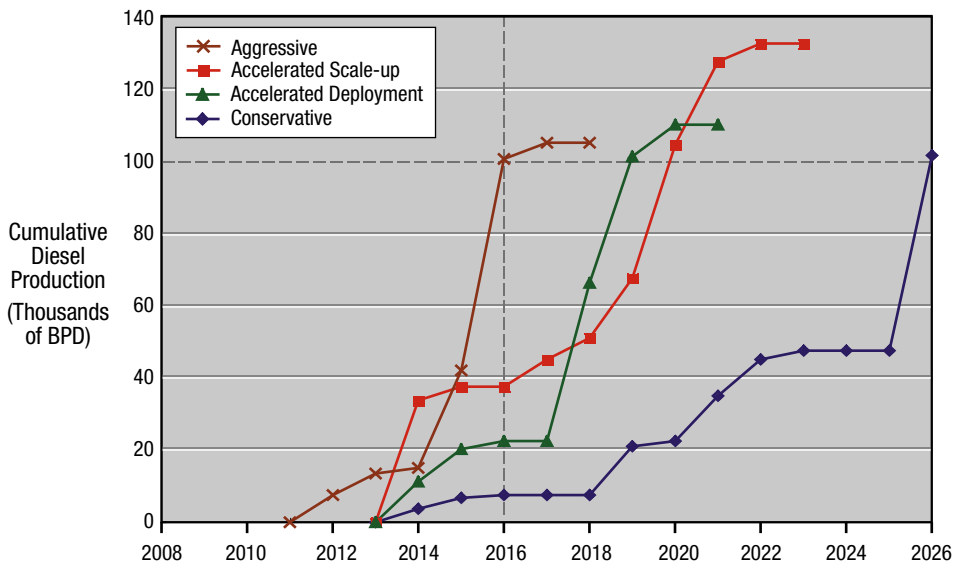


Figure 3. Scenarios for ramping up a CBTL industry. Of the four timelines, only the aggressive scenario meets the USAF production target (100 BPD) and deadline (2016). Each timeline assumes that the first plants use corn stover, since it is already available. The entry of CBTL plants that use switch grass or woody biomass occurs in 2015 or later, allowing sufficient time to cultivate and mature these crops.

first developer starts the second-generation plant. This developer will focus on the two other biomass types. After these new plants have been in operation for a year, work begins in 2022 on a set of third-generation plants, which come online in 2026.

Although this scenario represents a conservative industry buildup, it is reasonable, if crude oil prices do not sharply escalate and the government does not implement any incentive programs to accelerate the development of alternative fuels. Under this scenario, the USAF target goal of 100,000 BPD of domestic synthetic fuels will be met in 2026.

Accelerated

Although reasonable, the conservative scenario is a decade behind in meeting the USAF’s target goal. The accelerated ramp-ups in Figure 3 come much closer to meeting the 2016 deadline, but most likely, they will require the government to implement one or more incentive programs to encourage alternative fuels. In this scenario, technology is rapidly deployed, perhaps by having more developers enter the market or by having developers build more plants than in the conservative timeline.

The accelerated deployment timeline would be more likely if the government

implemented incentives such as a guaranteed floor price or guaranteed market for the diesel fuel produced. In the accelerated scale-up timeline, the movement to large-scale plants is rapid. Large-capacity plants have significant economies of scale, at least up to the size of 80,000 BPD total product, but they require extremely large capital investments. This rapid scaling

would be more likely if the government provided loan guarantees. The scenario represented in the accelerated deployment timeline attains 38 percent of the USAF’s target production by 2016, fully meeting the target level four years later. The scenario represented by the accelerated scale-up timeline attains only 23 percent of the target production by 2016, but it fully meets the target level a year earlier, in 2019.

Aggressive

None of the scenarios thus far meets the target production level of 100,000 BPD diesel by 2016. Meeting that deadline—the aggressive timeline in Figures 3 and 4—would require combining the scenarios in the accelerated timelines (deployment and scale-up) or compressing the design and construction timelines and eliminating the learning period between the completion of one plant and the initial construction of the next. This aggressive scenario would be more likely if the government could implement incentives such as time-limited guarantees of diesel floor prices.

The aggressive scenario also assumes the construction of seven CBTL facilities, the first two being small 7,500 BPD facilities of the same design as the reference plant studied in the economic analysis. These first plants would use corn stover. Over time more plants would be constructed simultaneously, and these would have larger capacity (up to 22,500 BPD) and use

Feed	Developer	BPD	2008	2009	2010	2011	2012	2013	2014	2015	2016
Corn stover	1	7,500					3,750	6,750	7,500	7,500	7,500
Corn stover	1	7,500					3,750	6,750	7,500	7,500	7,500
Corn stover	2	15,000								13,500	15,000
Switch grass	2	15,000								13,500	15,000
Switch grass	1	15,000									15,000
Corn stover	2	22,500									20,250
Short rotation woody crops	2	22,500									20,250
TOTAL							7,500	13,500	15,000	42,000	100,500

Figure 4. Breakdown of the aggressive timeline in Figure 3. This timeline, which represents the only schedule that meets USAF targets, is for ramping up to 100,000 barrels per day (BPD) production by 2016. As with the other timelines in Figure 3, the aggressive timeline assumes an initial period dedicated to acquiring a permit and designing the facility (yellow) followed by a construction period (orange) and then plant operation (green). During plant operation, a ramp-up scenario is applied to the first 1-2 years of operation, allowing for shakedown.

mixtures of switch grass, corn stover, and woody biomass. As Figure 4 shows, in this scenario, shakedown periods for startup will grow shorter.

This study shows that it is clearly feasible to use the CBTL process to meet USAF's target production and environmental goals. The concept of joining coal and biomass as feedstock to produce high-quality FT fuels through gasification should benefit both coal and biomass technologies. Co-processing biomass with coal can significantly reduce the carbon footprint of a CTL facility, and the gasification route allows the use of non-food product biomass like cellulose and lignin for energy production. The use of coal with biomass significantly improves the economies of scale compared to a biomass-to-liquid facility and also dampens the impact of biomass supply fluctuations.

The study has also provided insights that have evolved to recommendations. The first is that considerable research and development will be needed to determine the pretreatment and optimal system for reliably feeding these biomass types to high-pressure gasification systems. Biomass preparation and biomass impact on gasifi-

cation are other issues that warrant further investigation.

Another recommendation is to perform a more detailed biomass resource and infrastructure assessment. The goal would be to determine the maximum CBTL plant size that is technically feasible as well as the optimum plant size for which economies of larger scale balance the increased cost of collecting larger quantities of biomass.

Finally, because biomass availability is often seasonal, any CBTL plant should have processing equipment suitable for several biomass types. The woody biomass should be available most of the time depending on the cutting cycle. The coal would act as the flywheel to keep the plant operating at a fairly constant output.

Future work is likely to result in additional recommendations. The results reported here are for a limited range of CBTL processes—all using less than 20 percent biomass. Noblis is already conducting a more comprehensive study to quantify the CO₂ emission benefits of CBTL plants that use larger proportions of biomass—all the way to 100 percent biomass.

This study underlines the intriguing possibilities of having both energy security and environmental responsibility. The DOD's

successful use of synthetic fuel could motivate the commercial sector to examine its potential benefits, thereby taking a huge step toward reducing U.S. dependence on oil. ❖

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David Gray and Charles W. White III are coauthors of "Harmonizing the Three E's of Energy Security." Their biographies appear on p. 14 of this issue.

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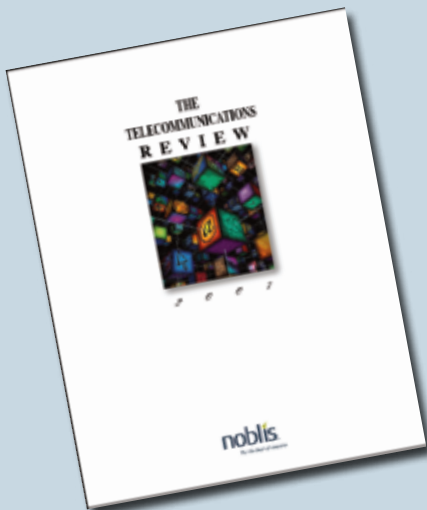


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