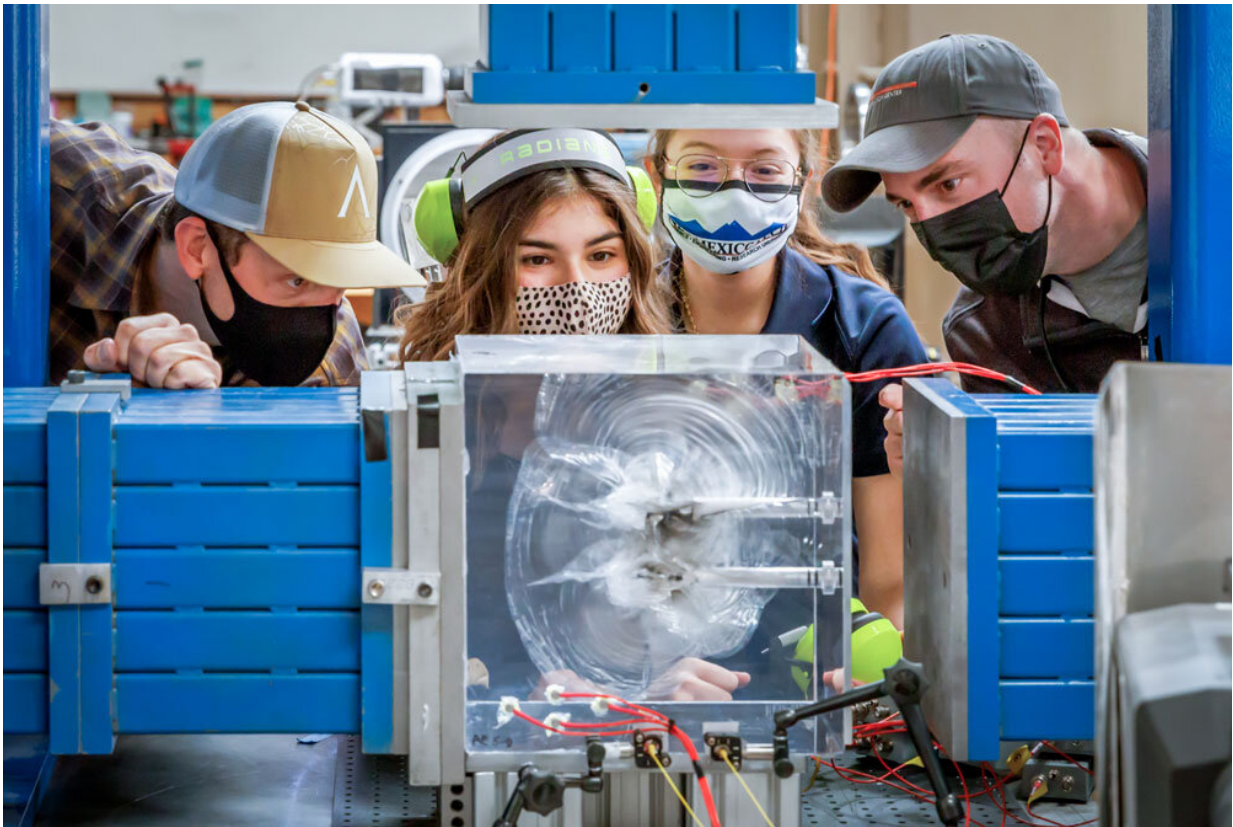


Exploring explosives for expanding geothermal energy

June 16 2022, by Mollie Rappe



From left, Joseph Pope, a Sandia technologist, Sivanna Torres, a New Mexico Institute of Mining and Technology doctoral student, Veronica Espinoza, a New Mexico Tech student, and Eric Robey, a Sandia mechanical engineer, examine a plexiglass cube fractured by a small-scale explosion. This study could inform the creation of new geothermal energy systems. Credit: Bret Latter

Why are scientists setting off small-scale explosions inside 1-foot cubes of plexiglass? They're watching how fractures form and grow in a rocklike substance to see if explosives or propellants, similar to jet fuel, can connect geothermal wells in a predictable manner.

Geothermal energy has a lot of promise as a renewable energy source that is not dependent on the sun shining or the wind blowing, but it has some challenges to wide adoption.

One challenge is that there are only a few places in the U.S. that naturally have the right combinations of hot rock close to the Earth's surface with available underground water. Another challenge is the initial start-up cost of drilling and connecting geothermal [wells](#). Eric Robey, a Sandia mechanical engineer, is leading a team to explore whether explosives can reduce those two challenges.

"Our goal was to come up with a new way of creating a geothermal fracture network that you have a clear idea where it is going to go—it's steerable and manageable—and you are utilizing fewer resources and being more environmentally friendly," Eric said. "This is where explosives and propellants come in. The idea is that they'll allow us to get away from pumping a lot of fluid down the wells. We're collaborating with Lawrence Livermore National Laboratory to model the explosions and improve the predictability of forming fracture networks."

Starting with 1-foot cubes of plexiglass, which mimic many of the properties of rock, the team watched the [explosion](#) shockwave ripple through the cube and listened with specialized microphones to the formation of tiny fractures. The team is using the information on the location of the fractures and the timing of fracture formation to refine existing computer models of underground explosions.

Challenges of cracking hot rock

Because natural formations with the right combination of hot rock and underground water aren't located throughout the U.S., the DOE's Geothermal Technologies Office supports the research, development and testing of enhanced geothermal systems. An enhanced geothermal system takes a location with hot rock and turns it into a location suitable for producing geothermal power by drilling deep wells and carefully fracturing the hot rock so that water can reach the hot rock and carry that heat up to the surface to produce power.

Enhanced geothermal systems have the potential to [power](#) 100 million homes, according to the Geothermal Technologies Office.

"They're finding out it's a difficult problem to get fractures to go where they want them," Eric said. "The goal of our project is to see if we can steer the formation of fractures a bit more."



Eric Robey, left, a Sandia mechanical engineer, and Joseph Pope, a Sandia technologist, prepare a plexiglass cube for a small-scale explosion. The information from this study could be used to create new geothermal energy systems in locations where it is currently not feasible. Credit: Bret Latter

Watching the shockwave

Using plexiglass cubes with small amounts of explosives or propellants ignited in the center, the research team can watch small-scale explosions ripple outward with ultra-high-speed cameras while monitoring the formation of tiny fractures using other sensors. Surprisingly, the mechanical properties of plexiglass are quite similar to granite at about

750 degrees Fahrenheit, said Oleg Vorobiev, a computer model expert at LLNL. To further mimic the properties of hot, hard rock deep underground, the team, including Sandia technologist Joe Pope, applied dozens of tons of pressure to the plexiglass cubes to stress the material and see how the stresses impact fracture formation, Eric said.

Working with Michael Hargather's group, which uses advanced imaging techniques to study explosions and energetic materials, at the New Mexico Institute of Mining and Technology in Socorro, the team watched the explosive shockwave ripple through the plexiglass using schlieren imaging, a technique that uses ultra-high-speed cameras and mirrors to "see" the differences in density.

These differences can be caused by the compression of a shockwave or even differences in temperature like shimmering air over a hot highway, said Sivana Torres, a doctoral student who conducted the experiments at New Mexico Tech's Energetic Materials Research and Testing Center. For these experiments, the team recorded the explosions at 1 million frames per second.

"This project has been a really cool experience: Being able to be my own test engineer and being able to visualize the shockwave propagating through plexiglass," Torres said. "One of my biggest concerns going into 1-foot cubes was that they would be too thick for our imaging system. I do small-scale tests in plexiglass. It was a pleasant surprise that we were able to see the shockwave propagation."

The team also used a technique called photon Doppler velocimetry, which measures the speed of the shockwave as it reaches the outside of the cube by detecting tiny changes to the frequency of a laser. The team hoped that they would be able to see the weaker waves caused by fracture formation, but they were only able to see the initial shockwave, Eric said.

'Listening to a whisper in a hurricane'

After recovering from his initial disappointment, Eric borrowed some specialized microphones called acoustic emission sensors. With an array of microphones on the surface of the cube, the team was able to hear the weaker waves caused by fracture formation and triangulate where they were coming from within the cube.

"This is kind of like listening to a whisper in a hurricane," Eric said, as the [shockwave](#) is much stronger than the fracture waves. "This was a bit of a breakthrough because A, it has never been done before and B, it was very uncertain that we'd be able to hear that whisper in a hurricane, but we could."



A schlieren image of an experiment 80 microseconds after detonation. The image shows the leading edges, fingernail-like protrusions from the center, and emanating bands, lighter ripples. Sandia scientists hope this kind of data on fracture formation in plexiglass can be used to make geothermal energy more assessable. Credit: Eric Robey

The acoustic emissions data not only allowed the team to correlate what they could hear from outside the cube to what they saw within the cube, essential for transitioning from doing experiments in plexiglass to doing experiments in granite, but they could also accurately track when the fractures occurred, which is important for the computer modeling efforts, Eric said.

"We're in the process of learning how to 'fly blind' while we can still see," Eric said. "The instruments we're deploying in the clear plastic are the same instruments we'll deploy when we move to opaque rock."

The team conducted similar experiments in cubes formed from different pieces of plexiglass joined together to mimic faults in rock, to see how explosive-formed fractures react to rock faults. They learned that the explosive-formed fractures tend not to cross pre-existing faultlines, but the amount of stress the plexiglass is under and orientation of the rock fault are important, Eric said. These results will also be used to improve the computer models.

Computer modeling to scale-up solutions

LLNL has trusted computer models of underground explosions based on decades of experiments, starting with underground nuclear testing in the 1960s, Vorobiev said. However, the experiments these models were based on were mostly conducted in cold rock rather than the hot rock needed for geothermal energy production.

"Eventually, the goal is to understand how to create fracture networks in hot, compressed granite at significant depths," Vorobiev said. "This is very challenging, computationally, because events occur at different timescales. Shockwave propagation is very fast compared to

microfracture formation caused by the explosive gases."

The experiments conducted by Eric and Torres are great because they not only provide the information about the final cracks, but they recorded the series of events that produced them, Vorobiev said. His task is to analyze the data from Eric's experiments to refine LLNL's existing models. These models can scale up the results from lab experiments to be able to predict what might happen in actual geothermal field sites, he said.

One of the significant findings from the experiments is that the fractures can start anywhere around the explosive or propellant and grow outward, but due to explosive gases, these random fractures will eventually grow toward the areas with less stress such as along existing fractures, Vorobiev said. The random initiation is good, he said, since it is a way to connect pre-existing parallel fractures into a network, which is needed for [geothermal energy](#) production.

Now, the team is conducting experiments with explosives or propellants in 1-foot cubes of granite, with the eventual goal of moving to 3-foot cubes of granite. If these lab-scale experiments prove promising, the team hopes to test this in the field at the DOE's Frontier Observatory for Research in Geothermal Energy, Eric said. There are still several hurdles to overcome, but if everything goes smoothly, it could take as little as three to five years to reach field-scale testing, and from there, commercial implementation.

Provided by Sandia National Laboratories

Citation: Exploring explosives for expanding geothermal energy (2022, June 16) retrieved 23 April 2024 from <https://techxplore.com/news/2022-06-exploring-explosives-geothermal-energy.html>

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