ABC

HD **Artificial photosynthesis – the future of solar?**

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Plants make energy very efficiently: they take sunlight, water and carbon-dioxide and turn it into fuel to make them grow. So what if humans could mimic that process for their own fuel?

Barack Obama: The first step in winning the future is encouraging American innovation. We'll invest in biomedical research, information technology, and especially clean energy technology. We are telling America's scientists and engineers that if they assemble teams of the best minds in their fields and focus on the hardest problems in clean energy, we will fund the Apollo projects of our time. At the California Institute of Technology they are developing a way to turn sunlight and water into fuel for our cars. So instead of subsidising…

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Antony Funnell: Barack Obama might see potential in renewable energy technology, but in Australia the sector is having a hard time of it. The current federal government in Canberra has been busy winding back Australia's commitment.

It's now considering the findings of a review it commissioned into the nation's renewable energy target, a review chaired by a former oil executive, who critics deride as a climate change sceptic. As you can imagine, the overall mood is gloomy, to say the least.

Hello, Antony Funnell here, welcome to Future Tense.

Fran Kelly, RN Breakfast: As anticipated, the federal government's review of the renewable energy target has recommended a significant scaling-back of the scheme. The inquiry suggests two options; either closing the scheme to new entrants, or supporting new renewable energy power generation only when electricity demand is on the increase.

Antony Funnell: But all of that doesn't mean enthusiasm for renewables has been diminished completely.

Today on the program we'll meet an Australian scientist with a passion for renewable energy and innovation. And we'll learn about research into a potentially game-changing form of solar technology called 'artificial photosynthesis'.

But before we go there, it might be instructive to get a quick snapshot of just how significantly the clean or renewable energy market has changed in recent years.

Giles Parkinson is a former business editor and deputy editor of the Australian Financial Review, and he is now the founder and editor of the website RenewEconomy.com.

Giles Parkinson: Well, the size of the renewable energy sector worldwide is about US$260 billion, and that is forecast to grow pretty rapidly to over $1 trillion within a few years, and that's from the rather conservative forecast from the International Energy Agency. So they are seeing a combination of factors that will drive that. One is focused on climate policies, one is incentives which are provided to drive the transition to clean energy, and the third and the most important factor is the fact that very soon in many countries clean energy will be clearly competitive with other technologies and therefore will be installed without the need for subsidy.

Antony Funnell: And, as you say, the cost of renewable technologies has really come down in recent years, hasn't it.

Giles Parkinson: It has plummeted. Solar, for instance, has fallen about 80%, and most predictions are that it will continue to fall, maybe by not quite the same quantum but significant decline in any case. Wind technology is the other major one which has probably fallen maybe 25%, but that's because that's technology has been around a bit longer. Other technologies are also falling as well, but those technologies are probably not quite ready for **commercial** development, and I'm probably thinking here of solar thermal and wave and geothermal technologies.

Antony Funnell: And how significant has the investment of **China** in renewable energies been, particularly over the last half-decade or so?

Giles Parkinson: Well, it has been quite crucial. If we go back we saw the big incentives provided by the German government because they wanted a rapid transition to renewables, and that provided the investment impetus for all the **Chinese** manufacturers to invest in solar manufacturing, and that brought down the cost of manufacturing by a significant degree and basically underlined that.

What's interesting now is that those manufacturing costs are continuing to fall because there is great competition there between them and also US manufacturers and the few remaining European manufacturers, but also **China** has now emerged as the biggest market for the consumption of solar panels. That has changed their dynamics as well. And the second-biggest market is Japan which is looking for alternatives after the Fukushima disaster. And the third biggest market is the US where solar is increasing very rapidly.

Antony Funnell: So from an economic as well as an environmental perspective, renewable energies, they are going to continue to have significant potential, even if our government at the moment doesn't see them as the way ahead.

Giles Parkinson: Look, that's right, and our government has got this problem with providing incentives to renewable energy. And the issue in Australia and in some other developed countries is that demand has fallen. And so what's happening now is that the more renewables you bring into the market, the more that the coal and the gas generators get displaced and have to close down early. And there is just this massive pushback by those generators, the owners of those generators, which in Australia includes state governments (and they are very powerful, they are very influential) to stop the renewables.

What's interesting is that in the other markets where demand is increasing because they are emerging economies or because those countries do not have a big energy infrastructure, then solar and wind energy is proving competitive with all the other investment choices that they can make. So someone in India now choosing between a coal-fired generator and solar, it's about line ball at the moment and very soon it will be pretty much in the court of solar because that will be the cheapest option for them.

Antony Funnell: Giles Parkinson from RenewEconomy.com.

So, to recap, it's still a fossil fuel world. But at $260 billion US dollars and growing, the global renewable energy sector is not to be sneezed at. In the last decade or so, the industry has made significant advances. And who knows what new disruptive technology exists just around the corner? Well, now that I mention it, one approach that's got very little coverage but is showing enormous potential is what's called artificial photosynthesis.

Artificial photosynthesis video: The ingredients are simple; sunshine, carbon dioxide and water. For at least 2 billion years that recipe has worked for plants. Through the process of photosynthesis, leaves convert the Sun's rays into their own energy source. What if we could develop a technology that mimics the chemistry of a leaf and produces clean, abundant fuels directly from sunlight?

Antony Funnell: Across the world, teams of scientists are working to develop systems that will produce energy by mimicking the way in which plants work.

President Obama referenced that effort in the clip I played earlier in the show:

Barack Obama: At the California Institute of Technology they are developing a way to turn sunlight and water into fuel for our cars. So instead of subsidising…

Antony Funnell: Recently a **group** of leading experts in the field of artificial photosynthesis met in the UK for a conference organised by Australian academic Thomas Faunce.

Professor Faunce holds a joint position in the College of Law and the College of Medicine, Biology and the Environment at the ANU, the Australian National University. His vision is for a world where every human-made structure is covered in solar panels, not traditional photovoltaic panels, but devices that use sunlight to split water.

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Thomas Faunce: Well, essentially it works very similarly to the way photosynthesis works at the moment. If you look out a window you can see small photosynthesis going on with grass and big photosynthesis going on with trees. And essentially what those plants are doing, using sunlight as a source of energy to split water, H_2O, into hydrogen and oxygen, oxygen which goes off to create the atmosphere that allows us to breathe and keeps solar radiation away, and hydrogen which can be used in a variety of different energy forms, either hydrogen itself which can be burnt, produce energy and water as a by-product, or hydrogen which could be mixed with atmospheric nitrogen to make ammonia. So this is what plants are doing across the Earth at the moment, making hydrogen and oxygen, absorbing CO_2. So the simple vision is that we start doing our own photosynthesis in our buildings, not using biology, and all these structures that the increasing human population is putting across the surface of the Earth start to do photosynthesis themselves.

Antony Funnell: So it's about mimicking the energy generation that goes on every day in trees and plants, and in that sense it's a more natural form of solar energy generation, isn't it, then the traditional form of solar energy generation that we are used to.

Thomas Faunce: Well, it's a more evolved form. I think seeing that grabbing photons, as our solar energy collectors do at the moment, and sticking that energy into the electricity grid, is a very simplistic way of looking at the energy solution. You then have all sorts of problems with how do you cope with the diurnal supply of the energy, how do you store it and so forth, whereas for over a billion years plants have worked out that the crucial scientific question is how do you transform solar energy into chemical energy. Because once you've got that energy so transformed you can…as a structure you can move around, you can use it in different ways, you can use it at different times, you can store it.

The part of the science that is the most clearly worked out is the splitting of water. That's been going on for almost 50 years now. Scientists have been using rare earth metals in particular, like ruthenium and iridium to use solar energy to split water into hydrogen and oxygen. That part of it could be improved. We are still looking for a catalyst which is as efficient as the way plants work. Plants use manganese. People are looking at doped dioxide and cobalt and other forms of catalysts. But if you're going to come up with a form of water splitting that's capable of being used across the planet, it has to have a good life cycle analysis. You want to make sure that that catalyst, when it goes off into the biosphere, is not going to create problems.

So in answer to your question, that side of things—the water splitting and the catalysis—is the side of the artificial photosynthesis that's most fully worked out, although there is still a long way to go in coming up with a prototype water splitting device that could be commercialised.

Antony Funnell: So that's the grand vision, a radical new form of solar technology. And, as Thomas Faunce mentioned, it isn't simply a theoretical one.

Daniel Nocera: What we have here is the leaf itself and it has silicon and it's coated with my catalyst. And now what I'm going to do is drop it into this container, put in some water…

Antony Funnell: What you're listening to now is a clip from a BBC video in which Harvard scientist Daniel Nocera demonstrates artificial photosynthesis at work.

Daniel Nocera: And so as we turn on the Sun…

Presenter: I'm seeing some bubbles…

Daniel Nocera: And now it's making oxygen. And then the protons are running around to the back side here. So this is looking just like the leaf; sunlight in, wireless current, I charge it up, two catalysts make oxygen and hydrogen.

Presenter: That's very good, that's very good.

Daniel Nocera: Thanks…

Antony Funnell: In 2011 Daniel Nocera unveiled a device called the Artificial Leaf. We've linked to the video on our webpage if you want to take a look.

Essentially his device proves that you can make a relatively simple artificial photosynthesis panel, a panel, says Nocera, that's not only efficient, but also solves the great problem faced by traditional forms of solar technology; the problem of storage.

Daniel Nocera: So photovoltaics in all of the energy systems you think about solar, you use it when it's there. So when the Sun is out it's generating energy into a different form. But you're using it when it's there. And the piece that is missing is energy storage, it's the storage of that energy. And so the artificial

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photosynthesis gives you a means to basically bottle up the sunlight in the form of a fuel, and you can use the fuel when the Sun goes down. And so artificial photosynthesis really is a storage mechanism, that's what the plants do with photosynthesis, it's a storage mechanism. When the sun is hitting the plant it's converting it into a fuel—carbohydrate—that you can use and eat at some later time. So they're very paralleled, the artificial photosynthesis versus photosynthesis. They are basically storing sunlight in a usable form that you can use on demand. It gives a storage mechanism for the photovoltaic, in effect.

Antony Funnell: And that's a very important point, isn't it, because one of the criticisms of traditional solar systems and what is said to have held them back, is that storage issue.

Daniel Nocera: That's right. So I'm going to put it in a different way. Say you're a power **company**. Right now power companies don't really care if you are using renewable energy or not. And the reason is, if you are generating electricity on your roof, they can't make money off of it. If they had storage you could then send the electricity from your roof to them. They would store it, and then at night they could sell it back to you. So with storage, energy becomes a commodity because you can sell it once you store it.

So my feeling is, with good energy storage, that's what will make renewable energy take off. And so when people talk about solar panels and it's too expensive, I actually have a different view, that the only thing holding back renewable energy right now is storage. And once you have a good storage mechanism…and chemical fuels is the best way to store energy, it's the most energy dense form of storing energy…once you have a storage mechanism, I believe renewable energy will take off and you will see solar photovoltaics everywhere.

Antony Funnell: Because it's making it **commercial** in that sense. That's going to achieve the scaling up of the technology, isn't it, because artificial photosynthesis, as you know, as you've been part of demonstrating, can work. This isn't theory. But the problem has been to date, hasn't it, trying to get it to a **commercial** level, trying to scale it up.

Daniel Nocera: Yes, whether we like it or not, things don't take off until you can make profits and people can make money. And so there has been no impetus or motivation because people can't make money off of solar energy easily without a storage mechanism. So you can put some solar panels on your roof and run your house, but the only person making money there is the people who install them, effectively, and sell them. You don't have a long term basic financial model unless energy is being dealt with and becomes a commodity.

And I can tell you, just out of personal experience…you have alluded to my work and I have this invention called the Artificial Leaf, but I had a **company** that was spun out of the Artificial Leaf, and as we are speaking it is being **sold** to a Fortune 100 **company** because they want to get into the energy game because they see what I'm telling you right now; there's money to be made in the future if you have good energy storage mechanisms. And so I'm starting to see it everywhere. A lot of times people think, oh, the oil companies are suppressing the development of energy. It's not, they just don't have any motivation to do it. But there are other companies, Fortune 100 companies that are just as big as oil companies but historically they haven't made money in energy, they've done other things, and they see their growth area as the energy market, and it will be those types of companies that start driving these technologies.

Antony Funnell: So from your first-hand experience then, we are just on the edge of this taking off, are we?

Daniel Nocera: Where on the cusp, it's about to happen. If you take a lot of companies right now that historically haven't done energy, say a big defence contractor, they will get their future…for instance, I'll just use defence funds are drying up, so you have big engineering companies and they look to the future and they say, well, what is a growth area for us? A growth area will be energy. And so I'm starting to see lots of companies (and these are big companies) internally starting to restructure as their internal R&D efforts to start out on an energy pathway. And a lot of it really gets down to exactly what you said—the storage—because once they can store energy, they have something they can market and people will want to **buy** it. And so I believe we really are on the cusp of all of this, yes.

Antony Funnell: Harvard University's Daniel Nocera.

So artificial photosynthesis could provide the cheap, clean energy solution of the future. But the ANU's Thomas Faunce sees far more than just a new form of solar technology. He speaks of its development as having a moral dimension. And what he means by that is that it represents a way of correcting the damage humans have done to the environment through the use of fossil fuels. Because, if you think back to your school days and to biology class, you'll remember that the process of photosynthesis actually reduces the amount of carbon dioxide in the atmosphere.

Thomas Faunce again:

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Thomas Faunce: Really if you ask why people such as myself are most enthusiastic about this as a solution to a lot of our problems on Earth at the moment is that it's not just an energy solution, it's a distributed energy solution. So it's an energy solution that puts power into the homes and the structures around individual families and individual communities. Once these structures are created with this technology, they will have their own locally sourced fuel which is cheap and readily available.

But not only that, when the technology is fully developed, each of those units will be capable of taking carbon dioxide either from concentrated areas such as engines or other areas where there is high concentrations of CO_2, buildings and so forth, but even just from the atmosphere where it's quite diffuse, and then incorporating that to enrich the soil through mechanisms like using it to create biochar, potentially using it to create starches in the same way that plants do at the moment, which could include buildings making their own paper supply or basic starches that could be incorporated in food, and then incorporating atmospheric nitrogen to make ammonia fertiliser or combining it with the hydrogen to make fuel.

So it's a package that, once it is fully worked out and spread across the planet, will change a lot of the power structures and the way in which human beings live by giving families and local communities a lot more autonomy over their food and fuel.

Antony Funnell: There are various research projects underway looking at the development of artificial photosynthesis, but you've been pushing for the creation of a global artificial photosynthesis project. Why? And what does that say about the research efforts to date?

Thomas Faunce: People may not be aware, but most developed nations have now large national projects working on artificial photosynthesis. The largest is the Joint Centre on Artificial Photosynthesis at Caltech, which was funded by the Obama administration with $122 million. The South Koreans have a Korean artificial photosynthesis project, the **Chinese** have a large project, the Singaporeans at Nanyang University, the Max Planck Institute in Germany, most European nations, particularly thinking about Sweden, the United Kingdom. Australia has a centre of excellence called ACES which is working on artificial photosynthesis, and a lot of other researchers working in the field.

So we have a situation now where governments through their funding structures have set up what you could call centres of excellence or national projects working on aspects of artificial photosynthesis, but the nature of the grant funding challenge with academia is that researchers tend to write proposals in which they can show the funders, the government, that they've achieved something within a short time frame, which means that a lot of these proposals are focused on developing new catalysts for splitting water because it's possible to do this or show that there's been some improvement over the standard lifetime of a grant, which is about, say, five years or so.

The problem is that a lot of these harder areas of the science—the carbon dioxide reduction and the nitrogen absorption—are sort of left hanging because it's much harder to show funders that you've made progress in this sort of very difficult area. So that's one of the main reasons why we think we need to shift to some global initiative.

I think the other problem is that these national projects have some wonderful researchers, but in a sense they are replicating a lot of each other's work. There's a sort of competitive race going on, that's understandable, but at the same time there is no doubt that if we can foster collaboration, particularly where we could cherry-pick the best researchers, say, working on CO_2 reduction, and bring them together into projects, that would be an advantage. Or even if individual researchers who are outside these national projects and perhaps not receiving large amounts of money but came up with a fantastic idea, there could be some mechanism for helping that along and then using resources to encourage that sort of outside the mainstream development.

Antony Funnell: You recently held an international scientific conference on artificial photosynthesis, supported by the Royal Society in Britain. So what came out of that particular meeting?

Thomas Faunce: Yes, well, that's actually the second large international conference that I've organised developing the idea of a global artificial photosynthesis project. The first was held in Australia at Lord Howe **Island** in August 2011, and yes, in July I coordinated a meeting funded by the Hooke Committee of the UK Royal Society to actually go much further and try and get towards what you could almost call a business plan for a global project.

So we invited to that meeting representatives from Deutsche Bank, from Shell, from the Wellcome Trust, and the Moore Foundation, which is a large charitable foundation that funds environmental projects, and we opened up the meeting with the Wellcome Trust and Moore Foundation in particular saying, well, this is what we would like to see from the field if we were going to fund a global project, and so in a sense giving writing instructions to the 50 or 60 representatives of these large national projects who are gathered. And as the meeting went along these researchers were encouraged not just to present a snapshot of their

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cutting-edge research on artificial photosynthesis but try and discuss how that research could be facilitated, accelerated, taken to the next step by a global project.

So it was a fascinating series of discussions. Outcomes of the meeting is we hope to produce a series of principles, like a sort of ethical statement about why you'd want a global project and what its visionary goals are, how it's going to help humanity. That's a particular interest of mine. I guess we saw it as a way in which we could start shaping the field to create the sort of structures that would be necessary if we were going to get to the next step of having a global project on it, which I think to me is a critical endeavour of this field, is to take off…there's no doubt that this technology, the artificial photosynthesis technology will evolve, but have we really got 50 or 100 years to wait until this happens?

I think the vision behind a global project is that humanity doesn't have this length of time, and if we can get a project going on artificial photosynthesis as, for example, the Wellcome Trust funded the project on the human genome project, it may be that we could see an exponential acceleration in the pace of research which would lead to both a global energy and a climate change solution in time to reduce some of the dire consequences that we are all aware of of leaving these problems go unchecked.

Daniel Nocera: It's interesting to listen to Tom talk about it, because he talks about it as a moral imperative, which I believe it is. And the reason is that we are changing the planet, and that's going to change the lives of future generations. And I do believe in what he is saying, that it's a moral imperative since we are the ones doing it, we need to fix it and deliver a future planet to the population that's sustainable. So the moral imperative idea is one that I fully believe in, and if we are messing it up, it's our job to fix it.

But then there's a second piece which is coordination. So the United States and most countries have a Department of Energy, and the problem is there's a Department of Energy in America and we do science, and then there is a Department of Energy in Australia and people are doing science, and there is no coordination among all these efforts. And so it's extremely inefficient, the way this field is doing research and moving forward. So if you had basically a global Department of Energy that was saying what are the strengths, what projects are going on over here, how can we coordinate the projects going on over here in this part of the world, it would be a lot more efficient I believe and a lot quicker we would get to a solution.

And so besides the moral imperative, just from an efficiency point of view, a global effort would start to coordinate people and money would be used more, I believe, wisely and more directed and targeted to a solution. So on both sides of the coin I think there is great power to having a coordinated effort in solar energy, solar energy storage, in this area of artificial photosynthesis.

Antony Funnell: And the realistic possibilities of that happening, given the **commercial** potential I guess of this type of technology and all that that means in terms of competition?

Daniel Nocera: Yes, at some level…so there's the research that's got to be done and I believe that should all get coordinated. But then down to the realism again, if people are going to make money there's got to be some level of competition internally. So I think when it finally starts getting spun out to companies, I doubt they will globally coordinate. That's not how they make money. But before you get to **commercial** ventures there is this massive amount of research that needs to be done and proven, and there's got to be prototypes, prototyping to prove that it can be done at scale. That should all, in my opinion, be coordinated, and it could be coordinated with a global effort.

Once you get to commercialisation things are going to move quickly. It's probably best they not be coordinated and there would be internal competition because that's what would drive it to market more quickly. But when I talked to Tom, the part I'm more interested in is…if you get to that stage it's a home run. Once you have companies fighting over a technology to develop to go to market, you've won, it's going to happen. But before that, there's a whole bunch of research and then even engineering to prototyping to prove it can be done at scale. That should be coordinated. And I don't think that should be competitive, it should be a coordinated effort.

Antony Funnell: Professor Daniel Nocera from Harvard University, ending our look at the science of artificial photosynthesis, a potential new form of renewable energy, and also—according to our other main guest today, the ANU's Professor Thomas Faunce—a moral imperative. Our third guest was Giles Parkinson from the website RenewEconomy.com.

The sound engineer for this edition of Future Tense was Peter McMurray. I'm Antony Funnell, until next time, cheers!

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