Nuclear Power

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Greg Dalton: Today on Climate One our topic is the future of nuclear power in the age of climate disruption. I'm Greg Dalton, welcome everyone.

More than three years after a tsunami crippled three nuclear reactors at the Fukushima nuclear power plant in Japan, we look at the status of the atomic industry. Every day the Fukushima reactors are spewing 70,000 gallons of radioactive water into the Pacific Ocean with no real end in sight. In the United States, the industry faces more systemic challenges – abundant and cheap natural gases making new nukes uneconomic despite the efforts of the Obama administration to jumpstart a nuclear renaissance. But severe weather driven by fossil fuels is causing former foes of nuclear energy to say it must be part of a low-carbon strategy to meet growing demand for energy without frying the planet.

Over the next hour we'll discuss the economics, waste, technology and other aspects of nuclear power. Joining our live audience here at the Commonwealth Club in San Francisco we're pleased to have with us three experts. Jon Koomey is a research fellow at the Steyer-Taylor Center for Energy Policy and Finance at Stanford. He works for more than two decades as a researcher at the Lawrence Berkeley National Laboratory. He's also author of the book*Cold Cash, Cool Climate.* Other guests are Dave Lochbaum, director of the Nuclear Safety Project at the Union of Concerned Scientists. He's the author of *Fukushima: The Story of a Nuclear Disaster.* And Per Peterson was a member of the Blue Ribbon Commission on America's Nuclear Future. He's a professor of Nuclear Engineering at UC Berkeley. Please welcome them to Climate One.

[Applause]

Dave Lochbaum, let's begin with you. What is the story of Fukushima? How did it really impact the nuclear industry and what are the most severe consequences that you've seen?

Dave Lochbaum: I think the accident at the Fukushima revealed some vulnerabilities that need to be better managed so that it lessens the likelihood that we have that kind of problem here in the United States.

Those vulnerabilities in terms of upgrades, procedure change, training and so on have a cost associated with them. So there's a cost associated with the industry. The industry is also concerned about as they implement these lessons learned, these upgrades that it doesn't distract from their focus on day-to-day safety of the plants. So it's the challenge of maintaining what you got and adding onto it with the Fukushima upgrades.

Greg Dalton: Per Peterson, what do you think has been the impact, the lessons of Fukushima and how has it affected the global industry? Has it slowed down nuclear power plant deployment?

Per Peterson: Well, I think that there has been some significant impact from the Fukushima accident. The key lessons that we did learn involved what you do to manage beyond design bases events and how being flexible capabilities to restore basic safety systems if they've been damaged by things that they didn't anticipate originally. Also, we know that there were some mistakes that were made in terms of anticipating what could happen. The Japanese should have been knowledgeable

about and have taken more action with respect to the potential tsunamis. In the end, you can integrate those lessons into the design of new plants and probably the most important feature that we've introduced into the new U.S. designs is what's called passive safety. That is, the ability for the plant to shut down and remove decay heat without needing external sources of electrical power, which was ultimately the primary cause of the damage to the plants at Fukushima.

Greg Dalton: And how many of the U.S. nuclear plants have fully implemented passive power ready so that a Fukushima can't happen here? Because the problem is the storage in the basement gets flooded and it knocks the whole thing up. So – Per Peterson?

Per Peterson: Our current plants don't have passive safety and it's not really practical to back-fit them with those capabilities but what we're doing is to introduce additional equipment and capabilities so that they can cope with essentially indefinite loss of electrical power supply and still not have fuel damage or release radioactive materials.

This is a back-fit to the existing plants. With new plants you have a flexibility to actually make significant additional improvements. That's one of the things that make it attractive to try to upgrade our infrastructure. This is a part in what our country has pretty much universally is that we have a lot of urban infrastructure that's not as safely as what we could build if we were to make the investments to replace it.

Greg Dalton: Jon Koomey, how did Fukushima affect China, Germany, other countries? Did they take their foot off the gas on nuclear or did they keep going ahead?

Jon Koomey: For some countries like Germany, they did take their foot off the gas and changed their – since – I think Per can talk more specifically about what's happened in China but it seems like they are forging ahead as far as I can tell.

Per Peterson: I think that that's what – certainly the Chinese have the largest and most rapid program today for the deploying new reactors and they're working with a wide variety of technologies including essentially every option that we're knowledgeable about that doesn't use water as a coolant, which would be the next major step in reactor technology beyond what we've been doing for the last 60 years.

Greg Dalton: It was actually the former head of the U.S. Nuclear Regulatory Commission I think is involved in overseeing the nuclear reform initiatives in Japan and he actually said that it's the water that keeps him up at night, what are they're going to do with the water, all the water cooling going out into the ocean. Is there a solution for that?

Per Peterson: The issues that the Japanese are facing right now I think are being driven in large part by the complete breakdown in trust and confidence and the regulatory authorities, because currently they have capabilities to clean the water to levels at even drinking water standards and certainly acceptable for release into the ocean, but they had not yet been able to authorize those releases because of the breakdown in the political process.

It's really critical that they do so because continuing to store these increasing quantities of water deters them from taking other actions that are important to clean up and eventually remove fuel from the damaged reactors.

Dave Lochbaum: Just to add a little bit to that, the Japanese planned to install an ice wall around the plant.

Greg Dalton: Yeah, that sounds wild.

Dave Lochbaum: It's been done on the smaller scales, but when you don't have many options you tend to take the few that are available and try them. Their biggest problem is they have a lot of groundwater intrusion into the plant that then becomes contaminated and they can't discharge it, so it adds to the backlog of contaminated water. The ice dam, if it works, will divert water around the plant so you don't continually add to your backlog so you better manage the water that you've got. Over 80 million gallons of water has to be dealt with.

Greg Dalton: And are you concerned we eat fish from the coast of California, concerned about a little bit of Fukushima being in your salmon?

Dave Lochbaum: No, I don't have that concern. If you're able to detect radiation in the fish or off the California coast, it's well below the acceptable levels of – I wouldn't have any concerns at all.

Per Peterson: Yes.

Greg Dalton: Per Peterson?

Per Peterson: Right now, we have – since the accident, Berkeley has been monitoring independently radiation levels and rainwater and fish and food and other things. And basically what we're finding right now is that we can detect and say welcome such cesium at a level of radioactivity that's 10,000 times less than the naturally occurring potassium-40 but also in the milk. So, you can detect the cesium. You can also find out whether it's coming from the bomb testing or the 1960s versus from Fukushima because of the ratio of cesium isotopes and most of what you detect around now in the United States at these very low levels is the residual stuff from the bomb testing.

Greg Dalton: Okay. So it's our own darn fault there. So, go out for a sushi dinner in Tokyo, your game, you're in?

Dave Lochbaum: I don't like sushi at all.

Greg Dalton: Okay. [Laughter] Per or Jon, sushi dinner in Tokyo?

Per Peterson: I have confidence in public health capabilities so that I would be perfectly confident about what we do in the field that I would consume in Japan.

Greg Dalton: Let's talk about the state of the U.S. industry. A lot of reactors, about a 103, 104 reactors built in the 60s, 70s going back to the 50s. A couple of new ones in the south part of the U.S. Jon Koomey, how would you describe the health of the U.S. nuclear industry today?

Jon Koomey: The first to remember is that the history has some great success but also some serious issues. And we saw with about 15 to 20 percent of those reactors that you named, we have very high costs – high costs that were unanticipated. No one expected that it would cost that much. And there were a number of factors that led to that. One was you had slower demand growth. In the 70s and 80s, you had competition. You had people starting to build independent power so that also led to competition with complete nuclear plants. There were high interest rates, there were cost overruns, there were structural issues in the industry itself where people are building plants before they were fully designed. And so, some of the changes that have been made in the regulatory process and in the industry we're meant to deal with some of these issues. And so, we've spewed up licensing,

although it sounds like from our conversation earlier that the licensing hasn't been fully reformed. We've also standardized reactor designs and become I think a lot more sensible in how we design and build reactors. The question remains whether those changes will be enough to allow the industry to build plants on time and on budget. We just don't know yet.

Greg Dalton: Because the industry record of delivering on budget is not so good.

Jon Koomey: Historically that's true.

Greg Dalton: Remember there was the too cheap to meter, it's going to be everywhere, it didn't work out that way?

Jon Koomey: Right. A lot of those issues have been addressed and so the question is whether we've done enough to allow the industry than to come to the point where they can give us the plants on time and on budget.

Greg Dalton: And Per Peterson, the two plants that are under construction in the southern part of the United States with some federal subsidies, costs are going up, they're $10B projects, why should we trust the industry's ability to deliver power at the price they promised?

Per Peterson: That's a very good question. I think that if you look back, we've had 60 years and remarkably that are innovation in reactor technology. The first water-cooled submarine reactor was launched 60 years ago and we're still using water as a coolant for reactors. This set the new plants that are being built in South Carolina and in Georgia, they do have some major improvements over previous designs, one of them is the passive safety that I've mentioned earlier. But the other is the use of modular construction technology which now does the majority of the fabrication of the buildings and the equipment modules and factories. And the AP1000 that Westinghouse developed and is in construction there, there's also several of them being built with the same design in China. And the implementation of modular construction does have the potential to give you much better control over schedule and cost. This said, it's still a puzzle why the construction prices are as high as they are. Because it takes twice as much steel and concrete to build the coal plant as it does to build a nuclear plant of the same capacity, and yet the nuclear plant costs two to three times more than the coal plant.

So why is there this factor four to six per kilogram or per ton of steel in concrete between the price that you have to pay to build the coal plant than build the nuclear plant? There must be some way to bring these numbers closer together.

Greg Dalton: And how about regulation? Oftentimes, the industry would try to say that it's the regulators' fault because they make it hard or there's red tape. Does government bear some of the responsibility for some of the cost overruns? Dave Lochbaum?

Dave Lochbaum: The studies we've done have shown that typically, it's not a matter of regulations driving the cost up so much as the companies have mismanaged their activities and run afoul with the regulations. Those drive costs up far more than the few regulations that don't have a safety nexus. Time and time again it's been mismanagement that causes nuclear power plants to be shut down for extended periods. We've had 50 reactor shutdowns of over a year since the Three Mile Island accident. We estimate the cost of each of those to be nearly $2B for electricity that was not generated. So, it's mismanagement more than an overzealous regulator that's crippling the industry.

Greg Dalton: Jon Koomey?

Jon Koomey: There's another interesting aspect of that. One of the great success stories of the nuclear industry has been their improvement in the management of the operation of the reactors. And so, in the 60s, 70s, early 80s, the capacity factors of these plants were, on average, 55-60 percent. Now they're typically 85-90 percent. And so that means they're running almost all of the year and the reason for that is that all the big players, they started to consolidate, they started to share their knowledge and became a lot more clever about how they manage the plants. And so the operation of the plants has gotten a whole lot better. I suspect that those shutdowns that you're talking about were concentrated among some of the less sophisticated reactor operators.

Per Peterson: I would add that there are other industries that are heavily regulated like biotech, commercial aviation and commercial space launch which have managed to be far more innovative than what we've seen within the nuclear sphere.

I think that what we need to be looking at least in terms of facilitating innovation is developing markets for smaller reactors because they can be built more quickly and you can take greater technical risk without putting so much money up – and placing this much money at risk. So the current U.S. strategy to look at developing smaller reactors and deploy them commercially both nationally and internationally may be the direction to go where you can have an ecosystem that encourages and facilitates more reactor innovation.

Greg Dalton: See, that's puzzling because – I mean, nuclear engineers are some of the smartest people on the planet, right? [Laughter] And yet, they – what you just said is they're not innovative, unable to solve some basic managerial problems.

Jon Koomey: Don't get me going on civil engineers.

Greg Dalton: Oh, okay. The nuclear engineers versus civil engineers. Dave Lochbaum, a lot of these plants have been designed to run for 40, 50 years; they're now at the end of their designed lifetime. A lot of utilities want to keep them running for another 20 years because they're cash cows, right? Once they're built, it’s all profit after a certain point. Does the Union of Concerned Scientists feel safe with – comfortable with these plants running for another 20 years beyond their designed lifetime?

Dave Lochbaum: We looked at that and we looked – the risks has really dominated and what's called the bathtub curve of failure, chance of failure versus lifetime, the bathtub curve due to its shape. As plants get older, they approach or enter the wear-out phase where the chance of failure goes up. If you shut down a nuclear plant and replace it with a brand new one, the new one starts on the break-in phase of the curve where the chance of failure is also high. So it's hard to avoid high risk; the best way to do it is through good management and solid oversight so you can properly manage the risk even during the break-in phase or the wear-out phase.

We've had nuclear power plants in the United States get into trouble far shorter that afford to your lifetimes. We've also had some nuclear power plants running longer than 40 years. So it's not what the calendar says; it's how well you maintain the plant and ensure that safety measures are maintained, whether it's one year or 41 years.

Greg Dalton: Are there any plants in the U.S. that the Union of Concerned Scientists think ought to be shut down?

Dave Lochbaum: Well, Diablo Canyon and Oconee would be strong candidates, yes, because they're

unsafe. Other than that, we wouldn't have a problem.

Greg Dalton: And Diablo Canyon because it's on an earthquake fault?

Dave Lochbaum: No. The fact that it doesn't meet the fire protection regulations from the minute that it's ever operated gives us a little cause for concern.

Greg Dalton: This is run by the company just indicted of criminal things or something else – right, okay. And why does the Nuclear Regulatory Commission allow that to continue to operate?

Dave Lochbaum: That's a good question because the – Diablo Canyon is not alone. Roughly half the plants in the United States don't meet fire protection regulations. They're adopted because of a fire in 1975 at the Browns Ferry plant. Among the reactors that don't meet the fire protection regulations are the three reactors at Browns Ferry. It's the poster child for that near-miss. I don't know why the Nuclear Regulatory Commission chooses not to enforce its regulations.

Greg Dalton: Per Peterson, is the Nuclear Regulatory Commission captured by industry a lapdog more than a watchdog?

Per Peterson: The Nuclear Regulatory Commission has to interact with the industry in a way that – the best way to describe it is that when you operate a nuclear plant, the most important thing is to make sure that everybody who works at the plant is willing to report problems. This is what we would call as strong safety culture. There is this natural tendency to want to punish any mistake no matter how minor, which in the end, can end up causing you to not report mistakes.

There's a societal contract that we have when we use technologies like nuclear energy or spacecraft or biotech, which is that we have to encourage the reporting of problems and at minor levels so that they get fixed. And this I think is an area where significant improvement has been made in terms of culture and it would be great if we could see the same thing within our medical system. If you think about a place where there are dissonance to report any kind of problem and we have a lot of mistakes made because of it. When it comes to compliance with regulations such as those for fire protection, I think that the NRC has concluded that plants have taken compensatory measures which are judged to be adequate. This said, it would be much better if we could move to have in other plants in full compliance with fire protection. And in fact this is one of the reasons why we should probably be moving towards the risk-informed approach for fire protection which has been implemented by some but maybe not all of the plants.

Dave Lochbaum: The new regulations were adopted in 2004, a decade ago. All the risk-informed and they don't meet those, either.

Greg Dalton: How much would it cost to be fire-compliant?

Dave Lochbaum: $40M at Diablo Canyon is the estimate by the company.

Greg Dalton: And can the California regulators enforce them to do that or is that because of federal – it's the federal Nuclear Regulatory Commission has jurisdiction over safety and the state regulators have jurisdiction over price?

Dave Lochbaum: Exactly. NRC is the only game in town in terms of nuclear safety. But to get back to a question you asked Per earlier, we don't really – the Nuclear Regulatory Commission has captured or anything like that, and exactly we say that most recently is that Fort Calhoun plant in

Nebraska was shut down for two and a half years, started up last December, because the NRC inspectors found safety problems there and required those to be fixed. So it's not a case of the NRC's Sergeant Schultz or always turns a blind eye. In a fire issue, they believe that serious fires can't happen so that the slow resolution of fire compliance issues is okay.

Greg Dalton: And is fire a concern at San Onofre? Could an earthquake trigger a fire at San Onofre? What I've heard about concerns at San Onofre, it's the earthquake concern that – here in California. So, Dave Lochbaum?

Dave Lochbaum: It could. Nuclear plants use a lot of flammable materials – hydrogen gas and highly flammable fluids for lubricating and an earthquake could cause those to be released and start a fire. The NRC's senior managers testified to the commission that the fire hazard represents 50 percent of the core meltdown risk at the average nuclear power plant, which means it's equal to all other hazards combined. And that's if you meet the regulations. If you don't meet the regulations, the risk management gets worse.

Greg Dalton: So I've done a number of programs on nuclear – fire has rarely come up. We think about earthquakes and other things – terrorists, planes flying and that sort of thing. If this is such a big risk, it seems under-reported, under – it's not very known?

Dave Lochbaum: Well, we've been trying for years, so thanks for the compliment. As for this fault –

Greg Dalton: I guess I should read more of your stuff, but –

Dave Lochbaum: The reason fire is such a hazard is the same – it would perform the same model that the tsunami floods did at Fukushima. Fire can wipe out the electrical cables for primary systems and their backups as they did at Browns Ferry in 1975. It's been unreported because we haven't had a serious fire in the structure. Yet we tend to fight this because as de jure, we haven't had a serious fire since Waterford in '96, so it's fallen off the radar screens. We're trying to put it back. I swear we were.

Greg Dalton: And so yours is not always saying that the Diablo Canyon plant is – its license should not be renewed and that's in the works, but you're saying it should be shut down for safety concerns?

Dave Lochbaum: When the NRC passes a regulation or issues an operating license, we view that as a three-way contract between the NRC, the plant owner and the public. They protect the owner from NRC – require more stringent regulations or more stringent requirements. They cost more.

It should also protect the public from the NRC accepting less. For 10 years, the NRC has accepted less than what the safety bar is set at. They don't have a right to do that.

Greg Dalton: Dave Lochbaum is director of Nuclear Safety Project of the Union of Concerned Scientists. Our other guests today at Climate One are Jon Koomey from the Steyer-Taylor Center for Energy Policy and Finance at Stanford; and Per Peterson, professor of nuclear engineering at UC Berkeley, I'm Greg Dalton. Jon Koomey, on relicensing, do you have concerns about these plants eke out another 20 years of life? Or you think that's case by case you're finding about?

Jon Koomey: I think it's a case-by-case thing and as long as they're responsibly managed and they're meeting the regulations, then I don't have a problem with it. But I think it's important that those regulations be enforced and that we have healthy safety cultures. We also – it's important to

recognize all energy technologies have risks, and it's how we manage those risks that allows us then to go on with our lives and use these different technologies to accomplish the goals that we have. So we need to figure out a way to innovate not just in technology but also in our institutional structures, in our incentives, in the ways that we encourage people to report problems. And if we don't do institutional innovation as well as technological innovation, then we're not going to be able to count on many of these technologies that we would like to count on to reduce climate risks.

Greg Dalton: And speaking on climate risks, let's talk about the shale vale, shale gas that has fundamentally changed the energy landscape in the United States and around the world. It's made people like John Rowe who used to run the most numbers of nuclear power plants in the United States say they're uneconomic right now in most markets. Per Peterson, how is cheap natural gas hitting the nuclear industry?

Per Peterson: Well, it's really specific to the United States. Every other place in the world pretty much except a few places in the Middle East has much higher natural gas prices than we do.

The interesting thing is that if you look at fracking technology, over two-thirds of the revenues in 2012 by my calculation came from the liquids, the oil, but only one quarter of the energy from the fracking is coming from this. So, I think that the fracking that's going on in the United States right now is really oriented towards getting the liquids out, which you can sell at $100 a barrel, which is about five times the price of the energy that would be in this equivalent amount of natural gas.

Greg Dalton: You're talking about fracking for oil? Is that [crosstalk] associate fracking with natural gas, it's also done quite well.

Per Peterson: And right now, natural gas is a byproduct. But with it being about a factor of four to five later on price than it is most of the rest of the world you can expect that there is going to be efforts to take advantage of that both by exporting it and by bringing additional manufacturing back here. And as Jonathan has said in the past, one of the key things we know about natural gas prices is that while we can't predict them, we know that they will be volatile. So having an energy system or electricity prices are completely and tightly coupled to the price of natural gas may not be a wise policy decision.

Greg Dalton: So you're saying if the price of natural gas goes up, then economics of nuclear will look more favorable in the future, this is just a snapshot in time. Gas will not stay cheap forever. In fact the U.S. has already approved the North Export Terminals to be the number two exporter. What's really the question, whether it will be number one or two and if fracking is deployed around the world, then on the flipside of that, natural gas could compete with nuclear and other – in China; China doesn't have fracking yet. If China gets big into fracking, that could pull the rug under nuclear. Is that plausible?

Per Peterson: That's plausible, and also I think we need to step back a bit and look at the global picture for nuclear technology. Because the United States arguably has been the most innovative in areas such as introducing improved approaches to safety and the design of new plants and other features that I think would like to see deployed worldwide.

And if the U.S. is not active in bringing these technologies out into the rest of the world as we've been successful in China, then we're not really fulfilling one of our fundamental responsibilities. And if we do step back and look more at the picture of the international market for the planning of new reactors, I think that the United States and its vendors and its designers could be playing a much larger role than we are currently but that would take a more comprehensive national strategy that

would aim partly at making sure that U.S. can better export technologies to countries that meet requirements for non-proliferation security and safety.

Greg Dalton: So we're a good actor and rather stay in the game but not be marginalized is what you're saying?

Per Peterson: Well certainly, again I think David would probably agree with that overall, the designs that the United States has developed compared to many others in the world are better and that we'd like to see them more readily deployed.

Greg Dalton: Well, David? David Lochbaum?

Dave Lochbaum: We did a report in 2008 called "Nuclear Power in a Warming World" and the safest – the best reactor we evaluated was the EPR – evolutionary power reactor.

Per Peterson: Well, I would disagree [crosstalk]

Greg Dalton: Okay, we're getting somewhere now.

Dave Lochbaum: It's from France.

Greg Dalton: France?

Per Peterson: The EPR basically, it doubles down on the whole concept of using redundancy and diversity of active complements, and that puts –it requires electrical power to operate reactors which are smaller and which have the intrinsic capability to remove heat without electrical power for emergency decay heat removal and then reach out active normal shutdown cooling systems for diversity, it's simply better and cheaper and it eliminates the need to worry about Fukushima type of accidents.

Dave Lochbaum: Not only true because the passive safety systems are generally only good for 72 hours, and then you need to replenish the tank or whatever you're using. The Fukushima accident involved the power [crosstalk] –

Per Peterson: The AP1000 can go indefinitely with the passive heat removal after you shut it down. Now, in a loss of coolant accident it's different, but when you shut it down, It removes decay heat and it rejects it to the air. So, it does it indefinitely.

Dave Lochbaum: We're going to disagree. The U.S. is not at the lead of the safest reactors. EPR is way ahead.

Greg Dalton: How about China? China is the biggest deployer right now of nuclear technology. Are they safe?

Dave Lochbaum: The biggest problem is they're building U.S. reactor technologies instead of the EPRs.

[Laughter]

Per Peterson: So, they're building EPRs as well but this is – I think this really is a critical area where the ability to remove decay heat without relying on electrical power and to demonstrate that

you can do it reliably through tests and modeling and other methods, is the correct direction for nuclear energy to go. Because the other thing that we worry about and Union of Concerned Scientists worries about a lot is the question of security. And it is far easier to protect the plant that has passive safety systems than one with active safety systems. Because active safety systems, it's equipment that you have to go and routinely inspect every single shift, whereas the passive systems you can knock the equipment down in ways that makes it much less accessible.
So the physical protection of passive plants is far easier than it is for the EPR.

Dave Lochbaum: I forgot to mention we did that report in 2008. We evaluated from both the safety and the security standpoint and EPR still came out way ahead of anything else.

Per Peterson: I understand but we should go back and look at that one closely because I think you missed a few things.

Dave Lochbaum: Well, I think the others were dropped but we can do that if you like to.

Greg Dalton: So, you're saying the country that makes Renault and Citroën makes the best nuclear power plants in the world?

Dave Lochbaum: They make the safest ones, yes.

Per Peterson: Right. That's partly because they take so long to build because they're so large that you just don't end up building them.

Greg Dalton: How about China's also pushing ahead under thorium reactors? There's a possibility for a new type of material, a new type of reactor. We hear breeder reactors, thorium reactors, different kinds of fuel, Per Peterson?

Per Peterson: I think the Chinese have excellent approach and strategy with respect to looking at how to develop molten salt technology for high-temperature reactors, and ultimately to implement a thorium cycle. They're working closely with us in the United States and they're taking the intermediate step of working with salts as a coolant for high-temperature fuels, solid fuels, which then sets things up so that you could potentially move on to fluid fuels that enable sustainable use of thorium. That's a pretty exciting activity that they have underway there.

Greg Dalton: You've mentioned nuclear security. There's the Megatons to Megawatts Program that took fuel from equivalent of about 20,000 nuclear warheads and made into low enriched uranium. That recently ended, it was an $8B project, no cost to taxpayers, supported by Republicans and Democrats. Where does that lead us, Jon Koomey, in terms of the security of this enriched uranium now things aren't going so well with Russia, right? Is security of nuclear power plants a new concern because that program has ended and that's happening with Russia.

Jon Koomey: I'm not sure it's any worse now but I think that the work that Per has done on the proliferation stuff is something that he should comment on. This is an area that's a little outside of my –

Greg Dalton: Okay. Per Peterson?

Per Peterson: The conventional reactors that we operate today, the fuel that goes into them is not a security concern. It's low enriched uranium. I think everybody's quite comfortable with that security dimension. The issue that emerges is if you use highly enriched uranium which really is not

necessary for serving nuclear energy, or if you use separated plutonium which is also a substantial concern for theft.

There's not any need to use separated plutonium within the fuel cycle even if you transition to closed fuel cycles as long as you make the step past water-cooled reactors. So, the way we operate reactors currently in the United States, they're quite secure from the perspective of theft of materials.

Greg Dalton: Let's talk about waste; the economics didn't work out so well. What is the waste solution for nuclear waste? Right now, it's kind of lots of little pools all over the country. How is that going to be solved? Per Peterson?

Per Peterson: Well, the United States – we're at a standstill right now for political reasons with respect to our program for waste and that's really a shame. What we know is that no matter what you do within fusion energy systems, there's no way you can avoid the need to develop geologic disposal capability. There's a strong scientific and technical consensus that deep geologic isolation can provide appropriate and safe disposal of residual materials from nuclear facilities. So the challenge has been developing that kind of disposal. Sweden and Finland had now successfully done it. But in the United States, right now we're pretty much at a political logjam that Congress needs to break. I hope they do it by following recommendations from the Blue Ribbon Commission and –

Greg Dalton: They always follow blue ribbon commissions…

Per Peterson: I was told that sometimes those reports go into the drawer of a desk and stay there. I'm just crossing my fingers [crosstalk] but you couldn't restart a new program that would look for new disposal sites, wouldn't preclude restarting Yucca at some point in the future, but we could certainly find better places than Yucca Mountain for geologic repositories and we should be moving forward to do that.

Greg Dalton: Yucca was a political decision, right? I mean, Nevada they had test sites. No one's there, no one will notice, it's kind of hot already so let's put it there, right? Dave Lochbaum?

Dave Lochbaum: The nuclear waste policy of 1982 had Yucca Mountain among nine other candidates for repositories. The idea was for the Department of Energy to look at these 10, study their geologies, meteorologies, et cetera and rank them from most suitable to least suitable, recognizing what site was going to be most perfect, no site is likely to be absolutely ruled out. But 1987 Congress changed that and said, "Just pick up Yucca mountain." It would have been better to look at many sites, whether 10 is the right number or not but pick a number of sites if you get a number that's going to be perfect, a number that's going to be bad but – and then rank them from most suitable to least suitable. We got off that track, forced Nevada to be selected before you did the homework which made the people of Nevada upset. And it was the wrong dynamic to get to that – to solve the solution for such a long period.

It's a little late now to turn back the clock and un-ring a bell but we do need to do something. I think that Blue Ribbon Commission recommendations are closer to being enacted in Congress at any time over the last 10 years even though Blue Ribbon Commission's not that old but there's more interest in Capitol Hill right now on ending the status quo. Everybody's motives are different but everyone agrees that what we're – the interim status quo is just untenable. So it's likely that many of those recommendations will be implemented, perhaps not all – maybe all. But I think that would be a step in the right direction; maybe several steps in the right direction.

Greg Dalton: Because isn't the waste that's stored at the nearer nuclear sites vulnerable to the

types of things that are in these pools, that sort of thing, it's not a long-term solution.

Dave Lochbaum: Roughly 75 percent of these spent fuels is currently in wet pools. Twenty-five percent is in dry cast. Our analysis shows that you can actually flip those numbers and accelerate the transfer from pools to cast which will reduce the safety and security threat of the fuel lots in the pools. You would increase the safety and security threat of the cast but much less than the reduction on the pool side. That's what we recommend doing.

Greg Dalton: And – okay, so that's moving from pools to casts and then there should be one or a few places around the country where this is centrally stored? Then you have a transportation problem of getting it there and people who don't want it going through their backyard. Per Peterson?

Per Peterson: We have experience with transportation. We do it routinely with the defense waste and with naval spent fuel in Europe. On the quality of waste of spent fuel that's been transported is similar to the total quantity that we have because in Europe, most of it has been reprocessed, and therefore had to be transported. And it's been done safely but you have to put in place the infrastructure to do that in the local emergency response and all of the other things that are necessary. We have a well-functioning system right now on the defense side for waste that is generated from national laboratories and weapons programs. And what we need to do is keep that system operating so that we maintain that capability until we have the systems in place to manage commercial spent fuel. It makes a lot of sense to consolidate the fuel that's shut down the after sites and to a smaller number sites. And that could be a good and intermediate step toward ultimate disposition of spent fuel.

At the same time, we do need to develop geologic disposal for high-level waste and spent fuel. And in that case, it makes a lot of sense for us to be trying to put high-level waste from the defense sector into geologic disposals as soon as we can because that provides a way to demonstrate that geologic disposal worked.

Greg Dalton: Per Peterson is a professor of Nuclear Engineering at UC Berkeley. We're talking about nuclear power at Climate One. I'm Greg Dalton. I'd like to talk about the liability shield, the Price-Anderson Act and financing and how that – the sort of the assignment of risk for nuclear power plants in terms of the social lives, risks, as well as the risk that's borne by the companies that build these and the rate payers that – the Union of Concerned Scientists were very interested in consumers, reviews on sort of the liability shield that taxpayers are bearing for nuclear power plants.

Dave Lochbaum: About 10 years ago, I testified for Congress saying that the Price-Anderson Act and the federal liability insurance is a barrier to safety improvements, because if you develop a safer plant, a better containment design, a better risk management tool, that adds cost to the bottom line of the plant but you don't save any money in liability insurance. When I bought my house at Tennessee by installing a fire extinguisher and dead-bolt locks, my insurance premium dropped more the first year than those things cost. So, federal liability insurance is – wasn't _____ [0:42:37] but the consequences to provide an impediment to safety improvements.

The new reactors that are said to have passive safety systems and things like that, we've asked their owners to opt to add a federal liability insurance. If they're really as safe as they claim, let them go down to State Farm and get their own liability – as long as my money is backing up their claim, I'm going to remain skeptical.

Greg Dalton: Per Peterson, you wrote the article about sort of stifled innovation and here's a case

where he's saying that government – essentially, government subsidy stifling innovation?

Per Peterson: There's a couple of dimensions. The first is Jonathan gave the numbers earlier in our discussion but the effect of subsidy for coal right now is somewhere between four and eight cents per kilowatt hour, and that's because of the external costs, public health damage and other things. And if you multiply that by the total amount of coal that is being used, that turns out to be $2 trillion per year subsidy. And it absolutely dwarves – you would have to have multiple Fukushima accidents every single year to get anywhere close to the subsidy that we have currently for fossil fuel use. So when you view the Price-Anderson subsidy in that light and in the light of all the other subsidies, it's very difficult for companies to ensure risks that involve very rare or infrequent types of events.

The utility industry in the United States is on the hook for the first $10 billion of cost that might emerge from any accident. And I think in some ways it's just going to be difficult to see industry being willing to run defense sites or run reactors if there's not some sort of public acceptance of some of the risks associated with very rare type of events.

Jon Koomey: There's two parts of this. So one part is that people probably wouldn't build reactors unless there's some sort of shield and then there's the question of how you structure that shield. And there's ways to change that to make the incentives a little more sensible, but all energy sources have externalities and some of them require subsidies to make them at least attractive to private investors, and so you have to balance, you have to do a fair comparison across the different technologies as Per was alluding to. And so, this is a subsidy, yes. Probably people wouldn't build reactors without it. And the question is then what is your alternative, and there are alternatives but you need to account properly for all of them if you're going to think about it. You can't just look at one technology and say "Here's the subsidy." That's a bad thing. You have to look at the whole life cycle for all technologies.

Greg Dalton: Whenever subsidies come up, people often point to someone who's "getting the bigger one." That's like "Corn is bigger, oil is bigger, oil is – Oh, no, corn is bigger." And just to find their own subsidy.

This is Climate One and we're talking about nuclear power, I'm Greg Dalton. Our guests are Jon Koomey from the Steyer-Taylor Center for Energy Policy and Finance at Stanford University; Dave Lochbaum from the Union of Concerned Scientists; and Per Peterson, a Nuclear Engineering professor at UC Berkeley. Let's have our audience questions. Welcome to Climate One.

Dave Madison: Hello. I'm Dave Madison with Citizens' Climate Lobby. And we are in fact lobbying Congress for a carbon tax to internalize those external costs of using fossil fuel and also to greatly speed up the clean energy revolution which is starting already. We have Mark Jacobson and Mark Delucchi's analysis that the entire world can be powered by renewable energy in 20-40 years. That's without fossil fuel or nuclear. Given the considerations of cost, safety, waste, need for public subsidy, I'm wondering why we're talking about nuclear power instead of talking about a carbon tax and letting our entrepreneurs really get to renewable energy going?

Greg Dalton: Per Peterson? Why do we even need nukes?

Per Peterson: Well, the first thing is that while wind has a low production cost, if you take a look at statistics for its production for example, 2012 in California, the daily average production varies – if you do it on a scatter plot day to day by a factor of 100 over the course of a year, so when we start looking at the question of how do you store it so that you can have it be available on a reliable basis, you begin to discover that we just do not have affordable storage technologies that allow you to

make this work. So then you begin to get into more complicated solutions and theoretical solutions that involve things such as depending on long-distance transmission, depending on various types of demand response.

There are risks that that will not work and that indeed we'll end up stuck with a substantial amount of our electricity continuing to be generated by fossil plants that are operating during those periods of time when the wind and solar are not available.

Greg Dalton: Jon Koomey?

Jon Koomey: One of the recent studies that Dan Kammen at UC Berkeley has done, he looked at the western states' power grid. And what they found was that they could – within 20 years or so, you could have roughly a third of electricity associated with these variable sources with much less storage than we've thought. So I think part of what has to happen here is that we need to learn to be a lot more clever in how we operate the grid, we need to be smart about forecasting, because you can actually, a day ahead, pretty reliably forecast wind. And so, with smart forecasting with better demand responses you alluded to and some storage but not as much as people think, we can operate electric grids with very substantial fractions of variable resources.

Greg Dalton: Let's go to our next audience question. Welcome to Climate One.

Paul Carroll: Thank you. My name is Paul Carroll. I'm with the Ploughshares Fund here in San Francisco. I think this has been an excellent discussion but a couple of things underlying a lot of these conversations I think are missing. Let me explain it, it's sort of a human factor. We're talking a lot about technology, how we can improve safety through passive or active systems and so on, but Per you mentioned our defense waste and said that's actually going pretty well. Well, in fact the one location we have in New Mexico which is called WIPP, the Waste Isolation Pilot Plant, recently had a mishap. And plutonium escaped and was found nearby. It's barely been open a decade. And these are constituents that are dangers for millennia. And so I wondered if you could address sort of the fact that while these may be low-probability high-consequence kind of events, the constituents that contaminants were talking about, unlike coal or gas and so on, last essentially forever – nuclear fission products. And then the second piece I wanted to get at was also about sort of human fallibility.

Fukushima became a nuclear catastrophe not because of one thing but because of a whole bunch of things that came at it that were unforeseen. An earthquake that caused a tsunami that caused a wave that was I think six feet higher than diesel generators for emergency backup were positioned. And so it was sort of a failure of imagination like Richard Clark said after 9/11. "We think about one or two things going wrong but not five, six or seven." So I wonder if you can sort of get out of the technical box of it ~~and talk about that.~~

Greg Dalton: Per? Human fallibility. Per Peterson?

Per Peterson: Well, the ability to take into account human failure is very important and this relates to safety culture and willingness to report problems to senior people. When you begin to look at some of the challenges that the Japanese have faced, many of the most important ones that caused for example, delays in venting of containments and much larger releases of radioactive material than were necessary, many of those related to the way that it was difficult within that culture for people to report problems to higher levels. So, that's one dimension.

The very long-term nature of radioactive waste is one of the critical reasons why we do need to

develop geologic disposal where we can place it in environments where we know it can be safely isolated for long periods of time, and therefore the human exposures can be kept to minimum. Again, one needs to go back and remember that our current reliance on fossil fuel comes at enormous public health cost and furthermore, if you think about what's going to happen to climate not just in the next hundred years because of the perturbation of what we've been doing, but in the next millennia and multiple millennia because this is an extraordinarily large perturbation on the climate. Long-term consequences of our current activities are enormous, and we can debate whether nuclear renewables are going to, then in the end, will be most effective but currently fossil fuels are going far faster than anything else that we're using. And I don't know how we get to a solution unless we pursue multiple options that can take the place of fossil fuel.

Greg Dalton: Dave Lochbaum?

Dave Lochbaum: Just a quick follow-up on the second part of that question with the human fallibility. We've been advocating what we call the "x+1" approach to safety. Anytime you build a 15-foot-tall protective seawall or you design a plant to withstand a 9.0 magnitude earthquake, we need to ask and answer the question what if a larger occurs. And make sure you have some contingency plans other than relying on a miracle to save the day. If you have those plans and identify what those contingencies are, you can build them into your risk management schemes to ensure that they stay – they're installed and they remain reliable for the life of the planet.

Greg Dalton: Absolutely. Let's have our next question. Welcome to Climate One.

Aaron Burdick: My name is Aaron Burdick. I'm with Sierra Club Beyond Coal Campaign. And I was wondering if you could speak to some of the nuclear retirements that have been announced in the last year or so. We had San Onofre here but we've also had some plants in the deregulated wholesale markets and – so I'm curious how you are thinking about new plants potentially being proposed as well as how existing plants in deregulated markets will continue to fare. And also that question in the context of increasing renewables that may be depressing the wholesale prices like they have in Germany.

Greg Dalton: Who would like to tackle a piece of that? Retirement – Dave Lochbaum or Per Peterson?

Dave Lochbaum: Last year was an unusual year. We had four new reactors begin construction in the southeast. We also had four other reactors permanently shut down or announced their permanent shutdowns last year. There's a fifth reactor that's going to be shutting down this fall. The difficulties of economics as many people have said is it's a difficult environment. It's difficult to make money at nuclear power right now. The challenge is the old Benjamin Graham thing for picking stocks: when you buy a stock, is the seller right or is the buyer right. Chances are they're both not right.

So are people investing in new nuclear power right or the people that are shutting nuclear power plants not right? Chances are, they both could be right. Chances are one of them is wrong.

Per Peterson: The shutdowns of these plants come from two different kinds of factors. Some of them were because they had major equipment replacement requirements that were not affordable because of failures of steam generators or failures to be able to prepare a containment job that had been botched. And ultimately it goes back to management mistakes as Jonathan was pointing out.

The other ones that are shutting down, it's happening in markets where we're starting to see

negative electricity prices on a periodic basis. And a negative electricity price is a kind of strange thing. It says that electricity is a waste and you're paying people to dispose of it. You're paying people not to put electricity into the grid. And the reason that you're seeing that is because wind generation is perfectly happy to take a negative price all the way to two cents a kilowatt hour before they will shut off and go off of the grid. And that's –

Greg Dalton: Because of subsidies?

Per Peterson: If storage was easy, people would be taking those negatively priced electricity and making money by dumping it into batteries, but storage is not cheap unless you can cycle it on about a 24-hour basis. And when you look at the variability associated with renewable energy, it depends on weather patterns that have variability over weekly, monthly, seasonal timeframes and there is no storage technology that works over those timeframes. You can develop studies that say that things work in the future if you do a bunch of stuff, but there's not any existence proof that you can do it.

Greg Dalton: Jon Koomey?

Jon Koomey: What you have is an archaic utility grid that needs to be upgraded in many ways for different challenges that we're facing. And if we were to change how we operate the utility grid, these negative prices would not prevail. We would build more transmission, we would be better at forecasting, we would be better able to modulate demand and response to the changing price.

Dave Lochbaum: And if we're not successful in getting that to happen, then there's lots of large-scale infrastructure dreams that we've had that would not quite work out the way we wanted them to. We'll be stuck with needing to use a lot of fossil fuel in the future. That is a real risk.

Greg Dalton: Let's have our next audience question.

Female Participant: I'm Luka Scarlet. I'm a post-doctoral scholar at UC Berkeley and my question has to do with liability insurance for nuclear plants. What kind of influences that US have on the liability systems and countries to which it exports nuclear technology, and do those countries have systems that incentivize continuous safety improvements?

Greg Dalton: Per Peterson?

Per Peterson: Well, that's a very good question and to answer in detail, you need to look at a wide variety of different countries. I think that we know that there is a wide range of capabilities in terms of ability to operate plants safely and responsibly. I think David might also be able to comment on this. What we'd like to see is a convergence of two factors. One is, we know that humans are going to have to manage nuclear risks competently pretty much in perpetuity. Even if we don't use nuclear energy in the long-term, we will be managing large inventories of nuclear materials with all the attendant security risks. So, we'd like to see an international order emerge that encourages responsible behavior and discourages irresponsible behavior with respect to safety, nonproliferation and security of all nuclear materials. And this is something that takes a lot of effort and it's one of those areas where the United States sometimes has botched things; other times we've done spectacularly well.

The whole existence of an international framework where the majority of countries in the world are required – have signed on to essentially allowing their infrastructure to be monitored for nuclear materials and to spot diversion is a pretty remarkable achievement. It hasn't worked perfectly but boy, it's much better than the alternative.

Greg Dalton: Let's go to our next audience question. Welcome. We're talking about nuclear power at Climate One.

Male Participant: Most in the discussion has been on light water, reactor technology. You had your way with things, how much would you increase the emphasis on breeder designs versus continuing with old-fashioned technology?

Greg Dalton: Breeders have been around the corner for about 40, 50 years.

Dave Lochbaum: Yeah, my father worked for the Westinghouse Electric Corporation. They were developing the Clinch River Breeder Reactor in Oak Ridge, Tennessee. But I worked for the Union of Concerned Scientists, not the Union of Concerned Science-Fictionists, so – [laughter] I don't see it ever seeing fruition. We've tried – many countries have tried that; none of them have got it to work. So I think it's time to throw in the towel on that idea.

Greg Dalton: Bill Gates gave a TED Talk, talked about small nuclear reactors in the ground. Was that a breeder reactor? Is that a possibility?

Per Peterson: People are looking at a number of different options. Russia and China are constructing reactors. The alternative coolants include helium, liquid metals and molten salts. And all of them have potential advantages over current reactor technology. The thing that deters people from using them is the fact that you're dealing with new materials and when you do that, there's a learning curve associated with it.

But if we were developing and deploying smaller reactors where it could be affordable to replace complements if something unexpected happened, I think that that reduces the barrier to shifting towards systems and – for example, molten salts are intrinsically low pressure. They're chemically stable. They have a number of attributes including excellent retention of fission products but arguably make them simpler to work with and safer and you can deliver heat at higher temperatures so can get higher efficiency. But to get to that point we need to address a bunch of other problems such as just the ability to construct any kind of nuclear plant on schedule and on budget. Modular technology may help there.

John Koomey: One important aspect of this also is the more smaller scale technologies you have, the more experimentation and learning you can have. And so there are these technical issues with new materials and so on but there's also more rapid innovation that can happen when you move to smaller scale, and you can have economies of manufacturing scale because you can make more of the plant and the factories. So these are critical advantages and so we've always, in the nuclear industry, focused on economies of unit scale, building a gigantic plant because it's going to get that much more efficient. But as we've seen in some of the other energy technologies if you moved towards manufacturing scale technologies, smaller scale technologies, you can innovate much more rapidly. So it's a critical part.

Greg Dalton: Let's go to our next question. Welcome to Climate One.

Male Participant: Thank you. I have a question for you regarding the state-of-the-art regulatory infrastructure. Drawing on the example of the BP oil spill in the Gulf, we found that were kind of two different problems associated with our regulatory infrastructure at that time. There was the cozy relationship between the regulators in the industry and there was also the fact that the regulatory agencies were significantly understaffed and did not have sufficient resources. Mr. Lochbam, earlier

you dismissed the idea of collusion between the nuclear industry and the nuclear regulatory agencies. But I was wondering if you could speak to whether or not the nuclear regulatory agencies have enough resources both in terms of staffing and kind of tools at their disposal for punishing offenders in order to properly police the industry as it should be.

Greg Dalton: Dave Lochbaum.

Dave Lochbaum: That's a great question. We currently believe that the Nuclear Regulatory Commission has sufficient staffing to discharge its abilities or its duties. There's a couple of things that we think guard against collusion or regulatory capture or however you want to characterize it. The first is that the Nuclear Regulatory Commission, as many federal agencies, has an inspector-general that's done some very good work about looking about agency malfeasance, misconduct or whatever. So, the inspector-general was basically the public's guardian to ensure that the Nuclear Regulatory Commission is acting upfront and fairly. The second component of that helps provide that is transparency. If you look at the Nuclear Regulatory Commission and its records to look for information dealing with privacy, trademarks, and nuclear security, most of the information is available on the NRC's website. You can download it 24/7.

So we believe transparency and in our NRC Inspector-General that's rigorous and robust. Our good protections against regulatory capture, regulatory malfeasance or whatever the adjective is.

Greg Dalton: We have to wrap it up but I want to end by asking each of you quickly what you do or what's the next thing you will do to manage your own personal carbon footprint. Jon Koomey? Aside from having a breeder reactor in your backyard, what are you going to do to lower your carbon?

Jon Koomey: We still have a few halogen bulbs in our house. Almost all of them are LEDs but there's a few halogens.

Greg Dalton: Yeah, I got a few of those, too. Those are tough. Per Peterson?

Per Peterson: The very next thing I'm doing is hoping on BART to go back home.

Greg Dalton: Should we let him off that easy? I don't know.

Per Peterson: You asked me what's the very next thing was.

Greg Dalton: Okay. [Laughter] the systemic or the next systemic thing maybe.

Per Peterson: Okay. Well, I'm going to try to improve the situation so that nuclear energy may be able to play a safe and useful role in the future. And that might have an impact, too.

Greg Dalton: So your students will have jobs. Okay, Dave Lochbaum.

Dave Lochbaum: I work out of a home office where the commute is down two flights of stairs and drive a Honda Insight. I have a pretty small carbon footprint to start with. Plus I'm a cheap son of a gun, so I don't – thermostat's real low and other things. I think I'm doing pretty good.

Greg Dalton: We have to end it there. We've been talking about nuclear power at Climate One. Our guests have been Dave Lochbaum, director of the Nuclear Safety Project at the Union of Concerned Scientists and author of *Fukushima: Study of a Nuclear Disaster.* We also heard from Jon Koomey, a research fellow at the Steyer-Taylor Center for Energy Policy and Finance at Stanford, and author

of *Cold Cash, Cool Climate*. And Per Peterson is a professor of Nuclear Engineering at UC Berkeley and a former member of the Blue Ribbon Commission on America's Nuclear Future. This and other Climate One programs are available on the iTunes Store. I'm Greg Dalton. Thank you all for coming today.

[Applause]

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