Mark Nelson: All Things Nuclear Energy

January 4th, 2024

Erik: Joining me now is Radiant Energy founder Mark Nelson. Mark, you just returned from the COP28 conference in Dubai, where just a few years ago, Greta was considered the ultimate intellectual authority on climate change. And pro-nuclear guys like you are kind of persona non grata. But from what I've seen online, this was a totally different COP conference with a totally different attitude among the delegates toward nuclear energy. So please give us the lowdown on Triple nuclear and the mood and attitude swing that's occurred there and generally what your experience was with this climate conference as opposed to others that you've attended earlier in your experience as a pronuclear activist.

Mark: Yeah, thanks, Erik. I'm just off the plane, shall we say late last night from Dubai after a 14-hour flight. I've now been to COP or Conference of Parties 3 times. This is a Conference of Parties to the climate agreement signed it previous versions of these conferences. We're now on COP28, some of these climate conferences have very famous names and agreements that come out of them. For example, the Kyoto accords that was caught up in, I believe 1997 in Kyoto, Japan, and then the Paris Agreement in 2015, with most world leaders and a President to sign it that was very famous in 2015. And then, this year, in 2023, we had the first global stock-take, as demanded by the Paris agreements, where we looked at all the carbon in the ground, all the carbon in the air, all the development left to be done, who has money, who needs money, and try to come to an agreement about what path to take in a real world with real emissions and real trade-offs in development. So, 2023 here in Dubai was not unusual for being a COP, physically powered by nuclear power plants. The UAE has a big plant down the coast, at Baraka in Abu Dhabi, and I was lucky enough, extremely lucky, shall I say, to be able to visit it by helicopter, one of the coolest things I've ever done in my life. But Paris in 2015, Erik, that was a COP almost totally powered by nuclear electricity, where the host governments itself was anti-nuclear, and practically banned any discussion or presence of the nuclear industry or nuclear advocates at the event.

So really great question, what has changed in that massive, massive cultural leap from 2015 to 2023, even though it's only been eight years? Well, I think one of the big things is this, a COP or these global climate conferences had a very unserious attitude towards energy. Now, I only go back three years, but I'm hearing from people who were there before it, there was the climate science, the environmental activism, the social activism, but there was very little presence of hardcore energy discussion, energy reality. And I think it would have been almost impossible to have a COP presidency in the host nation of United Arab Emirates without a very serious, some people say, too close of connection to the realities of energy production, both fossil fuels and nuclear energy. So I will say that one of the big changes is that this host nation, unlike France in 2015 but probably like France would be vetted, hosted this year, was extremely interested in nuclear energy for its own sustainable energy goals for its own energy security. And I think that that meant that as long as the world was willing to step up, as long as countries around the world were willing to step up and meet the host nation, UAE, in talking about and agreeing about what to do with nuclear energy, there was going to be a big nuclear energy presence in the official inside world.

So, I say official inside world because this brings us to another important part, which is what was the role of the NGO and advocacy community this year versus previous years? Well, for many years, there's been a building movement where organizations, large and small, in the nuclear nonprofit world, think groups like American Nuclear Society, European Nuclear Society, Generation Atomic started and run by my friend, Eric Meyer. These are civil society initiatives that have gotten involved with getting the all precious Blue Zone passes, the Blue Zone badges, the so called UN Blue Zone, that is the area where the climate agreements are actually negotiated, and determined. Well, this is the sort of the inner sanctum that have these giant festivals, these giant trade conventions, really, sort of global expos, the Blue Zone is hard to get passes for, and you have to have been involved for quite a while and aiming for them in order to have them. Well, year after year, more and more nuclear advocates are filling up spots, both from their host nations and in these nuclear NGOs that are continuing to win permission from the UN to get badged up as observers of the process or parties to the negotiation. So nuclear advocates are permeating all levels of government and NGOs. It's very difficult to run an anti-nuclear NGO and still get good, young talent these days. And that carries over to these COPs where nuclear advocates are inside, they're outside, they're in the Blue Zone with the passes in the negotiating room. And it makes a difference because most people are not really against nuclear with all their soul, and meeting multiple nuclear advocates of different ages, education levels, backgrounds, inside and outside the global nuclear industry really starts to wear people down, if it's just a matter of ignorance, or just a matter of fear of the sort of corporate unknown. And eventually they have that one really serious conversation with one of us that changes their minds.

Erik: Let's move on from the COP conference to more generally, the attitude toward nuclear as it's evolving around the world. It feels to me like there's just been a seat change here. You know, when I met you a little over a year ago, you were an easy guy to book, wide open schedule, want to do an interview with, no problem. When I caught up with you a little over a month ago, you had literally been to five countries on three continents in the week before we spoke, and you were flat out with speaking engagements, it was a challenge just to find one day in your calendar to record this interview. So it sounds to me like the nuclear renaissance that we both predicted in last year's interview is happening and it's happening in spades, or at least I want to believe that that's true. And certainly, the rally in the spot price of uranium would seem to confirm that. So give us your insights on what's happening in the world. Is this a major moment of change in public attitude? If so, what's driving it? What kind of audiences are you speaking to? And how does their reaction to your pro-nuclear message different now from, say, what you were experiencing two or three years ago?

Mark: Great question, Erik. And I'll say this about my schedule, I am rapidly getting to the point where I'm going to have to just start turning down outstanding speaking opportunities that I feel like I've waited my whole life for. And it's kind of a crazy thing. I'm not saying that to brag, but I will say this, I don't really advertise what I do. I don't have a lot of information about my organization and our consulting work on the internet. I don't post a lot on LinkedIn. I rarely post about even my big speaking engagements on Twitter. I don't know why, I just don't. If people find me, that means they were looking for me. So the fact that my schedule is filling up like this, I think is really a sign of the cultural interest in nuclear, which has gone crazy. You want me to diagnose it? I'll tell you, it's this: a generational shift from older folks who had some reason to fear nuclear energy, the word, the concept, the connection with nuclear weapons. At some point, that generational shift was going to happen to us younger folks who, from our first moments of memory and consciousness taking place after the fall of the Soviet Union. Eventually, as young people, we're going to keep filling up important positions in society, in finance, in culture, and the interest levels, we're going to overwhelm older folks who were scared and wanted to keep it out. So part of that generational shift has been kicked into hyperdrive by the Ukraine war, and the shutting off of major gas pipelines that were assumed to be uninterruptible. So really, you had Europe, where it's, quite frankly, the stronghold of anti-nuclear officialdom, anti-nuclear NGOs, and that Europe was severely shaken by the cut off of gas pipelines. And really, that led to a massive loss and prestige for anti-nuclear officials, anti-nuclear parties, that I don't think that will probably ever recover from even meltdowns at this point, I don't think would be sufficient. The countries with the great nuclear meltdowns, USA, Japan and Ukraine, are both strongly pro-nuclear nations who were three of the nations that came together at COP28 in Dubai just a few days ago to sign a pledge, saying that they wanted to triple nuclear energy capacity by 2050. So what you have is a bunch of things building, kicked over all at once by a massive disruption in decade long planning around energy.

Erik: Have there been any surprises or new developments in the last year that you didn't anticipate? If so, what were they and what do you see on the horizon as you look forward into 2024?

Mark: I guess, seeing the rise of centrist and center-right and far-right parties in Europe that are stridently pro-nuclear, almost a reaction to the elections in 2018, 19 and 2020, that turned in Green Party victories all over Europe. I guess I wasn't expecting that kind of smashing turnaround in so many countries all at once. Seeing Italy is pretty crazy, where ministers in the government love nuclear and are a little apprehensive but are strongly encouraging civil society nuclear ambitions to help them guide their own government into more nuclear in the future. That's just one single country. But since they're one of the only countries to have conducted a total nuclear phase out, despite being an early technology leader, I think it's a sign of something bigger. Another thing that I think is quite interesting is that as far as I can tell, Russia's international nuclear projects have not slowed down significantly, despite the economic dislocations of the war in Ukraine. So that's the nuclear reactors under construction in Egypt and in Turkey, and continuing in China and several other places. Which means that as Russia is one of the most important exporters of civilian nuclear technology, them not slowing down, but the west with a shock suddenly realizing they need to catch up, I think that's setting the stage for pretty strong nuclear decade coming up.

Erik: Mark, you and I both got interested in nuclear energy to start with, after being inspired by some of Kirk Sorensen's YouTube videos. You told me off the air that in the beginning of your journey, you were really jazzed up about the potential for Molten Salt Reactors (MSRs), liquid fueled reactors, thorium, potentially replacing uranium as the fuel for the next generation of nuclear energy. But then you went to nuclear engineering school to get your degree and somehow during that journey, your views, I guess changed and you no longer feel quite as excited as you used to about some of the technologies that I guess I'm still excited about. You've been at this longer than I have, and you've got the degree that I don't have. So I'm still very much sold on Kirk's evangelism of molten salt in particular. So in this interview, I'd like to take a deep dive on what I think the most exciting nuclear technologies are starting with molten salt reactors.

Listeners, as I warned you a couple of weeks ago, we are going to get fairly technical here. Please, if you want the background on this, watch episodes 5, 6 and 7 of my Energy Transition Crisis docuseries which anybody can watch for free at energytransitioncrisis.org, that's where you're going to get the prerequisite knowledge of what we're talking about: what's a Molten Salt Reactor? We're not going to start at those basics in this interview, so that's where to find it. Mark, electricity from nuclear energy was first demonstrated in a laboratory in 1951. By 1958, it just blows my mind 65 years ago, they had already figured out that the big problems were going to be fuel rod meltdowns and hydrogen explosions. And in the case of pressurized water reactors, which had been the favorite design now for decades, there's also the risk of core depressurization, resulting in the coolant flashing to radioactive steam. All of those risks were manifestations of the choice of water as the reactor core coolant. So in 1958, the US government commissioned the Molten Salt Reactor Experiment, which began in 1960 at Oak Ridge, Tennessee. The purpose of that was to experiment with the use of molten salt rather than water as a reactor core coolant. They completed the construction of a Molten Salt Reactor in 1964 turned it on in ‘65 ran it to ’69. Maybel Mark, I just drank too much of Kirk Sorensen's molten salt kool-aid, but I'm still sold on the idea that molten salt just seems like a profoundly better choice than water as a nuclear reactor core coolant. And I'm in the camp that resents the US government's decision to cancel that program for what seems to me to be purely political reasons that I think undermined energy policy in the United States. You told me off the air that you really believed all those same things back before you went to nuclear engineering school and learned all about it. So I'm shaking in my boots. What am I missing? What did you learn that has changed your view about molten salt as what I thought was kind of a panacea of replacement for water as a better core coolant?

Mark: Yeah, Erik, I'd say this. There's a very famous quote from Admiral Hyman Rickover, who pioneered the United States Nuclear Navy, and many people forget that he worked on two different major technical directions for his submarines. He wasn't just wed to pressurized water reactors, it's just that that was the program that worked extremely well. Pretty much straight off the bat to meet his needs. He also worked on a sodium fast reactor designs and while they worked, and we commissioned a sub, they just weren't quite as good. So I'll say this, a giant variety of nuclear reactors and nuclear reactor technologies have been tried, whether some of those would work better with full scale national development programs, I think is without a doubt, true. But the reason that the pressurized water reactor has spread around the world is that, it operates extremely well over extremely long life, lifetimes once you get it built. So there's a question. Are countries continuing to switch to pressurized water reactors because of just the overwhelming weight of initial development? Or are they switching because the performance, as built, is just so much better than everything else that it's worth the downside you mentioned? I think it's a little bit of both. But something to note about the Molten Salt Reactor Experiment. By the time they shut it down, a completely novel cracking, induced by a surprising element was already starting to wear down parts all over the reactor. And it's become clear that if they had continued to operate, they would have had very severe issues they would have needed to fix. Furthermore, as we expand our knowledge of molten salt reactors, it's almost inevitable that we'll discover more downsides than upsides. Downsides, we may be able to address with engineering, or breakthroughs in materials. But downsides nonetheless, that dampen the advantages that we can see before we actually build and run the damn things.

Now, we're quite lucky. The Chinese are going to figure some of this out for us, I think they are running and they've just gotten permission to turn on and have started, I believe they've started up their Molten Salt Reactor Experiment out in Gansu Province out in the Gobi Desert. So what this is, is a very, very small, a few megawatts thermal reactor. So like a few 1000 hairdryers and heat if I'm going to compare it that way. And they're going to help us discover, rediscover a lot of the same features that we discovered, both good and bad, in the Molten Salt Reactor Experiment that you described from 1965 to 1969. But this, this Tellurium, Tellurium is an element that was formed in several decay chains and it turns out that it induced intragranular cracking in a lot of the parts of the reactor. Now, again, like I said, it might be that we figured out ways to solve that. But when you're creating a solvent matrix of all the different fission products that can come out of fission reactions, and they don't stay in one single fuel pellet being weird to each other, but they spread throughout your reactor core with this fluoride salt, dissolves almost everything, I think that you're going to have very odd, very surprising, and almost universally negative findings, when you're scratching at the edge of the unknown. Now, it doesn't mean these reactors can't work. It just means that as we build them to commercial size, we try to expand them. Almost certainly we're going to create these surprising downsides that we have to fix, sometimes expensively. Something I would mention is that a number of the advantages that people talk about with say, Molten Salt Reactors, are advantages of say, the high temperatures. Well, over in the UK, the Brits operate reactors with higher thermal efficiency, that are these gas reactors. They're not as hot as some of the designs proposed. They're not as hot as the gas reactors, the Chinese have just turned on at Hsiao Bay, but they are still more efficient than our reactors. And you'd look at it and you think, okay, the Brits had gas reactors that really wouldn't melt down the same way they would, they have a lot of safety advantages over ours, if you want to look at that way. They have this temperature advantage, they have online refueling, if you listed only the advantages for the British reactors, and you listed disadvantages for the pressurized Water Reactors, I think any citizen looking from outside would say the Brits have a better system. But even by the mid 1980s, it was becoming clear that the Brits did not have a

better system. And this is with these gas reactors having a run of outstanding performance that made them the leading nuclear fleet in the world, briefly in the early 2000s.
What was the problem? In the end, the British reactors have a design that cannot be refurbished. For longer life beyond, say, I don't know, 50 years might be the limit. Whereas at 50 years, you have nearly a brand new pressurized water reactor waiting to go for a second, third and fourth financial lives. So that may not matter from the view of year zero or a year =10, when you're planning out the national fleet. It definitely matters if you're Britain and you've gotten all the way up to 2023. You do not have replacement reactors ready to go. All your old reactors have graphite cracking in the core and will eventually need to be shut down in either six months or one year or five years, so maybe in hindsight they could have designed their gas reactor with online refueling system to not be unrepairable. But that's in hindsight. What we know now is that pressurized water reactors are going to be, I don't know, somewhere between extremely long lived and functionally immortal. And if you can build them on time and on budget as they are in China, it makes the barrier, the bar that advanced reactor system has to clear to beat existing 70 year heritage PWR technology, it makes that bar extremely high to clear. And yet, I absolutely love that you're talking about this, Erik, I love that companies are working on it. I love that the Chinese have a national program on it. I love that we're going to get different aspects of molten salt that can work really well, like the salt as a coolant, even when it's not the salt as a fuel matrix. I love that we're working on all that. I just see that the PWR is such an outstanding technology. Even with the downside you listed that the bar to beat it is nearly impossibly high.

Erik: Now, I know that back in the 1960s when they were shutting down that program, the one big hesitation that they had about commercializing Molten Salt Reactors was ‘corrosion.’ And I've asked quite a few people to explain to me okay, what kind of corrosion specifically are we talking about? Are we talking about the, you know, neutrons being given off by the chain reaction are corroding something? Are we talking about the salt is corrosive? What's corrosive? What are you talking about? And I haven't been able to get a straight answer. It sounds like the cracking you're describing is the corrosion that I've heard so much about, that nobody's really had the details on. Can you give me a little bit more perspective? What’s corrosive? What's getting corroded? Which parts are getting corroded? And what's doing the corroding?

Mark: Sure. So before I say that, I'll say that I think people can critique nuclear engineers for being educated to think and work in a certain direction. Certainly for myself, upon entering engineering school as you're talking about nuclear engineering school, enough of these initial objections were put up that I didn't feel super bad that I was being taught mainly about our existing and expected future, large commercial fleets, rather than more and more about little bitty experiments that until recently, didn't go anywhere. So all of that to say, I am not the expert you should be speaking about specifically on this corrosion issue. I can speak more about the corrosion issues in large light water reactors, because that's what I studied and know a lot more about. But I will say this, when you break apart uranium, you produce a range of different products, you could get two equally sized chunks that come across, come out of the fissioning of that nucleus of the uranium atom, you can get one small chunk and one large chunk, you can get all sorts of different things. Some are more likely than others, Tellurium is a metal, and it is one of the products in some of the decay chains, and one of the possible fission products that come out of fission. It turns out that when dissolved in salt, when forming a salt, Tellurium has the ability to attack and get into the metal alloys used in the Molten Salt Reactor Experiment. So that's an example of a substance that wasn't there before you started the reactor. It's not present in the fuel being produced by the reactions themselves, even in small amounts, and eventually finding a way to attack the structure of the reactor vessel itself. And the different parts and pipings used to transport the fuel as dissolved in the salt around the reactor. If you continue to operate these reactors at high power over long periods of time, almost certainly you would discover that a number of other substances, it turns out, not just interact with each other to produce even more novel substances, but find their ways to attack almost any substance you would use to contain the reactor. That's not maybe as helpful as you want. But like I said, if we got into details that tight, I would want to turn to those who are more expert in the chemistry itself.

One of the reasons that nuclear engineers might love to stay with the light water reactor systems was solid fuels, especially with solid ceramic fuels, is that the point of these ultra-durable ceramic, so like extremely tough coffee mugs if you're thinking about it at home, is that they trap almost all of the exotic things that come out when you break apart a chubby atom like uranium. It traps it within the pellet and the pellet itself is trapped in a tightly sealed metal tube, so that almost none of the reactions that might be possible take place. Now, if you have the Fukushima Daiichi meltdown, suddenly some of those reactions start taking place, but it's still built into the functional design of the working reactor. If you're selling attributes of a nuclear reactor system as in a disaster, X, Y or Z won't be as bad, you may tend to forget that it needs to work when there's not a disaster, and it needs to work really well over long periods of time, in order to keep that reliability that nuclear has become so famous for. A reliability, I might add, that pressurized water reactors themselves took many decades to obtain.

Erik: Now another innovation from the Oak Ridge research was the elimination of fuel rods and therefore the elimination of any risk that the fuel rods could melt down, which seems to be the general public's greatest fear about the safety of nuclear energy. The gist of it was that the Oak Ridge Molten Salt Reactor dissolved the nuclear fuel in the circulating molten salt core coolant. The nuclear fission chain reaction occurs when the salt passes over a graphite moderator, but it could easily be stopped by simply draining the fuel salt by gravity, out of the core section where the moderating graphite was located. The most important benefit that was claimed was the complete and total elimination of meltdown risk, a secondary benefit but still an important one is that liquid fueled reactors can more easily be designed to load follow, meaning that the reactor output can be modulated to match demand. Mark, to my novice ear, all of this sounds like a way better way to design a nuclear reactor than an old school design where if the circulation pumps stop, you have a meltdown in Fukushima kind of a situation. I know you used to think the same thing, but you changed your mind. What changed your mind and what did you learn?

Mark: I referenced in my answer previously, that upon going to engineering school, a few pithy quotes were used to take my mind away from the very miracle technology that had brought me into nuclear itself. Here's one of those pithy quotes right here ready for you, Erik, is the following: It's a professor saying something to the order of, of course, we can't have a meltdown, we melted it already. In other words, the point of the fuel being solid is in large part to keep the fuel and efficient fragments tightly locked in position. If you have a meltdown, what's so bad about that is that your fission products start migrating beyond the fuel and potentially beyond the reactor. So, in the design of the molten salt reactor, yes, you can't have a meltdown, per se, in the same way. But that's because you've already broken down that barrier that would keep fission products, highly radioactive fission products trapped, doing no mischief, just sitting there. So, although you do have this, you might say continuous and ongoing meltdown, it is intentional. So you design your reactor system to deal with the fact that you had to have your fission fragments bouncing around and going all crazy inside of there. However, that is still one barrier, fewer in keeping them away from the biosphere. So yes, you can't have a meltdown in the sense of fuel going from non-molten to molten, but you have a constant meltdown in the sense of fission products and radioactive transuranics, already bouncing around free within the reactor vessel itself.

Now, some of the other things you mentioned, though, in terms of what the public fears most, I will say that there's something magical in the public thinking about what is dangerous in a nuclear plant, what's dangerous in a meltdown. And I think there's a lot of confusion about what a meltdown is. For example, if you have fuel damage of any type, there seems to be an imagination threshold of where it goes from meltdown to just a routine fuel quality issue that needs to be fixed. About two and a half years ago, in China, there were crazy headlines and CNN basically, calling that Chernobyl in China is about to happen, when in fact, it was a fuel quality issue with fuel leaking a tiny amount of fission products into the cooling water, right? So the narrative in the public was such that they were talking about a meltdown condition with just a few of the fission products that would normally be kept in fuel getting into the cooling water. And it didn't really matter that that was not a meltdown or not even close. And similarly, there have been multiple fatal accidents, sometimes highly fatal, like six or seven workers killed at once from nuclear plant accidents that, because they did not involve fuel damage, are completely ignored, and are completely out of the public mind. You know, steam explosions, death by hot water, really brutal things that are absolute tragedies for the working men that were killed, but they don't matter to the public because they didn't do anything to the core.

All of this to say there's a lot of the argument for novel types of reactors formed by the public imagination about what happened in previous accidents. And I think that the culture turning more pro-nuclear is going to answer a lot of those concerns and make it to where if there's not an outstanding and compelling engineering and economic argument to make a certain advanced reactor investment, the public isn't going to expect them. And we'll be happy with existing technology because it's no longer that nervous. When you mentioned the high efficiency, I think that's an example of something you do indeed get from high temperature reactors that would be an outstanding and compelling part of decarbonizing heat industry, or even just providing it at secure costs, once you build the reactor. I think that's really cool. And all high temperatures are harder engineering problems in low temperatures, it's just a fact. High temperatures are harder engineering in low temperatures. Almost all higher temperature reactors to date have achieved uptimes, have significantly less than the best, pressurized water reactors and heavy water reactors and boiling water reactors to date. Do I think that that's inevitable? No, but it's a great difficulty that stopped the nuclear capable nations like Russia and China from ploughing ahead most of their investment in novel technologies even if they could control all the IP and control the supply chain. They've tended to choose the PWR (Pressurized Water Reactor) for its astounding dependability.

Erik: Mark, the next topic is thorium as a replacement for uranium as reactor fuel. Now on this one, I'm going to be the first to agree with you that thorium has taken on this cult following on the internet and some of the things that some of the people on the internet say about thorium being the solution to all known problems to mankind is total nonsense. But with that disclaimer in place, I'm still sold on thorium having a lot of benefits. And I think more than it's been given credit for specifically, the primary benefits that I see are around weapons proliferation, and waste disposal.

Starting with weapons proliferation, a thermal spectrum thorium breeder reactor only needs a tiny tiny little dose of kick-starter fuel, which could be either LEU or MOX fuel in a waste burning design. But my point is, the operator never needs to possess more than a tiny amount of enriched uranium or MOX fuel, and not enough that you could ever you know, try to repurpose it to do anything nefarious with it. After that, they can run it entirely on thorium, where there is no requirement for enrichment. So it seems to me you can have a whole national program without ever owning a centrifuge, you just get a little bit of MOX fuel for your Kickstarter fuel. And maybe that's something that's carefully regulated by the IAEA or something, you know, so that everybody else in the nuclear community knows how much of that kick-starter fuel you've got and what you're doing with it. And then you manage your own uranium process. So it seems to me like there's a big advantage there.

The other advantage is with respect to nuclear waste disposal, although I do agree with you that nuclear waste is not nearly as big of a problem as people perceive it to be. The point is, people do perceive it to be a big problem. And I think we have to focus on perception being in some cases even more important than reality. Thorium reduces the waste storage horizon from 100,000 years to like 300 years, it seems to me like that's a really effective way to antidote the public's perceived preoccupation with nuclear waste disposal. So what am I missing in the thorium story?

Mark: Right, so I agree with you that thorium is taken on mythical proportions online. I think that a lot of people who have genuine positive optimism for human species, positive optimism for what we can do to live well together on a finite planet, like to think of thorium as unlocking this potential. I know that thorium is a critical part of what people typically describe when they say molten salt reactor or advanced nuclear, there's a bunch of technologies that are all thrown in a jumble and somewhere between high temperatures or low pressure operation or breeding or conversion. There's all these features of which only some are being proposed for most of the advanced development, advanced reactors, and that's often for good engineering reason. All of these features together end up bearing a very heavy burden for a bunch of social ideals and optimist visions of technology and humanity. I will say this about thorium, I do think that some very serious nuclear people, perhaps underplay thorium after having to deal with so much over optimism about thorium. One of the companies that I work with has a very compelling vision, in my opinion, or I wouldn't be working with him to put thorium to use in reactors very soon. But ironically, because it's not a revolutionary technology, it's an evolutionary technology that will probably make a very good business. A bunch of thorium reactor people are not as excited as they should be about a thorium technology entering the market in near term. So what this company, Clean Core Thorium Energy is proposing is, taking one of the existing major families of reactors, heavy water reactors as used in Canada and India, and a few other plants in Romania, Korea, China, Pakistan, and Argentina. they're proposing taking the standard on enriched uranium fuel that these reactors are on. And then simply putting in mostly thorium with some high assay low enriched uranium, that is uranium enriched above 5%, lower than 20% spiked into the fuel, and then having that increase the performance of the reactor system in ways that are worth money to both the fuel manufacturer and the operator of the reactor. So when I propose this technology as an answer to the winners story, I'm going to give us these advantages, proliferation advantages, perhaps the economic advantages. When I proposed this last year at a thorium conference in Albuquerque, I had a few angry responses from people who wanted the full revolution, the full revolution of humanity that they feel is offered by using thorium energy. And they seemed quite upset that we could actually use thorium in the near term for mild but real economic advantages that can be made into a strong and continuing business. I thought that was very interesting and revealing the heavy revolutionary burdens that people are putting on thorium. When you mentioned the proliferation aspects, I'd say this a country needing and wanting energy security, a country having the intellectual independence to develop a nuclear program. Even if they get started by working with another country, both of those things put a country far along to the nuclear defense path without doing a single thing against the rules about nuclear energy materials. So I'm not saying that nuclear energy itself is going to cause proliferation, just the same impulses and state capacity that would lead to a functional nuclear energy program, whether based on uranium and thorium, puts you into the realm of nations capable of having nuclear defense, and vice versa.

I might mention that there are countries out there getting aspects of nuclear defense, whether like North Korea the bomb, or Australia nuclear submarines that don't actually have nuclear power. And so the story around using thorium for extremely specific control of the nuclear fuel cycle, I don't know if that's going to end up being the case, you certainly need some of the spicy stuff to get a thorium fuel cycle running. And if our argument is that you give a new country a bit of the spicy stuff in their reactor, so like highly enriched uranium or plutonium in order to get a thorium reactor cycle process or cycle moving, or that you get a country everything you need to breed uranium 233 from thorium, and also the out of core processing equipment in order to separate out different materials and keep the stuff you need to keep your reaction going in the thorium, I find it very difficult to believe that that materially changes the proliferation argument, the proliferation story. I will say that, if you do have a thorium reactor, and it does require some higher enriched uranium or some plutonium, it's going to be very difficult to claim to countries that they don't deserve to have the technology to produce their total fuel element themselves. So I would be a little bit careful with that. I would also generally caution and say, nuclear energy is going to be pursued by countries around the world for its energy needs. And someone will be out there to provide those countries with nuclear technology. If we continue to be the hardest country to work with that, by we, I mean, the United States, we continue to be a very hard country to work with, countries will naturally want to pursue their nuclear technology through other vendors. So we have to be very careful to what extent we think we can control the energy outcomes and other countries by selective limitation of access to technologies. And if those countries decide they want to start a thorium program, we shouldn't automatically believe that we are safe from anti proliferation concerns, just as much as we should think that we have anti proliferation concerns, specifically from countries getting uranium technology.

Erik: Mark, I want to talk about small modular reactors or SMRs next. I've really enjoyed listening to several of your interviews on Bloomberg and elsewhere. This is definitely an area where I'm in violent agreement with you on some aspects of this, but also, strong disagreement with others. So let's start with, you've opined on several different media interviews that you're not nearly as sold on SMRs being the future of nuclear energy, the way many other people, myself very much included, who see SMR is doing most of the heavy lifting for energy transition. You've argued that while you do agree that nuclear energy should be the primary baseload solution to energy transition away from fossil fuels, you think that large scale conventional nuclear power plants, based on the latest generation 3+ large scale gigawatt reactors, such as the Westinghouse AP1000 are the way to go for most large power plant applications. So please share your arguments with our listeners who may not have heard those excellent interviews on Bloomberg and elsewhere. What is your beef essentially with SMRs? Why don't you agree with many of us who think that SMRs are going to be the way of the future?

Mark: Sure. So SMRs, small modular reactors, is a marketing term that popped up not that long ago. And from the beginning, I had a sort of unease with it. It's not that exactly overlapping what people mean, when they often talk about the thorium molten salt reactors, though, I sometimes see the word being used almost interchangeably, where people fundamentally, when they say SMRs, don't really strictly typically have a size limit. They don't necessarily mean modular in the construction sense. But they definitely mean reactor. So that's one of three I think I can agree, they're reactors always, so that's good. Typically, modern, full scale nuclear reactors are about 1000 megawatts on up to 1750 megawatts. That's the size of a modern full-scale reactor. Different definitions of SMRs by size are out there. They are typically 300 megawatts and below with reactors, 10 megawatts electric and below sometimes being called micro reactors, right?

So, if we have 10 megawatts on up to 300 megawatts, that's what most people are calling SMRs. Although there's certainly the Rolls Royce SMR being proposed by the maker of the British submarine reactors, that is 470 megawatts. At some point, I got tired of all this nice, just started having fun, I now call everything an SMR, Erik. So if an SMR is out there, that's, say one gigawatt, so three times bigger than the normal definition, I simply call it an SMR L or SMR Large, or I sometimes call it a large Modular Reactor. If the reactor is built with modular construction techniques, we could call the medium sized ones, MMR, Medium Modular Reactor, but that acronym is already taken by the measles, mumps and rubella vaccine for children. So I think I'm going to leave MMR alone and just go with SMR L and LMR. So one of the reasons I'm making this joke is because I just thought of a story I shared, meeting an experienced General

Electric Hitachi nuclear engineer, in a bar in Tallinn, Estonia, when we were both there for a conference last year. And I'm talking to this General Electric guy, and he's describing his experience as a young man working on the Kashiwazaki-Kariwa, unit six and seven projects in Japan. These are 1300 megawatt General Electric events, boiling water reactors, ABWRs. And what's astonishing about these things, 1300 megawatts, is that under the official timeline that the IAEA has for reactor construction, they were built in 36 months from the first concrete poured under the reactor vessel all the way to initial criticality. So that means nuclear reaction starting with the core, then it was only 48 months total. So one year later, when the reactor was certified as entering full commercial operation. So you have 36 month construction timeline for 1300 megawatts, that is astonishing. And it happened in the 90s with an American design reactor. So I asked this engineer in this bar in Estonia, I said, okay, so how did you build it that fast? And they said, easy, it was modular, modular construction. So I'm thinking, wow, you really don't hear people talking about the modularity of large reactors much. And then I asked him, why did you guys change the design then, If you had a design you can build in 36 months on it on an existing nuclear site? Why did you change the design? And I quote to you, notion, he said, oh, to make it simpler. And we haven't built anything in that time span since, even though China is now approaching it with some of their western designs, their AP1000 reactors by Westinghouse that China's building, they are on and I quote, 40 month construction timelines, about a third to a half into the project. I heard that from Westinghouse engineers themselves in a visit to their offices in Pennsylvania, only a few weeks ago, and I was blown away. So what we're talking about when we say SMR is the idea that, something between the reactor itself would be a module or the plant itself would be made with modules. Typically, what people mean is they imagine the whole reactor system coming on a truck or a barge or something and being just put onto site. One of the reasons that the NuScale projects have had such a troubled development and NuScale being the most prominent and famous SMR technology, I mean, heck, Erik, it even uses the stock ticker SMR In case you missed it. Well, the actual giant plant itself for putting these reactor modules in was an immense construction problem requiring an immense amounts of skilled labor to build. So you have to ask yourself, if the reactor is a module, but the plant is a massive construction project, then you've got to set up your factory to make a novel reactor type anyway. But then each one doesn't make that much power. And you have to build a giant facility to put them all in, you start to wonder what the actual claim was.

Now, some people go all the way and they talk about, you know, micro reactors, so under 10 megawatts that you can truck to site in one shipping container, maybe three or four put together. The most advanced one of these reactors at the moment that's being proposed is the Westinghouse eVinci reactor, which Saskatchewan has up in Canada, has just announced they're going to pay something like $80, 90 million to buy one of these and help the development. Well, these Westinghouse reactors will come on a few different trucks, trailers, barges, and will be 5 megawatts electric or 15 megawatts dermal, so they definitely count as micro reactors. But they will be competing in price, even when made in large quantities. Not with baseload electricity, there'll be competing in price with diesel generators. Now Westinghouse folks think that they can beat it. But that's the range of prices they're expecting to get to, with reactors that small with economies of scale for each reactor itself, that small. One of the interesting things about SMR designs is that almost inevitably, after a company announces they're going to build an SMR, you can expect a doubling or more of the reactor power, NuScale was actually very conservative and only going from 55 megawatts electricity or so or 50, I think it was up to 77. That's only about a 50% upgrade, you have whole texts, SMR 160, getting a recent upgrade to 300 megawatts before even detailed designs are done. You have Oklo, I believe starting at something like 10 and now aiming at 100 megawatts. So that's maybe 10x, and so on. The reason why is that the closer you get to a detailed design that includes your daily construction needs and your equipment and the tasks and the blueprints and all of that, the more you see that a small increase in scale of the reactor output leads to very, very few differences in the construction cost, but large differences in eventual operating economics. And that's where we got the large PWRs in the first place, except for some of the most recent giant jumps. So for example, the 1750 megawatts, the upper end of the range that I defined at the start of this answer, except for those having two massive shells that clearly make it to where it will never be competitive in construction. With simpler designs, you have pretty much the same structure sizes, same building sizes, same amount of metal or so in order to have a much higher power output. The Westinghouse AP1000 is an exceptional design. If you look at it from how much steel, how much piping, how much wiring, how much concrete is designed in to have 1000 megawatts of output, it actually does a lot better on those metrics than say, NuScale does, to my understanding. So NuScale with its 77 megawatt electric modules, you would need a dozen of those to start to approach one, plain old AP1000, which as long as you're good at construction and manufacturing and could build both things.

All things else held equally, of course, I would want the AP1000 and not the NuScale modules where NuScale might have an advantage. I've heard some experts I trust suggest, is if you had a construction project in a country where you did not need the same extreme structure around the reactor, so if you did not have to meet the aircraft impact requirements, which as the International Atomic Energy Agency, IAEA has declared some countries isn't should be following that in some countries is probably not needing to follow that. Well, there you go. Yeah, that might be in advantage for some types of SMRs, if you could build them in non-western environments with different requirements for external threats. But then you get back to conversations that make some people uncomfortable, not to mention the host countries that might say, wait, are you saying we have lower safety requirements than the original nations? That might piss some people off, but it might be something good, solved by just cheaper energy that might come from those projects.

So summing up, all of these SMRs are really intense buzzword marketing term that I loathe. I'm like a one-man army marching against the use of SMR as a marketing term to solve public acceptance issues that leads to, in my opinion, a lot of sloppy thinking around nuclear economics itself. Are there SMR companies that I like? Oh, heck, yeah, there's even one that I've put an angel investment into, because I love the team and I love the concept. But that that does not mean that I think that it's going to be taking over the role of mature large light water reactor technology anytime soon. I think it's again, instructive to look at Russia and China, with incredible capabilities, astonishing ability to get projects launched and completed. And in both cases, advanced reactors or SMR reactors are seen as a side project to work on, while they plunge ahead with the large scale reactors, and no one's telling China, they aren't allowed to do

SMRs, or that they should have to go through the NRC. And for what it's worth, I do not think the Nuclear Regulatory Commission is as big of a barrier or as problematic as many people assume. And I think that, just assume that you can't have a nuclear renaissance until you seriously degrade or remove the NRC. I don't think that's a good argument that will bring capital into nuclear projects itself. That's a side quest. Maybe we'll get to that later in a future episode, Erik. I think that China is showing that when they have freedom to choose to build whatever they want. They are finding excellent returns, building American style reactors, over and over with experienced workers.

Erik: Mark, you make several excellent arguments there. And I'm in violent agreement with many of them, most of them, in fact, so let's start with what we agree on. SMR has become or has always been a marketing term that doesn't specifically mean much of anything. I think a lot of the SMR designs that have been proposed are not particularly small. And they're not at all modular. And I would go so far as to say that, in my opinion, most of the entrepreneurs and companies that are introducing SMR designs are missing the point completely on modularity and why it is or should be so important. I would also agree with you that you know, something like NuScale, I've made the joke before that, you know, the most innovative, creative, forward looking thing that NuScale has done as a company on advanced nuclear technology, was obtaining the ticker symbol SMR on the New York Stock Exchange, that was a really good move for them. As far as their reactor design, it's an old school pressurized water reactor on paper, they haven't built anything yet. And it is not particularly modular, it's not particularly small. And it requires a whole bunch of bespoke on-site construction to occur. So it's going to be expensive to install and build. What I would like to do now, though, is explain why I have a vision for how at least, the very, very small part of the SMR industry that's actually focusing on modularity, I think is going to be responsible for completely obviating the need for the large scale reactors that you favor. And maybe I'm just missing something here. But I'd like to talk you through the way I see this and get your critique and feedback on my approach. And listeners, I also have a video that will go into much more detail on what I'm about to go over with Mark, that should have been published at energytransitioncrisis.org/SMR, by the time that you listen to this episode.

So Mark, referring to page 2 in the slide deck. The problem with conventional nuclear is it costs too much and takes too long. And something else I agree with you on, this levelized cost of electricity thing that's in liar’s figure and figures lie, everybody's got their own numbers for nuclear. But the point is, it costs more by the time you spend, in many cases, upwards of seven years building a large scale nuclear power plant. By the time that you spread that cost into the cost of electricity, it costs more than electricity from coal and gas. My argument is we need to make electricity from nuclear cost less than electricity from coal and gas, and I think SMRs interpreted the correct way is exactly what can get us there. Moving on to page 3 in the slide deck. I also agree with you that what we need is gigawatt power plants, not megawatt power plants, in order to solve energy transition. So this whole idea that most of the SMR industry seems to be focusing on, of small community reactors, I just don't think it's viable under current rules. You would need armed guards around these small community reactors and the economies of scale just don't work for that. So I don't really think this micro reactor trend has a lot of application. Maybe something like in a mine in a remote place where you need to get electricity and to run the mining equipment, it would make sense, but I don't think it's a big part of the energy transition solution, the vision that I have for the future.

Moving on to page 4 is small modular reactors that are actually modular built in modules the size in the form factor of standard 40 foot shipping containers. So you have small modular reactors that are contained inside of a shipping container. Moving on to page five, zooming out on the same picture, the way you build a gigawatt power plant is to gang together 25 of these reactor modules. These are each 100 megawatt thermal modules based on a 40% thermal efficiency of using steam turbines to convert that thermal energy to electricity. We need two and a half gigawatts of thermal energy to get one gigawatt of electricity out. So you need 2500 megawatt reactor modules. They all sit in a building which does not have to be built to nuclear construction standards. Those tubes that the reactor modules are contained in, address the airplane impact requirements, they also provide a containment if there was some kind of natural disaster, earthquake, tsunami or something, they would contain those reactor modules and make sure that nothing ever leaks out of them. One of the advantages there, is in terms of decommissioning cost, which contributes significantly to the cost of nuclear electricity, that building doesn't have to be decommissioned and treated as low level nuclear waste. So you develop your gigawatt power plant out of a bunch of modules. Well, why in the world would it be better to build a gigawatt power plant out of 25 separate nuclear reactors instead of one big one? The answer is on page 6, because you could mass produce those reactor modules on fully robotic assembly lines with state of the art quality control, with all of the test and inspection and everything occurring, robotically produce them on those mass production assembly lines in order to bring the cost down dramatically. If you were to build an automobile, a modern automobile designed to your own personal specifications, and custom build just one of them, they will cost several million dollars. But if you buy a car off a lot that comes off of a production line, you know, it's a much different cost equation.

So my answer to how we're going to solve energy transition is building gigawatt power plants out of Lego blocks, out of 100 megawatt thermal reactors, which fit in the form factor of shipping containers. If you wanted to replace all of the energy that we now derived from fossil fuels worldwide, which according to the Our World in Data series, is about 137,000 terawatt hours of energy. And that's from coal, oil and natural gas, you would need about 217,100 megawatt thermal reactor modules in order to completely replace all of the energy we get from fossil fuels today. And my vision of the future is doing exactly that, building 217,100 megawatt thermal reactor modules in the form factor of shipping containers. So you can use the existing container ship based logistics infrastructure that the world already has to ship these things to wherever they're needed, and build modular nuclear power plants that are just a completely different approach to building a nuclear power plant. And I contend that we could eventually build those in 7 to 10 months, instead of 7 to 10 years. So I think less than a year to build a nuclear power plant, when all the nuclear reactors came off of an assembly line. Okay, so if this is as great as I say it is, how come nobody's doing it?

Moving on to slide 8, now, Mark, this may be at odds with some of what you said earlier, but every single veteran investor that I've talked to since 2011, about all this advanced nuclear stuff has told me exactly the same thing, which is yeah, molten salt sounds fantastic, you know, great idea, but there's no way we would ever consider investing in anything that is not part of the existing accepted norms of nuclear energy because this is the most over regulated industry in existence. The notion of the US NRC, approving something that's new and different and that they haven't done before is beyond their comprehension and ability. And as investors, we know better than to invest in any idea that depends on nuclear regulators approving something new and different. And that, I think, is the major impediment. Nobody wants to invest capital in advanced nuclear technologies, because investors are smart enough to realize that regulators are standing in the way of progress. And I'll just close my argument here with slide 9, which I threw in to say, look, if what I'm doing, you know, there's less than 500 nuclear reactors, power reactors operating worldwide today, I'm saying I want to build 217,000 more of them in the form factor of shipping containers. Obviously, that's a very ambitious plan. I that too ambitious? Is that unrealistic? Erik, you're crazy, whatever. Take a look at slide 9, the picture on the left was taken in 1951. That was the laboratory experiment, where they first demonstrated producing electricity from nuclear energy. For short years later, in 1955, the USS Nautilus nuclear submarine set sail full of US Navy sailors, and actually went to do its mission as a nuclear submarine. That's what happens when the government wants to make something happen, as opposed to creating bureaucracy and bullshit to stand in the way of allowing it to happen. And I'm convinced that the real reason that the US nuclear regulatory commission was created in 1974, was to make sure that nuclear energy could never compete economically, with energy from coal and gas. And I think they're doing a fantastic job of fulfilling that mission. But as far as helping to advance nuclear technology, I think that it is the government that’s standing in the way of progress. So that's the way I see it, I think the solution is to get the government out of the way of progress, and to build 217,100 megawatt thermal reactor modules, which I contend can be built for less than $10 million unit cost, if you're building them on a fully robotic assembly line, you build modular power plants, and that's the way you solve energy transition. So that's why I think small modular reactors that really and truly aren't modular, are the most important thing going and the answer to the future. But I do agree with you that most of the SMR craze is not about that. Let's focus on my vision and what do you think I've got wrong? What do you think about what I've just proposed?

Mark: Well, Erik, before I say anything about what I might disagree with, let me just say your vision is beautiful. And no matter what I'm about to say, and whether I'm correct or not, no matter what the world has to say, I want you to stick with me, stick it out, find a way to help make a nuclear powered world, because I think it's a world that works out better for everybody. So having said that little intro, here's one of the issues. I checked in with, sort of you might call it my Council of Experts, people who work mostly inside the existing nuclear industry, but also the advanced nuclear industry. And I've worked at several different companies and have deep archival knowledge about all the different things the world has experimented with nuclear and I asked him, what is the size of reactor they expect to eventually see within a shipping container. And one of the points somebody made is that the largest reactor we've ever seen, the size of a shipping container, so that would meet your form factor to date, is actually one megawatt thermal not honored. So the reason why this is quite important is although we might be able to bump that up a little bit more, even that reactor required humans to stay really far away from it because of radiation shielding issues. And as you start to add shielding, just to make sure your nuclear reactor is safe to be near or work around, like on the submarines that you cited, you start to rapidly make it not a shipping container reactor. Now, the reactor vessel in some of the most powerful nuclear reactors that have ever existed, is barely larger than a shipping container. It's just installed in a very large plant, built around it to deal with that sort of extreme power density. So with that said, we're not going to get 100 megawatts thermal ever, in my opinion out of something the size of a shipping container, we might at best, do a few megawatts thermal in a commercial way, but much more likely, we're going to have to have either much bigger than a shipping container, multiple shipping container sized units, installation at the site in constructed structures. All of these things are going to have to happen to get above even a few megawatts thermal. So there's the first little thing I would complain about with a vision. I don't think I'm going to complain about having lots of nuclear reactors out there. And that being a proliferation threat, that just doesn't bother me quite as much for various reasons, but says that wasn't a particular concern of yours, I'm not going to dwell on it here in this answer.

In terms of making a nuclear powered world with large numbers of reactors, I think something that is part of the pressurized water reactor world that people don't mention, as much as if we have the patience to build it in the first place, it's likely to remain running for an extremely long time. I want to answer something about the NRC. I want you to just imagine for a second we reverse the problem. Imagine a world that is anti-nuclear, and they're pressing their governments, they're pressing legal structures, they're pressing in all different ways to try to shut down nuclear energy. What would it look like to create a regulatory structure that shielded nuclear plants that shielded nuclear operators against interference by the public? Now, is this the story of NRC? Not perfectly, but there's something to this, the NRC Nuclear Regulatory Commission creates a very well understood one stop shop that can put a stamp of approval on your nuclear plant. Now, they can shut it down at any time. But if you're operating your nuclear plant to global quality standards, that's not going to be an issue, you're going to be able to keep operating it in the US. There are certainly countries around the world that would love to have the NRC as their nuclear regulator. And there are lots of anti-nuclear experts that I've talked to that hate the NRC for what they see as it being totally captured by the industry, which is the opposite of the vision that I think you laid out when you were describing your conversations with investors. The NRC caught quality program problems on the most recent reactors that were supposed to know how to build well, Vogtel in Georgia. The NRC provides a shield that, if you get through them, they will be the defense against overzealous states, they will be a defense against overzealous lawsuits and NGOs. If you meet NRC standards that will protect you and you're likely to be operating really well in a way that makes your nuclear plant a great performer for your utility. Although it's possible that the NRC is slowing things down, that would go faster. Otherwise, it's absolutely possible that going faster and breaking things could lead to a retraction of social license that would produce an entity like the NRC or worse, shut down the nuclear reactor project entirely before our nuclear renaissance and sort of call it the nuclear libertarian world actually comes to fruition. So I think that the NRC, you could be justifiably critical about creeping regulation, back in the 70s and 80s, as we were progressively losing our capability of building large things. Although for the reactors that eventually got completed, they've become outstanding performers over time. I would say that until we have a tried, tested, fully blueprinted and supply chain proof design available, like the AP1000, is now if we get the supply chain ready to roll again, and we have the NRC that's stable, is not changing rules, knows how to regulate, knows how to license that particular design. And we combine that with some experienced management in the nuclear project and eager capital wanting to give nuclear try. I think that that will show that some of the criticisms of the NRC are perhaps unfounded. I know that I've heard more NRC from some companies that have struggled with the novelty of their design. And this is an issue of novelty of design, as much as is of the NRC being a stick in the mud.

Nuclear Reactor innovation is not going appreciably faster in other places, even ones putting hundreds of million dollars, millions of dollars of state money behind reactor development. If there starts to be some insane gap between extraordinary technology in China and Russia, and the technology we have here, obviously, it'll be a little bit too late in some people's eyes to revisit that. But I just think that a lot of the complaints of the NRC come from companies over promising without the experience to actually deliver their project, at least not as envisioned. And as they're running into problems, the NRC is a very popular punching bag now. I share concerns with some of the smartest friends of mine in nuclear that say that if we damage the NRC's predictability by inducing changes in it, if we declare to investors that we could never invest in new nuclear until the NRC is changed, then we're putting up barriers in the way of nuclear that don't have to be there. I think that the pressure on the NRC to be as open minded as possible as fast as possible, I think that's great. I think it must be noted that the NRC has never rejected license application for extension of life of our reactors today. I know that's not the same as licensing new reactors, but the problem that NuScale had, I do not believe are actually truly connected to the NRC existing. The Chinese put several 100 million dollars of investment and something like 12 years into their Molten Salt Reactor Experiment in the desert. This is like a few megawatts thermal right? Is that because they have the NRC? No, in fact, their regulator and as many regulators around the world are sometimes more conservative than ours. I know that there were major and expensive design corrections that were ordered on the French EPR design, after it went through the British regulator, compared to when it went through the American regulator. And the British regulator has fewer employees, has a more expansive philosophy of licensing advanced designs. I know this because I studied it for my master's thesis in grad school over in the UK at Cambridge. And yet, that hasn't led to the UK being some hotbed of nuclear innovation. Now we can spread and say, oh, well, the British regulators are bad, too. At that point, I think the argument gets a little thin. And although maybe if I were today, working at advanced reactor company and I were today struggling with endless back and forth between the NRC and myself, maybe I would have a more critical view. But sort of being on the outside right now of both existing industry and of the advanced nuclear companies and as a very small investor in an advanced nuclear company that I really want to succeed, I think I'm coming down on the side of the NRC as a flawed, but necessary and mostly nuclear positive way to ensure that social license is retained. And if there's any blips in social acceptance, it will not have the ability to threaten or derail existing operated plants as long as they meet existing NRC rules.

Erik: I want to save some of the discussion of Nuclear Regulation for a little bit later, because I'm planning to come back to that anyway. But let's go back to the viability of the vision because I want to focus on what you said about the limitations of what's possible in the form factor of a shipping container. First of all, I don't have the technical expertise to have any qualified personal opinion one way or the other on this. The guys that Copenhagen atomics tell me that they can fit 100 megawatts thermal into a shipping container. They seem like smart guys. But yeah, that's what I go on. Let's assume that they're wrong, and that it's not really possible to do that. It doesn't really change my view about the reasons why I think the vision that I've described it, at least in its fundamental concept, is still valid. And let's say that in order to get 100 megawatts thermal, it's not one shipping container, but it's five shipping containers, or is 10 shipping containers. The point that I'm making is, I think we're at an unprecedented moment in history, where there is a very strong movement afoot with between climate change, and Peak Cheap Oil really starting to put pressure on the price of petroleum derived energy, where the world is ready to do a complete refit of the entire planet to a new energy system. That's a circumstance we've never had before. And it creates the opportunity in my mind to take things that used to be bespoke custom construction on site and put them into fully robotic mass production assembly lines in factories.

So if it turns out that the Copenhagen atomics guys are wrong, and they fail it their attempt to put 100 megawatts into a shipping container. And it really takes 10 shipping containers to build 100 megawatt reactor, my argument would be okay, as long as we can still build those 10 shipping containers, or those 10, shipping container sized modules in fully robotic mass production assembly lines in factories and then ship them all over the world using the existing container ship based infrastructure, then I think we can still build modular power plants in less than a year as opposed to seven plus years for conventional nuclear. Maybe it's more shipping containers than I thought because of what you said. But I think the vision is still valid. And the opportunity that exists is to take what you already said earlier about the modularity of how most large scale nuclear power plants are made and say, let's not talk about modularity in the sense of you've got teams at Westinghouse that are building AP1000 modules by hand, but you've got a factory, which is mass producing all of those modules on fully robotic assembly lines in the volumes that we need to build what would eventually be about 3200 gigawatt power plants with an average electric capacity of two gigawatts each, worldwide over the next 25 years. I think we've got to get to mass production on fully robotic assembly lines in order to embrace as the economies of scale inherent to that kind of manufacturing, I think when you do that you can make nuclear energy cost less than energy from coal and gas. And I think that's where the really big wind comes. What do you think of that version of the strategy?

Mark: Well, Erik, there's a lot of metaphors used in manufacturing of X versus nuclear or building of Y versus nuclear plants. Let's just say that, if you look at the economics of, say, nuclear submarine reactors, nuclear aircraft reactors, I think that even if you posited these existing assembly lines, putting these exact reactors in sites on land, you would struggle to have that be comparable to the costs that the Chinese are able to make their giant American style reactors. And the Chinese are building powerful nuclear power plants for prices that are competitive with their coal plants, and certainly competitive with their natural gas plants, before they have a giant supply of pipeline gas to be able to lower that cost. So the natural gas plants themselves have achieved something like what you're describing. And even then, in many countries, natural gas power plants are struggling to make money for various reasons. So you have a really interesting situation where, if you want to you can use the analogy, let's have nuclear, that's as good as natural gas power plants. And for various reasons that natural gas power plants are also struggling to make money in electricity. So what this means to me, what I just said, is that even if you get the metaphor right and you get manufacturing right, it doesn't guarantee the outcome you're looking for with an energy revolution. And I say this, as an immense optimist of nuclear, who thinks that nuclear energy is the best energy source we have. And that we need to move as much as we can towards nuclear energy as fast as possible. And that's what I've dedicated my life to, I just wanted to pump the brakes a little bit on the analogy itself.

So having said that, where do I think we're going to see improvements? Well, first, it's starting nuclear projects with every bit of the technical design fully done, before you start it, starting nuclear projects, with a one to one perfect living operating example of that power plant that you can judge off of, it's starting nuclear plants with all the regulations in place before you start to know exactly what the regulator is going to want to see. And having experienced people who can deliver on that, whether that is only going to come when we set up robotic factories to manufacture immense numbers of specific modules. I don't think it's necessary to get to that scale, before we get to reactors that are cheap enough to greatly expand our nuclear construction and to pour trillions in capital into it. As for the vision of the modules that are shipping container size, I think it really does matter, that at the point you start having real reactors actually delivered in the real world, you rapidly see why we ended up with something like the designs and the scales that we have today. I think one of the first things you do if you could deliver a reactor of a few megawatts thermal in a shipping container or a little bit larger, is that you would want to increase the size to get double, triple or 5x the power, in barely more shipping containers and the shielding for even the shipping container reactor we posited that small, for that to work out right, you still need to structure anyway. And so you start the cycle all over again of rapidly scaling up your reactors to sort of power plant size. Does that answer all of the question?

Erik: I think so. Let's move on to a couple of other technologies that I've been hearing quite a bit of fuss over lately. One is pebble-bed reactors. I don't know anything about pebble bed reactors, but I've been hearing a lot of excitement about it. So please explain what is a pebble bed reactor? How does it differ from other reactors in common use such as pressurized water in boiling water reactors, and what are the benefits and drawbacks of pebble-bed reactors?

Mark: Sure. So here's a way to think about it. Imagine a bag of marbles, like you may have had growing up, I don't even know if kids have marbles these days, but I did grow up in the 90s. Imagine a bag of marbles and imagine each marble is a uranium fuel marble, and they sort of flow together, imagine pouring them out from a cup into a bowl. Now, these marbles, when close together and passing a gas through them, start to heat up red hot because they've got uranium inside that starts a fission reaction and then the gas flowing through heats up and then you use that to make steam, either high temperature steam that you use for industrial processes or high temperature steam that you then run through a turbine and make electricity. So the pebble-bed is the fact that you are using a bunch of these marbles, a bunch of these pebbles, with different sizes being proposed in different reactor designs. These fuel elements, it's sort of, you can think of it as the opposite end of fuel dual of durability, and hardness and toughness from the liquid fluoride reactors, where in that case, liquid fluoride you're dissolving the fuel entirely within the liquid fluoride and anything produced in the reactions just go straight out into the salts. These pebbles are supposed to be some of the hardiest objects ever made by humans and thoroughly contain all fission fragments, right?

So one of the issues with these pebbles is that manufacturing this fuel is extremely expensive. So far, we have this TRISO fuel, which is an acronym or phrase that's referring to the ceramics used. And at the moment, TRISO fuel is expected to be astonishingly expensive, so expensive that it materially shapes the price of energy you're going to get out of even an efficient design built and operated well. One of the issues with pebble-bed designs, and there are several of these in operation at the moment in China to have these reactors and there are several that have been designed and operated in the past, the technology ultimately comes out of Germany, I believe there's a South African connection too, is that the pebbles can, it's difficult to ensure that each pebble has the right burn-up and comes out of the reactor at the right point. It's also difficult to ensure, at least has been in the past, that they do not create dust, and that they do not chip against each other. In the past, these reactors have had relatively bad uptime, we will see if it ends up being better than the Chinese design that's recently come online. In that case in China, they have two 200 megawatt thermal reactors or two 250 megawatt thermal reactors, each together feeding steam to one 200 megawatt electric steam turbine. So their reactor has just entered commercial reactor, commercial operation after a relatively lengthy commissioning procedure of about a year and a few months. So the way I read that is that this is the best opportunity we've ever had of an extremely nuclear positive country, as opposed to say, Germany when they were working on their design, having a very large investment several billion into this technology, it took them longer to build than almost anything that the Chinese have ever done nuclear, which tells you something about the difficulty of novel reactors in a country that does not have the supposedly terrible Nuclear Regulatory Commission, and does not supposedly have all sorts of interference from civil society. And in a country that is very good at building large projects. This is China where they took again, three times longer to build this, this pebble-bed reactor, this high temperature gas reactor than they do currently for their fastest build times for their traditional reactors, again, showing you there's something fundamentally difficult with novel reactors, or at least non large light water reactors that we know how to build well now.

So we're going to see whether these pebbles with nuclear fuel inside of them are going to be the foundation for a reactor type that provides some things that our modern large water reactors do not do, which is very high temperature scene. And when I say very high temperature, in this case, the current reactors that we use around the world typically get up to an outlet temperature of about 300 degrees centigrade. Much of the industrial decarbonization that people think they want will happen at temperatures 600, 700, 800, 900,000 degrees C, if we can get up there.

One of the advantages of using molten salt as a coolant, even if you don't use a liquid fuel reactor, let's say you use molten salt with solid fuels like in the Kairos reactor in the US, a demonstration system of which has just been approved to be built at Oak Ridge. I think this is a fantastic and fascinating thing where we're going to take molten salt, which has some really good thermal properties, and we're not going to melt the fuel in it, we're going to keep it solid and we're going to use that. I think that this has a fighting chance to provide a fairly big breakthrough in industrial decarbonization, or if we're not even worried about decarbonization here, just industrial heat for countries that don't want to use fossil fuels because they don't have them, or they're worried about supply chain disruptions and importing them overseas.
Quite excited about that use of molten salt, and it does not require the pebble-bed approach necessarily, that the Chinese are going to try.

Erik: Mark I think you've touched on a really important point there that I want to amplify, which is the importance of these higher temperature reactors is that, if you want to do something other than produce electricity from nuclear energy, if you want to desalinate seawater or if you want to produce ammonia, liquid fuel, or even synthetic hydrocarbons that are created by mixing hydrogen with sequestered CO2, all of these processes require very high temperatures, higher temperatures than pressurized Water Reactors typically operated. So we just talked about the pebble-bed reactor, if the goal is to provide high enough temperatures to do seawater desalination, hydrogen production and so forth, what other technologies should people be keeping an eye on in order to support that objective?

Mark: Well, first, I want to mention that you can do all this stuff, you can produce these temperatures by just using electricity. The reason we're so excited and so interested in seeing higher temperature reactors is that you greatly increase the overall thermal efficiency of the process if you can use the heat directly without turning it into electricity first. And, you can still use 300 degrees C steam, if you want it to heat, you would just be doing pre heating or heating a bunch of the system up to those temperatures and then needing to add heat either from combustion or the use of electricity afterwards. And the more you can get done with the temperatures up to your target temperatures, which can be 1000, 1200, 1500 degrees C, the higher you can get with the nuclear heat itself, the higher total thermodynamic efficiency of the entire process. And why is this? Well, then we would have to actually get back into the dynamics itself. But if I had to say it, simply I just say this, higher temperatures means higher collision speeds between molecules. And you can capture more of the work at higher collision speeds than you can when you're using lower collision speeds. That's the way I'd put it. Okay, so the higher temperature reactors would get you a lot of the way closer using just the nuclear fuel reaction. And a lot of the world's decarbonization needs to happen from replacing reactions that happen well above the operating temperature of current reactors. So hopefully, that helps.

Erik: Mark one of the reactor designs that you've already mentioned, or that we've just discussed is the pebble-bed reactor, which is gas cooled, what other reactor designs meet this need for high temperature?

Mark: Well, one of the active development programs around the world, including in Russia, where several full scale commercial reactors are producing energy, is sodium. So sodium, the metal, not sodium chloride, the salt, and I've heard a lot of people get that confused, but sodium is a very lightweight metal that melts at relatively low temperatures. And there are many countries that have operated successfully, operated prototype sodium reactors. You mentioned Erik, in an earlier question, you mentioned the electricity from nuclear was first coming in 1951 from an experimental reactor, which itself was a boat, the first operational sodium reactor and the first breeding reactors and it was capable of making more nuclear material in itself than it was using up to run the reaction. So, sodium reactors, sodium metal reactors can operate at about 600 degrees centigrade, maybe 555, 560 C. Another type is lead cooled reactors, this lead cooled, so you have liquid lead, like the liquid lead that plays a role in the defense of Notre Dame, Hunchback of Notre Dame. This lead melts at a relatively low temperature, is extremely heavy and can move a lot of heat. And it is also itself an extremely good radiation shield and it also does not slow down neutrons much at all, the neutrons bounce straight off the lead and go straight back to the fuel. So it's used in fast reactor designs. It has powered Soviet submarines, not very successfully, they were kind of dogs and occasionally froze up in port, which caused the entire reactor to need to be scrapped with the lead frozen inside the reactor and stopped flowing. So lead cooled reactors are very interesting for a number of reasons, one of which that you could get extremely high temperatures theoretically. There's an Italian startup, Nucleo, that is a lead cooled reactor, you have a lead reactor concept that Westinghouse has been working on. The Russians are actively building a multi 100 megawatt prototype led fast reactor called BRESD, they're working on that. So lead fast reactors are one of the types that would presumably get you very high power densities meaning a relatively small device with relatively to high power output, and one of the difficulties there is that lead is so dense, so heavy that seismic events would pose a certain challenge. The shifting Earth in an earthquake would move this ultra heavy or ultra dense reactor back and forth, which makes a significant structural challenge.

Another type of reactor would be what I mentioned before Kairos. This is a molten salt, solid fuel reactor. So a lot of people first learn about nuclear through say, Kirk Sorensen videos, when they think that to get the advantages of nuclear not only do they need a novel reactor, but they need all sorts of novelties all at once. All sorts of features all at once. Well, Kairos is an attempt to make high temperature heat without the challenges of molten fuel where the fuel products are floating around and doing mischief. So that's going to be a molten salt solid fuel reactor that I think is interesting. Gas graphite reactors, so this is where you use graphite. This is a type of reactor that the British, most British reactors are of this design, although they're not building anymore. There used to be a lot of countries making gas graphite reactors of different types, where the idea is that the gas as coolant gives you the high temperature efficiency. And the graphite slows down the neutrons so you can make energy out of lower enriched uranium, that's going to be a type that that will continue to receive interest as long as people are looking at high temperature heat. So startups like X-energy, which is working with Dow Chemical, and Ultra Safe Nuclear Company, USNC, those are companies working on gas reactors that are going to use fuel of the design, similar design, but much smaller, compared to those pebble bed reactors. So the TRISO fuel, there's going to be embedded in graphite and used as the basis of those reactors with hot gases pass through them. So I'm trying to think of any I may have missed there, I'm sure there are ones I've missed, but some reactors combine sodium and potassium. So that's NaK, the MARVEL reactor, the micro reactor that was designed and is now being constructed in a sprint program at Idaho National Laboratory. I'm really excited about that project. Because the point is just to prove that we can design, license, build and operate in the shortest period of time, a novel reactor system. I think that that's quite exciting. And that's going to make a tiny amount of power, but it's going to show that we can at least get something novel prototype built and operated in a few years. And then we also have heavy water reactors, which are going to be lower temperature, like the light water reactors, but may offer other features that are really compelling, like extremely long uptime, and the refueling and flexible use of different fuels.

Erik: Mark, you've mentioned China several times in this interview, and I want to focus on China next. First of all, we have a lot of Chinese listeners. So I want to congratulate you guys, because it's just fantastic to see, as a technologist, the progress that's being made in China. It's really amazing. Starting with page 10 in the slide deck, Mark, look, let's face it, the Chinese are running circles around the West and I do congratulate our Chinese listeners, you guys are doing a great job. But in terms of the geopolitical balance of power in the world, I'm really getting concerned that China is kicking ass, they're really doing a good job. I feel like Western governments are not doing a good job at all, at understanding how important the advances in nuclear energy are going to be. Yeah, they're starting to talk about it. But China's doing it not talking about it. Look at the number of planned and proposed reactors on page 10, China's already got plans, they're in the process of breaking ground to build more reactors in the next five years than the US has total built in the last 70 years. If you move on to the next slide, page 11, that's a diagram of the Gobi Desert reactor that you mentioned a couple of times, that's a liquid thorium fueled Molten Salt Reactor based on the research done at the Oak Ridge laboratories back in the 1960s. China's actually building it while everybody else is talking about it. They finished building it, they got proof to start it up last year. I've been having trouble finding information about whether it's actually been started and if not, why not but I'm assuming by now they probably have started it up in the Gobi Desert, just as you were in the last couple of weeks off at COP 28, China announced on page 12 that they're going to begin building molten salt thorium reactor fueled container ships, so they're going to build container ships powered by molten salt SMRs that are thorium fueled. So that pretty much confirms my prediction that China would eventually go into the SMR business with advanced nuclear technology. They're doing molten salt cooled SMR containerships, to exactly when that's going to happen isn't clear. But if you look at their announcement, they're describing, you know, the whole vision about the hydrogen and everything else. They've got the same vision that we've been talking about. We're talking, they're doing. Moving on to page 13, that's the high temperature reactor, which sounds like it's a pebble-bed reactor. I'm not even certain of that. Maybe you can confirm. But my point really Mark is, yeah, I want to congratulate our Chinese friends in the audience. But from a geopolitical balance of power standpoint, it feels to me like China is doing everything they need to do to put themselves in charge of energy globally for the next 100 years, while we're dragging our feet. And it really makes me concerned about progress in the West, am I missing anything to be seeing it that way?

Mark: I think so. So here's one, I think that the most effective countries in energy are going to be the ones that have cheap indigenous fossil fuel reserves and pursue nuclear programs. Now, those two things together make a powerful energy arsenal. I'll say this about nuclear, I do not see nuclear power as being closer to hard power, when you build overseas, more like soft power. So for example, Soviet reactors dot Eastern Europe, Westinghouse is going to be able to, it has been able to copy the fuel form, and once they debug it and pick up more customers, a lot of the Soviet designed reactors, even new Russian reactors will be fusible with Western fuel companies. Now, reactors as a general safety principle are designed so that they cannot be interfered with electronically from off site, they need to be air gapped, they need to be controllable by locals. One of the principles of buying a nuclear reactor is being able to operate it and service it as much as possible yourself. To the extent that you're getting outside services, often you can get those from either Westinghouse or Russia. So you're getting a situation where let's say China builds nuclear reactors outside of China, you're going to be able to service those without Chinese fuel and supplies. Meaning nuclear reactors, unlike natural gas power plants are truly owned by those who have the reactors on their soils, not by the builder of the reactor. The reason I mentioned the natural gas plants is because Germany suddenly discovered when pipeline gas stop flowing, that your own natural gas plants that you buy, that you finance, that you service, that you produce, they are only yours so much is that you can get natural gas from someone if you don't produce it yourself. So I think China will lead on nuclear energy in ways that point the way to others who want to do nuclear, I think that China will build American designed nuclear reactors in ways that point America towards their own designs. I think that China will try to make nuclear cargo ships in ways that jumpstart other nations making nuclear cargo ships, I do not think that China will be able to dominate global energy because they're pursuing nuclear technology and nuclear construction effectively right now.

Erik: Mark, I want to move on now to an area where I very much look forward to following in your footsteps, which is pro nuclear activism. I feel passionately that the world needs a global nuclear renaissance. I'm so delighted to see, it seems to finally be happening. And I think that our only realistic path to navigate energy transition is going to be a nuclear centric solution, because nuclear is the only technology that really scales to meet baseload electric demand needs in energy transition. I know many of our listeners feel the same way. So I want to tap into your experience, not as a nuclear energy expert, but as a nuclear activist, you've basically been doing this activism gig since college, you spent your entire adult life, you're in your early 30s now, but you've spent your entire adult life being a pro nuclear activist. So you've been through the worst of the post Fukushima era of negative anti-nuclear public sentiment, you've watched the transition into what now is turning into a very positive public sentiment or it's starting to come around to that. So presumably, you know, from experience, what works and what doesn't work, and what the world needs the most from people who want to help advance this cause. So what advice would you offer me and our listeners who share your passion and desire to help this cause, but maybe who don't have the credential of your nuclear engineering degree to lean on? How can we be most effective in supporting the cause of nuclear centric energy transition and bringing on a full scale nuclear energy renaissance that I feel the world desperately needs?

Mark: Great question. And you're saying this as just a few minutes ago, the California Public Utilities Commission voted to extend operations at Diablo Canyon. This was something that even experienced nuclear fans, nuclear NGOs said was impossible, a lost cause, something that would never happen. And it's in large part a result of people, many of whom have no engineering education, much less nuclear engineering education, believing that it was utterly wrong to shut down a large, stable, long lived source of clean power in California, and they simply would not shut up about it, they would start finding other people that believe the same, was not stopped making the argument and they won. So I, you described it well, I was tearing up just a little hearing it described that way. Because I'd like to think of myself as very professional and trained as an engineer and ready to do, continue to do good consulting for energy companies inside and outside the nuclear space. But when you say activist, I guess I sort of was, I like to think advocate, but the activism part is banding together with a tiny group of people standing up for what's right before anyone was willing to provide funding to do so, payment to do so. Even a platform to do so, we had to make our own platforms just talking out loud. And it was a very hard road, we're now entering a cultural tipping moment where nuclear energy is becoming more popular than we have good projects to absorb the capital and the talent.

So we have to grow up as activists, we had to grow up as advocates from the under siege guerrilla warfare mentality that I think was a product of being, you know, getting into nuclear in the post Fukushima era. And we have to get to the point where we can help people learn about the magic of nuclear energy, and help them get ready for the really intense, really hard work ahead of making good projects and getting them financed. And I think that there's a group stage that moves past the desire to make novel technologies, which will continue to be important. Erik, I love your enthusiasm, I want you to keep looking at different ways to do nuclear better, including technology. But I just want you to be ready for the most likely outcome in the near term being the need to put together financially solid project proposals on existing powerlines. With existing designs, with our existing regulator, trying to reanimate mostly existing supply chains, in order to deliver projects on time and on budget. That's going to be the bulk of the work. And I'm really excited to help the advocates that I work with around the world. Think in terms of that as an end goal, while being very much open to working at novel reactor companies, developing new technologies, new tools, new methods, so that if we do have a technology breakout, we're ready to pivot to that as rapidly as possible.

Erik: Mark, I so admire your enthusiasm, your positive energy. You're a young guy in your early 30s and it's just obvious to me that you've got so much passion, and you always come to everything with positive energy and optimism and I'm very amorous of that. I on the other hand, I guess have a different personality. I'm almost 60, I'm well on my way to becoming a grumpy old man. And I do feel very resentful of what I consider to be a lot of government bureaucracy standing in the way of progress and what I feel is most necessary. And what I'm going to try to focus some activism on is this problem that, you know, look at what NuScale had to do, they spent $600 million on regulatory compliance alone, they don't even have a reactor. All they have is designs and a CAD program for how they want to build reactors someday and a lot of cool videos, they spent $600 million on, you know, placating the US NRC. And that only gets you authorization to operate in the United States. And you have to start that whole process over again, for the next national governments regulator, if they want to operate in the UK, they've got to go through that whole process. And that's another however many hundreds of millions of dollars.

These companies that are innovating the most exciting advanced nuclear technologies can't possibly afford to spend billions of dollars each on regulatory compliance. And I feel that what we need is not a national regulator. And I'm not talking about IAEA which is more of a watchdog and policing organization, but an entity similar to what the US INL, the Idaho National Laboratory, has been doing which I want to come back to in a minute, but a National Reactor Innovation Centre concept as INL has for the whole world, I think we need a global nuclear regulatory and certification authority and I'm going to coin the phrase “open source regulator.” And what I mean by that is, instead of going and having to jump through hoops for the NRC and then jump through a different set of hoops for the UK regulator, and another set of hoops for the French regulator, I think we need a paradigm change where, what the world adopts. And I'm going to try to begin lobbying governments with this idea is to create an international consortium of different countries that want to advance energy transition through nuclear technology and say, look, let's create one blanket organization which is going to certify and test new reactor designs. And we're going to invite all of the member countries to send their best engineers from their regulatory agencies and so forth to come participate. But everything we do, every meeting is going to be videotaped, every document is going to be scanned, there's going to be a website where every single element of compliance is recorded and catalogued and indexed and provided so that once you go through this process of certifying your new reactor design, you don't have to go to every single regulator on Earth and jump through a new set of hoops. You say, look, everything's there at open source, nuclear.org/you know, certifications, go and look up all of our data there, it's already been done, we're not going to spend hundreds of millions of dollars on each different national jurisdiction, just because every government feels a need to be in charge of things, we're going to do this once, by tapping into a number of different country's regulatory staff, we're going to get it right we're going to do a better job and even safer job than the US NRC does, we're going to do it more efficiently with a management structure, which is organized from the top down to focus on enabling energy transition, rather than preventing it with bureaucracy and bullshit. And once we get it done, we're going to say to the world, look, here's our reactor, here's the certification that's done by this international consortium. If you want the benefit of our energy, then tap into the work that's already been done. Don't make us jump through a new set of hoops just because you've got your own set of egos in your national regulatory agency. Let's just do it once. Get it right, and have everybody rely on the same data in order to certify reactors. What do you think of that idea?

Mark: First of all, I think I can be really excited along with you, on almost every point you've raised here, and I get to be the first person to tell you, we are moving in that direction. We truly are one of the countries that I've done the most work with pro bono, but I'm really excited about what we've worked on there in the Philippines, the Philippines is a nation of 110 million people, one of the highest population countries in the world. It's geopolitically extremely strategic, it’s, you know, having issues with China, but also doesn't want to be just a plaything of the US. It provides a lot of the able bodied sailors around the whole world. It provides really high quality, great labor force for countries around the world, especially in service jobs, which is great for those countries like Dubai, the UAE where I just came from in Dubai, but is not great for Philippine families that are broken apart for families looking for higher wages abroad. And it's got a great population pyramid for, if you want human race to survive rather than die out. So they're continuing to have babies there. All of this makes it a very interesting case for nuclear energy. And it's got a grid that's a little constrained for their largest reactors, they would need to update their guidance on how big a single unit could be to fit these reactors that I keep bragging about. And it has so many 1000s of islands that it would seem to be an extraordinary test case for micro reactors.

So the question is, what are they doing with their nuclear regulator? Well, guess what? It's just been passed a law to set up that new regulator has just been passed in the Philippines house. It is now in the Senate waiting to go through. And the regulatory law was written by an outstanding and brilliant young Nuclear Regulatory lawyer based out of Australia, Helen Cook, and she's pursuing part of this vision of transportable nuclear law. One of the things in this Philippines regulator law is that reactors can be accepted by the Philippines for their NRC classification, their certification, the Philippines has the right but not the obligation to accept those licenses from overseas, if there are traditional reactors or after two years of operation abroad to accept those license designs in the Philippines. So you might call it an anti guinea pig law, but still one moving us in this direction of portable licensing as lawyers like Helen Cook to help countries set up their regulatory structures around the world, as a new generation of thinkers in nuclear regulatory law work with a new generation of countries that are increasingly excited about nuclear energy's potential, but have no pre existing regulatory structures for it. I think you're naturally going to see this legal advice converged around highly portable nuclear law where you can certify a reactor in one country and give another country that right, but not necessarily the obligation to accept that license. So that's not perfectly the vision you outline, but it's definitely moving towards it. And I think that that type of thing will become more and more common, as young countries get into nuclear with a huge amount of optimism. And although they don't want to be testbeds themselves, they don't want to be say, felt as dumping grounds, they would love to be able to take advantage of new reactor technology that gets through the regulatory system of the advanced nations as rapidly as possible.

Erik: Well, the approach I want to take Mark, is to work with a sovereign wealth fund to fund the creation of the Toyota of small modular reactor, manufacturing companies that creates that fully robotic assembly line to build reactor components in, in fully robotic mass production assembly lines. And frankly, I don't care whether 100 megawatts fits into one container or 10 containers, if we can make it in containers and make it possible to get the economies of scale of building those containers on robotic assembly lines and ship them all over the world and build modular power plants out of them. The question then becomes, okay, how do you overcome the regulatory hurdle? And my model for this is to work with the sovereign wealth fund to fund the creation of that business, but also, that country's government to seed the creation of this global consortium of countries that would all share in the creation of a single regulatory certification agency that they might have their own regulators to do their own in country monitoring and surveillance and regulation. But in terms of certifying new reactor designs, which is where the big hurdle is for investment in these small startup companies, if we could get a consortium where you only have to go through the certification process once, my approach to this is say, look, everybody who wants to join that club, join the club. Big countries, like the United States and the UK and France are going to say no, wait, you know, we're in charge, we have to do it our way. And my answer to that is fine, we'll sell our reactors that are going to deliver much more cost effective energy to the countries that want to play ball with us. And when you guys are ready to take advantage of that economic benefit, you can get on the bandwagon too. But I think there's an opportunity for somebody to prepare no, I can't do it as an individual. But for some sovereign government to propose to the rest of the world, look, we need to create a nuclear certification facility that's going to allow new reactor designs to get certified once, allow the companies that are designing and building them to only have to pay for that certification compliance overhead once, and then a whole bunch of countries are going to allow them to operate on their soil, based on that one certification. So I didn't know about Helen cook, I will definitely look her up after we get done taping this interview because I want to talk to her about how her ideas might jive with mine.

Let's move on now though, because I've been kind of bad mouthing the US government. One ray of hope I do see is INL, the Idaho National Laboratory, they've been doing a terrific job, I think of writing great stories about what they're calling brand new technologies like molten salt, which I think actually is 50 or 60 year old technology. But other than the dating, they're at least pushing the right technologies or what I think are the right technologies. They've got this National Reactor Innovation Centre, which is chartered to work with small startup companies to advance new designs. I don't think their budget is big enough. I don't think they have a high enough position on a national agenda to really be effective. But it seems like they're doing some really cool stuff there. Are there other rays of hope in the US government front that I'm not aware of? And what do you think of the work being done at INL?

Mark: So I've got to visit INL, I went there in late June, early July of this year, and I really was blown away. The folks that that lab really want to help and for the most part have been given the money to help advanced reactor developers get as far and as fast as they can. One of the things they are empowered to do is to offer sites at the lab themselves. So out at the remote operations away from the city of Idaho Falls itself, for companies that want to build reactors on site. They were extremely excited about hosting the first NuScale plant. And I think that's going to be a fairly disappointing blow if that doesn't happen. But they are ready with several other companies that will want to build at INL. I think that they are moving in the right direction with what you might call the picks and shovels side of this gold rush. They are working very hard on things like developing the probes, developing the instrumentation, developing the testing facilities. I think that they would be best served by being given a few billion dollars to make the VTR, Versatile Test Reactor, I think it's an absolute crying shame that that somehow got lost in the different congressional priorities around nuclear, I think we desperately need more advanced reactor testbed. We desperately need the VTR. And it was a huge blow to American innovation and nuclear to not have that get constructed, start in construction. I think that the Navy is right to commandeer lots of tests reactor time. But I think this leaves, you know, because they're crucial for our national defense, international security, really, with our naval reactors programs. But that means that we have very few places that we have the neutron levels, the radiation levels and the testing, physical volume that we need to advance lots of different nuclear companies at once. So we've got to have more funding for test reactors, I think that is a crucial bottleneck.

Another thing we probably need to do is have more funding for INL, to have staff to execute. On the funding, they've already been offered to help advance nuclear reactors. I think that there's a burst of funding that doesn't all come with the right parts and pieces to make best use of the INL's extensive facilities and nuclear friendly communities. What else? I think that the lab director and who I was fortunate enough to get to travel to Barakah nuclear plant with just a few days ago, that's John Wagner. And his second in command, Jess Jean, who also came to Dubai, I think that they are both absolutely outstanding, absolutely dedicated to the nuclear renaissance. And I think that I couldn't ask for a more nuclear welcoming environment if I were going to build a nuclear company in the US.

Erik: Well, I definitely agree with you, the INL guys are my heroes on the US government front, the rest of the US government, particularly the NRC, I think we'll just have to agree to disagree on. Mark, I can't thank you enough for a terrific interview. But before we close, I want to talk a little bit more about what you do at Radiant Energy. I'm just so impressed. Because these days, unlike when I first met you a year ago, I mean, you are just super swamped with paying work, people that want to hire you to consult for them and so forth, you still have found time to continue doing your pro bono projects, including one called a GPOI. Well, I'll let you tell us what it stands for. Tell us about that. And also your consulting services because it may be of interest to some of our listeners.

Mark: Sure. And thanks for that very kind introduction. Radiant Energy Group is a relatively small consultancy. It's me and a few staff members. And we primarily are in London and Chicago, we were just in talking to a major asset manager today, trying to get them educated on nuclear, both the opportunities and pitfalls. So we were chatting with Blackrock folks today. Again, something I pro bono is not quite the right word. And obviously, we'd love to advise groups like Blackrocks, and how to invest in nuclear and to like I said, avoid the pitfalls. But there's a great deal of education that just has to happen as fast as possible, paying or not paying. And I think that's pretty exciting work. The paying consulting work that we do, tends to be toured for established companies in nuclear, especially in the nuclear fuel cycle, that is uranium mining and fuel production.

So because we are on the ground in many different countries, both for me as a speaker and our staff in doing research, we are in a pretty good position to have a global view of what's emerging in nuclear. Because of our network of contacts around the world, both inside and outside the industry, we tend to hear and see lots of different things and can rapidly get an understanding of emerging issues in nuclear and technological, as well as social. So our advice tends to be at the executive level, and tends to be fairly broad strategic advice. However, thanks for mentioning our new polling project, we intend to have the finest polling practice in nuclear and that means not only asking questions that lead to positive nuclear answers, but asking penetrating questions on a broad scale with professional polling firms who are comfortable operating across the world to get an absolutely clear sighted view of what people really think about nuclear energy. We just completed our first global level polling, we spent quite a lot of money. I think we spent it well on polling in 20 different countries, 1000 respondents per country, 50 questions per respondent, giving us over a million data points about what people really think about nuclear energy, everything from whether they think it's low carbon or not, whether they priorities reliability or safety, or cost in their energy preferences. And we compared nuclear on all these metrics against a range of other energy technologies. What this means is we've got this million plus point data set that helps us understand what the nuclear industry could do better to either answer fears or talk to the public, and where the public might be ahead of the nuclear industry on his perspective of nuclear energy.

One of the most surprising findings is that in a number of countries that really love nuclear energy, nuclear energy is not seen as low carbon. Let me re-emphasize that some countries that love nuclear energy, don't even see it as low carbon. What appears to be happening there, Erik, is that low carbon energy policy seems to be associated with lower economic growth, and sort of Western outlook on the climate. And there are some countries that love that their countries are building nuclear really, really quickly. And that feels to them like a non-Western accomplishment, which makes it seem like nuclear may not be low carbon, but they love it anyway, because it's powerful. In the West, the fact that so much of the population, almost 50% doesn't know that nuclear is low carbon and that low carbon is a fairly vital attribute of energy going forward in many of these countries. There's an untapped advantage in informing the public as much as us in nuclear advocacy think it's already known, there's a huge upside advantage of nuclear of informing the public properly, that nuclear actually is low carbon. And having this data from around the world to show it is quite helpful, and I think should be a compelling argument to the nuclear industry, to spend more money on marketing, to have better public acceptance in the future.

Erik: For people who want to contact you for consulting services or just to follow your work, give us your Twitter handle contact information. Where do we get a hold of Radiant Energy? What is your website and so forth?

Mark: Sure. Our website is www.radiantenergygroup.com, you can find me tweeting including during this podcast recording if you forgive me for that, Erik. It was important news though in Diablo Canyon. You can find me tweeting @energybants. That's @energybants on X, formerly known as Twitter. And you'll find almost nothing of me on LinkedIn. But you'll find us posting our research and publicly available studies there along with my colleague Richard Allington, who leads our global polling program from London.

Erik: Mark, thanks again for a terrific interview. Listeners, we know that most of you value actionable trading advice in addition to high level big picture interviews like this one and last week's Broken Energy interview with Lyn Alden. So let me address that issue before we close. Unfortunately, there aren't many good ways to invest directly in nuclear energy yet, Cameco, ticker symbol CCJ, owns half of Westinghouse, the company that built most of the old school conventional Pressurized Water Reactor fleet in the West. So that's the most obvious play if you expect the nuclear renaissance to focus on building more of the same, which is not my personal outlook. Unfortunately, investment in the advanced nuclear startups, that I think are doing most of the important work, is limited to accredited investors who can participate in private placements. For example, Copenhagen Atomics, a company that I've invested in myself, is conducting another capital raise right now, if any of our accredited investor audience are interested in that private placement, email me and I'll put you in touch with their CFO. But unfortunately, the advanced nuclear industry is still in its infancy, and there are very few public companies in the sector. Investing in the reactor fuel rather than the reactors themselves is the best proxy available for participating in the nuclear renaissance and uranium mining shares have been on fire since early spring of 2023. So to satiate the desires of our listeners looking for more actionable trading ideas, we'll be bringing Uranium Insider newsletter publisher, Justin Huhn back for an in-depth interview, specifically on investing in uranium and uranium mining shares. Justin and I will also discuss conversion and enrichment and how recent US legislation restricting importation of Russian enriched uranium products will affect that market. So that's a wrap for our 2023 New Year's Special. On behalf of Patrick Ceresna, Nick Galarnyk, Mark Nelson and myself, Happy New Year everyone! We will be back to our regular show format next week on January 11 2024.