Season Three: Episode One
Will Fusion Power (or "Stars in a Jar") Replace Fossil Fuels?
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[Mux:CEZ_ISCS_0021_01601_Turn_Back_the_Time_Alternate_APM]

Luke Charest: Just in the last decade, things that felt like part of a science fiction wish-list have become a reality. Humans figured out how to edit genes, build self-driving cars, and reuse space rockets.

But one sci-fi item that has felt harder to check off that wishlist is an alternative way to produce energy – through fusion. Governments, institutions, and private firms have tried for decades to make this a reality. So far it's felt just like part of a movie, a reality we can't reach…

> ***Back To The Future****: Steven Spielberg presents Back to the Future Are you telling me you built a time machine? Out of a DeLorian?*

[Mux: MYMA_JUST_0151_01401_Computerized_APM]

Luke: Like in the 1985 classic where Dr. Emmett Brown -played by Christopher Lloyd- powers his time machine by feeding trash into the Mr. Fusion Home Energy Reactor.

Back To The Future: Are you telling me that this sucker is nuclear? Precisely

[Mux: MYMA_MYD_0015_00101_Sustainable_Nature_APM]

Luke: But thanks to continued investments and scientific innovations, we're looking at a potentially exciting new reality.

[Mux: APM_APMC_0166_04501_L_Is_A_Strong_Word_Rhythm_Mix_APM]

Katie Rae: If the world had endless clean energy that was cheap and plentiful, do you just imagine what that world looks like?

Luke: I'm Luke Charest and this is Unseen Upside by Cambridge Associates, where we explore investments beyond their returns. This whole season we're talking to innovators and investors that are helping to bring what once was thought of as science fiction into the real world.

[End Mux Theme]

Act I - Hypothesis: Fusion Power will transform the planet.

[KPM_KPM_0797_04401_Golden_Sun_b_APM-02]

Luke: Our sun shines because of nuclear fusion. Now, fusion isn't something new. We have been studying it for almost a century! In 1926, British astrophysicist Arthur Eddington was the first to publish the theory that stars produce energy from the fusion of hydrogen to helium. And while for many decades fusion energy was the purview of research laboratories, steady advances in computational and material science have enabled us to be on the precipice of harnessing fusion energy at scale. And this is important because the vast majority of energy we use still comes from fossil fuels. Just in 2021, about 79% of the energy we used in the US came from oil, gas and coal. It works like this…

Bob Mumgaard: We burn a chemical reaction and in there we produce heat, and we convert that heat to electricity. And in fusion the thing that you quote-unquote burn is actually a different reaction altogether, that makes more energy per unit of thing you put into it than if you were to do it with fossil fuels.

Luke: Bob Mumgaard is the co-founder and CEO of Commonwealth Fusion Systems or CFS, a fusion energy startup company spun-out from MIT.

Bob: It's the difference between 50 gigatons a year of CO_2 versus 250 tons of CO_2. And so it's this huge difference.

Luke: The remaining 21% of energy we consumed in 2021 came from renewable sources and nuclear power plants, like the one that powered Bob's house when he was growing up near Omaha, Nebraska.

Bob: And that's also why you put things like data centers there because they have really reliable, low cost power.

Luke: But these nuclear power plants use *fission* instead of fusion.

Bob: They're actually completely different reactions with completely different materials. So in nuclear power and traditional fission power, what you're doing is you're taking the heaviest items in the universe, the heaviest atoms,

Luke: Think Uranium

Bob: And you're splitting them. And in that process, you're turning a tiny bit of mass into energy. And that's the exact opposite of fusion, which is taking the lightest and combining them. And so they're basically different sides of the coin of how you change elements.

Luke: So you can think of fusion as the reaction that occurs when 2 atoms combine and form a single new atom, releasing a lot of energy. It's actually the process that stars -like our sun- use to make energy.

Bob: So it's the most prevalent physical process in the universe. We're actually all built up of the products of a bunch of fusion reactions. Through that process, the stars burn, they produce a lot of heat, and they combine the elements up.

Luke: And CFS is working on taking that process - fusion - out of the lab and into the market.

Bob: So what you're trying to do on earth in a fusion power plant is you're trying to create that same reaction, which means you're trying to create the same conditions that are inside the stars. And if you're able to do that, you'd have the other things the stars have, which is basically very little or no fuel use–energy that's always on, a source of heat that never runs out.

Luke: Scientists have found multiple ways to recreate the conditions that are inside stars. And one that has been in the works for decades is called Magnetic Confinement, which is what Bob and his team at CFS are working on right now.

They are using an incredibly strong magnetic field to confine plasma in a special chamber.

Bob: So you have this machine that creates the conditions like the center of the sun. Those conditions actually are a plasma, and plasma is what the stars are made out of. It's what happens when you, you know, heat a solid it melts and when you heat a liquid, it boils and when you heat a gas, it becomes a plasma.

Luke: Bob often describes fusion like trying to put a star in a bottle. And in this case, the bottle is a donut-shaped machine called a tokamak. Tokamaks come in all sizes, from the one CFS is making, to the International Thermonuclear Experimental Reactor or ITER being built in France. ITER will be nearly seven stories tall and is being constructed by a consortium of 35 countries. And I'll spare you the long history of tokamaks but let's just say that they have been around since 1958, when the Soviet Union started operating the T-1 tokamak. Ok, back to CFS in Devens, Massachusetts…

Bob: In fusion, you have to get to conditions that are pretty extreme, which kinda makes sense, right? Like it's the center of stars.

Luke: It needs to be very, very hot.

Bob: So, like a hundred million degrees and, you know, it doesn't really matter, Fahrenheit or Celsius, a hundred million is a very, very big number.

Luke: That's actually hotter than the center of our sun!

Bob: That's not theoretical. We actually build those machines and we actually measure the temperature of a hundred million degrees. The machine at MIT is one of the hottest things in the solar system, and the only other things that are even the same realm are all other fusion machines.

And not only do you need to get it very hot, you also need to get it very well insulated. So the, the cold stuff doesn't cool the hot stuff. And it, the hot stuff, doesn't melt the cold stuff, because if you don't insulate it, it just leaks heat faster than you can keep it warm, right? And so you need it hot, you need it insulated, and you have to get enough of it, you have to get it dense enough.

Luke: Bob actually has a PhD in applied plasma physics, so this is his jam.

Bob: And so those three conditions, hot, dense, and insulated, have been the goal for the last about 50 years of fusion research. We've now done that across many different parameters, which is super exciting.

Act II - CFS's Experiment

[BASS GUITAR MUSIC]

Luke: Almost a century of research and legions of scientists studying fusion, and yet we still don't have commercial fusion power plants today. That's of course because the science and technology to get there is a work in progress. Fusion requires those very high temperatures and so far, the amount of energy required to generate that heat is much more than what you get out of the tokamaks. And, for people to get on board there has to be proof that this works.

Well, CFS in partnership with MIT's Plasma Science and Fusion Center are building SPARC, the world's first compact, net fusion energy device - and it's a tokamak.

SPARC is a smaller version of ARC, a full-scale commercial fusion power plant that was born out of an idea at a fusion class at MIT.

The teams have been hard at work finding ways to improve the technology, and in September of 2021, they tested a new high-temperature superconducting electromagnet that effectively broke magnetic field records.

Bob: …in a big empty room at MIT that we had to clear out because, you know, very strong magnet, you don't want stuff flying across the room with cranes where we lifted the magnet up and put it in its place with a bunch of refrigerators that got the magnet to be super, super cold, and then we turned it on and slowly ramped up the field. We actually live-streamed it, so there's people around that, like, you know, people all over the world watching a dial over a day creep up higher and higher and higher…

> *CFS video: We have in fact achieved 20 Tesla for the first time in a large boar fusion relevant coil.*

Luke: You're listening to Dennis Whyte, Director of the MIT Plasma Science and Fusion Center in his remarks after the successful test.

> *CFS video: And what this means is that we're gonna change the trajectory of fusion energy and we hope the world by supplying clean energy to mankind forever. Woo! [audience cheers].*

Luke: They ramped up the magnet to a field strength of 20 Tesla. That's 12 times stronger than an MRI machine.

Bob: That's like the biggest magnet that anyone normally comes across.

Luke: Which means they're effectively creating a stronger bottle for the star, to use Bob's metaphor. The physics behind SPARC have been verified, peer reviewed and published, and support the idea that this could be the first tokamak to make more power out than it took to heat it up.

Bob: If you're not making more power than to heat it up, you're not really a power plant, you're more of a science experiment. And that's where we've always been.

Luke: But this new tokamak's magnetic field changes the trajectory of fusion tech and paves the way for commercial fusion.

[KOS_KOS_0193_04901_Wind_Turbine_APM.0-04]

Luke: Now, it's easy to picture a wind farm with those big white turbines or an offshore oil and gas facility. In contrast, fusion tech has always been part of sci-fi imagery. Just remember the Arc Reactor that Tony Stark uses to power the Iron Man suits in the Avengers. So, what does the CFS's SPARC site look like?

Katie Rae: It essentially looks like a 2-3 story parking garage, so instead of being able to see the cars, it's all cement all the way around.

Luke: Katie Rae is the CEO and managing partner of The Engine, a venture capital firm - also spun out of MIT- that was one of CFS' earliest investors.

Katie: Inside of it is essentially a ball, which is the actual magnets that sits in a cradle so you can get underneath it. And around it is a connection to the grid.

Luke: There's actually a lot of other stuff that goes in there… there's instrumentation to measure the process. Things to cool and heat up the plasma... And the tokamak on its own looks very... science fictiony.

Bob: We like to think that everything the first time you build it looks science fictiony, right? The first automobile to the people at the time looks kind of science fictiony, and so this looks like a big piece of metal. It's a big, donut shaped thing made out of stainless steel. That's like for SPARC's case is the scale, like you know, half of a tennis court. So it's not something you put in your basement or in your pocket, but it's also not a mega project. And some parts of it look like a brewery. There's like pipes and vessels and things like that.

Katie: It's actually quite tiny, and I know that might be anticlimactic, but that's the power of it. It could be your next door neighbor.

Bob: And so you have there a situation where you have a hundred million degrees inside a machine and then a meter away you have just normal room.

Luke: It may sound kind of risky to think of a fusion power plant operating next door, but it's actually safer than using other energy sources. Fusion reactions occur in a vacuum.

Bob: And so that means, although it's hot, it's actually pretty wispy. There's not a lot of stuff there, and so the plasma itself actually has fewer particles in it than a breath of air, which means a single breath of air can overwhelm it, and you actually have to work very hard to keep the fusion going, not to shut it off, which is a pain in the butt if you're trying to build a power plant, but a really good safety feature once you do build it.

Luke: If SPARC's confinement fails, the reaction simply comes to an end and the plasma just expands and cools. No explosions, no end-of-the-world event. It’s just like blowing out a candle.

[MYMA_SCOP_0048_00501_Complex_Thoughts_APM-02]

Luke: Until very recently, governments, universities, and other institutions had been the primary driver of fusion research. In the US, the government has financed research in places like Princeton, the University of Wisconsin, and MIT, among others. And a vast majority of that work has been done on the tokamaks.

Bob: And so SPARC is like the 150th tokamak, but it's the first to be very high magnetic field with this new class of mag. And so in some sense, it looks a lot like what we've done in the governments before, but it's now being executed by a private company with sort of a different atmosphere around that. It's like the difference between a NASA and a SpaceX. They do similar things for different reasons. For us, we want to get to a power plant that we can scale and put around the world and sell. For the governments, they wanna show it can work, and that's why actually right now it's very important that everyone works together.

Luke: And to make a project like this commercially viable, they would need to scale it up.

Act III - How to get to results

[CEZ_CEG_5030_00501_Foxy_Brown_APM-06]

Luke: Investment in fusion research is already booming. The private sector alone injected over 4 billion dollars in 2021. In 2022, the White House announced the development of a strategy to accelerate commercial fusion energy, followed by $280 million allocated to the Office of Science at the Department of Energy for initiatives primarily related to fusion energy science and development.

And you have probably heard about strides in other technologies that are working towards harnessing fusion energy. In December of 2022, a team at the Lawrence Livermore National Ignition Facility in California made a breakthrough with their machine that uses extremely powerful lasers – not tokamaks – to make fuel hot enough and dense enough to create fusion.

But if we want to take fusion power out of the labs -and out of books and movies- we need to inject this new industry with more capital.

Since it was founded in 2018, CFS has raised 2 billion dollars from venture capital firms, energy companies, and prominent individuals like Bill Gates. When the Engine's CEO Katie Rae met with Bob at CFS, he had to present a solid case to back up his funding request.

Katie: He knew right from the beginning he had to have unassailable data that was peer reviewed, and people could not tell him he was making this up.

Katie: And so when you start to look at a data room like that, it's enormous. And you know, you look at the history of the tokamak and where that's headed and how we've gotten better every single year on tokamak design to get to net positive energy. Then you start to look at the team Bob is assembled around him, the partnership that they had the Plasma Fusion Science Center, and you start to think about almost the moral obligation to dive deep and see if this is possible. And so that really got the team super psyched, super motivated, and you know, unusual deal, like a first round, it was $78 million, like that's not your typical seed round.

Luke: So let’s say fusion becomes commercially viable. What happens to the other clean energy technologies like wind and solar power?

Katie: You know, there's nothing wrong with solar. There's lots of good energy generation, but if you think about the density and price of a fusion power plant versus a solar plant, you don't need that many fusion power plants and they last a long time. They don't need continuous maintenance.They don't take up land in the same way. There's so many positive things and they attach right to a grid that already exists. So it's like there are lots and lots of good things about it, and you don't actually need storage. It just keeps going.

Bob: They don't look that different from the way we do energy today. Meaning you're not going to like reimagine the entire landscape of the countryside with fusion power plants, the way that we've done with wind and solar, it means that you're gonna build like boxes that are like a Walmart. But in that box, we produce energy, and you'll site them in places maybe even that we already have existing infrastructure to do energy that is being retired like a coal plant. There's actually nothing that would prevent you from going where there's a coal boiler today and removing the coal boiler and and putting in a fusion machine and producing electricity at that same point on the grid. And so that's a big deal because it means we don't have to change our entire system.

Luke: Fusion technology is a concrete example of a bigger idea.

Katie: If you just look at some of the biggest problems that we're facing in the world, there's a category of them that can be solved with very light software or changes in human behavior, and then there's actually quite a broad category that need true innovation. Kind of a big step forward in order to have them have the positive impacts we want on the world.

Luke: Katie is talking about Tough Tech or frontier tech, an idea that taps into transformative technology that combines ground-breaking science, and engineering, to address the world's most pressing challenges. Think startups based on science and technology that need expensive equipment for experimentation, like fusion tokamaks, for example. This space is increasingly drawing interest from investors.

Theresa Hajer: Tough Tech is the idea of investing in fundamental technologies that are the backbone of creating, in some cases, new markets, in some cases, disrupting fundamental industries that in many cases do not have an ecosystem in place, but are solving some of the world's biggest problems.

Luke: This is Theresa Hajer; she's the head of Venture Capital Research at Cambridge Associates.

Theresa: Think about aerospace, space and defense, climate tech is another example, thinking about technology and life science and in fact engineering life science and thinking about computational bio.

Luke: Add to that clean energy, robotics, quantum computing and many more. A lot of the work that Theresa and her team does is in her words: peeling the onion.

Theresa: You do a lot of references, you really get to know the firms that you might invest in.

Luke: Theresa has been in the venture capital industry for 20 years, and has witnessed how things have changed.

Theresa: And the scalability of technology has had a profound impact on the venture market. If you look at the scalability of technology, one example would be in biotech and gene sequencing.

Theresa: Back in 2001, it cost almost a hundred million dollars to sequence a human genome. That dropped tenfold to 10 million in 2008, and today it's less than a thousand dollars. So when you think about the plummeting cost of this technology and the scalability of that, that's where innovation can really flourish and you also have, what I think is really interesting, is this convergence of tech and impact. Certainly climate tech will hit upon that, but it's so important across any industries today. Not only building a company for profits, but for purpose and doing so responsibly.

Luke: At the Engine, Katie's team has made it their mission to make it easier for Tough Tech companies to change the world...faster than before.

Katie: We are going after things that have hard to get to that impact because they didn't have an easy way to translate out of a lab… there was still engineering risk in making them. There was very little money for that. And so we went after that kind of valley of death with a venture capital firm and a place where people could build things like this and a community that would support and embrace and celebrate each of those wins.

Luke: In fact, The Engine recently opened a brand new campus in Cambridge, Massachusetts where new Tough Tech startups can build and test their ideas.

Katie: If you were doing software or something related to pharmaceuticals, there was a lot of capital from venture for those things.

Katie: And then if you looked at basically everything else, which is all these Tough Tech fields, you were seeing less and less capital over time. And so the question was, could an incredible university like MIT reverse that trend and show the way that these types of technologies are investable and therefore they would have a bigger impact to the world? So they answered that call by saying, okay, we need to form an organization. It'll be a for-profit. We will spin it out of MIT, but we will use the incredible network and our ability to build buildings and create spaces in order to make that happen.

And so when I joined it was like, okay, let's go raise the venture capital fund. Let's open our first building, which allows biology labs, chemistry labs, fabrication space, and run this as an experiment to see: Could we get these startups funded? Could we translate them out of the lab?

Luke: In that first fund there were several startups working on energy. One of them was CFS.

Katie: And that first fund, you know, about year three into that, we all looked up and said, you know what, this is really working.

Luke: Today the Engine continues supporting bold startups in their new space by providing them with access to specialized labs, equipment, and tools in a collaborative environment that makes the process economically viable. Katie says there's a particularly popular spot at the Engine's new campus.

Katie: Oh my God. When you go down to the machine shop, it's kind of like scary and amazing. We call it Caesar's Palace because Caesar runs it. And, um, sorry I don't have the trademark on that, but it's really fun to go in there because you can weld things, you can print things, you can mill things. And many of these companies build their early prototypes here and then can show the world what they actually mean.

Luke: Katie gets to see lots of ideas that might as well come out of science fiction, so deciding what ideas are ready for investment is not easy.

Katie: It's more art than science. There are tens of thousands inventions every year. Eh, who cares? What we look for, what we start with is, who is this team? What mission are they on? How painful will it be to them if this doesn't exist in the world?

Katie: And that set of questions are complicated and they're not exactly data points, but if we start to get super excited, “Wow, these people are serious. They know what they're talking about, and they are ready to truly make this their life.” You know, these things require time. All of your brain and your heart involved at the same time, and if we don't see that, it's an easy pass. Then the next level is, have they actually demonstrated they can do something? Because you might be able to get a lot of people excited about an area… if you can't actually do anything, who cares?

Katie: So that's kind of the second piece. And then the third: what is their North Star? How big could that market be? Even if it's a new market, like could this be a huge global company? And if those three things start to line up, then we get super, super interested and that's when we do a very deep technical dive to say, “Do we think it's real?” Because before those things line up, it won't matter. And so that's our bar.

Luke: From her seat looking over hundreds of venture portfolios, Theresa knows the delicate dance of investing at the frontier of technical breakthroughs.

Theresa: A lot of venture firms might have been onto something about frontier tech, but if you're too early, you can be wrong in venture capital. So I think that's one of the things that takes a lot of time. It's very important, but thinking about when can I take this technology and translate it to a commercial use. You could look at it in terms of ranges and begin to think about. “Is there adoption in a certain market for some of this technology? Have I cleared enough technical hurdles?” But ultimately one of the biggest challenges with Tough Tech is there's not a clear business plan that you have, right? Figuring out, you know, when exactly it will work is very difficult.

Luke: Bob knows the importance of *when*, too.

Bob: I think anytime that someone has a technology that sort of is easy to dismiss as “Oh, we've been working on that for a long time,” or, “Oh, that's never gonna happen,” you should always take a second look because it happens much faster than you think it will. In Fusion's case, there's a question of when's the right time and is it gonna happen this time? And that's something that happens over and over again in every technology. You can go back and find, you know, the AI winter where we're like, “Oh, AI's never gonna happen.” And now all of a sudden AI's a pretty big deal and you can see it actually doing things that are making a difference in the world.

Luke: And the progress at CFS…

Bob: That time scale has changed a lot of people's mindsets. So at the same time, there's still some trepidation of we don't know exactly how this is all going to evolve. So people, in some sense, still stepping into the unknown, but with a, some gusto.

Luke: In February 2023, CFS celebrated the opening of their new commercial fusion campus in Devens, Massachusetts. The company's new headquarters also features a manufacturing facility with the demonstration plant just next door.

Theresa: One of the things they talk about is creating sun in a bottle, and so it absolutely blew my mind.

Luke: Theresa Hajer from Cambridge Associates again.

Theresa: It is the epitome of a moonshot, and we need it. Nuclear fusion will be a critical solution to our climate crisis today. You can pick your favorite technology and your favorite solution, but the bottom line is that we need many different solutions to solve our crisis. And it's a very urgent problem, and Commonwealth Fusion has the potential to make an enormous impact.

Luke: CFS is just one of the many organizations working to open up this new industry. And though there are many challenges ahead, when you look up at the stars at night, remember that you are looking at thousands of natural fusion plants. The universe has already chosen Fusion energy.

–FOR PROMO EPI 302.

[MYMA_MYD_0010_03801_DNA_History_APM-04]

Luke: Next time on Unseen Upside:

Hillary Ribaudo: Have you ever dreamed of bringing an extinct species back to life?

Ben: Our goal is to bring back extinct species. Return them, or at least proxies of them to reintroduce them back into ecosystems that are degraded, for the purpose of ecosystem restoration.

Hillary: Well, a group of scientists are working to make that happen with the Wooly Mammoth *and* the Dodo Bird. Not just for fun… but to battle climate change.

[Closing Mux]

Luke: If you want to learn more about fusion power or venture capital, please visit us at "cambridgeassociates.com/unseenupside," or check out the show notes. Stay tuned for more upcoming episodes and if you like what you're hearing, leave us a review and tell your friends and colleagues.

For Cambridge Associates, our podcast team includes Hillary Ribaudo, Michelle Phan and me, Luke Charest.

From PRX Productions, Sandra Lopez-Monsalve is our producer and Genevieve Sponsler is our editor. Production assistance by Cara Shillenn and Megan Nadolski at Goat Rodeo. This episode was mixed by Samantha Gattsek. The executive producer of PRX Productions is Jocelyn Gonzales.

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Before you go, one of my colleagues has an important message about the contents of this podcast.

[Mux theme fades]

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