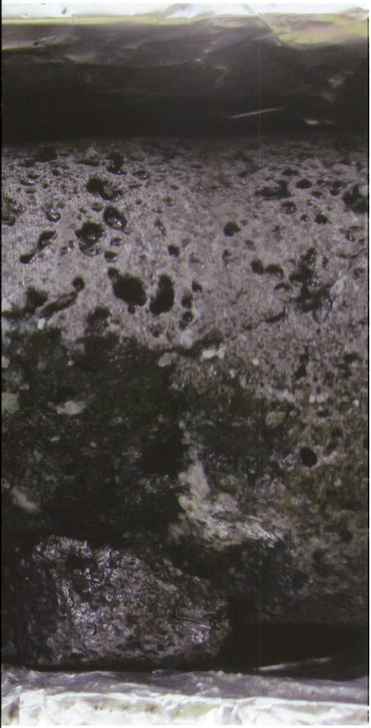
Storing Carbon Dioxide Permanently

PHOTO: GUNNAR SVANBERG

Iceland-led team finds a way to store CO_2 in volcanic rock and help lessen the impact of climate change.

By Don Hinrichsen



FOR THE PAST SEVERAL decades, scientists from the U.S., Europe, Asia and elsewhere have been trying to find a way to capture and lock away carbon dioxide, the major climate-changing gas that is emitted in large quantities from the combustion of fossil fuels. Conventional efforts at carbon capture and storage (known as CCS) have been dogged by the high costs of capturing the CO_2.

Icelandic scientists and colleagues in the U.S. and Europe, thought that one solution worth trying would be to dissolve the carbon dioxide in water and pump the resulting mixture, essentially soda water, into deposits of porous volcanic rock called basalts. Iceland sits atop some of the largest deposits of this type of rock on the planet. Once inserted into the basalt, a natural chemical reaction would solidify the carbon dioxide, turning it into rock.

The Hellisheidi geothermal power plant, located some 20 kilometers east of the capital, Reykjavik, was chosen as the site of the test because it emits carbon dioxide, has lots of water,

This core taken from the basalt formations under the Hellisheidi geothermal power plant, near Reykjavik, is what solidified carbon dioxide looks like; the white crystals in the basalt contain carbonates formed after the chemical reaction turns carbon dioxide gas into a solid.

sits atop a vast field of basalt and also had wells available for the experiment. It is also a fairly large plant, producing 300 MW of electricity along with 120 MW of thermal energy for district heating.

The project, known as CarbFix, was set up by four partner organizations in 2007: The University of Iceland, Reykjavik Energy, which operates the Hellisheidi geothermal power plant, the University of Toulouse, France, and the Lamont-Doherty Earth Observatory, part of the Earth Institute at Columbia University in New York City.

IN 2012 THE PROJECT GOT off to a modest start when the scientific team pumped 250 tons of carbon dioxide, mixed with clean water, some 1,500 feet down into very porous basalt at the Hellisheidi power plant. Researchers had laced the solution with radioactive isotopes in order to be able to monitor and trace its spread through the rock formation.

The scientists were pleased at what happened. Though laboratory experiments had demonstrated that mixing carbon dioxide gas with water and injecting it into basalt would eventually encase the gas in rock, the speed at which the process took place at the injection site was an added bonus. Within one year the submerged pump used to obtain samples of the carbon dioxide mixture as it spread throughout the porous basalt stopped working because it was encrusted with calcite–the mineral formed when the dissolved gas interacts with calcium, magnesium and iron in the basalt to form a solid.

Under more conventional CCS methods, it would take hundreds to thousands of years before the carbon dioxide would be converted into a solid. "Based on tests, the team thought the process would be rapid," commented Edda Aradottir, the project's manager from Reykjavik Energy, "but it happened even faster than we had anticipated!"

The Hellisheidi geothermal power plant is the site of the Carb-fix project which stores carbon dioxide in basalt formations, turning the gas into stone for permanent capture of CO_2.

PHOTO: GUNNAR SVANBERG

Based on the pilot project, industrial scale injection of carbon dioxide began in June 2014. Both carbon dioxide and hydrogen sulfide (the gas that smells like rotten eggs)—by–products of geothermal energy use–were captured by a gas abatement plant through a simple scrubbing process, dissolved in water and injected back into the basaltic rock under the plant. By the end of 2015, some 10,000 tons of gases, including 6,300 tons of carbon dioxide, had been mineralized and captured permanently.

This year, 2016, the capacity of the gas abatement plant has been doubled. "We will capture about 10,000 tons of carbon dioxide and 7,000 tons of hydrogen sulfide annually," points out Aradottir.

> *Only some 10 percent of the continents contain basalt formations suitable for use.*

Without capturing this greenhouse gas, the Hellisheidi Power Plant would emit around 40,000 tons of carbon dioxide and 12,000 tons of hydrogen sulfide gases every year. Still, the carbon emitted is just five percent of what a coal-fired power plant of the same generating capacity would spew out over the course of a year.

"Put another way," says Aradottir, "this geothermal plant emits just 21.6 grams of carbon dioxide for every kWh of electricity produced, while a coal or oil fired power plant emits anywhere from 385 to 1000 grams of carbon dioxide per kWh of electricity produced."

The other big advantage of this type of carbon sequestration is the relatively cheap cost. "Our system, including capturing, transporting, injecting and monitoring the entire process, costs around $30 per ton of carbon dioxide," explains Aradottir. "This is significantly less than the $60-130 per ton for conventional carbon capture and storage methods."

A more conventional method might involve, for instance, storing the gas in sedimentary rocks in exhausted oil fields under the North Sea. Such conventional "solutions" often have major drawbacks. Not only do sedimentary rocks lack the minerals needed to convert carbon dioxide into rock, but constant and expensive monitoring systems need to be in place to make sure the gas stays trapped in the reservoirs.

THOUGH THIS CAPTURE AND STORAGE METHOD HAS enormous potential in efforts to reduce the amount of carbon dioxide in the atmosphere, where it is the main climate-change driver, only some 10 percent of the continents contain basalt formations suitable for use. Most of continental Europe, for instance, lacks this kind of rock; they have extensive sedimentary deposits instead. However, those countries lacking basalt formations on land could use the sea bottom for storage, since most of the ocean floor contains basalt.

The other drawback, though a minor one for developed countries, is the amount of clean water required in which to mix the carbon dioxide. The amount of water needed to fully dissolve carbon dioxide depends on the injection depth, water temperature and other factors. But, in general, 90 percent of the fluid injected into the ground is water, only 10 percent is carbon dioxide. Roughly speaking, the team found that the test site required 27 tons of water for each ton of carbon dioxide dissolved.

Again, countries without adequate amounts of clean freshwater could use

Technicians at the Hellisheidi geothermal power plant examine cores taken from the basalt fields under the plant; part of the monitoring process while documenting the suitability and cost effectiveness of converting CO_2 into a solid.

PHOTO: GUNNAR SVANBERG

The water that is pumped up after use is cleaner than the water that is pumped down.

seawater. The amount needed would be slightly higher compared to freshwater. The team estimated that it might take about 31 tons of seawater for each ton of carbon dioxide.

Another interesting side effect from the chemical reactions between basalt and the injected fluid, explains Aradottir, "is that the water that is pumped up after use is cleaner than the water that is pumped down. In other words, you could possibly use this CCS method for purifying water as well."

Since climate change is already happening, there is broad agreement within the scientific community, especially those involved in the Intergovernmental Panel on Climate Change (IPCC), that the world must limit the amount of greenhouse gases emitted, as well as capture and store carbon dioxide already released into the atmosphere.

Stuart Haszeldine, a professor of CCS at the University of Edinburgh in the U.K., told *The Guardian* newspaper that this type of capture and storage method was a big step in the right direction. "It may well provide a low-cost and very secure remedy for parts of the world where the suitable rocks exist" he observed, "but this needs to be used as well as all of the other existing propositions because the problem to be solved–pumping millions of tons of carbon dioxide into the atmosphere every year–is immense and no single remedy is anywhere near big enough or fast enough."

Indeed, the UN's IPCC has stipulated that carbon capture and storage is a crucial component in the fight to address climate change. According to a recent IPCC report, without CCS the costs of halting global warming would nearly double.

Professor Juerg Matter, from the University of Southampton in the U.K., and a member of the project's steering committee, calls the gas to solid-fix the "ultimate permanent storage solution." But he thinks the reason more CCS initiatives don't get sufficient funding is lack of action from politicians.

PROGRESS ELSEWHERE HAS BEEN SLOW. BUT TESTING IS ALSO taking place in the U.S. Columbia River Basalts, which cover large areas of both the northwest states of Washington and Oregon. India, another country afflicted with many coal-fired power plants, also has huge basalt deposits in the Deccan Traps. And there are other deposits spread out across the globe. Large basalt formations are also found in north central Siberia, southeast Brazil and Argentina, East Africa (mainly Ethiopia and Kenya), Japan and parts of northern Australia, among others.

Norway is another Nordic country actively carrying out CCS research. Since June 2015, Norwegian technicians have managed to pump 15.5 million tons of carbon dioxide into a deep saline reservoir, some 1,000 meters below

PHOTO: GUNNAR SVANBERG

Iceland is covered **with volcanic basalt formations, as here in the foreground. The steam is from a geothermal field in the background.**

the floor of the North Sea, about 160 miles east of Stavanger. The site, known as Sleipner, is one of the largest active gas fields in the North Sea operated by Statoil, the Norwegian state-owned energy company. The costs of storing the gas in this massive sandstone reservoir is $50 per ton; expensive, but cheaper than paying $70 per ton of carbon dioxide emitted as a carbon tax.

Meanwhile, Iceland is forging ahead. Scientists have estimated that the active volcanic rift zone in Iceland alone could theoretically store over 400 Gigatons (Gt) of carbon dioxide. Storing carbon in the ocean floor could sequester even more of the gas–by some estimates up to 250,000 Gt. This is significantly larger than all the carbon dioxide emitted into the atmosphere by all fossil fuel burning power plants on the planet, estimated at some 18,500 Gt per year!

Indeed, Aradottir thinks the next frontier for this type of CCS is the ocean bottom. "It would be interesting to see a test project on the ocean floor aiming for mineralization in suitable rock formations," she concludes. "If successful, this could have far reaching implications for carbon capture and storage, greatly contributing to efforts to limit the impacts of climate change."

Don Hinrichsen, an internationally recognized environment writer, has undertaken numerous assignments for United Nations agencies. He is the author of *The Atlas of Coasts and Oceans: Ecosystems, Threatened Resources and Marine Conservation*, published by the University of Chicago Press.