The most extreme geothermal plant in the world

Iceland is known for its geothermal power – but to make the most of this natural resource, you need to go deep. BBC Future Now visits the hottest geothermal well ever made.

By Chris Baraniuk

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The last time anyone in Iceland tried to drill this deep they ran into trouble. In 2009, Iceland's Deep Drilling Project (IDDP) hit a snag a little over two kilometres down. The drill bit kept getting stuck. The team had already used explosives to sever the line connecting the drill to the surface. Another time they poured in hydrochloric acid to free it from the rock they thought must be trapping it. But they were making little headway.

When tiny shards of volcanic glass started flowing up the borehole everything became clear. The drill had not just got stuck in a tough layer of rock – they were drilling into a chamber of magma. It soon damaged the drilling equipment and the borehole collapsed.

Iceland is dotted with geothermal power plants, each consisting of multiple wells - but to make the most of the underground heat, you need to go deep (Credit: Chris Baraniuk)

They had not planned to hit magma. But it confirmed that drilling deep into Iceland's volcanic crust was a good idea. The heat at the base of the well was fantastic, more than 900C (1,652F). When they pumped in water, it produced superheated steam at vast pressures – perfect conditions for generating energy.

> **A single deep well could match the output of an entire plant and provide energy to tens of thousands of homes**

Iceland is dotted with geothermal power plants, each consisting of multiple wells that tap into the country's underground heat. But most of these are relatively shallow. To make the most of the abundant natural energy supply, you need to go deep. The extreme temperatures and pressures encountered near the magma chamber would have produced 36 megawatts of electricity, 10 times the amount most existing wells produce. A single deep well could match the output of an entire plant and provide energy to tens of thousands of homes.

Which is why, seven years later, IDDP is trying again – and they are close to completing what could be **the hottest borehole ever made**. Geothermal power is one of the big untapped clean energy resources in the world. But taming the extreme conditions in deep wells is an enormous challenge. Projects like IDDP – a joint venture between several Icelandic power companies – are pushing geothermal technology into new territory. And where it goes, the rest of the world may well follow.

Geothermal power is one of the big untapped clean energy resources in the world (Credit: Chris Baraniuk)

In the last few years, geothermal wells have been sunk in several countries. There is a 2.5km-deep well in Cornwall, UK, and a 3.5km-deep well in California, for example. But at five kilometres deep, the new IDDP borehole is in a different league altogether.

IDDP-2 will reach depths where the temperature is expected to be as high as 500C (932F). At pressures of around 200 atmospheres and temperatures above 400C (752F), water takes a special form, becoming what is known as a supercritical fluid. Technically, it is neither liquid nor gas, but can flow like pressurised steam. This is the oil of extreme geothermal drilling.

> **At extreme temperatures water becomes a supercritical fluid. This is the oil of extreme geothermal drilling**

Gudmundur Fridleifsson is chief geologist at Icelandic renewable energy company HS Orka. Last month, he drove me from Reykjavik out to the new site in the Reykjanes peninsula in southwest Iceland. We are 200km (124 miles) from the IDDP-1 site at Krafla, in the northeast. As well as drilling to greater depths, IDDP is keen to explore what lies beneath different parts of the country.

The 4x4 zips along smooth, winding roads, taking us deeper into a region where the surface rock is only a million years old. The area is still being shaped by lava flows today. The ground – a deep purple-brown with streaks of yellow – looks newly burnt.

We pass geothermal fields that spew huge plumes of steam into the air and the rotten-egg smell of sulphur is everywhere (Credit: Chris Baraniuk)

We pass geothermal fields that spew huge plumes of steam into the air and the rotten-egg smell of sulphur is everywhere. The smell is so familiar to Fridleifsson, he hardly notices it. “We call it Iceland perfume,” he says.

In Iceland, volcanoes are a part of life. It was only six years ago that a **massive eruption from the Eyjafjallajokull volcano** grounded air traffic across Europe for several days. With around 30 volcanic systems dotted around the country, occasional disruption is to be expected.

> **In Iceland, volcanoes are a part of life. With 30 or so on the island, disruption is expected**

Fridleifsson’s first encounter with an active volcano was in 1973 during an eruption in the Westman Islands, an archipelago just off Iceland's south coast. A two-kilometre long, magma-spewing crack appeared in the Earth. The lava flow **destroyed many homes and displaced more than 5,000 people**.

The reason for all of this activity in Iceland is its special position in the world. It sits right on top of the mid-Atlantic Ridge, a place where two giant tectonic plates are pulling apart. Over millions of years, they are each bringing a bit of Iceland with them. The island is very gradually expanding to the east and west as the plates diverge.

When we arrive, the sound of machinery whirring to life echoes across the otherwise silent landscape (Credit: Chris Baraniuk)

All this volcanic activity got Fridleifsson and his colleague Albert Albertsson thinking. One day in the mid-90s, the pair were at another drill site on this same stretch of land in Reykjanes. Albertsson was peering into a microscope, looking at tiny minerals with an odd shape – like little balls of wool. Fridleifsson realised that they must have formed in extreme conditions, at temperatures greater than 300C (572F). The two stayed up late into the night talking about the energy that lay right under their feet.

They knew of a team that had hit an unexpectedly hot area while drilling a shallow well in 1985. At the time, nobody knew what to do about it, so the hole was blocked off and forgotten. But the pair thought that someone should have another go.

> **The team does not expect to hit magma. But then nobody expected to hit magma the first time either**

Two decades later, IDDP-2 is their second attempt. When we arrive, the sound of machinery whirring to life echoes across the otherwise silent landscape. Metal structures glint in the pinkish winter light. High up in the apparatus, a worker manoeuvres the next section of a drill shaft into place and sinks it into the earth.

As with the first IDDP borehole, the team does not expect to hit magma. But then nobody expected to hit magma that time either. Despite the geophysical imaging survey at Krafla suggesting that the drill tip would come nowhere near it, **they ended up drilling into magma three times**, twice without realising it. Nobody really knows what's down there until they drill through it, says project manager Ari Stefansson. "It's getting more and more interesting as we go deeper."

Stefansson sits in a heated cabin, looking at the latest readings. A screen shows various figures but the key one stands out near the top – the depth of the drill bit. "We are now at 4,090 metres," he says. Only a few weeks

earlier, the hole officially became the deepest in Iceland when it reached a depth of 3,640m. But there's still another kilometre to go, which they hope to achieve by Christmas.

These core samples are the only way the team can be certain of what they are drilling through (Credit: Chris Baraniuk)

Sometimes the drill apparatus spits cuttings back up the shaft – like the obsidian shards in the first well. But that is not happening this time. The cuttings are getting lost somewhere on the trip to the surface, perhaps in a layer of porous or fragmented rock. So the team plan to take some core samples before going further. “They are the only pieces of geological information that we can draw out of the shaft,” says Fridleifsson.

The success of IDDP-2 could lead to supercritical fluids being used as a source of renewable energy at sites around the world. Wilfred Elders, a geologist and emeritus professor at the University of California Riverside, who is working with IDDP, points to a map on the wall that shows a handful of other places where large geothermal resources have been found. It is very out of date, he says – there are probably many more.

> **California sits on top of the largest geothermal reservoir in the world**

“We could prove an important concept here and then apply it in these other places,” says Elders. One potential site is in California, which sits on top of the largest geothermal reservoir in the world.

If extreme geothermal energy takes off, we can expect more than just cheap electricity. The plant on the Reykjanes peninsula is **piping hot water directly to local businesses**, for example. Asgeir Margeirsson, HS Orka’s CEO, rattles off a list.

The plant on the Reykjanes peninsula is piping hot water directly to local businesses (Credit: Chris Baraniuk)

There's a **fish farm that rears Senegal sole**, an African flatfish that thrives in tropical temperatures. Another company uses geothermal steam to dry fish heads and bones. These are exported to Nigeria, where they can be stored without the need for refrigeration. According to Fridleifsson, they make a tasty soup.

Then there are the pavements, car parks and roads that have below-surface heating to melt snow and ice in the winter. "Fewer people fall and break their bones," says Margeirsson. "That reduces the load on health care."

> **Iceland's football team puts its European Championship success down partly to new indoor sports facilities built thanks to cheap energy**

Yet he is most proud if his role in Iceland's recent football success. This year Iceland reached the quarter finals of the European Championship for the first time. The captain of national team put this down at least in part to the fact that they were the first generation of Icelanders who were able to practise indoors in the winter. The building of new sports facilities was possible thanks to cheap energy, says Margeirsson. "So we take a piece of the glory," he says, laughing. "Put it that way."

Not everyone in Iceland welcomes the development of geothermal power, however. Some think **areas such as Reykjanes have been over-used** by the power companies, potentially depleting resources too quickly – something that HS Orka denies.

Gudmundur Fridleifsson, chief geologist at energy company HS Orka, has been planning deep wells for 20 years (Credit: Chris Baraniuk)

Others fear that drilling and injecting water into the ground could cause earthquakes. The risk is real enough that power company facilities in Reykjanes are built to withstand tremors. And in 2005, a new geothermal well in Basel, Switzerland, was abandoned after a series of earthquakes, one registering 3.4 on the Richter scale, **damaged buildings**.

Margeirsson accepts that injecting water can cause minor earthquakes, but considers frequent, small tremors a good thing. “Without the injection, you would have bigger earthquakes from time to time,” he says.

> **Injecting water into deep wells can cause frequent minor earthquakes – but that might reduce the risk of occasional big ones**

Whatever the downsides, many think geothermal energy is a big part of the solution to the looming energy crisis. “Geothermal energy is the nearest we can get to a silver bullet in terms of sustainable, renewable energy – without the high-level of radioactive waste associated with nuclear fission,” says Jon Gluyas at Durham University in the UK, who has been watching IDDP’s progress with interest.

“In the UK, for example, half of all the energy we use is to heat our homes and offices,” he says. “Even with our modest geothermal potential, we could heat all our houses for a minimum of 100 years and slash CO2 emissions by almost 50%.”

So, it is no surprise that Fridleisson and his colleagues are already planning their next project. By 2020, they want to start drilling on the slopes of Hengill volcano, in the southwest of Iceland.

Some think geothermal energy is the nearest we can get to a silver bullet in terms of sustainable, renewable power (Credit: Chris Baraniuk)

And then what? There is always more prospecting to be done, says Fridleifsson. As we drive away from the Reykjanes site, he points out that the volcanic rock in many geothermal regions can contain valuable mineral deposits – especially gold. There is twice as much gold in the basalt here than you would find in the basalt in mainland Europe, he says.

The long road back to Reykjavik stretches across a black, craggy landscape under a brilliant blue sky. Distant puffs of steam rise here and there from several peaks on the horizon – each plume a reminder of the riches beneath.

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