Wally Manheimer on the Tom Nelson podcast, 010824

[00:00:00]

Introduction

Now as it's expanding, you'd expect it to cool, right? But it's not cooling. It's heating. I think this is one of the most amazing results. I really think that 100 years from now, this will be regarded as one of the key physics experiments of the 21st century.

Guest Introduction: Wally Manheimer

My guest today is Wally Manheimer.

I've had a long career. I got my education at MIT, both graduate and undergraduate, and after that, I had a long career at the Naval Research Labs, years as a civil servant scientist,

ending up as one of the senior scientists at the ST 16 level. For the last 14 years I was there. And then, mostly, well, for a couple of reasons.

I wanted to spend more time with grandchildren, and I, uh, Also, as a senior scientist, I was pretty expensive for sponsors, and I really didn't want to run programs. I just wanted to be a [00:01:00] bench scientist. So I retired and came back on as a consultant, and that lasted for 20 years, and it would probably still be going on today if, uh, the project I was working on didn't lose a lot of its money, and I'll, I'll probably get to that in my talk.

Um, so anyway, I had 53 years at NRL, and I'm I'm not one of these people that, that, you know, I worked for a few years at a university, then I go be a vice president of some company, then I go be a under cabinet secretary of this or that department, then I go back to the university. You've had a lot of, a lot of, uh, people on your podcast, certainly someone like Will Happer who's That's his profile and that's certainly not mine, but you know, thinking back on 53 years of one employee, I feel sort of proud of that.

And even though I'm not on their payroll anymore, I'm still trying to do [00:02:00] scientific problems, which I think are important for the world. And one of them is that book I wrote, which I'll get to you. And the other is. A switch that I think the Department of Energy ought to make in its fusion program.

Energy for the World: Fusion and Fusion Breeding

So, the title of this is Energy for the World.

Uh, fusion and fusion breeding. And fusion breeding, I say, the ugly duckling becomes the beautiful swan. Uh, it's, fusion breeding has been denigrated by both the fusion and the fission community, and I'll make a case that I think it's unjust, and I think it's really the most likely option for fusion, and I think it's one that even the fission people would like.

The Goal of Energy Production

Okay, so what you want to do is, I mean, here's here's here's the overall goal. It's energy and energy is required for civilization. And what you want to do is bring the world's mid century population of about 10 billion people up to Western standards. And what that means is that [00:03:00] they should have energy use of about 45, uh, uh, four or five kilowatts of power use, I guess, more accurately, four or five kilowatts per capita.

And that means roughly tripling the world's power from like 14 terawatts, which is produced by the world today. to something like 35 or 40 terawatts. And that is a big, big job. That's not easy to do. It took us generations to get to 14 terawatts. And I'm saying in one more generation, we should get to 35 or 40.

Well, we probably won't do it, but that should be our goal. And if we can't do it by 2050, maybe do it by 2060. But that's a goal, which I think we should be conscious of. And the less developed parts of the world that are using power like one or two kilowatts or even less per person, they take this very seriously.

And they're making tremendous efforts [00:04:00] to bring their power levels up to this level. And I'll give you a few examples in a minute.

The Current State of Energy Consumption

But just as one example, uh, coal, which in this country we think of as one of the evils, uh, that's used, that has reached a worldwide maximum in coal sales in 2022. I, I don't know if the figures for 2023 are in yet, but the rest of the world is, uh, wants to, uh, get power, uh, just sort of the way we do.

And who are we to denigrate them for it? It makes no sense. And they're doing it whether we like it or not quick question here when you're talking about energy here.

Understanding Energy Conversion

Is this electricity alone? Or is it all every kind of energy? So when you think of, say, coal. If you're burning like one watt of coal, you're producing something like one third of a watt of electricity.

So this is, some of the, some of the energy is just being used, [00:05:00] other energy is, you're losing some of it to convert some other kind of it, to some other kind of energy. Uh, something like hydropower, you don't really have to You know, you just, you just have to build a, a dam and let the water run by and it, it, it does it.

So I would imagine it's very efficient, uh, very efficient to convert the hydropower to coal. But, but the, the terawatts and the 30 to 40, 35 to 40 terawatts of the net energy. And if it's all coal or nuclear, that means that the actual usable power is something like half or a third of that. Um, does that include the energy used like we use gasoline to power our cars right now?

Is that part of it? Or that's different? Yeah. Yeah. The gasoline is part of the energy. And, and both coal and both gasoline and electricity are now used to power the car. And they're about roughly equally, [00:06:00] uh, efficient. Gasoline engines are like maybe 30, 35 percent efficient. Uh, electric, uh, motors are like, uh, 90 percent efficient, but on the other hand, to produce the 90, to produce the electricity, that's about 30, 35 percent efficient too, so it runs into about the same.

I mean, an electric car isn't saving power, in fact. And in your last view podcast, I think I made the case that it's not saving anything, but wasting a tremendous amount, but, but that's for another time or a previous time.

The Global Perspective on Energy Use

So anyway, call is used to, uh, Reached a maximum, uh, maximum use this is just some quotes from some of the people in what we would call the less developed world. Uh, the one I don't have any picture, but at a DOE meeting, Department of Energy meeting in 2009 that I attended, a high ranking member of the Chinese Academy [00:07:00] of Science was there. Uh, this is when we were still getting along with China, I guess.

And said that in 2000, uh, the average Chinese used 10 percent of the energy of the average American. And at the time of the meeting, it was about 20 percent of the power of the average American. Now it's about 30 or 35%. And he was very emphatic. They're not going to rest until it's about equal to what we get.

They don't, they think that we're, they deserve it just as much as we do, and who are we to tell them that they're wrong? Uh, another one, and here's a picture of Sultan Al Jabbar. He was the head of, uh, the COP28 meeting, which in Doha, I think, was just finished. Uh, he suggested a fossil fuel phase out would not allow sustainable development unless, and here's his direct quote, unless you want to take the world back into caves.

That's his direct quote, and so he doesn't think we're going to get away from [00:08:00] fossil fuel anytime soon. Uh, the Indian Prime Minister, Mr. Modi, said in 2021, and here's his quote, the colonial mindset. hasn't gone. We're seeing the developed nations, we're seeing from the developed nations that the path that made them develop is being closed to the developing nations.

He doesn't go along with that. He actually was at this, at the Scottish meeting, and he said, yeah, sure, we're going to end cold use. We're not, we're going to, but we're not going to do it until 2070. So you can see how seriously they take it. Uh, the former president of Niger, a guy named Mohammed Bozum, who I think was thrown out a few months ago, had a prophetic quote, I think, Africa is being punished.

Uh, by the decisions of Western countries to end public financing for foreign fossil fuel projects by the end of 2022. We are going to fight this, [00:09:00] we have fossil fuel and it should be exploited. And they're going to exploit it whether we like it or not. And no matter how much Al Gore, John Kerry, Bill McKibben, Leon DiCaprio shake their fingers at these guys and ride around the world in their private jets to tell them to stop, these countries aren't going to do it.

There's, there's no stopping it. They want to live the way we live, and that's all there is to it. The beginning and end, and they're going to try to do it the best way they can, and right now it's by burning coal. Let me have the next view, Griffin.

Introduction to the Book 'Mass Delusions'

This sort of introduces a book that I had just published by the Generis Publishing Company, and it's available on, uh, On, uh, Amazon, and it's an effort that I'm relatively proud of, especially since my day as a paid employee was done at the beginning of, well, beginning of last year, I spent a lot of [00:10:00] time doing this, and, uh, It's not gonna replace my salary.

It might replace a book or two of it. But anyway, it's, I called it mass illusions, how they harm energy, uh, sustainable Energy, climate policy, fusion infusion breeding. And there are five parts of the book. And the first part just describes the energy that we need and, and, and how we might get there. The second two parts go to, and this was the part of this previous podcast, I think it was number 143, uh, some of the roadblocks that are keeping us from getting there.

Oh, and, uh, and, uh One of them is what I call the false, uh, the false fear of a climate catastrophe coming.

This is a small German town. And the main picture is that German tower with this [00:11:00] gigantic wind farm over it. And if nothing else, it certainly wrecks the scenic and tourist

value

that this town might have. I mean, I don't think any, I don't think they're going to attract, attract any tourists who want to spend a nice relaxing weekend as they are, especially if these windmills are turning around and making deafening noises and vibrations, which they don't seem to be doing now.

But, um, there is a, uh, And that's just one of it, and the book makes the point that there are many other harmful things that this, uh, what I call mass delusion is doing. But then the last two sections of the book are more on nuclear energy and fusion. And there are two other images on the book, two other small images besides this once pretty German town.

On the upper left, there's the configuration of the Lawrence Livermore Radiation successful laser fusion experiment. And on the [00:12:00] right, upper right, there's a, there's a schematic of the nuclear reaction for fusion, for what I've called fusion breeding.

now, fossil fuels are a finite resource, and in today's usage, let's say that we run out of them in X years, and that value of number of years to run out of fossil fuel varies all over the place. But once the world's entire population is brought up to Western standards, you're using about three times that amount of fuel.

So you'll run out in X over three years. So once the world is really hooked on fossil fuel much more than it, you know, to the extent that the more developed countries are, you're going to run out of it a lot faster than current estimates. So what I want to envision is a world powered by 35 or 40 terawatts of power, about 20 to 25 terawatts of nuclear power.

Now that's gross nuclear power, so the 20 terawatts is maybe [00:13:00] 7 or 8 terawatts of electrical power. Maybe 10 terawatts of fossil fuel, same consideration. If you want it for heating, then it's just 10 terawatts. If you want it for electricity, it's fewer. Maybe three terawatts of hydro, uh, maybe one or two other terawatts of various things, maybe trash to power, which some of the countries are using, maybe even a windmill or two in niche markets.

I certainly don't favor anything like on the book. Um, okay, could you skip two slides then? That's it.

The Future of Nuclear Power

So what about nuclear power? I mean, I said that I think the way to do it is with, like, 20 terawatts of nuclear power, and here's just a quick review of what nuclear power is. You take a uranium atom, uranium 2 35, and it's important that the number, which is the number of protons plus the number of neutrons, be an odd number.

[00:14:00] Uh, if the pro number of protons plus neutrons, the atomic weight is an even number. It's very different. But you take a uran, a uranium atom, and you add one neutron to it, and it becomes unstable and it breaks up into two. neutrons, but these neutrons have a tremendous amount of kinetic energy to them. Uh, uh, the, the two fission fragments, and there are many possible fission fragments, and in this one the choice is barium and krypton, and both of them are highly radioactive with half lives of something like 30 years, and I'll get to that more toward the end of this talk, and also the given average of two or three neutrons coming out also, and because you get these neutrons, you can get a chain reaction.

These neutrons can go and be absorbed by the next [00:15:00] uranium atom, and they produce a tremendous amount of power. The rough energy of this reaction is what's called 200 million electron volts, and if you don't know what an electron volt is, don't worry about it, but just think that when you burn something in a fire.

The energy released per molecule is something like one tenth of an electron volt. So this, you know, a chemical fire, burning wood or oil or whatever. So this nuclear reaction, the reaction itself produces about 10 million times more energy than the individual reaction in a chemical, uh, reaction.

The reactors that they use today are mostly light water reactors. which are, there are about 400 of them in the world, and I'll get to the why it's light water in a minute or two. Every year it's fueled with about a ton of U 235. [00:16:00] And that's not the only thing you put into the reactor, you usually mix it with something like 24 tons of uranium 238, which does not react like this, and I'll, we'll get a little more into what it does do.

Uh, and a ton of fuel, and the reactor generates about a gigawatt of power. Now, a gigawatt is a billion watts of power, and, uh, You know, to take that, if you have a 10 watt light bulb, uh, that's 100 watts, and if you keep it on for 10 hours, you've increased your electric bill by about a dime or 15 cents. So this thing is producing about a gigawatt, about a billion watts of power.

And I'll keep using the word giga rather than billion because it's something I'm more used to. So it's generating about a gigawatt of power. And the raw fuel, the U 235, is dilute enough in the U [00:17:00] 238 that it's not a proliferation risk at all. You'd need much, much greater amount of isotope separation to turn this into a bomb.

Uh, the reaction produces two or three neutrons. Uh, one is needed to continue the chain reaction, and the rest, after losses, can be used for other purposes, including breeding some plutonium to replace some of the U 235, and that burns also. So after this reactor is on a while, it's burning not only U 235, but it's burning some plutonium also, because that's made from the U 238.

After a year, it's produced so many inefficiencies, so many impurities in it from lots of other nuclear reactions, they've got to refuel it. And after a year, that 24 tons becomes, after a year, that 25 tons becomes about still pretty much the 24 tons of U 238 that you [00:18:00] started with, really a little less than that, about eight tenths of a ton of highly radioactive fragments like these barium and these krypton atoms, and about two tenths of a ton of plutonium 239, and other higher actinides, actinides which might have higher atomic numbers.

So now skip a slide, Tom. So in these slides, I'll just mention the ones we're skipping are in the archive that you're making, so if anybody wants to take a look at that, all of these will be there, but I think, like we were saying earlier, I think it may be easier in some of them to just continue looking at the pictures than to look at, uh, You know, a page of wonderful dialogue.

So how many, well, here's some dialogue, and there will be some pages of dialogue that are in here. Maybe, maybe too many. So how much nuclear fuel is available? And [00:19:00] there are various estimates. Uh, Hoffert, and I have references of these in some of the written papers I have. I have references to all of them, and you'll just have to take my word here.

I mean, there's nothing in here where I thought I probably should have Now that I think of it, I probably should have had an extra view graph of all these references and I didn't, but these aren't hard to find. You can get any of them with a Google search. Uh, Hoffert estimates that there are about 60 to 300 terawatt years of mined uranium.

Uh, Fryberg terawatt years. But at 20 terawatts, which is what I would think I'd like to, I'm proposing that we want for mid century power. This would last at least for 50 years, and each nuclear plant, and these are standard nuclear plants, give about three gigawatts thermal and about one gigawatt electric power.[00:20:00]

Other people suggested even more, other people suggested even more nuclear power plants. Ralph Moyer, expert at Livermore, said we should have 10, 000 gigawatt plants worldwide. So the fuel would last at most 30 years. So, what's called breeding fuel might become necessary, in fact, it almost certainly will become necessary if we start using nuclear power at 20 terawatts or 7 or 8 terawatts of electric power, now we get maybe 1 or 2.

So breeding could be necessary much sooner than we think. And let me switch to one slide.

The Process of Nuclear Fusion

And I'm not the only one saying this. I said some of the real honchos of the nuclear field have, uh, made this, uh, you know, share this concern. And, and I've been in touch with two of them. Two of them I've been in touch with at George [00:21:00] Stanford, a real expert.

He's one of the main designers of the integral fast reactor, an American fast neutron reactor. I had an extensive email conversation, uh, conversations with him. He died in 2013. And to set one particular email conversation, his quote is, Fissile material will be at a premium in four or five decades. I think the role for fusion is the one you proposed.

Namely, as a breeder of fissile material, If the time comes when the maximum, uh, it's real fast reactive reading rate is insufficient to meet demand. Let me have the next slide, uh, Tom. Another one is Dan Henley, who is the head of the Canadian program, and he, he and I spent a week together at a meeting in Canada, and we were in constant, fairly constant email communication since then.

And [00:22:00] I got two emails from him. One is I've nearly finished prepping my talk for the CNS, that's some nuclear meeting in Las Vegas, and June 13th, 2006. From what I can see now, we will need a lot of fissile isotopes if we want to fill in the petroleum energy deficit that's coming on us. Breeders cannot do it.

And then goes on a little more after that. And another one I got on another email, we, I'm on the executive, I'm on the executive of the environmental science division of the ANS and held a sustainable nuclear double session at the Reno meeting weeks ago. I have copies of all the presentations. The result was an interesting mixture of, we have lots, just put up the price and we'll deliver, like we've heard from Saudis recently, and better be sure you have a long term fuel contract before you build a new thermal reactor.[00:23:00]

So, there's at least Some, there's at least some, uh, you know, concern about running out of nuclear fuel if the world goes not largely nuclear. And these are from people who really understand that, that world a whole lot better than I do. Let's, let's, let's talk about breeding a minute. So, whoops.

The Potential of Fusion Breeding

So there are three possible options for breeding sustainable power.

Uh, one is fast neutron reactors, which I'll get to in a little bit. Uh, the other is thermothorium breeders, which I'll get to even less. And like I suggested, that you might want to at some point get an expert on both fast neutron reactors and thermothorium breeders to, uh, fill you in, uh, you know, better than I can.

I have sort of a rudimentary knowledge of them. [00:24:00] But the other is fusion. And one way you can use fusion is for direct power. Or in the, the, what I think is the best way of using fusion, and I'll make this case here, is fusion breeding. And the fusion breeding makes many, many fewer demands on the fusion device you have, and it has many advantages as a breeder over, say, fast neutron or thermal neutron breeders.

Any combination of these can power civilization at 40 terawatts, at least as far into the future as the dawn of civilization was in the past. Fast neutron breeder people are actively making their case. Thorium breeder people are actually making their case. And the one person arguing for fusion power, and that's me, is actively making my case.

The Challenges of Fusion Breeding

But certainly, I [00:25:00] certainly don't have the kind of, uh, uh, I haven't, let's just say I haven't convinced as many people as as, as the other two groups have. Although I think if you look at fusion breeding, you might conclude that it's the best way to go, although it's obviously the most difficult way to do.

Fast neutron breeders and thorium breeders have already been established in various places. But any of these or any combination of them, which I think it'll probably be a combination though, can power civilization at 40 terawatts, at least as far into the future as the dawn of civilization was in the past.

So any combination of these are certainly, uh, sustainable power. I mean, if you can power something for 10, if you can power civilization for the next 10, 000 years, It's the 20, the 10, 000 years after that really isn't a problem.

The Role of Fast Neutron Reactors and Thorium Breeders

Well [00:26:00] fast neutron reactors are inevitably very complicated and expensive.

And I, what I have is cross section plots of neutrons hitting uranium 235 and uranium 238. And there are two things a uranium atom, a nucleus might, a nuclear, a neutron might do as it hits a uranium nucleus. Uh, if you look at the red curve, that's sort of a measure of what happens to cause fusion. And if you look at the green curve, that's sort of what happens if the neutron just gets absorbed.

and spits out a gamma ray. So these are fairly complicated, and it's not worth knowing so much what these numbers are, but the neutron coming out of the thermal reaction is about 2 MeV, which is about here on the graph. But look, if you slow the neutron down, and this is the energy in [00:27:00] these units of electron volts, and again, don't worry about what they are in detail if you don't know them.

If you slow the neutron down by like three, four orders of magnitude, to maybe one electron volt, or like a thermal temperature, the, the reaction rate of these, I'll just call it the reaction rate, even though it's really a cross section, but it's, it's a section of how fast the reaction can go. The reaction goes up by about four orders of magnitude.

So in any thermal nuclear reactor, uh, you, uh, want to slow the neutrons down, so, before they can, uh, react. Uh, and the way you do it in a thermal reactor is you put water in it, and when the neutron hits the water, the oxygen ad nucleus in the water, not much happens.

But when it hits the hydrogen atom, it pretty much slows down.

So you have a lot of collisions with the [00:28:00] hydrogen atom in the water, and it slows it down. And it's called a thermal reactor because the neutrons react at much lower energy, and uh, And, but there are other types of reactor called the fast neutron reactor, which don't slow the neutrons down at all, they just happen to react at to at least two mega volts.

Like at about, you know, one ten thousandth of the reaction rate that you get if you slow them down. And this means that the fast neutron reactor rate is very complicated, and going to be more expensive. One thing it means that there are very few coolants that you can use. Uh, the one that's typically used is liquid sodium, and that's not exactly the easiest industrial material to work with, although it's a common industrial material. Fast neutron reactors have been built. And there was the Super Phoenix in France.

And these, these can [00:29:00] breed a small amount of additional nuclear fuel for what they burn. Uh, there's the Integral Reactor, which George Manley and George Stanford greatly participate in building in the United States. And there are two of them in Russia actually hooked up to their grid. What they call the BN 600 and the BN 800.

And I imagine you know that, that N is, the N in the Russian reactor is the Russian word for neutron. And the B is the Russian word for fast, which is bistro. And so it's just fast neutron reactor. The reaction path is a lot more complicated. But there's one advantage that they have, and this is something George Stanford also confirmed for me.

That even though they produce a small amount of extra neutrons, they can burn any actinide. If you look at the red curve for [00:30:00] U 238, which is not fissile, it doesn't burn at low, at low, uh, energy. And the curve at U 235 at, uh, the energy that it's formed at, like the two, two megavolts. The reaction rates were about the same.

So one advantage of a fast neutron reactor is it burns any fast, any neutron, any actinide. pretty much equally. It doesn't care whether it's fissile or not. And as such, it's something that I think is really going to play an important role in treating nuclear waste, because nuclear waste is a complicated stew of All sorts of actinides, uranium, plutonium, americium, all of that stuff.

And with thermal reactors, you'll burn some of it, you won't burn all of it. And the ones that you don't burn, you're going to produce more [00:31:00] reactants of. Whereas if you, uh, use a fast neutron reactor, you just put it all in and you just burn everything in one, in one, uh, one trip through. So that's one real advantage of fast neutron reactors, which I see.

A real disadvantage of them is that they don't produce that many extra neutrons. If each neutron reaction produces about a half a neutron, which you can use to fuel another reactor, this means that you need two fast neutron reactors to fuel one thermal reactor, which I've demonstrated here.

It takes two breeders at maximum rate to fuel one light water reactor of equal power. So this is the disadvantage of them. If, let's say, you've built a lot of light water reactors and they run out of fuel, You've got to build twice as many fast reactors if you just want to fuel them. And, uh, and the world isn't going to go to fast nuclear reactors now.

They're more expensive and [00:32:00] complicated. They're going to have a lot of thermal nuclear reactors. And, uh, these things really can't fuel a lot of them.

Thorium breeders are not completely dead. You can use thorium, a thorium reaction produces more neutrons. So if a thorium reactor can't fuel a lot of thermal reactors, it can at least fuel yourself. It can at least fuel itself. And you can imagine a Nuclear infrastructure, every reactor is a thermal reactor.

And all you have to fuel it with is thorium. There's plenty of thorium. I mean, there's no shortage of thorium like there is for U 235. And this could, could be just something that could be a real advantage. One disadvantage, and the only one that I can really think of, is um, your Fuel is a mixture of uranium and thorium, rather than U 235 and U 238, like in a [00:33:00] uranium reactor.

And that means that if anybody can get a hold of this fuel, it's very easy to separate the uranium from the thorium chemically. And these could be a much bigger proliferation risk. thermal nuclear reactor. There are lots of advantages and disadvantages of each of them. Certainly not the authority on them, and as you can see at the bottom view graph, uh, the bottom line on the view graph Perhaps another Nelson podcast with an expert on fast new neutron reactors and thermal thorium breeders would be appropriate if you haven't done it already.

And I think that could really add some more insight. Um, I want to do that. Yeah. Yeah. You don't happen to have any suggested names there. Do you off the top of your head? That would be good. Uh, I'm not, not so much since, since my interaction with Dan Ley and George Stan, I mean, either, either of them would've been terrific [00:34:00] if they were still in this world.

But, uh, you know, I I, I haven't been into so much into that world since they were, but, but I don't think it's that hard to find out the fellow who wrote to you, to us, to both of us before this thing. It could probably either be one who, whose named Cal Alper or something. Uh uh, it was Cal Abel. Yeah. Cal Abel, probably either he could do it or could suggest someone to you.

Okay. Okay.

The Future of Fusion Reactors

So let me get to the next part, which is where I do claim some expertise, and that is in the fusion. And a fusion reactor without breeding is the most studied alternative, but breeding really may be the best use of fusion. ugly duckling. So let me go through this a little. Uh, here's a diagram of it.

If you have a deuterium nucleus and a tritium nucleus, and they're both isotopes of hydrogen, [00:35:00] deuterium Has one proton and one neutron. Tritium has one, uh, proton and two neutrons. They form a helium atom, which is, has two protons and three neutrons, which is unstable, so it spits out one of the neutrons, and then you just have spits out also a helium atom, and the neutron has an energy of 14 MEV.

And if you don't know what that means, that's about. about 10 percent of the energy that you get in a fission reaction. Remember I said that the energy in the fission reaction was around 200 MeV, and it's not so important that you know what those are, but what, but what I think is important to know is that the fission, the individual fission reaction produces [00:36:00] about 5 or 10 percent of the energy of the average, the average fusion reaction produces about 5 or 10 percent of the energy of the average fission reaction.

So this neutron is at 14 MeV, and this helium nucleus, that alpha particle, is at about 3. 5 MeV. But the problem is you can't do this in a solid like you can do a fission reaction because you have to overcome this, uh, this. Uh, Coulomb barrier, they're just charged particles, and so these need, you need to have these particles of at least 10, 10 keV, and to think of that, that's maybe a thousand times the energy of something has in a chemical reaction, a fire or an oil burner or whatever.

So these particles have to be energetic just to start it. And these have to get really energetic after the reaction. The energy [00:37:00] multiplication is about 450, they say. So there are two ways to, to contain this. One is in a strong magnetic field, or the other is to heat it by, and compress it by a powerful laser.

And there are both large efforts in this, in this country and, and the, uh, rest of the world. Deuterium is no problem to get. There's plenty of it on the earth. But one, one water. One water molecule in 6, 000 has deuterium, so it's relatively easy to separate. Tritium doesn't exist on Earth. It's itself radioactive with a 12 year life, half life.

So even if it existed on Earth, it would only exist for about 12 years. So you have to breed it from a reaction of a nuclear lithium atom with a neutron. It gives you a neutron, it gives you a, it gives you a tritium nucleus.

So fusion could be an ideal breeder, [00:38:00] but like I say, breeding has always been the ugly duckling of the fusion project, and condemned with really such ignorant and false statements as fusion breeding combines the worst aspects of fission and fusion. Forget it. Fusion breeding might add nuclear fuel, the one problem that fission does not have.

This guy obviously doesn't believe that there's a fuel problem. And I say this podcast and other material I've worked on hope to convert fusion breeding into, into the beautiful swan. I think that's about the third time I've said it. So let's go to the next one, and um, the fission reaction, the fusion reaction produces only a single neutron, but because it's much more energetic, it can produce, it can produce itself a few extra neutrons.

So, one neutron will produce the tritium, and one is probably lost in a [00:39:00] variety of other loss mechanisms, but there's still one to breed some U 233 from thorium. So each thorium atom, each neutron can produce something like one half to one U 233. Uranium nucleus. And since that has an odd atomic weight, it's perfectly fissile.

It's a perfectly good fuel for existing reactors, just like the plutonium 239 is. But the fusion reaction produces, and here's where this ratio becomes important. And you don't have to know what an MeV is. But the fusion reaction is 20 MeV, whereas the fission reaction that is breeding is 200 MeV. So the reaction produces fuel for 10 times more energy than the fusion reaction.

And what that means when you think of it as a breeder, and let me have the next slide, Tom. [00:40:00]

The ITER Project: A Global Effort

One fusion breeder can breed, can fuel something like 5 or 10 thermal reactors of equal power. And here it is in a, uh, here it is in a, uh, uh, a little schematic. Here's a three gigawatt thermal fusion reactor, which I took as a schematic of a tokamak, which we'll get to in a bit.

Um, then you produce, uh, then you produce with a chemical, chemical separation plant, you produce, uh, uranium 233. You mix that with uranium 238, which is the fertile material, so it's not a proliferation risk, unlike the thorium reactor, uh, and this, this fusion reactor can fuel at least five of these thermal reactors.

Maybe more, maybe as many as 10. The numbers are not easy [00:41:00] to get accurately. It depends a lot on the details. But I think 5 is, I think 5 thermal nuclear reactors from one fission reactor, fusion reactor, I think is a minimum. And now let's say that fusion, let's say that, so this alone suggests that fusion breeding should be taken pretty seriously.

And it may be, all that stands between thousands of electrical power generators are being an enormous pile of junk when they run out of fuel. How else can you fuel them? Uh, so what if in the development, which is unavoidable, the rest of the world does build thousands of nuclear power plants? And what if in 30 or 50 years, George Stanford's prophecy proves to be correct, and there's no fuel for this enormous investment, which is still sitting there, a pile of junk?

Uranium in the seas won't do it, it's[00:42:00]

so dilute that it'll take more energy to collect and process it than it'll give back, at least with any collecting and processing tools we know now. So these reactors could be stranded and out of gas. Fast neutron reactors and thermal nuclear reactors can't fill the tank. Only a fusion reactor could.

And, uh, I mean, only a fusion breeder could. And just skip one. I mean, maybe a children's book actually gives us a little insight on this. I took this children's book called Out of Gas, and I just changed last chance, last chance gas to fusion breeder, and I think this sort of illustrates probably the strength of fusion breeding.

If these possibly many thousands of fish thermal reactions run out of gas, There's only one way you can fuel them without tearing them all down and building thorium reactors instead [00:43:00] and that's with a fusion burrita. I think one of the main things that arguments for a fusion breeder to be ready for is, it's the only thing that can fuel large numbers of, uh, large numbers of thermal reactors, which, which may be a major part of, of the energy infrastructure for a long time.

And, uh, uh, thorium breeders can only. Fuel themselves and you might need something like two fast neutron breeders to breed one So if you've got 5, 000 breeders that don't have any you know, any fuel you're not gonna build 10, 000 Fast nuclear reactors, which are much more expensive just to fuel them You can do it with with you know, one fifth as many or one tenth as many Fusion breeders if you can pull it off I'm going to [00:44:00] abbreviate some of the, uh, the rest of this will be mostly talking about the approach to fusion, and I'm going to abbreviate it, what I call fusion's great white whale is, uh, a machine called ITER, and it's, it's a tokamak, here is a schematic, and, uh, here, here is the schematic of it. And it's actually being built in the south of France. And here's a picture of the construction side of it now. And it's about 75 percent constructed.

And this has a lot of problems. First of all, it was expected to go in, um, 2016 was going to be when they turned on the first plasma, and 2025 was going to be when they showed that they produce 10 times more fusion energy than heater energy. And the thing is heated with various microwaves and, and particle beams.

Uh, well anyway, [00:45:00] now they're expecting the first plasma in 2025 and the fusion experiments to finally be finished in 2040. So the, the cost overruns and the And the, uh, delays have really been unmerciful. Uh, it's sort of surprising that the world stuck with it this long. There are seven national partners building it.

There's the United States, Europe, Japan, Russia, China, Korea, South Korea, that is, and India joined late, was a late joiner. So it's a real worldwide project. And it's about 75 percent complete, and it, it, I don't think there's anything to stop it being completing, and I don't think we should, but it's got a lot of real problems, and I'll just go through them rather briefly.

What they want is they want to produce, have a heater in here, which like I say is, let's say it's a microwave source. So it'll run like your [00:46:00] microwave oven. And you want fusion, you want the fusion, the, uh, 14 MeV neutrons and three megavolt alpha particles to be the output of it, and you want ten times more power out than you could put in.

Well, when you, like we were saying earlier, when you produce this power, you don't produce electricity, which is what you really want, you don't, you don't want this thing just for heating. You want to produce electricity. So that they expect to produce something like 500 megawatts of fusion power. So that would produce about 170 megawatts of electrical power.

And since it's Q equals 10, you'd need 50 megawatts of heater power. But these heaters aren't 100 percent efficient either. They're also about 30 percent efficient. So the wall [00:47:00] plug power for the heater is about 150 megawatts. Which is just what, what is producing. And the people running ITER realize this.

And they say that this isn't going to be a power supply, but that it's going to be the step for the next power supply called the demo, which is going to have all these wonderful things. It's going to be smaller, it's going to be cheaper, it's going to be more powerful. Realistically, nobody has a clue of how you're going to build that.

And, uh, that's only one of its problems. And here I enumerate a whole bunch of other problems that it has. But mainly, even if it's successful, even in 2040, that's when you got to start on this demo, assuming anybody can come up with a convincing design of it. And, you know, you talk about producing power in the 23rd century, really.

Introduction to Stellarator and Tokamak

Another approach, which [00:48:00] is even more complicated, and skip three or four view graphs till you get to the next picture. There's something called a stellarator, and Germany and Japan are studying this. This has some advantages of a tokamak over the tokamak, which is what ITER is, and, um, and it's, uh, it's just so much more complicated.

Uh, let me say that if you have a tokamak which produces 3 GeV, uh, 3 gigawatts of power, a billion watts of power, like you want it to be a Uh, power supply.

Size Comparison of Tokamak and Stellarator

If you put one end of it on the goal line of an American football field, the other end of it would be on about somewhere between the 20 and 30 yard line of it.

So it's really big with huge coils and everything. Well, this thing's much [00:49:00] bigger. If you put this on the goal line, if you put, say, this, this end of it on the goal line of an American football field, and you want to know where the other end of it is. it would be on about the 20 or 30 yard line of the other team.

So it's really huge. And not only that, these coils would be about, oh, maybe about 15 to 20 meters top to bottom. The size of like a four story building. So, in that football field analogy, it would be, these coils would be reaching up to the second deck.

Challenges of Stellarator

It, it doesn't look inexpensive. And it doesn't, it, it, it's very immature compared to the tokamak.

I mean, there's piles of data on tokamaks, and there's just a little bit of data on this. Getting the data takes years, so.

Private Fusion Startups

Uh, then, you really can't, much as I'd like to, you really can't ignore these, uh, [00:50:00] Private fusion startups with private dollars and their goal is that they want to get fusion power on the grid in a decade and, um, and, uh,

and, and they, they think that they think they can do it and they, they just, they just, I mean, these are fusion experts. They should know they can't do it. The, the, the problems, just the problem of getting the tritium To fuel these things will take a decade to do, and let me have the next, uh, decade. Now, I'll go, yeah, next one more.

These are the privately funded, that they wanted, they're trying to sell it because they can get it on a decade, so they can just barely in the nick of time, uh, save us from the next climate crisis, which is coming in that decade. I [00:51:00] don't know which of those statements is more nonsensical, that there's a climate crisis coming in a decade or this is going to happen, and possibly these could be the subject of another Nelson podcast.

I could do it, but I think with three of these, you might be getting sick of me. I think that, um, I think that someone like Dan Sby or here, I do know some people who could do it. Someone like Dan Sby or someone like Don Steiner or someone like, um, uh, uh, Stu z Wayman could, could do this. Like I say in here, I, I gladly, I, I, I'm saying it's exceedingly unlikely that any of these startups will succeed, and I gladly.

I'd gladly get Betty Yu's pension on that.

Critique of Private Fusion Startups

Uh, so look at some various statements and predictions. Here's from GeekWire, just a few months ago, October 20th, 2023. [00:52:00] Uh, almost a decade ago, Helion, that's one of these startups, predicted reaching scientific break even in 2017, four years ago, and they are very far from scientific break even.

Zap. I'm not really familiar with this one. I'm pretty familiar with Helion. Protope to get scientific break even this year, 2023, although it almost certainly won't. This is from GeekWire, from Jasby in, in, uh, form of, form of physics and society in 2019. Tri alpha says it'll produce a working commercial fusion reactor between 2015 and 2020.

I mean, they're nowhere. Uh, they, they want, they don't D T fusion is too easy for them. They want proton boron 11 fusion, which is orders of magnitude more difficult. They can't even do D T fusion. Uh, general fusion, another one I'm sort of [00:53:00] familiar with. Tri alpha, I was on the committee that Convinced the Navy not to fund this, uh, they, they first went to the Navy and I was a colleague and I, the Navy.

The Navy gave it to us to review and our, our thing is say that, you know, for proton boron 11 it would, you know, it takes almost more miracles than you can count. I mean, some of these take only four or five miracles, but just, I mean, this just, it's just nonsense. They've been going for 25 years. They started in 1997, which was when we got the thing to review, and it's still nowhere near any fusion.

A general fusion predicts pure prototype. by 2015 and a working reactor by 2020. Needless to say, that hasn't happened. Lockheed will have a small fusion reactor prototype in five years. This was written in 2014. Uh, it's not, it's ten years and there's no small prototype, and a commercial [00:54:00] application within a decade.

So they're going to have it in 2024, which is today. They're nowhere near that. So, these people Talk big, but they, I, I doubt if any of these have produced a single fusion neutron. That's the point Dan Jasby constantly makes, where are the neutrons?

Success of Livermore in Laser Fusion

Uh, so anyway, but let me get to what has been, I think, a successful thing.

So, so, let me have the next view graph. So what do you do? Well, Livermore had an enormous triumph in laser fusion, which is a very different type of fusion. It made headlines on page one of the New York Times and the Wall Street Journal. And now achieve the Q of phi, 1. 5. Uh, nearly what Ida hopes to achieve 20 years from now, and it did it for a small fraction of Ida's cost.

Not that Livermore's laser was cheap, but it was a tiny fraction of [00:55:00] Livermore's cost. Uh, the Secretary of, the Secretary of Energy at, at Livermore's at the announcement. So my question is, how, how come, how can The Department of Energy, energy, nuclear, Livermore is there for nuclear simulation, nuclear stockhole, stockpile stewardship they call it.

They're not into energy at all, although many of the scientists are motivated by the energy and think they're going to contribute to it. But how can DOE ignore DOE's done nothing to change its bureaucracy to take advantage of it in the energy sector.

Challenges of Magnetic Fusion

And I don't know how DOE can possibly ignore this, especially with real problems with magnetic fusion, uh, so, so far, which are on the viewgraphs.

Uh, I just gave one of them for, well, really two of them for the tokamak, its size, and the fact that it needs another. [00:56:00] Uh, another even more advanced machine than either, and, and with the stellar rate of the size alone, and with magnetic fusion, that these private, private fusion startups are, are, are just, just snake oil salesmen, really.

Livermore's Scheme for Fusion

Well Livermore's scheme is to put the target in what's called a hole room, illuminate the walls and produce intense x ray bursts to implose the target and get it to fuse. And Livermore's simulation is sponsored by nuclear simulation, not energy, and bureaucratically these are two very separate. I think they'll stay, but what I think you have to do is change some of the energy bureaucracy to do some laser fusion, too.

Let me see where I am now. Okay, so let me have the next slide. This is also a word slide, but I think it's, I want to get it.

The Concept of Alpha Generated Burn Wave

So what they want to do is compress [00:57:00] their, uh, little target in the center. And once it produces, this is really the basic physics of it, once it produces the 14 MeV neutrons which escape, But the 3.

5 alpha particles, those alphas, those are absorbed locally, so they don't escape so easily. And they heat the surrounding region, heating it up so that they produce more fusion. So what the idea is to, uh, for these alphas, initiate an alpha generated burn wave. And the laser doesn't ignite the, the laser isn't what ignites it.

The laser is just the match that ignites it. And it's the fuel that burns and ignites the rest of it. Um, let me just show the configuration, let me have two slides, and yeah, there it is. No, back one, okay.

The Configuration of Livermore Experiment

If you remember the book, uh, this [00:58:00] little violet thing is what was on the upper left hand corner of the book, which was the configuration of the Livermore experiment.

So, what they do is have the laser shine the light on this device called a holorum, which is like a hollow can. And it produces a plasma which produces basically a very intense x ray source, and it's this x ray source which implodes the, uh, which implodes the, uh, target. Now, it has to be an X ray source because remember the, uh, their customer is not energy but is nuclear simulation.

And it's X rays which are very important, which are nuclear bombs. I mean, not, not, not radiation of the wavelength of the lasers. So they use it to produce these X rays, and the target explodes. You produce a little bit of fusion from the implosion, but then that produces a [00:59:00] burn wave. And they have a lot of evidence that they produced a burn wave.

Now, if you have something that's exploding and it's expanding, you know that it's cooling because it's expanding because a lot of the thermal energy in the target is converted into energy and by conservation of energy it has to cool. Well take a look at what happened in the Livermore experiment. Let's look at the graph on the right. Uh, that says T equals zero. That's when it's reached its maximum compression, and from there it starts to expand, expand. Now as it's expanding, you'd expect it to cool, right? But it's not cooling. It's heating. And that's just, uh, I think this is one of the most amazing results.

I think that this I, I really think that a hundred years from now this will be regarded as one of the key physics experiments of the 21st century, producing an alpha burn wave. And they showed other [01:00:00] things, unfortunately they haven't published it yet, this I got from one of their publications, but look at how convincing it is, it, it's expanded, and it's, it's expanded and, and, and it heats, the only reason it could be is that the alphas are heating it, and producing more fusion than what they started with.

And they gave us several seminars. They gave an online seminar, uh, where they, uh, where they just had a whole bunch of their guys talking, which I listened to, and if you look at the graph on the upper right, the red graph is the temperature after the implosion, and the black graph is the radius. So the radius is increasing and it's expanding.

But for a while, the temperature is increasing, just like the graph on the right. And then there was a guy from Livermore named Laurent Dival who gave a plenary talk at the 2022 plasma meeting, and he showed it a sort of a different way [01:01:00] with a color graph, and you know that blue means cool and red means hot.

And he had little pictures, which they do, and they had tremendous diagnostics at Livermore. And these are just my sketches of what they presented in the, uh, these two seminars. And you can see that in the one on the left, look at the red and blue. Uh, circle graph. The one on the left is just when it starts to, uh, fuse from, from the, the hope.

And then the next one is it's expanding, but before it expands too far, it can heat a little, so the hot region is even bigger, and then finally it all cools down. And in a time of less than a nanosecond, which is a billionth of a second, it's all over. Like I said, I think a hundred years from now this will be regarded as one of the key 21st century experiments.

I mean, it just blew my mind when I saw these diagnostics that they had of, uh, of, uh, of a [01:02:00] fusion burn wave. You know, I guess the best analogy is a spark plug in a car. It's not the electrical energy of the spark which does it, it just starts the ignition and the whole cylinder chamber burns. And it's, it's the same idea here.

The Future of Laser Fusion

Well, as much of an experiment as this is, it's, it's, it's not a configuration which is viable for, um, for, for energy. , first of all, their sponsors. The sponsor is Nuclear Weapon Simulation and Stockpile Stewardship, so they're not interested in laser parameters important for energy, such like efficiency, rep rate capability, bandwidth, average power capability, and also an ability to track a fast moving target as you shoot targets in one after the other.

I mean, you don't want just one implosion. You gotta do a lot of them. And these hole rooms are precisely engineered quantities costing [01:03:00] thousands of dollars, and each one contains expensive materials like, in fact, why don't you go back one slide. Yeah, the hole room, which is this little can that it's in, that these purple, purple light, uh, laser beams are hitting, that, that it has expensive materials like gold and uranium, and mass production will ultimately Reduce the cost of these, but let's say they get fusion energy of 100 megajoules out of this, which is like they have about two, they have about two megajoules of laser energy hitting it.

So let's say they get 100 megajoules out of it. Well that produces to, to about, when you turn it into about electricity, that turns into about 10 kilowatt hours of electricity if you do it with one third efficiency, worth [01:04:00] about a dollar. So there's a very, very low. Upper limit for the acceptable price of a Holerum if you want to use this for, uh, fusion.

Not only that, and let's skip two slides, three slides, because they're heating the Holerum, only a tiny fraction of the laser light is actually, actually hits the, uh, target. Most of it goes to other places. Some of it goes to heating the whole room walls, some of it uh, goes through laser plasma instabilities in the whole room.

So wouldn't it be better if nearly all of the laser light hit the targets? And to my mind it's worth a very, at least a very big effort if you can do this by going directly to the target. And there's another problem also. Turn one more slide, the next slide. Livermore, and here I have a picture of Jacob de Grom.

Uh, one of the best pictures of the Mets when we went to, [01:05:00] uh, Citi Field once to see a Mets game. They happened to be giving these away. And I'll get to him in a sec. Livermore demonstrated that it can hit the target if it's, you know, on a stalk or a tent. And the sports analogy, sort of like with the football, it's like hitting a golf ball on a tee.

But for energy, that's not going to cut it. These target, uh, the target and the hull rooms have to be continuously shot in at high speed and the paths aren't going to be quite predictable. So it's more like sitting, not hitting a golf ball on a tee, but a whole series of fast balls, curve balls, sliders, change up, everyone, by someone like the Grom on every pitch.

Not only that, the target axis would have to be perfectly aligned with the laser. So it's like the batter hitting a pitch at a particular point on the baseball spin. Seems mechanically impossible. And I think the analogy to give is that [01:06:00] laser fusion for energy is playing baseball. Laser fusion for nuclear simulation is playing golf.

So direct drive uses a spherical target, and most likely what's called an eczema laser. So no whole room is needed, and the target engagement is much simpler. I mean, you can actually watch this thing track in. I mean, the military has lots of experience between, of tracking things with microwaves and lasers and whatnot.

And so it's, uh, tracking this target as it's shot in at high speed and focusing the laser on it is, is a problem that they can at least formulate and probably solve. And all of the, all of the, uh, lasers are focused on the target, and something like maybe very nearly 100 percent of the laser light is focused on the target, rather than 10%, like in the Livermore target.

Let me just give a little plug to my former lab. Let me have [01:07:00] the next view, Tom.

The Role of NRL

At this point, Neville Research Lab is the only group looking into laser fusion with what are called eczema lasers. And these eczema lasers have real advantages over the lasers that Livermore used. Livermore used solid state lasers.

And because the lasing material is a solid, you're always worried. Optical damage to these, to the lasing material has just been a constant headache for Livermore. Whereas this is in a fast flowing gas, so it can take a lot more, a lot more average energy than it can. The program has done a lot of very good laser experiments.

I mean, we don't have nearly the power, energy, and the laser to do anything remotely like what laser, what Livermore did, but, but I think we've made nice contributions to the theory. The program also had a strong theoretical component, which I'm proud to say I participated in. [01:08:00] Uh, they also have a reparated laser.

, the electro facility is a reparated laser, which so far has the highest average power of any fusion relevant laser. It can go at like five, it can go at like, I think, I forget the energy, several, several I think a couple of kilojoules at KRF laser wavelength, which is 248 nanometers, and something like 200 laser, 200 joules at something like 190 nanometers, which is the wavelength of an argon fluoride laser.

And argon fluoride is the shortest wavelength available for laser fusion research, and NRL actually built the uniquely capable Um,

let me just look at some advantages, and I'll just go through these quickly, of argon fluoride eczema lasers. Uh, they calculate a laser efficiency of 16 percent possible and a wall plug efficiency of [01:09:00] 10%, which gets you into the right ballpark. The laser can have a bandwidth, very high bandwidth, which is needed for stabilizing some of the instabilities which take place.

And where the lasers are flowing gas rather than a solid, it can have a much higher average power capability than something where you have in a solid, at least it has that capability. XML lasers also have a strange capability of being able to change their focal length in the course of a nanosecond start, of a nanosecond implosion.

So they can actually follow the particle, their focal length can actually follow the particle as it implodes. And calculations, NRL calculations indicate that these, these configurations like this might have very, uh, very high Qs, very high ratio of laser energy to, uh, fusion energy. here are some of the [01:10:00] calculations for, uh, gains of various laser wavelengths. And for a 2 megajoule laser, which Livermore has right now, uh, the NRL calculations are that with the argon fluoride you can get something like 200 or 250, a gain of around 200 or 250.

So that means that if you have two megajoules of laser energy heating it, you might get 500 megajoules of fusion energy.

So at some point though, NNRL just, just doesn't have the capability or the interest. This, this just isn't the problem of Great interest to the Navy and at some point, NRLI think realizes that it has to transform, transfer this to a FU A-A-D-O-E Fusion lab. DOE has has the mission, it's [01:11:00] got the resources.

Uh, NRL certainly doesn't have the mission to, uh, to provide. To provide, uh, energy for the civilian sector. I mean, it's got enough problems, the Navy has enough problems as it is without saving the world. So really, the point I've made when I was at NRL the last time is that they really have to think in terms of transitioning this to some Department of Energy lab, either an existing one with a new, with a new, uh, mission or, or possibly some new one.

Well, I, I won't go through the calculation, but if you have a gain of 200, if you have a gain of 250 with a 10 percent efficient laser, you really can get, it's not like the ITER problem where ITER produces energy which just barely powers itself. Maybe 10 or 15 percent of the energy of this powers itself and the rest of it can be used to power the rest of the world.[01:12:00]

But I think, one question is, I think it's pretty believable that you can get a 2 megajoule argon fluoride or krypton fluoride laser, but the question is how believable are these gains? And here I think it's worth going through the experience of Livermore, and I'll just keep this on the slide now, let me get my light.

Okay, so Livermore also tried to do, tried to do, they did calculations of the game of their system with their whole rooms, and they, frankly, they brought much more resources to these calculations than NRL could possibly do, and I mean, I, I was involved in a small part of these calculations, and, uh. You know, there are two or three people doing these.

And Livermore had big teams doing it. And in 2004, when they thought that the NIF [01:13:00] was almost, you know, going to be ready and very shortly, John Lindell, who was one of the leaders of the program and eight co authors wrote a very, very long, detailed article on the physics of NIF. Indirect derived laser fusion.

And it examined a large region of parameter space. And they found that in a large region of parameter space, they're going to get a gain of 10. And as NIF got more and more delayed, another group under Steve Hahn, very many co authors, I think I have here that there are 40 co authors, re examined the issue and found the same large region of parameter space with a gain of 10.

So in 2012, they turned on their laser, and they fully expected the gain to be 10. And guess what it was? It wasn't much more than a tenth of a percent. So they worked very hard, and in this intervening decade, they've worked very hard, [01:14:00] and they got this wonderful result of a gain of 1. 5. An order of magnitude below their calculations of 2004 and 2010.

And I think there's a variety of, there's gotta be a lot var, a lot of unknown things in these game calculations. I don't think , looking at the Livermore experience, you gotta assume that that might be the case for other calculations too. So let's take the, let me take more conservative estimates. Uh, let me assume the laser efficiency is only, and I say only in quotes because.

This only is a big number, of only 7%, and that the gain is, again, only in quotes, because it's a really big number of 50. So then your 2 megajoule laser gives 100 megajoules of fusion power, or 30 megajoules of electricity, but to [01:15:00] produce the 2 megajoules of laser light, you need 30 of all plug power. So it's obviously not a viable scheme if these numbers that NRL is calculating would lose by just a little bit.

Let's examine it for fusion breeding. Well first, these breeding reactions of breeding the uranium U 233 from the, uh, from this neutron, these are all exothermic. And they basically double the power of your fusion blanket. So let's imagine producing 100 megajoules of fusion power, the example I just gave.

Targets shot in 15 times a second, and you see what I mean by having to hit a whole bunch of fastball and curveballs as they come in. Um, as a breeder, it would produce 15 gigawatts of maybe U [01:16:00] 233, and maybe even more if you can get better neutron economy. So with a single one gigawatt laser fusion breeding, with these more conservative parameters, you'd fuel about one, about five.

Or maybe even as many as 10 1 gigawatt thermal nuclear reactors. So, let me take this, uh, let me skip a slide or two, I'll tell you when to stop, Tom, I'm almost done. Keep going, keep going, keep going. Ah, what to do now? No, go back. I think what we have to do is take a lesson from an earlier, uh, earlier action from the Princeton Plasma Physics Lab.

Uh, in 1960, they were wedded to stellarators. Uh, which at the time got terrible results. The modern stellarators now do much better than these old ones. Well, then the Russians showed that tokamaks had [01:17:00] much better confinement, and at first we in the West didn't believe them. But then an English group went over and, uh, and, uh, did some measurements on it, which the Russians weren't able to do, and they showed that sure enough, the Russian claims were right.

Well, almost immediately, in the course of I'm sure less than a year, Princeton switched from stellarators to tokobaks and had a wonderful 35 year run. I mean, I think for 35 years, I think the Princeton Plasma Physics Lab led the world in fusion. Until tokamaks pretty much ran out of steam, they got, they had to get too big.

And I think nearly, I think really nearly all magnetic fusion has pretty much run out of steam, whereas laser fusion has just had a enormous triumph. And like I just showed on the other slide, assuming that you can get these only 7 percent lasers [01:18:00] Gains of 50. I think there's a real path from this tremendous triumph Livermore had to laser fusion via breeding, not via pure fusion, for the world economy.

Okay, well, the DOE Fusion Project should learn its lesson from Princeton's in the 1960s. It should mostly abandon, uh, magnetic fusion. Not completely. It should certainly keep up its, the, uh, the, uh, commitment it made to ITER, we're one of the partners. Uh, so it should certainly commit that, to keep that. But the rest of the fusion budget is 500 million dollars for a bet, for a effort which I see as being stuck in the mud.

Uh, the 500 million dollars I think has to be split between two branches, a magnetic fusion branch and an [01:19:00] inertial fusion branch, with the inertial fusion branch getting at least 300 million. Now of course, I think we should You should continue to fund ITER and even do some magnetic fusion. I mean, I think inertial fusion has it all going for him now, but, you know, nobody's crystal ball is perfectly clear, but I think you just want to put a lot more resources into, uh, into inertial fusion, and that means ending, at least in this country, some of the, uh, magnetic fusion projects that we're doing.

And this 300 million should go into a new or existing DOE lab, uh, for laser fusion with, uh, for energy. So there'd be two labs doing, like, serious laser fusion. Livermore for the lab, mostly for, you know, nuclear security, and this new lab for energy. And this will [01:20:00] just cause enormous bureaucratic wars. I mean, the people who are going to lose the 300 million dollars aren't going to take it easily.

And like I said, it's going to be like slogging through a quicksand a mile wide and a mile deep. But I think it's necessary. I think, I think the, uh, the fusion, the success of the fusion effort depends on it. And not only that, the rest of the world is all doing tokamaks. And the few tokamaks that we have in, uh, in the United States now.

I think there's really only one, which is at General Atomics. I mean, they're doing very good work, but no government project has a lifetime guarantee. And as needs change, the projects have to change. But the rest of the world is doing magnetic fusion. And in the United States, we're the only ones doing inertial fusion.

So it [01:21:00] seems clear to me that that's what we should do. Okay, now let me talk about what I see as the infrastructure, and I've talked about,

fast neutron reactors, and one of the advantages of them is, I mean they If the only thing you have are fast neutron reactors, they're certainly a sustainable source. But if they're really much more expensive as, as they are, at least at this point, from thermal reactors, you don't want every one of your reactors to be a fast neutron reactor.

But fast neutron reactors can burn any actinide. It doesn't matter whether it's U 2 235, or U 238, or Plutonium 239, or Plutonium 240, or Americium, whatever its numbers are, it can burn any of them almost equally, and, and, uh, George Stanford confirmed this to me and, and your correspondent before this meeting confirmed it to, to us also. [01:22:00]

So the waste from a fusion reactor, and I'll call it waste even though it has, some of it has a lot of value, is about 20 percent of the initial fuel load is these actinides, which are perfectly good fuel for a, for a fast neutron reactor. Then there's about 800 tons of these intermediate, the boron, the bariums and the kryptons and stuff like that, which, uh, which are radioactive with very, very short half life of like 30 years.

So they're intensely radioactive. Well, some of them might have economic benefits. Of value and those you could separate out and sell and the rest of them you could just save and you know, just put them in cooling pools or encase them however you produce them and, and, uh, [01:23:00] and, uh,

and, uh, maybe after 10 or 20 half lives, which is like a few hundred years, they'll become basically inert and you could, you know, put them, dilute them sufficiently and put them into the environment. So that's, that's the time that human, um, Human, human civilization can, can cope with, you can, you can store something for 300 years or 500 years, but the plutonium, which has a half life of 24,000 years, you can't do that.

You, you can't, it's immoral. You can't impose that kind of, uh. Of burden on our descendants for a million years that they have to worry about this plutonium, which, which, which we're inflicting on them. So I think there's a moral imperative and probably an economic and technical imperative [01:24:00] to burn it. And where do you burn it?

You, you burn all of it in a, uh, in a, uh, fast neutron reactor. So this led to something which I call more than a dream, but much less than a careful plan, which is, uh, architecture for a future sustainable energy. And go to the next slide, Tom.

The Energy Park Concept

It's what I call the energy park. And let me just go through what the various elements are.

Uh, where I have A, It's a high security fence. So, no, no, A is a low security fence. So, you know, same sort of security you'd have around ordinary nuclear reactors, but not the sort of security you'd have around nuclear bombs, let's say. And B is it has five thermal nuclear reactors, each about a gigawatt electric power.

Uh, C is electricity [01:25:00] going out from these five nuclear reactors. Uh, D is let's say you have some sort of a liquid or gaseous fuel manufacturing plant in it also. And here's a pipeline for the liquid fuel or gaseous fuel that you send out.

The Infrastructure of Energy Park

Uh, E is, let's see, oh yeah, E is the cooling pool for the intermediate, for the bariums and the kryptons, and this thing stays here for like 300 years, 500 years, it'll take some maintenance, but basically you renew it as it comes and after that you let it go.

This is time human society can reasonably plan for, not the half million years it would take for the plutonium base to be Buried in a repository like Yucca Mountain, creating something that's essentially a plutonium mine, which our descendants would have to deal with for the next half million or [01:26:00] million years.

F is this, uh, liquid or gaseous fuel factory that I mentioned. G is a high security fence. This is the one where you have the guards with serious guns and really mean dogs and things like that around it. And something so that helicopters can't jump in, you know, you have some heavy wiring over the top of it.

I mean, this is real serious security, because here you're producing material which might have a, uh, proliferation risk. Okay, so H, this H, is the separation plant. The, the, the stuff you take out of your nuclear reactors, your thermal reactors, you send to H, and what they do is they separate it between the, uh, they separate it from the intermediate atomic number material [01:27:00] from the aconides.

The actinides, the intermediate material, the ones with a 30 year lifetime, goes to these cooling pools in E, and the actinides go to a single fast neutron reactor here, here, E, where it burns. And J is the fusion breeder. So the fusion breeder breeds nuclear fuel for these five nuclear reactors. And the fast neutron reactor burns the actinide waste of these five nuclear reactors and it all seems to add up.

And uh, there's really no proliferation risk. This produces, the fusion breeder produces U 233, but as it's produced, you, you, uh, as it's produced, [01:28:00] You just diluted with U2 38 to get a 4% mixture, so there's no proliferation risk there. Uh, the separation plant separates it into the actinides, which are a serious proliferation risk, but then you burn them before they could do it.

So there's no long time storage and no long distance travel of any material with proliferation risks. It's all taken care of almost immediately. And this. small part of the energy park, which is protected by this very high security. Energy parks without the, uh, oh, and these are, so, so, so let's count the, the power it puts out.

You've got five, five, uh, thermal nuclear reactors producing a gigawatt each. You've got one fusion breeder, gigawatt. And you've got your fast neutron reactor, which produces a gigawatt. So this thing produces, [01:29:00] electric power or fuel power in units of seven gigawatts. And, uh, the, the parts without this exist already.

And there are several places in the world where there are many nuclear reactors together. My final view graph is a picture of one of them. This is the Bruce nuclear power plant in Canada on the shore of Lake Bureau. And if you can look at the nearer one, this is the Bruce A.

And there are two of them, actually eight nuclear reactors in it, Bruce A and Bruce B. And if you look in the upper left, far away, you can see Bruce B. But let's just take a look at Bruce A over here. And there are just four nuclear reactors, which produce about a gigawatt each. And, uh, it exists. Fifty, uh, seventy five percent of the, uh, of the energy park already exists.

Okay, well, that's [01:30:00] basically all I have, Tom.

Q and A

One question was from Cal Abel and he said, quote, Fusion is a very expensive way to make neutrons better to use the self sustaining way fast reactors while not fusion energy levels are high enough energy to burn all the transuranics. You have comments on that?

I, I think he's right, but I'm not saying that you want to use fusion to produce energy. I'm saying you want to produce it, you want to produce it for nuclear fuel, which actually has a chance of running out, uh, or becoming scarce, at least according to experts like Dan Manley and, uh, and, uh, George Stanford.

And probably many others too. I mean, you'll find other people who say there's no problem. We'll just keep digging it up. You know, maybe the George Stanley's and the Danman George Stanford's and the George mentally is the right. So, yeah, I, I don't see fusion is something as a standalone, uh, [01:31:00] As a standalone, uh, device, and I see it as something, I mean, even if it's process, I mean, one case I make and more work I do is even if it's viable and profitable as a standard device, why, why not just run it at half the power, put a breeding blanket around it and get up to the same power you had with twice the power of the laser, and meanwhile, you're producing all this nuclear fuel, which other people can use.

So, I mean, it, yeah. If you can really produce pure fusion, uh, you can probably produce, uh, fuel for thermal nuclear reactors, which are virtually too cheap to meter. Uh, so anyway, that's I basically agree with, with, with Carol.

Conclusion and Future Directions

I understand the whole lot less of your other, uh, [01:32:00] thing. I, I can, there was the, the United States, I have the paper in my closet.

It's been a while of looking at it. We did do a small scale thorium reactor. And what they do is they fuel it with U 235 and thorium. And instead of U 238, you know, like when you have a thermal reactor, you know, toward the end of its time before refueling, you're probably burning something like half U 235 and half plutonium 239, which you've read inside the reactor.

But it's not breeding enough that it'll just keep going. I mean, it'll, it'll, you eventually run out of fuel, and actually you have to take the fuel out before you even run out of it because there are so many impurities. But this had U 235 and thorium in it, and the, what you call the thermal material, fertile material, [01:33:00] is the thorium, and it produces U 233.

So, pretty soon, it's just breeding, just burning all the U 233, and this is something which was accomplished, I think, in the 1980s or 90s, and it's an impressive accomplishment. If you were starting now. And didn't, weren't worried at all about proliferation and didn't have a huge capital investment in light water reactors, which are only going to be increasing, you know, this might be a reasonable infrastructure, but, you know, as far as the future infrastructure, as far as how you divide it between the Thorium reactors, fast neutron reactors in fusion breeding, none of us can know how that's going to work out.

But there's one thing for sure, and that is if you're stuck with a huge capital investment that you've made in liquid water, in liquid water reactors, thermal reactors, and they run out [01:34:00] of fuel, there's only one viable way of fueling them, and that's with fusion breeding. Okay, let me just read that question in just for the record, so we have it here.

Uh, the question that came in that you responded to was, your next interview about nuclear, can you ask about thorium salt reactors, please? China is building one in the Gobi, no water to cool, and they can use nuclear waste as fuel. That was, uh, what you responded to. Uh, I don't have much of a response to that.

It's not something I can claim any expertise in. But, I, nah, there's no way I can find, it's somewhere in my closet buried. I think Friedman or Friedlander, look up, look up American thermal, look up U. S., do a Google search on U. S. thorium thermal breeder, and you'll probably find it. Alright. You'll probably find a bunch of other articles, I have the original article by the guys that did it.

It's very impressive. Okay. [01:35:00] Alright, uh, any other points you'd like to make before we finish this one off? No, I think I made about as many. I think I was a little ambitious. I mean, I had a lot of reasons, and if someone goes through the view graphs, I went through a lot of the problems of magnetic fusion, which, uh, which, uh, you know, which, frankly, which, which, uh, laser fusion doesn't have.

One of them, for instance, is that if you have a magnetic fusion device, I'll just go to, you're producing not only neutrons, which escape, But alpha particles, which stay in, in the fusion device. And they just, they just gradually build up the energy. I mean, you'd like to think of that, that they'll, that they'll heat the fusion, you know, that they'll heat your reactor, and then they'll just magically disappear.

And, but it, you know, nobody really knows what's going to happen with the alpha [01:36:00] particles in a magnetic fusion reactor, and frankly, the magnetic fusion, the magnetic fusion people regard the alpha particles as a nuisance. And they're right, they are a nuisance. But in laser fusion, they're an essential part of it.

And I think that's just a tremendous advantage laser fusion has over magnetic fusion. And there are a whole bunch of other reasons. How do you drive the current in the tokamak? Another one is, as we saw, the laser fusion reaction is over in a nanosecond. And in that time, light goes afoot. Well, so, anything that bounces off the wall and comes back into your plasma isn't gonna, the reaction's gonna be long over before anything gets back.

But in a magnetic fusion, which is steady state, and the wall is being bombarded by 14 megavolt neutrons, I mean, who knows what's coming back into the plasma, and, uh, you know, there's no experimental evidence on it, and no reason to think it's not gonna have, be a very deleterious effect. These are things [01:37:00] that the magnetic fusion people have hardly even begun to examine.

So um, you know, there are many reasons I think that laser fusion is the way to go. All right. And then, uh, for just to make sure people know that I'm going to put the full, uh, presentation on my sub stack and I'll put a link to that from the show description so people can dig in and look at all the view graphs.

Yeah, sure. Sure. And, and if they want to get the book, you know, it's available in Amazon and they can, they can see the cover and things like that. And if they forgot my name or the title's name, they can. They can see that. Yeah, I'll put a link to the book also in the show description. I have it on uh, Kindle and uh, yeah, yeah, very good.

All right, thank you very much. This is, um, this is, I think it's been a good experience for us. A lot of stuff. So yeah, thanks again. Hope to do more of this if you have more time. Talk to you next time. I don't know if I have anything more to say, but I have lots of time now that I'm not working at the lab anymore.

Okay, take care. All [01:38:00] right, talk to you later. Goodbye.