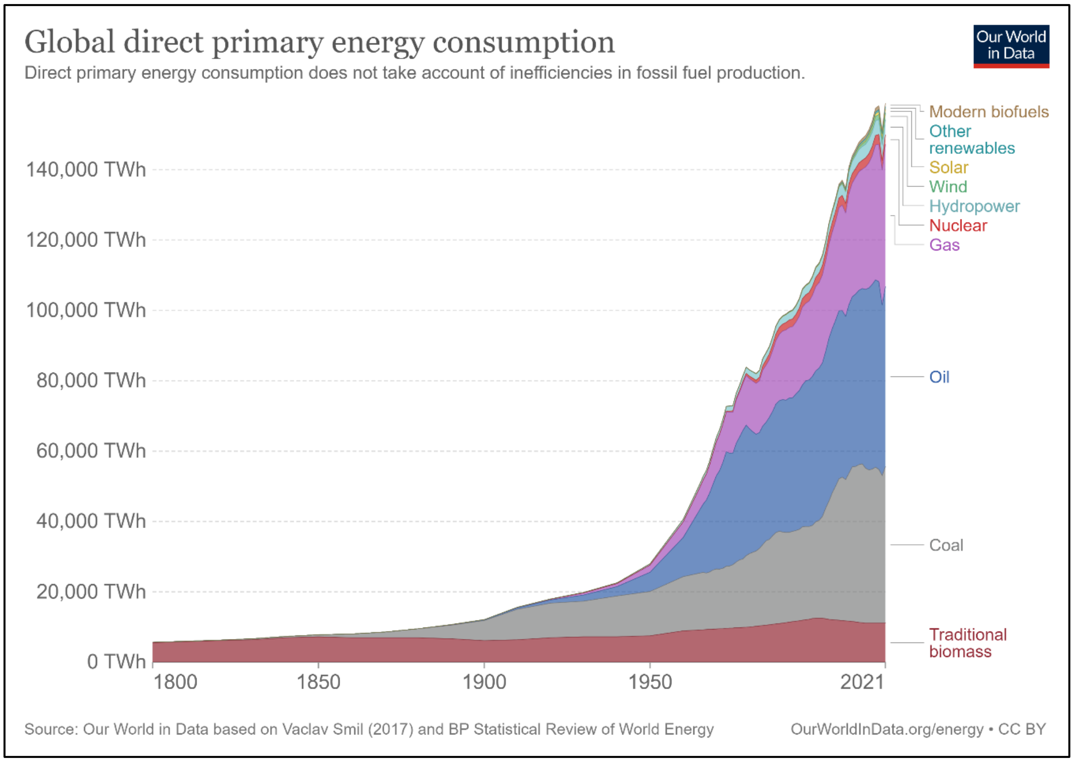
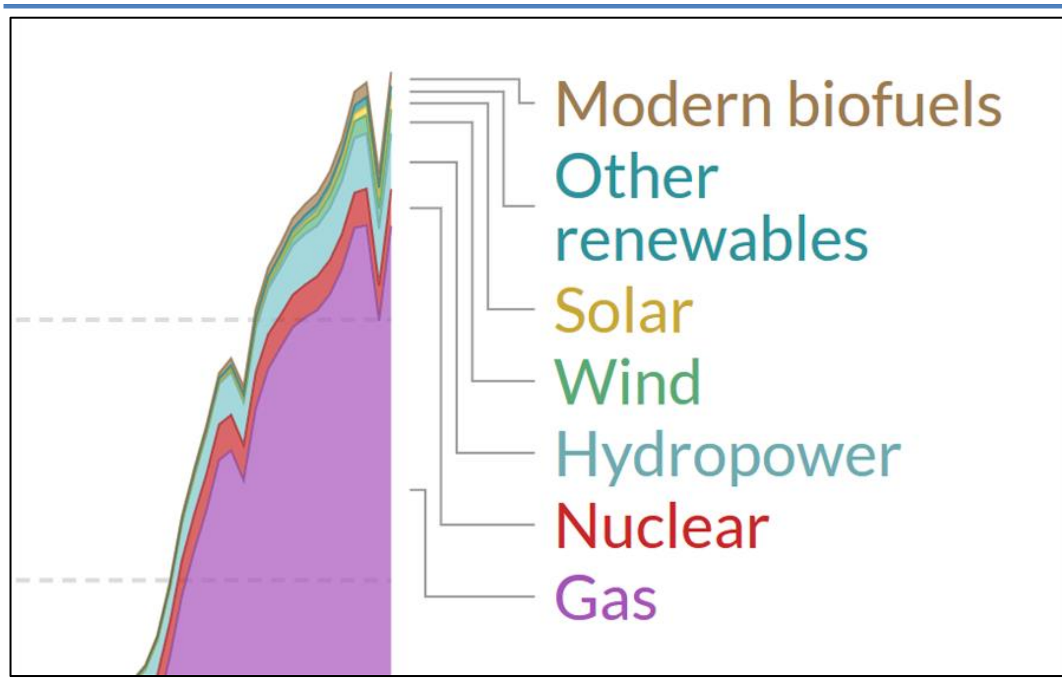
Energy Transition Crisis

Full Narration Script

FIFTH DRAFT (v2.1) FEBRUARY 8, 2023 (Numbered Paragraphs)





Sample of the video aesthetic intended for the YouTube Version: https://t.co/SNjvHRXDpF

Instructions for submitting your suggestions:

This document contains the full narration script for the 5-part "Energy Transition Crisis" docuseries with Erik Townsend. We are crowd-sourcing ideas for how to best tell this story visually, and welcome your suggestions.

Please include the paragraph number(s) your suggestion pertains to in the subject line of your e-mail, and send it to energydoc@macrovoices.com.

Our editors will be searching the received e-mails for the paragraph number they are working on, so it's essential that your e-mail's subject line include the paragraph numbers your suggestion pertains to.

We would love to receive your suggestions for:

- Graphs or charts that help explain a given concept
- Still images that help tell the story
- Video clips that help tell the story
- General suggestions and ideas about how to tell the story of the narration visually
- Please do NOT send generic photos or video clips of environmental pollution, oil refineries/rigs, pumpjacks, or other non-specific content. We already have plenty of this material.

Copyrighted Materials:

Please tell us if you know the materials you're sending us are copyrighted, but don't let that stop you from sending them. Even if we can't use the specific graphic you send us because of copyright issues, we can still benefit from the *idea* and either make our own similar graph or chart, or search for a similar image or video clip that isn't copyrighted.

Please understand that we can't reply to every e-mail we receive. We appreciate every suggestion but this is a volunteer effort and our video editor needs to focus on editing video as opposed to sending thankyou notes for every suggestion we receive. Thanks for understanding!

By-Invitation Video Review Advisory Board:

We plan to create a focus group comprising a small group of people we'll invite to watch early drafts of the videos for the purpose of giving us feedback on how to make them better. We'll send invitations to listeners who send us particularly helpful suggestions and graphic materials per the submission process described above.

THANK YOU for your help and for your interest in this project!

--Erik Townsend and the *Energy Transition Crisis* team

Episode 1, v2.0: Why *Energy Transition* is the most important challenge humanity faces

1.1 The *Energy Transition* away from fossil fuels is the single most important challenge humanity faces in the 21st century. Even if you're a climate skeptic, the transition away from fossil fuel dependency is still essential to our survival, *regardless* of whether climate change poses an existential threat to humanity. The challenge that lies ahead of us is immense, but the opportunity is even greater. If we aim not just to replace fossil fuels, but to supply an even larger amount of clean sustainable energy at an affordable cost, doing so will usher in a whole new era of human prosperity.
[Note to reviewers: The above opening paragraph is meant to "sell" the audience on this docuseries and grab their attention—it will be rich with engaging graphics to capture the imagination, *before* cutting to Erik's face introducing himself. The idea is to *sell the concept of the entire docuseries in one concise, attention-grabbing paragraph.* Frankly the above first draft needs improvement! Please feel free to send us your proposed re-writes!!! We already know this version needs to be replaced. Please put "1.1" in the subject line of your e-mail containing your suggestion for a more engaging re-write, and feel free to also tell us what graphics you imagine going with your re-write.]

1.2 I'm Erik Townsend. I was a software entrepreneur in the '90s, and later went on to manage a hedge fund. I'm fully retired now, but I remain passionately committed to helping solve the greatest problem humanity faces: the Global Energy Crisis that's certain to occur as we struggle to transition from fossil fuels to cleaner, greener sources of energy to power the global economy, while simultaneously decarbonizing our atmosphere.

1.3 Politicians care most about getting votes and staying in power. So they favor telling people what they want to hear over telling the truth. They assure us they already have a plan to completely phase out fossil fuels and achieve net zero goals by 2050. But they avoid discussing hard data, and focus instead on appealing to voters' emotions. They tell us the policies they've already adopted will achieve this energy transition by 2050. They give us the impression that all we need to do is build a few more wind turbines and solar arrays, and buy some more Teslas. And then, so long as you vote for them in the next election, everything will be fine, and we can all look forward to a wonderful new world free from greenhouse gas emissions by 2050.

1.4 They're lying. They're not being truthful about the full extent of our dependence on fossil fuels. They're not being truthful about how big and expensive a job it will be to transition the global economy away from fossil fuels. They're not being truthful about the extent of public infrastructure investment that will be needed to build a new higher capacity electric grid to charge all the electric vehicles they pretend we can build in only a few short years. They're not being truthful about the environmental challenges inherent to mining the specialized metals needed to make batteries for those electric vehicles. And they're not being truthful about how *much* energy we rely on fossil fuels for, or what a tiny percentage of that amount is currently being supplied by all the wind and solar that's ever been built to date.

1.5 They pretend that their policies will be enough to achieve their stated goals by 2050, but they never admit how little progress has been made to date, even after two decades of subsidies. They're not being truthful about how much *more* clean energy will be needed to achieve the goals they falsely claim wind and solar alone can achieve by themselves. And they're not being truthful about how utterly inadequate their policies will prove to be for replacing *all* the energy now derived from fossil fuels by 2050.

1.6 Instead of telling the public the truth about how big a challenge the coming energy transition will be and how long it will take, they've adopted tactics of appealing to emotion, political scapegoating, and use of hyperbole to avoid the cold hard truth, which is that the energy transition will cost more and take longer to achieve than they've led us to believe.

1.7 This docuseries will replace emotion, scapegoating, and hyperbole with data, logic, and reason. We'll examine the energy supply and demand statistics in detail. We'll analyze how much reliance we currently have on fossil fuels, and what it's *really* going to take to replace the *all* energy we derive from fossil fuels with clean alternatives. And we'll take an *honest* look at how long all of that will take and how much it will cost. I'll tell you the *whole* story, including the parts the politicians always leave out, such as how much environmental impact will be caused by mining all the copper and other metals needed to achieve this transition and how much work it will be to build a new electric grid to recharge all the electric vehicles you've been hearing so much about.

1.8 This episode includes a data-centric analysis of the energy transition challenges we face, and then goes on to examine the wind and solar energy initiatives favored by politicians and activists, explaining why they're a terrific start. But I'll also explain why wind and solar alone won't be enough to replace fossil fuels entirely. To phase out fossil fuels completely, we're going to need more clean energy than wind and solar alone can provide. I'll explain why in this episode, then in later episodes we'll examine where we can get the rest of the energy we need.

1.9 We'll look at energy supply and demand data, and analyze how much supply will be lost when fossil fuels are phased out, how much new clean energy supply is needed to replace it, and how much of the needed supply we can realistically expect to get from wind and solar.

1.10 For climate skeptics, I'll also explain why this energy transition is absolutely critical to the advancement of humanity, regardless of whether you are persuaded that climate change poses an existential threat.

1.11 Future episodes will explore where we can *realistically* get the additional clean energy supply that current initiatives alone will be insufficient to achieve, how long that will take, and how much it's going to cost.

1.12 We'll also examine why policy mistakes that have already been made virtually guarantee that a global energy crisis will occur in the mid-2020s. I'll explain why it's already too late to avoid that crisis, and what must be done to reverse the policy mistakes that caused it.

1.13 I promise to tell you the truth about how monumental the challenge ahead of truly is, and what it's going to take to pull it off. But put your seatbelt on, because I'm not running for office and I'm not selling anything, so I'm not just going to tell you what you want to hear. Once we dispense with the politicians' energy transition propaganda, the truth about how big the challenge ahead of us really is, how long it will take, and how much it will cost, might scare you.

1.14 Before we dive into the data, it's essential to understand just how much energy affects our standard of living and the quality of our lives.

1.15 *Societal complexity, and therefore, the pace of advancement of humanity, is a function of the amount of abundant and affordable **energy** available to the economy.* That's a somewhat nuanced but profoundly important statement, so let's examine its implications.

1.16 Please ask yourself why it is that for about 200 years now, society has advanced much more quickly than it did for centuries before that. Today we live and work in high-rise buildings with heat, air conditioning, electric lighting, and modern plumbing. In developed nations, nobody builds their own home or grows their own food unless they have a personal passion for doing so. Instead, people are free to pursue higher education and then move on to choose from hundreds of careers that never even existed 200 years ago.

1.17 If you look back in history, for many centuries before that, the human experience was far more primitive than today, and the pace of advancement was much slower. University education was extremely rare, and few professions even existed, other than the most essential ones such as law and medicine. Firewood provided the sole source of heating and cooking energy. Plumbing hadn't been invented yet, and human slaves were the primary source of work needed to operate the farms and plantations which provided the food supply.

1.18 Please ask yourself what changed that allowed society to progress so much faster in the last two hundred years, so that we now live in high-rise skyscrapers, and have the luxury of spending our leisure time reading social media on our smartphones, or even flying anywhere on earth in just a few hours' travel time? Most people answer that question by saying *technology* is the big thing that changed.

1.19 There's some truth in that answer, but *technology* is actually a second-order effect, not the driving force. The true underlying reason that humanity has made so much more progress in the last 200 years than it did in the 500 years before that, *is a marked increase in the availability of cheap and abundant **energy***.

1.20 With Gasoline now costing more than $3.50 per gallon on average in the United States, it might not *feel* like energy is "cheap" right now. But when you consider that one gallon of gasoline produces the same amount of useful work as up to 482 hours of human labor, the right way to think about the cost of energy now vs. 200 years ago is that a single gallon of gasoline costs three and a half dollars, while the equivalent 482 hours of manual labor costs nearly three and a half *thousand* dollars at the current U.S. minimum wage of $7.25/hr.

1.21 Energy is literally one thousand times cheaper than it would be if we had to pay minimum wage workers to do the work now performed by gasoline-powered machinery. Even a top athlete can't do as much physical work in one full day as the electricity you can buy for less than half a dollar! And that's precisely the reason humanity has advanced so much in the last two hundred years: because cheap energy to supplement and replace human labor allows more work to be done much more quickly and efficiently than was ever possible before.

1.22 The industrial revolution couldn't have happened until it was enabled by the invention of the steam engine. The newfound ability to convert the potential energy contained in coal into physical motion that could be harnessed to accomplish work and automate previously manual processes was the *turning point in history* which everything else followed. James Watt refined earlier inventors' prototypes of the Steam Engine into a commercially viable product between 1763 and 1775. That's when the rapid-pace advancement of human society over the last two centuries all started.

1.23 The age of oil began in 1859, when Edwin Drake drilled the first oil well in Titusville, Pennsylvania. The discovery of "rock oil" was an even bigger deal than the steam engine. Petroleum and the abundant and relatively cheap products refined from it such as gasoline, diesel fuel, and now jet airplane fuel, quite literally changed everything. The availability of abundant energy enabled the inventions of everything from the automobile to the airplane to mechanized farming equipment. Advancements such as modern cities, public infrastructure, and high-rise buildings would never have been possible without modern heavy construction equipment, which is powered by diesel fuel refined from petroleum. *Societal complexity is, quite literally, a function of the amount of abundant, affordable energy available to grow the economy.*

1.24 Please ask yourself how it's even possible that before the industrial revolution, people rationalized owning human slaves. The answer is that back in those days, there was no alternative to human labor to operate the farms and plantations that supplied all the food. As shocking and immoral as it seems to us today, back when there was no mechanized farming equipment, human slavery was rationalized as necessary.

1.25 It's no coincidence that the abolition of slavery coincides with the dawn of the age of fossil fuels. That's how important cheap and abundant energy is to the advancement of humanity: We literally eliminated human slavery thanks to the availability of energy derived first from coal, and then later from oil.

1.26 I have a question for you. Do you personally live and work on a farm? Do the vast majority of your friends and family live and work on farms? 200 years ago, almost everyone in society lived and worked on farms, *because there was no alternative.* The only way to sustain ourselves was to keep the vast majority of people directly engaged in growing and harvesting the food we needed to survive. The only reason that we don't *all* have to work on farms today is that *energy* derived from oil powers modern farming equipment, allowing just a handful of farmers to produce as much food as hundreds of farm workers two centuries ago.

1.27 The reason there are hundreds of different professions today, and the reason it's possible for a much larger percentage of society attend university, is that *energy* derived from fossil fuels makes possible a world in which we don't all have to work on farms just to feed ourselves. That's how much difference it makes to have cheap and abundant energy available to grow the economy. It's what advances the sophistication of society and the overall quality of the human experience.

1.28 Less than one billion human beings lived on planet Earth when the Steam Engine was commercialized in the 1770's. Today that figure is over 8 billion. That population growth was directly enabled by modern farming. We literally cannot feed the current population of our planet without modern farming equipment, which requires *energy* that's presently supplied by oil. *That's how much our way of life and our very ability to sustain the lives of everyone on the planet depends on having the energy we now derive primarily from fossil fuels.*

1.29 In the beginning, we didn't understand how badly we were polluting our atmosphere by burning all those fossil fuels. But now it's been decades since we figured that out, and yet we still haven't changed our ways. We've always known that we're slowly depleting a finite resource that can't possibly last forever, yet we never seem to take seriously the risk that it might run out someday.

1.30 Modern society is addicted to fossil fuels because we're quite literally dependent on the energy they provide for our survival. That means nothing is more important than ensuring we find enough clean energy to continue to allow society to thrive, because without the energy we currently rely on fossil fuels for, we'd be forced back into the dark ages. But if we continue to rely on fossil fuels for this energy, we'll destroy ourselves.

1.31 Most people agree that climate change is reason enough to demand we break our addiction to fossil fuels and find clean replacements for the energy we derive from them. But even if you're a climate skeptic, the fact remains that fossil fuels are a finite resource that won't last forever. In order for our species to survive, we need a credible plan to replace fossil fuels with abundant clean energy we won't run out of, and which won't pollute our atmosphere with greenhouse gases.

1.32 For the past several years, *talking* about replacing fossil fuels with clean energy has been the hottest topic in politics. But as any recovering alcoholic or drug addict will tell you, *talking* about breaking an addiction and having a credible plan to do so are two very different things! The purpose of this docuseries is to lay out a credible plan to do so, but first we need to talk about the backstory of global energy consumption, including the parts the politicians always leave out because they include some unpleasant and inconvenient truths.

1.33 Let's examine the global energy supply and demand data our politicians avoid.

1.34 This chart shows global energy consumption broken down by source. At the end of 2021, the last year for which data were available, we consumed a total of 159k TWh of energy globally. More than 85% of our energy is supplied by the three primary fossil fuels. Coal is shown in grey, oil in blue, and natural gas in purple. These three fossil fuel sources combined make up 136k TWh, or 85% of total energy supply.

1.35 Politicians talk as though wind and solar renewable energy have already solved most of this problem, so therefore, according to some of them, it's already time to outlaw fossil fuels. But the truth of the matter is that all the energy we get from every wind turbine and every solar farm ever built *combined* still provides less than 2% of total energy consumption.

1.36 That's such a tiny percentage that it's hard to even make out wind and solar at the top of the chart. Wind is shown in green and solar is shown above it in orange, but these are such tiny slivers on the chart that they're barely visible. And that's after public policy has aggressively subsidized building out wind and solar energy capacity for more than two solid decades. Even if we add in hydropower and other renewables, total energy supplied by all renewables is still less than 5% of total energy demand. *We've only just barely begun this energy transition, and unfortunately, we're still a long way from phasing out fossil fuels.*

1.37 The chart shows the total amount of energy supplied by source, but what's not obvious at first glance is how much of that energy goes to waste, particularly when it comes from fossil fuels. So the next topic we need to cover is *thermal efficiency* of energy conversion, which is really important. We get more than 85% of our energy from coal, oil and natural gas. In all three cases, the way energy is extracted from these fuels is by burning them to release heat energy. The 136k TWh figure I discussed earlier refers to the amount of **heat energy** released from those fuels. But with current technology, we're not very good at using that heat energy efficiently, especially when that heat is being used to generate electricity.

1.38 We use heat energy from burning fossil fuels most efficiently when that heat is used directly to heat something else. For example, when natural gas is used to heat a building with a modern high-efficiency furnace, up to 95% of the total heat energy released by burning the natural gas is put to good use, and very little goes to waste.

1.39 But when we burn natural gas to produce electricity, it's much less efficient. Only about 55% of the heat energy in natural gas gets converted to electricity. Almost half of the energy goes to waste, in the form of heat released into the atmosphere at the electric power station, contributing to climate change. Even the latest state-of-the-art high-efficiency gas fired electric powerplants only achieve 64% thermal efficiency.

1.40 Electricity generated from burning coal is even less efficient. Aging coal fired power plants operate between 35% and 38% thermal efficiency, and even the very most efficient state-of-the-art coal burning powerplants only operate at 46% thermal efficiency. More than half the energy released from burning coal goes right up the smokestack, along with all the greenhouse gases given off from burning all that coal. Nuclear is much better than coal, but even the most efficient nuclear power plants still waste half the heat energy produced by the reactor.

1.41 Internal combustion engines are even worse! Most gasoline engines operate at around 20% thermal efficiency. That means when you spend $100 filling your car's tank with gasoline, $80 of your hard-earned money will go to producing heat and greenhouse gases that all come out the tailpipe and do nothing to propel your vehicle. Only 20% of the energy released from your $100 fuel purchase was used to propel your vehicle.

1.42 The latest high-efficiency diesel engines can operate at up to 40% thermal efficiency, but even then, more than half your money is being spent polluting the atmosphere and nothing else. Less than half the energy released by burning fossil fuels in any internal combustion engine is used to propel the vehicle. Thankfully, electric motors are much more efficient.

1.43 We could make do with only half of the 136k TWh of thermal energy we presently derive from fossil fuels if we could magically convert heat energy into electricity with 100% thermal efficiency and zero waste.

1.44 Promoters of wind and solar renewables often argue that because wind and solar produce electricity directly, without needing to convert heat into electricity, the amount of renewable energy needed to replace fossil fuels is much smaller than this chart would seem to suggest. Some will even try and argue that two thirds or even three quarters of the fossil fuel energy shown on this chart goes to waste, so therefore the amount of wind and solar needed to replace it is actually just one quarter to one third of the 136k TWh implied by the chart. That's partly true, but it's not as simple as they sometimes try and make it out to be.

1.45 To understand this issue, it's essential to first understand the difference between baseload and intermittent electricity sources. Electrical demand is neither constant nor predictable. This chart shows typical electrical demand over the course of a 24-hr period. Demand is lowest in the overnight period when people are sleeping and relatively little energy is demanded. Of course electricity is always being consumed. Refrigeration is just one example of something that demands electricity on a 24/7 basis, regardless of whether anyone is awake or what they're doing. The electricity demand which exists 24/7 is known as *baseload* demand. But then there are peak demand periods, such as mealtimes, when energy is demanded for cooking. Beyond the daily variations in demand, there are also seasonal variations. In summertime, air conditioning usually demands the most electricity during afternoon hours, but that demand doesn't exist in winter. The electricity needed to make up the gap between baseload and peak demand is known as *intermittent demand*.

1.46 Some energy sources are best suited to supplying baseload power, and others are only suited to supplying intermittent power. Coal burning power plants can't just be switched on or off at the press of a button, so they are best suited to supplying baseload electricity only. Conversely, natural gas fired electric generators are much easier to turn on or off, so they're much better suited to meeting intermittent demand.

1.47 Wind and solar renewables are inherently intermittent sources of energy. They work great when the wind is blowing and the sun is shining, but solar doesn't produce any electricity at night and wind turbines don't produce any electricity when the wind is calm. So when it comes to meeting that mid-afternoon intermittent electric demand to run air conditioning equipment, wind and solar are ideally suited to the task.

1.48 Energy storage technology allows the electricity produced by wind and solar to be stored until it's needed. But energy storage introduces its own inefficiencies, just as burning fossil fuels to make electricity introduces inefficiencies. And as I'll explain later in this episode, we're going to need all the wind and solar energy we can realistically expect to deploy in the next 20 years just to meet daytime demand, so it really doesn't make sense to count on wind and solar for overnight electric vehicle recharging, where the most demand growth is expected as the energy transition proceeds.

1.49 This is today's version of the daily cyclical demand chart, but the energy transition is going to change the picture. Currently less than 5% of vehicles on the road are electric, so recharging them doesn't contribute much to overnight electric demand. At least not *yet*. But when we fully electrify the global economy, most vehicles will be charged overnight, and the wee hours before dawn will be a high demand period for vehicle charging as opposed to the lowest demand period now.

1.50 Not all renewables are inherently intermittent energy sources. Hydropower and geothermal renewables are much better suited to meeting baseload supply needs. In the case of geothermal, that's a good source of baseload electricity. And if we can achieve a few technological advances, geothermal has the potential to go from a good source of baseload power to a terrific source. So terrific that I've dedicated the entire third episode of this docuseries to it.

1.51 But let's keep this in perspective: Unlike wind or solar, geothermal electricity still involves converting heat energy into electricity, so therefore, it still suffers the same thermal inefficiency losses that fossil fuels suffer. But geothermal does it without the greenhouse gasses, and that's why it gets its own episode later in this docuseries.

1.52 Hydropower is a terrific renewable electricity source, but for reasons I'll explain later in this episode, it won't be possible to bring enough new hydroelectric power online to make a big difference.

1.53 Now that we're armed with an understanding of baseload vs. intermittent electricity, let's return to the energy demand chart. As much as two thirds of all the energy released by burning fossil fuels goes to waste. The primary reason such a huge percentage of that energy is wasted is the incredible inefficiency of internal combustion engines which waste 80% of the energy contained in the gasoline they burn.

1.54 When it comes to making electricity from fossil fuels, the process is quite wasteful, but nowhere close to as wasteful as internal combustion engines. Just less than half the energy gets wasted when natural gas is burned to make electricity. It's true that the oldest and least efficient coal burning power plants waste almost two thirds of the energy they consume, but it's also true that modern, high-efficiency coal burning powerplants only waste just over half the energy released by burning coal.

1.55 Wind and solar only enjoy the efficiency benefits of generating electricity directly when those inherently intermittent energy sources are consumed immediately, as the energy is being produced. But if the energy they produce is stored for later consumption, that introduces inefficiencies just like burning fossil fuels does, but thankfully without the greenhouse gas emissions.

1.56 Bottom line, wind and solar can contribute to *intermittent* daytime peak demand in a much more efficient way than fossil fuels do today. And that's terrific progress. But I promised to be honest with you about the extent of the challenges we face, and the unfortunate truth is that even with energy storage technology, wind and solar are not well suited to supplying baseload electricity.

1.57 Turning heat into electricity with zero waste and 100% thermal efficiency is impossible. But to my thinking, if we sent humans to the moon more than half a century ago, we ought to be able to figure out how to do a whole lot better than wasting *more than half* of the energy we derive from fossil fuels when they're used to make electricity. If someone could just figure out how to turn heat into electricity while only wasting 25% of the heat energy instead of almost half of it for electric power generation from natural gas, that alone would be a game-changer.

1.58 For humanity to advance, we need a solid plan for replacing ***all*** the energy now supplied by coal, oil, and natural gas with clean, environment-friendly substitutes. Replacing fossil fuels is a much bigger undertaking than most people appreciate, and it will take decades. The purpose of this docuseries is to do what politicians have been afraid to do. We're going to work from hard data rather than emotion, be *honest* about how big the problem really is, then explore the *realistic* options we have for replacing *all* the energy presently derived from fossil fuels. Wind and solar are a super important part of the solution, but they're only *part* of any realistic solution.

1.59 165 years after it began in 1859, the age of oil is finally slowly coming to an end. Fossil fuels won't go away as quickly as our politicians would like to pretend, but they absolutely do need to be phased out. Regardless of whether you personally believe that climate change poses an existential threat to humanity, an immutable fact is that fossil fuels are a finite resource that won't last forever. Even if we try and extend the age of oil, the cost of oil production will continue to increase as a percentage of global GDP, and that will *retard the pace* of societal advancement.

1.60 The pace of societal advancement has measurably slowed just during my own lifetime, and a big part of the reason is that gasoline no longer costs thirty cents a gallon like it did when I was a kid. Don't write that off as inflation. Gasoline in the United States cost about 31 cents per gallon in 1972. Adjusted for inflation that's $2 per gallon in today's dollars, or just more than half what gasoline actually costs today. When gasoline prices move back over $4 per gallon, which I'm convinced they will, we'll literally be paying twice as much for energy versus when I was a kid, even after adjusting for actual inflation.

1.61 Remember, societal complexity and the pace of human advancement is a function of the amount of *cheap and abundant* energy available to the economy. If $2 per gallon in today's dollars was still the going price of gasoline, a whole lot more progress could be made because the cost of energy, which ultimately determines the pace of societal advancement, would be about half what it is today. When gasoline prices eventually rise over $6 per gallon, as I'm convinced they will by 2025, we'll be paying three times as much for energy as it cost when I was a kid. And that directly translates to societal advancement slowing markedly from the pace it advanced during my childhood.

1.62 How many years are left before energy derived from petroleum becomes *prohibitively* expensive is a matter of debate. But at this point, it's an academic debate. Replacing fossil fuels with cleaner and greener energy sources is the most important challenge humanity faces. Decarbonization for the sake of arresting climate change is reason enough for most people. But even if you disagree with that sentiment, the fact remains that fossil fuels are a finite resource. We're not running out of oil yet, but the incremental cost of production will continue to increase as more and more technological innovation is required to extract oil from the earth's crust. I'll explain why in more detail in the next episode of this docuseries.

1.63 Many people have been misled to believe that electricity or hydrogen are viable replacements for fossil fuels, and that the Electric Vehicle revolution already underway is going to solve our addiction to gasoline and diesel fuel. That simply isn't true, so let's focus on that subject next.

1.64 Electrifying the global economy is a very important *part* of a larger strategy to replace fossil fuels with clean alternatives. Electric Vehicles have already replaced almost 5% of vehicles powered by internal combustion engines, and we need to accelerate that trend. It's an important step toward energy transition, but it's not a solution unto itself.

1.65 Electricity and hydrogen are not and will never be a *source* of energy. To say we're going to replace fossil fuels with electricity or hydrogen simply doesn't make sense. Electricity is a wonderfully versatile way of *transmitting* energy from where it's produced to where it's needed, and electricity achieves that with almost no pollution. So electricity is definitely part of the solution and hydrogen will be as well. Yet another way to move energy from where it's produced to where it's needed is called *ammonia liquid fuel.* But neither electricity nor hydrogen nor ammonia are energy *sources.*

1.66 It's true we can power vehicles with electricity, hydrogen, or ammonia, but that electricity or hydrogen doesn't grow on trees, nor does ammonia. There are no electricity mines or hydrogen wells. Electricity, hydrogen and ammonia all have to be produced from energy derived from another source. In the case of hydrogen, it's an element that occurs in nature, but there is no natural source of *pure* hydrogen. To get pure hydrogen suitable for use in a hydrogen fuel cell, you have to consume energy produced from another energy source in order to separate and compress the hydrogen into a usable form. To generate electricity, we still need another *energy source* from which that electricity can be generated.

1.67 So the right way to think of electricity is that it's a clean, environmentally friendly way to *transmit* energy from where it's produced to where it's needed. When energy is needed to propel a vehicle or in any other application where it's not practical to connect directly to the electric mains, the preferred solution is to use the electric mains to recharge a battery that powers the vehicle.

1.68 Hydrogen is **not** an alternative to fossil fuels. Rather, hydrogen is an alternative to batteries. It's another way to allow a vehicle to be powered from energy that was produced somewhere other than where it's being consumed by the vehicle. Hydrogen fuel cells can store more energy per pound of weight than batteries, so they're favored in applications that require more energy than batteries can supply.

1.69 Ammonia is another way to *move* energy from where it's produced to where it's used. It's a liquid fuel made by consuming energy produced by another source such as wind or solar. Its advantage over Hyrdrogen is that in many cases, it can be used as a direct replacement for diesel fuel, allowing existing diesel engines to burn a clean fuel that doesn't produce CO_2 emissions.

1.70 There aren't many viable options for replacing "baseload" electric power generation which is primarily supplied by burning coal today. We'll explore those options in detail in later episodes. The challenge is not *just* to replace the electricity we get from coal with something cleaner. We're going to need *much* more electricity than we ever needed before.

1.71 The electric vehicle revolution is a desperately needed step toward clean energy transition. Internal combustion engines should be replaced wherever possible with electric motors that don't directly pollute the atmosphere. Not just in passenger cars, but in construction and farming equipment and everywhere else internal combustion engines are used.

1.72 But hold on! For some reason, very few people realize that replacing internal combustion engines with electric motors in vehicles, construction equipment and farming machinery represents only one quarter of the challenge of electrifying our society. To electrify our world, four separate challenges exist, and very little attention has been paid to the last three.

1.73 The **first** challenge is to replace the vehicles and other machines that use internal combustion engines with new versions that use electric motors instead. The electric vehicle revolution already underway addresses this need. We still have 20 more gasoline and diesel vehicles left to replace for every electric vehicle we've built so far, but at least we're on the right track and off to a good start.

1.74 The part the politicians never tell you is that to build all the electric vehicles needed to replace internal combustion engines will require more copper than the mining industry can supply. This means copper will get much more expensive and the cost of electric vehicles will increase. Copper mining already threatens our environment, so more emphasis will be needed on *green* copper mining. We can and should be more environmentally responsible in how we mine copper, but doing so will help push copper prices even higher. The point is, this will cost a lot more than our politicians are telling us.

1.75 *Greenflation*, referring to economic inflation caused by the higher cost of being environmentally responsible about how we source raw materials including copper and many other commodities needed to support energy transition, will be a major economic trend for the next several decades.

1.76 The **second** challenge is one that nobody ever seems to talk about: where is all the electricity going to come from to recharge all these new electric vehicles, electric construction equipment, and electric farming machinery? We're used to living in modern society where it *seems* like all you need to do to get electricity is to plug an appliance into a wall socket and it just magically works. But there's a lot more going on behind the scenes to deliver electricity to that wall socket, and that's what we need to talk about next.

1.77 A lot of early buyers of Electric Vehicles never realized that if they live in areas where electricity is generated by burning coal, then driving their EV may have resulted in even *more* carbon emissions than driving a high-efficiency diesel vehicle, not less! Of course, there are no carbon emissions directly from the electric vehicle, but the electricity needed to recharge that vehicle was generated by burning coal that produced carbon emissions. Maybe even more carbon emissions than the old-school vehicle that the EV replaced!

1.78 Every bit of energy now supplied by gasoline and diesel fuel will need to be replaced with new electric generation capacity *we simply don't have yet*. And every bit of electric generation capacity we already have that relies on fossil fuels will need to be replaced with new green electricity generation capacity. Returning to this chart, most of the coal shown in grey and about 40% of the natural gas shown in purple is used to produce electricity today. Most of the oil shown in blue is used to produce liquid fuels for vehicles and other machinery.

1.79 To electrify the global economy, we don't *just* need to find enough new clean electricity to replace the energy we now produce by burning most of the grey coal and 40% of the purple natural gas. We also need to replace almost all the blue oil with new clean electricity to recharge all the vehicles that will no longer be burning liquid fuels.

1.80 *That's whole a* ***lot*** *of electric power generation capacity we* ***simply don't have yet****.* It's not possible for the EV revolution to replace all our internal combustion vehicles until we build all that new electric generation capacity that we don't even have a *plan* for yet. Remember, all the wind turbines and solar farms ever built to date *combined* supply less than 2% of current energy demand. We've only just barely gotten started, and we have a LONG way left to go!

1.81 And that's my real point: We don't even have a credible plan for where the electric power generation capacity will come from to replace every single watt of energy now derived from burning fossil fuels. Wind and solar help a lot, but they're not enough. They're intermittent sources that play an important role in the overall solution, but they will never provide the 24/7 baseload power supply needed to electrify the global economy. I'll substantiate that statement with data later in this episode.

1.82 We still need to replace all the grey, 40% of the purple, and most of the blue energy on the chart with continuous energy sources capable of meeting our baseload power demand. It's taken 25 years to build enough wind and solar to solve less than 2% of the problem. Just talking about solving this problem isn't enough. We need to get serious, and that means we need a whole lot more electricity than any politician paying lip service to climate change and energy transition has a credible plan for.

1.83 The **third** challenge is one that even fewer people understand: How are we going to get all that electricity from where it's produced to where it's needed? The current electric grid in almost every country on earth is already running at or near capacity. That's why, for decades now, California has been experiencing rolling blackouts during summertime when air conditioning demands the highest electric loads. The electric grid we have now can just barely meet *existing* demand for electricity. It was never designed to recharge electric vehicles.

1.84 We're still very early in the electric vehicle revolution. Less than 5% of vehicles on the road today are electric, and many of those are hybrids which recharge themselves by burning fossil fuels. Yet already, electric vehicle recharging needs are straining the capacity of our electric grids.

1.85 Our elected leaders should have recognized two decades ago that we need a massive public infrastructure investment to build out a new electric grid with far greater capacity than the current one. That will cost a lot of money and take at least a decade to complete. It will also require more copper than our mining industries can currently supply. Those two immutable facts are the real *inconvenient truths* that we should be talking about in public policy debate.

1.86 The **fourth** challenge is the scalability of electric vehicles with specific regard to the battery technology they rely on. The current state of the art in electric vehicles depends heavily on Lithium-Ion and Lithium polymer batteries. Lithium is an environmentally challenging metal to mine, and the global supply of lithium is limited. It's not clear where all the lithium would come from to make enough batteries to electrify the 95% of vehicles that still run on fossil fuels, nor is it clear that's even possible.

1.87 Lithium is just one of the raw materials needed to make electric vehicle batteries. We're also going to need lots and lots of Manganese, Cobalt, Graphite, and Nickel. That's a whole lot of mining that will have to occur to make all those batteries, and mining is an extractive industry with significant environmental challenges. Those environmental challenges are the reason politicians never seem to want to talk about this essential part of the energy transition.

1.88 To appeal to the emotions of their environmentally conscious constituents, politicians proclaim that mining is a horrible industry that should be banned because of the environmental damage it causes. Then in the next breath they tell you that wind turbines and electric vehicles are going to solve climate change, without mentioning that it's completely impossible to build either electric vehicles or wind turbines on the scale needed to replace fossil fuels, without first ramping UP the mining industry to the highest level of activity in its entire history.

1.89 This is just one example of the many *inconvenient truths* they never tell you because they have no good answers or credible plans to solve this dilemma. They don't want to admit the truth, which is that while it's possible to take steps to clean up the mining industry, doing so will be expensive and contribute to greenflation.

1.90 Disposal of worn-out lithium-ion batteries presents another serious environmental challenge. Scarcity of the rare earth elements needed to make the high-powered magnets in wind turbines, and environmental concerns associated with mining them, are yet another example of why the policies the public is being told will achieve this transition are not realistic.

1.91 All these challenges can probably be overcome in due time. We can take steps to improve the environmental impact of mining lithium, we can continue to search for new battery technologies that rely less on scarce and environmentally challenging materials, and we can institutionalize lithium-ion battery recycling globally, so that we don't replace an old form of environmental pollution with a new one. We can keep looking for new copper deposits and building more copper mines.

1.92 But it's important to appreciate that while these problems are almost certainly *solvable*, they haven't been solved *yet,* and they won't be solved overnight. We don't presently have anywhere close to enough copper, lithium, cobalt, nickel, and other raw materials needed to replace all our internal combustion vehicles with EVs powered by lithium-ion batteries. We don't know where to find the needed materials, and so far, we've yet to invent new kinds of batteries to avoid needing all those exotic materials.

1.93 The point I want you to take to heart is that the energy transition will take longer and cost more than we're being led to believe. Right now, nobody has any idea where all the copper and battery metals are going to come from to electrify the 95% of vehicles that still run on internal combustion engines. And when politicians don't have a good answer, they neglect to tell you about the problem!

1.94 This energy transition will cause a LOT of inflation and everything we buy will cost more as a result. These are costs we're going to have to learn to live with, but politicians don't want to admit how expensive or economically painful this energy transition is going to be. It's past time for *we the people* to demand the truth, and face the reality of how expensive this will be, so that we can prepare for what's coming.

1.95 These are just a few examples of the large number of very real and daunting hurdles which must be overcome to electrify the global economy. Building EVs and windmills is only a very small part of solving the overall problem. We should stop pretending this transition will be easier than it will really be. *We're only just getting started.* We should have started decades earlier, but we didn't. And frankly, we haven't made much progress yet. The hard work and necessary sacrifices still lie ahead.

1.96 What we need to do now is start being realistic, and looking at the problem in terms of logic, reason, and hard data, in place of emotion, hyperbole, and political theatre.

1.97 Now let's examine what it's really going to take to replace fossil fuels, and whether current renewable energy policy initiatives alone will be enough to solve the problem by 2050 as advertised.

1.98 Global energy demand is expected to grow by at least 15% by 2050, meaning that the total amount of energy we need will grow from 159k TWh today to at least 183k TWh by 2050. A linear extrapolation of this chart gives a figure of 203k TWh by 2050. So let's assume that's the target range—by 2050 we'll need somewhere between 183k and 203k TWh of thermal energy. And let me be first to say that while we should definitely work to conserve energy and stop wasting it, more supply is still better. The more cheap and abundant clean energy we can supply to society, the more we'll be able to lift billions of people around the globe out of poverty and accelerate the pace of advancement of the human race.

1.99 Let's assume the goal is to completely phase out fossil fuels by 2050. That means we're going to lose 136k of the 159k TWh of total supply we currently have. Existing non-fossil fuel energy sources currently provide 23k TWh, and less than 8k TWh of that comes from renewables. Since we need somewhere between 183k and 203k TWh, to completely phase out fossil fuels we need to somehow bring between 160k and 180k TWh of ***new*** clean energy online between now and 2050. That's going to be a real challenge.

1.100 The first question to ask is which clean energy sources can realistically grow to meet expected demand. Renewables are the most environmentally friendly, so we should start there. The four commonly recognized renewable energy sources are hydroelectric, wind, solar, and geothermal energy.

1.101 Hydroelectric power is a terrific source of clean renewable energy, but unfortunately it only works in places with waterways that are conducive to building that kind of power generation. As Peter Zeihan wrote in his recent book, all the best geographically promising opportunities for hydropower around the globe have, for the most part, already been developed. That explains why growth of hydropower in recent years has been so much slower than growth of wind and solar. So unfortunately, we can't expect hyrdo so solve a big share of the problem. But let's be optimists and assume that by 2050, we could double the 4,274 TWh of clean electricity we currently get from hydro.

1.102 We already produce 1,892 TWh of clean electricity from wind, and another 1,033 TWh from solar. For the last five years, we've added an average of 180 TWh wind and 141 TWh solar capacity annually. But there's good reason to be a lot more optimistic than using the *trailing* 5-year average to project future growth. 2021, the last year I have data for, was wind and solar's best year yet, with Wind adding a whopping 266 TWh and solar adding 186 TWh of new capacity in 2021.

1.103 Wind uses much more acreage per megawatt than solar, and we're eventually going to have difficulty finding enough space to install new wind turbines. But let's be really optimistic and assume we can eventually *double* the 2021 record of 266 TWh in a single year to 532 TWh/year in future years, and sustain that average rate of growth all the way to 2050. That means we can expect to add as much as 14,364 TWh of new clean wind energy by 2050. Put another way, we can expect to have more than 8 *times* as much clean energy from wind by 2050 as we have today.

1.104 I'm even more optimistic for solar, because it consumes less acreage per megawatt, and because the cost of photovoltaic solar cells has been dropping very consistently for several years. So let's really go out on a limb and aim to *triple* 2021's all time record for new solar power installations, and sustain that average annual rate of development all the way to 2050. Now we're really getting somewhere. That's another 15,066 TWh of clean solar energy we hope to bring online by 2050.

1.105 Between wind, solar and hydro combined, that's almost 34k TWh of clean electricity we can get from aggressively building out these renewable sources, and that's a lot! It's still less than coal at 45k TWh, but that 45k TWh figure for coal is thermal energy. Remember that the thermal efficiency of fossil fuels is terrible when they're used to generate electricity.

1.106 Intermittent renewables like wind and solar can't solve our need for 24/7 baseload power supply unless you employ energy storage technology to make the energy produced by wind and solar available for later use when it's needed. And doing that that introduces significant inefficiencies, similar to burning fossil fuels to make electricity, but without the greenhouse gases.

1.107 But let's ignore all that for now and give wind and solar credit for being clean sources of electricity which don't suffer those big thermal efficiency losses of fossil fuels when the energy they produce is consumed immediately. If we look at it that way, it's reasonable to double the 34k TWh figure to 68k TWh of equivalent fossil fuel thermal energy needed to produce the same amount of electricity from natural gas.

1.108 Frankly I'm skeptical that this hypothetical scenario is even possible, because I've completely ignored a whole bunch of challenges to sustaining that kind of wind and solar growth, such as shortages of rare earth elements needed to make the wind turbines, and environmental challenges to producing solar cells on that scale. But my real point is this: Even if we take the most optimistic view possible, and give wind and solar the benefit of every doubt, we still end up with only 34k TWh of clean electricity, or the equivalent of what we could produce from the thermal energy of 68k TWh of fossil fuels.

1.109 Even after ignoring the challenges that I expect will make it difficult to grow wind and solar as aggressively as I've described, and even using the most optimistic growth estimates I can fathom, we still wind up with renewables only meeting about 35% of total energy demand by 2050. It's long past time to get serious about figuring out where we're going to find the other 65%.

1.110 I only know of two realistic sources for producing that much electricity. We need to pursue both of them aggressively, in parallel with wind and solar, if we want to get serious about solving our energy problem. So three full episodes of this docuseries will be dedicated to where we can find the 113k TWH of baseload energy supply needed complement wind and solar in order to completely replace fossil fuels by 2050.

1.111 I want you to open your mind and imagine what the world would be like if we seize the opportunity not just to *replace* fossil fuels with an *equal* amount of clean energy, but to instead figure out a way to bring online a much *larger* amount of clean, environmentally friendly energy, while at the same time making it cheaper than fossil fuel-derived energy is now. And even cheaper than it was when I was a kid, when gasoline cost just over 30 cents per gallon. What if we could figure out a way to replace fossil fuels with new sources of clean, environmentally responsible energy which cost the equivalent of gasoline prices well below one dollar per gallon in today's inflation-adjusted dollars, or about 26 cents per liter if you prefer metric measures?

1.112 If energy from fossil fuels made it possible to *abolish slavery*, made higher education available to the masses, got most of us off the hook for having to work on farms, and created a society with hundreds of occupations to choose from, can you imagine what would be possible if we went through *another* similar magnitude increase in the amount of cheap and abundant energy available to advance society? If you favor universal basic income and free university education for everyone who wants it, cheap abundant energy is what would make those policy goals attainable. And it would mean the standard of living now enjoyed only by affluent people in "first world" countries could be shared with the entire human species.

1.113 ***I'm convinced that dream is attainable, and the purpose of this documentary series is to tell you exactly how we could achieve the things I've just described by 2050.***

1.114 Such a profound advance for humanity would threaten the interests of several well-entrenched industries which benefit from keeping energy expensive, even if that means throttling the pace of advancement of the entire human race. For decades now, we've allowed the necessary transition away from fossil fuels to be delayed by politics, corruption, and the conflict of interest posed by lobbyists representing entrenched industries which profit from keeping things the way they are. It's long past time for *We The People* to demand government policy that serves **our** interests.

1.115 But unfortunately, we've already waited far too long to get *serious* about solving these problems. Climate-inspired public policy has become all the rage in recent years, but unfortunately, despite good intentions, much of that policy has been ill-conceived and I'm convinced it's about to backfire in the form of a global energy crisis that can no longer be avoided.

1.116 The entire second episode of this docuseries will be needed to fully explain why mistakes that have already been made will cause a global energy crisis in the mid-2020s, and why it's too late to avoid that crisis now. Then the remaining three episodes will explore what it's really going to take beyond just wind and solar to achieve the energy transition and replace fossil fuels entirely with clean alternatives.

Episode 2, v2.0: Origins of the mid-2020s Oil & Gas Supply Crisis

2.1 I'm Erik Townsend. This is arguably the most important episode of this entire docuseries, and it will also be the most controversial, because I'm going to challenge some of your beliefs. In the first episode, I promised not to repeat the sins of politicians who just tell you what you want to hear rather than telling the truth about the full scope and magnitude of the challenges we face.

2.2 So put your seatbelt on, because I'm going to tell you things in this episode that some of you don't want to hear. But please, hear me out, because the mistakes policymakers have already made have set us up for a global energy crisis that's likely to cause great human suffering in the mid-2020s. I want you to understand what's going to happen and why, because it's critical that we reverse these policy mistakes as quickly as possible to minimize the damage they're certain to cause.

2.3 There are two separate reasons that breaking our addiction to fossil fuels is critical to our survival. The most well-known reason is climate change. The arguments for replacing fossil fuels for the sake of reducing greenhouse gas emissions are well known, so I'm not going to repeat them.

2.4 In my opinion, the second reason is even more compelling, but it's far less widely understood. I call it peak cheap oil. The executive summary is that we're not running out of oil yet, but we've already found and developed all the oilfields where it's cheap and easy to produce oil. There's still plenty of oil left in the Earth's crust, but from here on out, producing that oil is going to get much more expensive over time. I'll explain these concepts in much more detail later in this episode.

2.5 The number of years it will take to transition the global economy off fossil fuels, even if we make it our top priority, will be greater than the number of years we have left before peak cheap oil drives energy prices to economy-crippling levels. Again, we're not "running out of oil." We've *already* run out of *new* oilfields where oil is cheap and easy to produce. From here on out, more and more complex technology will be needed to produce more oil, and that means prices will continue to rise and the pace of societal advancement will slow as a result.

2.6 Like it or not, the whole world still runs on oil. We depend on energy from oil for almost everything we do, and it's not a luxury we could do without. We literally cannot feed all 8 billion people living on this planet without modern farming equipment which, unfortunately, still runs on Diesel fuel. And almost every single product you buy and use in your day-to-day life couldn't have been made *or* delivered without consuming energy provided by crude oil. We simply cannot live without the energy we still get from crude oil.

2.7 This situation absolutely must change, and we're already way past late to put serious plans in place to phase out fossil fuels. If you're persuaded by the climate change arguments, that by itself is reason enough. And even if you're skeptical of the risks posed by climate change, I'm here to tell you that peak cheap oil and a lack of investment in recent years are going to cause a global energy crisis that will cause massive human suffering if we don't take corrective action immediately.

2.8 To be clear, I very strongly favor building enough clean energy supply to meet *all* our energy needs, so that someday, we don't need to burn one more ounce of fossil fuels. And I favor phasing fossil fuels out as soon as we possibly can. So if you're passionate about climate change, please remember we're already in strong agreement on these points, so we're on the same team!

2.9 But we're so dependent on the energy we get from fossil fuels that we simply cannot phase them out until we first phase *in* enough clean energy to replace them. And unfortunately, we've made so little progress to date that we're nowhere close to being ready to even *begin* phasing out fossil fuels.

2.10 But politicians know they can get more votes by telling people what they want to hear, so they tell you they're going to punish Big Oil and put them out of business! *Down with those stinking oil companies that have been polluting our atmosphere for decades!* Then they impose government policies that make it harder for the oil & gas industry to continue delivering the oil we still need to keep society up and running and prevent mass starvation while we build out the clean energy we so desperately need.

2.11 Meanwhile, activists are petitioning banks to stop funding oil and gas projects which are needed just to continue supplying the energy we already get from oil and gas. Clearly, these activists have their hearts in the right place, but what they don't realize is that they're going to cause a disaster that will bring massive human suffering in coming years.

2.12 I want you to imagine living in a place where dangerous air pollution is poisoning you and your family. Would you respond by first denouncing the polluters and then ***stop breathing completely*** in protest, just to make your point? Or would it make more sense to ***continue breathing*** while simultaneously demanding that the pollution be stopped and taking aggressive action to bring about that outcome? And how could a person who ***isn't breathing*** succeed at bringing about the needed change?

2.13 A lot of people are understandably fed up with fossil fuels continuing to pollute our atmosphere. Their attitude is to just say no to fossil fuels. They feel we should *do no further harm* than we've already done to our environment, and they feel it's long past time to *Just Stop Oil* in its tracks!

2.14 If you feel that way, first and foremost I want to applaud you for your passion and conviction for wanting to protect our environment. I agree it's long past time to solve our addiction to fossil fuels, and I agree that we've already wasted decades making next to no progress on a problem that's been well understood for a very long time. But now I'm going to ask you to hear me out, because I want to make sure you fully understand the implications of *Just Stopping Oil*.

2.15 Like it or not, the immutable truth is that the whole world still runs on oil. We already agree that must change, and that time is of the essence to cure our addiction to fossil fuels. But now let's consider what the implications would be if we try and phase out fossil fuels ***before*** phasing in viable replacements.

2.16 Planet Earth simply cannot support 8 billion human inhabitants *without* the energy we derive from fossil fuels. Many of those people now live in poverty. *More* affordable and abundant energy is precisely what's needed to lift them out of poverty and give them better lives.

2.17 ***Just stopping oil completely, before phasing in viable alternatives, would literally mean committing genocide and culling the lives of at least three billion human beings.***

2.18 We simply don't have the ability to feed all those people without modern farming equipment that still relies on diesel fuel. If we just stopped using oil before replacing it with a clean alternative, the result would be the deaths of billions of people. That's not exaggeration or hyperbole. That's what would happen if we just completely stopped using oil before replacing it with something better.

2.19 Is that really what *Just Stop Oil* activists mean to propose, or could it be they haven't fully considered the implications and consequences of the radical policies they've come to favor? Their anger and frustration with decades of inaction on a meaningful solution to our fossil fuels addiction is completely understandable, but the policies they advocate would cause certain disaster!

2.20 To be sure, we should stop *wasting* energy, and prioritize using it more efficiently. But if you're tempted to suggest that we should just change our ways do without abundant energy, please remember that the advent of cheap and abundant energy is precisely what enabled the abolition of human slavery and made it possible for most of us not to have to work on farms. It's also the reason so many people are now able to pursue higher education, and the reason we can choose from hundreds of occupations other than just farming, which was the only choice for most people 200 years ago.

2.21 Periods of reduced energy consumption equate to economic hardship. This tiny little blip is the 1973 Arab Oil Embargo. This is the 1979-82 double-dip recession when Federal Reserve Chairman Paul Volcker sacrificed the economy to squash inflation, this is the 2008 Great Financial Crisis, and this is the COVID pandemic. Look how small these periods of massive economic and human suffering appear on the energy consumption chart. If we decided to cut our energy consumption by the 32% we presently get from oil, a global depression much worse than the 1930s Great Depression would result.

2.22 To *just stop oil* before bringing clean alternatives online would be equivalent to ***stopping breathing*** just to make a point. It would be suicide by suffocation. Now don't get me wrong. We definitely need to stop wasting time and get serious about making some real progress. But phasing out fossil fuels ***before*** phasing in viable replacements isn't the solution. It's suicide by suffocation!

2.23 From cancellation of the Keystone XL pipeline extension to withholding new drilling permits, government climate policy has shifted from *solving* the energy problem by creating more clean energy sources, to *exacerbating* the problem by vilifying Big Oil and discouraging new oil & gas exploration and production which, unfortunately, is still desperately needed for society to ***continue breathing****.*

2.24 I predict that the direct result of discouraging and even penalizing new oil and gas exploration in recent years combined with peak cheap oil will be a global energy crisis starting in the mid-2020s, which could have been avoided. That crisis will cause massive human suffering and starvation, not to mention another global financial crisis that's likely to be worse than 2008. Gasoline, diesel, and electricity prices will all skyrocket, crippling the global economy and limiting economic growth and human prosperity until the crisis is eventually solved.

2.25 In order to ***continue breathing***, we cannot afford to scapegoat and punish the fossil fuels industry for the sake of political theatre and emotional gratification. As much as it hurts to admit, we still desperately *need* fossil fuels in order not to ***suffocate*** while we're building out viable replacements, something that can only occur over a period of decades, not months or years. Remember, all the wind and solar ever built to date supplies less than 2% of our energy needs.

2.26 Politicians don't want to face reality when it comes to how long it will take to solve this problem, because doing that would underscore how reckless and irresponsible they've already been by waiting so long before taking the problem seriously. Their most grievous sin has been perpetuating the common public perception that renewable energy initiatives have already cleared the way to begin phasing out fossil fuels. Wind and solar is a great start, but even with aggressive continuing investment, wind and solar alone won't be enough to replace fossil fuels by 2050. Its long past time for the public to be made aware of how monumental the challenge that lies ahead of us truly is. We've barely even *started* solving this problem, and we're still many years away from being ready to start phasing out fossil fuels.

2.27 Now don't get me wrong—after spending the last 15 years of my life trading and studying the global crude oil market, I'll be the first to acknowledge that the oil & gas industry has no shortage of shady characters among its leadership. And history includes plenty of examples of Big Oil lobbying lawmakers to adopt legislation that served the interests of Big Oil over those of We the People.

2.28 So it's easy to understand why so many people have become outraged that fossil fuels still dominate our energy supply, decades after it became known that they cause climate-threatening pollution and deplete finite resources that can't possibly last forever. The situation we're in is outrageous and needs to be changed!

2.29 But super-gluing yourself to an airport runway, vandalizing centuries-old masterpiece artworks by throwing tomato soup on them in museums, or stopping traffic on major roadways by climbing gantries and threatening to jump off, does absolutely nothing to reform the injustices these well-intended but badly misguided activists want to see reformed.

2.30 I submit that the *Just Stop Oil* movement and many other environmental activists are focused on the wrong goal, to the point that their efforts undermine rather than advance their own agendas. Specifically, trying to get rid of fossil fuels ***before*** *installing suitable replacements* is counterproductive. Doing so would literally cause mass starvation and human suffering. So, my message to *Just Stop Oil* and other activists is that you have exactly the right idea that *we the people* should demand change, but you're seeking the wrong change, because you don't yet have an accurate understanding of the real problem.

2.31 What we need to focus on, and what all of us should *demand* from our elected leaders, is an aggressive but realistic plan to build out clean, environmentally friendly energy sources that can really and truly replace the energy capacity of fossil fuels. That's not happening today. Instead, politicians are *pretending* wind and solar alone can solve everything, and they're threatening our safety by trying to phase out fossil fuels before viable replacements are phased in.

2.32 In the wake of the pandemic, I started noticing some very concerning signals in the crude oil market, which I traded professionally for well over a decade. The signals I've been monitoring since late 2020 are telling me that it's already impossible for the global economy to return to its full pre-pandemic growth trajectory, because there simply isn't sufficient energy supply to meet demand in that scenario.

2.33 Depletion of existing producing resources, lack of investment to replace them, damage done to the energy industry by the whipsaw in demand during the COVID pandemic, and exhaustion of spare production capacity, are all coming together to form a perfect storm on the near horizon for the global crude oil market, and I'm convinced that a global energy crisis will be the unavoidable result.

2.34 The energy crisis I predict will be driven by supply shortages of oil and natural gas, and it's going to be a really big deal. Therefore, understanding its origins is vitally important. This entire episode is dedicated to explaining why a global oil & gas supply crisis is coming, why it will have a crippling effect on society, and why it's too late to prevent it.

2.35 Let's start with an abbreviated tutorial on the history of oil production, focusing primarily on what you need to know to understand why the pace of societal advancement has already slowed considerably since I was a kid.

2.36 I want you to imagine that your family just inherited a farmhouse with a big, beautiful apple tree in the backyard, which you plan to harvest to help feed your family. In the beginning, it would be silly to spend money on ladders or take the personal safety risk of climbing the tree trying to pick the apples at the top. There's plenty of *low hanging fruit* ripe for the taking, so at first, it's a simple matter of walking out in the backyard and just reaching out and grabbing all the apples you need to make apple pie every night.

2.37 But with the passage of time, you'll use up all the low hanging fruit. You're still a long way from running out of apples; there are still plenty left on the higher branches. But now you need a stepladder to reach more apples. Once you have that stepladder, you won't need a full-height ladder for quite a while, because the next tier of apples was just a couple of feet beyond your reach without the stepladder. But in due time, you'll eventually have to work much harder to get the apples near the top of the tree. If you're farming these apples as a business, that will mean the *cost of production* of each apple will keep getting higher as you have to work harder and harder to get the apples farthest out of reach from the ground.

2.38 The oil industry works the same way, but over a much longer time period. In the beginning, there was so much crude oil in the Earth's crust that there were a few places known as tar pits where crude oil would just seep up to the surface all by itself. Think of this like the very lowest hanging fruit on the apple tree. It wasn't even necessary to drill an oil well to get a low-quality grade of crude oil. It seeped up from reservoirs far below the surface all by itself. But that kind of crude oil wasn't suitable for refining into much other than asphalt for making roads with, because sunlight caused a lot of the lighter hydrocarbons that would have been useful for making fuels to evaporate off.

2.39 Early oil wells known as *gushers* were akin to the small stepladder in the apple tree analogy. One of the very first and most famous gushers was named Spindletop. It was drilled 3 miles south of Beaumont, Texas in January 1901. In a gusher, the natural underground reservoir pressure is high enough that all you had to do is drill a hole in the ground, and once you did, crude oil came gushing out at high pressure all by itself. In the case of Spindletop, oil gushed out at the rate of over 100,000 bbl/day for nine days straight before the well could be capped.

2.40 Spindletop marked the beginning of the Texas oil boom and a turning point in energy history. Before Spindletop, rock oil had been used primarily to provide lighting from oil-burning lamps, and as a lubricant for machinery, which was still relatively new at the time. It was only after the *abundance* of Spindletop's gusher was fully appreciated that *fuels* derived from oil began to replace coal as the primary fuel for engines, starting with oil-fired steam engines and then later, internal combustion engines similar to those that still power most non-electric vehicles today.

2.41 The analogy to the low hanging fruit of the apple tree is that in the beginning, the oil industry focused its efforts primarily on finding more *gushers*—oil fields with so much natural reservoir pressure that no more work was required than drilling a hole deep into rock below the surface, to release oil that would pump itself to the surface under its own pressure.

2.42 In the early days, when oil was discovered in reservoirs that lacked sufficient pressure to drive the oil to the surface, oil producers generally just moved on looking for the next gusher. After all, why put all the effort into figuring out how to *pump* oil from below ground up to the surface if you could just move on to *lower hanging fruit,* in the form of another gusher where the oil flowed to the surface all by itself. The apple tree was still full of fruit in those early days.

2.43 But before long, it was realized that oilfields with sufficient natural pressure to form gushers were becoming fewer and farther between. What's more, some oilfields that started out as gushers experienced a loss of reservoir pressure after a few years of oil production. In the beginning, they were just abandoned when they no longer had sufficient pressure for oil to pump itself to the surface without the need for mechanical pumps. But even in those early days, geologists knew they were wasting plenty of perfectly good oil below ground, for the simple reason they hadn't yet figured out how to get it up to the surface.

2.44 Soon the lift pump was invented. Those gizmos you see in oilfields that look like birds bobbing up and down are called *pumpjacks*, and they form the above-ground portion of a crude oil lift pump.

This technology made it possible to produce much more oil from any given oilfield after the gushers stopped gushing on their own, and it also made it possible to develop oilfields that didn't have enough natural reservoir pressure to form gushers when the well was first drilled.

2.45 I want you to notice a pattern that's already forming in this story, because that pattern is going to continue right up to this day. Each step along the way, the oil industry has always figured out how to overcome challenges that arose, and get more oil out of the ground. We weren't running out of oil then and we aren't running out of oil now. But there's a clear pattern here: For the sake of economics, the industry always starts with the lowest hanging fruit before they spend any money on ladders. In this example, they developed the natural gushers before they invested in inventing and then deploying lift pumps.

2.46 What that means is that even though we're nowhere close to running out of oil in the ground, the higher you reach up the proverbial apple tree, the more expensive it gets to produce each incremental barrel. In the beginning, the oil just came gushing out all by itself. Later on, you had to invest in building and installing lift pumps in order to get the oil you needed. And for decades after that, it kept getting more complicated, and more expensive.

2.47 The oil industry has had a long and interesting history with lots of fascinating developments along the way. But in the interest of staying focused on events that relate directly to the subject of this docuseries, I'm going to fast forward just over half a century to the next event relevant to the topic at hand.

2.48 In the mid-1950s, a Shell Oil geologist named Marion King Hubbert observed that the production profile of any given oilfield has a predictable shape and looks approximately like a bell curve. In the beginning of any oil field's development, production climbs quickly as more and more oil wells are drilled into the same underground reservoir. But eventually, all those oil wells sucking oil out of the ground cause the reservoir pressure to drop, and that makes it much more work to pump each incremental barrel out of the ground. At the peak, you're nowhere close to running out of oil in the reservoir. There's plenty of oil left down there. But it takes more and more work, and therefore expense, to produce each additional barrel. The result is that production begins to decline predictably.

2.49 Hubbert extended this theory to observe that the same phenomenon that applies to a single oil field applies to any collection or group of oilfields. In the late 1950s, Hubbert predicted that lower-48 United States oil production would peak around 1970, and that global oil production would peak around 2000. And his predictions were far more accurate than he's generally given credit for.

2.50 In Hubbert's day, the only known way to produce oil was what we call *conventional production* today. That means drilling good old fashioned oil wells on dry land or in shallow water, and then pumping oil out with lift pumps. Newfangled oil production technologies like horizonal drilling and hydraulic fracturing had yet to be commercialized when Hubbert made those predictions, so he didn't consider their effects on production in his calculations.

2.51 If you frame Hubbert's predictions in terms of the kind of oil production that was known in his day, he got both calls exactly right. Lower 48 U.S. *conventional* oil production peaked right around 1970 when Hubbert predicted it would. We'll explore non-conventional production in just a minute, but first I want you to take this important point to heart: *conventional production* also peaked globally in 2005, just a few years after Hubbert's 2000 prediction, and has never been exceeded. We've set new production records since then, both in the U.S. and globally. But those higher production levels were only possible thanks to the latest and greatest non-conventional production technology which didn't exist when Hubbert made those shockingly accurate predictions.

2.52 Now here's why this is so important to understand. Think of *conventional oil production* as referring to the oil that's easy to find and cheap to get out of the ground. In other words, the apples on the bottom half of the apple tree. When all you need to do to produce crude oil is drill a hole on dry land or in shallow water, install a lift pump, and pump the oil out, it usually costs less than $20/bbl to produce oil that way, even in today's inflated dollars. But unfortunately, we've already found and developed most of the conventional oil plays on Planet Earth. It's very unlikely there will be any major new oilfield discoveries which can be produced using the simple and cheap technology of conventional production. In other words, by 2005, the bottom half of the apple tree had already been harvested.

2.53 Returning to our story, the 1950s and 1960s were a period of great prosperity, and that prosperity was directly enabled by cheap and abundant energy thanks to oil. We didn't yet realize how much damage we were doing to our environment with all the pollution and carbon emissions, but the economic benefits were profound, and quality of life advanced considerably in those decades.

2.54 Lower-48 U.S. production peaked around 1970 just like Hubbert predicted, and energy prices started to rise. The 1973 Arab Oil Embargo greatly intensified the problem, and the 1970s energy crisis ensued. It's no coincidence that the 1970s were a decade remembered for crippling stagflation, poor performance for the stock market, and generally difficult economic times for all of society. Remember, societal complexity and the pace of advancement of the human species is a function of the amount of cheap and abundant energy available to the economy. We starved the economy of energy in the early 1970s, and we paid a high price for the rest of the decade.

2.55 Another important trend of the 1970s was the Women's Movement, which liberated women allowing them to pursue careers on equal footing with men. Obviously, the women's movement was a good thing, but a consequence that's seldom appreciated is that the positive effect of women gaining the freedom of choice muted our awareness of just how badly the 1970s energy crisis damaged our standard of living. Prior to the 1970s, before U.S. lower 48 conventional production peaked and before the Arab Oil Embargo, one man's salary was entirely sufficient to provide for a family of four in a respectable middle-class lifestyle.

2.56 Of course, it was an injustice when women were not allowed to pursue careers, but my point is that before the 1970s energy crisis and ensuing economic stagflation, one salary was all that was *needed* to provide for an entire family. All other factors being the same, when women began careers, creating dual-income households, our standard of living should have improved dramatically thanks to all that additional income. But it didn't. By 1980, working was no longer a *choice* for women—it was a necessity, because by then, two incomes were *needed* to experience the same standard of living that was possible in the 1960s with just one person earning enough money to provide for an entire family.

2.57 By the mid-1980s, oil prices had come back down in inflation-adjusted terms. Some people believe that President Reagan brilliantly architected a master plan to bankrupt the Soviet Union by suppressing global oil prices, starving the Soviets of their primary export revenue source, while simultaneously forcing them to spend beyond their means in the arms race. Other people give Reagan far less credit and suggest it just happened to work out that way without any master plan conceived by the President. But one way or another, by 1986, oil prices were the lowest they'd been in well over a decade, in inflation-adjusted terms. And it was no coincidence that the economy was booming! The 80's were a boom time for the economy and marked the beginning of an epic bull market in stocks. The good times continued through the 1990s and it wasn't until the dot com bust in 2000 that the music finally stopped for the economy. The 80s and 90s were a wonderful time for humanity, and affordable energy prices during that period were a big part of the reason.

2.58 But by 2003, the U.S. invasion of Iraq had dire consequences for the global supply of petroleum. Energy prices rose dramatically, and by 2005, gasoline prices reached unprecedented levels. The gulf wars were part of the reason, but another reason this happened is that just as Hubbert had predicted almost 50 years earlier, *conventional* oil production, referring to oil wells drilled on dry land or in shallow water with no fancy technology, had peaked globally.

2.59 Speculators in crude oil markets would soon become obsessed with a hypothesis known as *Peak Oil*, which was based on the idea that Hubbert's predictions of global conventional oil production peaking in the early 2000s would result in a massive global energy crisis. The popularity of that hypothesis was one of the factors that led to the meteroric rise in crude oil prices in the first half of 2008. It seemed like nothing could stop oil prices from rocketing higher, and it wasn't until the Great Financial Crisis took hold and demand collapsed, that oil prices finally collapsed as well. The jury is still out on whether high energy prices which lasted through July 2008 played just as big a role as the mortgage fraud crisis in crashing the economy by the 2^{nd} half of 2008.

2.60 In my opinion, the Peak Oil crowd had exactly the right idea. They just failed to anticipate that the energy crisis they feared back in 2007 because of **conventional** oil production peaking in 2005, could easily be delayed by at least a decade and maybe even longer, if non-conventional oil production technology could be ramped up to produce more oil than was possible using conventional production techniques alone. And thanks in large part to a mountain of easy money financing in the wake of the great financial crisis, that's exactly what happened.

2.61 The oil industry commercialized horizontal drilling and hydraulic fracturing, which helped us recover from the Great Financial Crisis and made the U.S. Shale Oil boom of the 20-teens possible.

We've also developed sophisticated new technologies for drilling oil wells in extremely deep ocean water, and even producing oil deep below the ice in arctic regions.

2.62 But my whole point is, all this fancy technology comes at a cost. We haven't run out of oil yet, but gushers like Spindletop that made it possible to produce oil for $5/bbl or less are a distant memory. *The low-hanging fruit at the bottom of the proverbial apple tree is long gone.* All the cheap and easy to produce oil accessible with conventional production had already been found, and that kind of oil production peaked in 2005. Since then, so called "tight oil" plays, deepwater offshore drilling, and other exotic and costly technologies are needed to meet global demand for crude oil.

2.63 *And that means the cost of production will keep going up.* It's completely impossible for global oil prices to drop below $40/bbl in anything short of a global pandemic collapsing demand, because it costs more than that to produce each marginal barrel using the technologies which are now required to produce all the oil needed to meet global demand.

2.64 The U.S. shale oil boom of the 20-teens was enabled primarily by a mountain of easy-money financing, thanks to unprecedented loose monetary policy from central banks in reaction to the 2008 great financial crisis. The shale boom brought energy prices down dramatically, and it's no coincidence that the economy and stock market bounced back with vigor as soon as energy became affordable again.

2.65 But very few investments in the shale boom were profitable. It wasn't so much the case that lots of money was to be *made* from producing all that shale oil. Rather, a mountain of easy money was *available to borrow* from the junk bond market at near-zero interest rates, thanks to loose federal reserve monetary policy intended to stimulate the economy after the great financial crisis. That mountain of easy money enabled the shale boom of the twenty-teens, but that series of events is very unlikely to be repeated.

2.66 And shale oil works like an apple tree, too. The shale oil producers carefully prioritized their production activities to focus on the low-hanging fruit first. They drilled and fracked their first shale wells in the very most productive deposits known in the industry as *sweet spots*, leaving the less financially attractive drilling sites for later development. The point is that while the shale boom may not be over, the cheapest "low hanging fruit" shale oil has already been produced, and production costs are unlikely to come down from here.

2.67 Energy now costs more than double what it did when I was a kid, even after adjusting for inflation. And that directly translates to two incomes rather than one being needed to provide for a family of four with a typical middle-class lifestyle. It means much harder economic times now than in the 1950s and 1960s, and the pace of societal advancement slowing to half what it was when I was a kid.

2.68 Remember the core lesson of this docuseries: The *pace of advancement* of human society is a function of the amount of cheap and abundant energy available to the economy. As energy becomes more expensive as a percentage of global GDP, the global standard of living goes down and the pace of societal advancement slows. And that's been happening for more than 50 years now, thanks to the ever-increasing cost of energy as we slowly move higher up the apple tree.

2.69 If we can find a way to replace fossil fuels with new sources of energy which are even cheaper and more abundant than energy was when I was a kid—and I'm convinced we can—then it will be possible to offer the entire planet the kind of prosperity which is only known to the rich today. I'll return to that subject in the next episode. But unfortunately, there's still more bad news to come about what I see on the near horizon for oil and gas markets, so let's return to that subject now.

2.70 Climate change became the favorite buzzword of politicians by the 20-teens, and it's about time we finally started to get serious about solving our addiction to fossil fuels! We should have started decades earlier, but there's nothing we can do now to change history.

2.71 Around the same time, a new trend known as "ESG" began in the investment management business. ESG stands for Environmental, Social, and corporate Governance responsibility. The idea was *meant to be* that instead of focusing only on how to make the highest possible profits from their investments, morally responsible investors would begin prioritizing making investments in things that did good in the world. They would favor investments that were environmentally responsible, socially responsible, and in companies whose senior management, or *governance*, conducted themselves ethically and with strong moral commitment to serving society responsibly.

2.72 To be clear, nothing could possibly be more noble, more honorable, more laudable, or just plain more awesome than the owners of wealth finally starting to take responsibility to invest their wealth in ways that focused on making the world a better place for *all* of society, as opposed to *only* paying attention to how the rich could make themselves even richer. So my hat is off to every single investor who embraced ESG in the beginning, believing it was a way to use their wealth to make the world a better place for all of us.

2.73 But unfortunately, the folks on Wall Street who were entrusted to invest those ESG investors' money in environmentally and socially responsible ways didn't all share the same moral compass as the investors who entrusted them to do the right thing. Self-serving opportunists on Wall Street quickly realized that since investors were no longer going to measure their investment managers' performance on investment returns alone, the opportunity existed to baffle them with bullshit, and disguise poor investing skill as socially responsible investing.

2.74 Soon the running joke on Wall Street was that ESG really stood for "Extremely Stupid and Gullible", which is what some of the ESG money managers really thought of their clients. A trend that became known as *greenwashing* had Wall Street salesmen disguising investments that had nothing to do with the environment or social responsibility as supposedly being "green" when they really weren't. The noble intentions of ESG investors were compromised by the strongest force known in the universe: the self-serving greed of Wall Street bankers!

2.75 Investors tried to fight back by establishing objective systems to grade investments based on their degree of social and environmental responsibility. These grades became known as “ESG Scores” and remain an important part of the institutional investment landscape today.

2.76 While ESG scores were conceived with the best of intentions, the law of unintended consequences has had a devastating effect. There’s some good news in this story: renewable energy projects based on wind and solar get the highest ESG scores, and this has helped attract needed capital to those industries. And that’s a good thing, because we very desperately need to phase in clean energy sources so that we’ll eventually be able to phase out fossil fuels.

2.77 Returning to the devastating effect of unintended consequences, virtually all investments in extractive industries such as mining and oil & gas exploration and production have the worst ESG scores, and that’s made these sectors off limits for many institutional investors. Having oil and gas stocks in your portfolio has literally been a career threatening offense for many institutional money managers in recent years.

2.78 The result was a lack of investment that was desperately needed just to maintain current levels of oil and gas production. Returning to Hubbert’s Peak discussed earlier, all conventional oilfields experience a production profile that looks like this. As producing wells peak and move into steady decline, new wells need to be drilled just to maintain current production levels.

2.79 In the case of shale oil wells, which is where most of the growth has been in the last decade, the production decline curves are much steeper. The reason shale wells can produce so much oil is that the procedure of hydraulic fracturing literally cracks the rock containing the oil, allowing it to flow into the well and be pumped to the surface. But once the oil seeps out of the cracks, production falls off very quickly. Therefore, with shale oil in particular, lots of new drilling and fracking is needed just to maintain current production levels, because existing producing wells are constantly declining in their rate of oil production.

2.80 Lack of investment means we’re not bringing new producing assets online fast enough to keep up with declining production of the older assets. The result is that global oil supply hasn’t recovered to its pre-pandemic levels. More to the point, I don’t expect oil production to grow sufficiently to allow a full economic recovery from the recession, because the investment needed to bring about that outcome just plain hasn’t occurred.

2.81 After going negative during the pandemic, oil prices had risen to their highest level in five years by summer of 2021, long before the February 2022 invasion of Ukraine. That was a strong sign that we simply don’t have enough oil supply to meet demand. And then in January 2022, prices rose even higher, even before the Ukraine invasion. And that happened when China, the world’s biggest consumer of crude oil, was still locked down hard with its Zero COVID policies in full effect, muting demand.

2.82 Goldman Sachs and several other analysts predicted that China’s economy reopening would cause oil prices to skyrocket even higher. But by the time China began relaxing Zero COVID policies in December 2022, many economists were predicting a global recession, and expectations of collapsing demand. The United States drew down more than one third of its Strategic Petroleum Reserve, causing oil prices to drop considerably from their peak just after the Russian invasion of Ukraine.

2.83 Whether demand destruction from the recession will be enough to keep oil prices down for the full duration of the recession was unknown at the time of this recording. But what I feel certain of is that because of insufficient investment to replace declining supply, the global oil market simply does not have the supply needed to allow the global economy to recover from recession and return to its pre-pandemic growth trajectory. There just isn't enough oil supply for that to happen. And all of this is before considering any war-related effects. Oil demand in 2022 slightly exceeded 2019 demand, despite that China was still locked down and international air travel hadn't fully recovered. To resume pre-pandemic economic growth trajectory, we need *more* oil than we consumed before the pandemic, and we just plain don't have it.

2.84 If Russia were to weaponize oil prices and withhold some of its exports for the intentional purpose of crippling the global economy with much higher oil prices, they could do so very easily. And there's almost no limit to how big the resulting price spike would be or how crippling it would be to the global economy.

2.85 There's another dimension to the global oil market that's essential to understand. OPEC, the Organization of Petroleum Exporting Countries, has played a key role in determining the cost of energy since its inception in 1960. The 1973 Arab Oil Embargo discussed earlier was orchestrated by OPEC members led by Saudi Arabia, as a sanction against countries including the United States that had supported Israel during the Yom Kippur war.

2.86 For decades, the way the system worked was that OPEC members agreed to produce *less* oil than they theoretically could, to avoid flooding the global market with too much oil and collapsing prices. For virtually all of OPEC'ss 63-year history, the name of the game has been to always produce and export *less* oil than the maximum amount possible.

2.87 The difference between the amount of oil *actually* produced, and the maximum amount of oil which could *theoretically* be produced if OPEC members pulled out all the stops and produced as much as they possibly could, is known as *spare capacity.* Exactly how much spare capacity each OPEC member country had at any given moment in time has been a closely guarded secret for decades.

2.88 OPEC derives its pricing power from agreeing to produce less than its full spare capacity would allow. And that means the more spare capacity OPEC has overall, the more power it has to control the global price of crude oil. From a negotiating advantage standpoint, it never made sense until recently for OPEC members to reveal the full details of their spare capacity limits to the oil importing countries.

2.89 In the last few years, OPEC has almost completely run out of spare capacity. In the old days, the OPEC member countries would agree to production *quotas* limiting the amount of oil each member country was allowed to produce and sell on the international market. But cheating was rampant, and the quotas were seldom fully complied with. It was normal for most member countries to try and get away with producing *above* their quotas so they could make more money.

2.90 But for the last few years, most OPEC members have consistently failed to *meet* their production quotas. In other words, they've been producing *less* oil than they're allowed to produce under the OPEC quota system! That's incredibly significant, because it means they've run out of spare capacity completely, and are already producing as much oil as they possibly can. Put another way, there is no decision that can be made in any OPEC meeting to cause those countries to start producing more oil than they already do today. *They're already pedaling as fast as they can!*

2.91 Meanwhile, the language used in OPEC press briefings curiously changed in 2022. They used to talk about *quotas*. Now they've begun using the phase *targets*. As if they're struggling to produce as much as the *target*, as opposed to restraining themselves not to produce beyond the *quota*.

2.92 Saudi Arabia and United Arab Emirates are the notable exceptions to this. Saudi Arabia currently produces about 11m bbl/day. In 2022 they announced that their maximum production capacity is 12mm bbl/day and that it would **never** be possible to increase their production beyond 13mm bbl/day, even with additional investment. Keep in mind that they derive negotiating power by overstating their spare capacity, so it's very unlikely these figures are low, and entirely possible they could be high. Saudi Arabia has at most 1mm bbl/day of spare capacity beyond current production levels, and even that might be a stretch. United Arab Emirates also has some spare capacity, but it's less certain how much.

2.93 The point is, OPEC no longer has anywhere close to the ability it used to have to limit oil prices by increasing production. Most member countries have been producing every barrel they possibly can for several years now. And the very few that have any spare capacity at all, don't have much.

2.94 The implications of this are staggering. For example, I've argued that if Russia wanted to weaponize oil prices as a tool of economic warfare, they might simply withhold half of the 8mm bbl/day they normally export, taking 4mm bbl/day off the global market. OPEC clearly doesn't have sufficient spare capacity to increase production by 4mm/day. At first, it's tempting to think Russia could never afford to withhold half its oil exports because of the revenue loss that would cause. But if doing so resulted in a doubling of the global price of crude, they wouldn't lose anything!

2.95 But even setting aside war-related risks, the global crude oil market is already showing very strong signs of being completely tapped out. Most OPEC member countries are producing as fast as they can, and have no spare capacity. U.S. Shale production has recovered nicely since the pandemic, but has begun to plateau at just over 12 mm bbl/day.

2.96 In order to arrest skyrocketing gasoline prices, President Biden ordered the release of more than 200mm bbl of oil from the U.S. strategic petroleum reserve, which was meant to be an emergency supply to be used in time of war or when foreign imports were otherwise cut off, not as a tool to suppress oil prices in a mid-term election year. The SPR releases created up to 1mm bbl/day of artificial supply, which is not sustainable. The U.S. SPR hasn't been run dry yet, but as of this recording it was at its lowest level since 1983, and was still being drawn down.

2.97 Putting this in context, the amount of oil that was drawn down from the U.S. SPR during the autumn of 2022 exceeded the entire 1mm bbl/day spare capacity of Saudi Arabia, implying that if the U.S. hadn't drawn down the SPR and Saudi Arabia had to make up the difference, doing so would completely consume all of Saudi's remaining spare capacity.

2.98 It's important to understand that crude oil prices are prone to dramatic price moves in reaction to even small imbalances between supply and demand. For decades now, the oil market has played a juggling game where there was always some spare capacity in the system and plentiful inventory in the storage tanks. Demand would rise as economic conditions improved, so the industry would respond by increasing production to meet that demand. When the economy turned down, the industry would reduce production to match demand.

2.99 This process involves time lags because production can't be changed instantaneously, and that's where commercial oil storage comes into play. All major countries have tank farms where crude oil is stored. If there's a short-term imbalance where supply exceeds demand, extra oil can accumulate in the tanks. Conversely, oil needed to meet a supply shortfall when demand picks up can be drawn down from those same tanks.

2.100 Both commercial and strategic petroleum inventory levels are now at generational lows around the globe, meaning that most of those big round crude oil storage tanks are nearly empty. That means that as economic conditions improve and demand picks up, there's not enough oil in the tanks to draw upon to meet that increased demand until more supply can be brought online.

2.101 Oil prices are famously inelastic to changes in demand, which is just a fancy economic way of saying that oil prices will go through the roof if demand picks up from here and insufficient new supply is brought online to meet that demand. And for several years now, we haven't invested in bringing sufficient new supply online. We were so busy pretending that wind and solar could solve all our problems that we lost sight of the fact that insufficient investment in oil and gas exploration due to ESG policies was setting us up for a global energy crisis.

2.102 The reason it's too late to avoid that crisis is that it takes years to bring new supply online once a new oilfield is discovered. So when prices skyrocket in the mid-2020s, it's not just a matter of pushing a button to make more supply. It takes a long period of extremely high energy prices to incentivize new investment, and the economy will feel that pain for a period of years until more supply can be brought online to fully meet demand. The longer we demonize Big Oil and punish investment managers for providing that desperately needed investment capital, the worse the problem will be and the longer it will last.

2.103 Taken together, these factors set the stage for a massive energy crisis, in which fuel prices could easily double if supply is lost due to geopolitical events or if demand picks up faster than supply can be created. The U.S. Strategic Petroleum reserve and commercial inventory are at their lowest levels in 40 years, meaning there's no safety buffer to hold us over if supply and demand fall out of balance.

2.104 The consequence of this is that the global economy could get locked in a prolonged recession or even a global depression thanks to unaffordable energy prices. The way this would happen is that as the economy begins to recover from recession, demand picks up for petroleum products. But that small increase in demand causes a gigantic increase in fuel prices, because we don't have any spare capacity or commercial inventory to buffer the bumps in the road.

2.105 Those skyrocketing energy prices could be exactly what crashes the economy right back down into recession again, effectively putting a cap on economic recovery due to lack of sufficient energy supply to allow the economy to recover. *In other words, we'll be suffocating ourselves and **not breathing**, because our obsession with pretending that wind and solar could solve everything for the last several years led to under-investment in desperately needed oil and gas production capacity.*

2.106 In recent years, central banks have responded to economic recessions by providing economic stimulus to help the economy recover. But while central bankers could certainly print up more money to stimulate the economy out of recession, they can't print crude oil. My prediction is that if central banks try and reverse a deep global recession or depression using economic stimulus, the money they print will go straight into inflating energy prices to unthinkable levels. Suddenly all those investment managers who signaled virtue to their ESG-minded investors by refusing to invest in oil and gas won't look so virtuous.

2.107 If there's any silver lining to be found in this gloomy story, it's that I predict the coming energy crisis will bring so much public attention to energy policy that we'll finally be *forced* to start taking seriously the work we should have begun decades ago: phasing in viable clean replacements for the energy now derived from fossil fuels, so that it will eventually be possible to phase out fossil fuels entirely.

2.108 But make no mistake: Phasing out fossil fuels *now,* as the Just Stop Oil activists are proposing, would equate to suicide by suffocation. We can't possibly solve the real problem of phasing in clean energy replacements for fossil fuels if we ***stop breathing*** entirely. And that's exactly what trying to phase out fossil fuels now would equate to.

2.109 So I propose a simple two-part plan for coping with the coming crisis. Notice my choice of the word *coping*, not *preventing.* Unfortunately, it's already too late to prevent what's coming. Under-investment in oil and gas production, and policy initiatives that pretend it's possible to phase out fossil fuels before phasing in viable replacements, have put us in a predicament from which there is, unfortunately, no escape. I'm convinced a global energy crisis is coming, and coming soon. It will have devastating effects on humanity. The best we can do is try and solve it as quickly as possible, and that can be achieved with the following two-part plan.

2.110 Step #1: ***Continue Breathing**.* As much as it hurts to hear, that means we need to urgently ***increase*** investment in oil and gas exploration and production so that we can continue to operate the global economy, which simply isn't ready to completely decarbonize yet. We have to face reality, which is that it will be years before we'll be able to phase in enough clean energy as to be ready to start phasing out fossil fuels.

2.111 Look, I know that's not what you wanted to hear. But I respectfully submit that it was politicians telling you what you wanted to hear, rather than the truth, that got us into this predicament in the first place! As unpleasant as it might be, the fact is that our entire planet runs on oil, and massive human suffering would result without it, because we've yet to make meaningful progress toward replacing the energy we get from fossil fuels with clean alternatives.

2.112 Our politicians haven't been truthful about how little progress has been made to date. The cold hard truth is that wind and solar combined still supply less than 2% of global energy demand, even after two full decades of government subsidies to those industries. All renewables combined still supply less than 5%. Our dependency on fossil fuels is even worse than you may have realized, and it's going to take more work than politicians have been willing to admit before we can phase them out.

2.113 Step #2: *Demand Clean Air to Breathe Just as Soon as we can* ***Realistically*** *get it.* That means we need to get serious about doing what we should have started doing decades ago. Wind and solar alone won't be enough to replace fossil fuels by 2050, and even if we build more wind and solar at twice the pace we've been building them until now, it would still take two more decades before we could even *begin* phasing out fossil fuels.

2.114 We can't afford to wait that long to break our addiction to fossil fuels! We need to start making *real progress* in this energy transition, not just lip service from politicians. We still need to continue building as much wind and solar capacity as possible, but we also need a credible plan to supplement wind and solar with *viable* alternatives that can scale up to meet our baseload electric needs as discussed in the first episode.

2.115 Wind and solar should do a terrific job of providing mostly-daytime intermittent energy that will provide about 35% of the clean energy needed to truly phase out fossil fuels by 2050. It's long past time to figure out where the remaining 65% is going to come from, and we need to focus on clean energy sources conducive to supplying baseload electricity. And don't let anyone tell you that wind, solar, and batteries will solve the baseload electricity problem. We don't have enough battery metals to make the batteries needed to electrify the vehicle fleet, never mind to supply enough batteries for both vehicles *and* grid-scale energy storage.

2.116 Before closing this episode, I want to caution you not to fall for the politicians' favorite trick of political scapegoating. Our elected leaders don't want to admit their own fault for wasting decades before taking meaningful action to build sufficient clean energy to replace fossil fuels. So they scapegoat Big Oil as the bad guys, and tell you they're going to punish the evil oil companies for polluting our environment and causing climate change.

2.117 They’re just trying to avoid being held accountable for failing to establish realistic policies to phase in sufficient clean energy to meet our needs, so that we wouldn’t still be dependent on those oil companies they’re scapegoating for their own failures. The oil companies produce a vitally important commodity that we still desperately need. They’re not the ones who set the policies, and they’re not the ones who pollute the atmosphere by burning all the oil they produce. The polluting is done by everyone who consumes their petroleum products, and we do it because we have no viable alternative. The oil companies are not the ones who failed to build sufficient clean energy alternatives. It’s our elected leaders who failed to act and who should be held to account.

2.118 I’m only aware of two plausible alternatives for producing the rest of the clean energy we need beyond wind and solar to eventually phase out fossil fuels, and we urgently need to pursue both of them aggressively, making them top priority in public policy. The remaining three episodes in this docuseries will explore those two alternatives in detail.

Episode 3 v2.0: Supercritical Deep Geothermal Renewable Energy

3.1 I'm Erik Townsend. In this episode, we'll dive into what it's really going to take to replace the energy we now derive from fossil fuels with clean, environmentally responsible alternatives. This episode will be dedicated entirely to deep geothermal renewable energy, and the technological advances needed to make it viable as a primary source of baseload electric supply.

3.2 Let's start with a quick review of the problem we're trying to solve, which was explained in full detail in the first episode. By 2050, the global economy will require somewhere between 183k and 203k TWh of energy. We already have 23k TWh from renewables and other non-fossil fuel sources, so that leaves somewhere between 160k and 180k TWh of new clean energy we still need to find in order to completely phase out fossil fuels.

3.3 Even with the most optimistic growth estimates for wind, solar, and hydroelectric renewables that I could fathom, we shouldn't expect them to provide much more than 34k TWh of additional supply by 2050. But since they produce electricity directly without the thermal inefficiencies of burning fossil fuels, we gave them credit for replacing up to 68k TWh worth of fossil fuel energy by 2050, meaning they can only be expected to meet *at most* 35% of anticipated total demand. And that was being optimistic.

3.4 From the 160k – 180k TWh we need to find by 2050, even if we give wind and solar full credit for solving 68k TWh worth of the problem, we still need to find another 92k – 112k TWh, and it will need to be baseload power since we're already giving wind and solar double points for their efficiency, which only holds true if we consume the energy they produce immediately. All these figures were discussed in more detail in the first episode.

3.5 So our mission is to figure out where to find at least 92k - 112k TWh of baseload energy supply before 2050, so that we can completely phase out fossil fuels by then. But remember, if we can figure out how to go beyond just replacing fossil fuels and find even *more* energy than we have now, we can usher in a gigantic improvement in our quality of life and accelerate the pace of human advancement! So, I prefer to focus on looking for scalable sources of clean energy that could provide the entire 160k to 180k TWh of clean energy needed to replace fossil fuels by 2050. That way we still meet the need by 2050 even if wind and solar capacity doesn't grow quite as quickly as the very ambitious pace contemplated in the first episode. And if they do, that extra energy becomes the icing on the cake that accelerates the pace of advancement of humanity and lifts more people around the world out of poverty.

3.6 And I do believe it's possible by 2050 to add 160k-180k TWh of new clean baseload energy beyond what wind and solar will provide, but only if we get serious about this energy transition, and stop pretending that wind and solar alone are going to fully solve the problem. So let's make finding at least 160k TWh more clean baseload energy by 2050 our goal, even though strictly speaking, we only need somewhere between 92k and 112k TWh.

3.7 Geothermal renewable energy doesn't get as much attention as wind and solar, because in its *present* state of technological development, it's not as promising as wind or solar in terms of the amount of energy produced per dollar invested. That means bringing anything remotely close to 160k TWh of geothermal energy online using *current* technology just plain isn't going to happen.

3.8 But unlike wind or solar, which are already well-developed technologies, I'm convinced that a game-changing breakthrough is possible for geothermal if we can just figure out how to overcome a few technological hurdles that are holding it back today. If we can advance existing drilling technology to drill deeper and through hotter rock formations, Geothermal has the potential to leapfrog wind, hydropower and solar to become the *most* promising rather than the *least* promising of the four primary renewable energy sources.

3.9 Geothermal power generation isn't as well understood as wind and solar, so let's start with an introduction to what geothermal energy is and how it works, including the reasons it's not presently as economically viable as wind and solar. Then later in this episode, I'll introduce my vision for the future of Geothermal energy, which isn't possible *yet*, due to limitations of current drilling technology. But as we'll discuss later, if we can overcome those technological limitations and figure out how to drill deeper and through hotter rock formations, geothermal energy could be a complete game-changer in our quest to replace fossil fuels completely.

3.10 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—ranging from 10- 75km on land, and even thinner under our deep oceans, where the crust is only 5-7km thick.

3.11 The next 2,900km of depth 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. Then there's another 3,400km of depth to reach the center of the Earth's core, which is mostly molten iron and other metals.

3.12 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.

3.13 A study by the Defense Advanced Research Project Agency concluded that if we could just figure out a way to harness only $1/10^{th}$ 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.

3.14 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, just waiting for us to figure out how to come get it. 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.

3.15 There are several different kinds of geothermal energy, but I'm going to skip the ones that don't offer a way to solve the impending energy crisis, and just focus on those which do.

3.16 To tap into the clean, free 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.

3.17 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. Some rock formations are under such high pressure that the oil flows to the surface all by itself, forming a gusher. When there's not enough natural reservoir pressure in the rock formation for that to happen, a mechanical lift pump is installed to lift the oil out of the well. Not all rock contains oil. In fact, rock that's full of oil is quite hard to find. The entire profession of petroleum geology was created to find oil deposits so they can be drilled, and oil can be produced from them.

3.18 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.

3.19 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.

3.20 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 until reaching the depth where the 100C dry rock formation exists. Then we'll turn the drill bit sideways and drill a horizontal hole several hundred meters long.

3.21 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.

3.22 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.

3.23 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.

3.24 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 to break even.

3.25 Let's up the stakes now, and aim for a hotter rock formation. There are two ways to find hotter rock. One that always works anywhere on earth is to just drill deeper. Remember, the deeper you go in the Earth's crust, the hotter it gets. The other way is to find unusually hot rock formations closer to the surface. This is the reason that deep geothermal electricity production is presently only economic in parts of the world where there's a lot of volcanic activity, making it possible to find hot dry rock much closer to the surface.

3.26 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 very hot steam. And that steam will come up under pressure because water expands considerably when it boils into steam.

3.27 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 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.

3.28 If this sounds like a terrific source of clean, environmentally friendly electricity with no reliance whatsoever on fossil fuels, that's exactly what it is!

3.29 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.

3.30 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 really help solve the global energy crisis that will begin in the mid-2020s.

3.31 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.

3.32 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 250C steam coming out the exhaust well and driving a much bigger steam turbine than we ever could have hoped for with 150C steam. Hotter rock makes a huge difference in how much electricity can be produced from geothermal wells.

3.33 But it's *much* harder to drill a geothermal well through 250C rock than 150C rock. Unless you're drilling in volcano country, you have to drill much deeper to get to the 250C 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.

3.34 But the cost of drilling deeper is actually the easy part. 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 often made from diamonds against the rock at high pressure, and then turning it to slowly grind the rock away through abrasion, slowly boring a hole through the rock.

3.35 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!

3.36 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 very hot 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.

3.37 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.

3.38 Now I'll explain why I'm convinced that a breakthrough is possible to change everything, making deep Geothermal a big contributor to the energy transition.

3.39 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.*

3.40 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.

3.41 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.

3.42 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?

3.43 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.

3.44 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.

3.45 Ok, what the heck is going on here? If the technologies that made the shale oil boom possible had all been invented 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.

3.46 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 expensive, and there was no economic justification for using them.

3.47 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.

3.48 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.

3.49 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.

3.50 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 to be dead, and predicted fracking would never be economically viable again.

3.51 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!

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

3.53 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 was cut almost in half thanks to innovation, hard work, and economies of scale.

3.54 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.

3.55 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.

3.56 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?

3.57 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?

3.58 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.

3.59 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!

3.60 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.

3.61 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.

3.62 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 in order 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.

3.63 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.

3.64 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.

3.65 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.

3.66 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.

3.67 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.

3.68 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 figuring out how to drill holes through hot rock over 374C and to commercialize a process for doing so economically, before this decade is out!

3.69 We can't get through the coming crisis without true *leadership*, and that's exactly the kind of message we need to hear from our elected leaders. The people with the skills needed to solve our greatest challenges need to hear that government is going to have their backs, not scapegoat them as villains, and that we will all come together to work in partnership to bring about the technological advancements needed to make economic, supercritical geothermal wells commonplace by the late 2020s if not earlier.

3.70 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.

3.71 Do you want to know the *ultimate* game-changing scenario, in which Geothermal energy could literally bring about another *acceleration* in the advancement of human society on the scale of the steam engine and the age of oil, while at the very same time eliminating carbon emissions and the need for fossil fuels completely?

3.72 Let's take this discussion of advanced geothermal energy a step farther and consider the scenario of drilling nearly to the bottom of the Earth's crust, and drilling laterals through 600C rock instead of 400C rock. Forget the supercritical water, and replace it with a closed-circuit molten salt circulation loop to move heat energy back to the surface even more efficiently than supercritical water. With a continuous supply of 600C molten salt, we could produce enough electricity to meet our energy needs for the next ten thousand years.

3.73 Now at this point I'm sure the geologists and petroleum engineers in the audience are rolling on the floor laughing their tails off, ridiculing me as an imbecile who obviously has no clue how impossible it would be to drill laterals in 600C rock formations. Just proposing to drill laterals in 400C rock already tests the limits of what's theoretically possible, and 600C would add a full order of magnitude of engineering complexity to the problem.

3.74 President Kennedy knew that his May 1961 speech proposing a mission to the moon had been received by some scientists and engineers as the ramblings of a lunatic politician with no clue about the engineering challenges involved. So, in 1962, he gave another speech saying this to the students and faculty of Rice University: "We choose to go to the moon in this decade and do the other things, not because they are easy, but because they are hard". He was trying to acknowledge the challenges involved, and rally the country around a common goal of great difficulty. And he succeeded.

3.75 So when I propose a hypothetical closed-circuit molten salt circulation loop geothermal well with laterals drilled through 600C rock, I do so not because I'm so naive as to think that doing that is easy, but precisely because I know how much is at stake if we could somehow pull it off.

3.76 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 180k 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 600C rock, we could easily pump twice that much heat out of them.

3.77 So, I have a serious question for the professional petroleum geologists and engineers I know we have in the audience. Look, as a former technology entrepreneur and engineering manager, I really do have an appreciation for how monumentally challenging it would be to figure out a way to drill laterals in 600C rock deep in the Earth's crust and circulate molten salt through them. But here's my question: Is that really and truly ***harder*** to achieve than it was to send a man to the moon in the 1960s? Is it even ***harder*** than that? Really? For context, remember that in 1961, when Kennedy gave that famous speech, electronic ignitions for production cars hadn't even been introduced yet. And Kennedy declared we should literally build space ships, travel a quarter *billion* miles to the moon, land there, take a few selfies, and then return to Earth. Now I get that 600C is awfully hot, but is drilling holes in really hot, really deep rock ***really harder than traveling to the moon and back in the 1960s?***

3.78 I'll even give you a head start: I know a company in Denmark that's already commercialized a molten salt circulation pump with magnetic levitation bearings, designed for continuous duty at up to 700C for ten years without service. Geology is not my field, so I have no idea whether the rest is possible. But what I do know is that the benefit to society if we could somehow pull it off would be much greater than going to the moon.

3.79 The energy crisis we're headed into is going to be a really big deal. We literally cannot feed all 8 billion inhabitants of this planet without the energy we now derive from oil. We're a long way from running out of oil, but we're at very high risk of a supply-demand imbalance that will force energy prices dramatically higher. Mass starvation and resource wars are very real possibilities. The stakes couldn't be higher, and we need to prioritize solving the coming energy crisis with the same kind of commitment we gave to the space race. Nothing is more important to humanity than solving this energy crisis.

3.80 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 technology 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.

3.81 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 energy we need.

3.82 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 wells today would be enough progress to make geothermal economically viable for baseload power generation.

3.83 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?

3.84 The things I've described in this episode aren't possible today, but in my opinion, if anything can change that and make them possible, it would start with a complete change of government attitude toward the oil & gas industry. The people with both the skills and the track record to pull off a clean geothermal electricity revolution are not our enemies.

3.85 Remember, the oil and gas industry aren't the ones polluting the environment by burning their own products, and they aren't the ones setting the policies that have failed to offer us alternatives to those products. All they do is produce those products, which the rest of us are addicted to and can't live without. It's true that Big Oil supplies us with the fossil fuels we're addicted to, but we're the addicts who keep burning them. They're just supplying us with something we can't live without because our policymakers have failed to forge a realistic plan to provide viable alternatives on the scale we need them.

3.86 We need to stop blaming the *suppliers* of fossil fuels for our own actions of *burning* fossil fuels, and recognize that the people supplying the fossil fuels **we** burn today have just the right skills to supply us with clean geothermal energy tomorrow. It's our policymakers who need to be held to account, not Big Oil. And the policymakers' favorite trick for ducking accountability for their own failures is to scapegoat Big Oil as the bad guys, to deflect blame from themselves.

3.87 Don't fall for their tricks! The problem isn't oil companies. The problem is a complete lack of alternatives to burning petroleum products, and a political class that's already wasted two full decades of precious time pretending that wind and solar alone will solve everything, when in reality, after two full decades of government subsidies, they still provide less than 2% of the energy we need to keep society up and running. It's not the oil companies' fault that they have no competitors and the government has done next to nothing to encourage meaningful competition!

3.88 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. The remaining two episodes in this docuseries will focus on the second one, which unlike geothermal, doesn't depend on technological breakthroughs that haven't happened yet.

Episode 4: What's wrong with Nuclear Energy?

4.1 I'm Erik Townsend. In earlier episodes of this docuseries, I explained the critical role energy plays in determining our quality of life and the pace of advancement of the human race. Next, I explained why a global energy crisis is imminent, and can no longer be avoided. Then, in the episode before this one, I explained that I'm only aware of two realistic solutions to this crisis, and went on to explain the first of those two options in detail: deep supercritical geothermal energy.

4.2 I've intentionally waited until now to tell you that the very best option before us is the one I know some of you already vehemently oppose. That's right, I'm talking about nuclear energy. But please don't jump to the conclusion that I'm a fan of the current generation of uranium-fueled pressurized light water reactors like the ones that melted down at Fukushima Daiichi. Quite to the contrary, I think the nuclear power industry has some significant problems to overcome, and my concerns go well beyond the usual objections about meltdowns, nuclear waste disposal, and weapons proliferation.

4.3 So I'll start with a short tutorial on how nuclear electricity generation works, and then focus most of this episode on what's *wrong* with the current generation of nuclear power plants. The overarching theme is that there's really nothing inherently unsafe or wrong with nuclear power. The problem is that governments tightly control and regulate the nuclear power industry, and until very recently, they did an atrocious job of protecting the interests of *We The People* from corruption, greed, and horrendous policy errors caused by political favoritism. I'll expose some of those violations of public trust in this episode.

4.4 Unless we can achieve some really big breakthroughs in deep supercritical geothermal energy technology, and achieve them very quickly, there simply isn't any alternative to nuclear that can generate clean electricity on the scale we're going to need to solve this crisis. Nuclear energy most assuredly *can* scale up to produce 180k TWh of new clean, safe energy by 2050, but doing so will require a complete reversal of public policy. And then it will take at least a full decade to build all the nuclear power plants we're going to need.

4.5 Nuclear power is already the cleanest and safest source of baseload energy by any objective measure. But similar to aviation, although the accidents are extremely few and far between, they always make front page news. Far more people are killed by drunk drivers every single year than the total number of passengers killed in airline accidents in all of aviation history. But the crash site photos after an airline mishap are so graphic and gut-wrenching that we never forget them. Drunk driving fatalities seldom make the nightly news.

4.6 By any objective measure, the number of accidents, deaths, and diseases, including cancer, is far lower per gigawatt-hour of energy produced from Nuclear than from any other baseload energy source. But the extremely rare events where something goes badly wrong in a nuclear power plant are so sensational that we never forget them.

4.7 Many nuclear advocates will tell you that's reason enough to stop worrying about safety and get behind nuclear energy. Sorry, but personally, I still have reservations. They're right that nuclear power is already safer than any other form of power generation, but the accidents at Chernobyl, Three Mile Island, and Fukushima all could and should have been prevented. Those accidents didn't happen because nuclear power is inherently dangerous or unsafe. They all happened because human beings did astonishingly stupid things that resulted in horrific outcomes.

4.8 Regulators have created a mountain of bureaucracy and red tape around all things nuclear that pushes the price of nuclear energy much higher than it needs to be, but all that regulation failed to prevent accidents that were easily preventable. We don't need *more* regulation of nuclear energy. We need smarter, more *effective* regulation in place of bureaucracy and red tape which is currently standing in the way of both progress and *safety*.

4.9 Much better and safer reactors were designed, tested, and proven decades ago. They produce much less waste, and it only needs to be stored for a few hundred years as opposed to one hundred thousand years for the waste produced by current-generation nuclear reactors.

4.10 I promised in the first episode to tell you the truth about the full extent of the challenges we face. So before moving on to the latest nuclear technology, let's take a look at what's wrong with current nuclear power plants. There are several different reactor designs, but for sake of brevity I'm going to focus on the most common type used in nuclear power plants in service today and currently under construction: The Pressurized Light-Water Reactor fueled by uranium.

4.11 A nuclear reactor works by harnessing the heat energy released from a sustained nuclear fission chain reaction. The core of the reactor contains fuel rods made of low-enriched uranium. For our purposes, all you really need to know about the nuclear physics involved is that there are a bunch of neutrons flying around, and they're moving too fast. To make the nuclear fission reaction sustainable, it's necessary to slow those neutrons down. This is accomplished by filling the reactor core with water. The water serves two main purposes. The first is to slow down the neutrons flying around between the fuel rods. The water is called the *moderator*, because it *moderates* the speed of the neutrons.

4.12 The second purpose the water serves is to absorb the heat energy being released by the nuclear fission reaction occurring between the fuel rods. That means the water gets really hot, really quickly. So it has to be continuously circulated out of the core into a heat exchanger, where the heat can be removed and used to produce steam to turn a turbine and generate electricity. Nuclear reactors are so good at heating water quickly that most of the problems arise only when that heat can't be removed quickly enough.

4.13 To shut down the nuclear fission reaction, control rods are inserted into the core. The purpose of the control rods is to absorb the neutrons flying around inside the core, which are essential to sustaining the nuclear fission reaction. With the control rods fully inserted, the nuclear fission reaction will completely stop. 94% of the heat being generated in the fuel rods will stop instantly when the control rods are inserted and the nuclear fission chain reaction stops. But the remaining

6% of the heat generated by the fuel rods is known as decay heat, and it doesn't just switch off instantly like a light switch. It takes quite a while after the control rods are inserted before the fuel rods stop producing decay heat, so it's critically important to keep removing heat from the coolant water to prevent the core from overheating.

4.14 That's why coolant circulation pumps are essential to reactor safety. If the circulation pumps stop working, the water in the core can overheat and boil off. If that happens, even though the nuclear fission chain reaction has already stopped, the fuel rods are still making so much decay heat that they can melt and burn through the bottom of the core chamber. That's the so-called *nuclear melt-down* scenario you hear so much about in Hollywood movies.

4.15 And that's exactly what happened at Fukushima Daiichi. When the earthquake hit, seismic sensors were triggered, and the reactors shut down automatically. All that was necessary to prevent disaster was to keep the circulation pumps running to cool the fuel rods in the core, and everything would have been fine.

4.16 Once the reactors shut down, the electricity produced by the nuclear plant was offline, but the pumps could run on electricity from the power grid. And just in case the power grid failed, which it did, there were diesel backup generators installed specifically to cover this exact scenario. The backup generators were supposed to provide electricity to run the circulation pumps even after the electricity from the power grid was cut off. But when the Tsunami hit, everything was flooded including the backup generators. The circulation pumps shut down, the cores overheated and eventually melted down, and the rest is history.

4.17 I want you to remember one very important detail about how this type of nuclear reactor works: The moderator used to slow the neutrons down, which also serves as the coolant used to remove heat from the core, is *ordinary water*. In the nuclear industry, it's called *light water* to distinguish it from a special kind of water known as *heavy water,* which I'll explain in the next episode. The vast majority of nuclear reactors in commercial use for producing electricity are moderated and cooled by light water. And as we'll see, that leads to quite a few problems.

4.18 The light water inside the core circulates through a heat exchanger so that heat produced by nuclear fission chain reaction can be used to boil a separate source of water into steam that drives a turbine to generate electricity. The amount of energy the reactor can produce, and thus the amount of electricity it can generate, depends primarily on how hot the water in the core can get.

4.19 Ordinary light water boils at 100C. In theory, you could operate a nuclear reactor with water which never gets hotter than 100C. But if your goal is to run an electric power plant, that's not nearly hot enough. To get the most out of the nuclear fission reaction and produce enough electricity to power the grid, you need to get the water up to several hundred degrees Celsius.

4.20 At normal atmospheric pressure, water can't get that hot. It boils to steam at 100C. The solution that's used by most light water reactor designs is to pressurize the water in the reactor core. Just as a pressure cooker makes it possible to heat food in liquid form to more than 100C without boiling, a pressurized core allows the coolant water to be heated to several hundred degrees Celsius, allowing much more energy from the nuclear fission reaction to be harnessed to generate electricity. This requires pressurizing the core to about 150 times atmospheric pressure, or about 2,200psi in a typical pressurized light water reactor design.

4.21 But as any engineer in almost any field will tell you, any time you build any machine that operates under such high pressure, there's always a risk that a failure will occur, and all that pressure will suddenly be released. If that happens to water that's been heated to several hundred degrees Celsius, the water will flash to steam instantly. And that's the whole reason that such large containment buildings are needed for relatively small nuclear reactor cores. If something breaks and the water in the core depressurizes, it will instantly flash to radioactive steam. One of the primary purposes of the containment building is to prevent the radioactive steam from escaping into the atmosphere.

4.22 I know, that sounds pretty scary, right? Hold on, it gets worse. The risk of the water in the core flashing to radioactive steam if the core depressurizes is just one of the inherent shortcomings of using light water as the coolant. To understand the next one, we need to recall the chemical formula for water, which everyone knows: H_2O. In other words, every water molecule consists of two hydrogen atoms and one Oxygen atom.

4.23 Hydrogen is the extremely flammable gas that the Hindenburg was filled with, and Oxygen is the stuff that makes everything burn faster and hotter. The combination of pure hydrogen and pure oxygen is an explosive mixture you could literally make a bomb with. Yet water, which is made of hydrogen and oxygen atoms, is what we use to put fires *out* with! Please ask yourself how this is even possible.

4.24 The answer is that the hydrogen and oxygen atoms in every molecule of water are bound together so strongly they can't be separated without consuming a huge amount of energy. It's what scientists call a *covalent bond*, and it holds those hydrogen and oxygen atoms together in a way that makes them perfectly safe. In almost any normal, everyday situation, there's no risk whatsoever that water could separate into the incredibly dangerous combination of pure hydrogen gas and pure oxygen gas, because it takes so much energy to break the covalent bonds holding the water molecules together that extraordinary amounts of energy and just the right chemical conditions are required to break them apart

4.25 NEWS FLASH! Guess what's going on inside a nuclear reactor core during a meltdown accident? You guessed it: extremely high temperatures, radiation, and the presence of another element called Zirconium which acts as a catalyst to make it even more likely that the covalent bonds in the light water will break, causing it to separate into incredibly dangerous pure hydrogen gas, which could explode and blow the roof off!

4.26 And to be clear, I'm not using the phrase "*blow the roof off*" figuratively. That's exactly what happened at Fukushima Daiichi. Here's the video of a hydrogen explosion literally blowing the roof off the building after the circulation pumps failed, and the reactor core melted down, separating some of the coolant water and releasing explosive hydrogen gas.

4.27 Are you getting the picture now why I'm not the biggest fan of water as a nuclear reactor core coolant when better choices have been available for decades? The alternative coolants don't separate into explosive gases if the core melts down, and they have other benefits too.

4.28 What if I told you that another coolant called molten salt has already been tested and proven to work in a nuclear reactor with no need for any pressurization whatsoever? And what if I told you that it could operate at temperatures up to 700C, removing heat from the nuclear fission chain reaction even better than pressurized light water, and without any risk of depressurizing or flashing to steam, because nothing needs to be pressurized to start with?

4.29 I'll bet you're thinking this molten salt stuff must be the latest and greatest 21st century invention, since it clearly seems like a much smarter way to build a reactor. Surely, we wouldn't be using light water as the coolant in our commercial reactor fleet if we'd known about this molten salt stuff back in the 1970s, when we started building the reactors in service today, right?

4.30 Sorry, wrong answer. Molten Salt cooled nuclear reactors were designed, built, tested, and proven to work in the mid-1960s, and I don't just mean on a drawing board. The Molten Salt Reactor experiment at the Oak Ridge National Laboratory built and *operated* molten salt-cooled nuclear reactors in the mid-1960s, and they worked beautifully, completely eliminating the need for a water coolant susceptible to hydrogen separation, and eliminating the need to pressurize the reactor core.

4.31 But wait, it gets better. The molten salt reactor project at Oak Ridge also proved a new reactor design that completely eliminated meltdown risk, by dissolving the fuel in the molten salt coolant so that there are no fuel rods.

4.32 In the liquid-fueled molten salt reactor designed at Oak Ridge, the nuclear fission reaction stops all by itself when the circulation pumps stop, so there's no need for control rods. In other words, they didn't *just* figure out how to eliminate the need to pressurize the reactor core, eliminating the risk of light water flashing to steam in case of depressurization, or worse yet, separating into an explosive mixture of hydrogen and oxygen. They *also* figured out an incredibly innovative way to completely eliminate any possibility of a fuel rod meltdown occurring in the first place, because they eliminated the fuel rods! Had the molten salt reactor been adopted as the industry standard when it was first proven in the 1960s, these safety innovations could have prevented the Chernobyl, Three Mile Island, and Fukushima accidents.

4.33 But there was one very serious problem with the molten salt reactor, which led to its demise in 1971. Molten salt moderated nuclear reactors were developed in Tennessee, but President Nixon was a Californian. There was a competing experiment in California called the liquid metal fast breeder reactor. The liquid metal fast breeder reactor didn't offer <u>most</u> of the safety benefits I just described. But the liquid metal fast breeder reactor project was in the President's home state. The Molten Salt Reactor experiment in Tennessee, which was doing groundbreaking work on reactor safety, was cancelled, in large part because President Nixon and the power brokers running the Atomic Energy Commission at the time wanted the money spent in California instead.

4.34 I'm sure you probably think I sound like a crazed conspiracy theorist to make such an outlandish claim, but you don't have to take my word for it. If you're familiar with the Watergate scandal, you already know that President Nixon had an odd habit of tape recording himself at what would later turn out to be the most inopportune times. So let's listen in now to President Nixon's June 1971 phone call with congressman Craig Hosmer, also from California.

4.35 (PLAY RECORDING OF NIXON-HOSMER JUNE 1971 PHONE CALL)

4.36 President Nixon made it quite clear in that call that Team California was "ruthless" and "playing it close to the vest", and they were ultimately successful at keeping all the research money in their own state. The safety of our civilian nuclear power industry would pay the price for that political favoritism for the next five decades. And still counting…

4.37 Breeder reactors will be a critically important part of our future, and I'll explain what they are and why they're important in the next episode. But let's return to the Molten Salt reactor story now.

4.38 By 1971, the scientists in Oak Ridge Tennessee who had already proven the benefits of molten salt as a coolant in a working reactor were hard at work designing a molten salt *breeder* reactor that had numerous safety advantages over the Californian breeder reactor design.

4.39 The Californians working on the fast breeder reactor had gone way over budget on their version of the breeder reactor, but at least that money was being spent in the President's home state. By September 7, 1972, testimony in a congressional hearing made it clear that cost overruns on the California fast breeder reactor project would cost the taxpayers at least $700mm, which was a lot of money in 1972. That's more than five billion in today's dollars.

4.40 The molten salt reactor experiment in Oak Ridge Tennessee was run by Alvin Weinberg, who was unsuccessfully trying to call attention to the profound advances in reactor **safety** that had just been achieved in the molten salt project. Weinberg's team had eliminated the risk of depressurization, steam flashing, and hydrogen explosions by eliminating the light water coolant. And they completely eliminated meltdown risk by dissolving the fuel in the molten salt coolant, eliminating fuel rods completely.

4.41 The liquid metal fast breeder reactor project in California was being run by Milton Shaw, who had a reputation for being ruthless in achieving his goals. The other man in a position of power and influence was Chet Holifield, who President Nixon mentioned briefly in the call we just heard. Holifield was a congressman from… you guessed it—California.

4.42 Alvin Weinberg, father of the molten salt reactor design would later write in his 1994 autobiography, "Congressman Chet Holifield was clearly exasperated with me, and he finally blurted out, 'Alvin, if you are concerned about the **safety** of reactors, then I think it may be time for you to leave nuclear energy." Weinberg wrote that he was speechless. It was instantly clear that the powers-that-be were not interested in Weinberg’s focus on making nuclear reactor **safety** the top priority. Especially if the nuclear reactors in Tennessee were safer than those in California.

4.43 Alvin Weinberg, the father of the molten salt reactor design, was fired. The molten salt reactor experiment at Oak Ridge was cancelled completely in 1973, and Weinberg’s reactor designs, which by the late 1960s had *proven* that the risks of fuel rod meltdowns and hydrogen explosions could be completely eliminated, were all but forgotten.

4.44 In the decades that followed, reactors at Chernobyl, Three Mile Island, Fukushima, and several others would melt down in accidents that Weinberg’s reactor designs could have prevented. The Three Mile Island incident was a partial core meltdown accident due to loss-of-coolant, which never could have happened with Weinberg’s molten salt designs. Then in 2011, hydrogen explosions that Weinberg’s reactor designs could have prevented literally blew the roofs off the buildings at Fukushima Daiichi.

4.45 Please ask yourself: is the problem really that nuclear energy is inherently unsafe, or is the problem that our government hasn’t done an ideal job of putting priority on what’s most important to *We the People*? I think it’s the latter.

4.46 Weinberg’s emphasis on designing *safer* nuclear reactors back in the 1960s was sacrificed for the sake things far more important to the people running the Atomic Energy Commission than eliminating the risk of reactor meltdowns or preventing hydrogen explosions like the ones that blew the roofs off in Fukushima. They cared much more about which state federal research money would be spent in, and they didn’t want competition upstaging their pet project, the liquid metal fast breeder reactor, which was being developed in Southern California.

4.47 Milton Shaw and Chet Holifield were, in President Nixon’s own words, “ruthless”, and “playing it close to the vest”. How thoughtful of them to record Craig Hosmer’s phone call with President Nixon, so there can be no question as to what the real priorities of the AEC were back in late 1971 when Alvin Weinberg was fired, and the stage was set for the Oak Ridge Molten Salt Reactor experiment to be completely cancelled 18 months later.

4.48 The groundbreaking work on nuclear reactor safety done at the Oak Ridge National Laboratory in the 1960s would almost certainly have been forgotten forever, if not for the efforts of Kirk Sorensen, a NASA Engineer who discovered the Molten Salt Reactor Project’s research papers when he was trying to figure out how NASA might colonize the moon. A human colony on the moon would require power to operate, and Sorensen was at first fascinated by the possibility that a Thorium-fueled molten salt nuclear reactor based on the Oak Ridge designs might provide the energy needed to power a moon colony.

4.49 Sorensen later realized that the work done at Oak Ridge in the 1960s could revolutionize how energy is produced right here on Earth. He would eventually leave NASA to become an outspoken proponent of Thorium-fueled molten salt reactors, and the founder of a company aspiring to build and commercialize them.

4.50 All the research papers from the Oak Ridge experiments somehow found their way to a storage room in a rural children's museum a few miles from the Oak Ridge laboratory, where they were scheduled to be destroyed! Sorensen launched a one-man effort to save the records from Oak Ridge, and managed to raise enough money to scan all the research documents just before they would otherwise have been lost forever.

4.51 To this day, Kirk Sorensen is a leading advocate of Thorium-fueled nuclear power, and his website energyfromthorium.com is well worth checking out if you want to learn more about the work done at Oak Ridge and the promise Thorium offers as an alternative to Uranium. I'll also address that topic in the next and final episode of this docuseries.

4.52 Putting all of this in context, many of the things that can go wrong in a nuclear power plant are a result of using light water as the coolant and moderator in the reactor core. Better alternatives have been known for more than 50 years, but the vast majority of nuclear reactors in commercial operation around the globe are still light water-moderated and cooled, as are the new reactors being built today.

4.53 Back in 2012, when I first became aware of Kirk Sorensen's desire to commercialize the Oak Ridge designs, I reached out to the most knowledgeable and successful energy investors I know, seeking their advice. I asked them, "Is this Sorensen guy for real? Is this molten salt reactor idea really as compelling as he makes it out to be? Should I consider an angel investment in the company he was launching at the time?"

4.54 My mentors all gave me the same answer. First, they said *yes*, both molten salt and thorium fueled reactors are just as exciting as Sorensen makes them out to be. But then, in the very next breath, they told me I would be crazy to throw money away investing in them in 2012. They went on to explain that nuclear energy is the most regulated industry in existence. The government makes the rules, and they alone decide what technology will be commercialized.

4.55 They said it was a real shame that the advanced designs pioneered by the Oak Ridge Molten Salt Reactor experiment of the mid-1960s were never commercialized. But then they explained that it would never happen unless the government were in the driver's seat, making it happen. My mentors told me that to lobby congress to approve an advanced reactor design, never mind a new fuel like Thorium, would be so expensive it would never happen.

4.56 The solutions to the problems of core meltdown, steam flashing of pressurized water cores, and hydrogen explosions, are anything but new. Most of the operational safety and waste disposal problems the nuclear power industry has experienced to date could have been prevented by the advanced reactor designs Weinberg's team at Oak Ridge proved in the 1960s. But that work was almost completely forgotten quite literally because it happened in the wrong state.

4.57 That's not to say that Americans' tax dollars spent on the Molten Salt Reactor Experiment at Oak Ridge went completely to waste, but hold onto your seat because if you're an American taxpayer, you're not going to like this part: Kirk Sorenson wasn't the only one to realize the incredible treasure trove represented by the Oak Ridge research on molten salt reactors. People in government figured it out, too. Just one minor detail: Those people work in the *Chinese* government. The Chinese wasted no time getting to work on their own molten salt reactor project, and their first molten salt reactor was cleared for start-up in August, 2022. So at least someone is benefitting from the research my parents' tax dollars paid for.

4.58 Back in the United States, things are finally starting to turn around for the better, at least on a small scale. On April 12, 2021, the United States Department of Energy, Office of Nuclear Energy, issued a flyer titled "Three Advanced Reactor Systems to Watch by 2030". The three designs they describe in that paper are the Sodium-Cooled Fast Reactor, the Very High Temperature Reactor, and the Molten Salt Reactor.

4.59 That's right, the last one on their list is the very same molten salt reactor design which was built, tested, and proven by Alvin Weinberg's team at Oak Ridge in the 1960s, just before Weinberg was *fired* by California congressman Chet Holifield and Atomic Energy Commission honcho Milton Shaw for making the outrageous statement that **safety** should be the top priority in reactor design.

4.60 Now, more than half a century later, the U.S. Department of Energy has finally declared in an official communication that the so-called "new technology" we should be keeping an eye on is exactly what Weinberg's team perfected in the 1960s. It's about time!

4.61 An old saying in Washington goes "Never let a crisis go to waste", because it's in times of crisis that the most progress can be made pushing through government bureaucracy and making important things happen. So, as I became convinced in late 2021 that a global energy crisis was unavoidable for the reasons explained in the 2nd episode of this docuseries, I decided to revisit the question of investing in advanced nuclear technology.

4.62 I learned that there are already several startups working right now on molten salt reactors, Thorium fueled reactors, and several other exciting advanced nuclear technologies. Almost all these startups are the pet projects of billionaires who have so much money they don't mind taking an irrational investment risk building a reactor that governments might never even allow to be turned on, because its design is miles ahead of anything the regulators are equipped to regulate. These guys are so passionate about inventing technology that could save the world from the coming global energy crisis that they're willing to take irrational investment risks to try and make it happen.

4.63 For example, Microsoft Founder Bill Gates has bank-rolled an advanced nuclear project called the Natrium reactor. Several other startups are building molten salt cooled and even Thorium fueled nuclear reactors, knowing full well that there isn't a country in the western world that will allow them to be turned on, because no regulatory precedent exists for operating that kind of commercial reactor.

4.64 My strong suspicion is that the billionaires bankrolling these pet projects in advanced nuclear technology see exactly the same writing on the wall that I see: A global energy crisis beyond almost anyone's comprehension is coming, and coming soon. When it happens, being the guy who already built the advanced reactor that could save the world if only the government would allow it to be turned on, is an awfully good look. Consider how governments fast-tracked COVID vaccines and threw outlandish sums of money at the companies that had plausible ideas for vaccine development in the hysteria of the pandemic.

4.65 When you factor in the effects the coming global energy crisis will have on the attitude of regulators, suddenly, investing in those crazy advanced reactor startups which are building reactors no country on Earth will permit operation of *today* doesn't sound nearly as irrational as it did when I first received the advice *not* to invest in this stuff over a decade ago. It wasn't time yet back then, but now it's another story.

4.66 Let's return now to the type of nuclear reactors that governments around the world already know how to regulate: Pressurized light water moderated reactors fueled by uranium, such as those built by Westinghouse, the company that designed and built most of today's operating fleet of commercial nuclear power plants.

4.67 An issue of great concern to the anti-nuclear lobby is Nuclear Weapons Proliferation. One of the biggest myths we need to debunk is the idea that the Uranium fuel that powers nuclear reactors could somehow be used to make a nuclear bomb. It just plain doesn't work that way. To make a nuclear bomb, Uranium must be enriched to at least 90% U-235, the specific isotope of Uranium which is fissionable. Natural Uranium mined from the ground contains only 0.7% U-235. To make fuel for nuclear reactors, Uranium is typically enriched to between 3% and 5% U-235. That low-enriched Uranium has no value in making a bomb, so this perceived risk is pure fiction.

4.68 That's not to say there are no bona fide weapons proliferation risks. To make the fuel for nuclear reactors, Uranium is enriched by converting it into gaseous form and spinning it very fast in centrifuges which concentrate the U-235. Although the centrifuge facilities that are used to make nuclear reactor fuel are typically not configured for making high enriched uranium needed for nuclear weapons, an argument can be made that once a country has the centrifuges needed for making nuclear reactor fuel, it's possible to reconfigure them to produce weapons-grade Uranium.

4.69 That's a legitimate concern, but please notice that the centrifuges aren't needed to operate nuclear reactors. They're only needed to make the fuel rods required to operate nuclear reactors. This means that if you're concerned about weapons proliferation, it really doesn't make sense to concern yourself with which countries are allowed to *operate* nuclear reactors. The important question is where the fuel is made, and who is in control of that process. Most of the weapons proliferation concerns can be overcome by restricting where nuclear reactor fuel can be produced, rather than restricting where nuclear reactors can be operated to generate electricity. Breeder reactors also play a key role this story, and I'll come back to that topic in the next episode.

4.70 The next big objection to nuclear power is nuclear waste disposal. There's nearly a quarter million metric tons of high-level nuclear waste in storage worldwide. High-level nuclear waste consists almost entirely of spent nuclear fuel that was already used in nuclear powerplants over the last 60 years. The reason so many people understandably freak out about nuclear waste is that some of the material stays radio-active for 100,000 years or longer. That's an awfully long time, but that statistic is misleading.

4.71 The radioactive decay of spent nuclear fuel waste declines rapidly after just a few years. After it's been stored for just 50 years, 99% of the dangerous radioactive decay has already occurred. There are still materials in that spent fuel with half-lives upwards of 100,000 years, but the radiation is so small that it barely exceeds safe background radiation levels.

4.72 Now to be clear, I personally don't like the idea of *any* radioactive waste needing to be stored for 100,000 years, and I think the nuclear industry has in the past been too dismissive of this concern. But to keep it in perspective, the *dangerous* radiation really is done and over with after the first 50 years. And even during those first 50 years, high level nuclear waste isn't nearly as dangerous as most people think.

4.73 To make this point, the Dutch government built a single building which serves as both a nuclear waste storage facility, and a children's science museum. Look at the big round circles on the floor in this picture. That's the floor of the children's museum, and those big round circles are the tops of the cannisters in which spent fuel waste from their nuclear reactor is stored. The children are welcome to sit on top of the nuclear waste cannisters just to prove to themselves and their parents that spent nuclear fuel waste isn't really the stuff of horror movies.

4.74 When spent fuel comes out of a light water moderated reactor, 95% of that spent fuel material is perfectly good natural uranium that can and should be recycled rather than left sitting in dry cask storage for 100,000 years. The process for recycling the spent nuclear fuel has already been proven and commercialized. So just going to the trouble of recycling spent nuclear fuel could reduce the amount of nuclear waste produced by today's nuclear industry by 95%.

4.75 But wait, the story gets even better from here. The remaining 5% is some pretty nasty stuff, called trans-uranics. Is it really better if we have to store *concentrated* nuclear waste for 100,000 years instead of storing a much larger volume of current-generation nuclear waste for the same period? There's some benefit to reducing the volume of waste material in storage, but that hardly solves the overall problem.

4.76 But **waste burning** breeder reactors do solve that problem, and they solve it in a beautiful way: They can actually burn the nuclear waste that's already been produced by the last 60+ years of operating light water moderated reactors, and use that waste as fuel! That's right, we already have the technology to take the nuclear waste we thought we were going to have to store for thousands of years, recycle it, then re-use the 95% of it which is perfectly good natural uranium, and then burn the rest as fuel in waste burning breeder reactors.

4.77 That means it's possible to have a nuclear renaissance that not only doesn't add any more nuclear waste to the quarter million tons already in storage. We can actually burn the waste we already have as fuel, and thus eliminate the need to store it long-term!

4.78 Remember, the reactor that Alvin Weinberg was working on when he was fired in 1971 was a molten salt **breeder** reactor. So the technology needed to solve the nuclear waste problem was actually developed and almost completed in the United States half a century ago. It just happened in the *wrong* United State, and that's why it was abandoned.

4.79 And there's still a catch: there's still no regulatory precedent for commercializing waste burning breeder reactors, so the guys who already know how to build them are currently working for those advanced nuclear startups that tend to be the pet projects of billionaires, waiting fingers-crossed for the day when governments get with the program. I'll tell you about one such company that's leading the charge on waste-burning breeder reactors in the next and final episode of this docuseries.

4.80 Until very recently, the government's performance in managing the nuclear power industry has been nothing short of abysmal. And I contend that's the real problem. Nuclear energy was never inherently unsafe. The problems began when our government fired Alvin Weinberg for the offense of making **safety** his team's top priority.

4.81 Some of my friends in the nuclear industry are completely dismissive of the waste disposal problem, because the true risk posed by nuclear waste is miniscule in comparison to how the public perceives it. They have their facts right, but I still disagree. I don't care how small the safety risk is; I don't want to be part of leaving behind *any* radioactive waste that future generations have to contend with for 100,000 years. But I'm also convinced that the technology to solve that problem was already invented by the time I was old enough to ride a bicycle, and I'm in my late 50s now. Maybe it's time we start using that technology which my parents tax dollars paid to develop back in the 1960s.

4.82 It's truly sad that it will probably take a global energy crisis punctuated by great human suffering for the government to finally get its act together and put to work the advanced nuclear technology that was invented when I was still in diapers. But at least we know from their 2021 pamphlet that the molten salt reactor is back on their radar screen. Hopefully Thorium fuel will be next.

4.83 I promised I wouldn't sugarcoat the problems with nuclear power, so we've already spent most of this episode on my critique of what needs to be improved. But let's step back now and put this picture in perspective.

4.84 Nuclear power is already the safest form of baseload power generation in existence. Despite the shortcomings of pressurized light water reactors and the political favoritism that prevented much safer molten salt reactors from being commercialized, the fact remains that nuclear is already far safer than any other option we have. Nuclear is the *only* option that can realistically scale up to supply 180k TWh of new clean energy by 2050, without relying on technological advances that haven't happened yet, as is the case with supercritical geothermal. The light water reactors of today still produce nuclear waste, but the path is now clear for how the waste burning breeder reactors of tomorrow will consume that waste as fuel.

4.85 It's essential to understand that there haven't been **any** serious accidents in the nuclear power industry except for those that were caused by human beings doing *really* stupid things they frankly should never have been allowed to do. In the case of Chernobyl, that reactor design would never have been permitted in the West to start with. Operators at the Chernobyl plant were trying to perform a safety test they had botched 3 times previously. They didn't bother to run their test plan past the reactor's designers or the nuclear regulator, despite that among other things, their test plan involved intentionally disabling the *emergency core cooling system* while the reactor was running. That's the system designed to protect the core from meltdown in event of a loss of coolant accident, so disabling it was reckless to say the very least.

4.86 The safety test was scheduled during the day shift, but it went badly awry, resulting in an unplanned near-total shutdown of the reactor. When they finally got the reactor running on only partial power, well below the threshold level their own written test plan called for, they still weren't sure why the reactor had almost completely shut down. But despite having no idea why the reactor wasn't behaving as expected, they decided to press on rather than abandoning the test.

4.87 Just after midnight, the reactor was being operated by a 25-yr old night shift technician with 3 months experience in his position. He made several serious mistakes that would ultimately result in catastrophic failure of the reactor. The accident was 100% the result of human error. There was nothing wrong with the reactor, and no significant malfunction occurred. The problem was with the humans operating the reactor, whose reckless test plans and egregious operational errors directly caused the disaster.

4.88 In the case of Three Mile Island, when a loss of coolant accident occurred, automated safety systems turned on the emergency coolant pumps to protect the reactor core from meltdown. Human operators responded by overriding the automatic safety systems, and turning the emergency coolant pumps back off!

4.89 After mis-interpreting the overall situation due to poor training, the operators had already convinced themselves there was no loss of coolant, but they were dead wrong. They decided the emergency cooling system, which had activated automatically to prevent a meltdown, wasn't needed. So they shut it off, and a partial core meltdown resulted. The meltdown could have been prevented had the operators not intervened to prevent the automated safety systems from doing the job they were designed to do.

4.90 In the case of Fukushima Daiichi, tsunami-related safety recommendations were made but then ignored not once but twice, first in 2000, and then again in 2008. Safety inspectors had informed the operator that the seawall wasn't high enough and recommended that it be extended to protect against a Tsunami, but no action was taken.

4.91 The diesel backup generators for the coolant system were originally located in the basement of the turbine building. Engineers from GE informed TEPCO, the operator of the plant, that this location was vulnerable to flooding and that the generators should be moved to higher ground. TEPCO responded by moving the generators to higher ground, while leaving all the electrical switching equipment for connecting the generators to the cooling pumps in the basement, where it was flooded by the Tsunami, rendering the generators on higher ground useless.

4.92 Regulators ultimately ruled that even with the extent of damage from the Tsunami, the entire nuclear disaster could easily have been prevented had safety recommendations been heeded. There was no unforeseeable freak of nature. The exact scenario of a tsunami hitting the plant and resulting flood damage disabling the emergency backup power for the coolant circulation pumps was fully understood and anticipated by safety inspectors who informed the plant operator in writing exactly what needed to be done to mitigate those exact risks, years before the accident occurred. Those written instructions were ignored not just once, but twice.

4.93 So history is clear: The problem is not that nuclear energy is inherently unsafe. The problem is that human beings prone to doing stupid things should not be allowed to operate nuclear reactors. The solution is automation, and that solution is well within our current technological capability. The latest Generation III pressurized light water reactors have far more sophisticated automation and fail-safe systems than the reactors that melted down in Three Mile Island and Fukushima. The state of the art in nuclear energy safety could still be improved a whole lot more, as I explained in great detail earlier in this episode. But it's already the safest form of power generation in existence, and we shouldn't hesitate to build more Generation III nuclear plants.

4.94 Going forward, we need to design fully automated reactors which don't rely on human operators at all, and which don't have big control rooms full of confusing instrumentation. The lesson we should learn is to design future reactors so that even Homer Simpson couldn't possibly cause a disaster by trying to interfere with automated systems that are better equipped to handle an emergency than human decision makers who have repeatedly failed to perform under pressure.

4.95 The final problem with nuclear power I want to address in this episode is the time horizon required to bring new nuclear power generation online at the scale we're going to need it. Sadly, large bespoke public works projects are something we're just not as good at as we once were. When the Golden Gate Bridge was completed in 1937, it took four years to build start-to-finish, and came in under budget at $35mm, which is just over $700mm in today's dollars.

4.96 A project is underway right now to add a suicide prevention net under the bridge. That's right, nothing more than a net strung up under the bridge to catch suicide jumpers. That project is now both over budget and late to finish. More than $400mm has already been spent. That's considerably more than half what it originally cost to build the *entire bridge*, even after adjusting for inflation. *Just to add a net under a bridge that's already built!* And the incomplete project to add the safety net has already taken more than the four years it took to build the *entire bridge*! We're just not as good at managing large construction projects and getting them done on time and on budget as we used to be.

4.97 In the nuclear industry, the same holds true today. Cost and schedule overruns at the Vogtle nuclear powerplant construction project in Georgia literally bankrupt Westinghouse in 2017. And even back in the 1970s, we had the same problem. The reason that nuclear power never delivered on the promise of making electricity cheaper than it ever was before is that every nuclear powerplant project ran massive cost overruns.

4.98 This is a really important point to understand: Nuclear power really is and always has been the cheapest way to generate baseload electricity, when you measure the cost of **operating** the nuclear power plant. The problem is that when you factor in the cost of **building** the powerplant including all those cost overruns, the fully loaded cost of electricity is far higher than the direct operational cost of producing it. That's the *only* reason electricity produced in nuclear power plants isn't much cheaper than it is today.

4.99 A personal friend of mine was a union construction worker who helped build the Seabrook nuclear power plant in New Hampshire in the 1970s, and the stories of corruption and malfeasance he told me would knock your socks off. He said the running joke among the union workers was that the day shift built the plant, and the night shift tore it down. Safety rules meant to protect the public made the construction contractors immune from penalty if they detected quality problems and had to re-do parts of the project. The contractors seized the opportunity to build the plant several times over, by intentionally allowing quality defects to occur, thus forcing reconstruction and horrendous cost overruns which only made the contractors richer.

4.100 My friend told me that ironically, clowning around on the jobsite was actually more common at the nuclear plant than on any other jobsite, because every union worker on the job **knew** that the first time they built *anything*, it was just going to be torn back down and rebuilt, so the contractors could gouge even more money by rebuilding it. And so long as they kept paying union wages, the workers never complained.

4.101 It's truly sad that our industrial capabilities have devolved to this level since WW II, but they have. And this leads me to the conclusion that large-scale nuclear power plants like Vogtle will always be plagued by cost and schedule overruns. I'm convinced that the only viable solution is to build nuclear reactors in factories, on assembly lines. What Honda did for the quality and rapid production of Automobiles needs to be done again, but this time to much more demanding nuclear safety quality standards.

4.102 The reason I've become focused on small modular nuclear reactors built on assembly lines is *not* because they're inherently better than much larger conventional nuclear power plants. I'm not convinced they are. The reason I'm convinced that small modular nuclear reactors are the way of the future is that I still have confidence we can manufacture them in factories on the scale we're going to need them. But sadly, I've lost faith in our ability to undertake large bespoke public works projects without screwing them up. The cost and schedule overruns at the Vogtle powerplant in Georgia which bankrupt Westinghouse in 2017 stand as evidence to my point.

4.103 I'm convinced that nuclear power can and should be the primary solution to the coming global energy crisis, unless a major breakthrough in supercritical deep geothermal energy changes the game. The reason I favor nuclear power is that it's the only option we have that can be scaled up to produce the 160k – 180k TWh of thermal energy we need to replace fossil fuels. But I want to be honest about the sadly unavoidable reality of nuclear power, which is that it will take well over a decade to roll out at the scale we're going to need it. That means the sooner we get serious about this energy transition and prioritize a nuclear renaissance, the better.

4.104 And it also means we're going to have to invest in keeping the oil & gas industry not just alive, but **growing,** for at least another decade.

4.105 It's true that rolling out nuclear will take more than a full decade, but the real conclusion to be drawn there is we should have started doing so at least a full decade *earlier*. We're late to get serious about this energy transition, and time is of the essence to put real plans in place that can deliver ***all*** the energy needed to replace fossil fuels.

4.106 The only option for adding more nuclear-powered electricity generation *right now* is to build more conventional nuclear plants using already-licensed light water moderated reactor designs like the Westinghouse AP1000. But the minimum time from commissioning a new powerplant construction project to delivering electricity into the grid is at least 7 years, and more likely 10+ years by the time all is said and done. Without significant new investment in oil exploration and production, petroleum prices will rise to economy-crippling levels long before enough new nuclear powerplants can be built to fully solve the problem.

4.107 It's easy for a futurist like myself to produce a docuseries like this one singing the praises of small modular nuclear reactors built on assembly lines, based on molten salt, Thorium fuel, fast breeder reactor technology, and other advances I'll discuss in the next episode. But as passionate as I might be about such things, the fact remains that there isn't a country on earth that's ready to permit the operation of a molten salt cooled reactor, never mind a Thorium-fueled commercial reactor. We desperately need to move past light water reactors and commercialize the even safer advanced nuclear technology that was invented when I was still just a toddler. But until we do, building more Generation III pressurized light water reactor powerplants is the best option we have.

4.108 Governments are notoriously slow to change until a crisis forces them to. Then they tend to act impulsively without much thought. My primary motive for producing this docuseries was to promote public understanding of these issues, so that when the mid-2020s energy crisis hits the stage, that crisis doesn't go to waste. We need to *use* that crisis to push through a top-level policy directive to embrace nuclear energy as the *primary* strategy to achieve net zero objectives by 2050.

4.109 It's taken this entire episode just to explain what's wrong with the current nuclear power industry. In the next and final episode of this docuseries, we'll focus on solutions, introduce some really exciting advanced nuclear technology, and I'll lay out a plan for solving the coming global energy crisis using a combination of nuclear power, existing renewable sources like wind and solar, geothermal energy, and yes, by extending the life of the oil & gas industry for at least another decade until we can phase in viable clean alternatives needed in order to eventually phase out fossil fuels completely.

<u>Episode 5: Advanced Nuclear Solutions & Prescriptions for Solving the Crisis</u>

5.1 I'm Erik Townsend. In the final episode of this docuseries, we'll explore more advancements in nuclear power technology, and then bring all the concepts we've covered together to lay out a roadmap for solving the coming energy crisis by building out clean energy at scale, allowing fossil fuels to finally be phased out.

5.2 For several decades, almost no progress was made on advanced nuclear technology. That's not to say that there's been no progress on improving *old-school* nuclear. Automation and passive safety systems have improved the industry-standard pressurized light water reactor considerably over the years. But until very recently, there's been almost zero progress moving beyond light water reactors toward better, safer designs such as molten salt or liquid fuel.

5.3 The latest generation of pressurized light water reactors are known as Generation III, and a variant known as Generation III+ is even better. An example of Generation III+ is the Westinghouse AP1000, that company's current flagship product. But unfortunately, we're still talking about pressurized light water non-breeder reactor technology where 95% of the uranium fuel goes to waste that must be stored for 100k years.

5.4 The primary reason there's been no progress on molten salt, liquid fueled, breeder, or Thorium fueled reactors is that there's been virtually no capital investment in advanced nuclear technology. The small handful of startup companies I mentioned in the last episode, which are already working on exciting advanced nuclear technologies, are usually the pet projects of billionaires who can afford to lose their entire investment. So far, institutional investors haven't been interested in advanced nuclear because they haven't seen a path toward profitability.

5.5 But finally, the tide is starting to turn! In January 2023, regulators approved the first Small Modular reactor, built by a company called Nuscale, for operation in the United States. Hopefully that event will send a signal to institutional investors that advanced nuclear is a field ripe for investment, and desperately needed capital will flow into the industry so that irrational billionaires competing with one another to be perceived as the guy who invented the technology that saved the world from the coming energy crisis aren't the only source of funding for these exciting new companies.

5.6 I'm nowhere close to being a billionaire myself, but I'm proud to say that in late 2022, I joined the *irrational advanced nuclear investor club* by making a private equity investment in a company that's already building a prototype small modular **waste burner** nuclear breeder reactor fueled by a combination of Thorium and nuclear waste left behind by the current fleet of light water reactors. I'll tell you more about that company later in this episode.

5.7 Other startups are already prototyping molten salt and Thorium fueled breeder reactors, and hopefully regulators will soon open their minds to those technologies as well. We're still very early in this story, but the tide is finally turning and it looks like Advanced Nuclear technology is set to really take off.

5.8 Nuscale's SMR, the first approved in the United States, is a very traditional pressurized light water reactor design, with relatively little advanced technology. But we had to start somewhere.

5.9 In this final episode, I'm going to explain the most important advanced nuclear technology concepts you need to understand, and then I'll lay out an overall game plan for solving the coming crisis and building enough clean electric power generation capacity to *realistically* phase out fossil fuels by 2050.

5.10 Let's start with an explanation of heavy water. The prior episode explained why ordinary light water has several serious drawbacks as a moderator and coolant for nuclear reactors. A superior alternative moderator is heavy water.

5.11 Heavy Water is just like regular water, except instead of regular hydrogen atoms, heavy water contains a special isotope of hydrogen called deuterium. The only difference is that the deuterium atom has a neutron inside its nucleus, whereas the regular hydrogen atom doesn't. This causes heavy water to weigh about 11% more than the same volume of light water, hence its name.

5.12 Heavy water has several benefits over light water. Canada's nuclear energy program relies on heavy water as the preferred moderator.

5.13 To fully explain the benefits of heavy water in full detail would require a longer lesson on nuclear physics than we have time for. The gist of it is that heavy water does a better job of slowing down all those neutrons flying around inside the reactor core. If you have an appetite for learning about nuclear physics and want to know more, start by reading the Wikipedia article titled Neutron Economy.

5.14 Heavy water has a negative stigma associated with it because India's nuclear weapons program built and then test-detonated a bomb in May 1974 that was made from plutonium that was manufactured in a breeder reactor that used heavy water smuggled into India from other countries. This resulted in a perception in foreign policy circles that heavy water was the "secret sauce" that allowed India to get the bomb.

5.15 I don't profess to be expert in this field, but so far as I can tell, this is like saying that because hand guns that kill people in violent crimes are made from steel, that makes steel an evil metal that should be banned. Heavy water is used for lots of things other than making plutonium for bombs, including making commercial reactors *safer* by eliminating several risks inherent to light water moderators. And there are plenty of ways to make plutonium for bombs without heavy water. So, to my thinking, this negative stigma that heavy water can be used to make bombs is undeserved, but it still persists and sometimes affects policy decisions.

5.16 Bottom line, what you need to know about heavy water is that it's a better moderator than light water, but in some jurisdictions there is a perception that it poses a higher proliferation risk.

5.17 A breeder reactor is a nuclear reactor that produces more fissile nuclear fuel than it consumes. At first that seems impossible, like an automobile that can start with 10 gallons of gasoline in its fuel tank, drive all day, and then somehow end up with 11 gallons of gas in the tank without refueling. Cars don't work that way, but breeder reactors do.

5.18 Imagine a magic automobile that consumes gasoline at the rate of one gallon for every 20 miles driven, but it can also transform ordinary water into gasoline at the rate of one gallon for every 18 miles driven. Although gasoline is being consumed, new gasoline magically made from water is replacing it even faster than it's being consumed. The result is that when you arrive at your destination, there's more gasoline in the fuel tank than you started with. All you consumed to make your trip was everyday water, which is much cheaper and more abundant than gasoline.

5.19 Here's how a breeder reactor works: it's consuming *fissile* fuel just as a car burns gasoline. But at the same time, it's also producing *more* fissile fuel by transforming some other *fertile* material into *fissile* fuel. Natural uranium consists of less than 1% U-235, the fissile fuel source that powers light water reactors. The rest is U-238, which is completely wasted by light water reactors because it's not fissile, meaning that it can't help to sustain a nuclear fission chain reaction. That's why Uranium needs to be enriched to bring the U-235 content from less than 1% up to about 5% so that there's enough fissile fuel to sustain the nuclear reaction.

5.20 The result of wasting the 95% of the low-enriched uranium fuel that isn't fissile is that 20 times more nuclear waste is created than would be necessary if all the uranium were being consumed as fuel. Now here's the key: While U-238 isn't fissile, it is *fertile*. That means it's possible to transform *fertile* U-238 into a fissile element that can be used as fuel, by bombarding the *fertile* U-238 with neutrons in a certain way.

5.21 In a fast breeder reactor, the neutrons aren't slowed down by passing them through a moderator. Instead, all those fast neutrons flying around are used to transform the U-238 into Plutonium, which can be used as fuel to power the fission chain reaction. Put another way, the 95% of the low-enriched Uranium that went to waste in light water reactors because it wasn't fissile doesn't have to be wasted in a breeder reactor. Instead, it's transformed, or *bred* into Plutonium fuel which works just as well as U-235 to sustain the ongoing nuclear fission chain reaction.

5.22 From a given amount of low-enriched uranium fuel, a breeder reactor can literally produce 20 *times* more electricity than a light water reactor which wastes 95% of the low-enriched uranium it consumes. And the benefit isn't just fuel economy. Breeder reactors also reduce the nuclear waste produced by at least 95%!

5.23 But wait a minute… Plutonium? Isn't that the stuff they make atomic bombs with? Yep, that's right, and that's why breeder reactors have had a controversial history. Now to be clear, atomic bombs are made from weapons grade plutonium, and uranium breeder reactors used for making electricity normally produce only reactor-grade plutonium which isn't useful for making bombs. But the very idea that plutonium of any kind is being produced raises a lot of eyebrows.

5.24 When Alvin Weinberg was fired in 1971, his team was hard at work on a breeder reactor of their own design. The breeder reactor being developed at Oak Ridge was molten salt cooled and didn't use a water moderator or coolant. But it wasn't fueled by uranium. Instead, it was fueled by Thorium, another element which is four times more plentiful in the Earth's crust than uranium. Instead of breeding U-238 into Plutonium like the Californian reactor, the Oak Ridge design worked by breeding Thorium into U-233, another fissile isotope of uranium which can be used to power a nuclear chain reaction and produce electricity.

5.25 In order to breed U-238 into Plutonium, a so-called "fast-neutron" reactor design is required. Neutrons that get slowed down by a moderator to create a sustained fission chain reaction won't do the trick; breeding U-238 into Plutonium requires fast neutrons, and that makes the overall reactor design much more complicated and expensive. A distinct advantage of Thorium as a fertile fuel source is that it can be bred into U-233 using slow neutrons—the kind of neutrons found in less complex reactor designs.

5.26 The point is that in order to build a Uranium breeder reactor you need a much more complex and expensive fast-neutron design, but a much simpler and more economical slow-neutron design can be used to build a Thorium breeder reactor. But just to confuse the rest of us, nuclear engineers don't use the word 'slow' to describe the slower neutrons. They call them *thermal* neutrons instead.

5.27 The liquid metal fast breeder reactor that was being developed in California eliminated the water moderator and therefore, the need for pressurization of the core. But aside from that it didn't offer any other safety benefits. Yet it was allowed to run *five billion* inflation-adjusted 2022 dollars of cost overruns. The Thorium breeder reactor in Tennessee had already delivered groundbreaking advances in **safety**, and it offered a much more efficient way to achieve the benefits of breeder reactors without requiring the complexity and expense of a fast-neutron reactor design.

5.28 And there was another significant difference between the two designs. The Uranium-fueled breeder reactor in California generated less nuclear waste than light water reactors, but that waste still needed to be stored for 100,000 years. In contrast, the nuclear waste produced by the molten salt Thorium breeder reactor that was being designed in Oak Ridge only needs to be stored for 300 years, because it doesn't contain the longer half-life transuranics produced by the Uranium breeder cycle.

5.29 A myth that's been widely circulated on the Internet is that Thorium completely and totally overcomes weapons proliferation risks because, according to urban legend, it's completely impossible to make a bomb from U-233. There is some truth to this argument in the sense that Thorium breeder reactors that operate in the thermal neutron spectrum are completely unable to produce plutonium of any grade, so therefore, they don't pose the risk of putting plutonium into the wrong hands. But the perception that it's completely impossible to make a bomb from U-233 is an exaggeration. A correct statement is that it would be much more difficult to make a bomb from U-233 than from weapons grade plutonium, so therefore, the weapons proliferation risk is lower. And presumably, bad guys intent on making a nuclear bomb would be much more likely to try and get their hands on some weapons-grade plutonium rather than tackling the complexities of trying to make a bomb from U-233.

5.30 The way this story ultimately ended was that the guys who insisted that **safety** should be the top priority in designing nuclear reactors, and who were working on a breeder reactor 20 times more fuel-efficient than even today's Generation III+ light water reactors, and which would have generated 1/20th as much nuclear waste that was only radio-active for 300 years instead of 100k years, and who figured out how to partially overcome weapons proliferation concerns with a breeder reactor that didn't make any plutonium—those guys all got fired back in 1973. But the Californians building the liquid metal fast breeder reactor capable of producing plutonium would go on to spend $700mm in cost overruns by 1973. And the cost overruns had only just begun at that point.

5.31 In case there's any doubt about whether the Thorium Breeder Reactor on Alvin Weinberg's drawing board could ever work, that was proven on August 26, 1977, when Uranium-233 fuel bred from Thorium was loaded into a breeder reactor and President Jimmy Carter personally turned it on. That reactor ran for 5 years, and at the end of those 5 years, the core was found to contain 101% of the initial fissile fuel load, proving that more fuel was produced than consumed.

5.32 Nixon and Holifield's liquid metal fast breeder reactor program would eventually be cancelled years later, after controversy arose about the weapons proliferation risks of using uranium breeder reactors that breed U-238 into Plutonium for civilian electrical power generation. Massive cost overruns were another factor.

5.33 The Oak Ridge designs for a much safer Thorium-fueled molten salt breeder reactor were all but forgotten, and eventually somehow wound up in a storeroom in a rural children's museum near the Oak Ridge laboratory. They would have been lost forever if not for the activism of Kirk Sorensen, who led an effort to get the documents scanned just before they were scheduled to be destroyed.

5.34 *Is the problem that nuclear power is inherently dangerous?* Or is the problem that for all its history, the development of the civilian nuclear power industry has been strictly controlled by government, and for most of the last five decades, government's priorities were not optimally aligned with the needs of the people?

5.35 For a full half-century after Thorium-fueled molten salt reactors were built, tested, and proven to work in Oak Ridge, Tennessee, the nuclear power industry has built nothing other than water-cooled uranium fueled reactors. The vast majority are the pressurized light water type, plus a few heavy water designs, particularly in Canada's nuclear program. But there has hardly been any substantive advancement of nuclear reactor design in the last 50 years, or even adoption of the best reactor designs that had already been proven half a century ago.

5.36 Most of the progress that has been made involves better automation and passive safety systems for pressurized light water reactors. But switching to a different coolant than water or a different fuel than uranium hasn't been in the cards until very recently. Nuclear power is so heavily regulated that no progress is possible unless the government is driving the bus and encourages that progress through policy. And no such progressive policies have existed for decades. **I contend that's the *real* problem with nuclear energy.**

5.37 But *finally*, just in the last 5 years, the tide is finally starting to turn, and we're starting to see signs of changing attitudes from regulators. The U.S. Department of Energy's flyer promoting 3 exciting reactor designs including the molten salt cooled reactor, is a long-overdue but very welcome sign of progress. In January 2023, Nuscale was the first company to have its SMR design approved by U.S. regulators. Finally, the tide is turning, and the future looks bright.

5.38 To solve the impending energy crisis, we need a new policy imperative that calls on the Nuclear Regulatory Commission to aggressively work in partnership with the private sector to define a new regulatory framework that actively encourages the development and commercialization of advanced reactor designs, particularly in small modular reactors that can be built in large numbers on assembly lines. The January 2023 approval of Nuscale's SMR design was a great start. Now we need to keep the momentum going and approve molten salt cooled reactors, liquid fueled reactors, and Thorium fueled thermal breeder reactors.

5.39 The most exciting news is that the private sector has already begun to anticipate the coming energy crisis, and already knows that wind and solar alone can't replace fossil fuels for baseload electric power generation. There are already upwards of 50 small modular reactor designs being proposed. In many cases, entrepreneurs are so certain of society's need for advanced nuclear technology that they're taking the risk of building advanced reactor prototypes right now, knowing full well that there is currently no regulatory framework to allow turning them on.

5.40 These startups are taking a really big gamble. They're betting the farm that if they can figure out the right technology to save humanity from the coming global energy crisis, government will eventually catch up and recognize the need to modernize its regulatory framework to permit using that technology. And close to a dozen of these startups are planning to use Thorium rather than Uranium as fuel, despite that so far, governments are completely unprepared to even consider permitting a Thorium-fueled commercial electric power plant.

5.41 One example of a leader in this exciting new field is Copenhagen Atomics, a company I invested in personally in late 2022. Copenhagen Atomics' **waste burner** is designed to consume a combination of Thorium and nuclear waste left over from the light water uranium reactors of yesteryear. It's a molten salt reactor design inspired by Alvin Weinberg's research at Oak Ridge.

5.42 Copenhagen Atomics' design is revolutionary because it completely separates the moderator from the coolant. In other molten salt reactor designs, the moderator is either dissolved into the molten salt or is installed inside chamber containing the molten salt. That means the moderator gets super hot, along with the molten salt. But Copenhagen Atomics completely separates the molten salt coolant, which the fuel is dissolved in, from the moderator.

5.43 That means the water moderator in the waste burner reactor never gets as hot as the water you shower with, so it doesn't need to be pressurized. The result is that the waste burner can be moderated by either light or heavy water. The company favors heavy water as a moderator because of its superior neutron economy, but if there's sensitivity to use of heavy water, the waste burner runs almost as efficiently using a light water moderator.

5.44 The waste burner is a modular design, built in the form factor of a standard 40' shipping container, meaning that it will be possible to ship waste burners anywhere on earth using the existing commercial shipping infrastructure. Building a large Gigawatt powerplant on the scale of today's massive nuclear power stations is as simple as erecting a building to house any number of modular reactors, which are each designed to produce 100MW of thermal energy. Those modular reactors are combined to build an electrical generation plant of any desired capacity.

5.45 Waste burners are designed to produce heat, not electricity. Part of the reason is that Copenhagen Atomics recognizes that thermal efficiency of producing electricity from heat is a field that needs improvement, as I explained in the first episode of this docuseries. So they leave the business of converting heat to electricity to Siemens and the various other companies that are already well established in that market. The second reason Copenhagen Atomics chose to focus on being in the heat business rather than the electricity business is that this allows them to target several other markets such as seawater desalination and ammonia liquid fuel production, which require great amounts of heat rather than electricity.

5.46 Ammonia liquid fuel can be used as a direct replacement for diesel fuel, but it doesn't produce any carbon emissions when you burn it in a diesel engine. So being able to produce ammonia liquid fuel with high thermal efficiency is a really important part of the energy transition. Copenhagen Atomics' desire to be part of that story is a big part of the reason the company prefers to be in the business of making heat rather than electricity from Thorium and spent nuclear waste. If electricity is desired, it's easy to hook one or more waste burners up to another company's steam turbine electric generator, creating a Gigawatt electric powerplant from off-the-shelf modular components without the need to custom-design or -build anything.

5.47 Copenhagen Atomics' vision is to eventually produce at least one waste burner per day on an assembly line, and then ship them anywhere in the world where they're needed. Each waste burner runs continuously for many years. Then it's de-fueled and moved to a storage area to allow the reactor core to cool, before it's eventually shipped back to the factory to be recycled.

5.48 The company believes its waste burners could, in theory, remain in continuous service for as long as 15 years. But the company intends to introduce its first waste burners with a 5-year continuous service life in the interest of proving the technology with ultra-conservative safety parameters, before eventually extending the service life incrementally to ultimately approach the theoretical limit of 15 years' continuous duty.

5.49 Copenhagen Atomics is just one example of more than 50 startup companies working on advanced nuclear technology. Right now, the only available source of investment capital for these startups are private investors like me—people who are so passionate about the prospect of saving the world that we're making what we know to be questionable investment decisions, because the products being developed by these companies aren't yet legal to operate anywhere in the Western world.

5.50 So long as institutional investors considering investments in this field conclude that a 100% loss is a significant risk due to government standing in the way of commercializing advanced reactor designs, there's simply no possibility of the technology advancing as quickly as we need it to solve the coming crisis, because there won't be sufficient investment capital to fund it.

5.51 ***We cannot continue to allow government bureaucracy to stand in the way of progress.*** The stakes are too high. We need to solve this energy crisis to continue feeding the 8 billion people we already have living on planet Earth. And if we get it right, we could usher in a whole new era of accelerated human prosperity thanks to cheap and abundant energy. It's possible to literally lift billions of people out of poverty if we get this energy transition right.

5.52 There are even a few startups that have intentionally made what they know to be poor technology choices in designing their small modular reactors, because their design goal is to favor what can realistically be approved by regulators, as opposed to more advanced approaches they know are better, but which they fear regulators are not yet ready to permit. You heard that right: They're intentionally pursuing what they know to be sub-optimal designs, because they're focused on building something the regulators might be persuaded to approve rather than designing optimal solutions for our energy needs. *Government is literally standing in the way of progress.*

5.53 We desperately need to reverse this situation with new policy directives from the highest levels of government! This industry cannot possibly save us from the coming crisis without a massive injection of investment capital, and that can only happen when investors see a viable path for the revolutionary products being conceived by these pioneering companies to be commercialized and put into operation.

5.54 Once we overcome a few hurdles, nuclear is the ideal energy source for the baseload power needed to completely phase out fossil fuels by 2050.

5.55 Nuclear power requires only a tiny fraction of the land required by wind and solar to produce the same amount of energy, and that makes Nuclear the most realistic and economic baseload energy source to complement the intermittent sources of wind and solar. In theory, deep geothermal is just as good if not better. But supercritical deep geothermal depends on technological breakthroughs that haven't happened yet. The needed breakthroughs in nuclear technology were made half a century ago. We just need to start taking advantage of them.

5.56 In theory, uranium shortages could be a real problem if we tried to do it all just by building more once-through pressurized light water reactors. But that would be crazy for other reasons we've already covered. By recycling the quarter million tons of nuclear waste we already have as fuel for new breeder reactors, and including Thorium-fueled reactors in the solution, fuel scarcity won't be an issue and the nuclear waste storage problems we already have will be solved.

5.57 Custom-building 50 times more nuclear power generation capacity than we have today by 2050 through large bespoke public works projects like the Vogtle powerplant in Georgia is a thought that causes me to take serious pause. But tooling up assembly lines to build small modular reactors that can quickly be deployed in modules to build large multi-gigawatt power plants using the approach proposed by Copenhagen Atomics seems much more plausible.

5.58 The final advanced nuclear energy topic I want to cover is nuclear fusion. Unlike nuclear fission, which involves *splitting* a very heavy atom such as Uranium or Thorium to release energy, nuclear fusion works by compressing two very light atoms such as hydrogen or helium together to form a new heavier atom. This process releases energy while also overcoming many of the drawbacks of nuclear fission.

5.59 Nuclear fusion has the potential to eventually become the primary energy source to fuel the advancement of humanity for the next several centuries. But since this docuseries is about solving the mid-2020s energy crisis and achieving a clean energy transition by 2050, there's really only one thing you need to understand about Nuclear Fusion: **It's still a long way off, and unfortunately, it won't be commercialized for several more decades.**

5.60 Fusion is an incredibly promising technology, and it makes sense to watch its progress closely. But scientists have been wrestling with finding a way to harness the energy potential of fusion for more than 70 years now. It was only in late 2022 that a major breakthrough was made when the first experiment ever to produce a net positive energy result was conducted. It will be decades before this technology is perfected into something we might actually build electric power plants with or use to build engines for the next generation of spacecraft.

5.61 So unfortunately, Fusion won't help us get through the coming crisis. We're going to need to rely on the nuclear technology we already know how to harness, and that's nuclear fission using Uranium or Thorium as the fuel, both of which were proven to work more than half a century ago.

5.62 There's plenty more to learn about advanced nuclear technology and Thorium fuel. The benefits of Thorium are so great that fully explaining them would require another docuseries at least as long as this one. And thankfully, Kirk Sorensen has already done that work at his energyfromthorium.com website. The world nuclear library at world-nuclear.org is another great resource for learning more about advanced nuclear technology, as is whatisnuclear.com.

5.63 Now I want to discuss a controversial topic: The *over*-regulation of the nuclear power industry. For most people, the very suggestion that nuclear power might be *over*-regulated will seem absurd if not maddening. After all, given the history of Chernobyl, Three Mile Island, and Fukushima, it *intuitively* seems that if anything, much *more* regulation is needed in order to make nuclear power safer!

5.64 The fallacy of that line of thinking is the presumption that government regulation has been effective in making the industry safer. I contend that the reverse is actually true. The United States Government spent a lot of its taxpayers' money on the Molten Salt Reactor experiment at the Oak Ridge National Laboratory. The result of that research was breakthrough advances in **safety** which completely eliminated the risk of meltdowns, hydrogen explosions, and steam flashing in core depressurizations.

5.65 The mission of government regulators should be to embrace and commercialize the best government research and use it to make the industry as safe as it can possibly be. Instead, they fired Alvin Weinberg for the specific *offense* of making reactor *safety* his team's top priority. So let's consider how well nuclear regulation has served *we the people* in subsequent decades.

5.66 Recall the words of my investment mentors who told me that the whole problem was that nuclear power is the most tightly regulated industry in existence, and that for that reason, much safer molten salt and Thorium-fueled reactors could never be permitted unless the Government was driving the bus and pushing for their commercialization.

5.67 Three Mile Island and Fukushima are the most well-known meltdown accidents in the western world, but there have been quite a few others over the years. All of them could have been prevented had the U.S. Government embraced the breakthrough research from Oak Ridge and promoted the commercialization of only the safest molten-salt cooled reactor designs which avoid pressurization and are completely immune from meltdown, steam flashing, and hydrogen explosion risks. But instead, nuclear regulators have quite literally *stood in the way of progress* on nuclear safety, because their insistence on keeping the government in control of which reactor designs can be approved has prevented the private sector from commercializing much safer designs that were proven decades ago, in the government's own research laboratories.

5.68 The rules for decommissioning nuclear power plants serve as another example of how well-intended but ill-conceived regulations can undermine rather than advance the interests of the people. Decommissioning rules were born from the noblest of intentions. Regulators were concerned that if a utility went bankrupt and just abandoned a nuclear power plant without first undertaking all the steps required to safely remove and properly dispose of radioactive materials, an environmental disaster could ensue.

5.69 So rules were put in place requiring nuclear power plant operators to pre-pay the cost of decommissioning the plant at the end of its lifetime, and set that money aside in a decommissioning fund. The whole idea was to ensure that even if the operator went bankrupt, money would be available to clean up the mess they left behind. So far, so good. These rules were conceived for good reason and with noble intentions.

5.70 But unfortunately, the regulations weren't crafted to consider their unintended consequences. The effect has been to create financial incentives for utilities to retire perfectly good nuclear plants which could easily serve their communities for several more decades. To the utility that owns and operates a nuclear power plant which already has a fat decommissioning fund built up, they can get paid top dollar to decommission a perfectly good nuclear powerplant, because the decommissioning fund can afford to pay the utility handsomely for the work required to shut the plant down. Decommissioning that perfectly good operating nuclear powerplant takes desperately needed electric generation capacity off the market, causing electricity prices to rise, allowing the utility to make higher profits from their coal-burning powerplants which pollute the atmosphere with carbon emissions!

5.71 Yet another example of over-regulation standing in the way of progress will come into focus as SMRs are commercialized. The most popular vision for SMRs that futurists fantasize about involves small communities being served by their own small modular reactor that provides them with all the power they could ever need. So when I noticed that Copenhagen Atomics focuses on a very different vision where dozens of SMRs are hooked together to form a single very large multi-Gigawatt powerplant, I asked them why. Their answer was simple: Just obtaining the *site license* from regulators to operate a reactor in a particular location costs more than one of Copenhagen Atomics' reactors is expected to cost! They concluded that the only rational way to cope with the very high cost of regulation is to put several reactors in a single building to spread out the cost, and then operate several reactors under one roof.

5.72 These are all examples of a much larger trend. The overall problem is that public hysteria about the safety of all things nuclear has led to the creation of an incredibly ineffective and inefficient government bureaucracy. Don't get me wrong. I'm not suggesting that nuclear energy doesn't need to be regulated. It does. But what we need are sensible regulations that proactively make nuclear energy safer without losing sight of the importance of keeping nuclear energy cost-efficient at the same time. Instead, we have a mountain of bureaucracy that makes nuclear energy much more expensive than it needs to be, **without** really delivering on the safety benefits all this regulation is supposed to achieve.

5.73 What's needed is a joint effort between government and private sector interests to *modernize and reform* nuclear power regulation. I'm not suggesting it should be de-regulated completely. I'm saying there's a mountain of regulation that serves no useful purpose, while at the same time, *better regulation* could do a lot to improve safety.

5.74 Government is *standing in the way* of making nuclear power safer, by failing to provide a regulatory framework for certification of molten salt, Thorium, and other advanced nuclear technologies. We need to reverse that situation, because it's the main thing preventing nuclear power from solving our fossil fuels addiction. And it's the main thing preventing advanced nuclear startups from getting the investment capital they need to save the world from the coming energy crisis and provide the baseload electric power needed for energy transition.

5.75 Now I'll lay out my prescriptions for how to solve the coming crisis, get the energy transition on track, and forge a path toward a whole new era of human prosperity enabled by cheap and abundant energy.

5.76 I'll describe what needs to be done in numbered steps, but just to be clear, these steps need to be undertaken immediately, simultaneously, and in parallel, not sequentially. The numbering is intended to denote priority, not order of execution.

5.77 Step #1 is critical to stabilizing the global economy, but it's one that many of you don't want to hear. We need to aggressively invest in new oil and gas exploration & production, to bring energy prices back down and build up some spare production capacity so that we can ***continue breathing***.

5.78 The cause of the coming energy crisis was trying to phase out fossil fuels *before* phasing in viable replacements. Ill-conceived ESG policies penalized institutional investors for investing in new oil & gas exploration and production desperately needed to replace declining production from aging oilfields already well past Hubbert's Peak.

5.79 The resulting supply-demand imbalance has already exhausted almost all of OPEC's spare production capacity. Meanwhile, both commercial and strategic inventory have already been drawn down to generational low levels globally.

5.80 We cannot possibly solve the *real problem* of bringing new clean energy sources online if we're ***not breathing***. Without investment in new oil & gas production, the global economy will suffocate due to energy starvation. Resource wars and a global depression could result. Millions of people could die of starvation. Without energy from fossil fuels, we can't run the modern farming equipment needed to feed ourselves. The situation really is *that* serious.

5.81 We can arrest the dramatic energy price increases that will come in the mid-2020s by reinvesting in new oil production, but over the long run, prices will continue to trend higher no matter what, thanks to moving higher up the apple tree as we consume a finite natural resource.

5.82 An abject disaster would ensue if we allowed ourselves to reach the top of the apple tree, meaning the point of being unable to produce enough oil & gas to run our society before we phase in viable long-term replacements for oil & gas. And that's exactly where we're headed if we don't change our ways and change them now.

5.83 Step #2 is to learn to conserve energy and prepare for a rough ride. What's coming isn't going to be pleasant.

5.84 We've always been wasteful of energy. At the dawn of the age of oil, when finding the next gusher required little more than drilling an oil well in the right part of Texas, we became spoiled by the illusion that energy was so plentiful that conserving it wasn't necessary.

5.85 Human *prosperity* is at its highest when energy is abundant and cheap. But human *nature* is prone to complacency, and the illusion that energy would stay cheap forever led society to form all sorts of wasteful habits.

5.86 The oil & gas supply crisis was man-made and can easily be reversed by reversing the policy mistakes which caused it. But there's a lag time of several years from initial investment in exploration and production until new oil supply comes online. That means this problem, which took several years of failed policy to develop, is going to take several years to cure, even just temporarily.

5.87 When we eventually complete the job we should have started 30+ years ago and roll out sufficient new clean energy sources to enable the phase-out of fossil fuels, it will mark the dawn of a whole new era of human prosperity and societal advancement. But until then, we're going to be in for a bumpy ride, and the sooner we learn to conserve energy and use it more efficiently, the better.

5.88 Step #3 is to aggressively and systematically roll out as much nuclear electric power generation capacity as we possibly can. The only way this can happen is with a top-down decree from the highest levels of government. The top priority for all developed nations on earth should be to aggressively invest in building nuclear powerplants. That's not a departure from the current global governmental degree to solve climate change by going net-zero by 2050. Rather, it's the very best way to *achieve* those net zero policy goals.

5.89 The current status quo is that government sets the rules, and the rules are that conventional light water reactors fueled by low-enriched uranium are the only thing regulators know how to regulate. We must reverse this in favor of government policy that actively promotes rapid adoption of the latest and safest technologies, starting with molten-salt cooled Thorium-fueled breeder reactors.

5.90 The question of whether to build more conventional large-scale pressurized light water nuclear power stations like the Vogtle powerplant in Georgia versus the much more compelling but less commercially mature technologies such as molten salt, breeder reactors, and Thorium fuel is a real mind-bender. On one hand, the benefits of advanced reactor designs over pressurized light water reactors are so compelling that it's tempting to say we should just invest heavily in fast-tracking their approval.

5.91 On the other hand, the nuclear power industry has been stunted for decades, and unfortunately, all the industry knows how to do right now is to build more large-scale nuclear power stations based on already approved Generation III+ pressurized light water reactor designs like the Westinghouse AP1000.

5.92 At first, that trade off seems daunting. The safety, weapons proliferation, and nuclear waste advantages of the advanced nuclear reactor designs are so compelling that it seems crazy not to choose that path forward. Yet time is very much of the essence, and we cannot afford to wait to act while a whole new generation of advanced nuclear technologies go through the process of proving to regulators that they are safe and worthy of being permitted to deploy in commercial operation. How can we possibly resolve this conundrum of which path to follow?

5.93 The answer is simple: We need to do both, in parallel, starting immediately. If the promise of the newer designs is realized, and particularly, if we can succeed at tooling up assembly lines to produce small modular breeder reactors at a pace of one unit per day as Copenhagen Atomics has proposed, then it's plausible that we'll have solved this problem with a new fleet of small modular reactors before the new fleet of large-scale power plants reaches completion. If that happens, it's cause for celebration, not disappointment.

5.94 But if it takes longer than hoped to scale up assembly line production of small nuclear reactors while still maintaining strict nuclear quality standards, we're really going to need those big new powerplants to hold us over. And it might eventually be possible to modernize those new Westinghouse AP1000-based power stations by later upgrading the reactor cores to molten salt Thorium breeder designs while still retaining the investment in the rest of the powerplant.

5.95 So Step #3A is to build as many new large-scale nuclear power stations as we can possibly build using conventional nuclear technology, and Step #3B, which should be undertaken simultaneously, is to fast-track certification and approval of small modular reactors based on advanced designs including molten salt cooling, liquid fuel, Thorium fuel, and breeder reactors in both the fast and thermal neutron spectra.

5.96 It makes perfect sense to allow the new fleet of SMRs to compete with the new fleet of large-scale conventional nuclear plants to see which can be first to provide sufficient electric generation capacity to truly phase out fossil fuels.

5.97 The key to all of this is government *leadership*. The Private Sector is already more than ready to build advanced new reactor designs and make nuclear energy much safer than it ever was before, while at the same time, burning up the existing nuclear waste we thought we were going to have to store for 100,000 years, and replacing it with cleaner waste that only needs to be stored for 300 years.

5.98 The only reason this didn't happen in the 1970s was that governments are in charge of all things nuclear, and without their active leadership, the industry cannot advance. It's time for governments around the world to step up to the challenge and start being part of the solution rather than the heart of the problem. U.S. approval of Nuscale's SMR was a very welcome first step in that direction.

5.99 Step #4, which should occur in parallel with the prior steps, is to prioritize and fund more research and experimentation on deep supercritical geothermal energy. The logical path forward for the oil & gas industry is to commercialize deep supercritical geothermal energy and make it cost-competitive with nuclear and other power sources. The same team that pulled off the shale oil revolution needs to repeat that performance with a clean geothermal renewable energy revolution.

5.100 We subsidize wind and solar, so why not geothermal? Supercritical deep geothermal is even more compelling than nuclear power if we can break through the technological barriers which make it impossible today. It's time to invest more in breaking down those barriers so the geothermal industry can really flourish.

5.101 Step #5 is to continue aggressively building wind and solar energy capacity. No matter how much of these intermittent sources we build, it won't be enough. We still need 24/7 baseload power, and a combination of nuclear and geothermal are the best way to complement wind & solar to address that need.

5.102 Step #6 is to figure out a more efficient way to convert heat energy into electricity. No matter what energy source we choose, increasing thermal efficiency is just as important as increasing energy supply. More research and investment are needed in this important field.

5.103 Step #7 is more research and development of synthetic fuels. We need to figure out how to efficiently turn the heat energy we get from geothermal or nuclear into liquid fuels that can run vehicles. Hydrogen and Green Ammonia liquid fuel are a good start, but they each have serious drawbacks. More research is needed in this area.

5.104 The reason I began developing this docuseries in 2022 is the old adage 'never let a crisis go to waste'. My sincere hope is that public awareness of the true cause of the crisis provided by this docuseries, alongside the work of others like Kirk Sorensen, will help people recognize the need to hold our elected leaders to account.

5.105 All we need to cure the crisis and usher in a new era of human prosperity is a realistic, viable strategy to phase in sufficient clean energy to replace fossil fuels by 2050. So far all we've gotten is lip service and empty promises that wind and solar alone can solve everything, with no attention paid to critically important needs like building out new higher-capacity electric grids. It's time to get serious and focus on what this energy transition is really going to take, rather than just telling people what they want to hear.

5.106 Now I'm going to ask for your help. I already reached into my own pocket to fund the docuseries which you're watching right now, because I'm passionate about doing my part to help solve the coming global energy crisis. Don't worry, I'm not going to ask you for money. The time and money I spent putting this docuseries together was proudly donated in the interest of doing my part to help save our planet from the coming crisis, and I'm not interested in making money from this.

5.107 But I need your help getting the word out! Since I'm funding this out of my own pocket, there's no budget for advertising or promotion. The only way to promote this docuseries is word of mouth, and that means I need *your* mouth to encourage your friends and family to watch it. And then I need you to spread the word on social media, starting with hitting the like and subscribe buttons right now, which make a huge difference attracting more viewers. We need to make this free docuseries go viral to make a difference, and I can't do it without your help.

5.108 I'm not selling anything, and I have no profit motive. So please, do what you can to help get the word out by posting links to the first episode all over social media.

5.109 The millions of people around the globe who are passionate about climate change have their hearts in exactly the right place. But most people don't understand the realities of scale that are involved. They think that wind and solar alone can solve all our problems within just a few years time, because for well over two decades now, that's what politicians told them to believe. To truly solve this problem and save the human species, and to open the door to a whole new era of human prosperity, we really need to get the word out about how big the task at hand really is, and we need to get it out quickly.

5.110 So if you've enjoyed this docuseries, please do your part by spreading the word far and wide. All it will take to get the whole world on track to **solve** this problem is to start by getting people to ***understand*** this problem.

5.111 We ***can*** solve this crisis and we ***must*** solve this crisis. And you can help by getting the word out about this free docuseries.

5.112 For people who prefer reading over watching, this docuseries is also available in book form. Just put my name, Erik Townsend, in the search box at Amazon.com and you'll find it in your choice of kindle or paperback format.

5.113 My goal is to replace this low-budget YouTube docuseries with a broadcast quality version for release on Netflix or another major streaming service. I already have a mental plan for how to design it, replacing my voice which you've been listening to for five hours now with a celebrity narrator, and including on-camera interviews with pioneers in the geothermal and advanced nuclear energy industries who already have the vision needed to usher in a whole new era of human prosperity based on clean, abundant, and cheap energy.

5.114 So, if you work in Hollywood and know people who have the skill, experience, and industry contacts needed to transform the docuseries you've just watched into a broadcast quality version for the streaming services, please ask them to send me an email if they want to talk about collaborating to produce the Hollywood version. They'll find the landing page for this project and a treatment for the Hollywood version along with my contact details at www.macrovoices.com/energydoc.

5.115 Thanks for watching, and thanks in advance for your help spreading the word! I hope you've enjoyed this docuseries, and I hope it's helped you better understand what we're up against. I'm Erik Townsend.