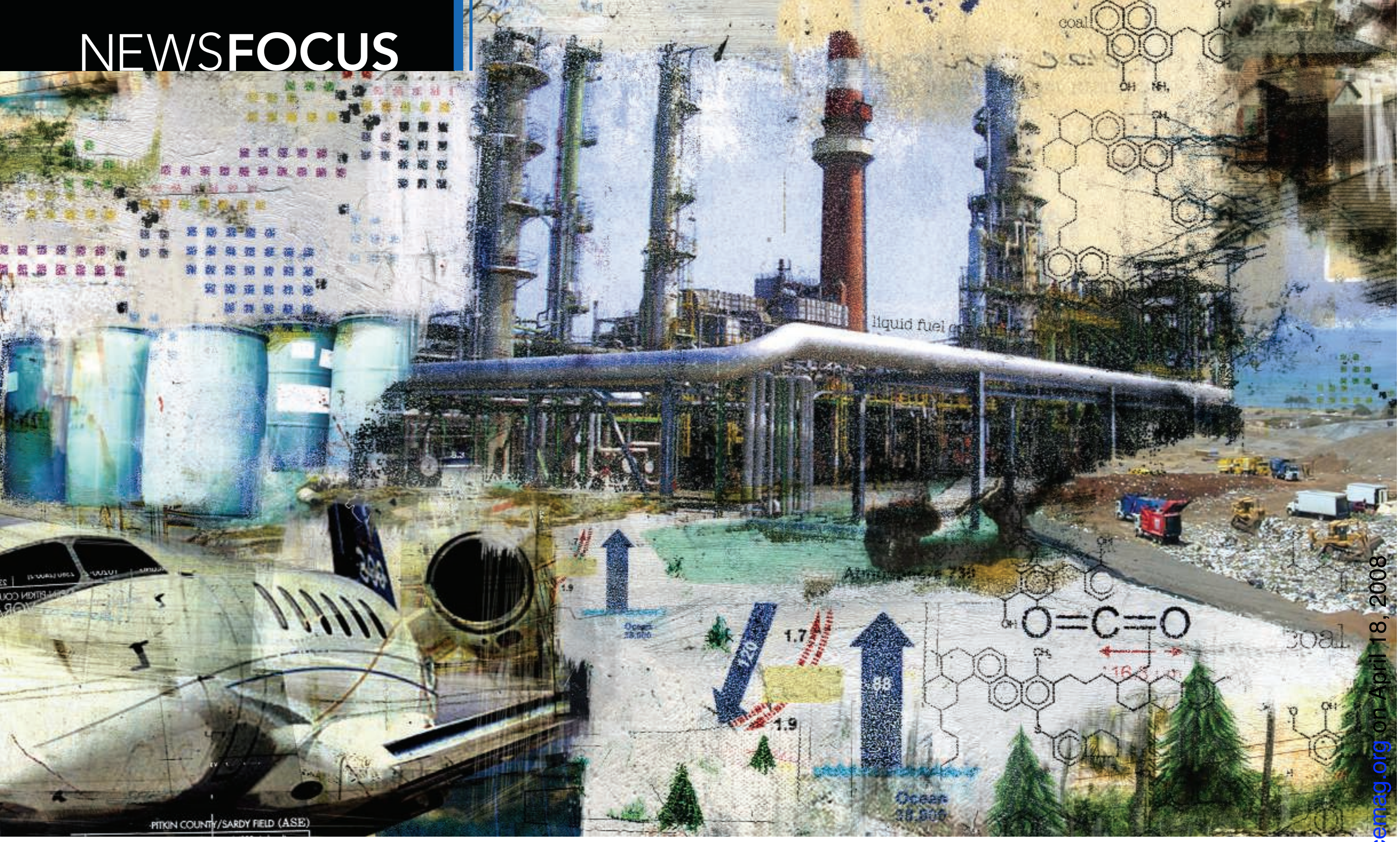

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The Greening of Synfuels

An old, dirty technology to make transportation fuels from coal could fight global warming, say proponents. The trick is using more biomass and burying the carbon dioxide that's generated

A multibillion-dollar U.S. effort to turn coal into gasoline was a colossal flop in the 1980s, plagued by mismanagement, political wrangling, and falling oil prices. Environmentalists concerned about the impact of additional coal mining cheered the end of the synthetic fuels program, which was aimed at cutting U.S. dependence on oil from the Middle East.

A generation later, the geopolitical reasons for reducing U.S. oil imports are more compelling than ever. And with oil prices above $100 a barrel, the economic equation has changed. So it's no surprise that a few U.S. energy companies have drawn up plans for synfuels plants that would produce millions of barrels of the alternative fuel annually.

But this time around, the technology is also gaining support from a seemingly unlikely source. A group of climate scientists believes that, barrel for barrel, synfuels can emit less carbon dioxide (CO_2) than oil and, at some point, even reduce the amount of carbon in the atmosphere. "When you make synfuels, you have an incredible opportunity" to tackle climate change, says Princeton University physicist Robert Williams, an advocate of the technology.

Living up to that promise won't be easy, however. The two keys to making synfuels green are using large amounts of plant biomass along with coal and storing in the ground the CO_2 emitted during the production of synfuels. And neither has been implemented on a commercial scale. Most environmental groups are still horrified by the thought of more synfuels plants and are loath to see coal mining expanded. They also point out that the process produces CO_2 at twice the rate of making gasoline from crude oil without CO_2 storage and the use of biomass, the result would be disastrous. At least eight synfuels plants are expected to open soon in China, with 17 more planned; they will spew forth millions of tons of CO_2. A coal-fed facility in Secunda, South Africa, built to cope with an apartheid-era fuel embargo, is the planet's single biggest point source of carbon, emitting 20 million tons of CO_2 a year.

"[Synfuels] may be worth looking into, and I have no doubt someone's going to make money with the process," says energy professor Daniel Kammen of the University of California, Berkeley. But he thinks those who see a climate benefit are underestimating the costs of large-scale carbon storage while overestimating the availability of biomass that can be harvested without having deleterious effects. As a climate solution, he says, "I'm a lot less sanguine that it's going to work out."

What a gas

The chemistry involved in making synfuels is not complicated. The process begins by turning coal into gas, which creates carbon monoxide and hydrogen (see diagram, p. 309). The resulting syngas, as it's called, is then converted with catalysts into products such as diesel fuel, jet fuel, or chemical feedstocks after scrubbing for pollutants.

Germany operated the first large-scale commercial synfuels plants in the 1940s to provide fuel for a Nazi war machine starved by an Allied oil embargo. Then the 1970s gasoline crunch led U.S. President Jimmy

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Carter and Congress to create the $20 billion Synthetic Fuels Corp. in 1980. The goal was to use coal to produce 700 million barrels of oil per year by 1992. The corporation spent $2 billion on demonstration projects in California, Louisiana, and North Dakota. But management scandals, battles between the corporation and the White House during the Reagan Administration, and, ultimately, the falling price of oil—it hit $21 a barrel in 1986—caused Congress to pull the plug that year. Experts said the only thing that would revive synfuels was $100-a-barrel oil.

And here we are. In the United States, two companies lead the Synfuels 2.0 effort. Baard Energy, based in Vancouver, Washington, hopes next year to begin building a $5 billion plant in Wellsville, Ohio, that would produce 50,000 barrels a day of diesel, jet fuel, and other chemicals. Rentech Inc., based in Los Angeles, California, hopes to open a plant in Natchez, Mississippi, in 2011 that would eventually make 30,000 barrels of fuel a day. Although the hefty price tag of a synfuels plant makes it less likely that enough will be built to have a major impact on global transportation needs, Baard's owner and founder, John Baardson, says the plant will make money as long as the cost of a barrel of oil remains above $50.

The companies plan to use 30% and 10% biomass by weight, respectively, and store the CO_2 they make underground. That mix, they say, will produce fuels with a life cycle carbon footprint much smaller than the one left by those derived from Middle Eastern oil. Future projects using greater proportions of biomass, advanced gasifiers, and carbon storage could result in a carbon-negative process, say proponents, storing indefinitely the CO_2 that plants had taken up from the atmosphere. Baard says that getting enough biomass for its Ohio plant won't be a problem. Rentech hopes to be able to use garbage, which is also plentiful. (A third company, owned by the power utility DKRW, is planning a coal-only gasification project in Wyoming that will inject CO_2 as well.)

A Dutch utility called Nuon has been pioneering this method, gasifying an 80-20 mix of coal and wood chips since 2006. (Its plant in Buggenum, Netherlands, generates power instead of fuel, but the gasification step is identical.) "They've solved a number of technical problems," says Baardson, including selecting the best feedstocks and preparing them for conversion.

> *"The thing that makes [synfuels] so bad for the climate could make [them] so good for the climate."*
> —DANIEL SCHRAG, HARVARD UNIVERSITY

Unlike coal, which is easily ground into tiny spheres, the fibrous wood gets stuck as it is fed into the gasifier, creating an uneven flow. Dutch engineers have developed a way of mixing the two feedstocks to make them flow better. A new process of drying and charring the wood beforehand, developed by the Energy Research Centre of the Netherlands, has also helped keep the mixture flowing evenly into the gasifier. The process requires extra energy, but by reducing the weight of the material it lowers transportation costs.

Engineers in industry believe that preparing the biomass is the main technical hurdle to gasifying it and cite Nuon's success as proof. But with Nuon keeping its methods secret, government researchers want to explore the new feedstock more. "We don't exactly know how biomass is going to affect the gasifier, gas cleanup, or catalysts systems," says Daniel Cicero of the National Energy Technology Laboratory in Morgantown, West Virginia. The lab announced a $7 million research program last month to identify the minerals found in biomass feedstocks such as poplar or switchgrass and to examine how they might affect the system.

Nuon's gasifier, built by Shell, operates above 1200°C. That temperature melts the inorganic ash that the process creates. But gasifiers that run at temperatures hundreds of degrees cooler could save in construction and operating costs, says Richard Bain of the National Renewable Energy Laboratory in Golden, Colorado.

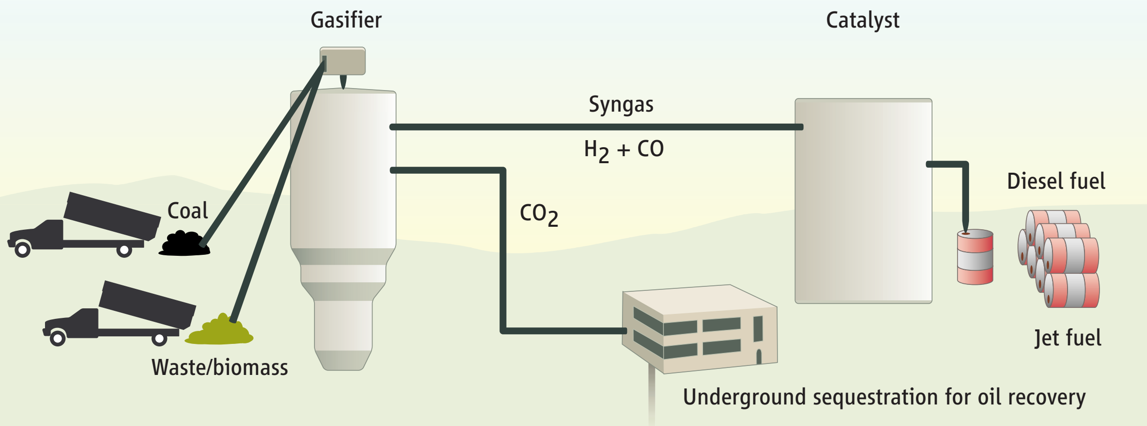
Cooler gasifiers have their own problems, however. Lower temperatures mean that less of the feedstock—be it coal or biomass—is converted into syngas. The toxic, carbonaceous muck that remains is costly to dispose of. Researchers hope that better computer modeling and new chemical techniques will help them more fully process the gunk.

New chemistry could cut costs even more dramatically. Two years ago, chemical engineer Lanny Schmidt of the University of Minnesota, Minneapolis, demonstrated how to gasify biomass by releasing tiny bits onto a catalyst made of rhodium and cerium, whereby it is converted instantly to syngas in an oxygen-rich vessel (*Science*, 3 November 2006, p. 801). Its industrial advantages include shortening the duration of the process—to roughly a tenth of the time of existing gasifier designs—and leaving behind almost no carbon. Because the reaction continually releases its own heat—700°C—the technique could eliminate costly external heating. But Schmidt acknowledges he still needs to solve a copious "ash problem" before synfuels plants can be shrunk to the size to ethanol facilities, which are small enough to sit adjacent to local farms.

Going under

To store the CO_2 that synfuels plants create, researchers hope to take advantage of the fact that the process creates a concentrated CO_2

It's a gas. Traditional synfuels plants take coal and turn it into syngas. The gas is then catalyzed into various liquid fuels. Proposed plants would also store underground the CO_2 that is created. Greater reliance on biomass would make the process more carbon friendly.



CREDIT: P. HUEY/SCIENCE

A burning question. South Africa's Secunda facility is the world's biggest point source for carbon emissions, but synfuels can be made cleaner.

stream that can simply be injected into deep underground formations. In contrast, CO_2 from a standard generating plant must be separated from other flue gases (*Science*, 13 July 2007, p. 184). "In a way, the thing that makes [synfuels] so bad for the climate could make [them] so good for the climate," says Daniel Schrag, a Harvard University geochemist who works as a part-time consultant for Rentech. Capturing and storing a ton of carbon from a standard coal plant would cost $40, according to a survey last year by a team of researchers at the Massachusetts Institute for Technology in Cambridge. Rentech says its Mississippi plant, strategically located near pipelines that currently bring CO_2 to oil fields, will do it for a net of $6 a ton.

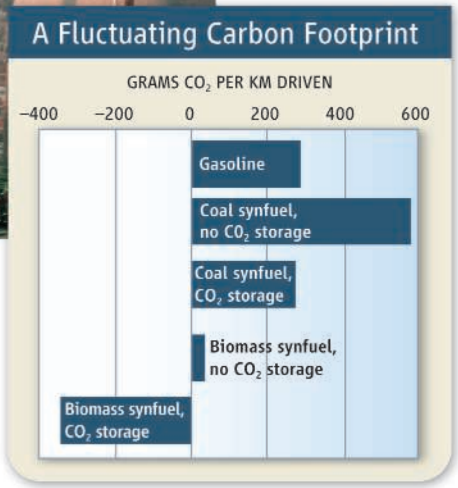
But the amount of CO_2 needed to be stored by a new generation of synfuels plants dwarfs current experimental efforts. The three largest projects worldwide—in Algeria, off the coast of Norway, and in Saskatchewan, Canada—are each storing roughly 1 million tons per year. Baard expects its plant alone will produce more than four times that amount. Baard and Rentech plan to sell the CO_2 from their plants to oil companies to help them squeeze the last drops out of existing wells, a process that geologists say effectively stores the CO_2 once the wells are sealed. But such opportunities are relatively rare. Fortunately, there's plenty of available space elsewhere: A government survey last year found that the United States has room underground and near power plants for at least 91 billion metric tons of CO_2, enough to absorb many decades of emissions.

The process involves injecting a stream of CO_2, liquefied by high pressure, into a series of wells drilled thousands of meters into porous rocklike sandstone. The formations are capped with impermeable layers of rock. Inside the space, the liquid CO_2 displaces briny liquids as it fills pores. Results of early tests on a small scale have been positive, but scientists say they still have a lot to learn as they scale up injections. "I wouldn't say there are any major technical [barriers]," says engineer Sean McCoy of Carnegie Mellon University in Pittsburgh, Pennsylvania. "We want to make sure there aren't any surprises."

To reassure the public that underground carbon sequestration is reliable and safe, hydrologist Diana Bacon of Pacific Northwest National Laboratories in Richland, Washington, says researchers need better computer models of how stored CO_2 behaves. Adding complex geochemistry to the models is a first step. Liquid CO_2 under pressure, for example, can cause the formation of solid salts such as sodium chloride that can block pores and alter the flow of the injected CO_2. Varying mixtures of calcium, dolomite, and sandstone found in deep sedimentary rocks could affect CO_2 behavior differently, says Bacon. Injecting CO_2 into the basalts found beneath much of the United States and India, among other places, can have similarly hard-to-model effects.

Megascale synfuels projects would give engineers the experience they now lack in long-term sequestration of CO_2. "We need to just get moving," says Bacon. But that's hard to do in the United States, where pure CO_2 streams are relatively rare despite the heavy use of fossil fuels. China's projected synfuels plants give that country the chance to become "a world leader" in CO_2 storage, says Princeton's Williams. But despite nascent partnerships with the U.S., European Union, and U.K. governments, the only large-scale test announced so far in China is a $1 billion power plant, dubbed GreenGen, in Tianjin. Several government-owned companies expect to begin construction next year.

Companies say that synfuels could become an important energy source sooner if the U.S. government lends a hand. One potentially huge customer for synfuels is the U.S. Air Force, whose planes now consume 11.4 billion liters of fuel a year. Synfuels makers want Congress to grant the Pentagon the authority to sign long-term fuel-purchasing contracts for synfuels. The lawmakers who oversee the Pentagon have been mum on the matter. A compromise requiring restrictions on carbon emissions for federally supported synfuels seems possible, although a similar deal involving tax breaks and production credits failed last year.



Environmental groups oppose such a deal. David Hawkins of the Natural Resources Defense Council in Washington, D.C., fears that any legislation will open the door to a surge in synfuels made purely from coal. Even if the CO_2 generated could be stored, he says, the effects of expanding coal mining could be extremely harmful to the environment.

Notwithstanding the technical hurdles, the fate of synfuels may hang on whether companies are forced to pay a price for the carbon they emit into the atmosphere. Opponents point out that Rentech and Baard, notwithstanding their pledges, are free to use only coal in their synfuels plants and emit millions of tons of CO_2 per year. "That's only a problem if you don't have a price on carbon," Schrag counters. Since they can use nonfood crops or plant waste, synfuels "can be better than ethanol," he adds, citing the negative impact of corn ethanol on food prices and its projected deleterious effect on climate (*Science*, 29 February, p. 1235). Economic policies that reward good behavior will not only serve as a huge incentive to the synfuels industry, he notes, but also have more global effects: "If there isn't a carbon price, we're not going to solve the climate problem anyway."

–ELI KINTISCH

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