

[Transcript] The Realignment / 331 | One Small Step Towards a Fusion Energy Breakthrough with Charles Seife

Marshall here. Welcome back to The Re-Alignment.
Before we dive in, a quick shout-out to the Supercast,
which is how we fund the show and deliver exclusive content.
Yesterday, Saga and I released our second exclusive
Ask Me Anything episode of the year,
part of our stepped-up cadence.
If you'd like to access that extra content
or just want to support the show,
go to realignment.supercast.com
or click the link in your show notes.
On to today's episode.
I'm joined by NYU professor and science journalist Charles Seif,
author of *Hawking Hawking*,
the settling of a scientific celebrity,
and more relevant to our conversation today,
sun in a bottle, the strange history of fusion,
and the science of wishful thinking.
Last December, the Department of Energy announced
a huge breakthrough with fusion energy research
and a step towards a near-limitless source of energy.
Now that there's been a month or so since the announcement,
I thought this is the perfect time to follow up,
considering our focus on energy and nuclear power in general.
Charles helps answer the question,
raised by his Atlantic piece on the announcement,
is this the Kitty Hawk moment for fusion energy
or something more symbolic?
Last but not least, tomorrow is obviously Friday,
so the sub-stack will be going out.
You should check that out.
The link is in the show notes there as well, too.
Thank you to Lincoln Network,
and I'm excited to see those of you who are here to be in DC
for the realignment conference next week.
Hope you enjoy the conversation.
Charles Seif, welcome to the realignment.
Thank you very much, realignment.
Yeah, I'm really glad to speak with you about this topic.
Let's just start with the very basic definitions section.
What is fusion energy?
So people are more familiar with vision energy,
where you take very heavy atoms like uranium and plutonium
and split them apart.

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And when you do something like that,
a little bit of math goes missing and is converted to energy.
You've heard of $E = mc^2$.
That means energy can be converted into matter and vice versa.
So a tiny little bit of math going missing with these fusion reactions
poses a huge amount of energy to be released.
And we've been doing that since 1942.
Fusion, on the other hand, is the reverse problem.
Very, very light atoms like hydrogen.
If you smash them together and force them to stick,
that releases energy as well.
And again, the 40s, I had to realize
that you could harness this to do release energy.
In fact, the sun is doing that right now,
that in the center of the sun you've got hydrogen,
which is an abundant element being smashed together
under huge pressure and temperatures
and releasing energy.
That's what makes the sun shine.
Doing this on Earth is a lot harder.
We actually succeeded in the 1950s by using an atom bomb,
which was powered by fission.
We were able to harness that energy and create a small amount of hydrogen
to collapse, pierce, and sorry, I'm going to just shut the plug.
We're going to, so you take a small amount of hydrogen
and cause it to fuse.
And so we could do that.
That's the center of the hydrogen bomb.
So you can wipe out an island,
how to wipe out a city with this energy.
However, doing it in a laboratory where you want a small amount
that doesn't wipe out your entire city is really, really difficult.
So since the late 40s, early 50s, this is what scientists have been trying to do
to do on a small scale using atoms together
and releasing that energy in a way that can be controlled.
And we have not been able to do that so far.
When you're referencing 1942 with fission,
obviously this brings to mind nuclear weapons, bombs, cold war,
all the things that are, by definition, dangerous.
To what degree is the fusion process tied to danger, risk, et cetera?
Well, both are tied to atomic weapons, as you mentioned.
So there's that level of danger that, so far, our only real useful output
of fusion energy is destruction.

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However, fission, as you know, has been used in power plant. We have successfully taken hunks of uranium, put them together, in a controlled manner, very kind of carefully tweaking that reaction so that it just produces a little more energy than we put in and we harness that. So fission plants have been operating since the 50s, and they're very useful. The problem is that they produce radioactive waste, as these large atoms break up rapidly. Other radioactive atoms, which is kind of hard to get rid of. There's other problems as well. You can take some of that material and leak into the environment. You need to radiate stuff. As we know, if you have something catastrophic, you have what's called a meltdown, where that fission reaction gets out of control, that very careful balance that we have to prevent it from running amok, gets out of control, and you can actually get an out of control reaction. With fusion, those elements are less of a worry. You can't really have a meltdown because to get fusion going, you have to ignite everything under very high pressure, very high temperature, and that's when you get the fusion going. If the reaction goes out of control and blow itself apart, so you get essentially a big puff once you escape the pressure of confinement. You clarify puff as benign as the word puff suggests, or is there something deeper than that? There are things called, for example, plasma destruction. Some of the bottles which have a magnetic field around them will lose control and the magnetic fields will whip around, and the entire reactor will jump up an inch. I mean, so you've got a 40-ton instrument going pop, but it is not like a nuclear bomb because the materials aren't there. It's not a real large amount of material under huge pressure. It's kind of, again, closer to equilibrium, so it's harder to kind of go haywire out of control in a way that's large. The other element is that the nuclear waste. A lot of the fusion advocates say that it's totally clean. This isn't true. That's when you produce fusion under most ways people are talking about producing fusion and producing what are called metron, which are particles that make up the atom, and they irradiate everything I make, things that aren't radioactive, radioactive, just by their crud. So when you have a fusion reactor running, the entire reactor slowly becomes radioactive.

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And now this stuff isn't as nasty as the heavy elements in fission, but it is still something you have to deal with, and it's a large volume of it, so you have to dispose. There's also another element that is of danger with fusion as well, is that it means, when I say hydrogen, I'm talking actually about what are called isotopes of hydrogen. Hydrogen comes in multiple flavors, which depends on how many neutrons the atom has. So you have hydrogen, which is the lightest version, then deuterium, which is the next heaviest version, and then tritium, which is heavier still. So tritium is really the crucial and hard to get stuff, which powers both the fusion reaction that we are going to be doing in the near term. And then it's radioactive, and it's kind of nasty stuff, and it's not easy to get a large amount of it. The good news is that once you have neutrons, like you have in a fusion reaction, you can create tritium. The bad news is that once you're creating tritium on large scales, it itself becomes a hazard. So tritium, which is created through a neutron activation of lithium or other materials, you probably will have a blanket around the fusion reactor containing those materials, but it creates tritium. One could imagine if there were a breach in the reactor or a fire or something like that, all that tritium would get out and be fired up. So that is an environmental worry as well. So that's a long answer to your question, that the environmental and safety concerns are not as acute as they are in fusion power plants, but they still exist and they are slightly different. Another question that comes to mind from this then is, what's just here about the most good faith articulation of like the promise of fusion? Like what would a world power by fusion look like and what problems would that effectively quote unquote, and this is kind of the point of, I think, your work, using the word solve kind of misses the point, but for the sake of this conversation, what would be solved by a fusion powered world? Yeah, so the main advantage of fusion, like vision,

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is that you are creating energy on demand based upon materials you've gathered. You're basically burning materials, but the materials don't contribute to climate change. These are not carbon producing fuels. So in theory, if you were able to produce fusion energy on a large scale and cheaply, it would be able to replace coal burning and gas burning and oil burning power plants. And so one could imagine we had this magic solution in 20 years, all of a sudden you have this cheap fusion energy source, it would significantly reduce our carbon footprint as a society. However, that's kind of in the best case scenario and I think that ignores a lot of practicalities including not just the difficulty of making these plants, but the cost of making these plants and the cost of putting the energy on the grid in a way that competes with existing very cheap methods of producing energy. I mean, if you could produce enough energy to satisfy you by throwing a log in a fire, you have to have a good justification for having a multi-billion dollar highly technical, very difficult to build operation to replace it. I think you just hit at a couple of things I want to discuss. So A, as you don't know the cliché about the failed promise of nuclear energy is that in the 50s it was supposed to be too cheap to meter. This was the promise of nuclear energy and this has frankly nothing to do with let's say like the climate change concern which becomes much more of a let's say selling point of nuclear energy like moving into the 60s, 70s, 80s and to today. So back in the 50s you're not talking about climate change, you're talking about industrialization, you need energy, there's all this promise from nuclear fission obviously. So to what degree are the ideal scenarios of fusion inherently cheap or is that a problem to be solved, right? So what I'm kind of getting at is, is nuclear, sorry, is fusion cheap inherently

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or is that something we're kind of saying,
assume we solve the cheapness problem,
assume we solve this, this, this and that.
Wow, there's a glorious future in front of us.
Yeah, I'm afraid it's not inherently cheap
any more than fission is inherently cheap.
On paper, I mean it's a great technological solution.
It's kind of in the abstract.
You just bash these atoms together, boom, energy comes out.
As you point out, in the 50s there was this equal optimism
about fission that all you have to do is stuff enough uranium
in a close enough space, throw some rods in and boom,
energy to cheap to meter.
In fact, that phrase came from Louis Strauss,
who was the head of the AEC in the 50s.
So, yeah, the problem is,
I mean, if you look at fission, he's a really good guy.
It's technologically simpler in many ways.
Again, all you have to do is take enough of this
fairly abundant material, put it together in a clever way,
throw some control rods in and you've got something
which will boil water.
It is obviously more difficult to do that in a safe way
in a way that disposes of waste properly,
but it is doable.
I mean, this is something that our society has figured out.
But on balance, we choose not to embrace that solution right now
because as technologically appealing as it is,
it has both political and social consequences
that we don't want to live with right now.
When you process uranium, you have the problem of nuclear waste
and we have to figure out where to put it.
And our national solution at Yucca Mountain fell through.
We currently don't have a plan for storing this waste.
So, the nuclear plant operators are running
and they're storing their waste on site generally
and it's something that has been deferred.
So, it's been punted to a future society to figure out.
But that aside, even if we had a waste solution,
if you look at the price of building a nuclear power plant
just to make it safe and reasonable
and have all the state guards keep all the regulations,
all the regulatory agencies happy, it is expensive.

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On a per kilowatt hour price,
it is several times more expensive than gas or coal
or even other renewables.
So, yeah, it is a part of our energy portfolio,
but it is not dominant and it is not solving the problem.
I think fusion in the best case scenario
is going to have that sort of contour.
It is going to be a solution of sorts.
It's going to have its advantages and disadvantages,
at least in the short and near term, it's going to be expensive.
So, I think that its adoption will depend very much upon
how much we need it, how much we're willing to pay
to forego the cheaper stuff that is already available
and out there.
You know, more questions come from that.
So, A, what does short, medium, and long-term
even mean in this context because you did an interview with CBS
and you said, quote, I have a running bet
that this will not be commercially available until 2050.
So, if we're talking almost 30 years,
what do the terms even medium and long-term even mean?
Because from a climate change perspective,
from a, wow, we're too dependent on Russian natural gas perspective,
30 years isn't particularly useful.
So, how do you think about the timelines?
Yeah, I think that's part of the problem.
I have to say, I made that bet more than 15 years ago.
So, we've already lost a generation of time between the bet and now.
So, yeah, climate change is urgent.
So, I think near-term solutions, we should be looking
in decade to decade of major change.
And I don't think fusion winds up on that list
just because it's not possible.
So, things like major engineering of nuclear power plants
or renewables even mean more radical questions
like geoengineering I think might have to be on the table
to ameliorate some of the problems
that we're going to see in the next couple of decades.
So, I think short-term is within the next 20 to 30 years.
Now, I think fusion is just off the table.
Midterm, we can say 30 to 60, 30 to 100.
Maybe fusion can contribute there,
but I think it's an unproven prospect right now.

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Again, we are still far away from getting something that is commercializable, much less even a proven principle. I would say it is possible that fusion will play a role in the midterm. But I honestly would bet against it's playing a significant role in the next 50 years.

And then long-term, I mean, if society is still around in 100 years, 200 years, 500 years, I would say probably fusion will play a role. I mean, it is something that our society will need as our energy demands increase.

There's a cost to renewables on some level, that there are material questions that come into many of the photoblogics and other renewables that we haven't really addressed.

So, I would not at all be surprised if we're around the year 2250 or 2500, that power is largely produced by fusion. That's quite possible.

But I think right now our crisis is getting through the next 50 years without serious damage to the environment.

I mean, we're already seeing an act of climate change now, and they think, hope for this Deus Ex Machina to come down and save us is ignoring the near-term problems that we have to make hard decisions to solve.

Yeah, I want to move ahead a little in the script because you just referenced Deus Ex Machina.

The book you wrote back in 2008, 2009 is *The Sun in a Bottle*, *the Strange History of Fusion*, and *the Science of Wishful Thinking*. The Deus Ex Machina reference kind of speaks to the wishful thinking aspect here.

So, can you just speak about that second part of the title and how you see fusion playing a role in the problem sets we just kind of described during this episode?

Yeah, this is where something, a solution on paper, is so technologically beautiful that in the abstract, it looks so lovely that you just are attracted to it.

You can't say no.

And fusion is one of those things for multiple generations. Scientists have been thinking, this is it. This is how we're going to solve our energy problem.

We call it, again, on paper, the most abundant element in the universe, producing energy, producing no real waste, and it's just there for us, for the picking it. It's like the fruit hanging down there that we can just out of our grasp.

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But again, unfortunately, this is the history of fusion, is that every time we come close, that apple seems to be further out of our grasp. There's complications and there's scientific complications and scientific complications can often be overcome and we've been overcoming them for generation after generation, but they're real big and they're real severe and we are still overcoming. But on the second level, I mean, this hope is technophics for, I mean, I think our problems are societal, more than technological, in that imagine that we had this great solution come down to us from the aliens, to serve mad before we got these wonderful power plants. Even if we were starting to produce those, the cost and the difficulty of the way those were put into a society where we're based upon scarcity and for determining value and kind of all the labor that goes into it forces kind of scarcity. It has to fit into our economic model. So even with this perfect solution, it's unclear how the economics would work. And again, with things that are high tech, high labor, high research, they tend to be expensive. So it's, again, we have come up with ways to land on the map. It's technologically feasible. It is within our hand, but we do not have Moon City because they are just not economically and societally practical. Maybe we will find a way to use that space someday and maybe there will be a need, but until then, I am not helling shares in MoonProper. And I think fusion is very similar to MoonProperty right now. We don't have a cost-effective way of exploiting that resource that we meet. You know, that brings to mind another question since you're referencing the Moon. Obviously, given the dynamics you're describing, aka it seems like we have a huge series of intractable problems combining with, you know, economic costs and scale, political grid locks with this idea of these moon shots, especially because we're trying to bring in models and rhetoric from like that early World War II at a Cold War period where it seems like we're making scientific progress, moon shots have become fashionable of late.

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What do you think about the concept of just setting that overambitious, seemingly impossible goal?

So I could see a critic of you on this podcast saying, okay, Charles, that's all well and good.

But if we were to sit here in 1959 and say, America is going to be in the moon 10 years so now, this, this, this, this, this and that, that's impossible.

How do you think about this framework of impossibility versus ambition and the trade-offs and the balancing act there?

Well, I think you raised a very good point.

I mean, before the moon shot, no one thought it could be done.

It was decades and decades away and we, we happened to do it.

I think the difference here is that this is not an ambition-driven story.

It's a kind of a humanity survival-driven story that if we had failed at moon shot, and the Russians did fail at the moon shot and they killed a bunch of people doing, there wasn't much loss besides the ego.

Right now, again, I think the stakes are very, very high that we need something to mitigate the climate change.

And I think by putting all our hopes on this one basket of things is a very foolish way of dealing with our crisis.

And I think I would absolutely agree.

I mean, if this were the abstract and I think money going huge in research, huge in energy, as skeptical as I am, I think that is a good thing.

I think it does help kind of explore a potential option.

However, given the nature of the crisis that we're seeing right now, is that the wisest way to mitigate our problems now?

And I would say that as part of a broader portfolio, yes, put more energy into fusion research.

However, there's lots of things that are important technologically within reach and just aren't as sexy to scientists.

Things like batteries and energy storage and energy storage on a large scale, improving the efficiency of our transmission and improving our grid system.

Looking at other kind of efficiencies of geothermal and wind and other renewables.

Solar thermal, all sorts of things like that,

which I think belong in a portfolio that are being ignored because this stuff is sexy.

This is the stuff of the venture capitalists.

This is the stuff that the Silicon Valley Technobros like, because again, on paper, it's so beautiful.

Let's do it. Let's do this moonshot.

I think there's a lot of other things that need to be done first.

A question that comes to mind then is that Biden moonshot timeline.

We discussed earlier, their official timeline is 10 years to a commercial reactor.

Obviously, you're not just skeptical.

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You're just making the claim that that's not going to happen.

There's very little euphemism there.

Could you just give us a articulation of what that would even look like given?

Let's just assume something is happening.

This is probably why the literal moonshot is different than this.

In the case of the moonshot, you could say,

okay, in 1960, we're going to orbit the earth, in 1961, we're going to do this,

and then you could just have a specific timeline of metrics and spaces you need to hit.

The Soviets don't make it all the way down that timeline, but they still do a timeline.

What would need to happen economically, technically, politically, investment-wise for that moonshot timeline to be hit?

Okay. Stage one is break even.

Break even, in any normal sense, is getting more energy out than you put into a reaction.

This very big announcement that was in December by Livermore, the National Admission Facility, had what they call break even.

It was a break even of sorts.

It's a definition that scientists can read upon,

that more energy comes out of a fusion reaction than was put in by lasers.

This is a laser fusion project where you've got a little pellet of high-vision, and lasers essentially shine to produce X-rays that compress that pellet.

For the two megajoules of laser energy that went into the reaction, three megajoules, 3.15 megajoules came out.

There is more energy out than put in.

That is a form of break-even.

That is kind of the worst little stack.

What's a megajoule?

I like to think of it as a healthy amount of energy that a piece of kindling gives you.

If you throw a piece of kindling on the fire, that's roughly a megajoule.

A watt is one joule per second.

100 watt ball burns 100 joules per second.

You could think of this as enough energy to have 10,000 watt bulbs for one second.

I think the kindling analogy is a little easier for us to grasp.

The problem here is that to get those three megajoules out,

we actually had to pour about 300 megajoules into these to generate that two megajoule B.

Even if you give them kind of this little kind of three megajoules out to two megajoules again, that isn't really a true break-even.

It's a scientific break-even and not an engineering break-even.

So, stage one is getting engineering break-even and you can see even this huge breakthrough is a factor of 100 away.

I think that, honestly, the laser, certainly NIFS laser version is a dead end for fusion energy.

I think the magnetic versions, which use a magnetic ball usually in the shape of a donut, are more likely.

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You can say we are 70% of the way there almost.

So, I think we're closer in that area.

Okay, but let's say stage one, one of these plants produces more energy than you get out, that you put in.

And that includes not just kind of producing it, but collecting it, converting it in an efficient manner, more energy out than it.

Okay, that's stage one.

And I don't think, honestly, I think we're at least 20 years away from something that can demonstrate that.

And the second stage is figuring out how to make that commercially viable, create a power plant design from that demonstration power plant.

So, say 20 years from now, we have that power plant demonstration working.

And I will say that 20 years is optimistic, even if you look at kind of diffusion projects, time lines for demonstration power plants, big eater and things like that are not talking about demonstration power plants until 2050.

But say we get one, you have to design it, you have to figure out how to get a design that the regulators will allow in a hopefully a kind of a reproducible sense and do that reliably.

So let's say we have a design like the G&E nuclear power plant design, that'll take another decade to turn from a demonstration plant to a commercial design.

And then from design, you have to build.

And that's assuming the cost is low enough that it makes sense to build.

But okay, so let's start building six, seven years per plant, and then the first fusion energy plants would come on the grid.

We're now talking 20 years to demonstration, another 10 years to design a plant, another decade to build the first plant.

We're talking two to three generations out before we see fusion energy on the grid.

So it's all possible.

It would be great if it could happen.

But again, I don't think it's realistic in the short to near term, midterm maybe, but again, why is this backing up so much of our attention and energy?

What it is simply not going to help us now?

Actually, help us understand the attention and energy aspect of this.

So basically like to what degree, what degree is like the research, the development, the news cycle time, like a zero sum game?

Yeah, that's a political, it used to be entirely a political question because almost all fusion energy research was in the governmental sector.

This has changed recently with a tremendous amount of venture capital flowing into commercial fusion ventures.

So I'm starting with the kind of the political question.

Yeah, I do think it was more or less a zero sum game in that the budget for science is finite, the budget for pure science is even more finite.

That science, governmental science advanced since World War Two based upon this kind of agreement that scientists had with the governments, the Department of Energy in particular,

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that physicists are a really important resource for you come wartime where we can build nuclear weapons, we can do your creepy toys that you need.

However, you have to fund basic research.

And so since the 1950s, there's kind of this, this quid pro quo where science where the government would fund these energy labs and give these accelerators and particle things at like Fermilab, which didn't have an immediate practical use because politicians were convinced that it was a good thing for society.

And it was usually through the weapons and was the most persuasive to politicians.

Since the Cold War, that agreement has kind of been failing.

And shortly after the Berlin Wall fell, you started seeing cutbacks in pure science in a way that there were before.

The superconducting supercollider went down the International Space Station, which won't argue whether that science or not was in trouble.

And I think you started seeing a very careful kind of measure of what should be funded and what should.

But I think that there's more of a zero stop game in science, even politics since the 1989 or so.

That being said, there's infinite, I mean, there's there's lots of venture capital that can do whatever it wants.

And so because fusion has caught the attention of venture capitalists, fusion is getting funded.

Who knows what kind of catches these people's fancy.

I'm not sure this is a zero stop game as much as it is a marketing game.

What is hot? What is hot now?

And I think you get trends and right now fusion is riding a trend way and more power to it.

I wouldn't want, I mean, I'm glad that this venture capital stuff is going into fusion energy rather than sports watches.

Or whatever. It's an unbalanced, I think it's a good thing.

But as with other venture capital, there's no, no, no guarantee that it's linked to any external economic reality or that had her need.

A question that comes to mind then is a couple of things in these last 10 minutes.

So number one, it seems like, especially in reference to your Atlantic piece that we'll link in the show notes that folks were really looking for a kitty hawk moment.

Obviously, a kitty hawk moment relating to, you know, the first flight, of course.

So what is, and you kind of answer this already basically point out like break, break even.

That is the that is the kitty hawk moment.

So I'd love for you just to talk about the importance of symbols that this is more symbolic. This is energy.

This makes you reach out to you to do the podcast.

Like how do symbols work in the scientific space?

Yeah, that's a good question.

So yeah, I would argue that again, this this big, big breakthrough.

And again, I don't want to diminish the fact that this is a real scientific achievement.

This is something that scientists have been trying to do for decades and it failed and they finally got it done.

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So first time in six decades, this has been able to have been achieved.

First, well, the first time since the definition of break even, that I would say goes back to at least late 90s.

Okay.

So, but yes, this is the first, the first, answers the first defensible argument that you've got control, fusion, break even, and the lab.

So it is not a practical step towards energy or reasons we've already talked about.

Also, the fact that this this laser is had to repeat 10,000 times.

If I get a piece of kindling, they've got a burn kindling endlessly.

And then if lasers can fire twice three times a day at most because the laser has to cool down.

So this, I don't think this is a pathway step forward towards fusion energy.

However, this is a symbol that we have achieved an external landmark, an external milestone that we are actually moving forward rather than spinning our wheels.

And I would say that to a large extent, we have spent a lot of time spinning our wheels for very little forward motion.

And the joke that fusion is 20 years away and always will be is a product of that because every time we think we kind of trying to make an assessment of how difficult the problem is and how much work has to go.

Yeah, and it seems like over two decades, the generation seems reasonable.

And yet we spin our wheels.

Eater, the International Thermonuclear Experimental Reactor, which is underway in Katarosh in France, the estimate was that it was going to have burst lights.

And that was 10 years back in 2004.

Currently, the current timeline has burst light in 2025, five years.

So over the past 20 years, 10 years, the 10 years has shrunk to five.

So there's this weird time dilation that's going on that 20 years turned out to be five.

And in fact, the Eater schedule is about to split probably by another five years.

So 20 years have basically done nothing in terms of our temporal view of how close we're getting.

So there's a lot of wheels.

These symbols, these external symbols are really important to give milestones and give the sense that there is stuff that we're learning just like all the difficulties that we're having all the inflated claims.

And a lot of these companies which are touted as startups that have been around for decades, I don't know anything else that could be called a startup that's 20 years old.

It has made promises of usually energy by 2014 and has failed.

So yeah, these symbols are nice because they are a way of grounding research with reality that they are a step out of what we could say.

This is something that we couldn't do before and we can do now.

With fusion, unfortunately those milestones, external real verifiable milestones are very few in part between.

So for these last three questions, number one, I'd love for you just to hear or tell us what writing about studying fusion has taught you about or maybe giving you when it comes to like a theory of how technological progress happens.

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For example, go back to Leonardo da Vinci's notebooks and he's sketching out like a rudimentary flying machine 500 years later, roughly speaking, Kitty Hawk.

Then we have in 10 years, you have biplanes dueling over Europe and then the atomic bomb on and on and on and on and on.

So that's how that period compresses.

How does thinking about maybe flight, for example, imagination to practicality inform how you think about progress, especially in this case too?

Yeah, no, that flight is a really good analogy for what's going on in fusion, technology generally.

So I think the first lesson is that the technological process is very nonlinear.

It moves in bits and starts and then also our imagination outruns practicality by quite a distance.

Leonardo da Vinci came up with essentially a rudimentary airplane, a rudimentary helicopter.

These things that he came up with were not practical to time for a number of reasons.

In fact, if you think about the airplane, it really wasn't until you had the internal combustion engine and one powerful enough to drag an airfoil through space fast about.

That you really were able to get that Kitty Hawk moment.

So what made something practical came from an unexpected direction.

And once you had the internal combustion engine, you had a practical reason for them.

So between 1900 and 1914, you had this development of the plane, which was fairly remarkable.

If you look at between 1914 and 1918, the development went much, much, much faster.

And it's because of the engine, but also because of the practical use.

It was all of a sudden something that was necessary.

And there was that fluorescence of innovation.

That's what kind of made, you know, even until kind of World War I, you didn't have a commercial passenger liner possible at that time.

But by 1930s, by 1920s, you started getting engines powerful enough to drag eight volts through the air at once and largely bomb things like that.

So yeah, I think a combination of unexpected technological advances that kind of break down one of the unexpected barriers,

plus the practical need for it to combine, kind of make that environment grow.

And if you think about it also, I mean, how has the airline industry progressed since 1960,

what's that kind of long and need diminishes the pace of innovation goes?

What are the big innovations, you could say supersonic, which were important,

I mean, but not on a commercial sector.

They're kind of a dead amp with this point and stealth.

I mean, it's compared to the the fluorescence back then kind of our modern technology hasn't made much of a difference.

The B-52 is still kind of an optimal element in our space of airplane.

And that is, they're so low that they're getting to be as old as the oldest human beings are.

And are going to be used to the 2040s.

I mean, they're upgraded, but it's the general airframe and the configuration,

the theoretical concept has been will be used for almost a century.

And that's the interesting point.

That's exactly it.

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That we optimize for our societal needs and what once you get there, you don't necessarily push beyond it.

And I'll point out that also, I mean, you don't there are other ways of getting flight besides fixed wing before Kitty Hawk.

They were the Mongolia blood and the hot air balloon and we also had Zeppelin and all of these things had limited practicality.

But could solve a problem or to the extent that they would solve a problem, they were exploited like observation balloons, warfare.

And so I think that you have to think of a technology without understanding its limitations and in which it will function.

And I think without kind of a real understanding.

Say, okay, hot air balloons are great.

You will get you up high, but I'm going from place to place.

They're not very useful.

So for this niche, it's very good and we will develop it for this and but for something else, we need another solution.

I think that's true in energy as well.

So his next question is a pure curiosity question.

So I obviously have my copy of Sun in a bottle here, strange history of fusion and the science of wishful thinking book came out in 2008.

It's not very common that I can book a guest who wrote a book, you know, in previous decades, it's still, I think, quite relevant.

So for folks who are interested in purchasing the book and checking it out, what would you say if you were to do kind of like the updated and revised edition?

Like what, aside from just the hook of this story, which we've discussed, what is 2009 to 2021 look like?

It's surprising how little has changed fundamentally about the book.

The book, the book is really stone dead art for everything.

The one real change is the creation of the commercial sector, the modern commercial sector.

That is a fairly recent thing.

When I was writing the book, there were maybe one or two weirdo companies out there trying to do fusion on their own.

Now there is a score of them and there's billions of dollars.

In fact, I think we're at the point where private capital is outspending public funding or we're close now.

So I would probably put another chapter in to talk about the commercial sector.

And there's this interesting history there too, actually, that laser fusion actually started off in the commercial sector.

There was a dramatic scene.

I skimmed over in the book because it was not as centrally relevant.

But there was a laser fusion aficionado who was making these claims of near break even with laser.

He was testifying in front of Congress and had a heart attack while hostifying and died that death.

So there's this kind of drama there.

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And so the idea that Silicon Valley, deaf in and all the problems that the government had been inefficiently grappling with for the past three generations is another theme.

And I think it's also, I mean, it fits in very well because it's a form of technological arrogance that we have seen a lot coming from Silicon Valley.

That is part and parcel with the entomological scientific arrogance of our society's whole thinking. We can just think through these problems and this is the way forward.

Let's just do it.

If we use our mind, we smart lab coats can solve it.

And sometimes it isn't that easy.

And for the last question here, I'm really proud of the fact that our audience is very solutions oriented and pragmatically focused.

And we kind of hinted at this during the earlier part of the episode, but I really wanted to drag this out so it could be specifically stated.

So if you are bearish on the prospects of fusion's ability to, let's say, solve or address the problems of climate change to reduce reliance on like petrochemical energy that for reasons not even related to climate change, let's say like

Putin, Middle East, et cetera, et cetera, we'd want to move on from what is your recommendation then kind of reiterating what you said earlier. So we could just clip it specifically for what we should do if you identified these sets of problems and you were excited maybe coming to the episode about fusion being the answer to those problems.

Yeah, I would really advocate at portfolio approach. And I think that we need from the Department of Energy a kind of a more coherent that of goals and demands not just across a generation of energy which fusion comes into.

But again, grid, revising the grid, making more efficient energy storage, energy storage, really kind of looking at the whole picture and saying what things can we hammer on now to get the best bang for our buck.

And it may not be in the generation sector at all. I mean, it may not be that even more solar power plant would be a good idea. It made me that if we spend our money on superconducting transmission grid, that would be better.

So I think looking at the picture holistically is really be important. And I think holistically also includes I mean this this prospect scares me to death, geoengineering and other kind of more radical mitigation climate mitigation techniques that it may be we could buy century by putting reflective particles in our upper atmosphere, in which case we should probably do that but of course the the unknowns are huge. I think I think those sorts of solutions need to be studied, as well as kind of all our energy production transmission storage issues.

Man, I said I said last question, but you just kind of provoked me there. Earlier when you're critiquing our tech row friends, you were describing like scientific arrogance.

If we were to describe something as arrogant, one could argue that particles in the atmosphere would qualify as arrogance. So what what is your what it then once again like arrogance is inherent to any human endeavors was a lot like that's, you know, kind of comes with the comes with what you're working with here but what's your guide for arrogance.

I don't know, you know, geoengineering. I mean, this is why it scares me to death because this is

about even what we the archetype of arrogance. I think I think though that there are ways of doing control tests that don't

are not irreversible and little kind of steps along the way. I think the arrogance comes in and saying, I can do this. I think that if I if I see to the sky, we'd solve global warming.

I think there's a difference with coming with a little bit of humility and saying, look, this is a somewhat crazy idea. I can go really wrong. But maybe this is something we should look at, given the severity of what we have.

Again, we're we're we're thinking as a patient. When you are healthy, you're less likely to risk things and take a radical, an untested pill.

When you are terminal, you're much more willing to do crazy things. And I think sadly, as a kind of patient, we are moving towards a greater element that have to take more risks, which indeed causes more kind of puts us in the hands of higher arrogance.

I mean, if you asked me 40 years ago and say it's way premature to start thinking about you and Sharon, we should we should do much more calm things first. But I mean, we're already seeing kind of warnings about be she's die off in the seas of the bad due to warming temperatures, all that. So we have to actually that's another thing we should really work on is kind of understand the timeline and figure out what risks, how much risk we need to bear now to mitigate in what time period.

Because I mean, we could we could do it slow and steady and make things all better my 2500 that they'd be suffering without cause and the environmental damage that would cause is just makes it impractical.

When do we really have to official cut me is probably the right way to think about it. Charles, this has been really fascinating. Thank you so much. Is there anything?

Could you just do a quick shout out to your recent book on Stephen Hawking, I was telling you before the recording, I really enjoy that we're doing my background research, but I think that's the most recent work of yours that folks should check out things with this conversation.

Well, thank you. Yeah, that I mean, actually, I think that's this last book was the best book ever written. It's a biography of Stephen Hawking.

And it's called Hawking Hawking, because it's partially about the selling of Stephen Hawking as the world's biggest genius.

And well, Stephen Hawking was really a fascinating character, a brilliant scientist. It's interesting to see how he was marketed, packaged and made into the world's smartest man. It tells us a lot about our perception of science or perception of scientists and our perception of disability to see kind of that

that sausage being made. So it's a biography of Stephen Hawking, but it's also a kind of a jaundice look at the way we look at science, the way we look at celebrity.

Is the spoiler that Stephen Hawking was not actually the world's greatest genius? Is that the implication folks should take?

Yes, he was definitely in the top rank of scientists, but if you had to pick an archetypal successor to Einstein, there are, I mean, within the scientific community itself, he was not in your top 10.

Wow. Okay, so that's the, that's the spoiler, but also I think the enticement for books. I've got the book in Audible. It's really enjoyable. Charles, thank you for joining me on the realignment.

Thank you very much for having me.

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