Lyn Alden: Broken Money

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Erik: Joining me now is Lyn Alden, best selling author and founder of Lyn Alden Investment Strategy. We have a slide deck to accompany this interview, you'll find the download link in your Research Roundup email, if you don't have a Research Roundup email, just go to our homepage, macrovoices.com, look for the red button above Lyn's picture that says "looking for the downloads." Lyn, it's great to get you back, and especially to have a long form opportunity to really dive into our topic this week, which is broken energy. Both of us feel a strong passion that our energy systems are broken, and that that poses a very significant risk to society. But I think we each have different perspectives on precisely what's broken, and why fixing it is so important to our future. So let's start there and listen to your thinking, what's broken about energy? And why is that important?

Lyn: So first of all, thank you for having me on. And like you said, energy is a topic I'm passionate about. And for context, my background is a blend of engineering and finance. And so, I'm an electrical engineer by training, I originally wanted to pursue energy systems, actually was one of the careers that I considered, and just kind of where the jobs were at the time. And also due to my kind of shifting interests, I am mentally shifted more towards aviation, than more towards engineering management of an aviation facility that eventually went full time into using that kind of quantitative background to go into finance and related areas. But this is like an area where there's, I think of an entry number of intersections, and perhaps not enough people looking at it from both the engineering side and the financial side. And if anything, it's too much from the political side. And so I guess to answer your question, why I think energy is broken. I think in large part, it's because we've been in an era for at least a couple of decades now, where politicians have a bigger influence on what kind of energy systems get built than engineers, whereas it should be the reverse and we should be running energy based on what is most efficient, what is cleanest, what is most long lasting, what is most resilient, what is safest all these different metrics of success and instead, we kind of latch on to these narratives and pursue those significantly. And then, you know, research comes out that always kind of emphasizes the strengths of those approach, what kind of overlooking or sweeping aside the downsides. And a lot of things are done for optics rather than outcomes. Things like putting solar panels in places that are just not even suitable for them, like cold or cloudy types of climates, just because then we can say, "look how much more solar we added," rather than saying, "was this even the right thing to do at this particular region?" And the reason this matters is, because people asked me like, what could go wrong over the next 10,15 years? Like, what keeps you up at night, or what are the biggest risks? And it's not really things like recessions, or kind of routine economic challenges, all of those can be overcome. Obviously, they impact people very negatively at times, they can be devastating. But as a society, we can move past these things. Whereas the absolute biggest things that can more persistently and severely disrupt us in terms of standard of living, and just overall kind of global safety and abundance is basically a few key things.

One would be obviously like, outright war. So that's obviously a variable. And the other main one would be insufficient energy security. So, acute energy shortages, we saw a taste of that in Europe fairly recently, we see it in developing countries on a more regular basis, at least some of them. And ironically, Europe's energy shortages, actually, in some ways came up more acutely in other countries. So for example, when they had to bid almost any price to get LNG, they're rich enough to be able to pay a very high price in aggregate. And that kind of sucks energy away from places like Pakistan that get outbid, and then they end up having outright power outages, for example, because there's a finite amount of LNG capacity that now more entities are fighting over. And so, the least wealthy entities are the ones that end up not getting a seat at that table. And so, war and energy security, I think, are like the two single biggest things to not fumble. And of course, energy security feeds into food security as well.

And, probably the third topic would be just overall quality of our money, which is why I wrote ***Broken Money***. But at the end of the day, it's what we want to do with our money, is you really want to buy energy, and we want to organize that energy in useful ways. So most of our economic development really comes from two key things. One is how much energy do we have to harness, to shape our environment in ways that suit us? And then, how efficiently are we using that energy? So for example, a processor today does a lot more computations per unit of energy that a processor 20 years ago, or even 10 years ago. And so those are kind of the two main variables that we're always trying to optimize for. And everybody is fully aware of the energy efficiency variable. But I think as a global society, at least, at least in the developed countries, we've become very detached from understanding where energy comes from, how bad it is, when we don't have sufficient energy. And that feeds into our politics, it feeds into our priorities. It feeds into how comfortable we are with certain scenarios. And so, I think that overall, that's what I consider to be broken about energy. And what I consider to be one of the larger risks going forward, is basically when narratives overtake math as how we manage our overall energy security going forward. So, I know your take is similar to that, but you probably come at it from somewhat different perspective. So, what would you emphasize or add to that or disagree with that kind of overall view?

Erik: Well, I agree with everything that you said, I would add a few things. One is most people and you alluded to this, but didn't quite say it directly. Most people have no comprehension of how important energy is, we take it for granted. There's a plug in the wall, you can plug electrical stuff into, and it works. There's a gas station in your neighborhood where you can refill your car with gasoline, petrol, whatever you call it. And it works. It's just there. It's available, costs more than you might like, but it's there. And what people don't realize is, if you look back in history, 250 years ago, we didn't have occupations and professions. Everybody worked on farms, doing physical labor, just growing the food we needed to survive. That's all we could do. There weren't any other choices for what you were going to do with your life. And the perception most people have, which is the technology is the big thing that changed in the Industrial Revolution, it's true, but really, technology is just what puts energy to work. Most of, I mean, some computer technology these days, as you say is using small amounts of energy, but mostly what technology really is, whether it be vehicles, heavy construction equipment that creates the big, high rise buildings we live in and so forth, it's all machines that put energy to work to make our lives better. Energy itself is the essential ingredient in that and I think that the fact that you know they don't teach you this in school, nobody thinks about it, causes us not to recognize it.

Now, the other thing that you said already, which I'll disagree with slightly and this goes to kind of the frog boiling in water analogy you said, you know, we almost had a run in with not having enough energy. Well, I'm going to make the argument that we've been having a run in for the last 50 years with not having enough energy and referring to the first slide in the slide deck on page 1, this comes courtesy of my friend Mike Green over at Simplify Asset Management. What it's showing us is from the end of WWII, we were on this nice uptrend in standard of living because energy consumption per capita is the most direct proxy that there is for our standard of living. So we were on this nice steady uptrend, and right around 1974, that broke down. And we've been gradually trending lower in standard of living and per capita energy consumption ever since. Well, why is that? It's all about affordability. When I was a kid, gasoline cost 30 cents a gallon. And even after adjusting for inflation, it's more than double that now. And when you stop and think about it, a lot of the inflation was caused by the increase in the cost of energy, because that's one of the biggest drivers of inflation.

So the reason that energy is broken is because we're paying way too much for it. And because it's happened over such a long period of time, we don't realize that the standard of living that we deserve, you know, back in the 1960s, they predicted that we'd have flying cars and all kinds of amazing things by now, that didn't happen. Why didn't it happen? Because we were unable to maintain that steady increase shown on slide 1, on the black curve of our standard of living and per capita energy consumption. And it started with the Arab oil embargo that only lasted a couple of years. I think a lot of it is abandoning nuclear energy, which is you said, the scientists and engineers knew in the 1970s, that we have a real serious problem with our dependence on fossil fuels, we're depleting a finite resource that can't possibly last forever. And what ends up happening is the engineers and scientists know exactly the right thing. The Nixon administration, apparently trying to take care of their friends in the oil and gas business, basically sabotaged nuclear energy in the early 1970s. And we haven't recovered ever since. And I feel that for my entire lifetime, you know, in 1974, I was nine years old. We've basically for my entire grown up life, we've had our standard of living stolen from us by malfeasance of the US government, not managing energy policy, as well as they should have. And almost nobody realizes that that's what has happened. So the climate change arguments have led us to this conclusion that, okay, we got to get rid of fossil fuels because of climate change. And I don't want to disagree with that. I think there's probably a lot of merit to those arguments. But I think there was an even better reason that was known long before climate change even hit the radar, which is energy cost too much, and our lives would be so much better if we were smarter about it. And I think that energy has been intentionally and consciously made scarce for the purpose of advancing money interests of people who lobbied the US government to get them to do that.

So I just, I feel like it's the most important thing that affects our standard of living. And as you said, it's become so politicized now that people almost aren't allowed to have independent views. If you're a Liberal Democrat, and you live in a world where you're surrounded by people who are Liberal Democrats, look, you just better think that wind and solar are the only acceptable solutions because that's kind of like the politically correct view to have. And if you're a Conservative Republican, you better not be caught even thinking about listening to the climate change arguments, because you're a traitor if you do. You know, we can't have a society where people don't think clearly because one of the most important, if not the most important issue affecting our standard of life has been politicized to the point where we're not really thinking objectively about it. And you know, there's actually legislation that has been proposed, although I don't think it's ever been passed anywhere, where they're trying to make climate denial a crime, just like hate speech. And the argument is, we know we have to follow the science of climate change. Well, Lynn, you and I both know, as did Galileo, that if you're not allowed to question or disagree with something, then by definition, it's not science. But we're being told that we can't even debate what the right strategy is. We just have to believe in what the gospel is that's thrown down to us from political leaders, which I'm convinced are intentionally trying to divide society over this issue of energy change. I think that the fossil fuels industry is traditionally a Republican supporting industry. I think that although the climate change arguments are very real, the Democrats latched on to it and said, this is a way to divide society and get control of energy over to our party, because energy is so much money. It's such a big part of the economy, we want to control it. And the way we're going to do that is by really championing these climate change arguments, and really pushing wind and solar and creating subsidies for wind and solar, because the wind and solar people are the ones that donate to our campaigns, whereas the oil and gas guys donate to the other party's campaigns. So it's become so politicized that we can't make any progress. And it's the most important thing that's going to affect both our standard of living and our children and grandchildren's standard of living. So those are my arguments.

And the economic component, in my mind, is not so much about climate change. I'm not saying I disagree with the importance of protecting the environment. I'm a planet friendly guy. But I think it's even more important to get cheaper energy, so that we can get back to page 1, on that black upward sloping trend line of human prosperity, which is enabled by cheap and abundant energy. And the thing is, it's not like we need Earth-shatteringly new technological breakthroughs and advancements, we had it figured out with nuclear energy in the early 1970s, 50 years ago. And then we intentionally sabotaged it in order to protect the money interests of the oil and gas industry. It's a horrible, horrible crime against humanity, on the part of the Republican Party. And I think the modern day equivalent to that is that although I do believe many of the climate change arguments, I think the Democratic Party is just as guilty of politicizing this to say, let's create lots of wind and solar subsidies so we can get donations from those guys. It's just so corrupt, and it's compromising our children and grandchildren's standard of living. But that's my take on it, I started to fall into the economic arguments, I think you've approached this question about the price of energy from a slightly different angle in some of your writing. So please elaborate on that.

Lyn: Energy is one of those things where, around the margins, we can always use more of it, there's really no kind of limit to how much energy that we'd like to have if the cost was driven as close as possible towards zero. And of course, there are some diminishing returns. So for example, if you go from consuming one barrel equivalent oil per year to 5, that's going to meaningfully boost your standard of living, whereas going from 5 to 10, or 10 to 20, or 20 to 40, these start having diminishing returns, and they start fixing kind of minor annoyances around the margins. And so, it is natural that the people in developed countries tend to slow down their energy consumption after a certain point. And one way of looking at it is that, even if the entire West just kind of flatlined their energy per capita usage, there's still like an energy emergency across basically the entire developing world, just to have, you know, make it easier for people and those billions of people to get up to the standard of living, energy wise, that we have now. So even just kind of having everyone say, a European level of energy consumption per capita require a tonne more energy than we have now on a global scale. And when it comes to price, I think this is one of the things where it really helps to approach this from both a technical perspective and an economics perspective, rather than entirely be siloed in one or the other. Because a lot of people say that, you know, if we just subsidize things enough that can fix it. And I think not enough people take a step back and listen to the price signals that, basically information signals that prices are giving us, I mean, this research goes back to high IQ and others that have pointed out, how that the price happens to be one of the best coordinating mechanisms for finding what is efficient, what the market wants, what is working, what's not working. And I think one of the issues in the past couple of decades is really not looking enough at price, instead kind of letting those narratives get in the way. And an example of that is, after decades and decades and trillions of dollars of solar and wind development, the question is, why don't they just wildly catch on? You know, a lot of the proponents will say, look how cheap it is, it's cheaper than fossil fuels. Well, if that's the case, why doesn't everybody just use them? I think their argument will often be, well, there's lobbying by the hydrocarbon companies. And they do all this and that's why people don't switch. But of course, lobbying only goes to a point where if a technology is available, and it's obviously better to the user, people start switching to it. Like for example, when we switched from flip phones to smartphones. Nobody really had to convince us of it once we experienced the smartphone, it's off, so you've switched to that, and you don't want to go back. Same thing for having a computer versus not having a computer. Same thing for, you know, multiple other technologies that we use. Basically, once something becomes obviously better or cheaper, we start switching to it and adopting it pretty quickly. And with solar and wind, there's the reason that hasn't happened yet is because there's actually quite a lot of expense associated with it. And then we have to ask if it's expensive, is it as green as we think it is. And that's a topic I don't see discussed enough.

So it's not like those costs just go into nothing. A lot of those costs are material, which means environmental. And one of the things we see in modern environmental discourse, is almost everything gets boiled down to one number, which is CO_2. And there's not really enough attention to, in my opinion, paid on every other variable of the environment. So how cleaner are oceans in terms of say, pollutants, or micro plastics, or things like that. Or what is happening to our overall quantity and quality of soil, which ironically, is a huge carbon sink. If you have plenty of soil building happening, how clean are our rivers? How much kind of chemicals are in the food we eat, due to the way that we operate our industries. So I think that's one of the things we're very, you know, if you polled people on the environment across the political spectrum, almost everybody wants a cleaner environment or two, if you're in a clean environment, you want to maintain that clean environment. And it just comes down to, it's generally politically easier to boil things down to one number, rather than kind of just approach this as the multiple variable thing that it is.

And when we look at, say, for example, solar and wind, I would argue that from every research I've done, and just from kind of the laws of physics themselves, the reason they're not as cheap as people hoped they would be, is arguably because they're not as green as people hoped they would be. And so in the early days, you could argue, well, the problem is that they're not at scale yet, if we just get them at scale, the unit cost will decrease. And there's a case to be made for that. There's other instances where price is not necessarily perfect indicator of efficiency either. So for example, if you have two manufacturers, and one is dumping waste into the river, and one is not, one is going through the extra cost of disposing of it properly, that second manufacturer is probably going to have higher costs in their products. And so obviously, we'd rather have that second manufacturer than the first one. And so when you analyze price as a mechanism, you do have to give certain allowances for, you know, what is it? What is the price look like now versus when it's matured and scaled? Or you have to look at the price and say, well, you know, is one area, kind of short cutting versus another? But when you have an industry that's been around for decades, with multiple different entities participating in it, and when you look at the full lifecycle of the energy, so for example, not just the solar panels, or wind, but also the battery backups, and you know, kind of the construction, the disposal of it, the maintenance of it, you know all the variables together, when you get down to the bottom of it and say why isn't this cheaper? Why isn't this so much, obviously better, that people just naturally switch to it? A lot of it has to do because the marginal cleanliness you get out of it, it's just not significant.

Now, that doesn't mean that those energy technologies have no role. But it just shows that people, I think, when they approach things from a narrative, they get into their mind from decades ago that wind and solar can fix everything. And then they kind of latch on to that. And then every kind of interpretation of information becomes how can we get to that view, rather than just always reassessing? What is the playing field we have to work with, what variables do we have, what technologies exist to us, either now or on the near term horizon, where they actually give us cheaper and more abundant energy, because they're doing things more efficiently. So for example, nuclear is, you know, if you don't have regulatory cost overruns, and things like that, if you use kind of cutting edge nuclear, you can get prices down considerably compared to many other sources of energy. And you do so without much CO_2 emission or much other kinds of environmental impacts, because it's actually an upgrade versus some other types of energy. Whereas some of the other things we're pursuing, almost like dogmatically, regardless of price, allows us to ironically overlook a lot of their costs. And so, for example, wind and solar, solar in particular, a lot of that supply chain is in China. And there's just heavy pollutants over there and heavy amounts of kind of energy consumption. And as the end user, we have a lot of really, we're kind of detached from all of that. And so, I think that overall, just price has not given enough weight, in terms of kind of assessing what energy technologies are actually inexpensive, when they are fully scaled up and understood, versus ones that almost seems like no matter what we do, we can't get them to scale, all inexpensively.

Erik: I just want to add a little bit to that, to point out that the way that energy has been so politicized, as we already discussed, I think is contributing substantially to the distorted price signal you're talking about. Because when you have governments putting subsidies in the, you know, they're monkeying with the balance of free market economics. And they're trying to force outcomes that might not actually make sense and might not be beneficial. So, as you said, people will say, look, wind and solar, it's cheaper than fossil fuels. Why wouldn't you use it? Well, part of that is that what's going on is, it's cheaper because it's subsidized, which means it's not really cheaper, it means we have to pay that subsidy in the form of taxes in order to get that benefit of it being cheaper. But also, there's so much monkey business going on, because this is such a politicized issue. You'll hear, for example, that solar photovoltaic, the price has come down so much in recent years, that is just incredibly competitive. It's the cheapest thing that there is. Well, what they don't tell you is, it's still true, that that's only when the sun is shining. And then they'll say, well, wait a minute, you could hook batteries up to it, and you can make it become a baseload energy source. Well, first of all, you can do that. But if you include that levelized cost of storage, in addition to the levelized cost of energy, all the sudden, it's not as much cheaper as you thought it was. And then as you look a little bit more deeper into it, you say, wait a minute, no matter what you do with batteries, if you have an extended period, because there's just a long storm or something and it's overcast for two weeks straight, and the weather is not conducive to solar energy, then you're going to have to rely on some other baseload energy source. Well, what's happened to those baseload energy sources that were designed decades ago, is that with the introduction of wind and solar, when you get a windy, sunny day, what happens is those intermittent sources produce so much electricity that they drive prices negative. And that actually adversely affects the stability of those baseload energy systems. Because as prices are going negative, they have to take capacity offline, it's not easy to take a coal burning power plant that's designed for baseload energy, and load follow with it. So they're being forced to do things they didn't have to do before.

In the grand scheme of things, what that means is the introduction of solar and wind in the way they've been introduced, is disrupting other systems. Well, of course, the wind and solar guys are like, hey, we're winning the fight. We're beating those SOBs over on the coal and gas side, we're shaming them with creating this negative price electricity that only lasts when the sun is shining, and the wind is blowing. And then we go back to a period where the wind is not blowing, and the sun is not shining. And we really need that baseload energy, and we don't have enough of it, because the wind and solar guys were kind of damaging their business at another time. So we're not designing these as an integrated system that work together cooperatively to deliver the most benefit to society. We've got these factions and teams that are fighting against each other within the energy infrastructure. And it's not healthy, it's not healthy competition. It's crony capitalism competition with government subsidies in the way. So I couldn't agree more with what you said, I just wanted to point out that there's a lot of the politicization of energy that's contributing to that distorted price signal. Let's move on, though, to another subject that I know you've written and talked to quite a bit about, which is the energy density of fuels and how that plays into the whole energy story, we've got a couple of slides on pages 2 and 3 of the slide deck. To support this tell us what that's about.

Lyn: There are a couple of different ways to measure energy density, people often mean different things when they describe it. And it could refer to a couple of them, depending on what context you're talking about. So in the most kind of basic sense, you have a slide on this, it's how much energy exists per either unit mass, or per unit volume. And so, you have a chart here, joules per cubic metre, and it shows solar wind, beef, oil and uranium. And of course, you exponentially up the energy density curve as you go through those different energy sources. And so, to give the listener a sense of low energy density, you know why it's low density, it really comes down to how much you're letting nature concentrate the energy for you. If you're collecting energy from ongoing flows of energy, you're generally going to have low energy density, whereas if you're letting nature concentrate it quite a bit for you, you're going to get much higher energy density. And so the vast majority of energy flows to Earth are solar. And so, of course, we have the sun that is just millions and millions of miles away, is pouring energy in all directions. And a very small sliver of it happens to hit the Earth. And then you know, a very small sliver of that hits any particular square metre of the Earth's surface. And plants obviously can gather that. Of course, as humans, we can build equipment that gathers that energy. But what we're doing is, we're gathering a completely uncontracted source of energy and we're trying to harness that. And then wind is a slight step up, because wind is ultimately slightly concentrated solar. Basically, solar comes in, it hits the earth unevenly, and that creates these pressure differentials and wind flows. And then we capture that wind at key areas where it happens, where it’s windier than average, it's still a fairly low energy dense source, it's basically just a slightly concentrated derivatives of solar. And then we move up the ranking to biomass. So we let plants collect solar over the course of their lifetimes, it could be months, for certain types of plant matter could be years or decades, for large plants like trees. But basically, they spent a lot of time collecting solar and other resources, they concentrate that energy into their structure. And then when we harvest it, we have a considerably denser energy source, is a lot of energy kind of packed into a pretty small unit. And so, we're able to harness that energy, then you move into hydrocarbons, which they're from plants and animals long ago, people often talk about like, fossilized dinosaurs, but a lot of it is trees that have become energy. It's algae in the oceans. Basically, it's not like, you know, there's a bunch of T-Rexes, they're basically a bunch of plants for the most part that we get. And this is just concentrated solar energy from long ago, that is even more concentrated than current biomass, because it's accumulated over millions of years, rather than decades.

And so, we take this concentrated energy. And that, of course, is what fueled the Industrial Revolution, that we could move locomotives, we could move cars, we could move planes, we could have, as you pointed out, we move from subsistence farming, to 1% of the population can do the farming to feed the other 99% of people. So this other 99% of people can specialize in things that have nothing to do with food acquisition. They can go and make medicines, they can go and make technology, they can go and teach, they can go and make art, they can go and preserve history for future generations. There's all sorts of things they can do that make society more efficient, because a handful of farmers with diesel powered tractors, and other useful energy mechanisms can go and produce all the food to feed all of us. And then of course, at the top of the energy density hierarchy is uranium, which is you know, it's made by nature and stars. And so, we have this hyper dense energy source to work with. And so as you go up that list, you generally get way more efficient, cheaper energy sources, if you're not overcome by other variables, like regulatory challenges and things like that. And then in addition, there are some types of contexts where energy density matters even more. So for example, transportation is an area where energy density, especially on a per mass basis really matters. Because in many cases, the object that we're trying to move with, say a car, or a train, or a plane is bringing its own energy source with it. And so for example, we can't power a plane with say, a wood burning stove, for example, it just that the mass, that weighs down on the plane, is insufficient to give it enough power to get the plane really going. Whereas, what allowed us to go from 1000s of years of unable to fly and always dreaming about it, to going from Wright Brothers to the moon, in one human lifetime, is that we finally put a couple of key things together, specifically aluminum and hydrocarbons pretty much. And that allowed us to make this absolute breakneck speed of development in that area so quickly, and a lot of that just comes down to energy density, and technology that allowed us to unlock that energy density. And so that's something that not a lot of people kind of focus on, when they focus on the different energy sources or another way of looking at energy density, and it's obviously highly related to it, because you're going to get pretty much a strong positive correlation is energy return on investment. And what that basically means is, how much energy do you have to put in to an energy production process, in order to get energy out? Like, do you get a 5x multiple of how much energy you put in? Do you get 10x? Do you get 50x? Do you get 100x. And that obviously matters in terms of, one, cost.

And then two, just overall speed of economic development. For 1000s of years of human history, we had extremely low energy return on investment. So for example, our people would eat food and then they go out and chop wood, or otherwise gather plant mass, and that's their energy price, CES. And it's obviously a very, very low multiple, for the most part, you're just covering, like your own heating needs, your own consumption needs, your really basic needs, and there's only a tiny surplus. And that's that tiny surplus is basically what allows a handful of people to specialize, and otherwise develop the technology and the processes for the culture. But that surplus is tiny.

And then we moved into higher energy return on investment sources. So we went to coal, we went to oil, we went to natural gas, we went to hydro, we went to nuclear. As we went up that higher and higher energy return on investment spectrum that allows basically, for every person that spends their time and resources and equipment to go out and gather energy, they're able to gather so much energy, that it's a huge surplus. Which again, much like the farmers allow the vast majority of us to not be involved in energy acquisition, and instead, we can pay for that energy acquisition, and then specialize in doing other things that develop our technology, including, ironically, how efficient we are at going out and gathering energy. And so the these things tend to feed on each other.

And when you look at the sources of energy that are less dense, they also tend to be the ones with low energy return on investment. Whereas, we look at the energy sources that have high energy density, they also tend to be the ones that have high energy return on investment. And then it just so happens that those also tend to be the more baseload types of energy. Because when you have a concentrated energy source, it basically means you have a lot of energy savings. And so, you're able to do it at nighttime, you're able to do to daytime, you're able to do it, whether or not it's windy, can do it through a variety of conditions. Whereas, if you are gathering a low energy dense source, you're probably gathering it from flow rather than savings. So you're either gathering from solar directly, or you're gathering from a first derivative like wind, which can come and go and it's not concentrated, it's not saved. And so you're both, you tend to be higher cost, at least over the course of a full week, let's say rather than just when the wind is blowing and the sun's on, you didn't have higher average costs, and you have to put up a lot of other equipment in order to kind of smooth out the problems with that energy source. And if you go back to the original question, why would I describe energy as broken, and it's because humanity spent the last two centuries or arguably longer, three centuries and longer, going up this energy dense spectrum, as we unlocked a new energy source that allowed us to focus more on technology, which then allowed us to unlock the next dense energy source. And we worked all the way up to Uranium. And then we kind of shied away from that, we kind of saw that power and became fearful of it, we kind of shied away from that power. And so now we've been stagnating in terms of energy density for quite a while. And then a lot of our society's future directions, ironically, take a step back in terms of energy density, they go, they want to go back toward much less energy dense sources that rely more on these flows and less on these kind of letting nature concentrate that energy for us,

Erik: Lyn, so many excellent points you just made, I want to comment on several of them, starting with the last point that you just made about, that concentration of energy, which is so important. As you said, almost all energy on planet earth comes from the sun, and it comes from solar radiation from the sun. uneven heating of the Earth is what causes the wind that turns the wind turbines. It is the sun that is growing plants. And those plants eventually decaying over millions of years that creates the hydrocarbons and the oil deposits and the liquid natural gas and so forth. It all comes from sunlight, energy. And what I don't think a lot of people who are focused on wind and solar really recognize is, you're going to the very bottom of the efficiency pyramid. Now there is an argument to be made when you say, well, wait a minute, we might be going to the bottom in terms of efficiency, we're getting the least concentrated energy by going to solar, wind is only one step away in terms of it. But if you look at the other things like natural gas, and coal and oil and so forth, yeah, it's true that nature kind of built a battery out of those things that took millions of years of sunlight and constantly concentrated them into these coal and oil deposits that exist miles below the surface of the earth. But wait a minute, that's a finite resource that won't last forever. And eventually we're going to use it up. And I think that what really is driving a lot of the increasing cost of energy now is we haven't used it up. But all of the low hanging fruit has been picked up already. Now, we've got to go climb higher up the apple tree in order to get the next apple off. So it's not a matter of drilling a hole in the ground and oil just comes gushing out. We have to use hydraulic fracturing and horizontal drilling and all of these fancy expensive technologies in order to produce more of that energy and it won't last forever. So, there is a valid argument there.

But what they never seem to see is that, if you're going down to the root source of energy, which they'll tell you is always solar, well, wait a minute, where did the solar energy come from? It all came from nuclear, all solar energy, all radiation from the sun comes from nuclear fusion in the Sun itself. That's where the energy all comes from. And we figured out more than half a century ago, how to harness the most powerful source of energy in the universe, which is nuclear energy. And what we did, you said, we got scared of it. I think the government scared us on purpose, because they were trying to manipulate society in order to not want nuclear, because they wanted to keep energy scarce. If we had stayed on course, and we had adopted nuclear in a much bigger way than we did, there's less than 500 nuclear reactors operating on planet Earth today, worldwide, it's still a tiny, tiny slice of our energy source. And it's tiny compared to what it could be, if we had let that trend go in the 1970s and allowed it to grow, we would have abundant, cheap, efficient, clean nuclear energy, which would mean energy is not scarce anymore, which means people, human beings can't make as much profit off of it. Because if it's not scarce, then the people who've got it can't mark it up as much as they want to. And it undermines the prosperity of the entire human race to protect some money interests.

And if you watch Oliver Stone's film, *Nuclear Now*, he goes into quite a bit of detail about how the Nixon administration intentionally sabotaged nuclear energy. And I think a lot of what they did was to intentionally scare the public and pretend that it was much more dangerous than it really is. And I think it's just such a horrible, horrible thing. If you go back, though, another point I wanted to make about nuclear, going back to page 2 and energy returned on energy invested, you have to remember that all these numbers are a function of history. In other words, nuclear has the best EROEI, which is 75, compared to 4, solar, so it's a much, much better EROEI, it's the best one there is. But that's also, after we've only built nuclear plants with just horrible, horrible costs and schedule overruns, that made that energy much more expensive than it needs to be. That 75 you see on page 2 for nuclear energy for its EROEI score, that would be at least double or triple that if we were building nuclear energy efficiently, which we could do and which I'm advocating that we should do. So, a lot of these things are also a function of how badly we've botched energy policy, it is a result of conflicted interests, money interests, influencing governments, and also governments using subsidies, which distort free market economics and prevent the right choices from being made automatically by the price signal, as you described earlier. So anyway, Lyn, let's come back to the next page, page 4 in the deck, which is talking about power plant energy payback. What's that about? And what is the chart telling us on page 4?

Lyn: Sure. So the prior comments around energy return on investment didn't necessarily focus on time, if you put in 10 units of energy, do you get 20 units out, 30 units out? And of course, that's a very important metric to know. But the other dimension to that is time. So for example, if you had two energy sources, they both require putting 20 units of energy in, and they both give you 50 energy outputs, but one of them does that over a 10-year period and one of them does that over 20-year period. There's still different at the end of the day, because one, you're putting in energy and you're getting that a lot more front loaded. And so on slide 4, I have a custom chart there that just kind of shows two hypothetical energy sources to illustrate what I mean by this. And so, you have the blue energy source, and the orange energy source. And so both of them during construction on Year Zero, they both require 20 energy units going in. And the blue one is a fast payback one. So it gives you 200 energy units out and it's front loaded. So you put 20 in, you get 200 out, that's a 10x multiple, and over the next 20 years, you get that energy back, but then in particular, you get it back in the first 5 and 10,15 years, a lot of that is front loaded. Whereas the second energy source, the orange one is a slow payback energy source where you put in the same amount, 20 energy units, and you get 320 energy units out. So you get considerably more total energy out of this project than the blue one. But that's over a 40-year period. And it's not front loaded, it's basically persistent year after year after year. And when you're deciding which one of these two energy systems would be better, it depends on the context. And so, for example, if you're in a developed country, where it's nice for people to have more energy, people want more energy, but everybody already has quite a bit of energy. And what you're trying to optimize for is, say total energy, and you're trying to optimize for maybe how clean that energy is, how sustainable that energy is, does that add to air pollution, does that add to water pollution or not? Or if so, how much? There's multiple variables you're considering. And so, if you're mostly trying to maintain the energy consumption that you already have, or grow it slowly, because there's a slow growing population, and people already have pretty high energy consumption per capita, the orange one is probably better. In many cases, you build this very long live project, that gives you more total energy back than the other alternative.

On the other hand, if you're in an economy, like let's say, India, you’re a fast growing population, and still very low energy consumption per capita, more prone to acute energy shortages, things like brownouts. For example, you're not just trying to maintain your energy, you're trying to grow it 5x, 10x as quickly as you can, on a per capita basis. And so that fast payback starts to matter a lot more, even if you get less energy out of it. At the end of the day, the fact that that energy is front loaded matters a lot, because you can use that front loaded energy to then turn around and build more energy, or do other things, get more food, reduce the number of people that have to work in farming so that more of your people can go and work in tech, or other areas. And so that fast payback becomes a lot more attractive, and that it's not surprising that we see, for example, in India, a tremendous amount of their energy is from coal, specifically their power grid, because they really kind of emphasize and they need to emphasize sort of fast payback. Whereas in the developed world, we've generally been able to say, step back from coal and folks in other types of projects, because we're in that phase where we can emphasize kind of total energy, or at least you know, again, if we went back to say, engineers, rather than politicians making the primary decisions, we can emphasize things like total energy more, because we have less of like a near term energy emergency. And so, we can think longer decades out when making optimization choices. So this is just another variable that I think doesn't get enough attention. And people are always kind of surprised, like, why is this country building coal? Or why is this? Why is this country doing the way it is, and a lot of it has to do with that payback period is, so it's not just the cost.

And you know, to your prior point, it is true that, for example, some of these sources are finite, or at least, perhaps another way of putting it is that they have diminishing energy return on investment over time. And so for example, the early oil wells, for example, would you know, fairly small amount of energy would give you tonnes and tonnes of oil out. And if you look at a chart of it, we don't have a slide on this, but if you look at a chart on US oil production, pretty much have 100-year period of steadily rising the continental oil production. So from like 1870s up until 1970, you had rising US oil production. And then we peaked in 1970, structurally, and that's that was a factor in what caused the 70s to be so inflationary. It wasn't the only factor, you also had faster money supply growth from Baby Boomers kind of entering their home buying years, their credit formation years, we had a lot of bank lending. And then, of course, we relied more on oil imports, which then gave OPEC more flexibility to embargo us for various geopolitical reasons that are outside of this context. But basically, we had 100 years of rising domestic oil production. And then that kind of just rolled over for a geological reasons. We had decades of declining US oil production, all the way up until technology and cheap capital help unlock shale. And that gave us kind of a surge to new all-time highs in a short period of time. But basically, as we go from these very conventional, low hanging fruit, hydrocarbons, and we start to say, okay, we've used up the easy ones, now we have to do shale. Now we have to do deep ocean, now we have to do oil sands. Now we have to, say, drill under the Arctic. So it's a much more energy and technologically more challenging thing to do, as we have to go to those more difficult environments or more difficult chemical structures or more difficult overall, you know, how much energy and effort we have to put in to get each barrel, that energy return on investment starts shrinking over time. So it's pretty hard for hydrocarbons to ever increase their energy return on investment, whereas the general expectation, Chevron is a gradual decline in that, for example, hydropower, and nuclear and geothermal. These are ones that can sustain a high energy density and high energy return on investment long into the future.

Erik: Going back to the chart on page 4, I'm assuming that the blue fast payback and the orange slow payback is determined primarily from which fuel source or type of energy we're talking about. Can you give us some examples of which are the fast payback types? And which are the slow payback types? You know, let's cover wind and solar and oil and gas and nuclear and so forth? How do they each rank in this fast versus slow payback paradigm that you're presenting here?

Lyn: So a lot of that the majority of it will be due to fuel source. And then a smaller variable is things like construction times. Coal is near the top of the list in terms of fast energy payback, you build a coal plant, it's not particularly complicated in terms of construction. And then the energy source is pretty dense. And you know, you start burning it right away. And in a fairly short period of time, you pay for the energy that went into building the facility, you pay for the energy that went into mining the coal, and you start producing an energy surplus in a rather small number of years. Obviously, the variables would depend on what kind of plant is it, how new is it, what kind of coal source are you using? There's all sorts of variables that can affect the actual number, but coal is near the top of the list. Same thing for natural gas, these are fairly straightforward, especially, you know, not LNG, but just like domestic natural gas, these types of energy and construction are among the fastest. When you get to nuclear, at least historical nuclear, it could certainly be different for small nuclear reactors. But for historical nuclear, you get a tonne of energy density, but it takes you a longer period to kind of fully pay for your upfront costs, and start generating a surplus, just because of the technological complexity of building these facilities, the overall kind of overhead of doing so, I think we'll get into it later. But I think that that's an area that could be improved. You could have nuclear that has a payback period that's more like coal, but then way cleaner, way more long lasting, lasting way more overall energy density and better energy return on investment. Then, when you get into things like solar panels, you know, pushing out further on the payback period, which is to say that, it's not front loaded at all. It's not energy dense. And then especially if you include a fully kind of baseload system, so if you have battery backups, and you know, all the equipment you need to have that to be fairly reliable energy, the payback period for all of when you have to go mine all those metals, all those materials, all the energy of the labor that went into constructing it, and then just the very slow amount of energy it gathers because it's only gathering the flow of solar, takes a long period of time. Same thing for wind, these are fairly long payback period projects, especially when you include things like maintenance on a regular basis. And so generally, when you go to these less dense energy sources, you will get longer payback periods. But so far, the example of nuclear is the outlier, where higher energy return on investment does not always mean faster payback period.

Erik: I want to add a couple of things to that Lyn, going to wind and solar in particular, you know, because this has become so politicized. One of the things that's happening is, people are playing games with the numbers in order to sell their story, as opposed to approach this like an engineering problem, where we're all trying to work together to solve a problem for society. So, one of the things that you'll hear is that solar in particular, has just an incredibly low, inexpensive, levelized cost of energy, which is the total cost of making that energy, when you amortize the cost of building the solar field to start with, across its operating life. And the total cost of energy, including building the solar field is presented at being as low as $25 per megawatt hour, which is just incredibly cheap energy, it couldn't be better.

Except in real life. What's happened in a couple of cases is, they build these things with a $25 LCOE. And it's because that solar array has an estimated lifetime of 30 or 40 years. And one or two years later, there's a hail storm, and it completely destroys all of those photovoltaic panels. And what was supposed to be a 40-year life was really a one and a half year life. And now the LCOE is $400 per megawatt hour or something. So it's completely distorted, or the price signals are completely distorted because people who are trying to push one energy source over another for political reasons, or not being truthful and realistic, and coming up with their numbers. The other thing that happened is government manipulation and government policy, Energy policy, particularly in nuclear, has really distorted the efficiency of how we do things. And an example of a phenomenon that's actually happened with some nuclear plants is, the government, for very good reason, insists that when you build a nuclear plant, you have to have a decommissioning fund set up so that the money has been set aside to eventually when you decommission that plant, to tear it down and to safely dispose of all of the nuclear waste, and make sure that you don't have a situation where a bankrupt utility just abandons a nuclear plant that's full of uranium and radioactive materials and so forth. So it was created for very good reasons, it makes perfect sense, but they didn't really think it through completely and think about cause and effect and incentives. So what's happened in real life is, there have been operators that run a nuclear power plant, they get to the point where they fully amortized their investment, so they fully depreciated the plant, they've got this big decommissioning fund set up that will eventually be used to take that plant apart and throw away the materials when we're done with it. There's nothing wrong with the nuclear plant, it's working just fine. But the executive management of the power plant utility company says wait a minute, we've got this fat decommissioning fund. And that's going to be used to pay us as the contractor to decommission this plant to tear it down, we could make a lot of money tearing this plant down. And if we do, we would be eliminating a bunch of electric generation capacity. And that would drive the price of electricity up and we make more money off of our natural gas power plants. Let's do that. So they destroy a perfectly good functioning nuclear power plant for no reason other than that. The way the regulations are set up, they can get paid a decommissioning fee, and they can be the general contractor for decommissioning a plant that should not be decommissioned. Other than they saw an opportunity to make a buck decommissioning, and making electricity more expensive for society, so they can make more on their other power plants. We didn't think through the regulations, when we put them in place to consider that they might actually create incentives for people to do things that undermine the public interest, as opposed to advancing it. Let's move on to pages 5 and 6 in the deck. This is about negative electricity prices. What's the story there?

Lyn: Right, so as we discussed, some of these less concentrated energy sources, particularly wind and solar, because they're not always on, they're on sometimes or not on other times, and that's largely outside of our control. They can produce power when we don't need it, in addition to sometimes not producing power when we do need it. And of course, storage and things like that can somewhat buffer this, but storage is very expensive, both in terms of energy materials and in terms of money. And so we generally don't have a significant amount of energy storage relative to our production.

As we look at the map, United States, the map on the left there shows the frequency of negative energy pricing. And the areas that are the worst that are over 10% or 20%, tend to be the middle of the country. And that's because that's basically our wind belt. It's some of the windiest parts of the country, it's the most rational place to build wind turbines to generate power. But the problem is, if you build a lot of them relative to your total energy production, electricity production specifically, you'll get a lot of instances where you just have a tremendous amount of say, wind and solar energy, say the middle of the day when you're not using it, or maybe you have a lot of wind in the middle of the night when people aren't using it. And so, what happens is, if you produce more electricity than people need in that moment, and in that specific location, it risks being wasted. So electricity cannot be transported endlessly, we transport in several 100 miles, the further you go, the more loss it has, in terms of heat dissipation and just overall friction of going through the metal. And so, energy is a fairly local phenomenon, electricity specifically, I mean. And so, when you generate more power than you know what to do with at that specific time, and it's hard to save, a lot of gets wasted.
And so, a lot of times when we talk about, say, the cost of wind and solar, it's a very different metric that we say, okay, what is the cost including, say, batteries, things like that, when we

need it. And so this map shows, basically, the coasts, especially the West Coast due to the incidence of solar, and then particularly that center of the country where you have kind of both solar and especially wind, these tend to be negative energy pricing. So this is inefficiency. The chart on the right of that slide, slide 5 shows that this has been increasing over time. And if we had more slide space, I probably would include multiple maps here. If you kind of look at a video of this map over time, you'll see generally it gets darker and darker, meaning more and more instances of negative energy pricing, which the chart on the right kind of shows. And of course, the chart on the slide 6 is the same chart, it's just zoomed in a little bit to see it more clearly, that over the past decade or so, we've had, as we kind of build out solar and wind, even though they're a fairly small percentage of our total electricity production, because they're a large percentage in certain areas of the country, we tend to get pretty wild swings in terms of either energy costs or wasted energy. And it's not an accident that, for example, a lot of the Bitcoin miners in the United States are centered in Texas. And that whole wind belt is because when those places have so much, here's a negative energy pricing, that's basically, it's a rational energy pricing environment. And so, Bitcoin miners come in and say, you know, we'll buy it, when you're selling it for negative cost. You don't really see Bitcoin miners in New York City, for example, they go to out there where you have all these kinds of stranded energy resources that are not being used properly. And that's just an ongoing thing. So it's like, a lot of people say, people’s optics are, their targets will be how much wind and solar can we build? A better question is, are you making energy cheaper? Are you making energy more abundant, because as this map shows, just because you're building these energy sources, doesn't mean you're necessarily solving a problem. Because if you're producing energy, precisely, when people are using less energy, that's not helpful. The most helpful thing is to produce energy on demand in or when people tend to use it the most, which is certain times of day, or certain seasons, rather than kind of just the problem of nature's schedule, not really matching human consumption needs.

Erik: I really think this is a case of politics trying to force a square peg into a round hole when you start with, okay, we're going to create subsidies for wind and solar so that we can get some political favoritism to get the people behind those energies to support the political party that's behind wind and solar. And that I think, is a main driver, then, you figure out that the wind and solar is actually damaging the overall energy system. That's something I hear very consistently from everybody I've talked to who works in not just the oil and gas sector, but in electricity, and people who manage electric grids and so forth, say, the intermittency of that wind and solar is causing more problems than it's solving. It provides, as you said, a huge amount of electricity when we don't need it. It doesn't give us electricity when we do need it. And then the reaction to that is, the people that are just obsessed with wind and solar has to be the answer to everything. We'll say, okay, well, what we can do is we can hook batteries up to it so that we use that excess energy to charge the batteries. And then we draw the batteries down during those later periods. Well, the problem with that is, they're not thinking about the big picture of energy transition over the next 25 years. Right now, we've only got 5% of the vehicles on the road are electric, the coming electric vehicle revolution is absolutely necessary for energy transition, we need to do that. Most experts already are convinced that there simply won't be enough battery metals, even if we, you know, forget about environmental restrictions, or just go wild on mining as much of those battery metals as we possibly can, there won't be enough for the vehicle revolution. Well, how are we going to make all the batteries to support wind and solar becoming a baseload energy source, if we're using the same battery chemistries that are used in vehicles, which in many cases they are.

And the other aspect of that is cost. Right now, because the cost of those battery metals hasn't yet been squeezed by this coming, electric vehicle revolution, which has only just barely begun. We haven't got to really high cost battery prices yet. When we do, will the economics still make sense then, for using batteries to supplement wind and solar? And I just keep coming back to why are we trying so hard to force this wind and solar square peg into the round hole of what we actually need, which is primarily to get cheaper baseload energy. And we do need some intermittent supply, but not nearly as intermittent is what's being supplied by wind and solar.

Let's move on to page 7 in the chart deck. I put a slide in laying out my own analysis of our energy transition options. And the essence of this is, if you look at where the baseload energy, which is what we're really going to need the most of, and we need to make it cheaper than it is today. Not more expensive. A lot of people are focused on wind and solar, because of its intermittency. And because of the various challenges I just talked about, with trying to force that square peg into a round hole, it will help a little bit, but it's doing as much damage as it's doing good from everything that I hear. Hydropower is a fantastic green energy source. The problem with it is, it's dependent on geology, you've got to have a high elevation source of water that's flowing to a lower elevation. So you can build a dam and generate electricity from it, that places are around the planet where it's possible to do that have, for the most part already been discovered and developed. So we've already pretty much exploited the hydropower opportunity. There's not a whole lot of opportunity to do more geothermal, deep geothermal, where you drill a hole deep, deep down into the Earth's crust, to where the rock down there is so hot, that you can pump heat energy back to the surface and use it to turn a turbine and make electricity. Geothermal electricity is a fantastic idea, the economics just don't work. It costs way too much to drill those holes. And the primary problem there is that, in order for it to work, you got to be drilling through really, really hot rock about 400 degrees Celsius granite. And that's super hard rock that's super hot. Any drill bit that's known to man is going to melt under those temperatures. And there are some new technologies that have to do with kind of tasering the rock instead of drilling it with friction. So they're sending very, very high current electromagnetic pulses down into the wellbore in order to drill the hole by, it's called spalling the rock. Great ideas, great stuff under development. If we have a breakthrough in geothermal technology someday, it's going to make everything better. But guess what, it hasn't happened yet.

Meanwhile, nuclear energy has been staring us in the face since the 1970s. But the US government sabotaged it and created this morass of regulation that has nothing to do with keeping nuclear energy safe. I would argue that a lot of Nuclear Regulation forces nuclear to stay unsafe. In other words, a lot of things that we could do to make nuclear energy much safer are, to get away from water cooled reactors, use molten salt, which is a superior coolant. But the problem is, there's no framework for even considering the approval of a molten salt cooled reactor in the United States. Because the NRC doesn't do new tricks, you know, it's a government bureaucracy, they won't change, they won't consider another fuel like thorium, they won't consider liquid fueled reactors, which eliminate meltdown risk completely. So we could completely eliminate the risk of meltdowns by going to liquid fueled reactors, except there's actually a regulation that says they won't even be considered by the US NRC. So these nuclear regulations that a lot of people just want to believe are making it safer, are actually not making it safer. And they're making it more dangerous. And we've been neglecting that opportunity of nuclear for my entire lifetime now, and this slide is kind of a macrocosm of what my energy transition crisis docuseries is about. So for anybody who hasn't looked at it yet, at energytransitioncrisis.org, I go on for four and a half hours about all of this stuff on this slide. I don't want to do that here now. I want to get your reactions to this and what you think about our best alternatives for energy transition. So Lyn, I don't want to go on for four and a half hours talking about this. What are your feelings about our best options for energy transition? Where should the energy come from? Should we be using wind and solar at all? If so, to what extent and which other sources should we be looking at?

Lyn: Well, so I agree with your list, I think you've laid that out very well. That basically, the problem is that some of our accumulated energy sources like hydrocarbons, even if we're not going to run out anytime soon, we could have trouble doubling or tripling our annual production of the sources that we're tapping into, a saved resource from long ago. And that's obviously not ideal when looking out over the long arc of time. Nuclear, I agree with you is the best bet in any sort of like reasonable timeframe, especially if we consider transitions towards newer technologies, small modular reactors and other things like that. Hydropower and geothermal are both valuable and particularly for geothermal, any sort of breakthroughs that make that better and more kind of broadly useful, are powerful. What these have in common is that they're energy dense sources that have a very long expectation for how long they can provide us with energy, in some cases indefinitely.

For wind and solar, it's not that I don't think they have a role. It's just that when you have a variable energy source, it has to be matched to the context in the location. So for example, it's not an accident that solar panels have been a key power source for spacecraft. You know, once they're in space, if you want them to operate for decades, solar is the best for that context, at least historically. And you can't have a coal burning satellite, even though it's more energy dense, you know, you're up there, you don't have the atmosphere as you have like unmitigated solar activity. And you can operate for decades without additional fuel sources. And it's very lightweight. Similarly, if you're in San Diego, for example, solar is going to work better for you than if you're in Maine, right? So trying for solar panels in Maine is not ideal. In addition, solar is useful for people that want to be off the grid, if you don't want to rely on centralized energy production, like nuclear power, or hydrocarbon power, and all these others or a big hydro dam. If you want your own little power generation, that's where your own personal solar panels can certainly come in handy. And then similarly, there's particularly windy parts of the world that can benefit from wind power, if they happen to have that resource in abundance. So yeah, it's not that they're not useful, it's that we try to, as you put it, try to put a square peg in a round hole. When politicians dictate where they go rather than engineers, I think that's where you run into the key problems. But the one I would add to your list, and I mentioned it off the air is OTEC, which stands for Ocean Thermal Energy Conversion, that's one of the other fairly energy dense sources, that is also kind of indefinitely sustainable. And so, slide 8 on the deck, shows an example of an OTEC plant. And the way OTEC works. We talked before about letting nature concentrate the energy, if at all possible. and OTEC does that for solar. And so, when we consider, let's say, we consider a typical hydro dam first. So, as you pointed out, hydro dams need a specific set of things, you need high elevation, and you need a water source coming down from that elevation. But when we back up a second and say, you know, where's that energy coming from? Ultimately, hydropower on a river is concentrated solar. So solar is shining on an area, and it's evaporating water over 1000s of square miles. And then it's dropping that water via rain on a high elevation. And then just the shape of the geography of that area is concentrating that falling water towards denser and denser rivers. So you know, a bunch of little small rivers turn into medium rivers, turn into big rivers. And then we put a dam right on that concentrated spot. And so, what we're effectively doing is we're gathering 1000s of square miles of solar energy that has been converted to kinetic energy. And we're using it to spin a turbine and because it's kind of saved up, it's been solar that's kind of saved up over a longer period of time, not millions of years, but just kind of that season that evaporation and rainfall and river cycle. It's fairly baseload power, is quite energy dense. And it's pretty cost effective. And OTEC is similar, except that instead of relying on that kinetic power, instead, they rely on oceans. And so, most of the solar energy that hits Earth hits the oceans, just simply because that oceans are a larger percentage of our surface area.

In addition, water retains energy better than air does, it's a better kind of heat battery than air. It's still not fantastic, but it's naturally occurring, and it's a lot better than air. And so, something like a century ago, engineers figured out that if you have hot water and cold water, you can produce power, you can spin a turbine. And so what OTEC plants do, you know, ocean thermal energy conversion, any sort of sufficiently warm water, so equatorial waters are the best, but they don't have to be exactly on the equator, just any sort of like pretty warm water area. If you build a plant that gathers that warm surface water, typically over 70 degrees Fahrenheit, and then you have a long tube that goes down 1000 metres, and you get cold, like 40 degree water, you now have a differential, you have hot water and you have cold water. And you can use that to power a turbine. And so, what you're effectively doing is, all this solar energy is hitting the ocean surface, and it's not being used right away, it’s being allowed to concentrate. And then these plants can go out to the hottest parts in the water and make use of this more concentrated energy. And because it's concentrated, it's also baseload. So this is not energy that fluctuates too much throughout the year. Certainly not throughout the day or the month. Basically anything other than you know, you might have to shut when you're hit by a hurricane or something. But other than that, it also just so happens that these, like hurricanes and other storms like that, don't cross the equator, so they also happen to be in particularly calm waters, and you can build these plants that either can run infrastructure to the mainland and produce electricity directly. Or they can do things like produce liquid fuels, like hydrogen fuels right out there in the water, and then they can be shipped anywhere. And so, I think it's an untapped energy source. And the history of it is interesting, because it's not a new technology, it's like I said, it's been around for like a century. And the challenge with it, is that it's uneconomic except at large scales. So if you do it on a small scale, like all of the models have done so far, so all of the practical research, deployments of the technology, have been on a fairly small scale, like far less than a megawatt. Whereas, if you do the facility at 100 megawatts, that is modelled to be quite efficient, that you can get fairly low cost baseload power, that is sustainable and clean. But the challenge is that nobody's going to build 100 megawatt plant, which is like the size of a very large container ship, or like an oil platform, very expensive, unless you prove 10 megawatts in 1 megawatt plants. But the challenge there is that they're not economic, and nobody is going to build those. And so this technology has been around for a long time, there's occasional marginal improvements, that they find a way to make it more efficient. And there's these various kinds of paths going forward, that are plenty promising to make 10 megawatt ones more efficient, so that they could potentially be deployed, prove the technology more and then eventually get to the far more efficient 100 megawatt ones. And one of the past, you know, there's a company called MCI, they're spearheading all these new technologies, there's thermal technologies, there's pumped technologies, all these ways to make it more efficient to hopefully kind of get that barrier down lower. The other one is a company called Bid Ocean. And what they've actually proposed, ironically Bitcoin mining, because they say, okay, well, one of the challenges with OTEC is, if you build a small plant, you have to have all that infrastructure to get power back to land. And because there's almost nothing you can do with power out in the middle of the ocean, they said, okay, well definitely, if you have Bitcoin miners on board, you can put that power into Bitcoin and you can prove your energy cost without all that infrastructure. So you could make a 10 megawatt plant economical, potentially, which then allows you to build, down the road, 100 megawatt plants that can be used for any purpose.

In addition, the engineer that was leading that one, Nate Harmon, he also realized that Bitcoin miners expel heat and need to be cooled. So that can actually be integrated right into the process. So you can use the cold water that you're getting to cool the miners. And you can put the waste heat from the miners right into the hot water. And so, it actually makes the process more efficient, basically gives you, you know, the Bitcoin mining is almost free, other than the upfront equipment costs when you do it like that. And so there's kind of these new ways and say, okay, well, we can kind of make these intermediate types of OTEC plants economical, that then hopefully allow you to build out those larger ones in the future, including ones that have all the infrastructure that goes back to land to generate power.

I think the last thing I'd point out on that is, that there's a lot of like other kind of context specific things you can do with OTEC. So for example, if you're using an OTEC plant out in the ocean, you don't want the infrastructure to go way back to land, you can produce liquid fuels, which could be useful. For example, as a stopover ocean port for transportation vessels, so container ships and things like that it can be used as a way to Greenify the ocean transport business, for example. In addition, they can be used as power plants for oil production facilities out in deep water environments, as long as that's warm water environments. And the last kind of observation is that there are these fields out in the ocean, there's these areas that they call them polymetallic nodules, which is that there are certain parts in the ocean floor, like let's say, in the Pacific Ocean, where you have literally these little metal balls, just sitting on the ocean floor miles down. And those little metal balls happen to be battery metals. So things like copper and nickel and cobalt, and like all these kind of trace metallic elements that we need for a lot of things. And there's estimates, that there's literally trillions of dollars worth of these battery metals, literally to sitting, these little like egg shaped little metal balls, to sitting around in the ocean floor. You can Google them, polymetallic nodules. And so, one of the proposals for people that kind of advocate for this technology is another thing you can do with power out in middle the ocean is, power the equipment that's needed to kind of go down and, for lack of a better description, kind of vacuum up all of these polymetallic nodules. And it's basically a way to mine some of these necessary metals in a way that we've not really kind of explored before. So I think this is kind of in addition to nuclear, deep geothermal, and hydro. This is like another potential vector I think of, for people that are researching it or capital allocators, I do find that to be a pretty promising long term path. It's not something that's going to give us any meaningful energy like in the next decade. But over time as some of these paths are proven, I think that's an over the long arc of time, harnessing more of our ocean energy, I think is another kind of way to go.

Erik: I'm fascinated by this Lyn, it's clearly a brilliantly innovative way to capture electricity. And if you think about it, in a way it is deep geothermal, deep geothermal is normally about going to a deep depth where you can take advantage of a higher temperature differential from the surface. In this case, you're taking advantage of a lower differential, you're using that differential in temperature in order to spin a turbine and make electricity, sounds great. But it seems to me like it's inherently subject to exactly the same limitations as deep geothermal, which is, there's a few places on Earth where it works. In the case of deep geothermal, you need to be in Volcano country where there's super, super hot rock very close to the surface. So you don't have to drill very far to find it. In this case, Hawaii, you can run a pipe from a Hawaiian island, and it's not that far off shore to get to where the water is 1000 metres deep. There's only a few places on Earth where that's true around an inhabited place. And I'm just having a hard time seeing where the breakthrough would come from, in order to make this really work at scale.

Lyn: Yeah, it is a good set of observations, I think. So some analysis have suggested that there's many terawatts of electricity and energy, total energy production available from this method. And, you know, it's not just one. Obviously, the sweet spot is coastal regions that are populated in, say, the 20% margin around the equator, that's kind of the sweet spot. But when you use some of those extending ideas, which is a, okay, you go out to the middle of the ocean, and you generate liquid fuels, or you serve as, you know, kind of mining fuel, or you serve as a producer of liquid fuels for the world's shipping industry, for example, these additional kind of extensions of where that technology can be useful. You can even for example, create liquid fuels, and then send it back to land. For other types of onshore transportation, obviously, the more conversions you do, the less efficient it's going to be. But that is then somewhat offset by having just larger and larger economies of scale, to make sure you're doing it in a cost effective way, once the technology is kind of, you know, hopefully more proven at scale. And so kind of that path dependence is okay, how to bootstrap these kind of intermediate sized ones, to prove the concept further, compared to the little ones that already exist, to then build out even the bigger ones. And so it's not something that, for example, the whole world can run on OTEC. But I think it's another one of those areas where you could add another, say 10%, or another 20% of the world's energy coming from this method, which can then accompany things like nuclear or hydro, like a river, hydro, or geothermal. And so for example, if a country is worried about its uranium supply due to geopolitical reasons, or if it doesn't have the technology to build nuclear, but it has the technology to build this, or if it just happens to kind of like how, if you're in a country that has really good river resources, you're going to use them for hydro, if you happen to be in a country that's, you know, near equator waters, this tends to be, potentially a long term thing to be interested in. And then like I said, the other things that can make it so that even if you're a landlocked country, if some percentage of, say the shipping industry or some percentage of these other things, are powering their energy production with this method, that leaves more of the other energy production for you. And so, I think it's just one more kind of tool in the tool chest for how we can have long term energy abundance, because this is one of the only other mechanisms that we know, that produces fairly energy dense power, that's not relying on like a finite resource, it's still ultimately from the sun. It's just that, much like river hydro, it's letting that sun concentrate before, we, for lack of a better word, harvest. So Erik, you added two more slides about turbines that convert heat energy into mechanical energy that can be used to produce electricity. Turbines are admittedly not an area that I've spent a lot of my time looking at. So I'd be curious to see what you have to say about how turbines are particularly important to this.

Erik: Well, I think what's really important is, actually the underlying problem that turbines solve, which is most of the energy that we know how to produce is heat energy. And it's true that wind and solar can produce electricity directly, but they're producing it intermittently. And they're not producing it on the scale that we need it, even it's not at all unique to fossil fuels and burning fossil fuels. We have something like geothermal renewable energy, that's heat energy that we need to convert into electricity somehow. Nuclear energy also produces heat that needs to be converted into electricity. And that process for converting heat into electricity is profoundly inefficient. In the case of most fossil fuel burning power plants, it's like 40%. So more than half of the energy that is released by burning those precious fossil fuels just goes up the smokestack, it contributes to greenhouse emissions, and it doesn't actually make any electricity. Only about 45% of the electricity in a coal burning power plant actually gets used to make electricity, the rest is wasted.

Internal combustion engines are even worse. When you drive a gasoline powered car, 80% of the energy released from gasoline is heat that goes out the exhaust pipe and out your radiator. It's not actually propelling the vehicle, only 20% at most is propelling your vehicle forward. Electric motors are much more efficient. And that's why a lot of people are excited about electric vehicles. But you have to remember, somebody has to kind of recharge the electric batteries in the electric vehicle somehow, where does that electricity come from? From the most part, it comes from electric generation plants that look like what you see on page 9 here in the deck. The big yellow thing is a steam turbine that spins around, basically the heat energy from the nuclear reactor, or from the coal burning power plant or from the natural gas burning power plant, that heat energy is used to boil water, and the water turns into steam, the steam is pumped through that big round yellow thing. Well, that yellow thing costs more than a billion, with a B, dollars. It's a very, very expensive piece of machinery that's incredibly inefficient. And unfortunately, this is not my field of expertise, so I can't speak with any real depth to this. But what people tell me is, there are some inherent laws of thermodynamics that just say you can't make a steam turbine, which really works on the expansion of gas, in water vapor turning into steam. You can't make it much more efficient than it already is. If you get to supercritical temperatures and pressures, it gets more efficient. But the very best you can do is 55% or 60% efficiency. And that's, you know, if you're really trying hard, so these steam turbines are inefficient. And I think a really important problem is, we don't think enough about how to use heat energy more efficiently. In other words, if you've got a coal burning power plant, and you're using a lot of that energy to produce electricity, that 60% of the energy goes up the smokestack, only 40% of it gets recovered as electricity. You then deliver that electricity to a home, which is using electric heat. And as a result of that, you've already wasted 60% And now you're going to use it just to heat something. Well, why not have district heating, where first you produce electricity, and then you take the steam that's coming off of that turbine, run it through a fluid to fluid heat exchanger, and have a circulating loop of district heating energy that provides 1000s or hundreds of 1000s of homes with heat during the wintertime that doesn't suffer all of those efficiency losses? Well, I think what happens is people building power plants are focused on building power plants and making electricity, they don't think about how much energy is being wasted. And we need to do something better.

One of the things that I'm really excited about, these turbots are so expensive, and as I think about how to make nuclear energy much more cost effective, which is kind of what I'm obsessed with lately, is how to make nuclear energy cost less than energy cost back in the 1960s. When I was a kid, well, even if you modularize the nuclear reactors with small modular reactors, which I'm going to talk in detail next week with Mark Nelson about, even if you do that, you might be able to get the cost per kilowatt of building the nuclear plant down to only about $200 or $250 per kilowatt of nuclear reactor modules. But guess what, you still got to hook it up to a steam turbine, and it might cost you another $1,000 per kilowatt, just to build the steam turbine that powers the generator to make the electricity. If you move on to page 10 There's this new invention called carbon dioxide turbine, said don't worry, the carbon dioxide is circulating in a closed loop system. So there's no carbon dioxide emissions. There's no current, there's no greenhouse gas emissions. It's a perfectly green, environmentally friendly technology. But that tiny little turbine you saw it going back to page 9 in the foreground, you can just barely make it out but there's a fully grown man, a six foot tall man walking across the floor there, you can see how big that great big yellow SST-9000 Siemens turbine is that's running the blue thing is the electric generator, there's a guy walking across there, look at this turbine in front of two guys on page 10. That's a 10 megawatt turbine because this is a brand new technology. And this is the only one they've built so far. But if you imagine one that's big enough to run that great big generator, that's, let's say, a half a gigawatt of power that is being generated by that generator. So half a gigawatt electric, which is probably a full gigawatt of thermal energy, it would probably be about the size of a shipping container or smaller, because these things are 1/10, the size and weight, and they're also much less complex. Therefore, they're much less expensive to build. That big steam turbine on page 9 costs well over a billion dollars. Now, these carbon dioxide turbines are brand new and experimental. So therefore, you know that we don't have the efficiencies of economy of scale of mass producing them yet. But I'm extremely excited about this idea of carbon dioxide turbines, because in addition to being lighter, and more efficient and inexpensive to build, they're also much more thermally efficient. And that means you need 20% less thermal energy. So you're burning 20% less coal or natural gas, or nuclear energy. Or put it another way, you need 20% less nuclear reactors in order to power the same electric grid, or 20% less natural gas, whatever your fuel source is. And that means 20%, if you're using something that pollutes the atmosphere, like fossil fuels, that's 20% less pollution as well. It's also because of the size, much more conducive to modularization and mass production, in factories on assembly lines, which is what I'm convinced is the future of nuclear energy. So I just think this whole field of how you get from heat energy to electrical energy is so ripe for more research, you know, the carbon dioxide turbines are a terrific idea. But as long as you're spinning a turbine, using expansion of gas, my friends who know more than I do about thermodynamics tell me, there's certain limits on how efficient it can get. Somebody needs to figure out a whole new way to convert heat energy into electric energy that doesn't involve spinning a turbine, which is the way we've been doing it for 150 years, and figure out how to make it more efficient. And that could just change the face of energy overnight if somebody had the breakthrough, that figures out a better way to make conversion of heat into electricity much more efficient than it is. So I wanted to just make that point that it's a field of research that I really hope gets more attention than it's gotten so far. So Lyn, before we close, I want to come back to wind and solar. We've made a few comments, I think you and I both agree that wind and solar are overhyped by some people. But I think it's also true that you and I both see that wind and solar do have a place, they are important technologies, they do have a place in energy transition. So how do you see that? What should we be thinking about in terms of the overall picture of what energy sources we should use and where do wind and solar fit into that story?

Lyn: So a point I made earlier in this discussion is that economic development really kind of comes down to two key variables. One is more and more energy, and two is using that energy more efficiently due to better technology. And then, of course, one feeds back into the other. So better technology allows us to get denser energy sources. And you provided some examples where we both did have more efficient technology. And so for example, more efficient designs allow us to make natural gas plants more efficient than they were 30 years ago. For example, you just went into detail, but how turbines of all things, even though we probably consider them pretty standard technology, they're clearly not, there's clearly a lot more efficiency gains we can have from our turbines. And so that's an example of where technology can better harness existing energy. Similarly, you mentioned deep geothermal, how you have a drilling problem into very hard rock, a very hot rock. And, you know, if instead you use other methods that don't rely on friction to go through that rock, if there's enough breakthroughs there, you can unlock an entirely new energy source because of that technological efficiency. Similarly, OTEC you know, what can potentially move it past the finish line into being a fully kind of workable energy source is to kind of these small little efficiency gains, either having slightly better thermal and pumping technologies to kind of get it over that finish line. Or, you know, Ocean Bid’s usage of Bitcoin miners to kind of harvest any sort of strength and energy they might generate along the way, more profitably, and then kind of prove the technology and build it at scale. These types of things are all different sort of efficiency gains and technology gains. And of course, most people are familiar with this, even if they're not from with the details, they kind of have an expectation that our that our technology gets better over time.

The other variable is just the raw physics one, which just comes back down to energy density, energy return on investment. And that's the area where there's almost no amount of technology that can overcome certain challenges. And so, when we look at nature, for example, it's still at a technological level that we know we're not even close to. So for example, plants are solar panels that are self cleaning, self reproducing, compared to like our imitations, which are there 30-year panels that need cleaning that can easily be destroyed by a hailstorm that need all these kinds of metals that are not renewable. So even though the solar itself is renewable for billions of years, the ways we harness solar and wind are not necessarily renewable, just because we're tapping into energy intensive, finite resources in many cases. And so, when we think about our approach of energy, one, it's about as efficiency gains, but then two, it’s taking a step back and kind of looking at overall process. And so if you imagine a world that's entirely wind and solar, as some imagined it to be, maybe a little bit hydro in there too. Picture a world where it's just tonnes and tonnes of solar, tonnes and tonnes of wind and tonnes and tonnes of batteries to smooth some of that variability out. But then when we picture that going forward, one, it's just an unfathomable amount of materials to produce an entire world worth of wind and solar, and then two, every few decades, you know, the lifetime can maybe vary depending on how good technology is. But let's say every 30 years, you have to replace virtually that entire global set of energy infrastructure, which is very material intensive, and do that for eternity. So you have to just constantly replace and renew the fact that, you know, your metals are corroding, they're rusting, weather is damaging some of them. Just over time, all those metallic systems degrade, they're not these like self-cleaning, self-renewing systems like nature has. Whereas, when we think about what is ultimately a solution for energy is basically about to whatever extent possible, minimizing the materials, we need to gather energy. And so you know, for example, OTEC can give you quite a bit of energy for the size of a ship. And it doesn't need any more ongoing fuel for it, it can last for a very long time. And it's just giving you quite a bit of energy for that a hydro dam on a river is, it's a big upfront cost, but then it can gives you energy for a century before you'd need to maybe replace it. So the amount of energy you get out of what you put in, is potentially tremendous over its full lifecycle.

The same is true for a very well-designed nuclear facility, especially using some of these later technologies. And the same is potentially true for things like geothermal. And so, I think going forward, we have to have an awareness. And that kind of way of questioning it is, how can we let nature do most of the work for us? Because ultimately, letting nature do most of the work is how you, one, get the energy density up, two, get the cost down. And three, it ends up being cleaner as well, because you know, you're mining, installing, and then replacing on a regular basis. All this metal is just not going to be long term, environmentally sustainable. Whereas harnessing kind of the natural concentration force of the Earth is how we ultimately get towards sustainability. So, it's letting rivers and oceans concentrate the solar, it's harnessing the fact that the entire Earth under our feet, all that molten core, all that molten energy, is from all that kind of power of gravity, to the extent that we can tap into that. That's tremendous. And then, of course, nuclear. To the extent that we have all these energy, dense uranium and other materials, we can produce tremendous amounts of baseload power from it, for fairly low material inputs. And so, it really just comes down to constantly improving energy efficiency, but then always with the philosophy of how can we let nature do as much of the work as possible, because that's what solves as many of the variables as possible.

Erik: You know, something I'd like to add to that, Lyn, is, I think one of the most important things is we need to do public education to get people to focus much more on cost, but from a different perspective. You know, people say, oh, he wants to think about the price of this, typical business guy trying to make money. Capitalism is evil. You know, it's kind of the public attitude that we hear. I want people to think about the cost of energy is directly determining our standard of living, the cheaper that energy is, the higher the standard of living, the more expensive the energy, the lower the standard of living. And I'm all for greening the environment, protecting the environment, taking climate change seriously, I'm all for it. But I think what happens is people who become obsessed with climate change, get so obsessed that they think cost is no factor. It doesn't matter how much it costs, and they don't understand that. But it's not just how much somebody has to pay, it's literally determining our standard of living. Whether we go back into the dark ages or whether we have flying cars someday is going to be determined by the cost of energy more than anything else. And I think we really need to get that into the public awareness and to recognize that the cost of energy is, is just so important and so underappreciated.

Lyn, we're running out of time here, even in our long form. And I want to thank you for taking the time. Our listeners tell us during the holidays, they really loved the long form interviews, not so much because they're addicted to our brilliant insights, but because it allows them to escape their families and tell them oh, I have to listen to this thing. It's for work. Sorry, I can't talk to you, Uncle Tom and grandma Jane. I'm busy. So thank you so much for doing this.

Before we go though, I just want to ask you to give our listeners a little bit more perspective since we've got this long form on what you do, both as an author and in your business at Lyn Alden Investment Strategy. Your book, ***Broken Money,*** is a best seller, a well deserved best seller, we did an interview with you recently on MacroVoices, anybody who missed that just put Lyn Alden into the search box at macrovoices.com to look for that interview. But tell us a little bit more about what you're working on and what services you offer at Lyn Alden Investment Research.

Lyn: Well, I appreciate you having me again, I really enjoyed this discussion. I feel like this is an area that's just not getting a focus, I'm glad I was given the log form that it deserves. My work is primarily at lynalden.com and I provide investment research for retail and institutional investors. What I try to do is kind of take institutional type of research and put it in plain English with the topics that I tend to focus on the most. And so, because of my background, I tend to focus on quantitative systems, engineering approaches to macroeconomics, I focus on energy, and I focus on assets like Bitcoin or Stablecoin, visit monetary, technological disruptions that can change things that can impact macro, kind of those areas. You know, we all have our areas of expertise, are areas where we don't really kind of focus. So for example, I have very few insights on anything, say healthcare related, for example, it's just not my area of focus. But on these other areas of say, monitor technologies or energy or just kind of capital flows or systems engineering approaches. That's what I tend to emphasize for my subscribers. In addition, I work with Ego Death Capital, a venture fund for accredited investors, where we kind of invest in some of the emerging technologies in the space. But I know that you're also working on a video that that's going to come out soon. And so I'd be curious to hear more about that.

Erik: Slide 11 in the deck shows that more than $4.6 trillion has been spent on renewable energy in the last two decades alone, resulting in exactly zero reduction of fossil fuel demand. I have a new video coming out to explain my own master plan for how to completely replace all the energy we presently derived from fossil fuels with clean, safe nuclear power, generated by small modular nuclear reactors. My video editor Larry Chuck over at lcdigitalproduction.com is hard at work producing that video as I'm recording this. The planned release date is December 27. But there's a good chance it'll be published earlier. So please check www.energytransitioncrisis.org/smr, like small modular reactor, which is also linked in your Research Roundup email. The video lays out exactly what it would take to replace every single watt of energy we presently get from fossil fuels, with nuclear power by 2050, for less cost than the $4.6 trillion we've already spent on renewable energy, with nothing to show for that investment in terms of fossil fuel demand reduction. I'm going to be discussing many of the concepts presented in this video with Mark Nelson in next week's New Year's Special, which will also be a long form interview with no postgame segment or market wrap. So I encourage everyone to check back at energytransitioncrisis.org/smr and watch that video before listening to next week's long form interview with Mark Nelson. And while you're at it, please try and make time to watch episodes 5, 6 and 7 of Energy Transition Crisis because we're going to consider all of that content is prerequisite background for next week's show. Mark and I will be taking a deep dive into the ups and downs of molten salt coolants, liquid fueled reactors, thorium fuel SMRs and several other topics that would be difficult to make sense of if you try and listen without having the background knowledge of advanced nuclear technologies. which is communicated in episodes 5, 6 and 7. So now you've got even more excuses to avoid the in-laws this holiday season, as you prepare for next week's long form episode. And that's a wrap for our 2023 Christmas holiday special. On behalf of Patrick Ceresna, Nick Galarynk, Lynn Alden, and myself, Happy Holidays, everyone. And we'll see you back here next week for a deep dive on all things nuclear energy, with Radiant Energy founder, Mark Nelson. We'll be back to our regular show format on January 11, 2024.