OPINION

Geothermal quake risks must be faced

Discussion needs to be open about how exploitation of Earth's internal heat can produce earthquakes, says **Domenico Giardini**, so that the alternative-energy technology can be properly utilized.

Deep geothermal energy is increasingly being explored as an attractive alternative energy source. Conventional hydrothermal resources, such as hot springs in geothermal areas, have been effectively exploited in the past century, but their distribution and potential for supplying electricity is somewhat limited. Tapping deep geothermal energy offers new prospects.

An enhanced geothermal system (EGS), originally called a 'hot dry rock' system, involves drilling a hole at least 3 kilometres deep into a layer of non-porous rock where temperatures are higher than 100 °C. Fluids are pumped under high pressure into the rock (a process called stimulation), which induces it to fracture, generating micro-earthquakes, thereby increasing its permeability and creating a reservoir for the fluid. The ruptures generate elastic waves that are detectable by sensitive seismic networks. Once a reservoir of permeable rock larger than a cubic kilometre has been formed, additional holes are drilled to extract heat from the rock mass by circulating fluids through the fracture network.

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Enhanced geothermal systems, such as this planned one in California, must undergo quake risk analysis.

The brute-force approach of EGS is attractively simple. And it has, theoretically, the capacity to generate large amounts of alternative energy by tapping a virtually unlimited source — the heat stored deep inside Earth. An expert panel convened at the Massachusetts Institute of Technology in Cambridge in 2006 estimated that EGS could provide up to 100,000 megawatts of electricity in the United States by 2050, or about 10% of the current national capacity — a very large proportion for an alternative energy source. In October, the United States announced that up to US$132.9 million from the recovery act would be directed at EGS demonstration projects, and big names including Google have invested in the technology.

The drawback is that such enhanced geothermal systems can induce earthquakes. The initial stimulation creates micro-earthquakes that might be felt at the surface or even produce damage. And the pressurized water forced into the rock could interact with existing deep faults, generating potentially large quakes. The probability of this happening is not large, but needs to be considered. In addition, geothermal energy is more profitable if it generates electricity and heating at the same time. That means that customers have to be close to the energy source, so it is attractive for operators to develop geothermal-energy sites in urban areas, where earthquakes are more problematic.

Thousands of deep geothermal sites will have to be developed for geothermal energy to supply a sizeable component of the global energy need. If a significant fraction of these induce seismic action under dense urban areas that is felt or is damaging, this will exceed the natural rate of activity in stable continental areas. Man-made rather than natural earthquakes are already the dominant component of seismicity in mining districts in countries such as Poland and the Czech Republic, but is society across Europe and elsewhere ready to accept this threat in urban areas?

In a recent case in California, a planned EGS site at the Geysers, a geothermal power field about 100 kilometres north of San Francisco, met with public resistance and fell under review by the Department of Energy (even though the company involved had completed an appropriate seismicity review). In September, that project was suspended because of technical difficulties.

For an enhanced geothermal system located near a city or in an area already hit by past large earthquakes, the increased seismic risk requires developing mitigation strategies, such as restricting the pressure or location of pumped fluids. Open and comprehensive information and education needs to be provided to the public and to authorities before, during and after the project. The risks must be openly recognized and assessed, and thought needs to be given to how to insure against damage caused by the projects. Discussion is needed with all stakeholders — including scientists, politicians and the public — to decide what level of risk is acceptable. Otherwise society risks a public backlash that could unnecessarily quash a promising alternative-energy technology.

The Basel story

One of the first purely commercially oriented EGS projects — the Deep Heat Mining project — was initiated in Basel, Switzerland, in 1996 by the Geopower Basel (GPB) consortium. In my view, what started as a promising green-energy initiative turned into a messy affair. It is a textbook example of how the failure to come to terms fully with the possibility of producing earthquakes in an urban area (by everyone involved — including the public) became in itself the largest risk to the whole concept of geothermal exploitation. We can learn important lessons from the case, which should serve in securing a long-term future to this promising energy source.

Basel, an industrial centre of Europe's chemical and pharmaceutical industry, borders France and Germany, and more than 700,000 people live in the area. It has a history of earthquakes; in 1356, the city was severely damaged by a magnitude-6.7 quake, the largest ever recorded in central Europe.

Preparing for a commercial EGS project in an industrial zone took several years. In October 2006, the injection well reached its final depth of 5 kilometres, and was ready for the injection of high-pressure fluids into the granite. A monitoring system was installed, with six borehole seismometers installed near the injection well and up to 30 seismic surface stations in the Basel area, and a contingency shutdown plan in case of felt earthquakes. Nevertheless, the Swiss Seismological Service, which had no regulatory power in this case, communicated to GPB and the Basel authorities that the service had not seen what it would consider an adequate seismic risk analysis for the project.

The local authority confirms that GPB had a valid permit, and had met all that permit's conditions. On 2 December 2006, GPB began injecting water into the well with increasing flow rates. As expected, thousands of micro-earthquakes were recorded. Because of the strongly increased seismic activity felt at the surface, injection was stopped on 7 December. A few hours later, a magnitude-3.4 event rattled the local population, causing fear and anger, and receiving international media attention. In a press release on 9 December, GPB announced its regret for the incident, saying the tremors produced by the project were larger than expected. Slight non-structural damage, such as fine cracks in plaster, was claimed by many homeowners and paid by GPB's insurance. The incident also led to a court case against an individual — not GPB — that starts this week.

Since the water injection stopped, seismicity in the area has slowly decayed. Three years later, sporadic seismicity inside the stimulated rock volume is still being detected by the down-hole instruments.

This EGS project has been on hold, awaiting the completion of an independent risk analysis by a consortium of seismologists and engineers, selected by state authorities following an international bid. The study was released on 10 December this year, and public authorities have now decided to suspend the project.

There have been several other forays into

Sweeping up: a geothermal project in Basel, Switzerland, has been suspended.

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enhanced geothermal energy projects in Europe, some of which have been associated with earthquakes. The European Hot Dry Rock geothermal-energy project in nearby Soultz-sous-Forêts, France, has been developed to a depth of 5 kilometres over the past decade. During stimulation, seismicity was generated there with a maximum local magnitude of 2.9. The plant was adapted to reduce the earthquake risk, and is scheduled to begin producing electricity in January 2010. At 2 megawatts, it will be the largest commercial EGS site in operation. Felt earthquakes are also occasionally associated with natural geothermal systems. In Landau, Germany, a 3-kilometre-deep system was constructed in naturally permeable layers, and earthquakes were not expected. However, seismicity was felt a year after the start of energy production, in 2007, and suspended operations for many months. In both of these cases the geothermal exploitation is carried out in more-rural areas without a known history of large earthquakes.

Realistic approach

The risk of overreaction to the risks inherent in deep geothermal projects is very real. The establishment of an overly harsh regulatory framework would penalize the geothermal industry in comparison to other energy sectors that carry a recognized risk of inducing seismicity, such as gas extraction or coal mining.

> "Society risks a public backlash that could unnecessarily quash a promising alternative energy technology."

From their outset, EGS projects need to be thought of both as pilot projects with scientific unknowns and as commercial ventures with technological and financial risks. Companies need to have allocated enough of their budget to scientific investigations not directly related to the exploitation of heat. Local authorities need to avoid being enticed by the promises of alternative energy, and to remember to ask the right questions. Risk evaluations need to be done before — not after — these projects begin.

Even if the right questions are asked at the right time, the scientific and engineering community is hard pressed to provide a consensus opinion on how seismic hazards can be assessed with confidence and minimized. The empirical data include only a handful of well-monitored EGS experiments; models are consequently poorly constrained. The European Commission has approved the Geothermal Engineering Integrating Mitigation of Induced Seismicity in Reservoirs (GEISER) project to improve the knowledge base and suggest procedures and regulations for the future exploitation of deep geothermal energy. However, many EGS projects are expected to open in the years before the GEISER project produces useful results.

The Basel programme is likely to have a strong effect on the insurance cost of future projects associated with induced seismicity. The damage claims in Basel amounted to more than $9 million, which seems a high toll for a local magnitude-3.4 event (although this is hard to say definitively, because data on small non-structural damages from past earthquakes have never been comprehensively collected). The damage in each building never reached the 10% property level that is normally applied as deductible by home insurance policies. For a natural event, the damage would have been covered by the homeowners, but for a man-made event, the whole cost was picked up by the company's liability insurance. This of course opens a difficult issue. How would we treat a magnitude-5.5 earthquake hitting Basel in, say, 30 years? Could we prove whether it was natural or not? Who would cover the damage?

The public reacts with a vengeance if it perceives that a known problem has been hidden. More than this, earthquakes invariably raise primordial fears. Waking up the sleeping terror that lurks in the deep is the plot of numerous horror movies; here it has an all-too-real meaning.

It is now becoming clear to the public, local authorities, the geothermal industry and regulatory agencies that deep geothermal systems carry a small risk — as do most technologies in the energy sector. Dams can break, nuclear power plants may fail, carbon dioxide released from the oil and gas contributes to global warming, and EGS projects can create damage through induced earthquakes. The open question is whether or not society is able to find ways to balance and accept these risks. A well-informed discussion is needed to find out. ■

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