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Tapping the Earth's Heat

The temperature at the center of the earth is more than 10,000 degrees Fahrenheit (5,700 degrees Celsius), roughly the same as on the surface of the sun. As this geothermal energy radiates out from the earth's core and mantle, it can be converted into electricity or used directly to heat facilities like buildings and greenhouses.

Geothermal resources around the world are richest in areas of high tectonic activity. The so-called Ring of Fire, which encircles the Pacific Ocean, is one such zone. It includes the Andean countries (such as Chile, Peru, and Colombia), Central America, and the West Coast of the United States and Canada. On the other side of the Pacific, it includes Japan, China, the Philippines, and Indonesia. Another concentration of geothermal resources is found in the Great Rift Valley of Africa, encompassing Ethiopia, Kenya, Rwanda, Tanzania, and Uganda. The Eastern Mediterranean region is also well endowed.

But the geothermal capital of the world is Iceland. Straddling the Mid-Atlantic Ridge where the North American and Eurasian tectonic plates are spreading apart at a rate of about four fifths of an inch (2 centimeters) per year, this island of volcanoes is one of the most geologically active places on earth. Geothermal energy figures prominently in nearly every aspect of life in Iceland, from electricity generation and home heating to vegetable growing, fish farming, and bathing.

Many parts of Iceland have underground temperatures of up to 480 degrees Fahrenheit (250 degrees Celsius) within a mile of the surface—excellent conditions for geothermal power generation. With 660 megawatts of geothermal power capacity installed by early 2014, Iceland generates 29 percent of its electricity from the earth, the highest share in the world. (Hydropower accounts for nearly all of the rest.) Hot water and steam are brought from underground reservoirs to the earth's surface through wells drilled into porous rock. The steam from the reservoir or from the hot water drives a turbine to generate electricity. Because of its abundance of cheap geothermal electricity, Iceland has become a powerhouse of aluminum manufacturing, a very energy-intensive industry. Nearly 70 percent of Iceland's electricity goes to aluminum smelting.

Iceland's natural hot springs have been used for centuries, likely since settlement began some 1,100 years ago. Over the last 100 years or so, roughly 150 geothermally heated recreational swimming centers have been built in virtually every community nationwide. Most are public facilities operating year-round, many of them outdoors. Iceland's most famous tourist destination, the Blue Lagoon—which each year receives far more visitors than Iceland's population of 330,000—boasts an extensive series of pools ranging from 95 to 117 degrees Fahrenheit. They actually contain the brine released from the Svartsengi geothermal plant, which produces electricity and supplies hot water for residential use.

Geothermally heated water is sent from cogeneration plants like Svartsengi or from "low-temperature" (less than 300 degrees Fahrenheit) geothermal fields through a network of pipes to heat buildings. In 1970, over 50 percent of space heating in Iceland came from burning oil, while geothermal accounted for 43 percent. The government reacted to oil price hikes in that decade by giving priority to district heating expansion, and today geothermal energy provides nearly 90 percent of all space heating directly. About 10 percent is from electricity (also partially geothermally produced), and oil is now less than 1 percent of the total. The 184,000 residents of the capital, Reykjavik, warm themselves with geothermal district heating.

Iceland uses its geothermal resources in a wide variety of other ways. For example, nearly 13 million square feet of sidewalks, parking spaces, and streets, mostly in Reykjavik, are heated from below by warm water (often water that was already used to heat a building) to prevent icing and to ease snow removal. Direct uses of geothermal energy by industry include cement curing and salt production. Geothermal energy is used to heat 48 acres of greenhouses that produce vegetables, fruits, flowers, and other plants. In some 15–20 fish farming operations, Arctic char, salmon, and Senegalese sole are raised in geothermally heated water.

While Iceland is clearly a model, China leads the world in the amount of geothermal energy harnessed for direct use. China's installed capacity is estimated at 6,100 thermal megawatts, about 30 percent of the world total. Roughly half of this capacity is used for district heating, which has grown by a factor of five in China over the last decade. The rapid growth is owed in part to Icelandic expertise: Orka Energy, based in Reykjavik, teamed up with China's Sinopec Star Petroleum Co. to form Sinopec Green Energy Geothermal Development Co., Ltd. In late 2013 the partnership announced that it had tapped enough geothermal energy to heat 161 million square feet of space. It expects this figure to double by 2015. Another 40 percent of China's direct-use capacity is for hot baths and spas, with the remainder divided among fish farming, greenhouses, agriculture, and industry.

Coming in a distant second on the world stage is Turkey, with 2,800 thermal megawatts of direct-use geothermal capacity as of 2014. More than one third of this is used to heat the country's numerous baths and spas, another quarter goes to district heating, and 20 percent heats an impressive 740 acres of greenhouses.

After Iceland (third in the world ranking of direct-use geothermal capacity, with 2,200 thermal megawatts) comes Japan, with 2,100 thermal megawatts. A geothermally rich country long known for its thousands of hot baths, Japan was an early leader in this field. Nearly 90 percent of the country's direct-use capacity serves the 2,000 spas, 5,000 public bathhouses, and 15,000 hotels that use nature's hot water. India, number five on the list, has developed 990 thermal megawatts of direct geothermal capacity, virtually all for bathing and swimming.

Italy, France, and Germany have also tapped their geothermal resources to heat both water and space. Half of Italy's 800 thermal megawatts of direct-use capacity is for bathing and swimming. It has some district heating, for example in Tuscany, but this has not been widely developed. The opposite is true for both France and Germany, where district heating makes up at least 80 percent of the geothermal direct-use capacity. The Paris metropolitan area has an estimated 170,000 households that are geothermally heated, with 10,000 more expected by 2015.

To the east, Hungary stands out for its direct use of geothermal energy. Bathing and swimming uses account for up to 44 percent of its 615 thermal megawatts of direct-use capacity. Geothermal energy heats 1,200 swimming pools there during the winter. And 173 acres of greenhouses get heat from 193 geothermal wells.

Geothermal direct-use applications in the United States, also with 615 thermal megawatts of capacity, include greenhouses, industrial process heat, and district heating. The first U.S. city to turn to geothermal energy for district heating—in 1892—was Boise, Idaho, a city that now has some 214,000 people. It uses this subterranean heat source to warm hundreds of buildings, including the Idaho Statehouse. In 2014, Boise State University started using geothermal energy to heat nine of its buildings. Other U.S. cities with geothermal district heating include Reno, Nevada, and Klamath Falls, Oregon.

At Ball State University in Indiana, the school's two remaining coal-fired boilers were closed on March 19, 2014, to be replaced by geothermal energy. Jim Lowe, director of engineering, construction, and operations, calculates that using geothermal heating and cooling to replace the 33,000 tons of coal burned each year will save the university $2 million annually while cutting its carbon footprint in half.

The United States is also among the 21 countries that use geothermal energy for fish farming. In California, for example, Pacific Aquafarms produces tilapia, catfish, silver carp, and striped bass year-round in geothermally heated ponds and tanks. The firm supplies some 2 million pounds of fish each year to live-fish markets in the greater Los Angeles and San Diego areas and to lakes stocked for recreational fishing.

In Israel's Negev Desert, 100-degree Fahrenheit brackish water from underground is used to raise tilapia, catfish, sea bass, red drum, and barramundi. Rich in nutrients from fish waste, the water from the fish farms is then used to irrigate olive groves, date palms, and alfalfa in this water-scarce country.

Beyond district heating, aquaculture, hot baths, and the other direct-use applications just described, there are ground-source heat pumps, also known as geothermal heat pumps. These systems take advantage of the remarkable stability of the earth's temperature just a few feet from the surface, using it as a source of heat in the winter when the air temperature is low and as a source of cooling in the summer when the air temperature is high. The great attraction of this technology is that it uses 25–50 percent less electricity than would be needed with conventional heating and cooling systems. Unlike the other direct uses of geothermal energy, heat pumps can serve homes, schools, and other structures virtually anywhere in the world, even places without deep high-temperature resources. The estimated worldwide capacity of ground-source heat pumps is some 50,000 thermal megawatts.

While 82 countries report using geothermal energy directly, a comparatively modest 24 countries convert energy from the earth into electricity. Over one fourth of the world's installed geothermal electricity generating capacity—which stood at 11,700 megawatts by the start of 2014—is in the United States. Another one fourth is in the Philippines and Indonesia. Italy and New Zealand round out the top five countries. Next up in the capacity ranking are Mexico, Iceland, Japan, Kenya, and Turkey.

In terms of the importance of geothermal power as a share of national electricity generation, however, the world ranking changes dramatically. Iceland, as noted earlier, tops the list. Not far behind, with 26 percent of its electricity coming from the earth, is El Salvador. In Kenya, the share is about 19 percent. The Philippines, Costa Rica, and New Zealand all get close to 15 percent of their electricity from geothermal sources. Also ranking high on the list are Papua New Guinea, Nicaragua, and Indonesia.

Several of these countries could go much further in harnessing their resources. The U.S.-based Geothermal Energy Association (GEA) has identified some 40 countries that could satisfy all their electricity needs with geothermal power alone. Among these are Costa Rica, Ecuador, El Salvador, Ethiopia, Indonesia, Kenya, Peru, the Philippines, Tanzania, and Uganda. Together these countries are home to 860 million people, or 12 percent of the world's population.

The United States has 3,440 megawatts of installed geothermal electric generating capacity, enough to power some 1.4 million homes. For several decades, U.S. geothermal power was confined largely to the Geysers project north of San Francisco. With nearly 1,500 megawatts of generating capacity, this is easily the world's largest geothermal generating complex. But now the United States is experiencing a geothermal renaissance. Some 124 power plants under development in 12 states are expected to add roughly 1,000 megawatts to U.S. geothermal capacity. As of April 2014, states developing projects of at least 20 megawatts each include Alaska, California, Colorado, Idaho, Nevada, Oregon, and Utah.

Most of the new facilities being developed in the United States today are "binary" plants. Hot water from the earth heats a second fluid like isobutane, which has a lower boiling point. When the fluid vaporizes, the vapor drives a turbine to generate electricity. Whereas temperatures above 350 degrees Fahrenheit were historically needed to generate electricity at geothermal power plants, binary plants can use geothermal resources at around 210 degrees Fahrenheit. The potential to use such lower-temperature geothermal fields for power generation is also helping countries like Germany begin to bring geothermal energy into the power mix.

Currently, California and Nevada have over 95 percent of the total U.S. geothermal generating capacity. Utah, Hawaii, Oregon, and Idaho account for nearly all the remainder. In California, CalEnergy—a subsidiary of Warren Buffett's MidAmerican Renewables—announced in May 2014 a plan to invest $1 billion to sustain its 10 geothermal facilities around the Salton Sea. The GEA estimates that roughly 50 percent of California's available geothermal resource remains untapped. The comparable figure for Nevada is 60 percent.

Nationwide, the U.S. Geological Survey estimates that 42,000 megawatts of geothermal electricity generating capacity could be developed, enough to supply 30 million American homes. In other words, 90 percent of U.S. geothermal power potential is waiting to be tapped.

The Philippines, currently the world's number two generator of electricity from geothermal sources, is also planning new projects. A 40-megawatt project in Oriental Mindoro Province that was set to begin drilling in late 2014 is expected to lower local electricity bills by some 40 percent. The Philippines' Department of Energy aims to increase total geothermal power capacity from 1,900 megawatts to 3,300 megawatts by 2030.

Indonesia, a country with 127 active volcanoes and thus a wealth of underground energy to harness, has so far developed just 1,340 megawatts of geothermal generating capacity. Although geothermal power has grown slowly there in recent years, it is picking up momentum. A 330-megawatt project in North Sumatra began construction in June 2014. Key regulatory reforms that year opened up new areas to geothermal exploration and made projects more financially attractive. In late 2014, Jakarta announced that 25 project sites would be open for bidding in 2015. The near-term goal is to nearly quadruple geothermal power capacity to 4,900 megawatts by 2019. By 2025, Indonesia intends to have 10,000 megawatts of geothermal capacity, enough to cover one third of its current electricity consumption.

The huge geothermal potential in Indonesia is fortuitous, since its oil production has declined by half over the last two decades, transforming it from an oil exporter into an oil importer in recent years. Pertamina, the state oil company, has been the principal geothermal power developer. As Pertamina shifts its development efforts from oil to geothermal, it could become the first oil company—state-owned or independent—to make the transition from oil to renewable energy.

Japan could develop more than 80,000 megawatts of geothermally generated electricity—enough to meet over half of its electricity needs. Unfortunately, today it has only 500 megawatts of geothermal generating capacity, due in part to a long-time ban on geothermal development in national parks and monuments, areas housing much of the country's geothermal resources. In March 2012, one year after the Fukushima nuclear accident, the government changed that law, giving the green light to small-scale geothermal projects at several park sites, with close governmental oversight. A feed-in tariff for geothermal was also introduced in 2012, guaranteeing the producer a long-term purchase price for all electricity sent to the grid. As a result, Japan now has 47 projects under development.

New Zealand, a country with 4.5 million people and the world's largest boiling lake, generates about 14 percent of its electricity from geothermal power plants. This share is set to rise because of the 166-megawatt Te Mihi plant inaugurated on the country's North Island in August 2014 by Contact Energy, a large power provider. Because of the climbing cost of natural gas in New Zealand, the company has been replacing some of its gas-fired generation with geothermal power. Te Mihi will allow the company to produce even less gas-fired electricity. Contact's chief executive Dennis Barnes said in late 2014, "I used to have a gas bill that was $300 million to $400 million—next year I'll have a gas bill that is $100 million. I've replaced that [gas] with…geothermal."

Contact is not the only power company in New Zealand ditching natural gas. Mighty River Power, another large electricity provider, has replaced some of its gas-fired capacity with geothermal plants and wind farms in recent years as well. In fact, it appears that geothermal power is replacing natural gas as New Zealand's number two electricity source behind hydropower: for the 12 months up through October 30, 2014, geothermal accounted for 16.3 percent of the generation mix, edging out natural gas at 15.8 percent.

Back in the northern hemisphere, Italy—the world's number four producer of geothermal electricity—had 880 megawatts installed by the start of 2014. Larderello, the site where geothermal energy was first harnessed to generate electricity in 1904, still hosts a power plant that began operation in 1913.

Turkey, with just 220 megawatts of geothermal power installed by the beginning of 2014, is adding handsomely to its capacity. In December 2014, Alexander Richter, founder of the geothermal news website ThinkGeoEnergy.com, reported that Turkey had reached 400 megawatts of installed capacity, and that dozens of geothermal developers had enough projects in the pipeline to nearly double that total again.

In the Great Rift countries in Africa, Kenya has emerged as the early leader. It now has over 250 megawatts of geothermal electricity generating capacity and will soon add several hundred more megawatts. For the longer term, Kenya has set the ambitious goal of 5,000 megawatts by 2030. In a country where only 19 percent of the population has access to electricity, this would be a welcome development.

Neighboring Ethiopia is also setting its geothermal sights high. In 2014, the Icelandic company Reykjavik Geothermal began drilling the first of two 500-megawatt phases of the Corbetti geothermal project. To put this planned 1,000-megawatt capacity in perspective, Ethiopia's current generating capacity from all sources is about 2,000 megawatts, mostly in the form of hydropower.

In Central America, Costa Rica is aiming to be carbon-neutral by 2021, with 100 percent of its electricity generated from renewable sources. With more than 90 percent of its electricity already renewably produced—about 70 percent hydropower, 14 percent geothermal, 5 percent wind, and slightly less than 2 percent biomass—Costa Rica is well on its way. But its heavy dependence on hydro leads to electricity rationing and the use of oil-fired power late in the dry season. The government is looking to add to its 200 megawatts of installed geothermal capacity to help address this seasonal problem. Three 55-megawatt geothermal plants planned for the northwestern province of Guanacaste, financed largely by the Japan International Cooperation Agency, will generate enough electricity for 200,000 Costa Rican homes.

Exploratory drilling for geothermal resources in El Salvador began in 1968. Despite political turmoil in the subsequent decades, including a bloody civil war in the 1980s, two major geothermal fields were developed that today generate 26 percent of the country's electricity. El Salvador's goal is to boost this share to 40 percent. In late 2014, however, Italy's Enel Green Power sold to the government its shares of La Geo, the company that owns and operates El Salvador's geothermal plants, making it fully state-owned. It is unclear how this will affect the country's geothermal expansion.

Globally, with some 60 geothermal power plants under construction in 2014, GEA expects at least 1,400 megawatts of new geothermal generating capacity to come online over the next few years. Among the countries housing these new projects are Kenya, Mexico, New Zealand, Nicaragua, Turkey, and the United States. Other countries where geothermal power development could move forward include Argentina, Australia, Azerbaijan, Chile, Germany, Guatemala, Malaysia, Rwanda, Thailand, Uganda, and Zambia.

As with both wind and solar, the principal expense in harnessing geothermal energy is the up-front cost. For developing geothermal power, this means well drilling. Exploratory wells often reach a mile or so deep. The test-drilling phase is both expensive and uncertain—it may account for 15 percent of the project's capital cost, with no guarantee that a viable site will be found—typically making financing difficult. Once a field is discovered, the major cost is for drilling to reach the hot water and steam below the earth's surface. After a plant is built, operation and maintenance costs are relatively low—importantly, because there is no fuel cost. Over the life of the generator, geothermal plants are often cost-competitive with all other power sources.

Developers are still finding new conventional reservoirs with sufficient hot water or steam for geothermal power plants, but a relatively new technology—enhanced geothermal systems (EGS)—holds the greatest potential for expanding electricity generation from the earth's heat worldwide. Where hot rock resources exist but the rock is too dry or impermeable for conventional geothermal technology to work, EGS injects water deep underground to reopen existing fissures and create a new geothermal reservoir. A second well brings heated water to the surface, where it flashes into steam and drives a geothermal turbine.

EGS technology is adapted from the oil and gas industry's hydraulic fracturing techniques, but there are key differences. Writing in *Science* magazine in 2013, Joseph Moore and Stuart Simmons of the Energy & Geoscience Institute at the University of Utah noted that "the target geologic formations are deeper, no toxic chemicals are used, and the risk of adverse environmental impacts is much lower" than with fracking for oil and gas.

At this early stage, the few EGS projects that have come online are quite small. The first grid-connected EGS facility, a 2-megawatt plant in France, began operating in 2008. In Australia, a 1-megawatt pilot project reaching roughly 2.5 miles below the earth's surface started up in 2013. And that same year in the United States, the geothermal firm Ormat Technologies Inc. brought online its 1.7-megawatt Desert Peak system in Nevada. Built alongside an existing 18-megawatt geothermal plant, early results show that this EGS facility can boost the electricity production from underperforming wells by close to 40 percent.

Desert Peak's initial success is promising, but it only hints at the magnitude of potential electricity generation from EGS. A team assembled by the Massachusetts Institute of Technology wrote in 2006 that EGS could provide 100,000 megawatts of generating capacity in the United States alone by 2050. The U.S. Geological Survey estimates the country's total EGS potential at more than 500,000 megawatts. For comparison, the world as a whole is estimated to have a conventional geothermal potential of about 200,000 megawatts.

In 2014, the U.S. Department of Energy (DOE) launched an ambitious initiative called FORGE—Frontier Observatory for Research in Geothermal Energy—with the stated goal of reaching the 100,000-megawatt mark. Under DOE direction, FORGE will bring together industry, academia, and the national laboratories to develop an EGS research and demonstration site. The aim is to test EGS methods and technologies, to model reservoirs, and to collect and share data in order to greatly reduce the risk and cost of EGS, allowing the technology to take off. This will be an international effort to some extent, with participation from Japan, Switzerland, Taiwan, and others.

One of the strong selling points of geothermal power is that it is a steady, reliable source of electricity, able to run virtually non-stop. But perhaps an even better selling point, as the energy transition proceeds and as more wind and solar installations connect to the grid, is that geothermal plants can ramp up generation quickly as needed. This reduces the need for expensive fossil fuel generators to be on standby for when the wind stops blowing or night falls. In places endowed with enough underground heat to develop geothermal power plants, the potential benefits are huge.

Data, endnotes, and additional resources can be found at Earth Policy Institute, www.earth-policy.org.