The Transforming Power of Research

[MUSIC PLAYING]

KAREN WEATHERMON: Folks, since we're just past 4:30, I think we'll go ahead and get started. I want to make sure that I am considerate of your time, and thank you for coming here. I'm Karen Weathermon. I am the chair of the Common Reading Program within the Office of Undergraduate Education. And I want to thank you for coming, and coming to be part of our series.

This is one of a yearlong series of events and different kinds of programs that are designed to complement this year's use of the book Soonish as our Common Reading book. Some of the talks this year are pointing out and highlighting different areas of cutting-edge research that happen here at WSU. Others are more designed about your own student development, and ways in which you might design your time here to take advantage of the opportunities that you have here at our campus to propel yourself into your own soonish future. I especially today also want to welcome our folks from Global Campus, with whom we are joined via livestream. So thank you very much for Global Campus for making that available.

There are still several Common Reading events left this semester. I just want to highlight a couple of those. The week after Thanksgiving, there'll be a talk on Monday, November 26 also at 4:30 PM in this room by physics Professor Brian Collins on organic electronics that are being developed in his very interdisciplinary lab, drawing from engineering, and chemistry, and biology, and physics to create whole new kinds of instruments that allow us to measure and coordinate all kinds of different things.

Then also on Tuesday, that week after Thanksgiving break, Dr. Robby Cooper from Human Development will be giving a presentation from 7:00 to 8:30 in Spark G45 on the value of self-care. And that will both incorporate ways in which you can take great care of yourself now, at this stressful point in the semester, and also talk about some of the ways that self-care and well-being are being incorporated into different cutting-edge ideas about health practices also.

And then I also just want to point out that the last week of classes-- so the last week right before finals-- you also have the opportunity to see the public presentations from two different classes, HD 205 and School of the Environment 110, that have used the book Soonish as starting points for projects. And more about those remaining events can be found on the Common Reading CougSync page, and also on our Common Reading website. And that's commonreading.wsu.edu. So more information about those possibilities.

If you're attending for Common Reading credit, we'll be verifying attendance by card-swiping you into CougSync with your CougarCard at the conclusion of the event out in the hallway. To have this show up on your CougSync event, this is one of the events at which there's a required post-event survey with a few questions. That gives us some great information about who attends, and from what classes, and your responses to different events that we offer, and helps us plan forward with different kinds of Common Reading events for our future.

If you have any questions about how to verify attendance, there's also instructions on the Common Reading home page. But that survey will be emailed to whatever email you have attached to your CougSync account. You can also get to it from your CougSync involvement page. And again, your instructions about that on the Common Reading websites, if you have any difficulties finding that.

And now to introduce tonight's speaker, Dr. Chris Keane. Dr. Christopher Keane joined WSU in 2014 as vice president for research, as well as a professor of physics. He earned Bachelor of Science degrees in both physics and engineering from the University of Rochester, and has PhD in astrophysics from Princeton University. His career as an astrophysicist has taken him to the Office of Defense, to the National Nuclear Security Administration, and to Lawrence Livermore National Laboratory, where he was the director of the National Ignition Facility.

And I learned today from his website that that facility houses the world's most energetic laser. I'm not even exactly sure what an energetic laser means. But the world's most energetic laser is at that facility, and it's the focus of a user group of about 400 members. Dr. Keane has authored more than 100 scientific publications on his own research.

Here at WSU, Dr. Kean has played a major role in shaping the direction and visibility of research on our campus. And this is especially true in his work with faculty across the university to articulate several Grand Challenges, which are interdisciplinary problems that address issues that are urgent on a regional, a national, and a global level. In fact, the Grand Challenges have influenced our selection of Common Reading books for the past several years, as sort of interdisciplinary places where there's lots of energy and different kinds of exciting research happening on campus is exactly what we want to focus on with our own program.

In this year when we're showcasing WSU research, I'm especially pleased to have Dr. Keane talk to you about the ways that research transforms the world we know. So please help me welcome him this evening.

[APPLAUSE]

CHRISTOPHER J. KEANE: OK, I need to get that one too, right?

KAREN WEATHERMON: So I'm going to pass off this one to you. Thank you very much.

CHRISTOPHER J. KEANE: Yeah. That's a given. I have them all.

KAREN WEATHERMON: You have them all.

CHRISTOPHER J. KEANE: OK. Hopefully, it won't electrocute me. OK.

KAREN WEATHERMON: [INAUDIBLE]

CHRISTOPHER J. KEANE: Yeah, right. OK, good afternoon, everyone. Thanks for that great introduction, Karen. Yes, so I'm Chris Keene, the vice president for research and professor of physics, and I'm really glad to be here today. Let me just say, I'm going to give about half of my talk on WSU research, a quick perspective on that, and about half of it will be on fusion, which is chapter 4 in the book. And-- oh, that worked. OK, that's good.

And let me just say, the book asks, will fusion run your toaster? And the answer is, yes, it will some day. Fusion is nature's energy choice, as I'll talk about later.

Basically, the fuel is hydrogen. It's water, essentially. So the fuel's limitless, it's clean. Essentially no radioactive waste. I'll show you about that.

There's sort of a joke amongst all of us-- and I worked in this for quite a while before I came to WSU. One of the jokes about it, though, is it's the energy of the future and it always will be. That's because it's very hard, actually.

The world, including the United States, has spent more money on fusion research than any other research program by far, actually, because we've been working on this since the '50s. And I'll show you some of the big machines under construction in the world right now. There's a machine under construction in France, which is a multinational project, interdisciplinary project which is going to total probably $50 or $60 billion before it's done. And there is a big laser facility does fusion in California at Lawrence Livermore Lab, which was about $3 and 1/2 billion and it's the size of a football stadium. So I'll be showing you that today.

OK. But first, just to start off, a little bit about who I am and what research is at WSU, and then I'll get to fusion. So first of all, who am I? So I'm the vice president for research, and I got my PhD at Princeton in astrophysics in 1986. I can't believe it was that long ago.

And then I worked for a while at this National Laboratory Lawrence Livermore, which is in the upper right there. And that's 1 square mile. You can see the site was put together by technical people. It's a square 1 mile on a side. That's what it is.

I also worked at the Energy Department in DC, in Washington there, where I was a deputy assistant secretary, so I managed a lot of the big programs, and did a lot of policy development for the fusion energy program. And then I then actually went back to Livermore after my DOE spell, and so I was at Livermore as the director of the NIF User program. As Karen said before, I came to WSU in 2014.

And I actually started research as an undergrad doing gravity wave research. And some of you may know that the Nobel Prize was awarded for the detection of gravity waves, which are predicted by Einstein back as part of the general theory of relativity, and they were detected just a couple years ago. Actually, one of the detectors is right over in Tri-Cities in Richland called

LIGO. Long-wavelength Interferometric Gravitational Observatory. I have a little bit on that at this talk too.

But anyway, I started working as an undergrad. And so I would urge any of you who are interested in research-- actually, whether you're interested in research or not, working as an undergrad in research is a great experience because it really exposes to how you think about it, and it's great skills for anything you do, whether you do a research career or not. We have a great undergrad research program here at WSU, so I hope you take advantage of it.

The top picture is me actually at the christening. That's our CAMIAC research computer behind us. Those are some deans and other VPs. You may recognize Provost Bernardo, second from the left, and Darryll DeWald, who was dean of arts and sciences. Sasi Pillay in the middle, the CIO, and then Kim Kidwell, who was dean of CAHNRS on the far right, but she left about a year ago.

But I like that picture because that's the way I work. I work collaboratively. And that's how we get things done in research nowadays.

So you might be wondering, actually, what does a person with my title do? My daughter asked me, dad, you're vice president for research. Do you do all the research?

No, I don't do all the research. In fact, I don't do much at all myself anymore, unfortunately. I think about that every day.

But the things I do do are, I work with the colleges and the faculty to develop our agenda, like the Grand Challenge, the multidisciplinary agenda that Karen mentioned. I'll talk about that in a little bit.

The research support and compliance. WSU, we're a big institution. We have five campuses. Our annual budget's about a billion dollars. About a third of that is research. I'll talk about that in a few minutes.

And we have, actually, 20,000 animals here on-site in all our campuses which are used for research, teaching other activities. If you want to do anything with them, you have to get approval from my office. We have 1,200 laboratories, some of which use special biological agents. Some radiation, some use other special things. If you want to do experiments with any of that--

[CLATTER]

Oops. Uh-oh. If you want to do experiments with any of that, that has to get approved as well. I'm obviously not approved to use these mics, but anyway. Can you still hear me OK? So that one did not hold on, so I'll just put that in my pocket.

OK. So those are all special approvals, and I do that. We have a large program to engage with industry. WSU is really the innovation engine for a lot of the state's agriculture industry.

Obviously, you know what we do at the Wine Science Center in Tri-Cities. Over 60% of the wheat varieties in the state are ours. Fruit trees, especially apples-- pretty soon in the stores, you're going to see some really amazing new apple varieties come out from WSU. So working with industry is really a big deal for us.

And then finally, we also support a lot of the core instrumentation that our faculty use. It's common use instrumentation. That picture there on the lower right as a sequencer. Basically takes material and figures out what the entire genome is, what the DNA structure is, the base structure.

And that's a really common technique now in research. 10 or 15 years ago, that was unheard of. The first human genome sequencing took place in the late '90s, and that was a gargantuan effort. We can now do that very simply with more modern machines, and it's now a routine research tool for us, the sequencing of genes.

And of course, the Drive to 25. That's President Schulz's drive to be a top 25 public. Research is a really big part of that.

One of President Schulz's goals is to increase our research spending from what it is now, about $350 million a year, to, in current dollars, about $550 million a year by 2030. I always joke with him that-- no pressure. It's not a big-- so it's a big increase. And so planning all that is a big part of what I do, and I work with the faculty on that.

But research is crucial. And I should say that research is not a standalone thing. It's inextricably entwined with our education and outreach missions. They each make each other better.

So research provides tremendous opportunities to students, our grad and undergrads. In the same way, the students and the whole learning experience enriches our research program too. So it's just a great combination. I really enjoy working here. It's the students that make this place really special, actually.

OK. So just a little bit more. This is a plot of what we basically spend on research expenditures since 1994. The numbers are a little hard to read, sorry about that.

But if you go over to 2017, the far right, you can see that's actually our highest year ever. It was almost $360 million. It's about a third of our system budget.

That's about number 70 in the US, which is actually about the top 11%, which places us-- as I'll show in a little bit-- as so-called R1, Research 1, which is just the highest category of research universities by the Carnegie Foundation. So we are a top-tier research university in the United States.

The different bands are different components of it. The orange-ish piece is federal spending. The bluish piece is institutional support. The light gray is state spending. So our research is supported by a wide variety of sources. Federal, state, industry, and other.

On the federal side, this gives you an idea of some of who our big sponsors are. So the largest piece over there is the Department of Agriculture, USDA. Actually, in 2016, we led the country in USDA research expenditures. So agricultural research is a big thing. And by the way, these are all system-wide numbers. This is all of our major campuses and programs, including the four extension centers and CAHNRS.

NSF, $20 million. Energy Department, about $20 million. DoD is actually similar to that. It's actually low here, but this is a different chart. It's actually closer to 15 to 20 now. This is a little bit old. And then Health and Human Services is a little bit over 20 as well. So a wide variety of sponsors.

And where do we do our research? Well, everywhere. You can see here, the five major campuses. Pullman, Spokane, Tri-Cities, Vancouver, and Everett are shown. Of course, at Spokane, we have a new medical school. Our research funding there has gone from $5 or $10 million up to $40 million in the last year or so.

It's kind of hard to see-- and this isn't a great chart, I apologize-- but we also have four significant research stations where the test tubes are in Puyallup, Mount Vernon, and also Wenatchee and Olympia. So we do a lot of work there, especially in agriculture. But some other things are being developed there as well.

And finally, through our extension program, we have a presence in every county. So that's really a wonderful feature of the land grants. And again, we are a land grant university. Our 125th anniversary was a few years ago, you may remember.

But we were launched, in principle, by the Morrill Act in the mid 19th century, and the goal there was to produce universities to train folks in daily arts of living. That's why we got such a heavy start in agriculture. But since then, we've expanded to all academic areas, including medicine, of course, just a few years ago.

So as I said a few minutes ago, we're a Carnegie Tier 1 institution with a lot of world-class research that we do here. I'll give you some exciting accomplishments in a minute. But here's just a little bit of what we do.

We have a Center for Global Animal Health as part of the vet school. This is an institute that looks at the connection between animal health and human health. It was started by a donation from Bill Gates of $25 million and Paul Allen of $26 million. You're probably aware, unfortunately, recently passed away, Paul Allen did. 26 from Paul, just to-- a little bit more than Bill.

And that's a world-class program. And they're looking at things like the resistance of our antibiotics is decreasing as bacteria evolve and new diseases evolve. So research like that is what we do. And it turns out a lot of that resist-- any microbial resistance is due to interaction between human and animal phenomena, actually. So that human-animal interface is a really big deal in research right now.

Our new College of Medicine in the top middle. That's President Floyd, who, as you know, was president until 2015 when he died, unfortunately. And that was one of his last acts, was to get the legislature to sign an act that allowed WSU to have a med school. There was a law that said only the University of Washington could have a medical school. And that law had to be changed, and that's what was done in that picture in the middle.

We do a lot of work with composite materials. And that picture there of a building is actually a building designed by a company called Katerra, that little K in the lower left. And that building is wood-framed.

And it turns out that, with some of these novel wood composites, we can make buildings of 10-ish stories or more which are wood frame, not steel. And this is great for sustainable development. These buildings are also more earthquake-resistant and cheaper to build, and they can be prefabbed.

And they could lead to a revolution in construction. If you think about it, we build large buildings the same way we did many decades ago. They're steel, and they're welded one piece at a time.

If we could figure out a way to do that with composite wood and other materials, we could build them in sections and assemble them. And actually, some-- in fact, I think one of the hotels near here, the Marriott's, was partially done that way. Very fast assembly. Much cheaper. So potentially revolutionize construction.

Water. WSU has the Washington State Water Research Center here. We have tremendous amount of activities in water, as you might-- Washington State having a large fraction of its energy produced via hydro. We're a leader in that area. We're a leader in renewable energy. It's a big emphasis point for our governor.

And we do a lot of water studies for the state. Water for agriculture, for drinking, for transportation. All uses. Actually, the Columbia and the associated dam systems are a vital means for us to get our agriculture crops to market, so that's a much bigger thing than just water for drinking or agricultural use.

Another area you probably don't hear a lot about, but we are actually the leading university in the world-- certainly the United States-- for the study of matter under very high pressures, millions of atmospheres, like you see in the center of the Earth. Turns out that, from a physics perspective, we don't really have a very good understanding at all of the Earth's iron core. How much is liquid, how much is solid, what the phase is. Don't know.

But we're starting to understand it now, because with devices like we have here at WSU, and experiments like are being-- the APS is a very big facility at Argonne National Lab in Chicago. I can tell you about it, but we're starting to get facilities that can make those very high pressures right here in the laboratory so we can do experiments on material just like at the center of the Earth.

And then, lastly, part of our agricultural program, not just making new varieties of fruit or wheat, but also things like precision agriculture. Looking at robots to actually pick apples and pick fruit. That turns out to be really a hard problem to design a robot to pick an apple tree accurately. It's actually a very intensive AI issue. It's being studied a lot by companies like Microsoft and others on how to do that.

We also develop drones for looking at fields to see when they're ready to harvest, to try and remotely measure water content so we can water as efficiently as possible. That's just a little snapshot of what we do.

Now, when you add up all those activities together, they allow us to pursue problems of societal impact. And this is what the Grand Challenges are that Karen mentioned earlier. They're multidisciplinary research in areas of science which are really of broad interest to the public.

And there's five of them. Sustaining health, sustainable resources, advancing an educated and equitable society, or we call it opportunity and equity. Smart systems and national security. These are areas of research which are very multidisciplinary and rely on researchers coming from different parts of the university.

It turns out, nowadays, if you're a vice president for research, one of the key metrics that I get measured by and we all worry about is how much research funding we attract. And it turns out a lot of our sponsors really want to focus on solving societally-important problems, and they tend to be multidisciplinary. But they also rely on having our individual faculty detect them, because it's the individual faculty and staff here that do research, and the excellence of those individuals that are the bedrock of the enterprise.

And so one of the things that I do in my office is really do everything I can to support our faculty, both at the individual level and at the team or multidisciplinary collaboration level. Because it's the people that really make it go, and the students are really actually a very critical part of it, if not the most critical part. So that's what the challenges are-- very broad, all disciplinary problems.

So I mentioned this earlier. Our ag school is a key part of the innovation engine for industry. This just shows some of the accomplishments they've had.

The Cosmic Crisp is going to be in stores soon. Actually, by the end of next year. When you bite it, it doesn't turn brown. It's really juicy. You'll see that soon.

Otto is a wheat variety. Again, I mentioned that we're one of the largest wheat producers in the country, and a good fraction of the varieties-- over half-- are ours, from WSU.

That's one of our drone planes on there in the far right. Here is our food lab which is looking at sustainable food. And what this is actually is advanced microwave sterilization techniques.

And so some of the things our researchers are doing is looking at and making-- you probably have heard of MREs, meals ready to eat for the military. Military eats on its stomach, but we're looking at trying to dramatically improve the quality of those MREs that are served to our soldiers, and also that astronauts take. And it turns out we can do a lot better than has been done historically.

This is the WSU Wine Science Center down in Tri-Cities. It's actually probably the leading such wine center in the world now. And you probably know that WSU is really one of the key founding partners in the state wine industry. The work we did early on was essential to the growth of the industry, which is down around Walla Walla and Richland. And so we have a lot of partnerships there.

And then over here is some of the breeding programs we do. Things like strawberries and huckleberries and things like that. So we do a lot of work in breeding new varieties, improved varieties that are drought-resistant and hardier.

This is kind of fun. We also have a very strong program in biofuels and bioproducts. And what you're seeing here is-- this commemorates a regularly scheduled commercial Alaska flight from Seattle to Ronald Reagan Airport in DC that happened a couple years ago and was powered by jet fuel fully certified that was made from bioproducts. In this case, waste from cutting down trees, which in the world of bioproducts, is actually very low-quality feedstock.

So the key part of the research was to take that lower-quality biowaste and turn it into really high-quality jet fuel. And we succeeded in that, and that was really a cool new innovation. And we flew a plane with it over-- and we had folks from the legislature and other dignitaries on there to celebrate that achievement. It's a great technical achievement.

One of our grand challenges is in theory of opportunity and equity too. And we've had a number of major grants in that. So Paula Groves Price from the College of Education has really gotten-- and this was based on a seed grant out of the Grand Challenges. Has some very exciting work. They're looking at culturally responsive indigenous science.

This is a picture from the 1960s of the women's basketball team from a indigenous peoples tribe here in eastern Washington. There's actually-- I have my phone here, because I want to make sure I got the name correct. But if you go look at the Plateau Peoples' Web Portal, this is part of our Digital Humanities Project here at WSU.

There is all kinds of-- we're going to great lengths, Paula and some of her colleagues, to basically digitizing catalog-- photographs, books, other memorabilia from the people here, the tribes. And so it's really a very cool thing. We're inferring all kinds of things about how people lived back then, and which feeds back into some of our understanding today of things like addiction, and how the tribes really are in economically a very tough way.

We also have a major research effort in health equity here. Again, why certain populations? Why outcomes are so unequal? Again, we have a lot of work in addiction, and things of that sort.

And our Grand Challenges Program actually funded the formation of the Health Equity Research Center, HERC, which is based significantly in Spokane and here. And it involves social scientists, sociologists, as well as students at our med school and folks in the med school and others. So very interdisciplinary, looking at trying to look at the sources and address unequal societal outcomes, especially for us in the health sciences.

OK. And then one other thing which is fun is that-- so I talked about Grand Challenges and applied research, but WSU also excels in some very basic research. This is just a little slide on the gravitational wave thing I mentioned earlier. So again, some of you may have read the news that the Nobel Prize was awarded a couple years ago for detecting gravitational radiation.

So a simple way to think of gravitational radiation, if you imagine a pond of water, you throw a stone in it, it goes in there, and you see waves go out. They basically are waves created by the energy from the stone, and they use the water as a propagation medium.

In the same way, when a body of any mass accelerates, it produces gravitational radiation. So when my hand goes like that, that produced a gravity wave because I accelerated. It's really, really, really weak. Gravity waves are really weak.

And they were predicted by Einstein, and they were never found. They're too weak. And I worked as an undergraduate on this, actually. I didn't see them either.

But it turns out that people built this very, very sensitive detector, one here in Washington state, and then one in Louisiana. And they're physically distinct so we can correlate the two. And the way this works is that, when there's a massive gravitational wave event in the universe like that-- what's pictured up there is a merger of two black holes, and they were not that close to Earth. Otherwise, we wouldn't be here.

That's a massive energy event. Enormous. It's not even possible to think about how much energy that was. But it was so energetic that the gravity waves it produced were actually visible. We detected them here.

And the way we did it is when the wave goes by, it compresses one arm and extends the other. And you can look at the difference in lengths of those two arms. We do that with lasers, which we won't get into.

But it turns out the difference in length was one millionth of the diameter of a proton. And we detected that. So just think about that. This length versus that length changed, the relative length changed by one millionth the diameter of a proton. But we could detect that.

And we did, successfully. And that was proof that Einstein's theory was correct. And one of the last major tests of Einstein, and WSU participated in that.

Very basic research. But one of the fun things about how this winds up having practical application is when you build a technology to be able to detect a length change of one millionth of a proton, you're developing all kinds of technologies that have applications you never heard of.

The space program is a great example of that. We went to the moon. People initially thought, well, that wouldn't have a lot of applications. But the applications from the Apollo program many years ago-- I remember it barely, but I'm sure, obviously, you don't-- have been just huge. And similar things will come out of this from detector technologies.

OK. So almost done with the overview part. I'm going to get to a little bit on fusion.

So I did want to mention one thing, for those of you that are interested, is that we've launched a major collaboration with the Pacific Northwest National Laboratory, a DoE laboratory about two hours from here in Richland. We work with them on the power grid, on nuclear physics. That's our WSU nuclear reactor. Bioproducts that I talked about earlier.

We also have a joint program and graduate education program with the lab, and we also have undergraduate internships with the lab. This is our first class of graduate students that started a little over a year ago. And there's Senator Cantwell along with President Schulz and Steve Ashby, the director of Pacific Northwest National Lab, formally launching our joint institutes earlier this year.

I mention this because these are sources of tremendous opportunity for those of you that interested in taking advantage of it. PNNL has internship programs. You can go and work there in the summer. And let me tell you, the stuff they have there is unbelievable. You have never seen anything like the capabilities available at DoE laboratory.

So I know, obviously, a lot of people that have been interns. And for many of them, even those that didn't go into research, it just changed their life to see what the leading edge in computing and other technologies is. It's just an amazing place, so I urge all of you to think about that. You can ask me about it. You can have Shelley Pressley in Undergraduate Research Office.

But the lab is always looking for interns. They typically bring in couple thousand a year, so it's not that hard to do. So I really urge you to think about that.

OK. So we talked a little bit about nuclear stuff here, and that's our WSU reactor. That's a fission reactor. I'm going to use that to transition out a little bit into discussion on fusion, which was in the book.

So first of all, let's talk about two kinds of nuclear reactions. So I just showed you the nuclear reactor, WSU. That's a fission reactor, whereas chapter 4 in the book is about fusion.

So you might say, what's fusion, fission? They sound almost the same. Are they almost the same? The answer is they are not the same. They're polar opposites.

So what does that mean? Well, fission is when you take heavy atoms-- like uranium is the classic example-- and you split them. A neutron comes, hits a uranium [? atom, ?] and it splits into two pieces.

And it turns out that you wind up with extra energy. And it turns out that the parts that are left, if you add up the mass of the parts that are left compared to the original atom, it's a little bit less than what you started with. That difference in energy corresponds to E equals mc squared.

So you take the little difference in mass, that's the m. Calculate it, and you get-- that's the energy. And c's the speed of light. That's a big number.

So just a tiny change in mass results in an enormous energy release. And this is why nuclear fission is such a powerful source. I'll show you some numbers on this in a minute, but there's way more energy in fission than there is in fossil fuels per unit mass.

But fusion is even more energetic. Fusion is the opposite. You take light nuclides. Like in our case for fusion reactors, it's just deuterium and tritium, which are-- basically, they're isotopes of hydrogen.

Deuterium is hydrogen with one neutron on. It's a proton and a neutron. Tritium is proton and two neutrons. But it's basically hydrogen.

So you fuse two hydrogen together. You get a helium. That helium weighs a little bit less than the two hydrogens put together, the way it works out. And that difference is available as energy. And so this is another tremendous energy producer.

Fusion is hard, because to get two hydrogen atoms to fuse like this-- remember that there's a proton, so it's positively-- a hydrogen's positively charged. So if you just put down two hydrogen atoms right next to each other, they're going to go like this, and they're going to repel, because each is positive.

So how do you get them to smash together and fuse? The answer is you heat them up. They have to be hot. And when they're hot, they move around really quickly, and they move so quickly, they get a chance to fuse before they repel.

So fusion has to occur at high temperature. And I mean really high temperature, like 100 million degrees. And you'll see that in a minute. Fission occurs at room temperature.

So that's the biggest difference. Fission at room temperature, fusion at high temperature. Like the center of the sun. The sun burns hydrogen for fusion. That's how it shines. Therefore, it occurs at very high temperature.

OK. This just shows a few of the numbers here. So here, I'm just contrasting chemical energy, which is basically, say, burning a fossil fuel. Carbon and oxygen makes carbon dioxide.

Carbon dioxide, of course, bad for global warming. So it's these chemical energy reactions that are the source of our global warming. Automobile combustion engines, coal-powered power plants.

But it turns out, if you have things like coal or things like that that make energy from chemical reactions, there's typically about 10 to the seventh joules per kilogram available from that by burning. And you can forget about the joules per kilogram and what's a joule. You know what a lot of that is. But just keep your eye on the fact that this is 10 to the seventh for coal.

For fission per unit mass, you get 10 to the 12th. So that's 100,000 times more energy. So fissioning atoms produce 100,000 times more energy per unit mass than coal, which is great. That's great.

So fission's are a lot more efficient, uses a lot less fuel, a lot less material to make energy. That's why nuclear power was attractive. Of course, nuclear power has waste problems which have made it problematic.

Fusion's even better. It's 100 times better than fission, which means it's 10 million times better than coal. So if you look at how much coal it takes to run your standard large power plant, it's almost 100-ton rail car. So it's about 10,000 tons a day of coal to do that, to run a big power plant of fuel.

A fusion plant would need 30 grams of water to run for one day. And that's the advantage of fusion, is it's so efficient because of equals E equals mc squared. There's no equal mc squared here, but there is over here.

And again, you can see the temperature I talked about. The thing with fusion is it's got to be 100 million degrees. And so when you heat something up to 100 million degrees, guess what it does?

It wants to expand. It does not want to stay together. It wants to heat up and fly apart. And so the real question for fusion is how you keep something that's 100 million degrees together.

And there's two ways to do it that have been looked at, and this is a picture of one of them. So this is an artist's-- I'll show you some photos of the actual machine in a minute. This is an artist picture of a device called ITER, I-T-E-R, International Thermonuclear Experimental Reactor.

This purple stuff here, it's actually a donut. This is a cut cross section. It's a donut. And inside, this is a glowing hydrogen gas, basically. This is your 100-million-degree hydrogen in the purple.

And it goes around in this donut, and it just stays in there, and it's confined. And as it's confined, it fuses and makes energy. And this machine-- by the way, it should be on here, but the size of a man is about this tall. So this thing is enormous. It's huge.

And this machine, when all is said and done, will cost probably around $30 billion, and it will take several tens of billions to run it for 20 years. But it will produce more fusion energy than went into heat the hydrogen, and that's its goal. It's a reactor. ITER.

And so this is called magnetic confinement, because that is a hot hydrogen gas there, it's 100 million degrees, but it wants to fly away. It wants to escape. It's not going to stay there. But there's magnetic fields that-- it's kind of hard to see here, but this orange thing is a magnetic field coil.

Electric current goes through it, magnetic fields produce, and the magnetic field is what confines the hydrogen. And that's why it's called magnetic confinement. Magnetic field confines the hydrogen, when the hydrogen's confined, it fuses, makes energy.

And so the whole game for fusion research has been how to confine that hot hydrogen, because guess what? Nature's really clever, and when people first tried to do this, they thought it'd be easy. They built the first easy machine to do it. It was actually invented by a Russian. Andrei Sakharov, the famous dissident. Invented the tokamak.

They built the first tokamak, and it did not work at all. It didn't work anywhere close to what the physicist said it would work like. It was terrible. Nothing was confined at all. It was just a total-- it was a mess.

And it turns out that nature's very clever in finding ways for that hot heated hydrogen gas to escape and not be confined. But we've figured out how to get around that.

So I'm just going to-- this is the other kind of way to do it. So the other way to get fusion to occur is-- that little pellet up there, you fill that with fusion fuel, and you take a giant laser or something else, shine a bunch of energy on it, and crush it. And when you crush it, all the hydrogens are forced together, they're heated up. And the way this works is they fuse before it has a chance to explode.

So there's no magnetic field here confining anything. It's just confined by the own pressure of the laser beam driving it. It's confined by its own inertia. And so it's called inertial confinement, which means it's just confined because it was pushed on, and it all fuses before it explodes. In this case, a laser pushed it together.

And the laser-- I'll show you in a minute-- is the largest laser in the world. It's the size of a football stadium. That's how much laser you need to compress all that little capsule.

So again, I'll show you some of this in a minute, but the way laser fusion works is you're going to take a laser the size of a football stadium-- a pro football stadium, bigger than ours-- and you're going to use it to compress that capsule which is 1 millimeter in diameter. That gives you some idea of the scales in fusion. That's one of the reason it's so much fun. And these enormous machines that work on just very small scale targets.

OK. So again, I just went through some of this, but this is really quite interesting. So here are the two types, magnetic and inertial. The magnetic is relatively low density. It's confined in a magnetic bottle by low density. It's about 10 to the 13 nuclei per cubic centimeter.

What does that mean? That's about one millionth atmospheric density. This room is 10 the 19th particles per cubic centimeter. Molecules. In our case, oxygen, nitrogen. But there's 10 to the 19th particles in here per cubic centimeter. In a magnetic confinement, it's about a million times less.

And you need to confine it for about 10 seconds to get the energy out. And the product of those two is 10 to the 14th. For the inertial, you take that little capsule I showed a moment ago, you crush with a laser, and you compress the hydrogen all the way up to 10 to the 25th hydrogen nuclei per cubic centimeter. So you compress it so it's a trillion times more dense, but it only lasts for 10 trillionths of a second, and so the product is the same.

And so this is just a really cool example of how physics works. You've got these two schemes-- they're completely different-- that operate at a trillion times different density. But the fundamental quantity is the product of density and the confinement time, and they are the same.

And that's the great unifier between the inertial and the magnetic. The name of the game is to get this quantity as high as possible, either by high compression for a short time, or low density for a long time. That's the unity of physics.

So now I'm going to show you some cool stuff in a movie. So those of you that-- it's getting late. Hopefully, this will wake everybody up.

So this is a picture of the ITER facility. It's under construction in France. So the main tokamak machine will be in that building. So what you're looking at here is-- this is about $30 billion worth of work when it's all done. And a lot of it's because there's a lot of high-tech stuff going on, obviously, here.

Let's see. I show this picture because it shows that ITER is an international project. And the partners are very proud. You can see the flags there. China, the EU, Russia, Japan, Korea, the US, and France.

And the US is a one ninth partner in this, actually. And France is the major partner. And that's because it's sited in France. And the European Union's also a big partner.

And you may have noticed, it's in Provence. It's a lovely area. The NIF laser that I'm going to show you in a minute is in California near wine country. So the fusion machines are located in really lovely areas, so if you like that kind of lifestyle, nice wines, fusion's good. It's a good place to work. So anyway, that just shows the international nature of the project.

So now I'm just going to show you a movie about ITER, because this movie can say it way better than I can. So let's find that.

[VIDEO PLAYBACK]

- Energy is like oxygen for life.

- As long as you are a human being on the Earth, we need energy.

- The planet is fine, but you better get rid of us.

- And so we need innovation.

- We have the potential and the capabilities to have cleaner sources of energy, and more diverse sources of energy as well.

- One of the ways we think is the best way to do it is trying to replicate what happens on the sun.

- So principle is quite simple. When you have two atoms of hydrogen, if you make them collide, they will fuse.

- When doing so, they liberate a huge amount of energy. The energy we will then use to actually produce electricity. It sounds simple, because stars have been burning on fusion for billions of years.

- It's the fundamental energy of the universe.

- But we need to control it on Earth.

- Here we are. It's ITER.

- ITER is a large international program in order to demonstrate the feasibility of fusion technologies.

- Probably one of the biggest scientific and technological challenges that human race have to face.

- In the sun, the pressure's very high.

- To get that same kind of collision of nuclei, we need really high temperatures.

- 150 million degrees in ITER.

- It's quite hot.

- Probably going to be the hottest point in the universe right here in Cadarache.

- You can't really make the same scale of the sun on Earth. We have to a special device called a tokamak, which is basically like a donut.

- So we are now constructing the old platform, and then starting to construct the machine itself before we can actually use it.

- Here, you'll have the tokamak.

- The plasma is the state of the hydrogen when you heat them, and you produce fusion power.

- So you can think of the plasma as a ring of lightning, if you wish, which is traveling around the machine held in place by strong magnets.

- There is many challenging technology to be assembled in working all together, and it is a challenge we have to face.

- So where I stand, there will be the vacuum vessel. And attached to vacuum vessel, we will have 440 modules of a blanket covering all the vacuum vessel and facing the plasma, and roughly about 600 meters squared in area.

- Basically, the main fuel source will be seawater. This huge machine is fueled by this tiny part.

- We are now making things which have never been done before.

- Just to give an idea, these neutrons have so much energy, if there was nothing to stop them, if it was in space, it will travel from here to the moon in eight seconds.

- There is, like I would say, a miracle around ITER.

- It's always shown that the planet is able to collaborate on a scale somewhat above the normal argument level.

- It's more than 30,000 people all over the world working in order to deliver and manufacture the different component.

- Obviously, it's quite a challenge to keep the plasma contained inside the tokamak. So to do that, we need some super-strong superconducting magnets.

- This is the superconducting cable to be wound in a circle shape.

- It's the largest magnets that have ever been manufactured in the world.

- You need these very large magnetic cages in order to maintain this 150-million-degrees plasma away from the wall.

- The magnets are supercooled because they have to be really strong. They're one of the coldest things in the universe.

- So in 10 meter, you go from nearly absolute zero to 150 million degrees. I can't imagine anywhere in space where you can find this kind of gradient.

- As a scientist, I have been looking for this technology for several decades.

- Everybody knows what they're doing. They're just going to get on and do it.

- If we succeed, it will be a real breakthrough for the energy supply for the world for not just a century, but million of years.

- We really need to work on this as soon as possible, and prove this as soon as possible.

- The future energy issue will be on our shoulders.

- If we don't then prove that fusion is a possibility, then I think that this as an energy source for the future will be lost.

- Now, we as a team need to prove that we can do what we promised.

- A dream is just getting reality.

- If ITER works, we have demonstrated that you can create large amount of power from fusion reaction. And it gives rise to the hope of designing, then, fusion reactors which can produce electricity in the future.

- If we master it in an efficient way, we have no more problem with any energy issue.

[UPLIFTING MUSIC]

[END PLAYBACK]

CHRISTOPHER J. KEANE: OK. Let me just say that these machines are truly monuments to the human spirit. If you ever want to see one, there are machines closer than Cadarache. We have some in the US too.

We actually only have one major one operating right now. But if you'd like, let me know. I can tell you how to get a tour.

OK. Let's see. So we're almost done. I'm now just going to talk about the laser for a minute. OK.

So now I'm going to shift to that inertial scheme where we have the laser crushing the little capsule. So these are some pictures of the laser fusion facility. It's the size of a stadium. It's a lot closer than Provence, France.

It's in the Bay Area. It's in a town called Livermore, which is about 40 miles-- 45 minutes, I should say, with no traffic-- southeast of Berkeley. It's near Pleasanton, for those of you that know Pleasanton. It's right off 580, which is now the busiest freeway in the Bay Area.

Anyway, so there's the building up there. This is a picture of-- it's got 192 laser beams in it. I'll show you a little schematic of how it works, but right there, that's a individual beam.

Each beam is a square. Each beam is this big. So you can see how 200 of them fills a really big building.

This is the control room. And then that's the chamber where all that energy is focused down. It's hard to see this in pictures. The movie will show it to you a little bit better.

This is a schematic of how the whole thing works. So inside this target chamber right here, which is 10 meters in diameter, sits that little P-shaped object I showed you earlier, the 1-millimeter-diameter capsule filled with hydrogen. It's right in the center of that chamber.

And all this enormous high-tech stuff-- most of which was invented for this laser, by the way. None of this is bought. I mean, its pieces are bought, but the laser system itself is itself a piece of research. There have been tons of papers written on the laser, and there will be tons of papers written on the ITER tokamak, just the machine.

But so these are all-- there's 96 beams here, 96 there, 192 total. These red tubes are the beams coming in all focused down onto the capsule. And right in here is just where the light gets amplified. It goes back and forth in these amplifiers. It's kind of a super big version of a laser pointer, except that this thing has-- it's 10 to the 18th times as powerful as a laser pointer. Just an order of magnitude estimate.

So that's how it all works. So all the energy from that football stadium is focused down, in this case, onto the little capsule. In this particular case, the laser beams come in and they go into a hohlraum. The laser beam strike the hohlraum. They're converted to X-rays, which compress the capsule, rather than the laser doing it directly. You can have the laser do it directly, or you can make X-rays which compress it either way.

But the point is, this is 1 to 2 millimeters here. This is blown up. This is just about a centimeter or so in length. A few centimeters. So it's a target that's this big. And it's irradiated with a laser the size of a football stadium. So it's just real interesting scale.

So just for the end, for our last slide, I will show you-- whoops, that is truly the last slide. I'll show you the NIF video. It's called the National Ignition Facility, because it's supposed to get fusion ignition. More energy out from the fusion than went in. So this video basically takes you through the entire sequence of building a target, and then shooting it.

[VIDEO PLAYBACK]

[MUSIC PLAYING]

[ELEVATOR DINGING]

[ELEVATOR MUSIC]

[ELEVATOR DINGING]

[MUSIC PLAYING]

I don't think that robot actually does anything. I don't know what it does. This is some of the equipment used. OK, that's the thing that holds the target.

That's the center of the chamber. So a lot of concrete because of all the fusion reactions produced. Radiation.

- I repeat, all personnel must leave capacitor bays 1, 2, 4, laser bays 1 and 2, laser bays 1 and 2, and the target bay areas immediately. Main laser operation will begin in approximately one minute.

- Trial sequence running. Minus 3, 0.

- Target is ready.

- Target lined up. It's ready.

- Direct range. Sequence for [INAUDIBLE]. T-minus 10, 9, 8, 7, 6, 5, 4, 3, 2, 1. Shot.

[END PLAYBACK]

CHRISTOPHER J. KEANE: OK. Let's see, I don't know what the next YouTube video is. OK, anyway. So I hope that gave you a little flavor of fusion research. So thanks very much for your time.

[APPLAUSE]

KAREN WEATHERMON: If you have individual questions, please--

CHRISTOPHER J. KEANE: Yeah, any questions. Yeah.

KAREN WEATHERMON: [INAUDIBLE]

CHRISTOPHER J. KEANE: OK, I'm going to take this.

[MUSIC PLAYING]