Episode 4 – "Deep Geothermal Renewable Energy"

Previously, on Energy Transition Crisis: Prior episodes explained the true scope of the challenges we face, laid out a plan to replace fossil fuels with clean energy, and explained why a global energy crisis is unavoidable in the mid-2020s. Now, here's Erik Townsend to explain Geothermal renewable energy.

Geothermal renewable energy is currently the least practical and economic of the four primary renewable energy sources. But we're already on the cusp of making technological advances that could be game-changers. In this episode of Energy Transition Crisis, I'll show you what it would take for Geothermal to leapfrog Wind, Solar, and Hydropower, to become the very best source of baseload power needed to replace fossil fuels.

To phase out fossil fuels by 2050, we need to build 80k TWh of new clean electric generation capacity. That's equivalent to 160k TWh of thermal energy. By my calculations, no more than 35% of it could come from wind and solar, and that's intermittent supply. So to phase out fossil fuels, what's left to find is the other 65% of baseload supply needed to finish the job. That's 52k TWh of electricity, or 104k TWh of thermal energy needed to make that electricity.

But our goal shouldn't just be to replace what we already have. We should strive to make clean energy more abundant than fossil fuel energy is today. For that reason, I prefer to focus on finding a clean source of baseload supply for the full 160k TWh of thermal energy needed to completely replace fossil fuels. That way, if wind and solar fall short of my admittedly very aggressive 35% target by 2050, we'll still have enough energy. And if wind and solar deliver the full 35% or more, then the extra energy we create will be the icing on the cake that helps usher in a new era of human prosperity just like the steam engine did beginning in the 1770s.

Geothermal renewable energy, at its current state of technological development, is the least promising of the four primary renewable energy sources. So why am I dedicating an entire episode to it? Because we're on the cusp of making technological breakthroughs in geothermal that could easily be game-changers, leapfrogging Geothermal from last position behind Wind, Solar, and Hyrdropower, and making it the MOST attractive source of renewable energy to supply the 160k TWh of thermal energy needed to completely phase-out fossil fuels by 2050.

Geothermal is less popular and less well understood than other renewables, so let's start with how it works. There are several different kinds of Geothermal energy, but I'm only going to focus on the one that could be a game changer for Energy Transition, which is Electricity generated from deep Geothermal wells.

If you ask most people what our planet is made of, they'll probably say dirt, rocks, and the water in our oceans. But these things are just what make up the earth's crust, which only accounts for 1% of the planet's overall mass. The crust isn't very thick—generally no thicker than 100km on land, and even thinner under our deep oceans, where the crust is only 5-7km thick.

It’s another 6,300 km straight down to get to the center of the earth. The next layer below the base of the earth’s crust is the mantle, which is very hot rock, some of it solid and some of it magma, or molten rock, similar to the lava that flows out of erupting volcanoes. Below the mantle are the Earth’s inner and outer core, the center of which is mostly molten iron and other metals.

The deeper you go, the hotter it gets. The earth’s core has a temperature over five thousand degrees Celsius, or almost 10,000 degrees farenheit. The deepest base of the earth’s crust is about 1,000C. Within the earth’s crust, the temperature gets hotter as you go deeper.

A study by the Defense Advanced Research Project Agency concluded that if we could just figure out a way to harness only 1/10th of 1% of the heat in the earth’s mantle, we could meet all our energy needs for millions of years. Put another way, all the energy we could possibly ever need is already right at our feet. Or more precisely, just a few miles straight down below our feet.

At those depths, the heat of Earth’s mantle—or even just the deeper regions of Earth’s crust, offers us all the energy we could possibly need, if only we could figure out how to drill a hole deep enough to access all that heat that’s right there below our feet. The really hot rock that has enough energy to solve all our energy problems is found at less depth below the surface of the earth than our commercial airliners fly above the surface of the earth.

To tap into the heat energy beneath our feet, we need a way to get down there and pump some of that heat up to the surface where we can use it. For decades now, the oil & gas industry has been perfecting technology which could be re-purposed for doing just that. Oil drilling technology was developed to drill oil wells in porous rock formations deep below the surface, which contain crude oil in the rock’s pores, like a sort of sponge made of rock that contains oil.

The way an oil well works is that a hole is drilled deep into the porous rock containing oil, allowing the oil to seep out of the rock and into the oil well. Not all rock contains oil. In fact, rock that’s full of oil is quite hard to find.

But now let’s imagine taking that same oil drilling rig to a rock formation we know doesn’t contain any oil. For geothermal energy, the whole idea is to avoid porous rock containing oil, and aim for dry, hot rock formations instead.

In some places like Iceland and Indonesia, which have a lot of volcanic activity, there are plentiful rock deposits not too far below the surface where very hot, dry rock can be found. This is ideal, because the shallower the hole, the less it costs to drill. In other parts of the world, where there are no volcanoes bringing hot magma near the surface, you might have to drill much deeper to find the hot, dry rock formations that are needed to produce geothermal energy. But if you're willing to drill deep enough, hot rock can be found anywhere in the world.

For our first example, let's assume we've located a dry rock formation not too far below the surface, which has a temperature of 100C, the boiling temperature of water. We'll start by drilling a well vertically into that rock formation until reaching the depth where the 100C dry rock exists. Then we'll turn the drill bit sideways and drill a horizontal hole several hundred meters long.

Turning the drill bit 90 degrees and drilling a horizontal hole through solid rock several hundred or even a few thousand meters below the surface might sound like an impossible trick, but thankfully, the shale oil revolution was made possible by the commercialization of horizontal drilling technology for doing exactly that: drilling long horizontal holes known as 'laterals' through solid rock deep below the surface. So as daunting as it sounds, we already have the technology needed to do this.

Finally, we'll drill another hole, similar to an oil well, which will connect to the far end of the lateral we just drilled back to the surface. The result is a U-shaped passage which goes straight down several hundred to a few thousand meters, then turns sideways and runs several hundred to a few thousand meters horizontally through hot dry rock, then turns up to provide a path back to the surface.

Now we can tap into free energy from the center of the earth by simply pumping cold water down one side of this U-shaped passage. As the water flows down into hot rock and then flows through the long lateral passage, the water is heated up to boiling temperature. The result is we're pumping cold water down one hole and getting boiling hot water out the other hole, without consuming any energy to heat the water. All we need to pay for is the electricity to run the pump to circulate the water through the underground passage. The hot rock formation does the rest.

The boiling water coming out from the other side could be used to heat a building. Or it could be passed through a heat exchanger to heat domestic potable water, eliminating the need for a water heater fueled by natural gas or electricity. But as novel as this system might sound, the fact is that we're not getting enough heat energy out of this system to produce electricity or do much else. We can heat a large industrial building almost for free this way, once all the holes have been drilled. But guess what? Drilling those holes through solid rock costs a lot of money, and it will take quite a few years just to break even.

Now let's suppose we can find a 150C rock formation by drilling a little deeper than we did in the prior example. So we drill another U-shaped circuit, but this time the lateral segment is drilled through 150C dry rock. Now it's a totally different story. We still pump cold water down one side, but the temperature of the lateral segment is much hotter than water's boiling temperature of 100C. So what comes up the other side is not boiling water, but rather hot steam. And that steam will come up under pressure because water expands when it boils into steam.

Now it becomes possible to install a steam turbine on top of the exhaust well, and to produce electricity with that turbine. Some of that electricity can be used to pump more cold water down the intake well, eliminating the need for any external power to operate the system. The remainder of the electricity produced by the turbine can be sold into the electric grid and used to supply homes and businesses and to recharge electric vehicles. The water contained in the steam coming off the steam turbine can be recovered in a condensing chamber and recycled by pumping it back down the intake shaft to produce more steam in the exhaust shaft, and therefore more electricity from the steam turbine.

If this sounds like a terrific, unlimited source of clean, environmentally friendly electricity with no reliance whatsoever on fossil fuels after the wells have been drilled, that's exactly what it is! But unfortunately, there's still a catch. Geothermal wells cost a lot to drill, and even at temperatures of 150C, the heat energy recovered from them is only sufficient to produce a modest amount of electricity. High capital costs to drill the well and relatively low electrical power output results in pretty expensive electricity, when you factor in the up-front cost of drilling the geothermal well. For this reason, geothermal electricity generation has outperformed wind and solar on a cost per megawatt basis only in locations where there's volcanic activity close to the surface. Geothermal electricity is still terrific news if you happen to live in Indonesia or Iceland, but for most of the world, the economics just don't work.

Or I should say, the economics don't quite work yet. With a few advances in geothermal drilling technology, a game-changing breakthrough that makes geothermal far more attractive than wind and solar would be possible. And that's the reason I've dedicated this episode to discussing the technological advances needed to make geothermal a game-changer that could play a key role in the energy transition away from fossil fuels.

The amount of electricity we can produce from geothermal wells depends primarily on the temperature of the rock the well penetrates. Even at a temperature of 150C, well above the boiling point of water, the amount of energy that can be extracted and therefore the amount of electricity produced, just barely makes geothermal wells economic sources of electricity in volcano country, where 150C rock can be found at unusually shallow depths.

But what if we aim for even hotter rock formations? Let's say 250C, much hotter than the boiling point of water. We can produce a whole lot more electricity with super-heated 250 degree steam coming out the exhaust well and driving a much bigger steam turbine than we ever could have hoped for with 150 degree steam. Hotter rock makes a huge difference in how much electricity can be produced from geothermal wells.

But it's much harder to drill a geothermal well through 250 deg. rock than 150 deg. rock. Unless you're drilling in volcano country, you have to drill much deeper to get to the 250 deg rock. The deeper you drill, the more it costs to install the geothermal well, and therefore, the higher the cost of electricity produced from that well.

But drilling deeper is actually the easy part. It's drilling hotter where the biggest problems arise. 250C is pretty darned hot. By comparison, Aluminum melts into molten metal at about 660C. The way most drill bits work is they grind a hole through the rock, by pressing a very hard, sharp drill bit (usually made from industrial diamonds) against the rock at high pressure, and then turning it to slowly grind the rock away through abrasion, boring a hole through the rock.

This process is incredibly friction-intensive. Drill bits used to drill through granite countertops above ground where the ambient temperature is only 25C can heat the drill bit and the granite at the bottom of the hole up by a more than 100C because the friction of drilling something as hard as solid rock creates so much heat-generating friction. When we take the same operation miles below the surface of the earth into solid rock that's already 250C and then heat it up even more from there with all the additional heat produced by the drill bit, temperatures rise to levels where even solid metal tooling begins to lose its strength. The engineering challenges are suddenly quite substantial!

At 250C, we're starting to approach the limits of current technology. The engineering challenges can be overcome with technology we already have, but overcoming them doesn't come cheap. The higher cost of drilling a geothermal well into 250C rock would negate the benefit of being able to produce more electricity from the hotter rock. The hotter geothermal well will produce much more electricity, but the cost per megawatt-hour won't be any lower because the hotter well costs so much more to drill.

This conundrum of geothermal electricity economics is the whole reason you don't hear very much about geothermal energy. It's a brilliantly innovative way to tap into a literally limitless source of clean energy that produces no emissions. But for now, it's generally less economic than wind and solar, except in volcano country, where very hot rock is found much closer to the surface.

The shale oil revolution of the 20-teens was enabled by two principal technological advancements. The first was horizontal drilling: The ability to drill an oil well down to the depth where oil is abundant, then turn a corner and drill a long, horizontal hole through the rock at the optimal depth for recovering oil. That horizontal segment of the well deep below the surface is called a lateral.

The second major technology breakthrough behind the 20-teens shale oil revolution was hydraulic fracturing. This involves pumping water and sand into the newly drilled lateral, and then subjecting it to extraordinary pressure shocks that literally crack the rock around the edges of the lateral. The purpose of the sand is that it becomes wedged into the cracks in the rock, preventing them from closing again after the pressure is removed. This process allows much more oil trapped in the rock to flow into the lateral and be pumped to the surface.

The shale revolution began with natural gas, starting in 2006. By 2010, shale oil became a hit as well. By 2011 U.S. oil production really started to take off. By 2017, total U.S. production set a new record high, eclipsing the prior record set when conventional oil production peaked in the early 1970s, just as Hubbert predicted it would.

Now I have a quiz for you. Recall that the shale boom began in 2006 with natural gas, and shale oil hit the stage by 2010. The media hailed the "brand-new" technologies of horizontal drilling and hydraulic fracturing as technological breakthroughs that made it all possible. Can you guess when the very first horizonal oil well was drilled using this breakthrough new technology of horizontal drilling? Was it 2005? 2003? 2001? Or… 1929??? Ok that must be a typo and it's supposed to say 1999, right?

Wrong. The correct answer is 1929. That's when horizontal drilling really was a brand-new technology, and that's when the first oil well was drilled using horizontal drilling.

Hydraulic Fracturing is a much newer technology. The first successful commercial application of hydraulic fracturing wasn't until 1950. Yes, you heard that right; 1950, fully six decades before the shale oil boom really took off.

Ok, what the heck is going on here? If the technologies that made the shale oil boom possible had all been proven to work by 1950, why didn't we start using them much sooner? This is a critically important point to understand, and in just a minute I'll explain why it has everything to do with making a breakthrough in geothermal energy.

The oil industry knew all about horizontal drilling and hydraulic fracturing for decades before they were commercialized at scale. The reason they went unused was simply that they were too expensive, so there was no economic justification for using them sooner.

Does this sound familiar? It should, because the whole reason horizontal drilling and hydraulic fracturing went unused for fully 6 decades after they'd both been proven to work is exactly the same reason deep geothermal isn't popular now: because the economics don't quite work yet, and the expense of drilling deep geothermal wells through really hot rock is hard to justify economically.

In 2005, when conventional oil production peaked globally and offshore drilling was becoming more popular, the oil industry already knew all about horizontal drilling and hydraulic fracturing. But they'd done their homework and figured out that it wasn't economic to employ those technologies with anything less than $85 per barrel crude oil prices. At that time, oil had never commanded a price anywhere close to $80/bbl in all of history, so it made no sense to deploy these decades-old technologies, which were too expensive to be economic.

But then oil prices moved dramatically higher in early 2008, setting an all-time record price of $147/bbl before the Great Financial Crisis took hold and crashed oil prices back down below $40/bbl. Horizontal drilling and hydraulic fracturing were definitely not economic at $40/bbl, but the most visionary entrepreneurs in the oil patch read the proverbial writing on the wall and started making plans. By 2010, oil prices were back over $80, horizontal drilling and hydraulic fracturing finally became economic, and the rest is history. U.S. oil production took off, and by 2017 U.S. production had eclipsed its prior record level from the early 1970s, something most experts thought impossible.

Now here's the most important part of this story I really want you to take to heart. In late 2014, Saudi Arabia changed its competitive strategy and allowed oil prices to crash all the way down to $27/bbl by early 2015. Skeptics immediately declared the shale revolution was dead, and predicted fracking would never be economically viable again.

The reason they were dead wrong is that by then, the industry had learned to optimize horizontal drilling and fracking technologies, making them much more cost-effective than just a few years earlier. Suddenly a case could be made for drilling and fracking new shale wells with crude oil prices as low as $40/bbl, because economy of scale had transformed previously expensive niche technologies into much more affordable mainstream technologies. By 2015, horizontal drilling and fracking could be economic at oil prices half the break-even threshold for using these technologies just five years earlier!

Now let's return to the topic of deep geothermal clean electricity. If we take a narrow view and just focus on today's economic balance point, deep geothermal is very hard to justify. Drilling geothermal wells deep enough to get to really hot rock is very expensive because Geothermal is still a niche technology, and drilling through hot granite at those temperatures starts to challenge the limits of current drilling technology.

But let's take a step back and consider the big picture. We already have an extremely well-developed oil and gas industry which has become expert at cheaply and efficiently doing one thing incredibly well. That one thing is drilling wells deep below the surface, then turning them sideways to form laterals. Between 2010 and 2016, the cost of doing that for shale oil wells was cut almost in half thanks to innovation, hard work, and economies of scale.

But investment in that industry is in steep decline now because everyone agrees that the age of fossil fuels needs to be brought to an end. Long-term investment is almost unheard of in oil and gas, because everyone knows that governments around the world are united in the net zero initiative, and that oil and gas will be phased out just as soon as we can find viable replacements, something that will actually take decades longer than most people realize.

What if we stopped vilifying the oil and gas industry as public enemy number one as a matter of government policy, and instead supported that industry while giving it a new dual mandate that could extend its life indefinitely? Part one of that mandate would be to keep producing oil and gas for as long as necessary in order that society can continue breathing. Part two of that mandate would be for the oil and gas industry to evolve itself over time, transforming into the clean geothermal electricity industry of the future.

What if the smartest young engineers choosing careers, who avoid oil and gas like the plague now because they see it as a zombie industry, were presented with a very different picture? What if they saw entering the oil & gas industry as a stepping stone to becoming the geothermal renewable baseload energy pioneers of tomorrow? And what if we actually had leadership in government that was smart enough to recognize that the best way achieve net zero policy goals is not to scapegoat the oil & gas industry as the bad guys, but rather to create incentives for them to become heroes of the climate transition, by redirecting every bit of ingenuity and experience they have at drilling holes through rock, and using those skills to revolutionize geothermal energy and make it economic at scale, just like they did for shale oil & gas?

Geothermal is currently a niche field that doesn’t receive enough investment capital to make meaningful progress at the pace needed to solve the global energy crisis. But what if all the talent that made the shale boom possible were refocused on Geothermal? How long do you think it would take before geothermal suddenly became more economic than wind and solar?

It took the U.S. oil & gas industry less than a decade to commercialize horizontal drilling and fracking, cut its cost in half by optimizing its design and deployment, and then make the United States the biggest producer of Crude oil in the history of Planet Earth by 2019, something nobody thought remotely possible in 2010.

Do you really think that figuring out how to find hot dry rock deep underground and then drill holes through it economically is beyond their abilities? I sure don’t. But I also know that there’s no way for them to be the ones to solve the energy crisis with a Geothermal energy revolution on par with the shale revolution, if we continue to make it public policy to scapegoat them as if they're our enemies!

We need to stop thinking of oil & gas as an industry we need to get rid of, and instead think of it as an industry that needs to be re-purposed as the clean geothermal energy industry. What we need to do away with are the politicians who stand in the way of progress by making enemies and scapegoats of the very people who are most qualified to help solve the real problem at hand.

Now let's return to our discussion of the current state of the art in geothermal energy, because the story definitely doesn't end at 250C. Things really start to get interesting at 374C and hotter. Why that specific number? Because with the combination of temperatures above 374C and very high pressures more than 218 atmospheres, hot water takes on completely different properties than water or steam as you and I know it. Scientists call it supercritical water, and it could be a game changer for deep geothermal energy because it can carry fully ten times as much heat energy to the surface as regular water or steam.

But now we're really going to hit some technological barriers. 374C is the minimum threshold temperature for producing supercritical water. Let's assume that we'd need to drill laterals through 400C rock to heat the water we pump through it to 374C. After all, just pumping water through the laterals will cool the rock slightly, so we need to start with a rock formation a little hotter than the water temperature we ultimately need.

250C was already pushing the limits of what's possible with current commercial drilling technology. It's impossible to drill through 400C rock using a normal drill bit that uses friction to grind through the rock. Adding the heat of friction pushes the temperature even higher, and almost any drilling equipment anyone has ever invented would literally melt at those temperatures.

There are already a couple of experimental approaches to solving this problem. One is known as hammer drilling, where instead of holding the drill bit against the rock being drilled at high pressure, the drill bit is intermittently "hammered" into the drill hole instead. This technique has already been employed in at least one experimental geothermal project where the goal is to reach the temperature threshold for producing supercritical water.

Another experimental technology is the brainchild of billionaire entrepreneur Robert Friedland, founder of the Ivanhoe mining empire. That technology replaces drilling with an entirely new technology called spalling. With spalling, there's zero pressure between the "drilling" bit and the rock. It works by zapping the rock being drilled with pulses of incredibly high energy electricity, which only last a few nanoseconds. Think of it as tasering the rock instead of drilling it. This process literally vaporizes the rock formation for just a tiny fraction of a second, allowing the spalling operation to proceed without adding any heat from friction to the rock being drilled or the tooling. That technology is still experimental, but it has the promise of someday making it possible to spall geothermal wells in rock that's 400C or even hotter.

To be sure, we're talking now about experimental drilling and spalling technologies which aren't ready for prime time yet, and as of this recording, geothermal wells capable of producing supercritical water are not yet practical or economic.

But I want you to focus on what's possible, not just on what we have today. We literally sent a man to the moon more than fifty years ago. That was an incredible technological achievement, and it was possible only because we had political leadership focused on making the most of our technology industries, rather than on scapegoating them as villains in sophomoric political theatre.

I'm going to paraphrase the words of U.S. President John F. Kennedy, from his infamous May 1961 speech calling for a moon landing before 1970. I believe that all nations on this planet should commit themselves to the goal, before this decade is out, of figuring out how to drill holes through hot rock over 374C and to commercialize a process for doing so economically!

And by the way, if I were the coach assembling the dream team for that mission, my first draft picks would be the men and women of the U.S. oil & gas industry, who figured out how to commercialize horizontal drilling and hydraulic fracturing, cut their price in half, and then use those technologies to make the United States the biggest oil producer in the world, all in less than a decade. President Kennedy would be proud if he knew that story. President Biden and other politicians with his attitude toward the oil & gas industry need to wake up and stop looking a gift horse in the mouth. These are the people who are best qualified to develop and commercialize game-changing deep, supercritical geothermal energy, and they're not our enemies.

The steam engine and the oil age ended human slavery, got the vast majority of us off the hook for having to work on farms, made widespread university education possible, and enabled the development of the modern world we now live in. We could have another acceleration of the pace of human advancement on that scale if we could just perfect a process for economically drilling geothermal wells anywhere on earth in sufficient scale to pump at least 160k TWh of heat energy out of them globally on an annual basis by 2050. And if we could figure out how to drill laterals through 400C rock as economically as we drill shale oil wells today, we could easily pump twice that much heat out of them.

To summarize this discussion of Geothermal energy, to my thinking two key points differentiate geothermal from the other two popular renewable energy sources of wind and solar. The first is that I see clear and obvious technological breakthrough opportunities for geothermal which could be total game-changers. I'm not aware of any similar breakthrough opportunities for wind or solar. The second key point is that geothermal also offers the ability to produce baseload electric supply, that runs 24/7, not just when the sun is shining or the wind is blowing. That means geothermal is a perfect candidate for the 65% of energy demand that intermittent renewable sources like wind and solar can't meet.

For those who feel committed to the idea that our energy strategy should focus exclusively on renewables, this is a match made in heaven. If we could just figure out how to overcome a few technological hurdles, we could form a realistic energy strategy centered on Geothermal providing the baseload supply and wind and solar providing the rest of the intermittent energy we need.

And we don't even need to achieve supercritical temperatures over 374C for that to be possible. A geothermal revolution that makes it possible to drill geothermal wells through 250C dry rock as cheaply and easily as we drill shale oil wells today would be enough progress to make geothermal economically viable for baseload power generation. And if we started there, it would be reasonable to expect that after a few years, the industry would optimize and refine the process just as they did with shale oil, and eventually we might be drilling supercritical geothermal wells through 400C+ rock. That would deliver a game-changing increase in human prosperity.

The key take-away from this episode I really want you to focus on is that we already have a very well-developed oil and gas industry, which is expert at efficiently and economically drilling lateral wells in rock formations deep below the surface. That industry knows its days are numbered, and already needs to reinvent itself. What could be better than a strategic plan to re-purpose the oil & gas industry on commercializing and perfecting geothermal well drilling just like they perfected shale oil production?

The things I've described in this episode aren't possible today, but the only reason they aren't possible is the same reason horizontal drilling and hydraulic fracturing weren't possible before the shale revolution. The technology and the industry with a solid track record for making technology cheaper as it's applied at scale are both right at our fingertips. But until some breakthroughs are made in drilling technology, Geothermal remains an economically unattractive energy source everywhere but volcano country, at least for now.

Deep, supercritical geothermal was the first of two energy sources I'm aware of that could realistically provide the energy we need on the scale we need it to solve the coming crisis and achieve clean energy transition by 2050. The remaining episodes in this docuseries will focus on the second one, which unlike geothermal, doesn't depend on technological breakthroughs that haven't happened yet.