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Carbon Recycling: Mining the Air for Fuel

A solar energy collector towers over Rich Diver, a researcher at the U.S. Department of Energy's Sandia National Laboratories. The lab's "Sunshine to Petrol" project aims to recycle carbon dioxide into fuel with renewable energy.

Photograph courtesy Randy Montoya, Sandia National Laboratory

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Recycling bottles, cans, and newspapers is on any short list of simple actions for a cleaner environment. If only it were as easy to collect and reuse carbon dioxide—that greenhouse gas waste product that the world is generating in huge volume each day by burning fossil fuels.

In fact, a handful of start-up companies and researchers are aiming to do just that.

Recycling carbon dioxide is a great deal more involved than setting out separate bins for glass, aluminum, and paper. But many scientists believe that it is not only worth the effort, but a crucial endeavor. The climate change threat to the planet is now so great, they argue, that any effort to address the problem will have to include so-called "carbon negative" technologies. That means actually sucking the greenhouse gas out of the atmosphere and doing something productive with it.

The idea of capturing carbon dioxide (CO_2) from coal power plants or oil facilities and storing it underground has gotten plenty of attention. Several pilot projects are operating or under construction, although a major project in West Virginia was abandoned last month due to cost concerns.

There has been less focus on the idea of actually reusing or recycling CO_2. But science has long known that it's possible to recombine carbon from CO_2 with hydrogen from water to make hydrocarbons—in other words, to make familiar fuels such as gasoline. The problem, ironically, has been that the process requires a lot of energy.

But pioneering researchers and entrepreneurs argue the technology is close at hand for recycling CO_2 back into fuel for use in today's engines. It might even involve technology to absorb carbon dioxide directly out of the air, instead of out of coal plant flue gas. (See related story, "Out of Thin Air: The Quest to Capture Carbon Dioxide") Instead of drilling for oil to power cars and trucks, they say, we could be pulling the ingredients to make hydrocarbons out of thin air.

"You have all this CO_2—it's nasty stuff—what are you going to do with it?" asks Byron Elton, chief executive of Carbon Sciences, a Santa Barbara, California start-up. "People are saying, 'Compress it, hide it.' We're saying, 'No, give it to us and we can turn it back into gasoline.' "

Peter Eisenberger, a physicist who founded the Earth Institute at Columbia University, is cofounder of Global Thermostat, a company that is working on technology to capture carbon dioxide from air with the aim of recycling, not storage, in mind. "In my opinion, closing the carbon cycle and having the technology to combine CO_2 and hydrogen is a wonderful future," Eisenberger says. "Imagine a future where the major inputs for fuel are water and CO_2."

Energy In, Energy Out

Of course, the oil drilled and pumped from underground holds the energy of eons' worth of sunlight energy collected by plants and stored as organic matter. Over millions of years of heat and pressure, the energy in that organic matter has been further concentrated to yield hydrocarbons such as oil, natural gas, and coal.

(Related: "Is Motor Oil a Renewable Resource? Re-Refiners Say Yes")

Anyone who wants to create hydrocarbon fuel above ground will have to supply the energy to isolate the hydrogen and carbon atoms and put them together. "There's no free lunch," says Hans Ziock, a technical staff member at the U.S. Department of Energy's (DOE) Los Alamos National Laboratory, coauthor of a white paper on carbon capture from air.

"You have to put energy in to re-create the fuel," he explains. "And because re-creation is never 100 percent efficient, you end up putting more energy in than you get out." Due to the "energy penalty" of creating hydrocarbon fuel indirectly, he says, it has always made more sense for society to use the liquid fuels made directly from crude oil as long as crude oil is available. "If nature has done this for you for free, why not use it?" says Ziock.

However, in a world that is now pumping its crude oil from ultra-deep water, squeezing it from tar sands, and looking for it beneath Arctic frontiers, the time may be ripe for alternatives. Ziock says he believes the hope for greater domestic self-sufficiency for fuel alone makes research into carbon dioxide recycling worthwhile. But he warns that as a means to reduce carbon dioxide in the atmosphere, the benefits of this approach will be limited unless the energy to create the hydrocarbon fuel comes from a source other than the burning of more fossil fuel.

(Related: "Photos: Four New Offshore Drilling Frontiers")

That's why the focus of the "Sunshine to Petrol" project at U.S. DOE's Sandia National Laboratories in Albuquerque, New Mexico, and Livermore, California, has been on creating a high-efficiency chemical heat engine based on concentrated solar energy to power its process for making fuel.

"Hydrocarbon fuel has a lot of energy packed in," says Ellen Stechel, who manages the Sandia project. "All the energy came from the sun, and must again come from the sun—just faster and with greater efficiency." To create hydrocarbon fuel, she says it is possible to use solar energy, just as nature does. "But we need to collect it from a wide area to pack it into something very dense," she explains. "People say the sun is free, and that's true, but the collectors to collect all that sun are not free."

(Related Quiz: "What You Don't Know About Solar Power")

The prototype solar reactor that the Sandia researchers have developed is designed to use a huge array of mirrors to collect and concentrate the sunlight into a very strong beam that is funneled onto metal oxide rings inside each reactor. The rings rotate in and out of the sunlight, heating to a temperature of more than 2,550°F (1,400°C), and then cooling to less than 2,010°F (1,100°C). These rings are then exposed either to carbon dioxide or to water. At the high temperature, the metal oxide rings release some oxygen and at the lower temperature the rings steal oxygen atoms from either the CO_2 or the H_2O molecules. That thermochemical reaction leaves behind carbon monoxide or hydrogen gas (the mixture is often called "syngas")—the building blocks of hydrocarbon fuel.

The Sandia prototype's solar collector has an area of about 20 square meters (215 square feet) for a reactor the size of a beer keg, Stechel says. About 300,000 acres (121,400 hectares) of mirrors would be required to collect enough sunshine to make the equivalent of 1 million barrels of oil per day, she says. (The world currently consumes about 86 million barrels per day of petroleum and other liquid fuels, including biofuels.)

Stechel says that durability of the hardware remains an issue, and the researchers are continuing to work on making the system as efficient as possible so it can be commercially successful and used on a large scale.

Catalyst for Change

Elton's firm, Carbon Sciences, focuses on the post-collection phase: turning carbon into fuel. It does this by combining CO_2 with natural gas in the presence of a proprietary metallic catalyst it has developed and licensed. (The company says it is made of the common metals, nickel and cobalt, supported by aluminum and magnesium.)

Carbon Sciences says its test facility is successfully melding CO_2 with methane (the primary constituent of natural gas) to produce a syngas that can be converted into ordinary fuels.

The process of turning syngas into transportation fuel is a well-established technology, and there are already commercial gas-to-liquids facilities in the world. But those processes rely on steam or oxidation to produce the syngas. Carbon Sciences argues that its process—CO_2 reforming, or dry reforming, of natural gas—would be a game changer because it would produce fuel while using up waste CO_2 that otherwise would be emitted to the atmosphere. Also, says Elton, using readily available CO_2 as a reactant should make capital and operating costs significantly lower than current commercial approaches that use oxygen, since that's expensive and capital-intensive.

"We believe our approach will be the key to cost-effective transformation of greenhouse gases to fuel on a global scale," he says.

Although there have been efforts at dry reforming in the past, Carbon Sciences says its catalyst is uniquely robust and able to stand up to the harsh industrial process of making the fuel. The catalyst also is comprised of more affordable and abundant metals than those used in earlier efforts.

Of course, because the fuel produced will be a drop-in replacement for ordinary gasoline and diesel, driving will still release CO_2 to the atmosphere. But Elton says there are significant advantages in using recycled fuel. "The carbon . . . is used twice, instead of it going into the air," he says. "It also finally addresses the issue of energy security"—as the fuel can be made domestically from two abundant resources in the United States—CO_2 and natural gas.

Outside scientists say the CO_2 advantages of the system will depend on how it is designed, including where it gets its energy. Elton says minimizing net energy will be a high priority, with the potential for an integrated system that reuses some of the energy or fuel created in the process. He maintains that Carbon Sciences' process for creating fuel is CO_2-neutral, in contrast to the refining of ordinary crude oil into gasoline, which results in energy use that releases CO_2 before the fuel even gets to the gas tank. After encouraging test results earlier this year, Elton said in July that his company is working on a demonstration project to produce samples of diesel fuel that can be used by existing diesel vehicles, like trucks and buses.

It is important to note that in the reforming process, natural gas provides some of the hydrocarbons in the fuel. Other efforts at CO_2 recycling-into-fuel aim to get all of the hydrocarbons from CO_2 alone.

In the United Kingdom, Air Fuel Synthesis aims to use atmospheric CO_2 and wind energy to produce aviation fuels in a concept demonstration at an initial rate of 1 liter (about one-quarter gallon) per day.

Filling Up With Renewables

Although the challenges are great, the research is important, says a policy brief issued last month by the Centre for Low-Carbon Futures in England. Researchers from the University of Sheffield and the Energy Research Centre of the Netherlands said that what they call "Carbon Capture and Utilization" could overcome many of the drawbacks of carbon capture and storage, including the difficulty in finding enough underground storage space, the possibility of leakage, long-term liability issues, and problems with public acceptance. Creating something of value also would help offset the costs of carbon capture, the researchers said.

And creating liquid fuels through carbon recycling could be important in the long run for a society that aims to reduce its dependence on oil. Although there's been much excitement about electric cars, the report noted that electric batteries still can't provide the needed range for aviation and long-haul sea and road transport. The recycling of CO_2 could be the path for putting renewable energy into the fuel tanks of ordinary combustion engines, the report said.

That's why Stechel, of Sandia, says the benefits of "reversing combustion" or "closing the cycle" on CO_2 could be enormous. "We could have a technology that could produce the same fuels we get from petroleum and preserve today's infrastructure," she says, "fuels that could go into the vehicles of today as well as the ones of tomorrow."

This story is part of a special series that explores energy issues. For more, visit The Great Energy Challenge.