Episode 3

Nuclear Economics

Packy

What do you think the pie of energy sources in the US looks like in the year 2050?

Bret Kugelmass

2050 is a hard number to predict. But I can say in 2100 it'll be 300, maybe 500% nuclear. So it'll be five times what we're doing today, and it'll be entirely nuclear. That's how I feel about the world, too.

If you were an alien civilization that were to visit us at some point in the future, it would be obvious that not some of it, but all of it would be nuclear. You're talking about orders of magnitude, raw fundamental physics advantage. It would be asinine to think otherwise.

Packy

That was Bret Kugelmass, the founder and CEO of Last Energy, who we introduced you to in the last episode, and who you'll definitely hear more from in future episodes. He's a good interview. Based on our first two episodes, Bret's sentiment seems right. Isn't it just obvious that we should have way more nuclear power just based on the technology we have today?

Of course, there were some bumps in the road from the 1970s until now, but if we just put our minds to it again, we can quickly build a lot more reactors. Right, Julia?

Julia

If only. I am super excited to be back for episode three of this season of Age of Miracles. Last episode, we dove into the history of nuclear energy and started to unpack why the United States nuclear power buildout slowed starting in the late '70s, and why it's been fairly stagnant ever since.

Packy

We talked about these five factors that contributed to the demise of nuclear energy in America. One, the Atomic Energy Commission. Two, the environmental movement. Three, the economics of building nuclear. Four, regulation. And five, the disasters at Chernobyl, Three Mile Island, and Fukushima.

So where does that leave us today? Put another way: if we wanted to start building gigawatts of large-scale nuclear, what would it take?

Julia

I think what it comes down to, like so many things that aren't illegal, is just the economics. Is there a way to build nuclear plants cost competitively with other energy sources, like solar and storage or natural gas plants?

Packy

I don't know. Today we're going to talk to a bunch of experts, and we're going to explain how a large-scale nuclear power plant actually works. Then we're going to get those experts' take on the best ways to start building nuclear cheaply again. To be clear, for this episode, we're not going to be digging into new technologies in fission or fusion, or choosing a side in the battle between small or large nuclear reactors. We're starting from the premise of: if we just tried to implement and scale the technology that we have today for large-scale nuclear reactors, could we do it?

We'll dig into the nitty-gritty economics of actually building plants and point out some opportunities to improve key problem areas like financing and workforce deployment. And we'll even discuss some pretty creative ideas, the kind of ideas that I love, like building floating shipyards to manufacture nuclear plants, or repurposing old coal plants and putting them to work as nuclear plants. But I think the best place to start is with this idea that it's not impossible to build more nuclear cheaply.

Julia

It's happening elsewhere in the world right now. If you look at China, for example, they're building new gigawatt-scale power plants for $3 to $4 billion each. That's pretty impressive.

Compare that to Vogtle 3 and 4, the two new reactors coming online in Georgia right now, which are costing $31 billion in total to build. Something's off here.

Packy

It's even worse than that. We can't assume that China is building plants as cheaply as they could possibly be built. When we talked to Jake DeWitte, the founder of nuclear fission startup Oklo, he made a similar point to the one that Brett made at the beginning of this piece.

He used the phrase "cost physics" that I haven't been able to get out of my head since.

Jake DeWitte

Nuclear has significant advantages for all sorts of reasons. From a math perspective, it should be the majority of the energy pie. It provides significant value in the energy it produces, being both reliable and dispatchable.

Nuclear actually has all the cost physics on its side. It has the lowest material footprint, requiring the fewest kilograms of steel, copper, concrete, fuel, and so forth, per megawatt hour of energy it produces. So it should be the cheapest source of energy that we have. That means that there's obviously a lot of room to fully realize that potential.

Julia

If nuclear fission has the best cost physics of any energy source, but is currently the most expensive to build, there's clearly room for improvement. Making nuclear cheap isn't impossible. Fission itself is an incredibly cheap way to produce energy. But building all of the things around that nuclear reaction is where things get expensive.

If we want to build more nuclear power in America, we need to improve the economics of building new reactors. It's as simple and as complex as that. The complexity stems from a Gordian knot of three main intertwined issues, each of which has its own sub-issues: construction, financing, and regulation.

Packy

The hard part is that all of these factors are connected. The longer construction takes, the more the utility has to pay in financing costs without generating revenue, stacking debt on debt. Because projects, including their financing costs, are so expensive and unpredictable, utilities have a hard time underwriting and deciding to buy them. This means we build fewer plants and don't gain the efficiencies from experience that higher volume implementations benefit from. That makes construction slower, less predictable, more error-prone, and more expensive. And then we don't build them. It's a downward spiral.

Julia

The result of this tangled mess is an enormous gap between the cost physics and the construction reality. The energy source with the potential to be the cheapest is the most expensive to build. In Walter Isaacson's new book on Elon Musk, he talks about Musk's idea of an "idiot index." It calculates the ratio of a product's final cost compared to the cost of its raw materials.

A high idiot index, like ten to one, or as Musk said for rockets, fifty to one, meant something was wrong and therefore fixable. So what's the idiot index for nuclear? By that metric, Isaiah Taylor, founder of Valor Atomics, thinks nuclear is ripe for rethinking.

Isaiah Taylor

We're not even in the same world with nuclear construction. It's almost impossible to even talk about that.

It's as bad as 99 to 1 in a lot of cases.

Packy

How can we get back to building nuclear plants faster in order to bring down costs so that we can build even more nuclear plants?

How do we get those experience curves that solar and wind have going for them to work for nuclear?

Julia

To answer that question, we're going to get back to basics. We hooked you with some nuclear myth-busting. We talked about anti-nuclear advocacy. Now we hope that you're nuke-pilled enough to dive into the nitty-gritty with us because this is where this battle is going to be won or lost.

To start, we're going to do a quick refresher on the miracle of what generating electricity from splitting atoms is all about. We wouldn't be a very good nuclear podcast if you didn't understand at least a little bit about how nuclear fission works and how nuclear power plants actually produce electricity.

Packy

We talked to Josh Wolfe. He's a managing partner at Lux Capital, and he thinks that nuclear needs a rebrand. People are supportive of using the wind, the sun and the water to generate electricity, but they're forgetting about the rocks.

Josh Wolfe

Everybody loves solar. It's a beautiful thing. The sun is abundant. You've got a fusion reactor in the sky, and we've developed semiconductors to convert that into usable electricity. Electric cars are great and are the future. Electrification of homes is beautiful. We love solar and wind.

Wind is great. It's abundant pressure differentials from temperature caused by the sun, but also very expensive and capital intensive. We love water, hydro, hydroelectric, which are also abundant.

The only piece we're missing are rocks, and there's these beautiful rocks, and some of them have uranium. If you can release the uranium, it's just this wonderful power. So sun, wind, water and rocks - there's elemental energy.

Julia

Uranium has so much baggage attached to it at this point, but really it's just rock. What makes this rock so special is that the element it's composed of, uranium, is the heaviest naturally occurring element on earth.

Because it's so heavy, as heavy as nature is willing to get, it's actually the most prone to splitting apart when bombarded with neutrons. And that releases energy in the process.

Mark Nelson

Well, I can explain why I eventually became so addicted to nuclear energy. It's the idea that with just the metal available in the earth's crust and oceans, we can power a prosperous civilization until the sun expands and blows off the atmosphere.

By that time, if we haven't gone to space, we don't deserve anything else.

Packy

That's Mark Nelson, the nuclear advocate we met in episode two and a big fan of uranium. He explains what happens in a fission reaction with uranium, which leads to huge amounts of energy being created.

Mark Nelson

The uranium nucleus is the heaviest one we've got. It's heavy and stays together. But if you can knock it, jiggle it, or dislodge it, you can split it. If you split it, the two halves suddenly don't want to be together and slide apart at extremely fast speeds, like shotguns.

If you could weigh the pieces as they move, you'd find there's just as much mass there as before you started. But those particles don't keep moving. They start smashing into things. They're big chunks of matter on the subatomic scale, and they're slamming into things, knocking the crap out of everything. That leaves a lot of vibrating molecules and atoms. We call that heat. The process of these two chunks slowing down leaves everything a little hot and bothered in your local ensemble of atoms.

If you then measure your particles at rest, you'll find that your measurement is now different. When they're slower, down to the speeds of normal molecules bouncing around at only a bit hotter than room temperature, you find that you're missing mass. The mass has been lost as energy. And that energy is really large compared to messing with the electron configuration of atoms.

What do I mean by that? Combustion. Fire versus fission. When you burn one molecule of methane, you get about 10 electron volts of energy. An electron volt is really small, but you add it up over the number of molecules you have and it's a lot. But when you split one uranium atom, by the time the bouncing is done and you account for various losses, you end up with 200 million electron volts added to the world, lost from mass. That 200 million versus ten is what you're playing with and why the uranium and thorium we have on this planet can get us through to the end of our star.

Julia

That enormous yield, 200 million electron volts versus ten, is what makes nuclear fission such an efficient way to generate electricity. To reiterate the comparison Mark makes here, when you burn one molecule of methane, like in natural gas or coal, you get 10 electron volts. When you split one uranium atom with fission, you get 20 million times more electron volts.

Packy

Think back to your high school physics class. E equals mc^2. I know this is basic and might feel contrived, but it's maybe the most important formula in physics, and certainly for this season of Age of Miracles.

Mass and energy are the same thing. And because the speed of light squared is an absolutely enormous number, a little tiny bit of mass contains an absolutely enormous amount of energy.

Julia

1 kilogram of mass about the size of a liter water bottle could power New York City for five months. The question is how to convert it. That's where nuclear reactors come in. Essentially, the energy produced by the fission reaction comes in the form of heat. This would happen no matter what type of reactor we put the fuel rods into. It could even happen without man-made reactors at all.

The Oklo uranium mines in Gabon, Africa, operated as natural reactors roughly 2 billion years ago. They cycled on and off as water levels fluctuated in the mines. The heat from those reactors actually melted the surrounding sandstone into glass. We still have evidence of these reactors underground out there today.

Packy

Think about it. That's zero capital costs. How do we go from those natural reactors in Gabon to what we have today?

How does a nuclear plant work? How do you turn splitting uranium into electricity?

Julia

The most basic way is that you're producing heat from fissioning. That heat can heat up water, creating steam, which turns a turbine. Those turbines are the same as you'd see in a natural gas or coal plant.

That's what generates electricity. That's how nuclear power plants power a million-plus homes from a single plant. It's just so much heat and power that's able to be generated there.

Packy

That doesn't sound overwhelmingly complex or costly. Maybe it makes sense to just talk through the economics of a nuclear plant and start unpacking where things get expensive and go off the rails.

Julia

Let's do it. We talked in the beginning about how a lot of this cost is actually just in building the plant upfront. We don't really have a workforce for this. At this point, we're building these once every ten years. That is hard to do well. We're not coming down any sort of cost curve right now, but the actual operating of the plant is much cheaper. The fuel itself is incredibly dense and not particularly expensive. If you look at the operating budget of a plant, the fuel itself is a much smaller percentage than in a fossil fuel plant, which is 40% to 70% of the costs.

While nuclear isn't technically renewable like wind or solar, and we do need to mine and process it, it is much closer to the renewable side because it's incredibly abundant and energy dense. It's such a great source of fuel with many benefits for those reasons. Nuclear is unique among energy sources in that the financing costs associated with building it make it so expensive. People are worried, for good reason, about these projects getting finished. So the interest rates are quite high. If they go on for years and have delays, you're paying even more interest because you're not paying your debt back on time. These capital costs end up making nuclear power plants so expensive and slow.

I want to turn it over now to Nick Touran. He's the author of whatisnuclear.com. We met him in the last episode too. He's got a great guide to the economics of nuclear power on his website, and we asked him to give us the TLDR on nuclear power plant economics.

Nick Touran

There are a couple of different ways of looking at the economics. If you look at the levelized cost of electricity, the biggest component of a new build is the mortgage, especially in the West where there's no super cheap state financing. When you get a loan to build a huge capital project and you're paying interest on this loan, that's more than half of the total cost of the plant.

Julia

Nick points out that the materials cost about 20%, but that's far more than the actual raw materials themselves. Regulation requires all materials to be "nuclear grade", with extensive quality assurance processes, far more than any other industry, even something like aviation that's flying humans around.

Bret breaks it down for just one material input: concrete.

Bret Kugelmass

People love to cite this number: "$2 billion out of that $10 billion was spent on concrete." Well, no, it wasn't. The concrete itself cost a small fraction of that. But the regulatory requirements on how to pour the concrete were expensive. With the Vogtle plant, when they poured it slightly wrong, putting the rebar an eighth of an inch off instead of a quarter inch, a regulator flagged it and made them tear up a billion dollars of concrete.

Critics of nuclear cite these facts and statistics, but they're not telling the whole story. It's not that there's that much concrete; the concrete just cost 100 times as much on a per volume or per mass basis due to regulatory requirements.

Packy

To do some rough, back-of-the-envelope math here: materials cost about 10 to 100 times what they'd cost for you and I to buy, accounting for 20%. Fuel is 5-10%, maybe 15%. Operating the plant with management, security, etc., is 15%.

Then you throw in regulatory compliance, licensing fees, waste management, and insurance, that's another 10%. Construction costs like design, labor, and land acquisition are 15%. And then you're left with financing costs at the end, 25% at a minimum.

You even see that go all the way up to 40 or even 50%, depending on how delayed the project is.

Julia

Where is a utility going to come up with $30 billion to pay for something like this? As the costs are unpredictable and every day you delay adds more debt to repay, it really just becomes this snowball.

Packy

This is a dumb question, but you mentioned utilities coming up with the $30 billion. Who's actually paying all of these costs and buying large nuclear reactors?

Who's the person or the entity that says, 'I would like to order a nuclear reactor, please.'

Julia

Not a dumb question at all. It really gets to the heart of the issue. Power utilities are both the buyers of large nuclear reactors in the US and the project developers, responsible for bringing everything together. At Vogtle, for example, which is part of Georgia Power (a subsidiary of Southern Company), they ordered a Westinghouse AP1000 reactor and paid for it.

Let's take a moment to talk about who Westinghouse is exactly. Westinghouse has been involved in the nuclear industry since the development of the first commercial pressurized water reactor. They've developed various generations of PWR technology, widely used in nuclear power plants around the world. One of Westinghouse's most notable reactor designs is the AP1000, an advanced PWR reactor used all over the world. China has four of these AP1000 reactors in operation and six under construction. Ukraine has nine contracted and India has six.

Back to Vogtle. Southern Company was responsible for putting it on site, building all the shielding and infrastructure around the project, and they were on the hook for the costs and time overruns. Ultimately, they passed that price back to their customers over time, who eventually consumed that electricity. That's the bet you're making as a utility: by investing in a new plant today, you're going to meet future electricity demand profitably. You might be thinking about plants scheduled for decommissioning in the next few years. You're considering a decades-long time horizon. After factoring in all costs to get the plant operational, you're thinking about operating it well into the future. This typically works well in regulated markets but gets a lot harder in deregulated markets.

Packy

You mentioned the long time scales and the regulated versus deregulated markets. When I think of utilities, I think of big organizations that can think on 50-year time horizons. They can say, "This is what our electricity costs now," and people have to pay whatever they say it is. It's pretty much as good as investing in a bond. But I think the distinction between regulated and deregulated markets is important, and I didn't fully appreciate it coming in.

In the regulated market, which is what I typically think of, you have a set cost of electricity and you say, "Sorry, ratepayer. If you live here, this is what you have to pay." Deregulated markets, on the other hand, have to compete on price. If you make the wrong calculation, there are energy traders out there and real market forces that will just use whatever the cheapest cost of electricity is right now.

Is that the right way to think about it? And how does nuclear play in a deregulated market versus a regulated market?

Julia

That's exactly right. It's really challenging for nuclear to fit well into deregulated markets. If you look internationally, China and South Korea are great examples of top-down, federal government-driven, largely subsidized projects. They likely pay little in interest costs, which helps when capital comes from a large centralized place.

Whereas if you're a small utility competing on the market, you want your power production to be as cheap as possible. So you're incentivized to build things with shorter ROIs, like natural gas power plants or solar farms. That's what makes it difficult for utilities to make this huge bet on a nuclear power plant.

People joke that nuclear has been called 'the utility killer' for a reason, because utilities have gone out of business attempting to build a nuclear power plant. It's just so expensive. If they don't succeed, they're dead in the water.

So if we want more nuclear in the US, we'll have to convince utilities to start ordering more nuclear reactors, maybe with help from developers or others. That's the challenge here. Let's turn it over to Emmett Penny to explain why.

Josh Wolfe

I can tell you right now, no investor-owned utility is looking at the Vogtle experience and saying, "Sign me up, I definitely want to deal with that for the next 15 years." Even if it's only ten, they don't want to do that. It's steep. Maybe some project financing could be there. Part of it's also that when you do a major project like this, you basically have to go through the cost disease progressivism.

Let's say we go to subsidized nuclear. We want more nuclear plants. But then the regulatory environment makes it really hard to do. Where does the money go? The money goes to two teams of lawyers who are going to war it out in court about whether or not we can do this. And that will drive up the costs of the overall project that have nothing to do with getting it built.

Packy

James Krellenstein made a similar point. There are real people at the utilities on the hook for ordering these projects. As it stands, dealing with the complexities of a nuclear project just isn't a very appealing prospect.

James Krellenstein

We talk about Vogtle 3 and 4. We started construction on four AP1000s in the United States. We're finishing two of them, Vogtle 3 and 4. But there's also Summer 2 and 3 in South Carolina that are now a rusting heap of rebar, piping, and concrete, worth $9 billion.

Not only did that experience cost the ratepayers, who will be paying that $9 billion for decades in increased power bills, but it destroyed the company that ordered it. Scana, the lead utility that ordered it, doesn't exist anymore and was sold at a fire sale to another utility.

Even worse, the CEO and COO involved in building Summer 2 and 3 lied to the public utility commission under oath in an attempt to keep the project alive, thinking they would ultimately engineer their way out of it. They got caught lying and are serving time in prison. We need to be honest about this.

As physicists or engineers, we've been taught that to solve a problem, we need to accurately identify it. Imagine you're a utility executive now, watching your colleagues go to jail for ordering this.

Then you see Vogtle 3 and 4, which Southern Company and Georgia Power to their credit persevered through an unending nightmare for over a decade. It was $10 to $15 billion over budget and only a couple years over schedule. And then you're asked to do another one.

Packy

That's tricky. You're trying to convince someone to do something that's more expensive, riskier, and more subject to cost overruns. And if you do it wrong and lie about it, you could end up in jail. But as James said, "If we're going to solve a problem, we need to accurately identify the problem."

We've touched on many problems that have slowed nuclear's growth: NEPA reviews, the fact that anyone with a lawyer can sue a project to a halt and balloon costs, an untrained workforce for nuclear plant builds, long unpredictable timelines, and the nuances of deregulated electricity markets. But every way to make electricity at massive scale has operational problems and challenges. Yet we've built many new solar farms and more oil and gas facilities. These challenges don't explain away or excuse the underlying problem.

To cut the Gordian knot at the heart of nuclear stagnation, we need to fix the economics of building a plant and/or provide financing solutions that make it more comfortable for utility executives to order more plants.

Julia

I think that's right. After Vogtle 4 comes online, there are no new nuclear plant projects on the docket. None. If we want to hit our emissions goals, let alone get to a point of energy abundance, we need to fix that.

Packy, how do we build more large nuclear reactors? What have we started to hear from different people about the path forward?

Packy

Thanks for listening so far. We'll be right back after a quick word from our sponsors. Unfortunately, there is no silver bullet. The experts we've spoken to have offered a number of different solutions.

For large nuclear projects, they all come down to decreasing costs and risks for utilities and their executives. There are various ways to do that, from government insurance and backing of all projects like in China and South Korea, to a "war effort" for nuclear, or shipyards churning out large reactors to send throughout the country. There are a number of different solutions here.

Julia

The fact of the matter is we need many big, boring, beautiful, large reactors to meet our emissions goals and provide clean, reliable, baseload power to the grid. It's primarily an economics and cost problem we need to figure out, not an innovation issue. The technology exists and works.

It's just been shunted around in this weird mix of historical, cultural, and economic factors we discussed in episode two. Nuclear is a fantastic technology. It's just been under leveraged and we need to remember how to actually go implement it.

Packy

One of the fun parts of this podcast, and my job generally, is figuring out how to explain complex topics. This one seems particularly hard. We make it sound simple with economics, but there's so much that goes into that.

Do we start with financing costs because they're the biggest? Or do we focus on regulation, where the ALARA (as low as reasonably achievable) policy has plants spending millions, if not billions, on anything that could possibly lower radiation exposure risk?

This might sound good in theory, but not if it's essentially safety theater, like the TSA for energy. If these costs make nuclear unviable, we're unnecessarily missing out on a fantastic source of carbon-free energy.

Julia

Totally. Or do we focus on shoring up the supply chain, which has atrophied over time? If you're only building a new plant every ten years, that's not a great business for vendors, and they'll charge more for products. Do we focus on construction? Who develops these large reactors?

How do we get better at building them? It's hard to entirely blame regulators when many of the Vogtle delays can be chalked up to poor project management. You have to clean up your own house first.

Packy

We've had this ongoing question with each other and guests about whether nuclear is compatible with free markets at all. In China, Russia, even South Korea, the government can say "we're building more nuclear," and it just happens. Here, we have this tough mix of free markets and stringent regulation that makes building challenging. We have to assume free markets can work, but maybe the best place to start is ensuring nuclear is on a level playing field with other energy sources.

We spoke with Julie Kozeracki in the Department of Energy's loan program office about how market forces impact nuclear energy's ability to compete. Julie works with Jigar Shah, the director of the loan program office (LPO), which has over $300 billion in loans and loan guarantees available to help deploy large-scale clean energy projects.

Julie Kozeracki

Something that has consistently put nuclear at a disadvantage is an undervaluing of its benefits for a resilient decarbonized grid. Whenever Jigar posts about nuclear on Twitter or LinkedIn, more than half the comments say, "Why are we wasting money on nuclear when solar is right here?" It doesn't really matter if nuclear is never as cheap as solar because it provides such a different set of services to the grid. Nuclear needs to compete with solar paired with very long duration energy storage.

But when you look at cost estimates for long-term intraday storage that would make variable renewable generation on par with nuclear generation, you see that nuclear is likely pretty cost-competitive with other clean, firm options like renewables with moderation storage or natural gas with carbon capture. Similarly, although natural gas on an LCOE basis like solar or wind is very competitive, if you price in the decarbonization benefits of carbon capture, you're looking at a technology that's got to be demonstrated and deployed at scale. With nuclear, we at least have decades of operating experience on the reactors.

Julia

If you just look at the price tag for building solar, it does look a lot cheaper than building nuclear. However, it doesn't account for the lack of reliability or intermittency, as we discussed earlier.

If you build in long duration storage, like batteries or carbon capture, you're looking at something much more expensive than just the solar panels themselves. These technologies aren't fully developed or deployed yet.

A very small percentage of solar farms in the US are coupled with long duration storage. Most rely on natural gas peaker plants that turn on and off depending on sunlight and grid demand.

Packy

The undervaluing of the reliable 24/7 nature of nuclear energy does seem to be a big issue here. If we believe that reliable grid-scale power is a common good, it begs the question of whether the government, state or federal, should be playing a bigger role in setting standards or incentives around reliability.

Julia

Exactly. If you just left it to the free market, you might find that everyone just has to keep a backup generator at their house to use during blackouts. Speaking of generators, sales are up 250% since 2017. Reporting points to grid reliability issues being the driver of those increased sales.

We've heard from Julie about how market incentives don't necessarily point to new nuclear. Now let's hear about how she sees the challenges around actually building more nuclear power plants.

Julie Kozeracki

The question remaining is, can we figure out a way to manage megaproject construction to bring them in reasonably on time and on budget? There probably is some piece around actual market reform that might be required to ensure it's not just the rate-basing, regulated utilities looking at new nuclear, but that folks in deregulated markets are able to get compensated for and show the value that nuclear is providing to the grid. I hope it doesn't take folks experiencing blackouts to realize it's worth investing in resiliency.

Because we're in an exciting stage now where we are incrementally adding more renewables, I worry there may be a tipping point beyond which each incremental level of renewables gets more expensive, difficult, or leads to less reliability. We need as many renewables as we can possibly have, and I think nuclear is one of the best complements we have to successfully deploying renewables at scale. But it's some of those second-order implications around land use, transmission, and jobs benefits that we haven't fully addressed.

The conversation hasn't necessarily moved to what the realities of an 80% truly, deeply decarbonized, mostly renewable system would look like. The NREL clean future study, for example, that looked at what an all-renewables path would look like, has a tiny footnote saying it would require tripling the transmission capacity in the US. And if there's anything as difficult to build as nuclear power plants, it's transmission.

Julia

Julie's perspective is interesting because the DOE loan program office doesn't have a horse in the race. Its job is to accelerate energy transition investments by providing the cheapest loans possible to American companies working on the transition, whether it's building solar farms, batteries, specific pieces of the nuclear supply chain, or the reactors themselves. They had a $12 billion loan guarantee backing up the Vogtle project.

She highlighted the non-negotiable need for nuclear in the transition. She pointed out that while they're willing and ready to support these projects, the actual loan applications haven't been there. As we talked about before, there are no new large-scale nuclear power projects on the docket right now. She and Jigar Shah, who runs the DOE's loan program office, have both repeatedly called out the private sector for not bringing them enough projects.

There's a good episode of Jigar on the Decouple podcast where he lays into the nuclear industry, saying they need to actually start building because the loans are there, but no one's showing up to get them.

Packy

It was even crazier than that. We'll put the link in the show notes and the resources doc. But I've never heard a government official in a conversation with somebody representing the private sector so clearly say, "Hey, I think all of you are overcomplicating this. We are here. Fill out the applications. I know it's a lot of pages, but we're here with billions of dollars waiting for you guys to get your act together. Come and get the money."

Julia

Yeah, it's sitting there waiting. Before the IRA, which came out last year, there were so many subsidies for wind and solar - I think about 27 times as much as nuclear, despite nuclear being a much larger percentage of our grid. Finally, for the first time, there are now some subsidies for nuclear, so we're starting to level the playing field.

It's not quite completely equal, but I'm hoping that these types of incentives might start to move the needle here.

Packy

The cool thing about talking to Julie was that because she sits inside the federal government, they can talk to all of the industry executives and figure out what's actually holding them back. They recently surveyed the executives on why they weren't ordering more projects or submitting more applications.

And one thing came up more than anything else...

Julie Kozeracki

We often hear utilities and other customers say they need to go to their boards, shareholders, and public utility commissions to get permission to move forward with new nuclear projects. As grateful as we are for the perseverance of the folks at Southern Company on Vogtle, cost and schedule overruns there have had a strong cautionary effect on many folks. We heard a couple of things. One was a compelling answer to the question during the researching of the liftoff report: "What would it take for you as a utility to move forward with new nuclear?" The response was effectively cost overrun insurance. They said they're looking for the government or some third party to help share in what they see as potentially almost unbounded cost overruns.

An interesting draft structure was proposed: if a utility were to move forward with a $2 billion reactor, they could cover up to 50% of that overrun, so up to $3 billion. Past that, could they split it 50-50 such that if the total cost were to run to $4 billion, then either the government, a third-party insurer, or some other party could help provide some level of forgiveness on $500 million. This way, the total cost to ratepayers would be $3.5 billion versus $4 billion. I think some of these more innovative risk-sharing measures are often what I hear utilities and other customers say they need to move forward.

Because as huge as LPO's potential loan authority is - over $300 billion - it is debt that has to be repaid with interest, albeit very competitive interest. But we often hear that debt may not be enough, given that we're looking at first-of-a-kind projects where we don't have cost certainty. So I think more creative risk-sharing mechanisms might be what it takes to break through the current stalemate.

Packy

It's free markets with a backstop. Julie told us that given the size of the numbers at play, the federal government would have to have a large role in overrun insurance, which would likely require legislation. This is why popular support is important. Call your representatives, folks.

But she and others we spoke to also said that we should do what we can to minimize overruns in the first place.

Julia

The most resounding refrain was that we need to build lots of the same reactor over and over again. Probably the Westinghouse AP1000, which we just used at Vogtle, a 1000 megawatt reactor. We need to keep building it so that we get better at it and come down that cost curve.

We need to start now while we have the workforce that just got trained on the Vogtle project looking for work. Julie talks a little bit about that workforce.

Julie Kozeracki

A huge component of the nuclear supply chain is going to be the workforce we need to deliver that. That's not just nuclear engineers. It's a number of skilled craft and trades folks.

It's going to be tough to make a compelling case for people to move their careers towards training in those industries if we can't point them towards a clear path with more nuclear in our future.

We're particularly grateful to Southern Company and Georgia Power. Upwards of 13,000 people were trained working on Vogtle.

I really hope there's soon a path for those folks to work on new nuclear projects so we can take advantage of the workforce we've trained up here in the US.

Julia

Nick Touran talks a little bit about the workforce coming out of Vogel as well.

Nick Touran

We just built these Vogtle reactors and that team of people can build AP1000s. Now the AP1000 design is complete. It's actually been built and turned on. So it's very much de-risked on a technological and regulatory front. But it's still a matter of getting someone somehow to say, "Yeah, I'm going to take that team of people and that supply chain and build the next big one."

Having seen how much of a struggle it's been, I feel like that would be the best bet. Somehow get a consortium of utilities, which is how we did it in the old days. Ten different small utilities built the first PWR at Yankee Rowe. So just somehow coordinating an effort like that to say, "Let's just build the next big light water reactor," I feel like is the most sure thing.

It's really getting those serialized constructions where you start seeing benefits in overall cost.

Packy

Nick is proposing two important ideas here. First, he suggests pulling together a consortium of utilities to share the burden of developing a new reactor, like they did with Yankee Rowe. Yankee Rowe was one of the first commercial nuclear power plants in the US, coming online in Massachusetts in 1960.

Back then, since pressurized water reactors were such new technology, ten small New England utilities formed the Yankee Atomic Electric Company. They pooled resources, shared risks, contributed their own expertise, and banded together to have a stronger voice with regulators. They jointly managed the project, secured better financing with their collective balance sheets, and achieved economies of scale by building one large reactor instead of ten small ones. It seems like it would be hard to pull that off today, but I like it.

Julia

Yeah, I do too. It addresses a lot of the challenges that utilities still face today. And while those risks should have probably been mitigated over the last 63 years, they really haven't been. It's almost an admission that we need to go back to the beginning to then go forward. But we do have a little more momentum now.

This is where Nick's second idea comes in. He thinks we should just pick up a design that's been approved and the team that recently built it at Vogtle, and just keep building them over and over, getting a little bit better each time. That's what he means by serialized construction. And that rhymes with how Julie is thinking about addressing the problem.

I asked her what the world looks like when we order the same reactor five or ten times, and how we get to a place where we have the confidence to make those big orders again. She pointed to a shining example happening overseas.

Julie Kozeracki

That world is South Korea. South Korea did exactly this. They picked one design, the APR 1400. They stuck with it, got really good at it, and brought the cost down to about $2,300 a kilowatt.

What's key is that you really have to get up to that critical mass of, call it five to ten, for a number of reasons. It helps build up the supply chain confidently, and gives you enough at-bats to actually come down the learning curve. In the US, we'll likely have some tension between needing multiple designs to succeed at scale and having to consolidate designs to avoid proliferating onesies-twosies. It's important to note that different market niches will require different designs.

Traditional electricity-scale generation will be quite different from high-temperature heat for industrial settings. What's critical here is the private sector moving forward, identifying designs they feel most confident in, and hopefully working together. The easiest way to get up to that five to ten is to pull together a buyer's club, which doesn't necessarily have to be just utilities. Tech companies with enormous clean 24/7 power needs could help match cash and demand to pull utilities and project developers over the line.

Another missing piece in the nuclear ecosystem might be the developer model that helped wind and solar take off. This model allowed developers to take on risk, manage construction, and hand over assets to utilities to operate. Historically, utilities have taken on this role, but the Vogtle experience showed that having the utility take on the owner role earlier might have been beneficial.

I remember folks at the site saying, "we wish Southern had leaned in earlier to take on this owner role versus the technology vendor looking to provide that." If we could develop a model where companies are willing to take on construction risk, learn mega project lessons, and develop assets for risk-averse utilities or other customers (industrials, tech companies), it could unlock a huge amount of demand.

Julia

To ride experience curves like the solar industry has, we need to benefit from the experience we're getting. First, by actually building reactors, then setting up a model that ensures the entity doing it, whether utility or developer, is building on that experience across multiple projects.

James Krellenstein thinks we just need some bravery to kick us off, but agrees the tech industry has a role to play and that we need a developer model to compound learnings across projects.

James Krellenstein

What I would like to see is more smart, younger, disruptive thinkers working not on new reactor designs, but on the financial engineering necessary in the current ecosystem to allow new builds to happen. Also, on software development to ensure new nuclear power plant builds are on time and on budget. This could include building information management and supply chain management. But really, we need to deploy a developer model for the nuclear industry.

One of the biggest problems is that if a utility orders an AP 1000, they'll go to Westinghouse for the nuclear steam supply system and to Bechtel to manage construction and system integration. But there's no developer to take it from there. The utility has to build up its own shop to manage construction and contractors. Just like when you're building a renovation on your house, you need to manage your architect and manage your contractor, which is a full time job.

My historical analysis shows that while good vendors and contractors are important, without good management structure from the ultimate customer, you won't have a successful build. We can't scale this in the U.S. because each utility is relatively small and geographically limited. Even if a utility like Southern Company builds a couple, those lessons can't immediately translate to a different region 1000 miles away. That's where we really need to work - ensuring we don't have another Vogtle or Summer and creating a model conducive to capitalizing on lessons learned.

Packy

I feel like I'm a little bit on the outside here. Julie and James have all mentioned this developer model. I'm familiar with a real estate or solar developer.

Just for the avoidance of doubt here, what is the developer model in nuclear?

Julia

The developer model in nuclear is someone who brings everything together and is responsible for the project from beginning to end. This includes dealing with vendors like Westinghouse, sourcing materials, managing crews from engineers to welders, handling financing, and overall project management to keep the project on budget and timeline.

Packy

Is this like real estate development, where the person says, "I own the project. I'm responsible for building it on your site, utility. I'm going to the banks, but I'm also putting up cash myself"?

Or are they more of a project manager, including on finance, but not actually putting up their own money?

Julia

It's definitely a hybrid, with a few different flavors for how this plays out, but developers are putting skin in the game and taking their own risk. Consider a solar developer: they're here to make money, but they'll also invest in the project. They'll get loans from banks, hopefully at favorable rates due to their track record. They're putting it all together, investing, and securing financing from elsewhere.

The core point Julie and James were trying to make is that utilities lack the skill set to be this project manager, this financier overseeing a massive construction project, because it's not their day-to-day work. If a utility only does this every 40-50 years, an employee might do it once in their career. We know the first time you do something is rarely the most efficient. The benefit here is that a developer will go from utility to utility, place to place, running their playbook and getting better and more efficient at it.

Packy

The developer model makes sense. It's how any other industry would operate. A utility has built gas and coal plants, so it's not their first plant. But nuclear is unique, with all the regulatory aspects. It makes sense to have somebody who does this repeatedly and improves each time. I thought we'd hear more about regulators or the NRC (Nuclear Regulatory Commission) or NEPA (National Environmental Policy Act).

From the outside, I thought if you asked ten people in the nuclear industry what needs to change, they'd all say, "We need to get rid of the NRC. We'd be fine if we just didn't have this regulation in the way." - the Vivek Ramaswamy approach. But practically none of the answers we've gotten have focused on regulation. It's certainly not as big a part as I thought it was.

Is there some hesitancy? Has the nuclear industry been disappointed with the regulatory process for so long that they don't want to blame others anymore? It seems crazy that you can have something that delays projects, doubles their duration, requires full security teams, ALARA (As Low As Reasonably Achievable) radiation standards - all things that clearly make it more expensive and slower to build - and nobody's talking about that. Why do you think that is?

Julia

I think it's probably just out of vogue now. This has been the answer for too long, and people want to be contrarian and come up with something else. In all seriousness, I still think there's plenty wrong with how nuclear is regulated, and it's absolutely contributing to costs. I don't think anyone actually disagrees with that. People are probably just tired of talking about it because nothing's changing.

That said, Congress is aware of the NRC's slowness. There has been some regulation, for example, a couple of years ago, commanding the NRC to develop an advanced nuclear framework. People are aware of it. It's definitely an issue.

I think people have just been unaware of all the other factors: financing questions, construction challenges, poor project management because we haven't done these in decades. It's more about balancing it all out. Unfortunately, there isn't just one thing to blame; there are several pieces compiling to make this a real economics issue.

Packy

It makes sense not to go to regulators or Congress right after Vogtle and its overruns, blaming them. It's more credible if you can get 5-10 projects under your belt and say, "We're good at this. We want to bring cheap, clean energy to the rest of the country. Look how much we've improved. Here's the bottleneck. This is the last 50% we want to take out. Now you really need to help us because people love this cheap electricity."

They may not have that credibility right now to fight that fight. Interestingly, the only person we spoke to who banged the drum on specific policy changes and regulation as a major obstacle was Alex Epstein, author of "Fossil Future," whom you met in the last episode. Maybe because he's outside the nuclear industry, he's willing to put more blame on regulators and propose solutions.

Alex Epstein

I've been looking at which parts of the nuclear code are worse. Parts 50 and 53 seem to be key issues. Part 50 applies to all nuclear and involves things like linear no-threshold models, making it prohibitively expensive to build.

Part 53 is trying to set potentially new standards for new nuclear with a different risk model. Instead of minimizing nuclear risk infinitely at all costs, it aims to do a proper relative risk assessment, comparing risks to other things and basing it on science. This would require jettisoning LNT in particular.

The idea would be to change Part 50, but a crucial battle is how to make Part 53 reject much of what's in Part 50, giving new nuclear a shot at doing things. I'm talking to some Congress people, and there's a lot of interest in it.

Julia

Alex's proposal makes a lot of sense. Let's get rid of the "do anything possible to reduce any risk of radiation without weighing this against the alternatives" approach. The difficulty is that anyone close enough to the minutia of Part 53 language is probably working in the nuclear industry themselves, likely trying to ingratiate themselves with the NRC, not be overly critical of existing regulation.

This could be driven by a complacent nuclear industry focused on regulatory capture, or just a stagnant industry without much of a lobbying arm motivated to push for change. There hasn't historically been much push for NRC reform.

Packy

I'm not going to get the exact quote right, but it's something like, "once a regulation goes into place, it's there forever, it's impossible to turn it back."

Julia

The regulatory ratchet.

Packy

The regulatory ratchet. I doubt that'll be the first thing, but I hope it happens sooner. In the conversations we've had, I think my favorite idea - maybe from anybody, certainly from you - is about the coal plants being decommissioned over the next few years. You have this labor force that's going to be out of work. You have these facilities that aren't fully plug-and-play, but certainly better adapted to nuclear than a totally green field site.

Because these people are going to be out of work, and because they're kind of sympathetic to congresspeople around the country, and because these coal plants are spread out... My grandfather was a coal worker.

Julia

I wonder if coal plants scheduled for decommissioning are the answer here. We have almost 30% of coal plants today, about 60 gigawatts of power, scheduled to retire by 2035. This is an opportunity ripe for nuclear. There's a lot of infrastructure already in place, especially transmission lines, which are some of the hardest things to permit. You also have cooling facilities and other infrastructure already in existence.

As mentioned, you have the workforce there that's about to lose thousands of jobs. They're certainly not afraid of having a power plant in their backyard. I doubt there would be any NIMBY movement against this. In fact, this is actually a cleaner version of power.

The big question will be, why won't these locations go natural gas, which are cheaper and easier to build? This is what we're up against. I think there's a lot of potential here. I wonder if it really is about government incentives.

The utilities or developers working with the utilities need to be incentivized to build clean, firm power, not just another natural gas plant. We know subsidies work. We saw solar and wind developers benefit greatly from tax credits and other subsidies that made the renewables build-out possible.

Once we develop the know-how on building nuclear, and we can ease people into that with some subsidies, I wonder if that maybe is what gets the flywheel spinning again.

Packy

I love that one. It's practical and palatable. We need to replace that energy somehow, avoid killing towns, and avoid putting people out of work. Nuclear could solve all of that. What I really like about it is we've talked about the diffusion of popular support, that there's a lot of people who kind of like nuclear. This could be a constituency of a small group of vocal supporters who want nuclear because they want jobs, cleaner towns, and to be part of building the future. This feels like the right constituency to push for nuclear as a replacement.

Before we wrap up, we've heard many practical ideas today, but I want to give some airtime to big, bold ideas from private industry or the government. Nick Touran, for example, thinks we should build reactor gigafactories.

Nick Touran

My other favorite idea is to build a factory of large reactors, a shipyard factory. This has been seriously considered to the point that they actually bought and installed the world's biggest gantry crane in Jacksonville, Florida, for a reactor gigafactory. It was going to make four gigawatt-scale PWRs per year on floating platforms, delivered by floating them out.

They got a license from the NRC in 1982 to build the first eight of them, which is a story nobody's heard. That's like large modular reactors - Henry Ford comes to the AP 1000. If we wanted to get really serious about decarbonizing quickly, that's the kind of thing we should be looking into.

It's like bringing Henry Ford factory production at shipyard scale to floating reactors. The fact that it's been licensed before in a fairly modern regulatory regime sounds crazy because it's the eighties, but that's fairly modern in the nuclear world.

Julia

I love that from Nick. Gigafactories are obviously super expensive to set up, but we know the federal government has the money to do it. We just spent $400 billion on the Inflation Reduction Act - imagine how many gigafactories you could get for that amount. In all seriousness, we know the government has levers it can pull to encourage industry development. If it feels something is important to the country, it will back it up.

We saw this for the renewables build-out with tax credits and the CHIPS Act, which is trying to reshore silicon chip manufacturing. We also talked to Andreessen Horowitz American Dynamism partner David Ulevitch. He's an investor in hard-tech, American reshoring activities. We discussed this exact topic, and he thinks the federal government can play a more active role in accelerating nuclear.

David Ulevitch

I think that would be an incredible place for government to play a role. They can do that through legislation, funding, and more than just tax credits. They need to do something more directed and proactive. Like a nuclear version of the CHIPS Act, changing how the DOE and NRC operate by mandating a certain number of licenses or new designs be granted per year. There are lots of good ways to do this, and some of this is happening already. But we could 10x or 100x it.

I think a terrible place for government is when they constantly reaffirm and go back to existing incumbents. If they were to go back to Westinghouse or somebody and say, "Okay, you're the anointed energy provider for the country," I don't think that would be a good outcome. COVID was a good example of this. We want to see a framework created where anyone who comes up with a workable solution is guaranteed revenue.

In Europe, they went into full bureaucracy mode. In China, they went into full authoritarian mode. We went into full capitalist mode. We said, "Let's let everything blossom and see what works, and then we'll support anyone that makes something work." With energy, you do the same thing. Whether it's fusion, fission, solar, battery systems, or energy transportation, you just say, "Let's let them all go and see what happens."

Packy

I love that answer for a couple of reasons. First, it combines the government's might with the entrepreneurial spirit that makes America such an engine of innovation and implementation when we do it right. It flips how we think about nuclear - not as something to be approved when the NRC feels like it, but something that the NRC has to approve every year. Regulation isn't bad. It's a necessary part of capitalism. In nuclear's case, it's made it super safe and reliable. The reason plants run 99.9% of the time and are so safe is partly due to regulation. But the regulatory process has to be sped up to unlock innovation and bring down construction timelines.

Second, it focuses on changing the narrative around nuclear. Pro-nuclear is an atrociously good position, and we need to figure out the practical steps to bring down the cost of nuclear build-outs. But narrative can be the neutron fired at the uranium atom to catalyze a chain reaction. It can spark the energy needed for people, politicians, utilities, entrepreneurs, and developers alike to do the hard things required to secure an energy-abundant tomorrow.

Julia

It reminds me of what Josh Wolfe was talking about more than anyone we've spoken to. He thinks that despite nuclear's growing popularity, popularity is still the biggest lever we have. It's almost like oil and gas companies and Putin psyoped the world into hating nuclear energy, and now we basically need to psyop them back into being excited about it.

I think we're on our way. When we asked Josh about the biggest remaining hurdles, here is what he said.

Josh Wolfe

The practical one is really popularity, because politicians, in their self-interest, want to get elected. They need the popularity of the people. If something is not popular, they're not going to talk about it. So that's number one. Number two is capital markets and debt financing. But if you can reduce the regulatory restrictions on this, if you can increase the popularity, what happens is people release capital. This is true of any sector or market, particularly newly discovered ones. They speculate, which lowers the cost of capital. That increases experimentation. Yes, you get more failure, but you also get more progress.

Packy

I asked Josh about how, if he were the director of the CIA, he'd actually start a movement that forces change in Congress and the NRC to get more reactors built.

Josh Wolfe

Well, the two animating factors for anybody, particularly an intel operative, are motivated greed and motivated fear. The fear piece appeals more to a nationalistic instinct. In recent testimony I gave before Congress, China is building very aggressively in nuclear. You'd say, well, that's great. It's good for the environment. And it is. I'd rather see China build nuclear than continue building coal, as they've become the world's largest polluter. So coal bad, nuclear better.

But one of the things China is doing is exporting that technology to states that will become increasingly dependent on them. It cost us about $20 billion to build the most recent two-gigawatt power plant in Georgia. So call it $10-11 billion per gigawatt. China is doing it for $2 billion, for a tenth of the cost. If you're almost like a vassal state, and China says, "Hey, we'll lend you the money, we'll debt finance it, and we'll build it for you," now you're dependent upon them for the next few decades. You've got to pay back that debt or they're going to shut off your electricity. You're dependent upon them for the fuel, servicing, maintenance, and all of that. That's something national security concerns should care deeply about. That's the fear aspect.

The greed aspect is you typically need one story for people to rally around, one narrative of success. It could be a public company. It could be somebody that made an investment in an existing utility, like Exelon Chicago, or somebody seeing runaway success that suddenly galvanizes people. The third thing I would do is what the agency and intel community did during the Cold War: look at the mediums of influence and start to get really interesting attractions.

Those would be little messages inside books. We have a whole genre of climate fiction. You'd want to sprinkle in some pro-nuclear sentiment there. You'd want artists to galvanize around a big concert series promoting elemental energy, almost like a Live Aid event. You want some of these influencers, like Isabel Boemeke. What she's been doing is great. We have new mediums to attract attention. Those are the vectors I'd be playing on: neutral influence, positive attraction of greed through markets, and institutional and nationalist sentiment around fear, particularly as China is exporting nuclear reactors to African countries and South America.

Packy

And just to be clear, this podcast, Age of Miracles, is not a CIA psyop. Or is it? Maybe it does come back to narrative in a more important way than I wanted to admit, or at least I wanted to explore everything else. I think Josh's points make a lot of sense, even on their own, but they also tie back into things we've talked about before. These are movements needed in many cases. Certainly, the developer model is somebody responding to an economic opportunity.

But to change regulation, you're going to need popular support. I love Julie's idea of having insurance for cost overruns, but if you want the federal government to do that while they're getting more supportive of nuclear, asking them to put more federal budget at risk demands a lot of popular support.

If you can get cost overrun insurance in place, then you can get utilities or developers to order more plants. You can order them over and over again and come down that curve, then get to the point where it's cheap enough that you don't necessarily need the government to play an active role anymore.

I think we're in this spot now, though, where we're a little bit stuck and we need something to unstick us. Maybe that popular support and changing the narrative, as Josh suggests, allows us to get the one push we need from the government to set the flywheel off and go down that cost curve.

Julia

We spent a lot of this episode talking about economics, but I wonder if it's the narrative vector that could be the paradigm shift to get the flywheel going. Is it the people demanding their coal plant be turned into a nuclear plant, or those asking for NRC reform, or something else that can catalyze this? Maybe narrative change is really what allows us to move forward. In conclusion, where has all of this led us?

We're realizing that nuclear is neither impossible nor inevitable, but exists in an in-between space. It's about what actions people take today. Going back to the narrative, perhaps it will come from that direction to catalyze the flywheel moving forward.

It's about the policy that gets set, the decisions utilities make, the risks entrepreneurs and new developers take, and the collective voice of people that will all impact how this plays out.

Packy

The big takeaway for me, and an important lesson that can be applied to many hard tech industries, is unsexy. After that initial spark, whatever gets that flywheel going - and I think narratives, government, developers, and entrepreneurs all have a role - we just need to get better at the things we already know how to do by practicing. Pick a design, figure out the right developer model, and practice over and over. Build ten of the same reactors until we get really good, then build more. Export the reactors and our expertise in building them around the world to the countries that could benefit most from nuclear.

But you can't take the techno-optimist out of me that easily. Many folks we've spoken to have been on team large reactor. They've colored the way we look at the world and convinced me that we need to go big. But there's a lot of capital and smart people who believe we can innovate our way around all the mess by designing and building lots of advanced and small modular reactors.

Julia

We're going to need a mix of large and small reactors, existing designs, and advanced designs. So far we've focused on large reactors, but over the next couple of episodes, we're going small.

We'll talk to the people trying to build the future, the nuclear entrepreneurs with fresh approaches to old problems like reactor design, fuel sources, and paths to regulation.

Packy

Thank you for listening and watching this episode of Age of Miracles. If you like what you hear, please rate, subscribe, and share. And if you're feeling really generous, tell us what you think in the comments.

Plus, we have a ton of resources and references in our resource hub if you want to go deeper, and we've linked them all in the show notes below. See you next week.