21st Century Nuclear

We hope you enjoy the first article in our series on nuclear energy, to run over the next six issues of the journal.

Designed to inform you of the realities and innovations of nuclear technology, the series is being written by two South Australian experts on the topic, Professor Barry Brook and Mr Ben Heard.

Professor Barry Brook is a renowned environmental scientist, holding the Sir Hubert Wilkins Chair of Climate Change at the University of Adelaide's School of Earth and Environmental Sciences. He is also Director of Climate Science at the University's Environment Institute.

Professor Brook has received several awards for excellence in research and was named the 2010 Community Science Educator of the Year for his public outreach activities.

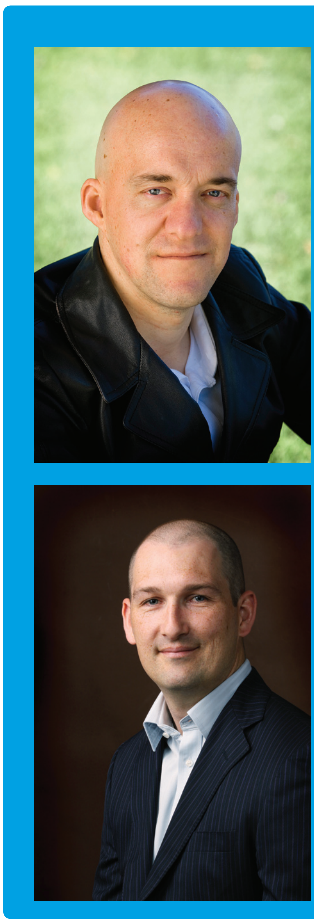
He has published three books, more than 190 refereed scientific papers and writes a popular blog at http://bravenewclimate.com.

Ben Heard is the Director of ThinkClimate Consulting and has more than eight years experience consulting in climate change, sustainability and stakeholder management.

He founded Decarbonise SA to promote understanding of the role of nuclear power in cutting greenhouse emissions in South Australia. He has written many articles on climate change and sustainability and provides lectures through the University of Adelaide.

Mr Heard holds a Masters degree in Corporate Environmental and Sustainability Management.

Megan Andrews Editor



Professor Barry Brook, top, and Ben Heard.

Living in the Present

The incredible reality of Generation IV nuclear is emerging, but that's no reason to ignore the excellent technology available right now. **By Ben Heard.**

Generation IV nuclear reactors bring the advantages of remarkable passive safety; the ability to recycle current nuclear waste (which is 98 per cent uranium) as fuel; and the ability to consume all isotopes of uranium and plutonium.

Put simply, this means extraordinary amounts of energy are produced per unit of fuel, resulting in negligible quantities of waste with truly negligible quantities of much shorter lived waste as a result.

The technology is proven, but not yet commercial.

So there is some time to wait before Generation IV reactors are deployed. But they are so impressive even hardened nuclear opponents are now thinking twice.

This imminent technology does however invite the question – should Australia wait for these Generation IV reactors rather than use what could be bought and built immediately?

There are many reasons why Australia should not.

Currently available nuclear power technology is already 99 times better than our current energy supply, when considering undesirable impacts from energy sources.

For example, the rate of greenhouse gas emitted from South Australia's coal power stations is about 1,100 g CO$_2$ per kWh. The greenhouse gas from nuclear operated in Australia (best estimate) for full lifecycle is 60g CO$_2$e/kWh.

Radiation pollution to the surrounding environment is about 100 times greater from a coal fired power plant than a nuclear plant. Other air pollution from coal or gas includes sulphur dioxide, nitric oxides, carbon monoxide, heavy metals (lead cadmium, mercury), arsenic, VOCs and particulates.

These pollutants are not emitted by nuclear. Nuclear produces very small amounts of high level nuclear waste. Once cooled and safely stored it does not negatively interact with the environment or people.

By comparison, the uncontained pollution from fossil fuel power stations is far greater - estimated at around 99 times.

In terms of mining impacts, the brown coal we burn here in South Australia carries 10-20 GJ of energy per ton. A ton of natural gas liquids carries around 45 GJ. The energy content of a ton of uranium in a modern commercial reactor is 420,000-675,000 GJ. So the mining impacts per unit of energy provided are much lower for nuclear power than fossil fuels.

Finally, nuclear power is the safest of all the major power sources (coal, gas, oil and hydro) when considering the performance of the whole industry, old reactors and new, over the past 40 years.

A Generation III+ reactor that would be built today is orders of magnitude safer again than its predecessors.

A Generation IV reactor, by generating abundant power from nuclear waste (which is around 99 per cent uranium) is about 100 times better again.

But holding out for Generation IV technology, which may be 10-15 years from full commercialisation, means saying "no" to fixing 99 per cent of national energy problems right now, instead insisting on a 99.9 per cent solution further in the future.

Even if we held out for Generation IV nuclear which ended up being just eight years later than achievable with Generation III+, the delay could mean an extra 65 million tonnes of CO_2-e in South Australia alone dumped in the atmosphere – together with all the rest of the pollution – from our baseload power.

Instead, greenhouse emissions and toxic pollution could have been slashed and an efficient and economical energy supply secured sooner.

Hesitation in the name of Generation IV nuclear is a luxury that flies in the face of an urgent response to climate change.

But urgent development of Generation IV is still vital.

By consuming 100 per cent of the fuel plus the depleted uranium from the enrichment process instead of just 1 per cent of the fuel, new generation nuclear provides over 100 times more energy than Generation III+. The 100 fold difference between the nuclear technologies delivers not a mere 0.9 per cent variance, but a 99 per cent+ change for the better from our current system.

So while Generation III+ does a 99 per cent job of solving the problems, Generation IV nuclear opens up incredible opportunities to solve even bigger problems and do even more wonderful things.

So bring on Generation IV.

But the de-carbonisation of Australia's energy supply has already been delayed for too long. Generation III+ nuclear is an excellent solution that can be deployed immediately - it's time to get on with it.

From left, Tom Blees, Shanti Blees, Barry Brook, Charles Till, Chad Pope, John Sackett and a PhD student pictured in front of the Experimental Breeder Reactor in Idaho, which became the Integral Fast Reactor Prototype (Generation IV). The development team was led by Charles Till.

Generation IV nuclear technology will:

- Provide clean, safe, low cost and limitless energy globally, accelerating reductions in poverty
- Power water supply and food production for a future population of 9 billion people
- Power solutions to draw down carbon dioxide from the atmosphere
- Provide abundant energy to assist in decarbonising transport

Nuclear power a safe option

By PROFESSOR BARRY BROOK AND BEN HEARD

An AP1000 under construction at Sanmen, China , October 2011

Prof Barry Brook

Ben Heard

Safety is a major public concern for nuclear power. There is no quick way to overcome this feeling, but a few facts certainly can't hurt.

The nuclear power industry has an excellent operational safety record. A major actuarial study conducted by the European Commission over 15 years examined 4,290 energy-related accidents across different technologies. They found the following: deaths from coal totaled 25 workers per terawatt hour of energy delivered, 36 for oil, 4 for gas, and hydro, wind, solar and nuclear all less than 0.2.

They state, "expected fatality rates are lowest for western hydropower and nuclear power plants". So, permitting ourselves to think in the context of the alternative energy supply options, there is no argument; nuclear power is very, very safe.

Serious nuclear accidents have happened.

The Three Mile Island reactor in the US experienced a partial meltdown of the fuel. The reactor pressure vessel was not ruptured, however, and the containment dome held the majority of the gaseous releases within the reactor building, but the core partly melted and was a write-off. No one was killed.

A much worse incident occurred in 1986 at Chernobyl, Ukraine. During a poorly planned experiment where the safety systems were deliberately disabled, a massive power surge blew the top off the reactor and triggered a fire in the graphite moderator. This Soviet-era design lacked a concrete containment dome, and the wind-driven smoke carried a plume of radioactive particles over Europe. The accident and its immediate aftermath killed 28 emergency workers.

Among local children and adolescents exposed to highly elevated doses of short lived radioactive iodine in milk, more than 6,000 cases of thyroid cancer were observed, 15 of these have proved fatal.

The UN Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) state: "there has been no persuasive evidence of any other health effect in the general population that can be attributed to radiation exposure".

For many, these findings from the peak global body are surprising.

This year, an extreme natural force disabled the 40-year old reactors of Fukushima Daichi and destroyed all back-up power supply. Prolonged loss of cooling led to a meltdown and the release of radioactive material in vented steam as well as possibly through some breached containment. There were no nuclear-related fatalities. Suitable precautionary measures for residents were taken, and the radiation released was 4.5 per cent that of Chernobyl.

The possibility of any latent fatality is exceedingly low.

These accidents frightened us more than they hurt us.

Modern reactors cannot run out of control in the way Chernobyl did because water plays the role of both the coolant and the moderator. If the coolant cannot shed heat, the water expands and moderation is reduced. The reactor loses reactivity and power levels decrease.

New reactors include safety systems that rely on natural processes. For example, the core-cooling tank in the AP-1000 design has valves held shut by AC power. During station blackout, emergency water is channeled into the reactor core by gravity, and re-circulated through passive convection and condensation.

> Modern reactors cannot run out of control in the way Chernobyl did because water plays the role of both the coolant and the moderator.

This class of reactors, known as a called Generation III+, are also built to a standardised design, with most component modules pre-fabricated in a factory and then assembled on site. These quality controls reduce cost but also enhance reliability and safety.

These improvements make a big difference.

Probabilistic risk assessment put the risk of core damage from design-basis events as 1 in 20,000 reactor years for a 1970s design. For the AP-1000, it's 1 in 24 million. Already engineered to be among the safest of power sources, today's designs are three additional orders of magnitude safer.

Yes, there is a miniscule risk that a terrorist could hit a reactor with pinpoint accuracy, breech containment, and cause the release of some nuclear material. It's just an incredibly low risk.

Our society functions by making rational decisions about risk and nuclear power is no different.

Many fear the impact of low-level, long-term exposure to radiation. Well, we already have such exposure; ionizing radiation is natural and with us every day.

UNSCEAR says the additional radiation exposure for those living in the vicinity of nuclear power plants through non-accident trace releases is 0.0002 millisieverts (mSv) per year, compared to a background level of 2 to 4 mSv per year. So it works out that 1/15,000 of your total yearly dosage could come from nuclear power. As far as meaningful risk goes, this one truly is not worth the worry.

As the conversation around nuclear power in Australia builds, fear will give way to a desire for information. In a fact-based discussion on safety in energy, nuclear proponents need not be concerned.

Nuclear waste realities

By PROFESSOR BARRY BROOK AND BEN HEARD

In the big hitting concerns about nuclear power, long-lived radioactive waste may just be the most powerful in the public eye.

But the fear-laden awareness of long-lived radioactive waste belies many of the realities of its management.

The best start for responsible management of any hazardous waste is to capture and contain it at the source. Nuclear power does this. Fossil fuels do not. The combustion of coal and other fossil fuels produces toxic fly ash, mercury, radioisotopes, nitrates and sulphates and, of course, huge amounts of carbon dioxide – globally, almost 30 billion tons each year.

Secondly, radioactive waste is perceived as complex. This is far from the truth. Radioactive material is one of the most predictable, easily monitored and best understood forms of waste. We know what it does, and how it does it, forever, and it is managed accordingly.

Imagine a very loud noise source that you cannot turn off, that is very, very slowly getting quieter. Stand too close for too long and you will get an injury or even go deaf. How would you manage such a thing? Contain it in dense material, put distance between it and you, and let it quiet down. That is what happens for radioactive material in long-term storage, and it is very secure. The material in Dry Cask Storage at Fukushima bore the full brunt of the tsunamis, with no damage. The image of the leaky, rusty barrel being stuffed into a tree by Mr Burns is, quite appropriately, a joke.

Thirdly, the quantities in question are relatively very small. Australia produces (and somehow manages) around 1.1 million tons of hazardous waste every single year. A large-scale 25 GW nuclear power industry would add a mere 750 tons, taking up just 250 m3 (six-and-a-half standard shipping containers). But of course that doesn't do it justice. This small quantity of contained waste would be displacing vast quantities of uncontained pollutants from fossil fuels; toxins and other unwanted by products that we have simply come to accept as the cost of reliable energy. The quantities for nuclear fission are so manageable that new reactor designs include a facility to hold all of the waste for the 60 year life of the plant, right there on site.

Still, a problem remains.

We must babysit the radioactive waste for tens or hundreds of millennia. For instance, plutonium produced in nuclear reactors has a half-life of 24,100 years, meaning you have to wait a few hundred thousand years for it to lose most of its radioactivity. Although storage in deep, geologically stable repositories is technically possible, the idea of bequeathing future generations this responsibility leaves many people understandably uncomfortable.

There is, however, a much better option: consume the long-lived waste, and in so doing, generate huge amounts of zero-carbon electricity. This can be done in Fast Reactors.

Plutonium and other 'transuranics' (elements heavier than uranium, such as neptunium, curium and americium – also called 'actinides') are the substances responsible for the long-lived radioactivity of nuclear waste. It makes up about 2 per cent of the spent fuel from current light water reactors. About 93 per cent is uranium.

The uranium is almost entirely the more plentiful, heavier and less-radioactive isotope U-238 which, unlike the rarer U-235, is mostly left unused in today's commercial reactors. The Fast Reactors are able to consume it all, as well as all the plutonium and other transuranics, converting them into energy. That increases the energy density of uranium about 150 times.

What's left behind after multiple recycles are the 'fission products', about 5 per cent of the original (once-through) waste, which are the lighter elements created when the actinides are split apart. This is the 'real' nuclear waste.

The fission products need to be managed for about 300 years, after which time they've lost 99.9 per cent of their original potency. To safely take them to this point, the fission products can be 'vitrified' (entombed within a highly durable glass-like matrix), or encapsulated within the Australian-designed 'synroc'. This highlights another huge plus for the future of nuclear power. Not only can all of the world's stockpile of spent nuclear fuel be consumed in Fast Reactors to produce copious amounts of zero-carbon energy, but what remains is a comparative cinch to take care of.

Nuclear dry tank storage

Not only can all of the world's stockpile of spent nuclear fuel be consumed in fastreactors to produce copious amounts of zero-carbon energy, but what remains is a comparative cinch to take care of

So nuclear waste stops being a major headache, and turns into an asset. An incredibly valuable asset, as it turns out.

In the US alone, there is 10 times more energy in already-mined depleted uranium (about 700,000 tonnes) and spent nuclear fuel, just sitting there in stockpiles, than there is coal in the ground. This is a multi-trillion dollar, zero-carbon energy resource, waiting to be harnessed.

To recap then: waste from nuclear reactors is tiny in volume and fully contained at the source.

It is well understood, and its safe management is relatively straightforward. By producing it, we would displace the vast uncontained toxic pollution from our fossil-fuel driven energy production, and take our most decisive step to resolving climate change. Within decades, it will be reused to produce yet more vast quantities of zero-carbon energy, leaving a tiny fraction of much shorter-lived waste behind.

On the road to sustainability, this would be a great leap forward for Australia.

In perspective

Barry Brook and **Ben Heard** discuss the carbon implications of the proposed Olympic Dam expansion in a global context.

South Australia is host to the largest known economic deposit of uranium in the world.

The plans to expand production at Olympic Dam would massively raise uranium production from 4,000 tonnes of uranium oxide (tUO2) in 2010 to a projected 19,000 tUO2 by the early 2020s. This enlarged, open-cut polymetallic mine would also produce vast quantities of copper and gold.

Some environmentalists have objected stridently to the project, including South Australia's Greens MLC, Mark Parnell, who said: "Our state risks being left with a huge carbon black hole as we become the greenhouse dump for one of the world's richest companies".

Such hyperbolic claims are easily made and can sound persuasive – but are they supported by evidence? Let's consider the accuracy and context of such an argument from a climate science perspective.

The greenhouse gas emissions from the expanded mine would come predominantly from heavy use of diesel and other liquid fuels for vehicles and mining equipment, and a 650 MW increase in electricity demand (likely gas powered), including the supply of 200 ML/day of desalinated water to the site. The result is that carbon dioxide equivalent emissions from the operation could peak at 4.7 million tonnes per year (tCO2-e).

The Environmental Impact Statement acknowledged that this would add 10 per cent to South Australia's forecast emissions in 2020 under a business-as-usual scenario.

> The uranium production from the expanded Olympic Dam mine would be sufficient to offset all of Australia's current domestic greenhouse gas inventory, or between 13 to 26 times South Australia's total emissions

Now, let us consider the net effect of this on global greenhouse gas emissions.

The uranium from the project would fuel nuclear power plants in countries like the US, France, UK, South Korea, China, Japan and probably India, to be used for electricity generation. A modern 1,000 MWe thermal nuclear reactor requires about 170 tUO2 concentrate each year in order to fabricate 16 tonnes of slightly enriched fuel rods.

This plant would then produce 8,000 gigawatt hours (GWh) of reliable on-demand electricity, used to displace baseload coal or gas directly.

This means that the 19,000 tUO2 from the expanded mine operations would provide enough fuel for a year's operation of 112 GWe of nuclear power, generating 900,000 GWh of electricity that releases no CO2 or other atmospheric waste like sulphur, soot and heavy metals.

To put this in perspective, all of Australia's power stations sent out 242,000 GWh in 2009.

One of us (Prof. Brook) recently published a meta-review in the peer-reviewed journal Energy which estimated the full life-cycle greenhouse gas emissions for coal, gas and nuclear power electricity generation.

The results for a typical pulverized fuel coal plant was 915 tCO2-e per GWh, compared to 470 tCO2-e for a combined-cycle natural-gas plant, and 20 tCO2-e for a nuclear plant. Some of the full life-cycle emissions for the nuclear plant were, of course, from the fuel mining and milling.

It is now simple to work out the greenhouse gas emissions that would result from generating 900,000 GWh of electricity from coal (824 million tCO2-e), gas (423 million tCO2-e) and nuclear (18 million tCO2-e). That is, the uranium from an expanded Olympic Dam, when fed to nuclear power plants, would generate 3.7 times the total current electricity demand of Australia, and avoid 405 to 806 million tCO2-e from being emitted to the atmosphere

Plant at Olympic Dam

by displacing gas and coal.

In this context, the 4.7 million tCO2-e generated by the mine expansion is little more than rounding error.

Indeed, Australia's total emissions (all sectors) in 2010 were 560 million tCO2-e, with the component for South Australia being 31 million tCO2-e. Therefore, the uranium production from the expanded Olympic Dam mine would be sufficient to offset all of Australia's current domestic greenhouse gas inventory, or between 13 to 26 times South Australia's total emissions. Note that these are not just emissions from stationary electricity generation, but also from transport, industry, agriculture and so on.

By any reasonable definition, that is not a "huge carbon black hole" – it is a massive win for global greenhouse gas mitigation.

The news gets even better.

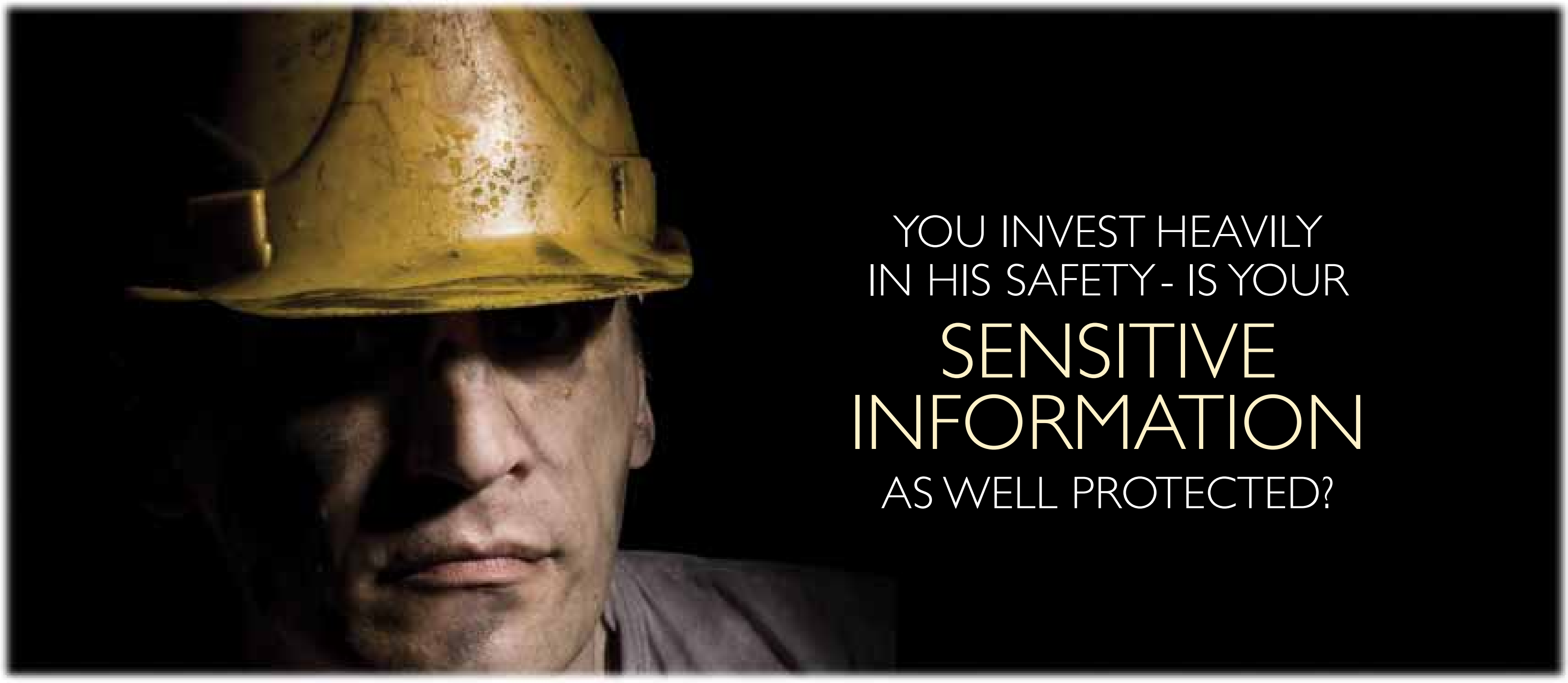
As we have explained in previous SACOME articles, current nuclear technology extracts less than 1 per cent of the energy from mined uranium. With the future large-scale deployment of next-generation technologies like the Integral Fast Reactor, which is able to repeatedly recycle the used nuclear fuel and use all of the depleted uranium, we will unlock the potential to extract 150 times more heat and electricity from uranium than we currently do.

If you crunch these numbers, you find that the 19,000 tUO2 per annum production from the proposed Olympic Dam expansion would eventually yield 130 million GWh of zero-carbon electricity, and so avoid up to 120 billion tCO2-e, which is four times the total current global emissions from fossil fuels each year.

All of this from one (albeit large) expansion of one uranium mine in one country.

It's easy to tell horror stories about uranium if you rob it of the context of its role in global energy supply.

We deserve much better than such rhetorical chicanery. Clearly, it's time that environmentalists got sensible about uranium mining, nuclear power and carbon emissions.



Small(ish) is beautiful

BARRY BROOK and **BEN HEARD** discuss how small modular reactors could soon be used to efficiently generate nuclear power for slow growing economies.

Back in August last year, 'born again' nuclear advocate and long-time environmentalist George Monbiot made a surprisingly harsh call about energy solutions for climate change: "Small is useless". Since the time of E.F. Schumacher in the early 1970s, we've heard the opposite.

So what's the deal?

Home solar PV systems are small. South Australia has easily the highest per capita installation of solar PV with around 15,000 systems, but this only adds up to 19.8 MW of (peak) capacity. It would take over 3.2 million systems just to match the yearly energy generated by the Northern and Playford coal power stations.

Considering Adelaide has only 500,000 households, you can begin to see Monbiot's point.

We need big solutions. So what could possibly be good about the emergent technology of "small modular reactors" (SMRs) as a zero-carbon power offering?

When people think about nuclear power, they typically envisage something large. That's reasonable, given that today's global nuclear fleet is made up of plants larger than 600 MW, with the new French EPR coming in at a hefty 1,650 MW. For context, the entire baseload generation capacity for South Australia is around 3,000 MW.

But SMRs are emerging. These units range from as little as 25MW to around 180MW. Their commercialisation will dramatically increase the flexibility and relevance of nuclear power in a range of settings, and South Australia is a good example.

As a mature, industrialised economy with a small population, South Australia's overall growth in energy consumption is slow. It is difficult to envisage circumstances, any time soon, where there will be a strong case for an additional 1,000 MW of baseload to be added, all at once. So, for meeting new energy needs, nuclear power is on the outer.

Of course, we have a looming need to replace a great deal of baseload generation, starting with the 760 MW of the Northern and Playford coal power stations. But it has been so long since Australia invested in significant quantities of baseload that the upfront price tag is going to be tough to swallow. That will be the case regardless of the technology, but nuclear is on the pricier end (more on the cost of nuclear for our final article next issue).

This leaves us stuck with the high greenhouse options of incrementally adding more low-efficiency gas for peaking (with high fuel costs), and smaller modules of higher-efficiency gas for new baseload.

But if nuclear power could be down-scaled... that changes things.

What if, instead of purchasing 700-1000 MW all at once, you could buy 200 MW (or less) at a time, and work up from there?

That is the promise of the small modular reactor: a compact, energy dense and zero carbon generating option for new power needs and fossil replacement in slow growing economies.

Suddenly, the major capital raising challenge replacing 1,000 MW of baseload could be spread over a series of discrete investments, with returns beginning to flow much more quickly.

Here is an example of the technology we are talking about: the Babcock and Wilcox mPower reactor. Each unit is 180 MWe, suitable for modest growth in overall load, or staged replacement of fossil baseload. Up to 10 of these modules can be built in series to form a much larger plant. The mPower reactor is designed to be contained underground. This is both a great safety feature, and a wonderful visual selling point for those concerned about nuclear reactors. Remarkably, it will only require refuelling once every four years, and the design provides provision for on-site storage of spent fuel for 20 years and the module

Conceptual drawing of a two module reactor, featuring full underground reactor containment, reservoirs for emergency passive cooling (top left and right) and fully contained below-ground spent fuel cooling pond (bottom centre).

Conceptual SMR site plan with two below-ground reactor modules in the nuclear island (left side, white building).

has a service life of 60 years.

At the very small end of the spectrum is the Gen4 Energy Power Module at 25 MW. This type of size would be ideal to power around 20,000 homes (equivalent to 115,000 rooftop solar PV systems), or provide reliable district power to hospitals and other major precincts. This design is intended to be returned to the factory, intact, at the end of a 7-10 fuel cycle for decommissioning.

At this level we can start talking about the notion of nuclear batteries.

All of the new SMR designs have applied the most up-to-date passive safety systems, meaning the safety of the reactor is in no way tied to external power sources. The units themselves will be standardised designs, delivered by ship or rail to the installation site. They are streamlined designs, with both the reactor and the steam generators held within one compact containment. This again makes them very safe. Fewer systems means fewer potential problems.

This is emergent technology; we cannot pick up the phone and place an order for a small modular reactor.

> "These units range from as little as 25MW to around 180MW. Their commercialisation will dramatically increase the flexibility and relevance of nuclear power in a range of settings."

But its potential value has been recognised through the commitment by the United States Department of Energy of $400 million and a federal site at Savannah River National Laboratory to support the design, licensing, commercial demonstration and manufacturing of SMRs.

There is huge benefit to be had from these new designs that improve the versatility of nuclear as a provider of zero-carbon baseload electricity while capitalising on major advances in safety and low-cost production. Somewhat perversely, the fact that Australia is currently so far behind in preparedness for nuclear generation -it is currently illegal under the EPBC Act-, might mean that we will be well placed to move straight into these designs as they hit the market.

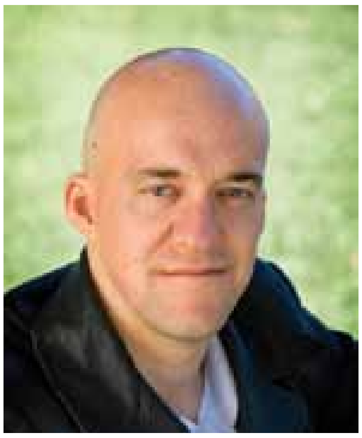
Small may be useless when it comes to tackling climate change.

But smallish nuclear reactors, which still manage to pack an enormous energy punch, could play a big role in hastening the costly transition from aging fossil plants to super reliable, super safe and super compact new zero carbon generation.

That is a big deal.

Costs and Benefits

In the final article on our nuclear series, **Barry Brook** and **Ben Heard** discuss the capital cost of nuclear energy


Barry Brook


Ben Heard

When it comes to nuclear power, some environmentalists morph into hard-nosed economic rationalists. If the solution can't pay its own way from the get go, bad luck.

This suggests a misunderstanding of energy economics. It also hints at an ideological position if the same criteria are not applied elsewhere.

In considering nuclear, we would be looking to replace baseload fossil fuels at 100s or over 1,000s of megawatts at a time. Take your pick of technology; it is never going to be a cheap task. If we want new, large-scale energy generation in Australia, there is a large price tag.

If response to climate change demands that any new baseload is zero-carbon generation, then the options are currently restricted to the more expensive end of the range for capital costs (fuel is cheap or free for these technologies).

So what can low-carbon options offer in terms of up-front cost? Let's take some real-world examples. If we take the often quoted Olkiluoto nuclear new build in Finland (which is suffering major cost and time over-runs), we find that the new European Pressurised Reactor (EPR) design, with 1600 megawatt electrical (MWe) of generation capacity, is coming in at a cost of EU6.4 billion. That normalises to $6.0 billion per gigawatt electrical (GWe) when capacity factors are accounted for.

A large (600 MWe peak) planned wind farm in South Australia, with proposed 120 MWe biomass generation as back-up, will cost $1.2 billion, plus an extra $0.2 billion for the connecting infrastructure. That's about $6.9 billion per GWe.

When we turn to face the sun, costs escalate. Based on the proposed Moree Solar Farm, this large solar PV facility with no storage or back-up (i.e. not a true baseload solution) comes in at $19.6 billion per GWe. A concentrating solar thermal plant (based on the Spanish Gemasolar plant) with molten salt storage back-up can be had at a cost of $25.1 billion per GWe.

Clearly costs mean nothing on their own. It is a question of choosing the best option. Even using a notoriously expensive 'first-of-a-kind' nuclear example, new nuclear is still the best value for zero-carbon generation.

If we look beyond the infamous Finnish example to some of the other 60 new reactors under construction or the more than 200 currently proposed, the picture becomes clearer. South Korea is undertaking a substantial program of new nuclear build and has sold its technology and expertise to the currently non-nuclear United Arab Emirates at a contracted price of $3.5 billion per GWe with 6 GWe to be delivered by 2018. Meanwhile the Chinese are delivering new nuclear based on the Westinghouse AP 1000 design for reported domestic cost of as low as $1.7 billion per GWe. So, if we want zero-carbon generation at scale, it would appear foolish to reject nuclear from consideration on capital cost grounds.

But what we really want is the product of the power plant, not the plant itself: that is, dependable electricity. Here nuclear excels, delivering electricity at an excellent price, with capacity factors exceeding 90 per cent in the U.S. and South Korea. And this price will be reliable. Thanks to negligible fuel costs and no carbon emissions in the generation, nuclear power is almost completely insulated from two of the biggest incoming pressures on power prices: carbon prices and fuel scarcity. These considerations matter a great deal.

So where does that leave us? Real-world experience tells us nuclear can provide well-priced and reliable electricity. In capital terms, nuclear is the best-value form of zero-carbon generation. That may be a surprise, but the industry has advanced and new designs that are predominantly more standardised in design, and more reliant on passive (rather than engineered) safety systems, and come in a range of sizes. All of this brings cost down.

That means the hurdle is up-front capital. Energy Economics Professor Tony Owen is clear about the situation, saying this:

'If the CEO of, say, Origin Energy said to the board "I've got a great idea. Let's spend $5 billion of the company's money, for which we will not start seeing a return for at least five years," he would be laughed at. In fact he would probably be sacked.'

Tony's point is a serious one. He is not saying it's difficult for fully private investments in nuclear, or other multi-billion dollar energy technologies for that matter. He's saying it's impossible.

If Australians want the best energy outcome as we undertake the challenging replacement of our aging fossil baseload, we will need to remember that such projects are nation-building works and some Government involvement will be required. This could be as simple as a loan guarantee like the U.S. Government is providing. Or it could be something more complex, like an emissions-trading scheme and power-purchase agreements.

But we can't have something for nothing, least of all major infrastructure. The 'barrier' of nuclear cost is one of our own creation, born of a lack of context and comparison. We have a job to do. It is going to cost a lot of money, so we had better make sure we get the best result.

If nuclear technology is a financial lemon, it won't get up, but this is no reason to exclude it from making its case on a fair and level playing field.