ABC

HD **Renewables take off - how the game is changing**

WC 10,317 words

PD 7 March 2014

SN Australian Broadcasting Corporation Transcripts

SC ABCTRS

LA English

LP

Carbon pricing needed to control greenhouse gas emissions – BHP chief

Solar energy challenges conventional power on price

TD

Scale the trick to getting algal biofuel cost down

Milestone for the fusion reaction

Fuel cell gets the power out of poo

Changing ocean currents change fish habitats

Deep sea being damaged by mining, trawling

Robyn Williams: This time The Science Show goes to the engine room of the Starship Enterprise to witness what could be a power source to help us run civilisation for the next million years. And it's working.

Fusion. Remember that? Like the Sun. The experiment worked and it has just been published in the journal Nature, as you'll hear. We'll also have news about power from poo, petrol from algae, a revolution in solar offering huge efficiencies, a shift in the prospects for renewables we really should recognise.

On Wednesday though in Houston, Texas, the managing director of BHP Billiton, Dr Andrew Mackenzie, made a speech about our energy prospects, with far reaching implications. Professor of geophysics from Cambridge, Herbert Huppert, knows him well.

Herbert Huppert: I've known him for quite some time, mainly scientifically. I have been very impressed with him. I knew him when he worked for BP, interacted with him when he set up the very successful BP Institute at the University of Cambridge, and then Andrew moved to be CEO of BHP Billiton after a short time with Rio Tinto, and I've interacted with him since then.

Robyn Williams: And of course he was talking in Houston, Texas, on Wednesday, giving a long speech about the future of fossil fuels and carbon emissions. What struck you most about what he said?

Herbert Huppert: I thought the most important statement he made was that BHP Billiton needs to think carefully about controlling their omissions. He in some sense wants BHP Billiton to lead the way. It is a direct quote: 'first we must reduce the emissions of our own operations'.

Robyn Williams: Of BHP Billiton.

Herbert Huppert: Of BHP Billiton, which is known as the world's largest miner and is the third biggest **company** in the world.

Robyn Williams: He also mentioned a carbon price.

Herbert Huppert: He talks about carbon price and about the economics. I think, Robyn, the point is that there are really three slightly separate issues here that run together. One is the science on climate change and the use of coal and oil and gas resulting in emissions, the next is the economics and then there's the question of policy. And sometimes policy can run counter to science, and economics can be different from both of them.

Robyn Williams: However, what was quoted in the newspapers largely was a warning from him in his speech that the poorer nations will depend on coal for the indefinite future, and there was no way one could reduce that without harming their economies and their prospects.

Herbert Huppert: Well, I thought that was a very important point. At the moment, 85% worldwide of our energy comes from the burning of fossil fuels. Some countries, the wealthy countries, might be able to change that mix, but I thought he was putting a very good point forward that the poorer countries will not be able to afford that. And while it's easy for the wealthy countries to say we should change our way of life, it would be quite disastrous for the poor countries. I think it's very nice of Andrew to give those countries thought.

Robyn Williams: Yes, but how do you then match those two seemingly contradictory statements; on the one hand reducing carbon by BHP and other companies, and on the other hand looking at what is going to be a colossal use of coal for the indefinite future?

Herbert Huppert: Well, the important thing is that Andrew did not say that we should stop burning fossil fuels. He said we should reduce our emissions, and the way to do that is to store carbon dioxide. There have been many projects, in particular in Australia, and I think the most successful project worldwide, the Otway Project, which has sequestered some 700,000 tonnes of carbon dioxide, and I think this could be done worldwide, and BHP could change some of its processes and sequester some of the carbon that it emits.

Robyn Williams: Carbon capture and storage, that has always seemed a long way off. You've been on this program before talking about Otway and talking about some of the success. You have reported to the European parliament about the latest ideas scientifically about how this might be done. What did you tell them?

Herbert Huppert: I was the chairman of a European working **group** preparing a report for the European parliament and the European president, and the report said that it's a technology that is safe and doable, it will add something like 30% on average to electricity prices, that that value could come down when we understand better the chemistry behind the capture, but that we thought it was really most essential for Europe to show the way. And I would then also say I think it's interesting if Australia would show the way.

Robyn Williams: How far away is it, that is the question. Can we afford it, and how far off?

Herbert Huppert: Well, I am positive that we can afford it. At the moment we sequester something like 10 million tonnes per year, and we emit something like 32 billion tonnes a year. So we are sequestering a very, very small amount at the moment. Can we afford it? I think that's a question of what will happen in the long term. We are seeing in Australia and in other parts of the world that the weather is turning nasty. There are more extremes, more droughts, more rainfall, more hot days.

Let me give you a little story. Imagine you throw garbage into Sydney Harbour. First nobody notices. As you throw more and more garbage into Sydney Harbour it gets more and more polluted and is more of a problem. You slowly get to a position where the cost of getting Sydney Harbour clean again is enormous, much more than you could have saved by not throwing garbage into the harbour in the first place.

Robyn Williams: Which might seem more prudent. Herbert Huppert is a professor of geophysics at Cambridge and also a visiting professor at the University of New South Wales. And the full speech given by Dr Andrew Mackenzie is linked to The Science Show website.

And so to Phoenix Arizona and a change of clothing.

Stuart Bowden: So these are booties, we need to put these on to go into the clean room, because what we want to do is make sure none of the dirt from the outside goes into the inside.

Robyn Williams: Paper booties. I've never done this before. So you have to be absolutely meticulously careful about dust.

Stuart Bowden: We have to be fairly careful about dust. Okay, so what we are going to do…this is a very large clean room, so I think it's about 40,000 square feet, and what we are going to do is walk right around to the back of the clean room. Most of the clean room is operated by the flexible display centre here at ASU. We do some work with them on flexible solar cells, but their main focus is on flexible displays.

Robyn Williams: I can't help noticing that you don't sound like someone from Arizona. Where are you from?

Stuart Bowden: I'm actually from Australia. So I grew up in Tamworth in New South Wales, and I used to listen to your Science Show when I was a teenager. So I go back quite a way.

Robyn Williams: On his way to collect eggs from the chicken farm, listening to RN. Stuart Bowden, now a professor at the ASU, that's the Arizona State University, heading a team with his American wife, Dr Christiana Honsberg. And the potential efficiency of the new solar is spectacular. They claim it is already cheaper than the fossil fuel driven grid.

Stuart, thank you for taking me on a guided tour of your incredible laboratory. And after the booties you had me in a mask, you had me in a funny little shower hat, a white coat and everything else. Why?

Stuart Bowden: Well, solar cells are like the rest of the semiconductor industry; they are incredibly sensitive to any dust particles that we might get on the cells or any other particles that come around. So what we do is we have to make sure that people who have a lot of particles, they tend to shed them, they are not putting them all throughout our lab. So that's why you could also hear that large noise, it's all the air-conditioners purifying the air all the time. It's great when you've got sinus problems.

Robyn Williams: So you're actually making the chips and you are printing. But you are not manufacturing them, are you.

Stuart Bowden: No, we are not manufacturing them. So when you are in research it's a lot different. You are expecting every solar cell to be a little bit different but you want to be different in a controllable way, and so you don't want uncontrolled things like dust particles on one wafer and not on the next one, so you want them fairly consistent.

Robyn Williams: What are you testing?

Stuart Bowden: A lot of the stuff I test for is just efficiency. So what I'm looking for is can we make a high efficiency solar cell? And we want to do that in a way that's manufacturable. So we're coming up with processes that are fairly cheap, easy to implement, and throughput. Throughput is really important in the photovoltaics industry because we do go through so many wafers, there are so many cells that we need to do in order to make large amounts of power.

Robyn Williams: Okay, so that's the trade-off. You worked with Martin Green famously at the University of New South Wales, and he holds the record, I think it's 25%, the amount of sun you get impinging on your device and how much energy you get out. If you are manufacturing at such a rate, what kind of efficiency can you expect? Surely not 25%?

Stuart Bowden: Well, what's interesting over the last 10 years is there was a big difference between lab cells which were a higher efficiency and **commercial** cells which were much lower efficiency, but over the years they've started to converge. So you can now **buy** solar cells which are getting up to above 20%. In fact you can get modules now which are above 20%.

Robyn Williams: What about yours? If it's 18%, is that because you are printing so many?

Stuart Bowden: In our case what we have for our line is the more standard production that would be used in industry, and they are at about 18%. For that part of the line, the pilot line, we have a student-led pilot line where the students can operate it, that's all run by students, and we want them to be able to interchange with industry, so once they've graduated they can get a job.

Robyn Williams: How far do you think you can make this efficiency grow?

Christiana Honsberg: So the thermodynamic limit of solar energy conversion is actually much higher than just about any other type of energy conversion. So the ultimate thermodynamic limit is about 87% and that's huge. So an old-fashioned light bulb is 4%, your car is roughly 20%, humans are about 15%. So much higher than any other conversion technology. And my research is very heavily focused on ways to get to that very high conversion efficiency. So today the record is about 44.7% and we are looking at ways to get it over 50% and all the way up to 70%.

Robyn Williams: What you have to do to make it so efficient?

Christiana Honsberg: For above 50% you can make it using techniques that are called tandems where you put one type of solar cell material on top of another. I estimate you can see 50% within the next five years or so, even commercially. Now, above 50% life starts getting really interesting if you are a physicist or scientist because then you have to do all sorts of new stuff. So very often the new stuff is sort of encapsulated by taking advantage of the new types of physics you can get if you put nanostructures into the solar cell.

Robyn Williams: Okay, in a minute I'm going to ask you what your projections are for the application of some of this technology, where we can go and how quickly. But I want to catch up on what you said before about churning them out. Why can't you just do them slowly? What's the haste for?

Stuart Bowden: Well, the haste is that you need a reasonably large area of photovoltaics in order to power a house or a city. So in the past we looked at powering small water pumps but now we are trying to power entire cities. And so that means that we literally need to produce billions of solar cells, so that means the production throughput of a photovoltaic plant is maybe 1,000 times greater than what you would get for an IC plant.

Robyn Williams: And the ingredients? You won't run out of sand, will you.

Stuart Bowden: No actually, although surprisingly we make solar cells out of quartz, so we don't actually mine beaches.

Robyn Williams: I see, and you won't run out of quartz either.

Stuart Bowden: We won't run out of quartz either, so I think silicon is like 30% of the Earth's crust, it's an enormous amount. Most of the Earth's crust is actually quartz, so there's no shortage of that.

Robyn Williams: One thing that strikes me personally, having heard of some experiments, many in Britain, of integrating your solar material in the building stuff, the tiles are actually solar receivers, how far has that gone?

Stuart Bowden: Well, aspects like that are an important part of our future research. We find that a lot of that is more on customer acceptance. So it's all very nice for us in the lab to make a higher efficiency solar cell, to be able to find out ways we can manufacture it fairly cheaply. But what we really need is ways to convince people that, yes, you don't need to put on a roof first and then put your solar cells on top, you can actually already just put in shingles which might already have the solar cells incorporated.

Robyn Williams: And they exist?

Stuart Bowden: They do exist. It's possible to **buy** them. The market for them has not traditionally been as great as what we would be for a standard module where you would already have a roof there and you put your module on top. But I think that's an important part of solar, it's not just research it's also marketing.

Robyn Williams: Christiana, the picture you are giving just before of this nano stuff seems to be a leap away from the scale of building the city. Can you actually have that kind of sophisticated solar technology available generally in the way that Stuart has been talking about?

Christiana Honsberg: I think that the advantage of the nano as to take it to applications where you currently don't have energy. So I think that energy is one of the really defining challenges that the world is going to face, and the ways in which it is used are going to undergo dramatic changes in the next 50 years. So the present solar is very much essentially a model duplicating what you already have. Every house is connected to solar. If you want electricity, you plug in.

I think the advantages of some of the nano stuff is that it can do things that you presently can't envision. So one of my favourite examples that is theoretically possible if we knew how to do it is that solar, for example, could not only create electricity but also scavenge CO2 from the air and convert it to carbon. Or you could integrate it with a light bulb so you have self-powered lights. Or you could make it small enough to sit under your skin and detect and send a signal out. Some marker in your blood has all of a sudden gone high. So I think that the advantages of the nano is really to enable new types of technologies, not for the bulk power generation.

Robyn Williams: And that CO2 absorption, can that be done on any kind of reasonable scale?

Christiana Honsberg: Well, you should be able to put it into a regular solar cell module, so then when you have so many solar cell modules out there you would get a significant amount of CO2 capture from it.

Robyn Williams: Well, that would be amazing. You get your energy for your house and you'd remove CO2 at the same time.

Christiana Honsberg: Yes. Technically quite challenging because you have to integrate two very, very different branches. So one is chemical conversion processes, and one is the solid-state conversion processes. It sounds very simple but the theory and the physics is actually quite hard.

Robyn Williams: I heard Ray Kurzweil at the American Association for the Advancement of Science representing the American Academy of Engineers, predicting that because solar is following IT and Moore's law, in other words the cost is going down and the efficiency is going up, he said by 2020 he could imagine solar providing all of the country's energy needs. Does that sound a wild prediction to you?

Christiana Honsberg: No. If you look at the growth rate of solar and just extrapolate that out, you'll find that it meets some kind of interesting milestones somewhere within the next decade or even sooner. And I think you are actually starting to see the beginnings of that right now. So in places with high sunlight, like we are in the south-west here, like Australia has, the cost of photovoltaic generated electricity is actually less than what you **buy** from your electricity **company**. So that's a huge game changer, and I think it's one of the few times in the history of the electricity grid that there has been a lower cost option than just string the grid to somebody's house and use whatever the grid **company** provides you.

Robyn Williams: Of course coal is very cheap, a coal-fired power station produces a lot of electricity. Are you suggesting that solar can soon become competitive?

Christiana Honsberg: Well, in Phoenix and probably in Australia as well, because there is very high sunlight there, it already is. So you can rent a system and you will immediately, with no initial cash outlay, start paying less on your electricity bill than you presently do during the times when the sun is shining.

Robyn Williams: Stuart, many people in Australia would find that a surprising statement.

Stuart Bowden: Yes, but I think Australians also have adopted solar fairly well, and as we are continuing to lower cost it is sort of a snowball effect. You lower the costs so that more people get interested, they might **buy** more solar, that drives down the price further. So there's just a lot of opportunities for solar to expand. And I think the situation is true in Europe. They are not particularly sunny places, but Germany gets I think about 5% of its electricity, Italy about 7%, and the really interesting part is that has only happened over the last few years. So it wasn't like they had to wait 20 years to do this, they were able to suddenly change the system.

Robyn Williams: Changes to a $100 billion industry, accelerating all over the world. Stuart Bowden from Tamworth, now at the Arizona State University, with fellow Professor Christiana Honsberg.

And this is The Science Show on RN, from Tamworth New South Wales, to Phoenix Arizona. And San Diego. Oil, petrol, comes originally from algae, just add a few million years. And there are several schemes to make the process immediate. They've tried in Queensland and in Victoria. Stephen Mayfield's outfit at the University of California, San Diego, was recognised this week by the US Department of Energy as, and I quote, 'the country's best'. Let's meet him.

In Australia some of the work on algae to make fuels seem to be going terribly well but then they hit what we know in Australia as a snag. How are you doing with them for biofuels?

Stephen Mayfield: Yes, so in the States we call that the Valley of Death. What happens is there is always early optimism and people get all excited and work on a new project, and then after about two or three years if they haven't been successful, 'I've spent long enough on that,' and off they run to go do something else.

We have made really good progress on algae biofuels for the last five or six years now. Not quite enough to be competitive with fossil fuels yet, but clearly on a path to achieve that in the next four or five years. If we continue at the same rate of advance that we've had for the last five years for another five years, we will be competitive with fossil fuels.

Robyn Williams: Well, I heard four years ago was the first plane going up, I think Richard Branson's Virgin Airlines were using fuel that came from algae to put planes in the sky, and that's as good a test as you'd like, isn't it?

Stephen Mayfield: Yes, so no problem at all with making fungible or drop-in fuels from algae, that has been achieved by very many groups. That shouldn't be a surprise to anyone. The petroleum that we pull out of the ground, that's ancient algae, it's not melted dinosaurs, it's not from some mysterious place, its ancient fossil algae. So the oil that comes out of algae that we grow in farms today, crack that in a refinery, out comes jet fuel, gasoline, diesel. So that part works perfectly well and many groups have shown that. The problem is cost. We are probably a little bit north at $200 a barrel now, we need to get down to less than $100 a barrel. But as I said, probably five years ago we were more something like $500-$600 a barrel, so we have made great progress over the last few years.

Robyn Williams: Critics of the biofuels and suchlike say that the figures really are so bleak that they will stay bleak for a long time.

Stephen Mayfield: You know, cost is a funny thing because what's the price of fossil fuel going to be in four or five years, who knows? The number that is really important is what is your energy return on energy invested, EROI. And now we know from doing a very careful what is called life-cycle analysis, looking at all the different energy inputs in, can be about 3 to 1, meaning that we get three times the amount of energy out that we putting. Just to put that in context for you, the tar sands up in Canada, the number one import of oil into the United States, that's about 3 to 1 energy return, so it's about the same as the tar sands, and I can assure you renewable fuels from algae are a little cleaner than the tar sands.

Robyn Williams: At what point will these algal sources be on a scale big enough to make a difference?

Stephen Mayfield: Yes, so therein lies the rub, as Shakespeare would say. In order to get cost competitive with fossil fuels you have to start to reach a scale that is proportional to fossil fuels. Estimates are that's about 10,000 acres, probably $500 million, $600 million to build that facility, take you three or four years to build it. So I think right now many of the renewable energy companies are out looking for that money, and if they can get $500 million or $600 million from the markets I think they will build that and we will see these things up and running in four or five years.

Robyn Williams: And the scale doesn't matter for the algae? You can grow them in a jar, but when you've got millions of them, huge acres of them, as you said, does that affect the growth?

Stephen Mayfield: Absolutely, it's agriculture, so in algae farming we have the exact same problems as any farmer has. If you grow 10,000 acres of corn you better hope the locusts don't come in and eat most of it. Sometimes they're good and sometimes farmers lose that battle. But what we've discovered is that you can use the same practices they use in agriculture, so they would call it integrated pest management, meaning you use crop rotation, you use some chemicals, you use predators to get the things that are eating yours. So all of those combined in together, we can keep these guys growing.

Robyn Williams: You've shown that with experiments here, have you?

Stephen Mayfield: So we've shown that both in experiments here in the lab and then a **company** called Sapphire Energy, which I am a founder of, one of the bigger algae companies, they are down in Columbus New Mexico, they have a 100-acre facility that has been running for the last two years, they use integrated pest management and keep that thing running 24/7.

Robyn Williams: Does that use CO_2, does it use direct sunlight?

Stephen Mayfield: Absolutely, sunlight and CO_2. So, as you say, there's a couple of different ways to make these things. There are some companies who think about making renewable fuels by doing photosynthesis in corn or sugarcane, extracting the starch or sugar out of that, and then, by fermentation, having a bacteria or yeast, turn that into a renewable fuel. That's how we do corn ethanol in this country, that's how they do sugarcane ethanol in Brazil. The way we grow it here is we take algae and we take sunlight and CO_2 and that sunlight fixes the CO_2 into the renewable fuels that we use.

Robyn Williams: Can you make a prediction; at what point will we have algae on such a scale that people in the street will just assume it is part of the process?

Stephen Mayfield: You know, it took 100 years for us to get petroleum to what it is today, and it took a good 50 years before it became ubiquitous. I think because the demand will be much higher it's not going to take us 50 years to do this, but I think it will take a generation. This is going to take 15 or 20 years. You can already **buy** it now in the United States. There are a couple of gas stations up in San Francisco that sell renewable algae diesel and you can stop in and **buy** it now, but before all of us see it I think it will be 10 years and, before it's ubiquitous, 20 years.

Robyn Williams: We've been casually talking about algae, of course they are in many standing bodies of water, both freshwater and seawater. Presumably the supply in terms of number of species is almost unlimited.

Stephen Mayfield: Yes, some people have estimated 3 million species of algae. I think a more realistic number is about 100 times the plant species, which puts it more at something like 200,000 different species of algae. They cover every ecosystem on the planet, they grow in thermal hot springs, they grow in Arctic waters, freezing, they grow in crusts on desert, and then of course in every birdbath and swimming pool in the world. People occasionally call me to ask me how to get rid of algae, and what I tell them is no, don't get rid of it, love it, learn to live with it.

Robyn Williams: Yes, live with it, and life from those algae. Stephen Mayfield is director of the California Centre for Algal Biotechnology at the University of California, San Diego. And work at the university and Scripps has just been ranked at number one in the United States.

Yes, Star Trek, let's go there, and catch up with a nuclear option that, as the cliché goes, always seems 30 years away. But suddenly it has just got much closer. Paul Olding takes us there.

Paul Olding: The prospect of clean limitless energy from nuclear fusion has been something that has taxed the greatest minds for decades.

Now, if you've seen the latest Star Trek flick, Into Darkness, you may not realise it, but the engine room of the Starship Enterprise isn't a made-up set, it's actually a real-life, operational fusion reaction chamber.

That chamber lies at the heart of the National Ignition Facility at the Lawrence Livermore Laboratory east of San Francisco in California. The program director is Yorkshireman, Professor Mike Dunn.

Mike Dunn: So the objective of this facility is to try to reproduce in miniature what's happening at the centre of the Sun, and by miniature I mean smaller than the width of a human hair.

Paul Olding: Surely it's something that makes you get up in the morning to say, 'Guess what, my dear, I made a sun on Earth this morning.'

Mike Dunn: It's an amazing time to be around, yes. The idea of doing this was created 50 years ago in the early 1960s, and we're standing here now actually realising that vision.

Paul Olding: The National Ignition Facility took 10 years to build and cost some US$5 billion. While it makes a great backdrop for Star Trek, in recent years it's been criticised for failing to reach its deadlines. There were even calls in the US senate for it to be scrapped.

But In February this year, the science journal Nature reported that the facility had reached a major turning point; getting more energy out of the fusion reaction than they put in. So how does it work?

Mike Dunn: Fusion is the process that drives the Sun and all of the stars. It's the crushing together of matter at the very smallest scale, at the atomic scale. So in the centre of the Sun and any star the gravity is so strong that it combines the hydrogen together to get helium and it releases energy in the same process.

Paul Olding: The fusion reactor here in California is not driven by gravity but by light. In fact it requires the most powerful laser light system ever built.

Mike Dunn: This is the master oscillator room. This is where the light starts its journey. The light at this stage is very low energy, very low power, about a billionth of a joule, a nanojoule, and it actually starts in fibre optics.

Paul Olding: At this first stage, pulses of low power laser light are carefully shaped and moulded to exact specifications. When they fire the system, what they call a shot, just one single pulse of this low power laser light is selected and gets sent off on an incredible journey.

Mike Dunn: So we're in the laser bay of the National Ignition Facility. This is where the light gets amplified to its maximum level, to an energy of two million joules.

Paul Olding: The laser system is boosted to world record levels in a complex yet ingenious way.

Mike Dunn: So we start off at a billionth of a joule in a fibre optic, that then gets sent into what we call a pre-amplifier to get to about one joule of pretty conventional energy. And then we take it a whole new level and the way we do that is by using very large glass amplifiers, and the glass contains a very special atom called neodymium. And neodymium has this **property** that when it's pulsed by a flash of white light from a fluorescent tube, a flash lamp as we call it, the neodymium excites and stays in a quantum excited state until that low energy laser pulse passes through the glass, de-excites the atom and basically duplicates itself. So one photon goes in, two come out, two go in, four come out, four go in, eight come out and so forth, so you're getting amplification again and again and again, and you're forcing the atom to give out energy.

Paul Olding: During the amplification process, that initial single pulse of laser light gets split into 192 giant laser beams.

Now, a laser beam in my mind is a shaft of light like a pencil. What sort of size are your laser beams?

Mike Dunn: In this case, yes, we go from the pencil point laser that everybody's familiar with at the supermarket or for the laser pointers, to a beam of light that's 40 centimetres wide, it's square, and it's about three metres long. So it's a shaft of light moving at the speed of light of course, and it only lasts for a few billionths of a second. But during those few billionths of second, it's the most intense laser light you would find anywhere on Earth.

Paul Olding: And having amplified your laser light, what's the next step in the process?

Mike Dunn: So the next step is to take that two million joules and 500,000 gigawatts, 500 terawatts' worth of power, and focus it down to a spot that's about the size of a human hair.

Paul Olding: And that happens down in the basement, in the target chamber, AKA the Enterprise warp core.

We've just walked through what must have been a metre-thick blast door, and we've now entered, quite clearly, a set of Star Trek.

Mike Dunn: That's right, this is the engine room of the Starship Enterprise in the new movie.

Paul Olding: It really actually is the backdrop isn't it?

Mike Dunn: It truly is, and this is what we call the target bay. This is the heart of our facility where the fusion itself happens. So standing in front of us is a ten-metre diameter sphere. It's a vacuum chamber, so all of the air has been extracted out from inside of it to allow the laser beams to focus down to a pinpoint at the very centre. And above us ringed around the top of the room are laser beams coming in from the top of the building; 96 from the top, there's 96 coming from below in this ten-storey building. This is a scale size that doesn't exist anywhere else in the world.

Paul Olding: In the middle of the target chamber sits the fuel cell, a tiny and rather innocuous pellet the size of a peppercorn, containing a droplet of frozen hydrogen.

Mike Dunn: It's not like the H2O you would find in water. It turns out that about one part in 6,000 of any kind of water isn't normal hydrogen it's heavy hydrogen, deuterium. So we take that out of water and combine it with super-heavy hydrogen which we call tritium, and then freeze it, freeze it to almost absolute zero, that's 17 degrees above absolute zero, so it forms a solid shell about two-millimetres diameter which the laser beams are then focussed on to.

PA announcement: All personnel must leave capacitor bays one through four, laser bay one and two, and the target bay areas immediately.

Paul Olding: The research program at the facility continues apace. With the claxon blaring, we're ushered out of the reaction chamber to the safety of the NASA-style control room.

Why 192 lasers?

Mike Dunn: If you just use one laser beam you would crush the fuel from one side. If you use two you may get a pancake. If you use many, many, and it turns out 192 is a good number, you get a very uniform, spherical illumination, and so you can crush that ball of fuel to a very, very small size.

Paul Olding: What happens when those 192 lasers strike a small little fuel pellet of hydrogen simultaneously?

Mike Dunn: You can imagine things get rather extreme. So we, we take 500,000 gigawatts' worth of laser power, about 1,000 times the electrical content of the United States for example, and focussing it down to that peppercorn-sized pellet of fuel. And so initially the fuel is raised to a few millions of degrees temperature, and then as the fuel gets crushed to about 100 times the density of lead, its temperature goes up even higher to about 100 million degrees or more, the atoms are forced together and they forced together with such high pressures, billions of atmosphere pressures, that the atoms themselves bond together. It converts hydrogen into helium and gives off lots of energy.

PA announcement: Main laser operation will begin in approximately one minute.

Paul Olding: With the huge team of scientists and engineers glued to their monitors, they begin the final countdown to fire the system.

PA announcement: Countdown.

Paul Olding: By assessing the results of these test firings and then tweaking the many thousands of parameters involved in the process, slowly but surely Mike believes they are making significant progress.

Mike Dunn: So the hope is that we can optimise this laser system and the fuel to get more energy coming out of the fusion process than the laser itself delivers. So a net source of energy, a net source of power. And if you can harness that, drive a turbine to generate electricity, then you've got an inherently clean, inherently safe form of energy that will last for probably a few million years.

Paul Olding: Mike is confident that turning this experimental facility into a **commercial** enterprise shouldn't be a difficult step.

Mike Dunn: So the kind of fuel that we're using here, this millimetre-sized pellet of fuel, doesn't have to get any bigger, the laser doesn't have to get any bigger, this is a full-scale device for a power station. Now, of course this is a research facility and it only operates every now and again, maybe once per day. So we have to operate it more like an engine; 1,000 times a minute, 1,000 rpm.

Paul Olding: What timescale are we talking about here? Are my kids going to benefit from clean nuclear fusion?

Mike Dunn: We hope it's better than that. We hope that both you and I benefit from this. The uncertainty is how long will it take us to prove the physics performance within this facility. Only Mother Nature knows exactly how long that takes. Once we get the fusion fuel performance, the step to building a power station can then be very rapid. You know, we're talking maybe ten years or something of that order to harness the energy and build the first-of-a-kind power station and, of course, learn a lot of stuff on the way. So far it's been a pretty incredible journey, a pretty rapid journey and we shall see how long it takes to get that final step.

Robyn Williams: Can't wait. Paul Olding reporting from the Lawrence Livermore Laboratory, with program director Mike Dunn. So that's one very high-tech fuel cell. Let's leap to another, from the sublime to the seemingly ridiculous, from fusion to faecal. You make it every day, for free. Could your bum power the planet? Tom Curtis is professor of environmental engineering at Newcastle University in the UK.

Thomas Curtis: So everybody produces waste, and around the world in just about every developed country we spend about half a kilowatt hour per metre cubed to treat that wastewater. Half a kilowatt hour is about 1,800 kilojoules.

Robyn Williams: So we've got that expense in terms of energy, and within that water nonetheless there is energy we could extract.

Thomas Curtis: Yes, amazingly we've done experiments with bomb calorimeters where we've found out exactly how much energy there is in the wastewater, and there is about 7,600 kilojoules of energy in each metre cubed of wastewater. So it's really crazy.

Robyn Williams: In the old days of course the poo and various other bits of slurry used to go on boats out to sea and you'd dump it at great expense. What do you do now?

Thomas Curtis: Well, the sludge in the conventional wastewater treatment is now heated in a big pressure cooker to break down the larger cell walls in that and then sent for anaerobic digestion and produces methane gas which they then inject into the national mains.

Robyn Williams: So that is used as natural gas.

Thomas Curtis: Exactly, that's natural gas, yes.

Robyn Williams: What are you doing to develop an idea of having a fuel cell?

Thomas Curtis: A microbial fuel cell is a technology in which at the anode the bacteria rip the electrons off the carbohydrates in the waste and send that into a circuit. The hydrogen ions which are released from that then travel to the cathode where they can be reenacted with the electrons, in the first instance to produce water. That's in a simple microbial fuel cell. However, if you add a very small amount of energy to the process and top up the electrons as they come around from the anode, then you can get the hydrogen ions that come from the carbohydrates to be turned into hydrogen gas at the anode, and that is not only a simpler thing to engineer, we believe, it's also a much more valuable product. So hydrogen is worth six times what methane is worth.

Robyn Williams: So there you have a fuel cell driven by bacteria, and coming off it you've got CO_2 on one side and hydrogen ions, in other words the hydrogen gas eventually, on the other, and you can actually use the hydrogen itself as a valuable commodity.

Thomas Curtis: Yes, the hydrogen is a commodity in its own right. It's just the beginning. If you can produce hydrogen you can produce all sorts of other things. So if you have hydrogen ions and these more energetic electrons then you get hydrogen gas, but if you were to introduce certain catalysts and carbon dioxide then you could get acetate or methanol or other even more high-valuable products out. So the hydrogen really should be just the beginning, we should in theory be able to get many other high-value products out of the waste treatment process.

Robyn Williams: So you're talking about a poo-driven power plant. Would it be cost-effective?

Thomas Curtis: Well, it wasn't cost-effective we certainly wouldn't bother. We want to make waste treatment cheap and useful for everybody. We are yet to see if it will be cost effective. On paper at present it is.

Robyn Williams: At the same time you've got fertilisers coming off. What percentage of the sludge is fertiliser?

Thomas Curtis: Well, potentially all of it, all the sludge can be used as fertiliser and indeed it is. There's no reason why all the sludge can't be reused and applied to land. And as nitrogen and phosphorus become more and more expensive, that's become a very important thing to do.

Robyn Williams: What stage has this development reached in terms of the energy production you're talking about?

Thomas Curtis: We've done things at what we call a pilot scale, that's with real wastewater at real low-temperature Newcastle weather, Newcastle England that is, and we've got about 70% energy recovery. We have had our first very first primitive pilot and we are now going onto our second generation in which we've learned a lot of lessons from the first one and we are hoping to get 100%, 120% of the energy we are putting in out as hydrogen by this time next year.

Robyn Williams: Okay, well, look at the world, you've been to Brazil, you've been to a number of other countries…have you been to Australia, by the way?

Thomas Curtis: I have been to Australia, only briefly, to Melbourne many years ago.

Robyn Williams: So you know the people in Melbourne actually poo as well. And around the world you've got all this stuff being produced every day by people, half the world's population living in cities. Can you imagine what scale this poo producing energy could reach if we did it right?

Thomas Curtis: Well, it will happen everywhere. I don't see any reason why we shouldn't have energy positive wastewater treatment systems in every city from Newcastle in Australia to Newcastle in England, and **China**, Africa, America and everywhere in between. In fact I don't see how we can avoid not doing this because we don't have to break the laws of thermodynamics, we just have to think hard.

Robyn Williams: But is the engineering hard?

Thomas Curtis: Yes, and there is a lot of science to be done yet. For fuel cells you need the synthesis of very good chemical engineering and electrical engineering, very good microbial ecology and biological engineering, and very good environmental engineering. But with engineers and scientists working in teams, with of course good relationships with the practitioners, I think this is possible.

Robyn Williams: And when you've got the hydrogen produced, say, as one product, it's always been a problem as how you transport it. Is that a difficult question or can you just put it in tanks or put it in pipes and take it anywhere you like?

Thomas Curtis: In the north-east we actually have our own hydrogen network, but more generally you could actually turn it into electricity on-**site** or you could transport it and sell it or, as I said before, hydrogen is just the beginning, you can use it to make acetate or methanol, which are easy to transport and have higher values still.

Robyn Williams: Are you getting support from the public, from government, from councils?

Thomas Curtis: We have fantastic support. We've found the fuel cell idea captures everybody's imagination. We have excellent support from the local water **company**, Northumbrian Water, and multi-million-pound support from the UK's Engineering and Physical Sciences Research Council.

Robyn Williams: Tom Curtis at Newcastle upon Tyne where he is professor of environmental engineering. So many options, renewables on the rise. The Science Show on RN.

One of the reasons we are talking about renewables is of course the effect of climate change, this you know. And our PhD this week, Stephanie Brodie from the University of New South Wales is studying one manifestation of it in the sea.

Stephanie Brodie: During the beginning of 2012, the waters off Hobart had a visitor which had never been seen before. This visitor was the popular yellowtail kingfish, a fish prized for its flesh and its fight. But why was this fish discovered almost 400 kilometres further south of its known range? The culprit is the East Australia Current, known as the EAC and made famous by the popular movie Finding Nemo. This ocean current runs along the east coast of Australia, shifting warm water from the Coral Sea towards Tasmania. Due to winds associated with climate change, the EAC has strengthened in recent years and is extending warmer and saltier waters further south, changing marine habitats along the way.

The arrival of new marine species to this south-eastern corner of Australia has not been uncommon in recent years and is a product of these shifting waters alternating oceanic habitats, resulting in remarkable ecosystem shifts and consequences for fisheries. The most commonly known example is the habitat expansion of the long-spined sea urchin, where this urchin habitat has expanded into Victorian and

Tasmanian waters, resulting in loss of kelp habitat and affecting the multi-million-dollar abalone fisheries in these states. This is not an isolated case, and the unknown effect of these shifting habitats is the reason why I have started a PhD at the University of New South Wales. I am examining how these dynamic and variable ocean currents influence the distributions of pelagic fish.

I am looking at the movements of two important recreational and **commercial** fish species, namely mahi mahi and yellowtail kingfish. Both species are associated with waters that are now moving further south, however we don't know how pelagic fish like kingfish and mahi mahi are going to respond to these changing oceanic environments. The first step in examining the movements of fish is to track them. Typically animal tracking involves GPS, however this doesn't work underwater, so instead scientists use sound, a technique referred to as acoustic telemetry. This method involves inserting an acoustic transmitter into fish using simple surgical techniques. Listening stations positioned along the coast record the unique sound transmitted from tagged fish. The noise signals are specifically coded for each individual fish, so once the information from all the listening stations is pieced together we are able to calculate movements for each unique fish.

I have just finished sampling fish movements using acoustic telemetry, and I am currently using the results to create a habitat preference model. This determines what oceanic habitats kingfish and mahi mahi prefer. It is easy to think of the ocean as being a static body, but in reality the ocean is analogous to terrestrial systems where you can have deserts and rainforests of great diversity. By describing the oceanic habitats of pelagic fish, my research will help fisheries management strategies adapt to a dynamic and changing ocean.

Robyn Williams: Steph Brodie at the University of New South Wales, doing her PhD tracking fish. And one of the reasons that the ocean is changing is because of mining and trawling. This was a feature at the American Association for the Advancement of Science meeting in Chicago where marine scientists warned of an effect that they say we are not really noticing, yet.

Linwood Pendleton: My name is Linwood Pendleton, I'm an economist. I have three things I want you to know about what's happening in the deep sea. First of all we have already industrialised many parts of the deep sea. We have deep sea trawling for fish, we have oil and gas extraction, but we have cables and we have barrels of waste.

What's happening now though is we are about to move into a different era, a new era of deep sea industrialisation. Keep in mind that all industrial activity in the deep sea has some environmental impact. Even oil and gas which seems to have a relatively small footprint has a relatively large at times impact on environmental conditions. For instance, the oil and gas platforms in British and Norwegian waters alone have produced 2 million cubic feet of drilling wastes. That's enough to fill the Hyatt Regency up to the 20th floor. That waste sits on the floor of the deep sea, smothering the organisms there. It has toxins of course. Accidents in the deep sea will happen.

The second thing I want you to know is that the goal of policy is to try to identify and stop extractive and industrial activities when the costs exceed the benefits. And the way to do that is the third point which is to develop a set of criteria that are agreed upon universally that are applied internationally in international waters and in the EEZs, the exclusive economic zones of all countries, because much of this activity is happening in the sovereign waters of developing countries and developed countries. And to have that set of criteria be very broad.

The kinds of criteria that should be included in that kind of assessment include economic criteria. Of course the benefits have to be greater than the costs, but in the deep sea the benefits have to be much greater than the costs because we don't understand the costs yet and there are bound to be unanticipated costs. We have to always ask if there are greener substitutes outside of the deep sea. Clearly with phosphates there are lots of places we can get phosphates from, including animal wastes, human wastes and pollutants that have already been dumped into estuaries, in places like the Baltic Sea, that are full of recoverable phosphates. The same thing holds for fish that are trawled, lots of sources of proteins outside of the deep sea. It is not so clear about minerals.

And finally, before we undertake deep sea extraction of any type, we have to understand whether or not there are representative areas that have equal ecological value that we can set aside and protect, or whether we can restore the damage that is done. So if you take these criteria, as I've loosely described them, and you start to apply them to deep sea activities that we've heard about, you find very quickly that things like deep sea trawling don't seem to make much sense, no matter how you slice it.

Oil and gas is another matter. Oil and gas, depending on how scarce energy resources are and what the price of oil is, can make sense in the deep sea. When it comes to deep sea minerals there are no easy answers. There are different kinds of minerals with different kinds of values, different kinds of extraction techniques taking place in different parts of the ocean, and the deep sea is a huge place; 70% of the

Earth's surface is covered by ocean, 70% of that is in the deep sea. So is going to be critical to have these criteria in place and apply them before the activity happens instead of afterwards.

Robyn Williams: Linwood Pendleton is director of the Ocean and Coastal Policy Program at Duke Nicolas Institute in North Carolina. He talked about minerals. Which ones? Lisa Levin has a surprising list.

Lisa Levin: It's really ironic that our alternative energy and advanced economy are a part of what's driving us down into deep water, for example a hybrid car battery I've been told uses more than 10 pounds of rare earth elements, things that we are now looking to the deep sea for. All computers and cell phones use vast amounts of rare elements. There's neodymium in magnets that run everything from our earbuds in our iPhones to wind turbines for alternative energy. So it's really the advanced economy that's part of what's driving us to think about mining the deep sea now.

Robyn Williams: Lisa Levin is professor at the Scripps Institution of Oceanography in La Jolla, California. She led the **group** calling for caution.

Lisa Levin: Yes, in fact most of the planet is the deep ocean, something like two-thirds of the planet is covered by deep sea, and if you want to look at it in terms of volume or habitable area, over 90% of our planet is actually deep ocean.

Robyn Williams: Sylvia Earle is famous for saying that we know rather more about the surface of planets than we do about the deep ocean. Is that right still?

Lisa Levin: That's true for the Moon. I can't really testify to the other planets, but we've seen less than 5% of the deep ocean floor, so most likely we do know more about the face of the Moon than the deep sea.

Robyn Williams: Why are you worried about the exploitation of the deep?

Lisa Levin: There are several reasons. Humans are starting to modify the deep sea without knowing what's down there. We do know that the deep waters hold life, a high biodiversity that is very important to us in terms of the health of the planet, it sequesters carbon and cycles nutrients. We have to have healthy deep sea ecosystems in order to have a healthy ocean, and we have to have a healthy ocean to have a healthy planet.

What's happening now is that humans are beginning to fish down there, they are drilling for oil and gas in the deep and they are starting or planning to mine for raw materials in the deep sea. And much of this happens without actually knowing what it is that is being disturbed or destroyed in the process or even how long it's going to take to recover.

Robyn Williams: Which particular parts of the ocean are you worried about most?

Lisa Levin: I would say our continental margins get most of the human activity. About a fifth of our margins have been trawled by deep sea fishers. And the oil and gas of course, it's common to drill at several thousands of metres. So these are the areas that are in greatest danger, but in terms of the planned deep sea mining there are a series of habitats, seamounts are being targeted for cobalt crusts, and the nodule provinces are being targeted to mine manganese nodules for cobalt, nickel, zinc, and hydrothermal vents are being targeted for the massive sulphides that host gold, silver and other precious metals.

Robyn Williams: All over the world, around America as well?

Lisa Levin: The US doesn't have much deep sea mining targeted. Many of the first activities are targeting less-developed countries where there is little policy in place at it's within their exclusive economic zones. For example, the western islands, Solomon Islands, Papua New Guinea, Vanuatu, Tonga, Fiji, those countries are being targeted for mining of hydrothermal vent sulphides.

Robyn Williams: Very much in our region in the Pacific.

Lisa Levin: Yes, very much around Australia. New Zealand has lots of mining activities going on. There is interest in mining phosphates which are a little bit shallower. There is also interest in mining these off Namibia and Mexico, and iron sands, and there are other kinds of mining I think.

Robyn Williams: And what are you doing as a marine scientist to draw attention to this problem?

Lisa Levin: Well, for starters we are trying to talk about it, but we also recognise that while we have many, many science gaps that need to be filled, the solutions to managing the deep ocean don't just lie with natural scientists. We need economists, we need people involved in policy and law because there are many governance gaps in the deep sea. We need to engage stakeholders, both industry, governments and civil society. And what we are trying to do here is basically pull people together, have the conversation and begin to look at how we can have some global cooperation.

Robyn Williams: Are you finding it rather difficult because people don't actually see this very much at all?

Lisa Levin: I think there is a lot of education and public awareness that needs to happen before we can get the public to embrace the idea of managing and preserving the deep sea. What we really need in the meantime is the precautionary approach where we minimise or avoid harm and we protect those unknown ecosystems until we have time to gather the necessary science and gather the political will to actually take care of the…

Robyn Williams: Is there much evidence of harm, or are you assuming that there might be?

Lisa Levin: Well, in the case of deep sea trawling we know there's harm. These trawls, they are like clear cutting, they plough through, they remove all the fish, fish which might be hundreds of years old, they remove the three-dimensional structure of corals that might be thousands of years old on our margins, and they leave bare mud. And so we basically know that those populations don't recover quickly. They are probably not sustainable, and so trawling needs to stop.

Robyn Williams: Professor Lisa Levin at the Scripps Institution of Oceanography where she is director of the Centre for Marine Biodiversity and Conservation. She was speaking at the AAAS meeting in Chicago.

Next week The Science Show comes from Peru and Canberra, where Inca gold flourishes.

Production as usual by David Fisher and Simon Brathwaite. I'm Robyn Williams, on the Starship Enterprise.

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