Lab successfully tests heat-powered system that could be used to monitor carbon sequestration efforts

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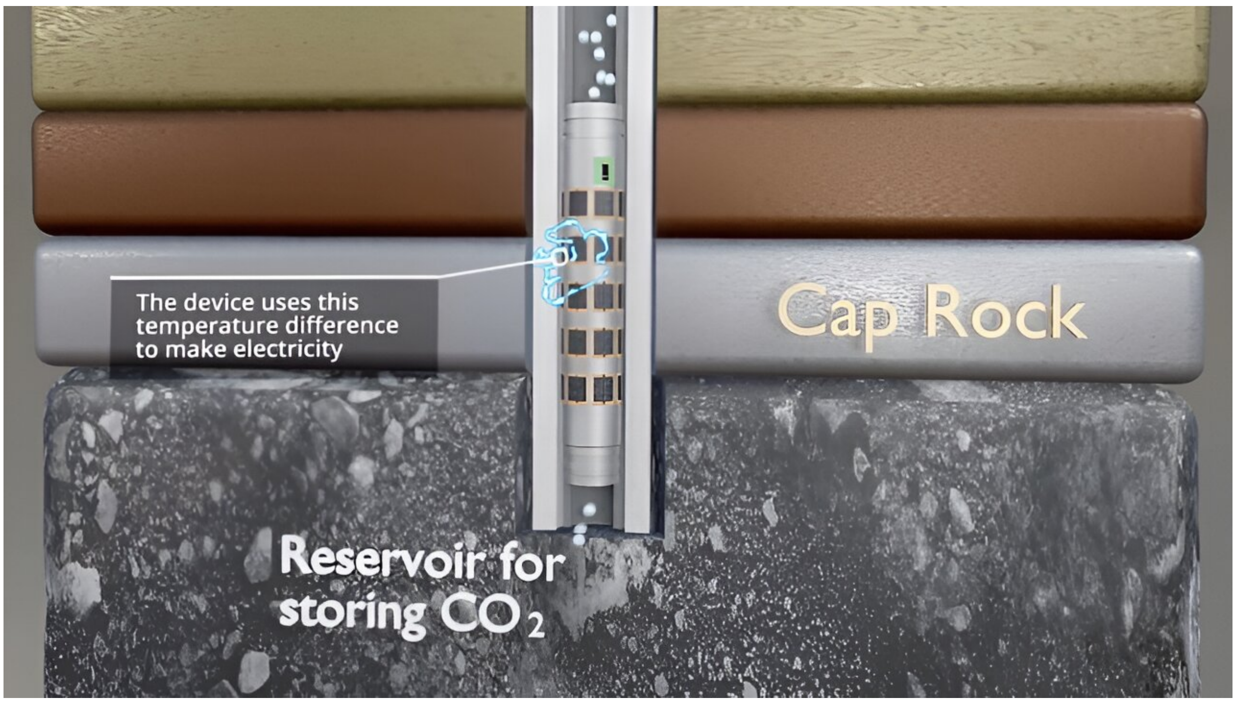

Credit: Ray Johnson, Sandia National Laboratories

Capturing carbon dioxide and pumping it deep underground could be an important part of mitigating the effects of climate change. However, ensuring the carbon dioxide stays trapped away from the atmosphere, where it serves as a heat-trapping greenhouse gas, is critical.

Researchers at Sandia National Laboratories recently designed, built and lab-tested a device that can use the temperature difference caused by periodically pumping carbon dioxide down a borehole to charge batteries to someday power underground sensors.

"Ideally, you would have continuous underground sensing, with several different types of sensors, that would tell you how the carbon dioxide is moving, if it is reacting with the groundwater or the minerals," said Charles Bryan, a Sandia geosciences engineer and leader of the project to develop the device. "You could demonstrate that it's not moving out of the reservoir. However, it's difficult to run power down a borehole: You can't just have wires running down a working borehole."

As heat flows from the hot earth through the device to the cooler carbon dioxide, it creates a voltage that can be used to charge a battery and eventually power sensors. The Sandia-developed device works similarly to the radioisotope thermoelectric generators used to power NASA space probes and even Mars rovers, said Ramesh Koripella, a Sandia materials scientist on the project.

While NASA's radioisotope thermoelectric generators use the temperature difference from hot plutonium pellets and the cold of space to produce power, Sandia's thermoelectric generator device uses the temperature difference from the hot earth thousands of feet down and the carbon dioxide being pumped down.

This technology is not nearly as efficient at producing electricity from heat as the internal combustion engine in most cars, Koripella said. However, it has no moving parts that could jam, making it ideal for hard-to-reach places such as space and deep boreholes.

Building a heat-powered generator

The device is a multilayered tube with an array of 1-by-1-inch square thermoelectric generators, Bryan said. Each of these thermoelectric generators can turn the heat flowing through them into a voltage and then power, Koripella added.

The inner tube is built to withstand the temperatures and pressures from carbon dioxide being pumped through it, while the outer tube is built to withstand the temperatures and pressures from being deep underground, Bryan said. In the area between those two reside the electronics to capture and convert the voltage from the thermoelectric generators to charge a battery. Former Sandia mechanical engineer Adam Foris came up with the original design for the tube-like device, he added.

Koripella selected the right commercially-available thermoelectric generators for the device and led the development of a small circuit board that converts and evens out the energy from the generators so that the device can charge a battery without damaging surges. He added that it was quite a challenge to find batteries that work above 160 degrees Fahrenheit, which is the typical temperature downhole at the depths used for carbon sequestration.

Power generation by the initial, foot-long prototype was tested in the lab by Sandia geosciences engineer Tom Dewers. He also used thermal imaging and computer modeling to look at how the temperature changed around the device when hot or cold fluid flowed through it. The modeling and tests helped the team refine the prototype for an in-the-field test.

Refining the device design

The field-test prototype, which ended up being slightly more than three feet long, was developed by Sandia mechanical engineer Jiann-Cherng Su, who introduced several innovations and improvements to the design, Bryan said.

The team made several improvements in the second prototype to ensure the thermoelectric generators had good contact with the inner and outer shells, and that the heat could not take a shortcut around the generators through the rest of the device, Koripella added. For the field-test prototype, the team added thermal insulators around the device and replaced the heat-highway metal screws that held the thermoelectric generators together with spring-based clamps, he explained.

Sandia geosciences engineer Jason Heath gathered data on an active carbon dioxide injection site to inform the building of the device for field conditions and led the selection of a site for the field test. Ultimately, the team selected the APS Technology Drilling Test Facility.

"They have an amazing array of facilities for designing, building and testing downhole tools," said Dewers, who went to the site for the field testing. "They were an ideal company for us to work with. The APS folks were great and patient with us and had a lot of good suggestions."

Successful underground testing

For the first field test, Dewers inserted the field-test prototype into a shallow borehole in one of APS's testing rooms. The researchers lowered the device to a depth of 62 feet. Then they pumped 170-degree water through the interior tube of the device to test the thermoelectric generators and the rest of the system.

Unfortunately, during the test the device sprang a leak, damaging the power conditioning board and battery, Dewers and Bryan said. Working with Dewers, APS was able to find and fix the leak location, dry out the device and replace the damaged parts. The second test, a repeat of the first, was a success.

The team also tested how well the field prototype could survive high-pressure environments. They subjected the inner shell of the device to pressures 400 times atmospheric pressure and the outer shell of the device to pressures 34 times atmospheric pressure. They also heated up the device inside the pressure chamber and measured the current from the thermoelectric generators, ensuring they worked under pressure.

"We successfully generated sufficient current to power downhole sensors with limited current draw," Dewers said. "In that respect, it was a successful device, but it was limited in terms of how long we could deploy the device."

Future improvements and tests

To test the device for longer times, they need to install more memory, Dewers and Bryan said. Additionally, Koripella would like to rebuild the power conditioning board so that it will work with higher temperature differences and possibly add a diode so that the board can charge the battery regardless of whether hot or cold fluids flow through the device.

Before the device is ready for a long-term field test at a carbon sequestration site, Bryan would like to collaborate with downhole sensor researchers to ensure that the power conditioning board can provide the right power for their sensors. The ultimate test of the thermoelectric device would be to see if it can power hardwired sensors downhole.

The kinds of sensors the device could power include pressure sensors, sensors to detect microseismic events, and those to monitor the health of the borehole, such as whether carbon dioxide is leaking up from the reservoir through the borehole, Bryan said.

Bryan added that the same thermoelectric technology could also be used to power sensors for other underground applications such as monitoring oil and gas exploration and production, but this would require periodically pumping hot or cold fluid down the borehole to maintain a temperature difference between the inside and outside of the device.

"I think the design is really innovative, really clever," Bryan said. "We had to overcome several obstacles; it was much harder than we thought to get this done. We were all excited when the field test was successful."

Provided by Sandia National Laboratories

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