Mark Nelson: Understanding All Things Nuclear

December 22nd, 2022

Erik: Joining me now is Mark Nelson. Mark is a nuclear engineer and consultant to the nuclear industry and also something of a pro-nuclear activist. Mark, it's great to get you on the program. I don't normally ask MacroVoices guests about their personal background because they're mostly well known figures in finance, and their bios are available to interested listeners on our website. But your background is quite a bit different from our usual guest. So let's start by setting the way-back machine to 2011. You were a young man in the enviable position of having earned a scholarship to attend graduate school at Cambridge University, and needed only to choose your major. Then you saw the same YouTube video that I saw around the same time, produced by a former NASA engineer named Kirk Sorensen. Tell us what that video was about how it changed your life and where it led you.

Mark: Sure yeah. I needed to study something having to do with engineering, but I just didn't know what I wanted to study. And I came from Oklahoma, which has oil and gas but no nuclear energy. It has wind, but no nuclear. And I came from a family involved in oil and gas on one side, and then on my mom's side, nuclear medicine. And the only thing I knew as a young person is that I had no interest in either. So I'm browsing the internet trying to figure out what to do with my life. And I come across this video where the tone sort of was, people don't want you to know that we have the craziest nuclear technology and the nuclear energy is actually incredible. And if we just chose the right reactor, we could solve all the world's problems. And so I started watching the video, and it started to explain that there's a new fuel we could use. There's a new reactor prototype we could use and that nuclear energy can make enough energy to power the world for a billion years without carbon emissions. Once I heard that opening pitch, I pretty much knew that I was going to do nuclear energy. I was just a very strong feeling where I finally found something where it mattered that I had the technical training of an engineer, because it is technology, it is engineering. And yet at the same time, there was this political side to it. There was the cultural side where we had a great treasure. We weren't using it. And surely there was going to be a hard battle to come up with a future based on nuclear. And I knew in a moment, that's what I wanted to do. I put my application in for the brand new nuclear engineering program overseas at Cambridge and the rest is history.

Erik: Well Mark, I really want to salute you because from what I've learned about your career, I know that you're motivated more by a desire to do the right thing for humanity than just to make a buck in a career like most people, and I really salute you for that. As a degreed engineer, you're an expert on the science of nuclear energy. How uranium atoms are split in half and self sustaining nuclear fission reactions, and so on and so forth. There are some of the people in our audience who would love to learn all of those details. But frankly, most of the finance people in the audience would prefer to skip the technical details and just understand nuclear energy from the perspective of the investment opportunities it's going to create. So we made an editorial decision. We're going to leave the nitty gritty technical details out of today's interview, but only after first inviting Mark to tell you where on the internet you can find free resources for those of you who do want to learn how the technology actually works. So Mark, for people who want to know where the neutrons hit the protons and how that stuff all works. Where's the best place for them to start and what should they be looking at?

Mark: A sentimental favorite for me is the website whatisnuclear.com by working advanced nuclear engineer Nick Turan, who's working on the Bill Gates sponsored advanced reactor that's due to be constructed in Wyoming to replace a retiring coal plants. So Nick as a hobby and as a service has put together a very indie website, shall we say, the type that you used to love stumbling across back when Google worked, and I recommend everyone check out what is nuclear. For an encyclopedic approach, a balanced, all encompassing approach to the world of nuclear, you can hardly do better than the World Nuclear Association online library where just looking at the number of topics they have available is itself an education in the nuclear industry, nuclear fuel cycle, and nuclear history. So gotta recommend that sort of big industry association approach and the Nick Turan, indie approach. Both of those are fantastic. It's a little more hit and miss if you're just Googling on YouTube. But we'll put in a few links to some of the videos I've contributed to some of the online large construction channels or some of the channels that focus on speeches on nuclear energy, and then I have to give a shoutout to the man who got me into speaking publicly about nuclear. Chris Keefer, Dr. Chris Keefer is an emergency room doctor with way too much energy. And he started a podcast and a movement up in Canada to help himself discover the world of energy while doing something about it.

So the Decouple Media Group is his baby. And that's where I first started recording podcasts. And at this point, I've I think I have 12 or 13 on a number of topics, where if I think I have a good piece of the story, I give it to him and he puts out an episode. So episodes on natural gas and coal and the levelized cost of energy paradox where it looks like you can build nothing but solar and that's cheaper than building expensive nuclear and we break down the disasters construction fiasco at Vogtle in Georgia. The only new plant in the US under construction. We take a look at Russian nuclear and how the Russians took over the majority of the global nuclear projects. And anyway, so that over at Decouple was probably where I have them most of the serious work that I've put out, and then you can always get a chuckle or a tear from my twitter @energyvents where I discuss issues of the day and occasionally go on long rants about electricity markets.

Erik: I've been really enjoying the World Nuclear library myself, and I can't recommend it highly enough. Listeners, as always, you'll find all of the external links to the materials that Mark has just discussed in your research roundup email, which accompanies this episode.

Mark, let's talk now about the history of the nuclear power industry. I remember as a kid growing up in the early 1970s, the message was that nuclear power, which they called atomic energy back in those days was coming, it was going to change everything, because it was going to provide society with the cleanest, greenest, safest, and cheapest electrical power generation ever seen by mankind. Pollution was going to become a thing of the past, and super cheap electricity would become the norm. We wouldn't need to import fossil fuels ever again, from the Middle East, and atomic energy would make electricity so cheap and abundant that it would last forever. Well, guess what? It didn't quite go that way. To whatever extent nuclear power may actually be the cleanest and safest form of power generation, it most definitely does not enjoy a favorable reputation with the general public in those regards. And when it comes to the claim that atomic energy would be much cheaper than burning fossil fuels like coal to make electricity. Well, that just plain didn't happen like they promised it would. So please give us the history of the nuclear power industry. What are the main events that investors need to understand in order to navigate this landscape of, you know, how come those promises weren't fulfilled in the 1970s? And what are the new developments in the industry today that we need to understand?

Mark: Great intro and I certainly have had the too cheap to meter thrown in my face more times than I can count. And it's funny that you get that because a lot of the arguments that renewables are taking over goes along the lines of well, we're going to have so much data on electricity that we'll need to throw it away. But no, you can't have it for free, because we have to pay for the upkeep of the grid. So there's a combination too cheap to meter, that plus, you have to pay more for your electricity that ends up meaning power that is too worthless to meter. And yet when it turns off, power is too precious to afford. So not to try to say that not other people have it worse, but nuclear did deliver on aspects of its promise in ways that are underappreciated. Here's one, nuclear electricity in almost every place in the world is cheaper than burning fossil fuels. But it doesn't mean you get the reactor for free. It just means the fueling upkeep and long term operation is the cheapest form of available energy. In Germany, for example, they optimize their newest reactors. The only ones they still have running, they optimize those reactors for very low staffing and extremely cheap, secure ongoing operations. Sure enough, their nuclear power costs about 20 euros per megawatt hour going forward, whereas their fossil fuels are costing between 100-400 euros per megawatt hour just for the fuel alone. For the fuel alone, it's up to 10 to 20 times more expensive than their nuclear plants. So I'm going to push back here and say that if you look at the details, nuclear did deliver. But that doesn't mean we had permission, approval, or ability to build as many plants as we needed to be at for everybody to be as reliant on nuclear as some of the leading countries of the world. So in terms of what it would take to get back to that point. Well, that's a long discussion but in short, there has to be a program and an effort by a nation to decide to get that much nuclear, because in order to replace that much of your power with nuclear, somebody is going to lose out. Existing players are going to have to step aside and that's where the battle gets quite fierce in policy circles.

Erik: One of the things that did go wrong in the 1970s nuclear build out was most of those projects were just dramatically way over budget. And you don't have to look any further than the Vogel project in Georgia that you already mentioned, to see that not much has changed today. We've still got massive cost overruns in these projects. What's the story there? What is it going to take to get to the point where we can create nuclear energy and stay on budget while we're doing it?

Mark: Yeah, great point. In fact, until recently Vogel was not even particularly bad by historical standards in terms of time, and budget overruns. I mean, that is not a justification, that is not acceptable. I'm not making an excuse, just noting that the crown jewel assets of our strongest utilities are nuclear plants that themselves were as big a fiasco just to build as Vocal is today. We were just doing a bunch of them at a time. And now they just work extremely well in the background, and nobody really notices them. And they'll keep working for up to a century, maybe more. I'm not trying to say that we should put up with any amount of incompetency or schedule overrun to build them because they're so valuable once we have them, that will keep them forever, and it'll make it up. But people almost never remember or mention in the utility spaces, the difficulty of building those last plants in terms of the ongoing operation record, which has been extraordinary.

Let me give you one little example here, the construction of Diablo Canyon Nuclear Plant in California, was costed out and justified on the assumption that 75% uptime was going to be your max for the reactor that you would get, say a capacity factor of 75%. Your total full power hours would be equivalent to that, you know, three quarters of the time. But instead, the reactors are lasting much longer than expected, at a capacity factor of 90% and above, which completely changes the game even when under the rosy projections of the past. Now we just adjust our expectations. We expect nuclear to be that good. And when it doesn't perform that well then we ask what's wrong here? Why is it doing so poorly? So in terms of Vogel, here's the story. In the US, the nuclear industry, the nuclear construction industry fell apart, contractors kept the same name. But everybody who worked there and knew how to run a nuclear plant site construction site, they left. A design for a nuclear plant was created, that design was an evolution of another design. But that other design, that first design was never created. So you had Westinghouse come up with a reactor that it never built. It changed the design to make it even harder to build. And then without having the design completely finished, they started construction. That is not a recipe for success anywhere in any industry. And in nuclear, it was particularly bad when the subcontractors who got the contracts for Westinghouse, they could not deliver. A lot of marketing terms were used. This was an advanced reactor. And it was advanced because it uses 80% less concrete and similar percent less steel and moving parts compared to previous generations. But that doesn't matter if you're on your critical path and the construction site, you're stuck on one thing for a year. Doesn't matter whether if there's 80% less concrete if it's easy to pour concrete, and that wasn't your problem. The materials usage was not the thing that needed to be corrected from previous generations. It was worksite productivity, labor productivity on the worksite. And when you have 1000s of workers waiting around because something isn't right and you don't know what how to proceed. And if you proceed, you might have to rework that's what starts to lead to the I believe at this point 6 years over time, and something like 150% over budget something along there we can discuss and get the numbers exactly.

So at Vogel, you had people working on nuclear for the very first time and learning the hard way how to do it and how not to do it. Eventually, once Westinghouse is subcontractors all collapsed. Well, they didn't collapse... Westinghouse had to buy them because they were going to collapse. Then Westinghouse was left running a nuclear construction job, which it had never done. Westinghouse had always worked with a big construction firm. But it found itself out on its own. And eventually Westinghouse, ran out of financial lease, it took Toshiba, its owner into bankruptcy. And then finally, to get the project done, they went to the last person you go to, they're the most expensive, you go to Bechtel. And even Bechtel has been having to relearn a lot of skills. In order to finish those nuclear plants, there was a great deal of rework that's had to happen over the last few years, where wires were not put in correctly, cables were not labeled and isolated correctly, which is one of the great principles of nuclear safety cables have to be separated so that a single fire or impact event can't cut a bunch of parallel safety systems because all the cables went through the same spot. All of this to say, we very expensively and painfully rebooted nuclear construction in the US. In order for that to last in order for that to matter, we would need to keep constructing. And now's the time where we're figuring out whether we will, and who's going to be doing that building.

Erik: Mark, I personally am convinced that nuclear has to be the way of the future. I think it is going to be the cleanest, safest, best way to generate electricity going forward. But one of my greatest frustrations is the people in the nuclear industry, who are so completely dismissive of what are in some cases, very legitimate safety problems and challenges that the industry has faced. A lot of these guys like to pretend that there's no problem, which is nonsense. One of the things I really respect about you is that you're willing to talk both sides of that story. But here's the rub. The perceived problems that most of the anti-nuclear activists like to focus on are not the real problems, which I know you're willing to discuss candidly. So let's take this in two parts. Let's start with the perceived problems and then move on to your own Frank analysis of what the real problems are that face the industry. The three big strikes against nuclear as its perceived by the public are number one, operational safety, particularly with respect to meltdown risk has happened in Fukushima and Three Mile Island. Number two nuclear waste disposal. And number three nuclear weapons proliferation. So let's take those one at a time starting with operational safety of nuclear plant. Those concerns are usually focused on meltdown risk where the cooling pumps fail, as happened in Fukushima or something else goes wrong. And even after the nuclear chain reaction has shut down, the fuel is so hot that it melts down creating an environmental disaster. After Chernobyl and Three Mile Island, nuclear experts insisted that modern reactors simply didn't have this risk anymore, because due to redundant systems design, it could never happen again. Then it happened again at Fukushima Daiichi leaving the public untrusting of so called nuclear energy experts. So what's the real story Mark on these operational safety risks?

Mark: So one of the first things I have to tell people is that the way Chernobyl blew up is of a fundamentally different nature than the meltdowns at Three Mile Island and even Fukushima Daiichi and that those Three Mile Island and Fukushima Daiichi events were slowly unfolding, relatively non energetic so that even though hydrogen gas built up in Japan and blew the roofs off of the reactor containment buildings, nobody was hurt by shock, or by impact or by blast waves or by radiation burns or exposure itself. So let's tackle Chernobyl first, the most violent and famous nuclear disaster in world history. Rather than talk about the very well covered and discussed accident, I want to talk about one of the lesser known things that changes the nature of what we think we know about Chernobyl. Chernobyl Nuclear Plant kept operating for 14 years. For the first three years after the accident, electricity output increased year after year after year to a new plant record and believe it was 1990 or 1991. So all of the cleanup efforts, all of the refurbishing efforts to make sure that the other three reactors on the site didn't blow up as unit 4, the baby of the site had. All of those efforts did not even interfere with higher electricity production at an operating work a day plant. Workers we're going to work and running that nuclear plant, and after four or five years for the good of a newly independent country for Ukraine. So people sometimes claim when they hear this, they're like well, maybe they were forced to keep running. No Ukraine, as a matter of national interest kept running one of their precious nuclear plants. It was one of the greatest assets available to them. The only reason that Chernobyl Nuclear plant closed down in year 2000 is that pressure from Europe was so severe and the amount of money being offered to the Ukrainian government to shut down the power plant was so great that they finally said, okay, the President of Ukraine in 2000 said okay and over the protests and disappointment of the workforce, shut down the plant and turned it into a big cleanup project forever and ever. Big make work project in some ways, reasonable environmental amelioration in other ways. And now, I'm sure Ukraine would be very happy to have the electricity production. But as it is, other plants have the same design as Chernobyl are in operation in European Russia Today powering multimillion person cities. So none of that was to excuse what happened at Chernobyl. Nor was it to say that we should build that reactor design again, nor wasn't to say that our reactors are of that design, just that even the world's worst nuclear disaster could not even shut down the industrial facility that was supposedly a dead zone forever and ever afterwards. So there's Chernobyl, about Three Mile Island.

Three Mile Island was a meltdown that occurred to reactors that were as old as the ones that ended up melting down at Fukushima Daiichi. That's actually quite important. The reactors that suffered the meltdowns at Fukushima Daiichi were hit with an initiating event, an earthquake and tsunami that ended up killing 16,000 plus people that was much greater than the the initiating event at Three Mile Island, which was nothing other than a faulty understanding of an existing valve that had gotten stuck. So there was no real initiating event of any sort at Three Mile Island, just a faulty understanding, poorly trained crews, an incorrect response, and then melting one of the two reactors on site and the other reactor continuing in operation until being shut down by low gas prices in 2019. Whereas at Fukushima Daiichi, a cataclysmic natural disaster, hitting one of the most disaster prepared countries on Earth, killing an enormous number of people doing immense amount of damage. And yet, because of the cultural fear of nuclear, our memory of that event has focused around the nuclear plant itself, were very few casualties were seen and were the environmental destruction was as much by the cleanup efforts around the plant as by the radiation itself. And it's not proper to second guessed those cleanup efforts. They were clearly important to people, they were important symbolically, they were important to administrators who ordered them. The gathering up of a foot of topsoil from a vast area and putting it into plastic bags and giant open air dumps. I think it must have made them feel better, or hopefully it did because they did it. But looking at Fukushima Daiichi, Japan had a terrible nuclear safety record for decades before that event, they had very lethal accidents in nuclear plants with broken pipes leaking steam into break rooms and killing workers. There had been issues with untrained workers or improperly trained workers at a fuel reprocessing plant suffering fatal radiation doses from an accident. Like Japan was not the model of good reactor operation. Japan had one of the worst reactor uptimes in the world. That is Japanese reactors were down for repairs, or for checks, or for refueling more than reactors in similar countries. These are all signs of a safety culture that isn't up to snuff. And it finally, it finally came to a head when at Fukushima Daiichi, the seawall that they knew was too low had not been raised. Then generators that General Electric had told the Japanese should be at on higher ground, were not put on higher ground. These are the generators where if a giant cataclysmic event knocks out your entire society, these generators will step in and provide the backup cooling to keep water on this still hot fuel, giving it time to cool down and lower the danger. Yeah, those reactors were flooded by water and then because of the huge amount of damage all around the plant, and the cultural sensitivity of nuclear, the chain of command and dealing with the incident and the ability of workers and managers to communicate with the outside world was so compromised, that in that fog, some bad decisions were made and the some of the oldest reactors in the West suffered meltdowns.

So all of that to say, every reactor on planet earth that has stayed in operation has learned important lessons and has undergone emergency training and stress tests. Based on what happened at Fukushima Daiichi. 9/11 was a horrible event. On 9/12 and all the days after that, cockpits got locked and hijackings effectively stopped. It would have been amazing if we hadn't have had 3000 deaths and that atrocity in order to learn to lock cockpits, but now they're locked. And it changes the nature of danger and safety in airline security. And there's a phrase that we you see in various branches of engineering, Erik which is, well, in this case, I was down in a uranium mine this summer in Saskatchewan and I went into a refuge room. It's like a combination, lunch area, meeting point and life support room if something were to go wrong, and their collapse happened in the miner, a fire happened 1000 feet below the surface. In this break room, the biggest words in the room, we're covering almost an entire dry erase board. The mind code is written in blood. The Mind Safety Code in Canada is written in blood. Well, unfortunately, that's the way a lot of engineering works. It is shocking that the Fukushima Daiichi triple meltdown, hydrogen blasts, and fear did not lead to actual people dying from nuclear, so much as it led to people dying from the panicked response to nuclear. So to a lot of people that's a difference without a distinction. But I think in the end, that's why I'm putting this set of famous occurrences in the perception rather than the actual problems with nuclear that I see if people were to discover they like nuclear. We accept risks, we think are worth it. As people are discovering nuclear and deciding they like it, it's becoming easier and easier to learn enough about the history of nuclear accidents to see what would be different about their own local nuclear plant in the case of a radically different design like Chernobyl, or a very different safety environment like post-Fukushima Daiichi. And that has been enough for the people that I've talked to, to relax and stop worrying so much about the nuclear plant.

I want to make one more comment, though, on the safety and and perception issue. I think a lot of people believe that even if Nuclear Regulation is too harsh in some countries. That regulation keeps us safe, because it keeps nuclear plants on their toes, maybe. But it's not the regulators that I feel, have the most respect and fear in the minds of nuclear plant managers when I visit them around the world. Instead, it's WANO and IMPO. WANO is the World Association of Nuclear Operators. So WANO is a voluntary association, where it would look be a very bad look, if you didn't join. Why? Because it's the top nuclear experts from around the world Russian experts, Chinese experts, American experts, British expert, French experts, and you invite these experts into your plant, they look at everything top to bottom, they completely turn you over. And then they leave say thank you, and they write a report to your owners, saying here's what was good, here's what was bad, here's what is critically deficient and needs to be fixed. I have talked to a nuclear plant that had been going through years of reforms after a blistering WANO report was given to their owners. A report so bad evidently that there was consideration of maybe shutting down the plant. Instead, lots of people were shuffled around, some people were retired, hard asses came in from other industries that are as dangerous or more, even if the public doesn't realize it. And then reform happened and the nuclear plant then got glowing reviews on subsequent safety visits. That has nothing to do with the regulators so much. It's the self regulation and cooperation. The pure pressure of the nuclear industry itself that does come out of this perception that a nuclear meltdown from a rotten safety culture like pre-Fukushima Daiichi, Japan can destroy nuclear businesses on the other side of the globe. Everybody has skin in the game, everybody's in it together. Whether it's Rosatom under Putin, or it's a you know, a privately owned nuclear operating company in the northeast of the US that only has one plant. Everybody, for better or worse is in it together to solve this perception of safety by actually making it to where nobody dies in a nuclear plant ever again.

Erik: Mark, let's move on to the topic of nuclear waste disposal. Many of us have images in our minds of the so called Superfund cleanup sites where 55 gallon drums of incredibly toxic chemicals were discovered buried underground in these landfills. And after a few years, the steel drums rusted through and the toxic chemicals leaked out, went down, and polluted the water table, poisoning entire populations of people were told then. We start with that image in your head of a thin steel walled 55 gallon drum, you know, buried in a landfill. And then we're told that this nuclear waste stuff can stay radioactive literally for millions of years. And that leads a lot of people to just question well, you know, how long before the 55 gallon drum that that's buried in your rusts through and it leaks out and something goes wrong. More recently, fears have arisen that spent nuclear fuel could be stolen from nuclear waste storage facilities, and used by terrorists to make dirty bombs that could render a small city completely uninhabitable due to radioactive nuclear waste being splattered all over the countryside. So what's the story on waste disposal.

Mark: So first, I have to talk about those 55 gallon drums. Highly radioactive nuclear waste does not sit in those. Highly radioactive nuclear waste sits in containers so thick, so strong, so sturdy, that specialized ultra strong machines are required to move them. And I have personally gone and hugged, put my arms around and put my body next to these giant nuclear waste containers while holding a high end dosimeter on my core over my heart, and I've gotten no notice, like not even a registerable amount of radiation. So the 55 gallon drums are a favorite of stock photos and of immoral publishers at newspapers because they're bright yellow and they can scare but in reality, those don't exist or where they do. They are used to contain radioactive waste so harmless that it is an actual moral and engineering question whether they should be counted officially as radioactive waste at all. Certainly, they're often less radioactive than chemical wastes that are not considered radioactive and other industries like coal tailings, or other mine tailings. So the drums, we've dispensed with.

In terms of the this being in the perception category, rather than the real category, I think itself is quite perceptive of you Erik because the nuclear waste itself when handled properly, which has been almost continuously in the history of civilian nuclear energy, has not caused any deaths or injuries ever, with one of the only possible edge cases being the safety culture issue at the nuclear fuel reprocessing plant in Japan, where a poorly trained worker undergoing a bad process hurt himself and died from radiation exposure. So unprocessed nuclear waste has not harmed anyone nor has there really been allegations of such real or not. That's because there's almost no access to this waste by civilians. And so people who are against it often don't even know what it looks like, or how to describe it, or how to even start explaining to people their physical fears. It's a phantom fear for this reason, that if you ask somebody who doesn't like nuclear waste, to describe for you what nuclear waste looks like, and what form it takes 99 times out of 100, they will struggle severely need to consult sources and suddenly be confronted for the first time ever, that nuclear waste is not in a 55 gallon yellow barrel with a nuclear symbol on it. Let's talk about two approaches to waste handling that I've seen in my time so far. One, each nuclear plant in the US has some area on site with large concrete drums that are about oh, I'd say they're about 12 to 16 feet tall. And inside of each of these is a thick steel canister. And inside of that are several spent fuel bundles that have spent, I'd say four to five years in a reactor followed by four to seven years in a spent fuel pool just getting cooler and cooler and cooler. Slightly heating up that water inside the nuclear plant in the pool, but just very easy to cool you could get a bucket and keep water covering those in the event of a of a emergency loss of power. So it's a very low energy crisis if you lose all power and have to refill the spent fuel pool. Now that was one of the greatest fears in the aftermath of the 311 events over at Fukushima Daiichi, there was a panic around the world that the spent fuel pools that needed to be replenished, would boil off and the nuclear waste would spontaneously heat up and catch fire, and it would pollute everything down to Tokyo and cause millions of deaths for mass evacuation. That was bullshit, it was always bullshit.

And this gets us to the 1 million years of radiation. Erik, if something is radioactive for a million years, it's not very radioactive, something you have to be scared of, or things with a half life of minutes, days, hours, weeks, or even a few years, that can be very dangerous. That means you have something breaking down extremely quickly, and therefore putting out radiation. If somebody claims to be scared of millionaire radiation, it means you're dealing with somebody who does not have a concept of what radiation means of what radioactive decay means. And they are likely to be walking around granite buildings with radiation as high as about, you know, the last 600,000 or 700,000 years of that radioactive decay that they claim to be afraid of. And that they're encountering that by walking around, say high altitude environments, taking a flight, walking next to granite buildings. And yet they claim that that same level of radiation that they would experience walking next to granite would be their fear for hundreds of 1000s of years, and that it needs special warning. That demonstrates you're talking to somebody who you do not share a physical understanding with yet. And either you need to gain a spiritual understanding that makes them feel better, or you need to slowly explain the physics. Either way, you're not dealing with somebody who's scared of nuclear waste the reality, but instead nuclear waste, the perception. So what are we going to do about it? For me, there's one important way forward, call it the Dutch solution, or going Dutch with waste. Perhaps if we're going to we're going to say it with a smile. So Netherlands has one reactor, it's not too big. It would be called an SMR, small modular reactor if it were made today. But it is a German design reactors, Siemens and I visited it, I've gone inside containment during operation. It's a little gym. It's absolutely fantastic. And they run a great facility, the Dutch. They even have really cool work clothes, they're bright orange, and they fit quite well, as opposed to many of the shift clothes that they have in American plants that are baggy and just a terrible look. So the Dutch look good while making nuclear energy out of a beautiful reactor. What do they do with the waste after a few years in the reactor, and a few years in the spent fuel pool, they send the waste packaged up in an impenetrably strong container over to France were in a large facility. France recycles the waste. What does that mean? They open the travel container, they pull out the waste, they chop it up to get the fuel inside the fuel rods out, they dissolve it in acid, they then use a chemical process to separate out the uranium and the plutonium and the fission products. What are fission products? Those are the smaller particles, particles much smaller than uranium and plutonium that come from breaking apart uranium as the reactor operates.

So these fission particles tend to be much more radioactive than that uranium plutonium that they're separated from. These highly radioactive fission products are then put in a glass block in a glass cylinder that's packaged up and that's returned to the Dutch. So fission products are not going to be radioactive for a million years. They're going to be highly radioactive for a few 100 years. The fission products are then put in these tall columns in a very large, strong concrete building. That is then painted beautifully and opened up to school kids so they can go on science tours. That's right. The Dutch have made a museum touring experience out of their nuclear waste storage. They have put a fantastic museum up front where they have examples of radioactive consumer products that used to be made before the nuclear era donned. Radioactive medicines, radioactive plates, radioactive scientific instruments. Then my favorite part of the museum tour. They have a cloud chamber where they show you the fabric of the universe in front of your very eyes. You see cosmic rays shooting through in a dark room, you're looking into this glass cube, where you can see because of the illumination in the cube, making any bubbles that happened to come and that cube show up cosmic rays shooting through cause condensation, they cause a little bit of bubble in the container. And it certainly makes little droplets. And you can see cosmic rays going through your body through the cube and into your friend, you can see much fatter globs of bubbles come from larger, higher energy particles breaking apart from say, if you put a thorium lantern mantle in, you can see the radiation popping off. So they're able to instruct in alpha, beta, and gamma radiation, the three main types that you're dealing with when you're protecting against nuclear waste, and then after showing children in front of their own eyes, the actual radiation popping off and then universe and off of consumer products, then they take everybody and tour you through the facility itself, showing you the protection against the radiation that they showed you in front of your face in the museum. It's a stunning display. Oh, and they have, they have radiation counters for those who want them, you can wear them, those who don't care, you don't have to wear them. And on this tour, you see how they handle low level, medium level, and finally, most fascinating the the high level nuclear waste. In this high level nuclear waste facility, there's a three foot thick door that slowly rolls open, then you climb over some steps. And you can see down this long haul all of these circles in the ground. These circles in the ground are the lids above the columns of nuclear waste. If you put your hand on the red painted floor around them, you feel heat rising up from the floor, just from the hot air circling through naturally into the building and out the out the stacks above that cool this nuclear waste. So the Dutch technique does not stop there. The Dutch approach just doesn't stop there. The Dutch approach is a social ongoing process where every 20 years or so they're going to hold key meetings to see what the public thinks and what scientific experts think about the next step. What's the next step? Oh, well, maybe they'll bury it in the ground if people want to. It'd be expensive. Maybe they will. Maybe they won't depends on what people want. But they show every day the active protection of health and safety within an entertaining, fascinating pro-nuclear energy tour.

Erik: Reminds me of a Saturday Night Live skit. Daddy, Daddy, what's that big building? Well, that's the nuclear waste facility. And mommy says no, actually, that's a theme park for kids. Wait, it's both a nuclear waste facility and a theme park for kids. It's fascinating that they've taken that approach towards education. Mark, there's a distinction that I just learned this morning from a Twitter thread that you sent me, which I think is, for me at least was really the breakthrough in understanding this. Let's talk about the high level nuclear waste that comes directly out of the reactor out of the cooling pool in the reactor building. That's known as high level waste. And it is very dangerous to human beings when it comes out of the pool. That's a fact we don't want to deny that fact. Another fact is that that stuff stays radioactive for millions of years. And that's what freaks everybody out. The thing they don't tell you at the anti-nuclear rally is what about after 50, the first 50 of those millions of years have gone by? How dangerous is it to humans at that point. And for the remaining 999 million years, you know minus 50, whatever the total half life is.

Mark: After 50, you would have to work quite hard and get access to unshielded waste to get injured. Which I mean, if depending on how you want to think about it, if you are inclined to fight nuclear energy for any reason, and you are looking for an excuse, that would be your way of saying well, that proves we can't we shouldn't do it. If you are actually curious about nuclear waste, it's relative danger. And you can accept that we've protected people against this 10, 20, 50 are nuclear waste now in the first 70 years of the nuclear era, and that there's no indication is getting any worse. And that the quantity of energy we get from each bit of nuclear waste is extreme. Each individual person share of that high level waste that's still dangerous if unshielded at 50 years, is so small to take care of all of their energy needs. That you almost have to be working on ignorance or bad faith. To say that a tiny amount of fuel that if shielded even a bit of 50 years protects people that that's unacceptable. For everyone else who's able to see a danger or understand a danger and then accept it. I think that learning the actual level of danger at 50 years and seeing that we've successfully even easily protected people from that without having to build any giant underground repositories yet, that should be a big confidence builder for people in nuclear for the future.

Erik: The point I just want to make sure is clear to our listeners is after the first 50 years of those millions and millions of years that you hear about, 99% of the radioactive decay is over and done with, there's only 1% left at that point. So although it is true that it stays radioactive for millions of years. The amount of time that it needs to be stored to get it down to the level where it's no more dangerous than, you know, any other kind of waste from a chemical process is not millions of years, it's more like 50 years.

Mark: Except can I put in a good word for the waste. The radioactivity itself acts as a characterizing warning sign, it tells you what's in there with either in cheap, easily available handheld measuring devices. Chemical wastes are often much more difficult to detect or understand as a danger. Nuclear waste has a self advertising property to it where you can't have the radiation happening without being able to detect the radiation, if that makes sense. It tells on itself as the kids might say. That's a very special attribute of this small amounts of high level waste that's actually there. The high level waste is 1% or so of the total nuclear waste, while being above 90% of the total radioactivity. That means the amount that's dangerous, is small enough to easily handle with reasonable budgets obtained from very light taxation of nuclear plants as they operate.

Erik: Now, let's move on to nuclear weapons proliferation risk. The nuclear industry is fond of pointing out that the low enriched uranium fuel used in power generation could never be used to make an atomic bomb, which is true. But I think it really misses the point. The argument that's been made by critics is that once a country has the centrifuges that are needed to make low enriched nuclear power plant fuel, it's not too hard to spin those same centrifuges a little bit longer to make or a lot longer actually, in order to make weapons grade uranium. And still another argument is that a byproduct of the nuclear power generation chain reaction is that it creates plutonium 239, which could be concentrated into purer form and in order to make weapons grade plutonium for a atomic bomb. So what's the story on proliferation risks?

Mark: Nuclear waste is not a good source of proliferation risk. For one, countries are in two categories. Those with nuclear weapons and those without. Within the nuclear weapons category of these nine, there are those who are the original havers of nuclear weapons, which means they're in a special kids club, they get to eat at the adults table, they do not have to undergo inspections of their facilities for proliferation reasons instead, they are the ones that help undertake the inspections of everybody else's facilities, those who don't have weapons. Now, of the countries that have that centrifuge technology, almost all of them are ones with nuclear weapons. One of the only cases where this isn't true, is Iran, which is why we hear about Iran around the news in half for a decade now. They have centrifuges. They say it's their right to have them under international antiproliferation law, which is technically true, but then they do not want so many inspections. And they want the ability to have the materials such that that extra spending time you talked about the extra centrifuge time is as short as possible to make material that could plausibly then be used in nuclear weapons. So Iran is at the center of this argument. But there's such a limit on countries having an excuse for these enrichment devices and access to them, that that's what makes Iran a special case. Other countries that proliferated tend to do it without enrichment. Instead, they used fuel coming out of very specific reactors, not power reactors, reactors designed to produce fuel for nuclear weapons or alternatively, reactors not meant for power, but for research purposes that were abused to make material for nuclear weapons. This all should indicate there's a relatively weak connection between nuclear infrastructure for civilian power and the choice to proliferate, which often doesn't even use the same equipment. I will argue in defense of the people, the anti-nuclear folks who say they're worried about proliferation. Administrators, scientists, and engineers sophisticated enough to run a nuclear energy program are likely to be sophisticated enough to if the desire is great enough work towards a nuclear weapons program. Here's another way to put it.

Almost every single country that has nuclear energy, worked on a nuclear proliferation program at the same time that they built their plants. So countries like Sweden, or Spain, or Finland. All of these countries got nuclear reactors during a period when they were also working on nuclear bomb projects. The vast majority of them gave up the nuclear bomb projects while keeping the nuclear energy. That's perhaps an issue for a longer discussion. And the reason I'm saying all that is because the urge to protect oneself to protect one's economy from manipulation from trade blockades of fuels, to protect oneself in the case of war, those are similar instincts. And it's not clear that the nuclear energy is the path towards the desire for the nuclear bomb, rather, that the desire to protect one's home and hearth leads one towards nuclear technologies, even if there are very different paths towards the defense and the civilian energy. The feeling is so safe, that you don't have to protect yourself with either nuclear energy or nuclear bombs, leads to a Europe where America's Protection of Nuclear bombs over Europe led to an environment so safe, that not only did countries give up their nuclear weapons program, which of course, reduced proliferation. But they eventually gave up their own energy supplies and got natural gas from Russia instead, completely forgetting any good sense of history of self preservation or of being good neighbors. So I don't know exactly whether you can say that. No, there will never be nuclear proliferation ever again, in world history, just that a feeling of security leads to countries maybe not wanting nuclear energy or weapons, and a feeling of insecurity can induce directions towards both the overlap between the two is the weakest part.

Erik: We've covered the perceived risks of nuclear technology Mark. Let's move on now to the actual real risks that you perceive to exist even though the anti nuclear lobby is not talking about them.

Mark: It is a fundamental fact that nuclear energy takes a lot of talented people cooperating over long periods. If there's not enough talent people, talented people. If there's not enough trust and cooperation, if there isn't excellence to be had in either government or private industry, then nuclear is just maybe too hard to do. And countries are not going to be able to do it. They'll get whatever you get if you don't get nuclear, but they won't get nuclear because it's too hard. An example I'm thinking of as I sit here in downtown San Francisco, construction projects in San Francisco are chaotic wrecks. Things like putting in a bus lane can take 10-15 years and hundreds of millions of dollars, putting in a bus lane and making it red, putting in signalling lights, that can lead to hundreds of millions of costs and a 15 year process to get it done. But one of the classic examples people bring up is that Golden Gate Bridge, one of the masterpieces of engineering in all of world history. Both in terms of beauty, utility, and design excellence only took a few years. Came in on time and on budget for an inflation adjusted cost of a few 100 million dollars during the Depression. So they did it without computers and they did it without cell phones and the project broke new grounds in worker safety. The guy who led the project wasn't brilliant at designing bridges, but he found brilliant people. But he was brilliant and pushing for worker safety and building a net that caught workers as they fell. There were almost no casualties on that bridge, extremely unusual for construction projects at that time in America. And it would be unusual even in some countries for large construction projects today. So how did we go from being able to build that bridge so quickly and so well, to construction projects of any type taking an extremely long time and having risks of not being ever completed? That is something nuclear will have to deal with no matter whether you have SMRs or you have small reactors or large reactors if you claim your reactor is going to be built in a factory and shipped at the site. Every different design is going to have its own challenges and will require talent, excellence, some amount of patience, and courage to get going after our existing construction projects have been so far behind. Nuclear involves people, it involves trust, nuclear is as big as society. If you cannot ask anything of society, and you cannot count on society, then it may become difficult to count on nuclear.

Erik: Mark, are there any other real problems that we need to understand relative to nuclear?

Mark: Yes, there are some countries building renewables so quickly that the business model of building nuclear on the grid may be itself disrupted without actually leading to a good outcome for the grid if the nuclear isn't there. So for example, there's a claim now that there is no such thing as baseload energy needs, because we have power plants that deliver energy from the wind or from the sun, and they deliver whenever they want. And because they've already been built, or they're so cheap, we're going to keep building them. Any power plants that get built to deal with the gaps in the solar and wind must have a self sustaining business model that works around the solar and wind. So the claim is perhaps that natural gas turbines were most of the cost of running a natural gas turbine is the gas you burn itself. And therefore, if you don't burn gas by turning the turbine down, because the wind and the sun are high at the moment, that it doesn't destroy the economics of that gas plant as badly as it would of nuclear plant, because almost none of the costs of running a nuclear plant is the fuel. T hen turning down a nuclear plant that barely saves fuel, and it saves almost none of the costs of running a nuclear plant. So it's hard to imagine that a nuclear plant can be requested to turn off repeatedly for other energy sources and still stay in business. However, if the nuclear power is so valuable in the times that wind and solar are not producing sometimes across entire continents or hemispheres at a time, then the nuclear plant may have a business justification, so long as a new technology that provides enough of the advantages of nuclear does not arise. So one of the technologies that people have spotted coming is from a company called Net Power. They have a revolutionary type of natural gas turbine that operates in a different fashion from existing turbans. It takes in natural gas into the turbine into an environment of concentrated co2. It burns the methane, the natural gas within that co2 environment, and just creates a bit more co2, the turbine spins efficiently makes power, and then you just bleed off extra co2 into a pipeline at high purity and that's your waste product. So a natural gas turbine like this actually working well. And provided you have a way to use that co2 or take it away or deposit it in the earth with high assurance that could give countries who simply do not want to entertain the thought of nuclear or have gone so far down the business path of intermittent wind and solar, that they cannot justify nuclear for the time being. It may give a path around nuclear for those places that are able to make those turbines work and are able to dispose of the co2. And crucially, we must mention in the middle of a global natural gas crunch can get the natural gas needed for the hours of the year for the chunks of the year, where wind and solar isn't sufficient for needs.

And then there's one more. One more way I see nuclear going very badly. If we have so thoroughly damaged our energy supplies, which had been steadily growing and growing and growing and growing for 100-150 years. If we damaged our energy supplies in such a way that we damage our wealth, and the societal complexity that you mentioned so eloquently in your in your opening Erik, then we may not be rich enough for the upfront costs of doing nuclear, and like a parent sitting on an airplane that is not able to get their own gas mask on before helping a child. If the rich countries don't have the capital to help themselves, they may not ever have the capital to help poor countries develop. Rich countries got rich on coal, oil, nuclear and hydro. If we have denied all those things to poor countries, and therefore do not put our own gas mask on our own oxygen mask on soon enough, we do not secure our own source of abundant wealth by building energy like nuclear. It may be that nuclear has less of a future because we and complex society has less of a future. Some issues I'm simply not concerned about is the quantity of uranium or plutonium or thorium. Those materials are present in our Earth in such a quantity and we need so little of it to run a large nuclear plant, that the exploration and finding of new uranium will be sufficient to run nuclear plants for an extremely long time. Even if that nuclear fleet expands to cover much of the world's needs.

Erik: Mark, something that occurred to me as you were speaking, that I think is really important to understand. First of all, my thesis of how this is going to go down is I don't think we ever get to nuclear energy until we get to the point where there simply is no other viable alternative. And that's not because it's not a good choice. It's because unfortunately, there's so much fear and emotion in the system, that I just don't think that public policy or public sentiment is going to be willing to accept nuclear until we get into the energy crisis that I think is coming as soon as the recession that's about to start is over. And as you point out, there's a risk that we get into this situation where the recession is so bad, that it's difficult to make that investment in nuclear. But I want to also put this in perspective, in terms of time. I think that we're going to get to the realization that, oh my gosh, we've got a real energy crisis, we're going to have to really invest quickly in trying to increase our oil and gas production capability. But it's still not going to be enough, we're going to need nuclear, and we're going to need it right now. And the problem is, you can't have nuclear right now. You can make a decision to make a strategic investment in nuclear power as the future. And then it takes about 20 years to build it out before it's really a solution. Is there anything that we can do in order to have nuclear be more helpful sooner because frankly once we get to the energy crisis that I think is coming, we're going to need a solution that's within, you know, a year or two, not within a decade or two.

Mark: Well, I think of a poem from the 1800s, "Where there's a line for all sad words of tongue or pin, the saddest are these, it might have been." It is maddening to watch videos of Liberal Democratic Party leader Nicholas Clegg from the UK, who entered government with the Tories back, you know, 12 years ago in 2010 I believe who claims and you can see these on videos, that you shouldn't build nuclear, because it won't be available until perhaps 2022. Well, the UK has a horrible energy crisis now here in 2022. It was more or less okay on energy for the first half of 2021. And they had more than enough energy in 2020. So in two years, that comment has gone from looking decent to being a farce and a dangerous one at that. So I think it is interesting that nuclear does take time. And in terms of surviving, surviving a severe drawdown in energy supplies, in order to just come back later with nuclear, I think it will be possible, and that maybe that's a little bit more optimistic than I was before. I think watching the degree that people who have to suffer, can suffer in Ukraine and surrounding countries to make it through this war of invasion from Russia. I think people have a capacity to suffer, that's much higher than we might give them credit for, if they know why they're suffering, and they see a light at the end of the tunnel. I think nuclear will have the ability to give hope that even if there's turmoil and hardship and anger at depravations from the energy crisis, one thing that will provide hope and political consensus in countries otherwise torn by disagreement will be the need to move towards nuclear. Will that lead to projects in every country? No. But in the countries that do get nuclear progress, prosperity will be restored faster than those that don't. And the rewards of getting a nuclear plant project off the ground will increase. And it will increase the relative disparity between countries that do make the decision to move towards nuclear and those that don't.

We're going to see a wave of countries that started nuclear before this crisis, get their nuclear plants. They will be very splashy turning on moments. COP28, the climate conference next year in the UAE will heavily feature that countries now long sided precious nuclear energy program. One that was attacked by many people in foreign press, who were claiming that UAE just wanted a nuclear plant for strategic reasons or maybe they were working on a weapons program or maybe they're trying to get an edge over neighbors, whatever it is. That program was started on the right time and has been completed in a timely fashion. And it will serve as a beacon of hope to other leaders in the world who are going to come into power after those governments that ushered in the energy crisis fall. So a little bit of cynicism and pessimism and optimism mixed together, Erik. But I think that after UAE, as countries like Turkey, and Bangladesh, and a few others bring online their Russian reactors, it will become abundantly clear to the non-Russian world, that to be on the same level, to be able to offer something to countries that are getting those reactors from Russia, it will not be enough to make moral statements against Russia. You'll have to provide excellent nuclear products yourself and that will lead to a push of those countries getting the same at home.

Erik: Mark, we spoke earlier about the problem or perceived problem that nuclear waste pose. I want to return to the nuclear waste topic now, but from a completely different perspective. And that's the perspective of opportunity. There's a new process or relatively new process that the whole industry understands. But to my understanding, at least so far, only the Russians have actually demonstrated and proven it in practice. The gist of it is that all of the spent fuel that's in storage from the last 50 plus years, or I guess it's 70 or so years of nuclear power plant operation around the world. All of that spent fuel isn't really spent is somewhere between 1% and 10% of the energy in that fuel actually got spent in those early generation reactors that are not very efficient. At least 90% of the energy is still in the fuel. And it can effectively be recycled to make new fuel to power new reactors. Now, to my thinking, the profound benefit here is that it seems to me from a PR perspective. From a public perception management perspective, you could roll out a plan that says we're going to bring on new nuclear power plants in order to meet the next 20 years of our energy needs. And in the process of doing that, not only are we not going to increase the total amount of nuclear waste storage globally by one pound over that period. But we're actually going to reduce it, because these new generation reactors are going to burn a new kind of fuel, which is actually made by recycling the old fuel. But there's a downside to that, which is if you've got the technology, so to speak, that you know how to run that recycling process, that gives you the ability to transform spent nuclear waste into new nuclear fuel, then you probably also have the technology to turn it into weapons grade products. So that means you've got a proliferation risk. So this new process to me sounds like it's a godsend if it stays in trustworthy hands. And the bad guys are somehow never allowed to get a hold of it. But right now, it sounds like the only people that are really leaders in this space just happened to be the Russians, which is kind of inconvenient for the West given present foreign policy. So Mark, please tell us the pros and cons of this new idea of or maybe it's not that new, but the approach of recycling existing nuclear waste both to get rid of it, and to make new fuel so that we don't have to continue making more and more waste in more and more waste storage sites around the countryside.

Mark: I'll have to introduce a new term here, fast reactor. Now fast reactor is short for fast neutron reactor. And what the fast is referring to is that in these reactors, you do not put in materials to slow down neutrons so that they collide with atoms of uranium at a slow speed. Now, there's some quantum weirdness here, but neutrons running into a uranium atom at a slow speed are actually more likely to split it then if they run into a uranium atom at a medium speed. Up at higher speeds, there's a maybe not as high chance of splitting but higher chance of the splitting causing more neutrons to come out upon hitting any given uranium atom, whether it's the type of uranium atom that's easier to split or harder. So all of that to say you can design your reactor to take advantage of the properties have extremely fast flying neutrons in the core. These fast neutrons can do things like hit uranium, bump it up, to plutonium and then split that plutonium or you can hit thorium with the uranium bumped that thorium up to very briefly protactinium and then that protactinium naturally breaks down quite rapidly into Uranium 233 and the next neutron that runs into that uranium 233 is pretty likely to split it into smaller bits and tons of energy. So these fast breeder reactors so called because they breed more fuel, usable fuel than what you put into them originally are what Russia has developed out at one of their sites in Belaya. Now, tons of countries were working on fast breeder reactors just off the top of my head. Here are countries that had operating fast breeder reactors, USA, United Kingdom, France, I believe Germany may have had something at some point Japan definitely did. India is building one of these facilities. China is building one of these facilities with Russian help.

So it's something we've known it has existed since the dawn of the nuclear era. One of the reactors that first actually the reactor that first ever powered a light bulb string was one of these fast reactors and if fueled properly. Could have bred more fuel in a sustainable way then it burned. Now, the Russians have just started up their newest version of this reactor with a load of MOX fuel. MOX fuel, mixed oxide. So this is plutonium and uranium from separated out processed nuclear waste that have gone into that reactor, and will be run for a long period of time making and using fuel as it goes. This is you might say, the holy grail of energy on this earth for humans, if we're not able to get fusion to work, and potentially even if we do get fusion to work, and it's just not a very effective way to make energy because it keeps shutting itself down, or it's hard to maintain, or it's a pain in the ass. So, fission running off of fast breeder reactors can be so light on our existing uranium resources, it can make use of our existing spent fuel, the material still in our spent fuel, that we can run the entire global economy off of nuclear energy from spent fuel for something between a few centuries to a few 1000 years. If we have a total recycling process that squeezes all the good out of each bit of fuel coming out of these reactors and our existing fleet and putting them in to these new reactors. You would probably need to switch to a reprocessing method that does not fully separate out uranium and plutonium, that would be best. Even if you did use recycled, spent nuclear waste from today's reactors. The plutonium is not going to be super effective for high yield nuclear weapons. There's debate out there about whether you could make a little one that would pop and do a lot of the fear mongering. And if that would have as much impact as a larger one that actually did have a bunch of explosive power. But the main point is countries that are attempting to proliferate, would not optionally choose the spent nuclear waste reprocessing as their path to do it. Even if they if they had the facilities to do that they would want to use specially made nuclear waste specially operated reactors that are not the same as energy reactors. Having said all that, it is physically possible. And eventually, I would think necessary, and it's going to happen on this planet that we will run reactors with these ultra efficient, continually reprocessed fuel cycles, in which case you would not just get 1, 2, 3, 4, or 5% of the energy out, you would get the proverbial 90-95% or more energy out of each atom of mined uranium from the earth.

Erik: Mark, one of the reasons that the 1970s nuclear energy build out in the United States failed to deliver on the promise of making electricity cheaper, is that large bespoke nuclear power plant construction projects were plagued by massive cost overruns. If you fast forward to today, as we discussed earlier, little has changed. The cost overruns on conventional nuclear reactor builds in the states of Georgia and South Carolina, literally bankrupt Westinghouse in 2017. Westinghouse is the biggest manufacturer of most of the existing nuclear power plant fleet. Necessitating its recent acquisition and bailout by Brookfield and Cameco. A lot of people are saying that the solution to these problems is to move away from conventional nuclear plants and focus instead on a trend known as SMRs for small modular nuclear reactors. The idea is that instead of building a gigantic gigawatt reactor like a Westinghouse AP 1000 that has to be assembled on site in a gigantic public works project like Vogel in Georgia. You could instead design small modular reactors of say 100 megawatts of power generation capacity which are built and tested in a factory and which fit in the form factor of a 40 foot shipping container. So if you need 1000 megawatt generation capacity, which would be equivalent approximately of a Westinghouse AP 1000, you just order 10 of these modular 100 megawatt units, and they'd show up in the form of 10 shipping containers that show up in 10 trucks. You don't have a gigantic construction project, all you have to do is hook them up, wire them together, and you've got your 1000 Megawatt or Gigawatt power plant. A lot of people seem to think that SMRs are going to be all the rage and the way of the future, I was surprised to learn off the air that you're actually a skeptic of that sales pitch. So Mark, what's your take on both sides of this story? First, tell us about these SMRs, what they are, why other people think they're the way of the future, and then explain why you have reservations about that approach and actually favor conventional nuclear over SMRs for most applications.

Mark: SMR is a marketing term that does not guarantee whether a reactor is small or not. Doesn't really guarantee whether it's seriously modular or not. And so therefore, the blanket phrase SMR can hide products that are just very bad ideas, badly designed, and would probably be badly implemented, while making other reactors that are effectively going to lead the nuclear renaissance if it's going to happen. And make them look not as cool because they don't look as modular they don't look as small or they... So let me give you an example. If you can build a large reactor quickly and effectively that will probably make cheaper energy than a small modular reactor that is multiplied several times to make the same capacity. But we here in the West have mostly lost the ability to build such reactors. Now, we might have re-learned enough lessons at Vogel that we could do some large ones. But if you wanted to get reactors from Koreans, or the Chinese, or the Russians, they will be able to sell you a reactor that is both large and built reasonably on time and on budget. Whereas they would probably advise you that smaller reactors, you'd better have a really good business reason you don't need much power, or your grid maybe isn't up to stuff. Because as they're capable of building large reactors, they themselves can see that the smaller ones are more expensive per unit energy over the longer run. Having said that, America needs to re-learn how to build and there are lessons and insights in shrinking reactors back down, that may end up making higher quality construction projects, higher quality managed projects that lead to a resurgence nuclear building in the US. One of the fastest things that you would probably see is upsizing the reactor core of those to make a little bit more power. Where that works, what you see is why we made the reactors larger in the first place. Why we went from reactors of 30 megawatts up to 300 megawatts and then to 1500 megawatts. Why did we do that from 1960 to 1980? Why did we continue to operate reactors? Because if you know how to build a plant, one of the easiest and fastest things to make more power is to just increase the diameter of the reactor just a little bit. And there's a sort of a cube power law that comes into play and in making a higher power plant without making it much larger. And we would be doing that as soon as we learned how to make the small modular reactors. In fact, some of the most talked about SMRs are as large or larger than the existing large reactors that were built back in the 70s. And you have to ask, were the ones in the 70s, if we were to do that exactly again would they count as SMRs. What exactly is it that makes it an SMR? Now, you could say you build it in the factory, but almost no proposals from SMRs. Or that perfect vision you see where it comes in individually packaged vessels. I am suspicious of anything claiming to be that small, while that high power, that sounds to me, like great compromises have been made somewhere in the engineering. But if people can make a strong case and show how they can do it safely, we'll see the history of nuclear has been taking a little bit more space, a little bit more complexity, a little bit more effort and finally more cost than you expected to just at the design level of the nuclear engineers working on a project. Does that make sense?

Erik: Absolutely. So your take here is that SMRs are more marketing than reality, but with respect to...

Mark: No that phrase is a dangerous marketing phrase that is used irresponsibly, but some of the projects not all of them. Some of the projects that will lead the resurgence of nuclear in the West are currently marketed as SMRs next to other reactors that will not lead the resurgence in the US. They will be unsuccessful business ventures, and that the biggest step is accepting that nuclear is worth exploring. And then the next step is putting together an appropriate project for the place that you're building it, for the country that's undertaking it, for the companies involved that may or may not be an SMR. And it may or may not be an SMR that's considered advanced versus old school, shall we say. One of the most promising SMRs for example, is the General Electric Hitachi BWRX 10 boiling water reactor. It is a relatively straightforward evolution of technology we already have today, of supply chains we already have today, and uses a straightforward evolution of the reactor safety case. The licensing safety case of plants that have already been given licenses to be built or even to operate. So it works with the society we have, it should work well with the industry we hope to rebuild. And that's not as assured for the more exotic or more, you might say, innovative reactor designs that people propose.

Erik: Okay, so the message really is do your homework and don't get sucked in that just because it's small and modular, that makes it a good reactor. What about the idea of building the larger plants by creating modules in factories with high quality control and assembling them on site rather than actually building them on site.

Mark: This is in fact the way we've built reactors for as long as we've been doing it. Russia has massive assembly lines where you can see a line of reactor vessels being formed and being prepared to ship to site. Russia can then choose between its many projects that has going simultaneously to make sure that optimal time to build is being achieved at each one by sending reactor vessels where they're needed most. I've even heard of examples where they've sent a reactor vessel to a site, they accidentally dropped the reactor vessel a few inches onto the ground, it spooked a customer and the customer requested a new reactor vessel, and then they were able to change out the reactor vessels between projects and get them both installed into plants that are about to be turned on. So that that is an interchangeability of parts that actually has been a feature of nuclear for a long time. It's just the Construction Management, the integration, the licensing, and the societal pushback, all combined in toxic ways to produce very slow construction and completion times for the last wave of reactors in the late 70s, 80s, and early 90s in a lot of the West. In Japan actually, I know I've talked about the problems with the safety culture there. But in terms of construction, large modular reactors were created in the 90s in 36 months at existing plants. 1300 megawatt reactors built in 36 months from first concrete to turning on and first nuclear reaction. 48 months when you include the time to enter full scale commercial power generation to sell electricity on the grid. That time would be considered very good by an SMR builder, except the SMR builder is going to have a lot less power at the end of the construction. This doesn't mean we can skip SMRs here in the West if we've gotten bad at building the large ones. I have to emphasize though, countries building nuclear programs that are life or death, are choosing the plain old standard large reactors on sale from vendors who know how to build them or have recently built them. That doesn't mean that countries won't come to rely on the SMRs to but countries faced with making ultra high stakes decisions that need the lowest amount of innovation, the least amount of risk in the product they're buying are choosing the reactors that SMR language is coded to attack.

Erik: Mark let's move on now to a collection of topics known as advanced nuclear. The nuclear reactors built in the 1970s are known as light water reactors because they use what's essentially regular everyday water as the moderator for the nuclear chain reaction. Listeners who are interested to learn the function of a moderator in a nuclear fission reaction can refer to the resources that Mark discussed at the beginning of this interview, which are linked in your research roundup email. There are some newer and better designs known as heavy water reactors, molten salt cooled reactors, and liquid fuel Molten Salt Reactors. But before we dive into those, let's first discuss what was wrong with those early generation light-water reactors that had to be pressurized in order to operate the nuclear fission chain reaction at super high pressures. So what are the pitfalls of that approach and why do we need something different?

Mark: Well, Erik nature abhors a vacuum and a relative vacuum is created when you have a highly pressurized bottle and a low pressure atmosphere. If you put too much heat in to a nuclear reactor under pressure and a leak develops or somebody crashes a missile into an occupied nuclear plant or something like that, a violent depressurization, that is water under heavy pressure bursting through a pipe and flashing into steam can disperse radioactive isotopes if there have already leaked into that water if there's already been some fuel damage or a meltdown and be dispersed out into the atmosphere. The reason why these Pressurized Water Reactors and boiling water reactors which are another type of water reactor under pressure have such strong containment domes is to contain within them the largest possible leak of pressurized water into this space under the containment dome. So the thought goes if we use fluids, heat transcoolants, and moderators in reactors that are not needing to be under severe pressure, then you remove an entire type of accident that comes from the interior of the reactors being at a higher pressure than the atmosphere. In which case you could dispense entirely if you trust your engineering, you could dispense almost entirely with a tensile strength hardened Pressure Vessel and you can just have armor around the reactor just protecting from external objects crashing in. In fact, the thought that the Fukushima Daiichi design had enough of that protection around the reactor itself because of the low pressures inside, relatively low pressures inside was part of what led to a somewhat weaker containment building that was then breached when there was a hydrogen explosion. So these are definitely things that you would look at step by step and a safety case for the reactor. But it is true that if you have a sodium cooled reactor and the sodium is at atmospheric pressures, even if it's at several 100 degrees hotter than water. That is going to lead to different and possibly reduced maximum accidents compared to Pressurized Water Reactors.

Erik: Something I really found interesting as I learned it recently Mark is the use of water as the moderator in the reactor. It seems to most normal people like water is super safe stuff. We use it to put fires out with and of course, you have to stop and remember the chemical formula for water, h2o, that's hydrogen and oxygen. Hydrogen is the very explosive gas that was in the Hindenburg. Oxygen is the stuff that makes everything burn hotter and faster. So you know, the last thing you want is hydrogen and oxygen, which is an incredibly explosive combination. Well, water is obviously safe. It's not hydrogen and oxygen, it's a combination. Those hydrogen and oxygen atoms are bonded together in a covalent bond that's so strong that nothing could break it apart short of oh say the neutron implosion of sustained nuclear reaction, which is exactly what's going on inside of a reactor. So what actually blew the roof off the top of the building at Fukushima Daiichi was when the water inside the reactor separated into hydrogen and oxygen and then exploded so getting the water out of or using something other than water as a moderator seems like a really good idea. What are the benefits of heavy water reactors and where are they used?

Mark: Heavy water is water that has as its hydrogen atoms, chubby hydrogen, deuterium that is hydrogen that instead of just being a single proton, and an electron is a proton plus a neutron and neutrally charged particle just as heavy as the proton. So what happens here is that it's a little bit less likely to absorb straight neutrons, meaning it reflects those neutrons back into the reaction and is therefore it's more stingy and less wasteful of the neutrons. This means you can run your reactor on lower radioactivity initial fuel. You can run heavy water reactors on natural uranium with none of the enrichment from the spinners that we were talking about earlier in the episode. This means you can make a fuel cycle independent of one of the technologies that is mistrusted for its proliferation concerns.

Erik: Okay, so if I don't want to let a country have the centrifuges, they could have heavy water reactors to make their electricity and they wouldn't need the centrifuges that might be abused in order to make nuclear weapons.

Mark: Correct but there's no free lunch. Heavy water reactors, as they exist today can be refueled without being turned off. That means you can put fuel into them as they operate continuously. This is a feature that could be abused to make materials that could be separated into uranium and plutonium later. So again, there's no free lunch here. And there are advantages to be obtained by putting in enriched fuel into heavy water reactors. An innovative startup company that I've worked with out of Chicago, Illinois. Clean core thorium energy is combining mainly thorium with a little bit of enriched uranium, in order to make fuel for these heavy water reactors that keeps all the advantages of heavy water reactors, but uses seven times less fuel. Now, fuel is not one of the major cost components of reactor. But if you have a drop in fuel replacement that saves a significant portion of the cost of the fuel over the 30 year life of one of those reactor cores, you could save up to a billion dollars or more just from the changing out of the fuel alone. And if you can do that with a relatively quick development period, and you obtain the enriched uranium to go in with the cheap readily available thorium, then you make a fairly compelling case for using enriched uranium in reactors that were originally designed to not require them. Then if if you're wanting to trust but verify that countries are not misusing their heavy water reactors for proliferation purposes, refueling the reactor seven times less will reveal if a country is starting to misuse the reactor and doing extra refueling. So you would be able to notice and monitor if extra refueling was being done. And if that refueling was being done with fuel that wasn't the long lasting thorium uranium fuel. So pluses and minuses everywhere. Nuclear really is the death of easy narratives in many ways. You almost want to run screaming back to just the basics, extreme energy density, ultra long lasting machines, almost all money to labor and operations rather than to materials harvested from the earth and steady, safe power.

Erik: Let's move on to the next one, which is the molten salt cooled reactor. You described previously, why it is beneficial to get the water out of the reactor so you're not using something that can separate into hydrogen and oxygen instead using melted salt, essentially, as the moderator for the nuclear reaction. What's the current status of molten salt cooled reactor development? Is this something that you can buy and use today and is it permitted by regulators?

Mark: No, you cannot buy an off the shelf reactor of this type. Now people cover a wide range of reactor designs and configurations with the phrase molten salt. Now, I like the fact that molten salt can operate at extremely high temperatures. I get a little bit uneasy when people suggest melting and dissolving the fuel itself into this molten salt because that takes one more barrier away between you and the atmosphere and your fuel and your fission products that are bouncing around in there by dissolving the structural integrity of the fuel form that would normally maintain all those fission products. So molten salt has this advantage. If you have any heat engine, any device like a power plant that operates at a hot temperature and puts out waste heat to a cold world, the maximum efficiency. The amount of useful work you can get out of the energy you put in is limited by how hot the hottest temperature of your devices and how much work you're doing at those high temperatures before you get waste heat. The hotter a reactor is, the higher the efficiency of energy conversion in that reactor. If you want to run industries that require hot temperatures, off of the pure BTUs, the pure energy coming out of these reactors, you will do best from an efficiency standpoint, and they're hopefully a cost standpoint if the reactors operate well, with having the highest possible temperatures for your heat transfer. That's going to come from molten salts. And it's not necessary to melt the fuel just to have the molten salt coolant. Those two things can be kept separate and I think that's where I'm most excited about Molten Salt Reactors. Their potential for use in high heat environments.

People can make arguments for wind and solar that I can accept. But one that I don't really care for is the idea that wind and solar are efficient because they don't have waste heat. But also we should use wind and solar for heat kneading industries. No if you don't have heat being generated that is a disadvantage for using that heat for industry. Nuclear plants that can operate at very high temperatures, and do it constantly will be superbly suited for decarbonizing currently impossible to decarbonize industries. Well, I shouldn't say impossible. But here's the idea for wind and solar to decarbonize some industries. You overbuild the wind and solar, when they're on, you convert some of that energy into hydrogen, then you store the hydrogen and transport the hydrogen and use that hydrogen burned at high temperatures for your industry. This involves so many energy conversions and so much loss. That is a preposterous proposal in many ways. However, if we can make these, although you can't order them off the shelf, there are companies in several countries working today on those Molten Salt Reactors. There are companies in the United States and then there are experiments going on with molten salt reactors in China that are considered to be on the cutting edge.

Erik: And I just want to put this in perspective for our investment centric audience, which is a lot of people seem to agree that molten salt reactors are kind of the cat's meow. It's really exciting stuff. It's a better way of doing things. However, the regulatory bureaucracy is apparently not ready to consider how they would regulate and how they would permit these things. So there are some companies doing really exciting research. Unfortunately, the investment play that says, let's build a company that's going to build all molten salt reactors and put them into production and deliver them and produce electricity with them next year. It's not happening and it's not likely to happen anytime soon. Is it just the United States or is it really everywhere that there's a regulatory barrier to the acceptance of this new kind of reactor and I shouldn't say new kind, this very old design which is becoming repopularized?

Mark: Well, it's yet to be seen what happens if countries come to nuclear under an environment of extreme enthusiasm at all levels of government society for nuclear. It is clear that the international community does have a say and does hold weight in how countries approached nuclear. For better or worse, nuclear is an internationally important industry. And the opinion of countries around the world will matter, especially if those countries are providing financial support, and regulatory support, and technologies. They're going to want to know that a receiving country is using that well. Some of the molten salt plays are coming out of Denmark is sort of a surprising location because of the famed wind energy program that supplies over half of Denmark's electricity each year. But that would be an example of Denmark suddenly getting excited about homegrown reactor technologies. And I think people will always feel more comfortable taking risks with something seen as their own. So, although I don't think of the SMR plays that I've seen, the molten salt are going to be first to come out, and they may not be as successful when they do. That's yet to be seen. I think that companies with crazy new ideas that are developing those within the culture of their homeland, may end up being embraced and be given a more gentle regulatory touch than outside technologies that feel like they were invented elsewhere, and therefore attract more scrutiny. In the past, America and other places have had reactor parks where almost anything that was reasonably safe could go reactors were built that were intentionally melted down just to see how they perform. reactors were built of a crazy variety in America and put into commercial operation in this first eager age of nuclear energy in the 50s and 60s and early 70s. If we get back to that pioneering attitude, we may find that reforming regulators enough to get faster progress on the more exotic and difficult to understand nuclear reactor processes. Molten salt fueled, molten salt cooled reactors would definitely fall into that category.

Erik: Let's move on now and briefly touch on the nuclear fuel cycle. I want to save most of the detailed analysis of the economics of the fuel cycle for my interview with Justin Hewn next week since Justin and I plan to discuss the fuel cycle in great detail, including how investors can position themselves to benefit from trends like underfeeding, giving way to overfeeding, which we'll explain in detail next week.

But speaking to Justin off the air, he suggested that I asked you to just lay the groundwork by explaining a couple of concepts. Natural uranium comes out of the ground with less than 1% of it containing U235. The isotope that's actually useful to make nuclear reactor fuel. The rest of it is U238, which is not really useful for producing a nuclear chain reaction. In order to get to enrich nuclear fuel that runs a reactor, you've got to go through first a process called conversion, which turns that powdered uranium into a gas. And then it has to go through a process called enrichment. The conversion and enrichment processes are of particular interest to investors, because a lot of analysts think that those processes are going to become bottlenecks, when demand for finished enriched uranium fuel products increases dramatically in coming years. So Mark, please explain why conversion and enrichment are necessary and how those functions are performed today.

Mark: The way most, almost all enrichment in the world works is that we use the difference in mass between U235 and U238. That is U238 has a few more neutrons in it, which makes it a little bit chunkier and heavier. But to be able to split those two things apart, you need to put them in a gas form to allow the U235 and U238 to bounce around and migrate apart from each other. That's the separation that you're trying to achieve in order to get higher quantities artificially higher quantities for U235. So you've got to turn the uranium into a gas. You do that by a few different chemical processes that are part of the flooring industry. And you end up with uranium hexafluoride, that's a heavy gas with one uranium atom, and six fluorine gas atoms, and one fat molecule. This gas is then spun at a very high rate of speed in centrifuges and uranium 238 goes out a little bit more, uranium 235 goes in a little bit more. And that leads to a concentration gradient that allows you to suck out gas with a slightly higher amount of U235 in it. And then you do it again and again and again and again and again, in what's called an enrichment cascade, until you have the concentration of uranium that you desire. So turning uranium into a gas is something that you need, not too much of in the world. But if you don't have it, your enrichment comes to a halt quite quick. So it's essential, but not very economically valuable if there's even a little bit more than the amount you need in around the world.

What's happened is that enough of that capacity was in Russia. That losing that capacity from Russia, puts us in a bit of a bind. We've got to stand up our own uranium hexafluoride conversion facilities quite quickly. Now, we do have facilities that were turned offline, that can be put back into service. And around the world, governments have such an inspiration to get this done. That it's don't want to say it's somebody else's problem so it'll automatically happen. But it's a relatively small worry for me. Perhaps a bigger worry is the enrichment facilities itself. Enough of that enrichment facility capacity was located in Russia, that if everybody suddenly needs to cut a new contract to replace their volumes that they're expecting to buy from Russia in the future, then we don't have quite enough enrichment for everybody to get it done at anywhere near the price that's available today. The question is, will there be actual shortages that lead to nuclear plants, having big enough delays on your that they can't operate? I've queried people involved in the nuclear industry and they seem to say no, but they don't want to say no so loudly that we don't invest in the Richmond capacity that solves the problem, if that makes sense. So yes, quite essential. Yes, somebody's going to collect economic rents for some time in this bottleneck. But it shouldn't be something that either is an argument against doing nuclear energy or that we cannot solve and will lead to shortages of nuclear electricity.

Erik: Well, it's definitely an opportunity that I think about from an investment standpoint, because I think there's complacency in the system where most people I'm talking to are saying look, don't worry about being able to get the enrichment services from Russia, because the people that are writing the sanctions understand we don't have that capability. We're not going to sanction and embargo Russia, so it's not allowed to sell us any any enrichment services. We're smarter than that. And I sort of say, wait a minute, did you consider whether or not Vladimir Putin is smart enough to figure out that he could do some real damage by cutting us off from those services? So I don't know how much important revenue Russia derives from selling enrichment services to the West. But Russia certainly is in a position to withhold those services as an act of economic warfare if they did so. As I understand it, we would be screwed. We would have a nuclear industry which does as I understand it have a fair amount of fuel stock, it's not like we're going to run out next month. But within a short number of years, you would have to really build out a whole bunch of enrichment facilities. If you do it the old way. It means a lot of those high revolution speed centrifuges are needed, we'd have to build plants to do all that stuff in the West. There's also a new approach, though, called Laser enrichment. Is that a better way to do it? If let's imagine that we lost access to Russian enrichment services, and had to replace that capacity. Would we be better off to start building out a whole bunch of facilities full of centrifuges? Or is this new laser approach better way to do it?

Mark: Well the truth is, laser enrichment has a few years to go. I've been told that the technology should be good to go. It does work at a small scale, but we'd need to commercialize it. America's the country that owns commercial laser technology. That laser technology needs about four years of really intense sprint development, or maybe double that of slow plotting development. If laser enrichment and the economic advantages that it could bring is considered important. Either investors or government can work together to accelerate that development and get that laser enrichment going at commercial scales by perhaps late 2027, early 2028 if the money spigot turned on straight away. The expectation for centrifuge enrichment is a little bit sooner. And if you just pay the Europeans to expand their already existing technology, already existing plants, then they can get even higher certainty of increased capacity in short order. I think that's the way I'd put it.

Erik: So it sounds like your preferred second source if Russian enrichment services were just taken offline because of geopolitical developments. Europe is the second source to go to. They don't have enough capacity, but they do have the infrastructure. They just have to increase their capacity in order to be able to service the need.

Mark: Right. And some of those European facilities aren't in Europe, they're in America. The Europeans own the main enrichment facility in the US.

Erik: Okay and as I understand it. The play if you're trying to bet, as a stock investor on laser enrichment, is actually an Australian company, Silex Technologies.

Mark: So that that would be directly involving yourself in the enrichment technology, but the Silex Technology is itself held in a cooperative structure called Global Laser Enrichment that is a subsidiary of Cameco.

Erik: Okay, so laser enrichment plays for investors are going to be Cameco or Silex, if you want a focused play.

Mark: Correct. And one thing we didn't mention is that if you shove more natural uranium into the centrifuges and only squeeze them a little bit, then you can up your amount of material coming out, but you have to use a lot more mined uranium. I would imagine Justin will thoroughly go over this next time.

Erik: Yes, he definitely will. We have a plan to attack the fuel cycle in detail in next week's interview. Mark, I'd like to return now to the subject of that video that inspired you to pursue this career in the first place, and that was the use of thorium rather than uranium to power nuclear power reactors. Thorium is four times more plentiful in the Earth's crust, then natural uranium, but more to the point less than 1% of that natural uranium is U235 which is the kind of uranium that's useful for making nuclear reactor fuel. So by my reckoning, the effect is that there's 400 times more useful thorium than there is useful uranium and what's more, the price of thorium is literally negative right now. Rare earth miners produce thorium as a byproduct, and will literally pay you money to haul it away and take it off their hands because they have no use for it presently. Now, here's what frankly pisses me off Mark. Every single knowledgeable investor in this space who I've consulted with, has told me exactly the same thing about thorium. And that includes people like nuclear hedge fund manager, Mike Alcon and billionaire mining tycoon Robert Friedland. These are people who clearly know what they're talking about.

And what they tell me is that thorium is every bit as exciting as guys like Kirk Sorensen make it out to be in terms of its potential. But then in the very next breath, they tell me that I would be a fool to try to invest in it, because regulators in the West are nowhere close to being ready to even consider permitting a thorium fueled reactor. Now, China has a big program to develop thorium fueled reactors, but in the good old USA I'm told that even considering any fuel source other than uranium is basically just categorically out of the question unless there was a completely new government-driven policy initiative where the government's driving the bus and making it the priority. And it sounds like that's not even remotely on their radar right now. So what's the straight scoop on thorium Mark? Is it really the tragedy that I'm hearing in the sense that they could potentially change everything for the better as Kirk Sorensen has said in his many videos, but the government is standing in the way of progress or is there more to the story than that.

Mark: The first commercial core we ran in the first commercial reactor built in the US was a thorium fuel. Its performance just wasn't as good and it wasn't worth the effort. So they switched it out. We've had several countries run thorium fueled reactors. There's nothing magic about thorium. You have to convert thorium into uranium to run your reactor in the first place. What's happening here is people are confusing thorium, the fuel with their favorite reactor type that they want, either for other reasons or because it's required in order to convert the thorium into Uranium in order to burn it. So as an example, heavy water reactors can run off of a combination of thorium and high assay low enriched uranium. That is uranium that's higher enrichment than the 5% most commonly used today as the cutting edge PWR fuel but lower than the 20% that's considered... above that is considered an unacceptable proliferation risk. So if you combined high assay, low enriched uranium, HALEU uranium around 20%, a little bit of it with thorium, without any real regulatory troubles, you can put that into heavy water reactors. I think that the thorium community has not focused on that. One because they didn't realize that combination was possible. And two because it wouldn't give them the sense of total all encompassing revolution that fits their narrative of what we're going to get from nuclear if we do it just right. So the idea that we've run off of run thorium reactors is not that welcome, because it means that we should understand why we were using thorium and then we stopped. The idea of India having an entire national program oriented towards thorium, and then seeing them sort of step away from that as soon as they get access to more uranium. That's important. We need to understand what is it people are getting out of nuclear and does that require thorium? Does it benefit from thorium? I think the clean core thorium energy has made it clear business case that has been essentially accepted by can do, by heavy water reactor operators that there is value to be gained anywhere from 5 to 10% of the operation cost of these reactors potentially of using a thorium plus HALEU uranium blend. But because that doesn't require a long development time or a revolution in permitting or new regulation or anything like that, it doesn't give the satisfaction of uncovering a revolutionary idea that folks in the thorium space have often been looking for.

I gave a talk at a thorium conference recently where I explained my history and how I got into nuclear through looking at a thorium video. And some people loved my idea that I brought forth to them of putting thorium plus HALEU and heavy water reactors. Other people rejected it because it didn't have the other properties they claim to one from their thorium reactor. Even though those are things you could get from a uranium reactor that's also cooled by molten salts or fueled by fuel mixed into molten salts, the thorium aspect is going to be relatively minor than that, compared to the choice of using nuclear because nuclear by its very nature doesn't use much fuel. It's like LED light bulbs. Now that we have LED light bulbs, lighting uses so little energy, that if we invented something new that used even less, it might be difficult to convince people to switch if there is even the tiniest disadvantage from cost or function. Because we have already made LEDs that are so crazy effective, so cheap, and so low energy use that there's almost nothing left to squeeze out of that. So to win nuclear, because uranium is a really incredible fuel. So dense, you need so little of it to run the world's reactors, that making it even more efficient, provides less of an advantage than people might think and overcomes fewer of nuclear powers real versus perceived issues and potentially would bring in new issues that we hadn't expected.

Erik: I think you bring up something that's really important at least that I only learned very recently which is I too was evangelized by Kirk Sorensen's view of a dissolved thorium fueled molten salt reactor or what Kirk likes to call the liquid fluoride, thorium reactor or LIFTER. I was so evangelized by that I didn't realize that most of the benefits that he's talking about in those videos are really benefits of the molten salt reactor design. You could use a molten salt uranium fueled reactor and get most of those benefits. And perhaps that would be easier to permit from a regulatory standpoint. Am I on the right track there in terms of separating those issues?

Mark: I think so and we could go further and say that a good chunk of the advantages he's talking about are from any nuclear of any design whatsoever. And I would say that Americans have a blind spot towards Canadian reactors, because that's not a type that we ever permitted for use in the US. And we never built it here. So it wasn't something that's on our mind. And there was some commercial mismanagement of Canadian reactors and some difficulties along the way that led them not to spread as far as American style reactors spread. So only six or seven countries use those Canadian-style reactors. And it just slips our mind when we're looking for a revolutionary technology. Something else, a lot of the advantages people talk about with LIFTERs are not just from nuclear as nuclear, but come from electrification and expansion of electricity access. So thorium, a little bitty atom is left to bear a very heavy weight for solving all the world's problems, when much of that is a solution that comes from any effective increase of nuclear electricity itself.

Erik: Mark, final question. We began this discussion two hours ago, with your favorite picks for high level learning resources for listeners who wanted to understand the science of this, and not just the industrial landscape. I've got to believe that after all this discussion, there's probably a few more suggestions you have for other resources. So what else should we provide our listeners with links to in their research roundup email.

Mark: If anyone has it in their heart to do some pro nuclear energy donating. Mothers for Nuclear is an extraordinarily effective group of people based in California originally, but now with chapters around the world, from two mothers who were working at a nuclear plant scheduled to shut down who decided to push back, educate their own workers about the problems of shutting down the plant, their own company, and eventually their state, and then the nation to try to overcome the closure of their plant. They were successful this year and are looking beyond other countries with reactors scheduled to close and countries that have never had the benefit of nuclear energy. So that is a tax deductible group that I know personally, and I know does incredible work. And I'm sure they would have a very good use of your donation if you thought that their goals matched what you want to see in the world. Next, if you're interested in this story of thorium plus Canadian-style reactors, you can certainly learn more either by contacting the team at Cleancor Thorium energy, or you can reach out to me and I'll put you in touch and show you what they're working on going into the next year. They're about to be the company with some of the most extraordinary new irradiation data for designing all types of advanced reactors because they're just about first in line for a rare spot for their test assembly in Idaho National Laboratories test reactor next spring. And then finally, you can always get a hold of me through direct messages on Twitter @energybants, or a hold of my team at my energy consultancy Radiant Energy Group where you can get a hold of me at mark@radiantenergygroup.com.

Erik: Thanks for a terrific long-form holiday interview, Mark. Patrick Ceresna and I will be back as MacroVoices continues right here, at macrovoices.com.