POWERING THE FUTURE

The clock is ticking on the drive for sustainable energy, writes Barry Brook

ACCESS TO CHEAP and reliable energy has underpinned Australia's development for decades. Fossil fuels – coal, oil and natural gas – provided the concentrated energy sources required to build our infrastructural, industrial and service enterprises. Yet it's now clear this dependence on carbon-intensive fuels was a Faustian bargain and the devil's due, because the long-run environmental and health costs of fossil fuels seem likely to outweigh the short-term benefits.

In the coming decades, Australia must tackle the threats of dangerous climate change and future bottlenecks in conventional liquid-fuel supply, while also meeting people's aspirations for ongoing increases in quality of life – all without compromising long-term environmental sustainability and economic prosperity. Fortunately, there are science and technology innovations that we could leverage to meet these goals.

SEEKING COMPETITIVE ALTERNATIVES TO COAL

How can Australia shift away from coal dependence and transition to competitive, low-carbon alternatives, and what role will science and engineering play in making it happen? To answer these questions, a key focus must be on electricity-generation technologies – electricity is a particularly convenient and flexible 'energy carrier' – and to consider the key risks and advantages with the alternative energy sources that will compete with fossil-fuel power.

In 2012, the majority of Australia's electricity was generated by burning black and brown coal (75 per cent), with smaller contributions from natural gas (13 per cent), hydroelectric dams (8 per cent) and other renewables (4 per cent). The nation's installed capacity now totals more than 50 gigawatts of power generation potential, with electricity and industrial-heat energy production currently resulting in the annual release of 285 million tonnes of carbon dioxide, about 52 per cent

Variable renewables, such as solar collectors, are 'clean' in that they harness energy that is constantly being replenished.

ISTOCK

The Gordon Dam is the largest power station in Tasmania.

JJ HARRISON

of our total emissions (see: **Understanding electricity units**).

Clearly, the non-electric energy-replacement problem for Australia would also need to consider transportation and agricultural fuel demands. In a world beyond oil for liquid fuels, we will need to eventually 'electrify' most operations: using batteries, using heat from power plants to manufacture hydrogen from water, and by deriving synthetic fuels such as ammonia or methanol.

Under 'business as usual' forecasts produced by government energy analysts, electricity use in Australia is expected to grow by 60 to 100 per cent through to 2050, with hundreds of billions of dollars of investment needed in generation and transmission infrastructure just to keep pace with escalating demand and to replace old, worn-out power plants and transmission infrastructure. At the same time carbon dioxide emissions must be cut by 80 per cent to mitigate climate-change impacts, via some combination of enhanced energy conservation and new supply from clean energy sources.

AN UNCERTAIN MIX OF FUTURE OPTIONS

Although there are a huge number of *potential* energy options now being developed that *might* one day replace coal in Australia, not all alternatives are equally likely.

The government renewable-energy target has Australia aiming to derive about 30 terawatt hours of electricity from some combination of wind, solar, wave and geothermal (hot rock) energy by 2020, compared to 10 terawatt hours

UNDERSTANDING ELECTRICITY UNITS

Dynamic electricity is the motion of electrons, and can be used to 'do work' (e.g. cause lights to shine, turn electric motors, run televisions or air-conditioner compressors). Electrical current is constantly pushed out of power stations through transmission wires, to your home or business. Power is the rate of flow of electricity, and is measured in watts. A solar panel on your roof might produce 1500 watts, whereas a large coal plant produces one billion (a gigawatt). Energy is the amount of power delivered over a period of time. So if that rooftop solar panel operated in full sun for one hour, it would produce 1500 watt-hours (1.5 kWh) – enough energy to boil a typical kitchen kettle about 10 times. A coal plant running continuously for a year will produce an enormous amount of electrical energy – about 8760 gigawatt-hours, or 8.76 terawatt-hours (TWh). Australia consumed 227 TWh in 2010. People pay for electricity in cents per kWh.

from these non-hydro renewable sources in 2011 (see: **Understanding electricity units**). The target is driven by legal mandates and financial incentives. But beyond this modest market penetration their future is uncertain.

The challenge is daunting. Although there are promising low-carbon exemplars – Norway gets almost all its electricity from hydro, and France derives 80 per cent from nuclear energy – historically, no country has achieved a penetration of solar or wind beyond about 20 per cent of supply. Denmark has the highest penetration of new renewables, per capita, based largely on wind power. Yet even the Danes still rely on domestic coal and imported nuclear and hydro to meet their reliable baseload power needs, and have high domestic electricity prices.

If Australia is to push significantly beyond the 20 per cent for non-hydro renewables to 50 per cent or more by 2050, this expansion will need to be underpinned by stunning advancements in large-scale energy storage with significant cost reductions, along with ubiquitous 'smart grid' technologies (see: **Energy efficiency** on p98 for more details) to balance supply-demand and improve the efficiency with which energy is managed. All this is possible but the key issue of whether variable renewables with storage can win the cost-benefit competition remains a large unknown.

FIT-FOR-SERVICE CLEAN ENERGY

To achieve the long-term goal of phasing out coal and slashing greenhouse-gas emissions, Australia must actively invest in the science, technology and commercial demonstration of next-generation electricity infrastructure. Ideally, the underpinning technologies will be fit-for-service, low-carbon 'plug-in' alternatives to fossil energy that are scalable, reliable and cost-effective, while also balancing issues of societal acceptance and fiscal and political inertia. Also, although infrastructure and fuel costs will be critical considerations, a technology must also constitute 'value for money' by delivering its intended service adequately.

The wholesale replacement of fossil fuels with cleaner alternatives represents a massive global conundrum, because we have to continue to provide reliable and affordable energy while reducing greenhouse-gas emissions.

For a new electricity generator to serve as a direct fit-for-service replacement for coal, it should be dispatchable (i.e. can be delivered on demand), without need for large or expensive external storage, or else have a reliable fuel supply. It must also have low or moderate carbon-emissions-intensity, and be able to produce at a high capacity factor (i.e. delivering a near constant supply across a 24-hour period or longer). This can potentially be achieved in diverse ways, via a portfolio of non-carbon or low-carbon fuels (nuclear and biomass), the tapping of constant or predictable flows of natural energy from geothermal, tidal and wave power, and by geographically spreading wind and solar collectors across nationwide grids, from urban zones to farmland to deserts.

Clearly, different electricity technologies will fill a variety of niche roles in future markets. Variable renewables, such as wind turbines and solar collectors, are 'clean' in that they harness energy that is constantly being replenished, and they enjoy strong community support. Their use will continue to grow in Australia, especially as deployment costs are reduced.

Three new and promising substitutes for coal that Australia might consider seriously pursuing are advanced nuclear reactors based on small modular (factory-built) designs, deep-earth 'hot dry rock' geothermal, and ubiquitous small-scale solar. These clean-energy technologies offer many attractive and often complementary features, yet none is currently cost-competitive with coal, oil or gas, being technically immature or at least unproven at a large scale. As such, all are considered financially risky. There are real and exciting opportunities for science to work to improve and demonstrate these innovative new technologies, but technologists must collaborate with government and industry to ensure the markets are ready.

Ultimately, there is no magic-bullet energy source that can solve all problems perfectly without any negative impacts on society and the environment (see: **No perfect energy technology**). Given this reality, energy plans that expand the role of both nuclear and various promising renewable and energy-storage technologies, and allow them to compete on a level playing field, seem to make most sense.

'BIG SCIENCE' FOR INNOVATIVE ENERGY FUTURES

The wholesale replacement of fossil fuels with cleaner alternatives represents a massive global conundrum, because we have to continue to provide reliable and affordable energy while

WIKI

This wind turbine under construction, the E-126 model, is 200 metres tall and can generate 7.5 megawatts of electricity at peak output.

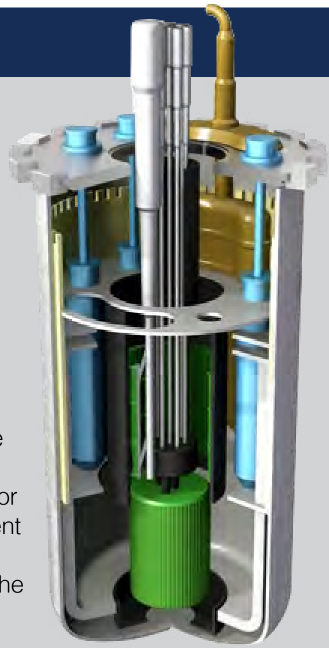
reducing greenhouse-gas emissions. So what can Australia – a relatively small part of the world economy – do most effectively to contribute to this effort, beyond supporting basic and applied scientific research?

Australia has been a world leader in the development of lower-cost and more-efficient crystalline solar photovoltaics, and is working at the scientific cutting edge in the research and development of new organic solar cells and solar-thermal dish technology. Support for such work should definitely continue, but we must not shirk from some risk taking, by engaging in more controversial fields like next-generation nuclear and carbon-capture-storage.

NO PERFECT ENERGY TECHNOLOGY

Fossil fuels have provided modern society with a cheap and convenient source of concentrated, stored energy. This has allowed us to build our industrial economies, information technology, global food production and transport systems, and many other foundations of society. However, people are also well aware of the damage they cause to the environment – explosions, chronic health issues from soot and heavy metals, and greenhouse gases.

Nuclear fission, an abundant and low-carbon energy source, has an enormous and proven potential to supply reliable baseload electricity and displace coal or gas power plants directly. Yet the prospect of nuclear energy concerns many people who worry about sustainability, spent-fuel disposal and radiation release from accidents. Innovative new designs like the integral fast reactor and liquid fluoride thorium reactor technologies (see: 311 megawatt PRISM module, right) could, if commercialised, avoid or heavily mitigate these hazards, by incorporating passive safety with inherent self-protection, and by recycling nuclear waste to generate zero-carbon electricity. However, no reactor can be made perfectly safe, and so, as is the case with technologies such as cars, planes, food supply, electricity and medicine, society must tolerate some level of risk.



WIKI

The 311 megawatt PRISM module is a next-generation nuclear power plant. Passively safe and able to recycle its waste, it represents a potential clean-energy frontier for fission-based electricity technology.

Clean-energy alternatives to nuclear are not without their hazards, on top of the concerns of on-demand reliability. The life-cycle greenhouse-gas emissions of photovoltaics are higher than nuclear power, and manufacture of solar cells uses a mix of highly toxic chemicals that do not degrade over time. In the United Kingdom there were 1500 wind-power-related accidents and four fatalities between 2007 and 2011. Wind turbines and solar-thermal plants use large quantities of concrete, steel and land per unit of electricity delivered, compared to nuclear or geothermal alternatives. Hydro requires massive land transformation and intermittent renewable energy sources typically rely on natural-gas back-up. There are also many 'system factors' to manage, such as intermittency-related effects on the stability and congestion of transmission networks.

Such problems do not mean that large-scale renewables are not worth pursuing or that advanced nuclear is the only viable option. But it does emphasise the fact that we must avoid arbitrarily closing off technology options without looking at the big picture.

All of the above are vital components of a cost-benefit analysis. Trade-offs are inevitable – there is no ideal energy option and urgency will help dictate the response. Ultimately, science can provide the range of potential options, but society must make the final choices.

Above all, we must ensure that scientifically grounded, government-led climate strategies are clearly focused on measurable and timely reductions in greenhouse-gas emissions, with the rapid deployment of high-capacity, clean-energy technologies that work as direct substitutes for fossil fuels. It will mean strategic investment in a portfolio of potential 'winners', while accepting that there will probably be more failures than successes.

In this context, it's necessary that the best technologies get their due opportunity by taking a firm, hands-on approach. Time is not on our side. This will require a sustained and timely injection of money from a coalition of nations to create the manufacturing, distribution, education, security and skills base that is absolutely necessary for a 21st century re-imagining of energy.

I'd argue that Australian participation in flagship big-science projects, based on active

SHUTTERSTOCK

Several older black coal-fired power stations are being sold off as society transitions to new energy sources.

multilateral engagement, will be crucial to making deep inroads and reducing costs. Examples such as the Large Hadron Collider and Square Kilometre Array are motivating illustrations of how such endeavours can work. In the energy realm, the $20 billion International Thermonuclear Experimental Reactor project for future fusion power is an archetype. But similar collaborations are needed for a range of the most promising technologies, with Australia contributing to both innovative science and ongoing financial support.

To realise this vision, Australia also needs an educated and engaged society that understands and embraces the need to pursue new – often unfamiliar – energy technologies. This will require a strong and sustained focus in the school curriculum on science and engineering, coupled with improved public outreach for all ages. People must be encouraged to think critically about sustainable energy options and the trade-offs Australia must inevitably face.

PROFESSOR BARRY BROOK is an environmental scientist who models global change and holds the Sir Hubert Wilkins Chair of Climate Change at the University of Adelaide.

FURTHER READING

CSIRO eFuture – explore scenarios of Australia's electricity future. http://efuture.csiro.au/.

MacKay, D.J.C. 2013, *Sustainable Energy – Without the Hot Air*, UIT Cambridge, Cambridge.

Science Council for Global Initiatives 2012, 'The case for near-term commercial demonstration of the integral fast reactor', white paper, http://www.thesciencecouncil.com/pdfs/whitePaper.pdf.