Paul Thies: Well, thank you for joining us today. I'm your host, Paul Thies. And in this episode of If/When, we're talking about nuclear fusion with Ian Chapman, the CEO of the UK Atomic Energy Authority, and Clive White, senior vice president for Jacobs Critical Mission Solutions International. Ian and [00:00:30] Clive, thank you both so much for joining me today. To begin our discussion, I'd like to start with Ian. So, Ian, you recently had a lecture to the Royal Society. And it was in tandem with your Kavli Medal Lecture. And it was called Putting the sun in a bottle: the path to sustainable fusion power. Congratulations, first of all, on this prestigious award. And the lecture that you gave, I really enjoyed it. It gives a very clear vision [00:01:00] of the main challenges that need to be addressed to harness fusion and a pathway for achieving this. So for people not familiar with nuclear energy technology, and I'll admit, I'm not a nuclear scientist but have just a passing understanding of it, can you briefly describe what nuclear fusion is and how it works?

Ian Chapman: Yeah. Sure. Well, firstly, Paul, thank you very much for your kind words. So fusion happens in our sun. It happens in all the stars. [00:01:30] It's the root source of the sun's energy. And what's happening is that inside the sun, very light elements, types of hydrogen, are being forced close together. And they fuse. They join. And when they join, they release a lot of energy. It's different to conventional nuclear. So working nuclear power plants that we have today work from fission. In fission, what's happening is you're taking very heavy things, uranium, plutonium. You break them apart, and that releases energy. So both release [00:02:00] energy through a nuclear process. But in fission, you break things apart. In fusion, you take light elements, force them together. Now, in the sun, that happens because of the enormous mass of the sun. So those light elements, those types of hydrogen, they want to repel one another. They don't actually want to fuse. It doesn't happen naturally. You have to force it. Now, it's forced in the sun because of gravity. The enormous mass of the sun pulls these things so close that they can fuse.

That can't happen here on Earth. Of course, we can't recreate [00:02:30] the mass of the sun here on Earth. And so instead, we have to give the fuel even more energy than the center of the sun. So you take it to a temperature of about 150 million degrees, which just sounds ridiculous. You can't think of temperatures that hot, 10 times hotter than the center of the sun. We do that here on Earth and make fusion happen that way.

Paul Thies: Just when I first heard that, it blew my mind. The fact that we could have a facility in a building that could have something that could get to 150 [00:03:00] million degrees is... It really is just kind of staggering to the imagination. Now, Clive, in doing a little background research on nuclear fusion, and I've got to stress little, because again, a very pedestrian understanding here. But it looks like scientists have been discussing the concept for about a century. But in terms of practical applications, it's still a fairly new idea and technology. Can you tell us a little bit about where it's at in terms of current development? [00:03:30] And how is it different from nuclear fission?

Clive White: Yeah. And thanks, Paul, for the invitation to join. It's nice seeing you again. So, yeah. I mean, as Ian said, fusion has been around for billions of years. It's there powering the sun every single day. It's there as we talk. It's being captured on the planet. So one of the facilities that Ian runs is called the Joint European Torus, JET. And that captures fusion and makes it work, albeit for a relatively small period of time. Other facilities around the world have done the [00:04:00] same. And the challenge is to make sure that you can keep that reaction going for a period of time so that you can get the energy out.

So probably the facility that is right at the forefront of that at the moment is something called ITER. It used to be called the International Thermonuclear Experimental Reactor. ITER is a little bit shorter and snappier. That's being built as we speak in the South of France at the moment, and will hopefully have first fusion in 2025. And that will demonstrate that you can get more power out of one of these reactors than you put into it. JET put [00:04:30] more power in and less power out. So ITER is that next step towards commercializing fusion.

Paul Thies: Now, coming back again to the idea of how powerful this technology is with the 150 million degrees and things like that, and also dealing with things like waste and whatnot. When people think of nuclear energy, they naturally may have questions about the safety and environmental [00:05:00] impact. And so, Ian, can you speak to the potential impact of nuclear fusion and how it fits into the global clean energy agenda? And what are some of the pros and cons of fusion energy in terms of the environment?

Ian Chapman: In many ways, fusion is almost the perfect energy source, in that it's carbon-free. It's baseload. You don't wait for the sun to shine or the wind to blow. It would be running continuously. It has effectively inexhaustible fuel. Our fuel, we get [00:05:30] from seawater. We have plenty of seawater. And lithium, and lithium is enormously abundant in the Earth's crust, so we're not short on lithium. It's inherently safe. So unlike fission, where one of the problems with fission is that inside a fission reactor at any given time, you've got a few weeks' worth of fuel. And so you do have this risk of a runaway event, as we saw happened in Chernobyl. Now, there are great safety protocols in place these days, so that risk is very well-managed in a hazard [00:06:00] environment. But that's just impossible in fusion. My whole career has been about trying to keep the reaction going. As Clive said, we keep it going for a short period of time. The challenge is trying to keep it going for a long period of time, so stopping it is dead-easy. So there is no risk of chain reaction.

And it's very low land use, so you don't have to take up a large area like you might have to with solar. It's very high energy density, so you produce a lot of power for a small footprint. And finally, [00:06:30] waste. We talk about waste. Fusion does produce waste. It is a nuclear process. It produces neutrons. That means that the steel, the structural materials that you build the power station from become irradiated. And they have a half-life. It's a relatively short half-life, so you don't have the waste that you might have with fission plants that can last for hundreds of thousands of years. So you don't have the same sort of legacy as you do with fission, but you do have some waste. But it's very manageable waste. We know how to deal with [00:07:00] that sort of waste.

Paul Thies: I'd like to ask you both to comment on a few large-scale nuclear fusion projects and share some insights on the steps and timelines to make nuclear fusion a practical reality. And so first, I'm going to start with Clive. You had mentioned the ITER thermonuclear fusion reactor in the South of France. I understand there are a number of countries involved. It's a very ambitious project. Can you describe it [00:07:30] for our listeners? Who's involved? And how is Jacobs participating in that project?

Clive White: Yeah. Sure. So this is international collaboration on a global scale. There are 35 separate countries involved ITER funding it in some shape or form. And this is a collaboration that will go on for 35 years. So the project's round about €20 billion in terms of cost. And it was mentioned earlier on, first fusion, first plasma rather, should be in 2025. [00:08:00] So it's hugely important. And for developing fusion on a global scale, probably needs that time for international collaboration to move forward. One of the great things is as well as putting money into the project, all those countries now get IPR out of it as well and have already built a lot of IPR, intellectual property rights, in doing the science, the engineering, the manufacturing that's enabled them to help construct ITER. So there's a huge amount of knowledge there that can now be taken back into [00:08:30] those individual countries, and develop their own fusion programs. Ian'll probably talk maybe a little bit about the STEP reactor that is being designed by UKAEA at the moment as well, which is one good example.

Just in terms of Jacobs' involvement, we've been involved in fusion for decades, almost pretty much since the very beginning. And that's everything from some of the really complex science that you need to understand and implement, in terms of the materials that are used in the core of the reactor, [00:09:00] the center of the reactor, through to the manufacturing techniques that are used, through all the engineering design work, and now project and construction management. And we support both the ITER reactor directly plus the European domestic agency, which is called F4E, Fusion for Energy. We support both those organizations as well as Ian's organization, UKAEA, as well. So we're hugely proud about what we do in fusion. And it spans the full capabilities that Jacobs can bring to bear to a global project of that scale.

Paul Thies: [00:09:30] Now, Ian, I'd like to ask you about the Spherical Tokamak for Energy Production, that's a mouthful, the STEP project. Clive I think just mentioned it. That's under the auspices of the UK Atomic Energy Authority, and it's being funded by the UK government. If I understand it correctly, it has some similarities to the ITER reactor. Can you tell us a little bit about it?

Ian Chapman: Sure. So ITER, as Clive said, is this big international collaboration. And it [00:10:00] will be the first time that we get to real fusion conditions. We get a lot more power out than put in. And the world needs ITER, absolutely. ITER will be the first to do this. And ITER must work for fusion really to have a chance of success. But in parallel to building and exploiting ITER, every single one of the ITER partners is thinking about the type of power plant that follows ITER and how you use all of the knowledge and the supply chain development and capability [00:10:30] that now exists from building ITER, to actually build power stations and put power onto the grid.

And what we're doing in the UK is the STEP program. Now, STEP is slightly different geometry to ITER. ITER is designed essentially based on the JET model. So JET is the biggest fusion facility in the world today, that we operate here in the UK on behalf of all of our European partners. And JET did what it was designed to do. And on the basis of JET, we're building ITER. But it is big, right? So ITER, to [00:11:00] orient you, is the size of a football stadium. So it's a really big, big machine. And so it's expensive. Clive talked about €20 billion, that sort of ticket price. And if every time you want to build a power station, you've got to raise that sort of money, then it might take fusion quite a while to penetrate into the market. Even if all the technical problems are solved, it then becomes a market dynamics problem, an economics problem.

So the idea behind STEP is to have a design [00:11:30] which is a lower capital cost. So it's smaller, it's cheaper. And hopefully, that means that it might penetrate into the market more quickly. So that's the approach that we're taking in the UK. But it comes with more technical risk, because as I said, ITER is on the footing of JET. It's on known technology. It's a scaled-up version, but it's relatively known technology. By going in this slightly different approach, we're on a less-firm technical footing. So there's a bit more technical risk to going that approach. But hopefully, [00:12:00] it leads to a lower cost to the consumer and to the utility that builds these machines.

Paul Thies: Mm-hmm (affirmative). Now, are there other fusion development projects of note across the globe that you'd like to briefly touch on?

Ian Chapman: Sure. So as I said, all of the ITER partners have their own plan for how they're going to build power stations that come after ITER. So Europe has a whole entity. So the wide collaborative European program probably has the most advanced power station design program, [00:12:30] a machine called DEMO, so Demonstration Reactor, which is essentially using ITER-like technology, a slightly bigger version of ITER.

And that's more or less the same approach that's being taken by the Chinese. They have a similar variant, slightly smaller than the European one and slightly higher performance. The Koreans as well also have a similar program, as do the Japanese. So they're all going in the same direction.

In the UK, we're going for this slightly smaller variant, lower capital cost. And the US is going in a similar [00:13:00] direction. So actually next week, the US

National Academies of Sciences will be producing a report which outlines a road map for the US fusion program. And my expectation is that that will come out and say they should target a low-capital-cost, high-innovation program to try to bring down the cost of power stations. So that's what the US is doing.

And then the last thing that's worth mentioning is that there's a really buoyant and ever-growing private sector. So everything I've talked about so [00:13:30] far has been publicly funded programs. But there's actually quite a lot of money going into private sector as well, now, where you can see the market has increasing appetite for investment in fusion. And if you go back maybe 10 years, it was largely philanthropists and people who really wanted to change the world who were investing in fusion. And now, you're getting oil and gas majors and sovereign wealth funds and private equity backers putting money into fusion. So the right types of investors, a much broader portfolio of investors.

And a few of the interesting [00:14:00] projects. So here in the UK is a company called Tokamak Energy, and in the US, a company called Commonwealth Fusion Systems, both of whom are looking at high-temperature superconducting magnets. That in principle is a really great thing for fusion. So to make fusion happen, you need big magnets. This would allow you to go to the strongest, highest magnetic field magnets that could exist in the world, which is a good thing for fusion. It allows you to get a lot of fusion power. And if they can deliver that, it's [00:14:30] really quite transformative in our field. So those are two projects to really watch out for.

Paul Thies: So when I was watching your video speech to the Royal Society, you explained... And for our audience at home, magnets are super important in fusion because of the effect that they have to stabilize, as I understand it, the atoms so that they can create that 150-million degree energy source without [00:15:00] just melting through the Earth or through the facility. So the magnetic field is super important. Now, in that video, Ian, you talked about the five main challenges for bringing this technology to reality. Can you briefly share those with our audience? And what have we learned from the development or failure of other first-of-kind breakthroughs to speed up development?

Ian Chapman: So the five big challenges that I talk about [00:15:30] for delivering fusion, the first in some sense is the one that people have heard about, is that we have a fuel which is 150 million degrees. So, 10 times hotter than the center of the sun, which sounds crazy. But we do that every day. And we do it, as you say, by using very big magnets, the biggest magnets that we've ever created here on Earth. And they effectively levitate that fuel. So you can't let that fuel touch the walls of the machine, because it would just instantly melt. Right? So you levitate it. You hold it away from the wall using these big magnets.

The second big challenge is [00:16:00] that ultimately, some of that heat does escape. So like every fluid, water going down a pipe or air going over an airplane wing, there's some turbulence in them. And when you have a gas which is thinner than air but hotter than the center of the sun, unbelievably, it has a bit of turbulence in it. Right? There's a bit of instability. And so some of the heat gets out to the edge. And then you have to think very carefully how you're going to exhaust that heat, how you're going to get the heat out of the machine. That's the second big challenge that you face.

[00:16:30] Then the third challenge is that as well as this incredible heat source, you also have the most intense neutron source on Earth. So, much higher energy and more numerous, more of them, neutrons than are produced in a fission reactor. And as those neutrons pass through the material that you build the machine from, steel or tungsten or whatever you might build the power station from, they will cause little displacements inside the material lattice, which then change the properties [00:17:00] of that material. It'll change its strength or its brittleness or its creep. And that affects the lifetime of the plant. So if you build a power station, you want it to run for at least 40 years. And if those neutrons affect that lifetime, that really matters to the cost of electricity. So that's the third big challenge.

The fourth challenge is where we get our fuel from. So I talked about we can extract one type of hydrogen from seawater, loads of seawater. The second type of hydrogen, an isotope called tritium, is radioactive. It's a short half-life. It only has a half-life of about 12 years. [00:17:30] And because it has this short half-life, you don't find it naturally. All the natural tritium that existed has very long-since decayed and gone away. All right? So you have to make your own tritium, breed your own tritium. We do that by putting lithium around the outside of the power station. Then as the neutrons pass through the lithium, they produce tritium. And then you have to extract the tritium from that blanket of material, and then freeze it into little pellets, little bullets that you then fire back into the core of the machine to [00:18:00] keep the fusion going. So we have to make our own tritium, and then keep injecting it in to keep the fusion happening.

And then the fifth challenge is about maintaining the machine and making sure that it runs as much of the time as possible. They often say about fission stations, if they're out for a month, it affects the share price. Right? So they have to be running to be cost-competitive. The same will be true of fusion. It has to be available. It has to be running. And so the availability of the power station [00:18:30] is really important. At the moment, if one of the components melts because some of the hot material comes out and melts it, you need to go in and replace that component. And because you irradiate the material, it's short half-life but it does get radioactive, you don't really want to send people in. So we want to use complex, first-of-a-kind robots that can go in, extract that damaged tile and replace it with a new one, and then get out quickly so that you can turn the machine back on and [00:19:00] make sure that you're producing electricity as much of the year as possible. So those are the five big challenges. And I forgot the second part of the question.

Paul Thies: No. It's really...

Clive White: Let me jump in.

Paul Thies: Oh, go.

Clive White: Because one of the other things was about how you avoid those first-of-a-kind sorts of issues.

Ian Chapman: That's it.

Clive White: And it's interesting. If you look back over the history of fusion, I mean, fusion reactors from initial concept through to implementation, a relatively short period of time. But when you look at fusion, a [00:19:30] huge amount of research and time and effort's gone into this. ITER is, let's say, first plasma in 2025. There's then reactors that will not only take it from the more power out compared to power in, through to being able to go online in the way that Ian talked about with either STEP or with the DEMO reactors. So, a huge amount of research is going in. But as Ian also said, the prize is phenomenal. Almost limitless fuel. Minimal amounts [00:20:00] of waste. Energy that will be there for the whole planet. The prize is very well-worth going after.

Paul Thies: No, and the environmental... Or, the decrease in the environmental impact compared to, I believe, petroleum-based fossil fuels and things that we were seeing as well seems to be immense, as well. Now, Clive, coming back around to the discussion on the difference between fusion and fission, is fusion complementary to fission and other technology? Or is the [00:20:30] development of a fusion supply chain dependent upon a parallel investment in fission and other clean energy technology? How do you see this all evolving?

Clive White: So, they're absolutely complementary in very many respects. So the technologies are different, but a lot of the science, the engineering, manufacturing techniques and the construction techniques are very readily transferrable from fission into fusion. So I think supply chains that are there at the moment can readily transfer across, and that capability is very good. You [00:21:00] look at what Jacobs has done, and a lot of the work that we do in fusion has been bred from our pedigree on fission in actual fact. So, a really good real-world example.

In terms of that complementary nature, if any country moving forward just relies on one form of energy, it's generally not a great policy. So I'm a big fan of having a diverse energy policy. So as Ian said earlier on, when the sun's shining and the wind's blowing, well, solar and wind's pretty good. But those days when it's not, [00:21:30] you need something. So you need the baseload that fusion and fission reactors can provide. So a balanced energy portfolio is generally, I think, the right sort of policy to adopt. Fusion and fission very much go hand-in-hand. If you look at the timescales, fission's been around for several decades.

Many of the reactors that are going online now have got another 40, 50 years' worth of life left in them. As fusion reactors come online in maybe 10, 20 years' time, probably 20 years-plus, then they actually fit together time-wise very well, as well.

Paul Thies: [00:22:00] So, Ian, we're living in really unprecedented times, of course. And we've been dealing on a global scale with the coronavirus pandemic now for about 12 months. If there's one lesson that we can pull from it, it's that when there's a will, there's a way. Right? When we really need to address something that's looming, society, commercial enterprises, and government and [00:22:30] the sector, in this case, healthcare, have shown a remarkable level of agility and activity in addressing a crisis head-on. And so, wondering if maybe we're seeing, given the growing energy needs of the globe and addressing the environmental pressures therein, if nuclear fusion and speed to adoption there, if there's not maybe an analogy [00:23:00] that we can draw from that. Wonder if you had some thoughts to share about that.

Ian Chapman: Yeah. Absolutely, Paul. I think there's two things that I would point out there. One is that solving COVID, solving a global pandemic needs to be done at a global level. There's no point in a country coming up with a vaccine for its people. It doesn't matter, right? You have to roll that out globally or you never actually deal with the problem. Absolutely the same applies to clean energy. Right? There's no point in the UK saying, "We've got a lot of wind. [00:23:30] We'll be okay putting up offshore wind farms." That doesn't solve the problem for China. Right?

Paul Thies: Mm-hmm (affirmative).

Ian Chapman: So we have to solve a global problem here, or it doesn't actually solve the issue. The second thing is imperative. There's a great quotation from one of the founding fathers of fusion, a chap called Lev Artsimovich, who was one of the inventors of the power plant concept that we use today, who was asked back in the '70s, a press conference. They said, "When will we have fusion? When [00:24:00] will it be working?" And, a very clever guy, so he didn't say, "It'll be in X years." Instead, he said, "Fusion will be ready when society needs it." And that holds true today as much as it did back then. Society needs fusion. So the imperative is there. We have to make it ready.

Paul Thies: Okay. And then, so Ian and Clive, just one final question for both of you. So, Ian, I'll start with you. And then, Clive, I'll come back around and ask the same question. So, Ian, given its potential, [00:24:30] in your view, does nuclear fusion get an appropriate level of media attention and interest from policymakers? And if not, why do you think that is? And what can change that?

Ian Chapman: Sure. Answer is no. I think the sea is shifting. I'd say the tide is turning on this. If you look at the recent UK energy white paper which came out, or The Ten Point Plan for a Green Industrial Revolution which the prime minister launched just before Christmas, in [00:25:00] both of those documents, fusion is mentioned. And fusion is an aspiration for the UK government. And they have a concerted policy and investment, and thinking about all the enabling factors that they need to do, like finding a site for a power station and making sure there's a regulatory environment and framework. So the government are really taking it very seriously. And they're doing all the enabling things that they need to do. But still, the prominence in the wider general public and policymakers at large is definitely not there. And [00:25:30] we as a community need to work hard to demonstrate the value of fusion and why it's so important, the things that we've discussed today, and could be so influential in tackling this net-zero climate emergency that we face that is, in my view, the biggest thing that our generation needs to solve.

In terms of why it doesn't get the right level of attention, I think partially, this is down to public relations mistakes that were made in the past in fusion. [00:26:00] So back in the '60s and '70s, there were very bold claims about delivering fusion in the next few years. Now, that never happened. And now, fusion has this narrative around it that it's always 30 years away and always will be. And so a lot of people that do know about fusion have written it off and said it's always tomorrow's technology. But actually, the field is evolving enormously.

And ITER will demonstrate a big net gain. It will show a lot more power out than put in. [00:26:30] And as Clive has said, ITER starts in five years. Five years is not forever away. It's five years. And all of a sudden, fusion is going to be on this scale, working on this scale, showing that you can have fusion on a commercial scale. And that will be a step change for our community. Genuinely, it will be. Because you're already beginning to see market appetite uptick. But when ITER works and demonstrates that fusion really can happen, I think you'll see that really exponentiate.

Paul Thies: And it seems like there's a bit of a zeitgeist going on, too, [00:27:00] where people are getting serious about energy production and the environment. And so the market is much more open to it than maybe they were in the '60s and '70s. Yeah. So, Clive, same question for you and just want to get your insights as well, the level of attention that it gets from the media and interest from policymakers? And what can we do to change that?

Clive White: Yeah. Ian's covered, I think, many of the key points, so just a couple of extra [00:27:30] ones from me. So if you look back at the way that public awareness of climate change has increased over the last five to 10 years or so, that's going up exponentially. And I think COP26 later on this year in Glasgow in UK will help to sharpen both individuals' interest, and also the global political community's interest as well. And I think that will potentially be a real galvanizing force to get some more momentum behind climate change. And with that will come the search for the energy sources that are going to give us the [00:28:00] carbon reduction that we need. Whether it's fusion or fission, they are zero-carbon. Wind and solar, zero-carbon.

So I think there'll be a lot more interest, I think, hopefully after the end of this year. But that interest isn't just going to come by us all being bystanders. So to Ian's point, as an industry, we can and should continue to lobby and message this to our politicians in all countries around the world. For equal, each and every one of us. Anybody listening to this podcast have got their own personal contributions to make. [00:28:30] We've never been in a more connected world than we are now. And that connection between individuals and their local leaders and their national leaders is a very short connection. And so people can reach out, make their voices heard and put the case for fusion, put the case for low-carbon, and put the case for a low-carbon future.

Paul Thies: All right. Well, Ian and Clive, thank you both so much for joining me today and sharing your insights and knowledge about nuclear fusion and where the industry's going. Really appreciate it. Ian and Clive, [00:29:00] thank you both very much.

Clive White: Thank you.

Ian Chapman: Thank you.

Paul Thies: At Jacobs, we're always looking for dynamic and engaged people to join our team. Bring your passion, your ingenuity, and your vision, and let's see the impact we can create together. Visit careers.Jacobs.com for details.