Proposal

To establish bipartisan agreement to lift the ban on Ministerial approval of nuclear power technology as an option for electricity generation in Australia.

This is necessary to --

- remove a 20 year-old obstacle to looking at this technology to help Australia reduce its greenhouse-gas emissions, while providing safe, reliable, all-weather electricity,
- encourage Australia's scientific and engineering community to engage in productive dialogue and investigation to determine if, how, and to what extent this technology should be implemented,
- enable valuable international linkages to be established to ensure that Australia can access the best knowledge available on modern nuclear power developments in other parts of the world, and
- open the subject up to the Australian people to provide accurate information about the technology in its most modern forms, and enable *proper consultation with the community to guide Ministerial decision.*

Barry Murphy
31 May 2019

as sent to various politicians during 2019.
no response. [signature] 16/11/19.

nuclear energy on the table

what australians need to know

Two-thirds of humanity now lives in countries that use uranium for the production of electric power. Australia supplies uranium to many of these countries for this purpose but cannot use it itself, having banned it by law 20 years ago. We are the only G20 country to do so. This has to change.

Regrettably, any discussion of this topic usually descends into a political brawl of competing ideologies with little or no consideration of the true facts of the matter.

The purpose of this brief discourse is to help public understanding of a few key aspects of the nuclear power question in several areas of popular contention viz. safety, radiation, waste, cost and benefits. Figs.1 – 6 are grouped at the end.

Only by understanding enough about the science and engineering involved in this remarkable technology can we hope to make better decisions about our clean energy future.

History might show that this was not an option, but an absolute necessity.

Barry Murphy
CSci, FIChemE, FTSE, FAICD

27 December, 2018

A PDF version of this can be found at https://gofile.io/?c=3ZH2bS

But first --

What is a nuclear reactor and how does it operate ?

(See Fig.1). A nuclear reactor consists of a core inner structure containing fuel rods in which neutrons from atoms of a particular kind of uranium called U^{235} are used to 'split' other atoms of the same material contained within the rods. This is known as nuclear fission.

The neutrons released by this process are slowed down by water or graphite to improve their effectiveness, and go on to split more uranium atoms within the rods in a chain reaction. This in turn releases energy, producing a lot of heat which is contained and fully controlled.

The reactor core sits inside a steel pressure vessel such that the circulating water remains liquid even at high temperature. The water passes around the fuel rods and steam is formed, either above the reactor core or in separate pressure vessels in a secondary circulating water circuit. The steam goes on to drive a turbine to produce electricity just as it would in a normal coal-fired power station, after which it is condensed and the water recycled.

Most large pressurised water reactors have all of the energy-producing components inside a large containment structure, but some modern designs using advanced technologies and different fuels at atmospheric pressure do not need this type of construction (see Fig. 2).

Can a nuclear reactor become a bomb ?

No. Nuclear fission for controlled heat generation requires that a certain, but limited, proportion of a particular 'isotope', uranium U^{235}, be present in the fuel before adequate fission can take place.

This is normally between 3 -- 5% for electricity generation. This is achieved at the time of fuel manufacture by enrichment of the 0.7% normally found in natural uranium ore (mainly U^{238}), and is monitored strictly by the International Atomic Energy Agency (IAEA). Australia's nuclear fuel would be manufactured overseas using Australian-supplied uranium.

At 3 -- 5%, there are not enough atoms of the right type in the fuel rods to be used as a precursor to an uncontrolled reaction which simply could not occur. For any military intention, this would require enrichment to a much higher level (around 90%+), as well as very obvious actions in a difficult and expensive process easily detectable.

Australia is a member of IAEA and a signatory to the *Nuclear Non-Proliferation Treaty,* meaning no such fuel or process would ever be allowed in Australia.

Safety

Nuclear power production is an industrial process like any other, and needs to be conducted to the highest standards of safety. There are 450 operable nuclear reactors in the world today producing around 11% of the world's electricity, with a further 54 currently under construction.

China alone has 37 reactors in operation, 19 under construction, and is planning to add another 290 reactors by 2050. The next two years will see 33,000 MW of nuclear capacity added to grids in 10 countries, including two newcomers. Older units are being shut down. It is unlikely this level of investment would continue if there were serious doubts about safety of operation.

Unfortunately, there have been three incidents over the past 40 years which have set back nuclear power acceptance. Although painful, these need to be properly understood if we are to make progress in understanding how this technology can be safely used. They are --

- Three Mile Island, USA, 1979 : A relatively minor incident, in which some radioactive gases from an operating reactor were released into the atmosphere due to poor early design instrumentation and operator error, no injuries, no threat to the public or plant workers.

- Chernobyl, USSR, 1986 : A poorly designed Russian reactor, badly executed operator test on cooling water shut-down, power surge leading to partial rupture of core and steam explosions, no containment structure, graphite fire, release of radioactive soot and fission products into the atmosphere. Death of two plant workers plus 28 firefighters within weeks, 6000 child thyroid cancers with 15 deaths over following decade, 19 other cancer cases attributed over next 17 years, estimated possibility of around 4000 later cancers, uncertainties in attribution exist.

  The worst nuclear power plant accident in history, inherently flawed design causing a positive void coefficient in the reactor core leading to a rapid increase in temperature, lack of safety culture exacerbated by top-heavy centralised supervision resulting in delay, indecision, and lack of appropriate response. The basic design causes of this accident could not have occurred in a Western-designed reactor.

- Fukushima Daiichi, Japan, 2011 : Magnitude 9.0 earthquake 100 km at sea, highest ever recorded in Japan, immediately detected by all 11 reactors in Eastern coastal regions, including Fukushima Daiichi, which automatically shut down, waves of 15m high tsunami followed, knocked out reserve battery power of decay heat cooling water pumps, eventual total plant power failure, reactors partial meltdown and subsequent hydrogen explosion, six plant worker deaths due stress-related causes. No deaths due radiation and none are expected, tsunami swept 18,391 local people to their death, additional 1,600 local deaths arising from evacuations, earthquake moved island of Honshu 2.4m closer to America.

Nothing can excuse serious industrial accidents wherever they occur, but learning from them is essential. Between 1910 and 1950 over 90,000 lives were lost in American coal mines ; a 1975 dam failure in China had 170,000 casualties ; in 1984, 3787 people were killed and 558,000 injured by a pesticide leak from a chemical plant in Bhopal, India ; a coal mine accident in Turkey in 2014 killed 301 workers ; 12,000 people died in the killer London smog of 1952.

While nuclear power plant accidents are as regrettable as any other, so far the record has been few in number. With better designs underway and the likelihood of smaller units in cooperation with other countries, Australia has a chance to inculcate a 100% nuclear safety culture into our beginnings with nuclear energy.

Radiation

Radiation is essential to life. Like gravity or magnetism, radiation can't be seen, heard, tasted, or smelt -- it only becomes 'visible' to us through measurement.

It is often described as "...*energy on the move*." Travelling electromagnetic waves and subatomic particles fill all of our living space for every second of our lives. Although unaware, radiation is passing around us and through us continuously. We depend on it for heat, light, and communication. It can be found in food, water, and the air that we breathe.

There are two fundamental kinds of radiation, viz. *non-ionizing* radiation, and *ionizing* radiation.

Non-ionizing radiation, such as radio waves, visible light, and microwaves, has relatively low levels of energy, too low to remove an electron from an atom -- a process called ionization ; *Ionizing* radiation on the other hand has enough energy to do this. X-rays, gamma rays, and high-energy particles like protons, electrons, and neutrons can all be ionizing radiation.

Radioactive elements are also a source of ionizing radiation. Such an element has an unstable nucleus which can eject some part of its energy or mass to reach a lower energy state, either spontaneously or after being struck by a high-energy particle as in a nuclear reactor. It can do this in the form of radiation which usually takes one of three forms, viz. --

- alpha particles (helium nucleus) emitted by heavy metals e.g. uranium or thorium -- travel only a few centimetres and are easily stopped by a sheet of paper
- beta particles (high-energy electrons), can be stopped by a sheet of alfoil
- gamma rays (packets of high electromagnetic energy) -- stopped by lead
- neutrons, highly penetrating, but not normally found free outside a nuclear reactor.

Type, exposure, and dose are all important variables. Some radiation can be damaging, especially if ingested where damage is measured by the amount of energy absorbed by living tissue. The earth is bombarded by electromagnetic radiation from the sun every day, and we are all familiar with sunburn. Human body cells do not discriminate between natural and man-made radiation, such as is used in radio, television, smoke detectors, mobile phones, microwave ovens, and wireless computer networks.

A millisievert is an internationally recognised measure of radiation exposure. On average, Australians receive 3.5 millisieverts / year as ever-present 'background' radiation, while residents of Denver in the USA receive around 5.0 millisieverts / yr. In the USA, almost 50% of radiation received by many people is due to medical and dental procedures.

A chest X-ray will radiate 0.10 millisieverts, while radiotherapy treatment of a tumour can involve 40,000 millisieverts per dose. A worker in a nuclear power plant will receive no more than 2.4 millisieverts / year. A maximum dose of 100 millisieverts / yr is considered safe.

The radioactive material that is used to release energy in a nuclear power plant is well understood and strictly controlled. In Australia, this is overseen by the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA), while the Australian Nuclear Science and Technology Organisation (ANSTO) is home to Australia's nuclear science and technology expertise.

Both these organisations have outstanding international reputations in the application of nuclear science and technology, and would provide a strong foundation for the safe and secure development of a nuclear power industry in Australia.

Waste

Every two years or so, a portion of the fuel in a nuclear reactor will be replaced. A typical 1000 MW pressurised water reactor will use about 27 tonnes per year after which it is removed. This spent fuel is first placed in a pond of normal water for up to 10 years or more to enable heat from the natural radioactive decay to dissipate, before being placed in strong dry casks made from steel and concrete for secure above-ground storage.

This nuclear waste contains the so-called fission products most of which are highly radioactive when removed and short-lived with half-lives of around 30 years, and some for only eight days. For these elements their radioactivity will decline to harmless levels within 300 years. The least radioactive and highest volume of the waste, the long-lived actinides, will decline completely in radioactivity over thousands of years.

To date, the entire world has accumulated about 280,000 tonnes of this material, most of which is safely stored above ground awaiting permanent burial. This compares with around 400,000 tonnes of solid waste per year from a single 1000 MW coal-fired power station containing ash, toxic heavy metals, and traces of some radioactive elements, plus 6,000,000 tonnes per year of greenhouse gas emissions. A nuclear power plant has no emissions in operation.

A factor that needs to be kept in mind is the very advanced work going on in the USA, China, and the UK to develop what are called 'fast' reactors. This technology can use the waste material described above as fuel, thereby eliminating much of the disposal problem while capturing more clean energy.

It should also be noted that there are now around 100 sites across Australia, mainly hospitals and specialist research establishments, licensed to hold low-level nuclear waste on an interim basis until the proposed National Radioactive Waste Management Facility can be built. In 2016, a Royal Commission in South Australia recommended that Australia should consider the deep geological disposal of radioactive waste as a commercial venture on an international basis. To date, there has been no action on this front.

Cost

This is usually the 'killer' argument against the adoption of nuclear power in Australia. CSIRO estimates for this in their Gen18 Analysis of generation costs appear very high.

Of course cost must be carefully considered, but something as important as nuclear power is not a short-term undertaking. It needs to be seen in its entirety as an investment in our longer-term need for reliable electric power generation which can also avoid emissions. Failure to do this could see Australia's prosperity drop if we are unable to compete in the Asian theatre of growth around us, much of which will be familiar with nuclear technology.

Some 15,000 MW of currently-operating coal-fired baseload electricity generation is due to be retired in Australia over the next 20 years to 2040. At present, there is no baseload power technology firmly scheduled to replace this.

Instead, a plethora of intermittent wind and solar investments in designated Renewable Energy Zones, connected to each other and major demand centres by new high-voltage and expensive transmission lines, is envisaged by the system operator AEMO in its Integrated System Plan through to 2040.

This is expected to be supplemented by lots of battery storage (698 times more capacity than the existing Tesla battery at Hornsdale in SA), and assumes that the Snowy Hydro 2.0 and Tasmanian Battery of the Nation projects will also proceed. Some 500 MW of 'flexible' gas generation will be added to provide peaking or emergency response. It would seem sensible to analyse if, and at what cost, modern nuclear power technology could bring low-emissions reliability to this task.

Case Study

In mid-2018 several senior Australian power engineers undertook a self-funded visit to the Republic of Korea, where they were hosted by the Government-owned Korea Electric Power Corporation (KEPCO). They were able to inspect for themselves some of the 24 nuclear reactors which supply 30 % of that country's electric power needs. Possible applications for Australia were discussed.

KEPCO has made great strides in designing and selling its most modern and successful reactor known as the APR 1000+. This a 3rd generation pressurised water reactor (PWR) which KEPCO now sells to others and is capable of installing internationally.

Careful comparison and conversion of all Korean costs to A$ has shown that one of these reactors could be built in Australia today for around A$ 6.2 billion. KEPCO is currently building four such units in the United Arab Emirates very close to time and budget. It is also in demand elsewhere. The Study Team found that the average price of electricity generation to all consumers in Korea is UScents 8.0 / kWh, of which UScents 4.0 / kWh is due to the nuclear component.

As far as Australia is concerned, it is the total **System Levelised Cost of Energy (SLCOE)** that counts in any fair comparison of generation costs in the National Electricity Market.

Analysis on return of the Study Team showed that a levelised cost of nuclear generation in Australia, using the Korean technology as described above, would be around Acents 7.9 / kWh based on a discount rate of 6.0% per year over the life of the reactor (see Fig. 3). For example, if this were to be embedded in the current Australian grid **system** of generation, replacing only existing brown coal use with 3,500 MW of nuclear, a SLCOE of Acents 7.2 / kWh would result. Fig. 4 shows the relationship between cost and emissions for a range of options.

As in all such comparisons, to this would need to be added the costs of transmission and distribution, making a total cost to the household customer of around Acents 21.5 / kWh. This compares favourably with current delivered costs of electricity in Australia for other forms of generation.

There would be some establishment costs in setting up the necessary approval and regulation architecture for nuclear power generation in Australia, i.e. in addition to what already exists for ARPANSA and ANSTO in their existing roles for oversight of nuclear safety, waste handling, radiation protection, and research and production of medical and industrial radioisotopes. This would be a sound investment in Australia's future.

Comparison of electricity generation costs must be fair

Much is made in newspaper and other comparisons of the apparently constantly reducing costs of solar and wind electricity generation. Such comparisons are often specious for the following reasons --

- difference between renewable energy capacity installed and actual energy produced due low capacity factors (ave. 18% for solar PV, ave. 30% for wind), thus incurring additional costs for dispatchable back-up power which usually are not shown. This compares with a 90%+ capacity factor for dispatchable all-weather nuclear power.

- grid integration costs to control variable and intermittent generation inputs to the grid while trying to satisfy unpredictable customer demands. This can also require new high-voltage transmission lines to bring the power long distances to areas of high demand, thus incurring additional costs which also are usually not shown.

- long lifetime for nuclear plants (60+ years), versus short lifetime for wind and solar renewables (15 -- 25 Years) thus requiring continual replacement of hardware.

- resources and land required : a typical 1000 MW nuclear power plant will occupy 100 ha of land versus 150,000 ha for equivalent generation capacity wind, and 27,500 ha for equivalent generation capacity solar PV ; 12,000 tonnes of steel for nuclear, versus 240,000 tonnes for equivalent generation capacity wind.

- many renewables investments are made to 'harvest' grants and subsidies while they still exist. These numbers do not show up in most journalistic comparisons of generation costs, but are paid for by all taxpayers irrespective.

- this is not to denigrate renewable energy when properly understood and applied, but comparison between all forms of power generation in a specific application must be comprehensive and factual.

Benefits of nuclear power

Australia is at risk of a future of unreliable costly electricity with relatively small effect on reducing global emissions.

This results from political neglect over many years focussing only on short-term thinking. The result has been massive subsidies for intermittent weather-dependent electric power generation, while ageing baseload power generation plants are progressively shutting down. A more balanced approach is needed.

The National Energy Guarantee idea previously floated by the Energy Security Board was an honest attempt to put this to rights and should have been supported, but regrettably it became a casualty of unexpected political upheaval which saw it abandoned.

The overwhelming advantage of nuclear is its energy density. There is enough energy in 1 x Kg of low-enriched uranium to light a 100-watt light bulb for 1142 years without producing any greenhouse gas emissions. The energy in a Kg of coal could do the same job for 3.6 days while producing 2.6 Kg of emissions.

This remains theory unless properly harnessed with expert design and regulation to produce a safe, reliable, and affordable outcome. This should be examined at the same time as short-term efforts are made to drive down electricity prices.

The tangible benefits of nuclear power might be summarised as --

- low life-cycle analysis greenhouse gas emissions, and none in operation
- high capacity factor in operation (90%+)
- not weather-dependent
- long lifetime (60+ years)
- low land use and resources requirement (see earlier)
- can be readily connected to existing transmission lines
- modern designs provide reliable back-up for renewables to produce electricity
- can provide heat for desalination and other industrial processes (see Fig. 5).
- clear and certain elimination of greenhouse gas emissions versus fossil fuel generation.

What about Small Modular Reactors ?

While the traditional light-water pressurised water nuclear reactor of around 1000 MW capacity has all of the benefits listed above, an evolving class of reactor under development overseas is the **Small Modular Reactor (SMR)** of capacities from 50 to 600 MW. These could be ideal for particular applications in Australia (see Fig. 5), although large-scale nuclear capacity might still be required to completely replace coal in the long run.

SMRs would have additional benefits, such as --

- not weather dependent
- modularity and simpler componentry
- standardised design, mostly factory construction -- like aircraft
- transportable to point of assembly
- passive and inherent safety features not requiring human intervention
- can be installed underwater and underground
- combined with smart grid technology, can work flexibly with renewables
- low land requirements (e.g. 18 ha for up to 600 MW)
- lower upfront investment by comparison with larger units, easier to finance

See Fig. 2 for an illustration of the NuScale SMR under development in the USA. There are also many other versions under active development in the UK, China, Russia, and Canada.

A Study released by the Massachusetts Institute of Technology (MIT) in September 2018 had this to say .... " *While a variety of low or zero carbon technologies can be employed in various combinations, our analysis shows the potential contribution nuclear can make as a* *dispatchable low-carbon technology. Without that contribution, the cost of achieving deep decarbonisation targets increases significantly. "*

Perhaps Australians are more alert to this possibility than our political leaders think. A Survey by the Australian National University in 2017 about public support for scientific advances showed results as noted in Fig.6.

Conclusion

Nothing in this document speaks for any vested interest in the adoption of nuclear power technology for Australia -- personal, commercial, political or otherwise.

It is intended only to help people understand that while the world of electricity generation is changing -- and for good reasons -- there are real differences in engineering approach which must be understood free of populist cant or political bias.

The complexities of power engineering and whole-of-system costs cannot be ignored. It is time for an honest look at the role modern nuclear power could play in a balanced mix of generations for our clean energy future. This can only be fully explored if the existing legal ban on nuclear power for Australia is removed.

To give certainty to long-term policy, this will have to be done by means of a bipartisan agreement . This is normal in defence, border control, and parliamentary salaries -- why not in removing an obstacle to examining emissions - free nuclear power production ?

Tell your Federal member.

27 December, 2018

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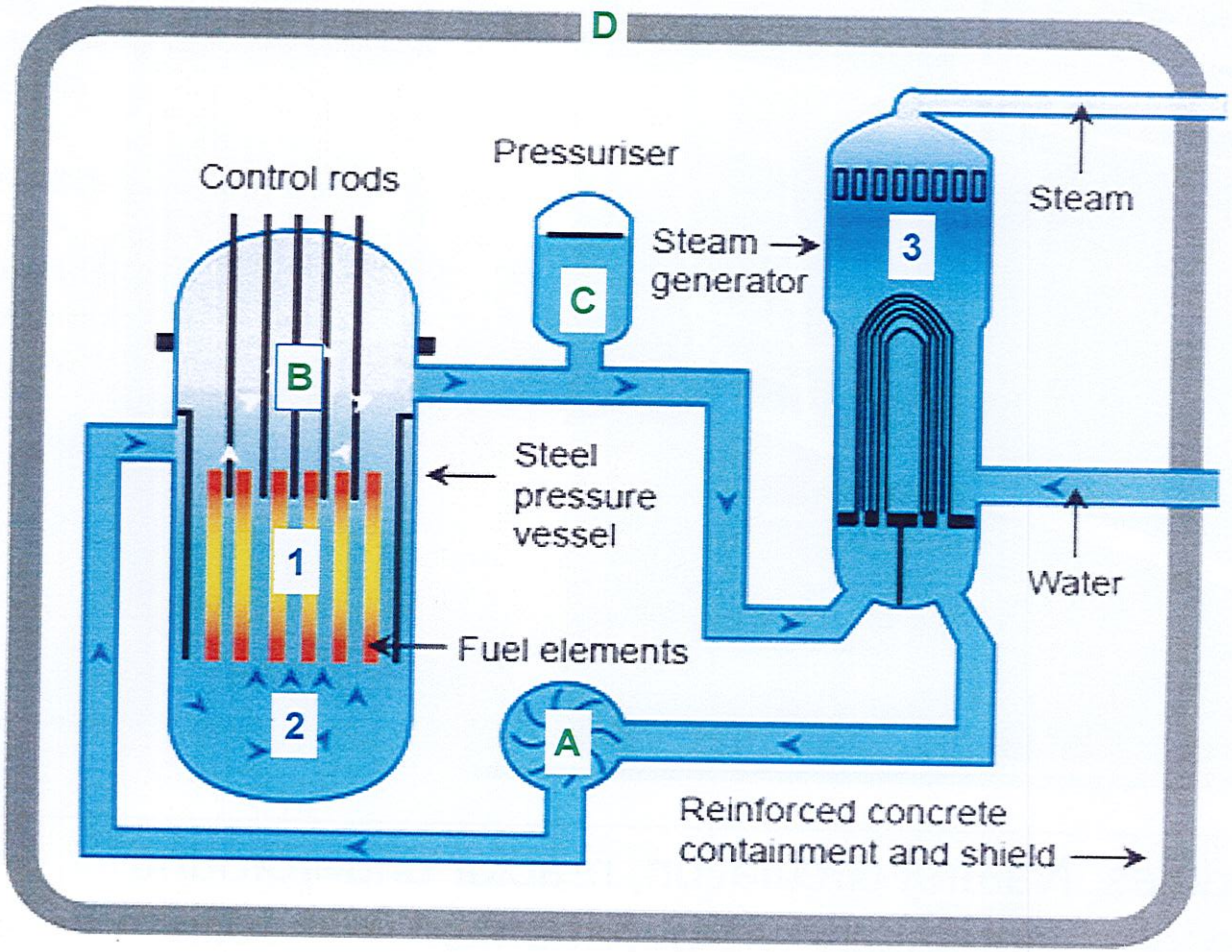
FIG 1

Pressurised Water Reactors



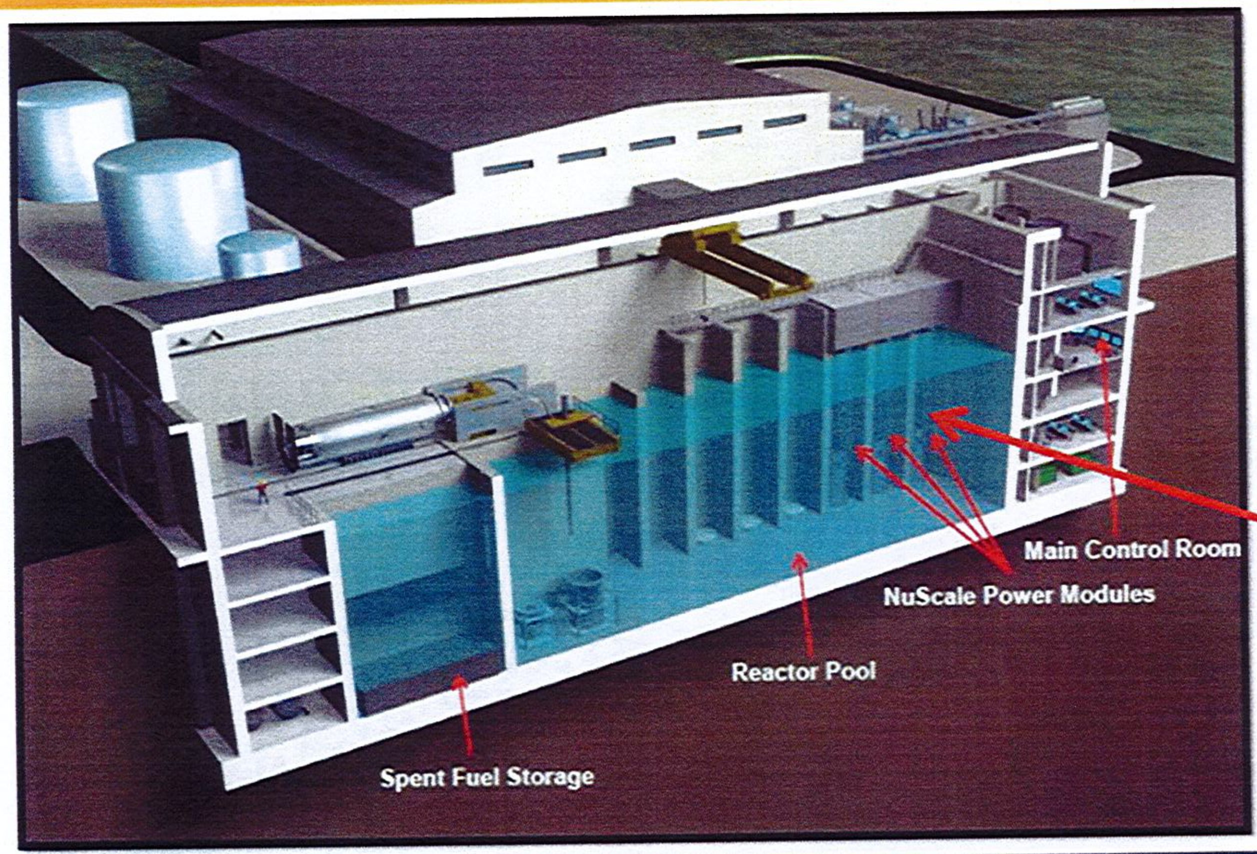
1. Core
2. Coolant
3. Steam Generator

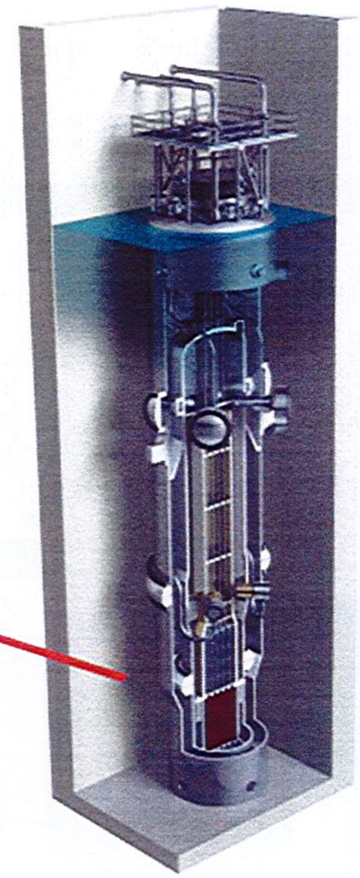
A. Pump
B. Control Rods
C. Pressuriser
D. Containment

Source: World-Nuclear.org

NuScale Power (USA) 50 MWe power modules

Reactor Building





Up to twelve x 50MWe modules. Natural circulation, reactor underground
Passive safety systems – cooled indefinitely without attention – "indefinite coping time"

Source: NuScale Power

FIG 3

Electric Power Consulting Pty Ltd
Power System Generation Mix Model Output

Scenario: Case 2 - Replace Brown Coal Generation with Nuclear (3,889MW)

Version 1.6 Run Number 78

Generation Type	Installed MW	Net Available MW	Storage Days	% of Load Energy Suppied	Levelised Cost of Energy (LCOE) $/MWh	Contribution to System Levelised Cost of Energy (SLCOE) $/MWh	Carbon Intensity T/MWh	Contribution to System Carbon Intensity T/MWh
Battery Storage	100	100	0.06	0.0%		$0.13		
Solar PV	323	323		0.4%	$117.32	$0.48	0.034	0.00
Wind	3,500	3,500		5.2%	$93.08	$4.80	0.012	0.00
Open Cycle Gas	10,660	10,500		1.7%	$348.91	$6.02	0.606	0.01
Hydro	4,200	4,200		8.0%	$80.78	$6.50	0.024	0.00
Combined Cycle Gas	2,116	2,000		7.0%	$92.23	$6.43	0.415	0.03
Black Coal Supercritical	14,286	13,500		61.6%	$50.90	$31.33	0.9635	0.59
Nuclear	3,889	3,500		16.1%	$79.09	$12.76	0.019	0.00
Total	39,074	37,623 MW			Subtotal Generation.....	$68.45 /MWh	Total.....	0.64

Energy storage decrease 0.0%

Total..... 100.0%

Extra Transmission...	$4.04	/MWh
System Levelised Cost of Energy	**$72.48**	**/MWh**
Base Transmission.....	$42.25	/MWh
Delivered Cost of Energy for Transmission Customers	**$114.73**	**/MWh**
Distribution...	$100.00	/MWh
Delivered Cost of Energy for small LV Customers	**$214.73**	**/MWh**

CO2 Emission Abatement Analysis

Reference $69.20/MWh

Base level.... 0.82 T/MWh

Cost of Abatement

$18.07 /Tonne

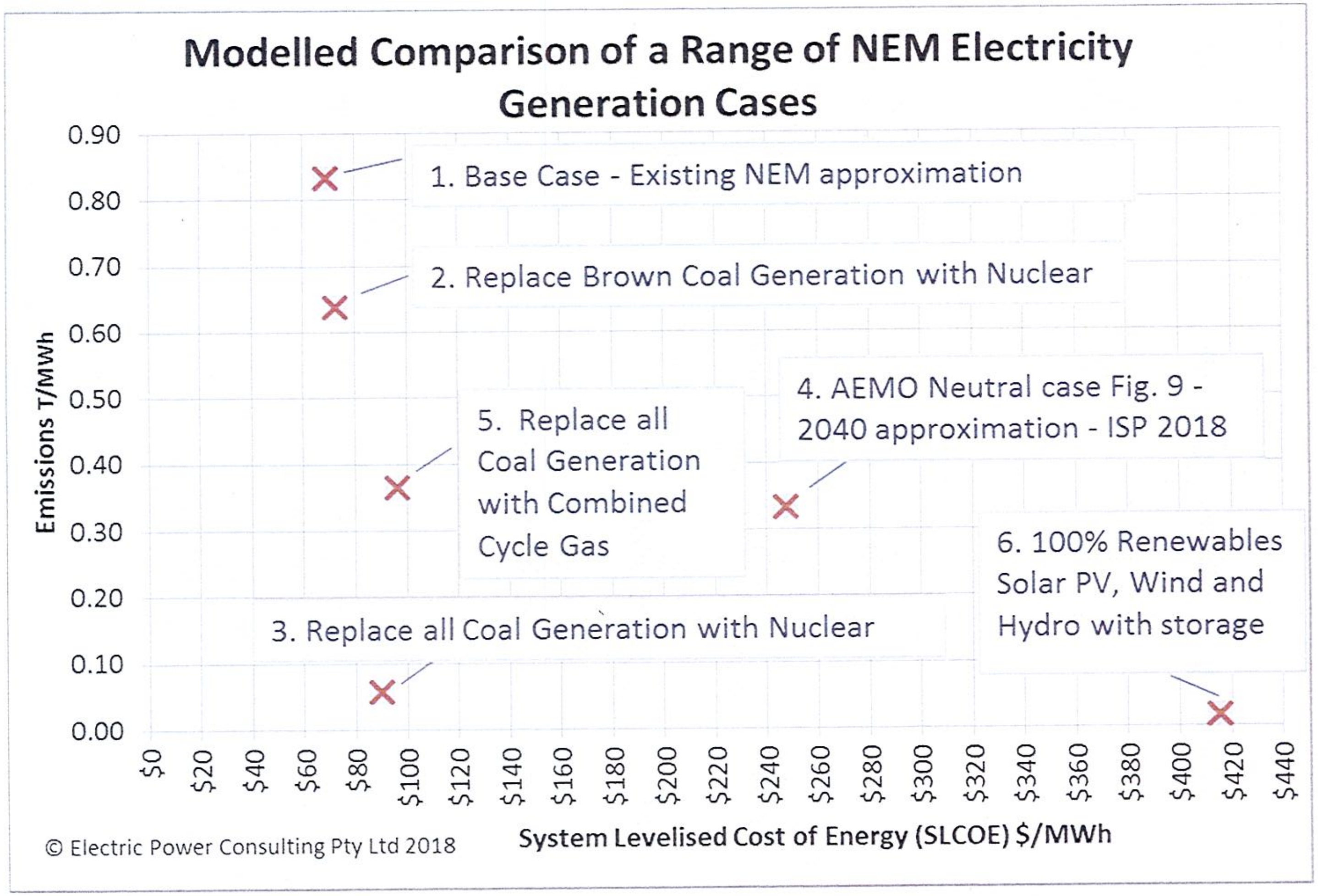
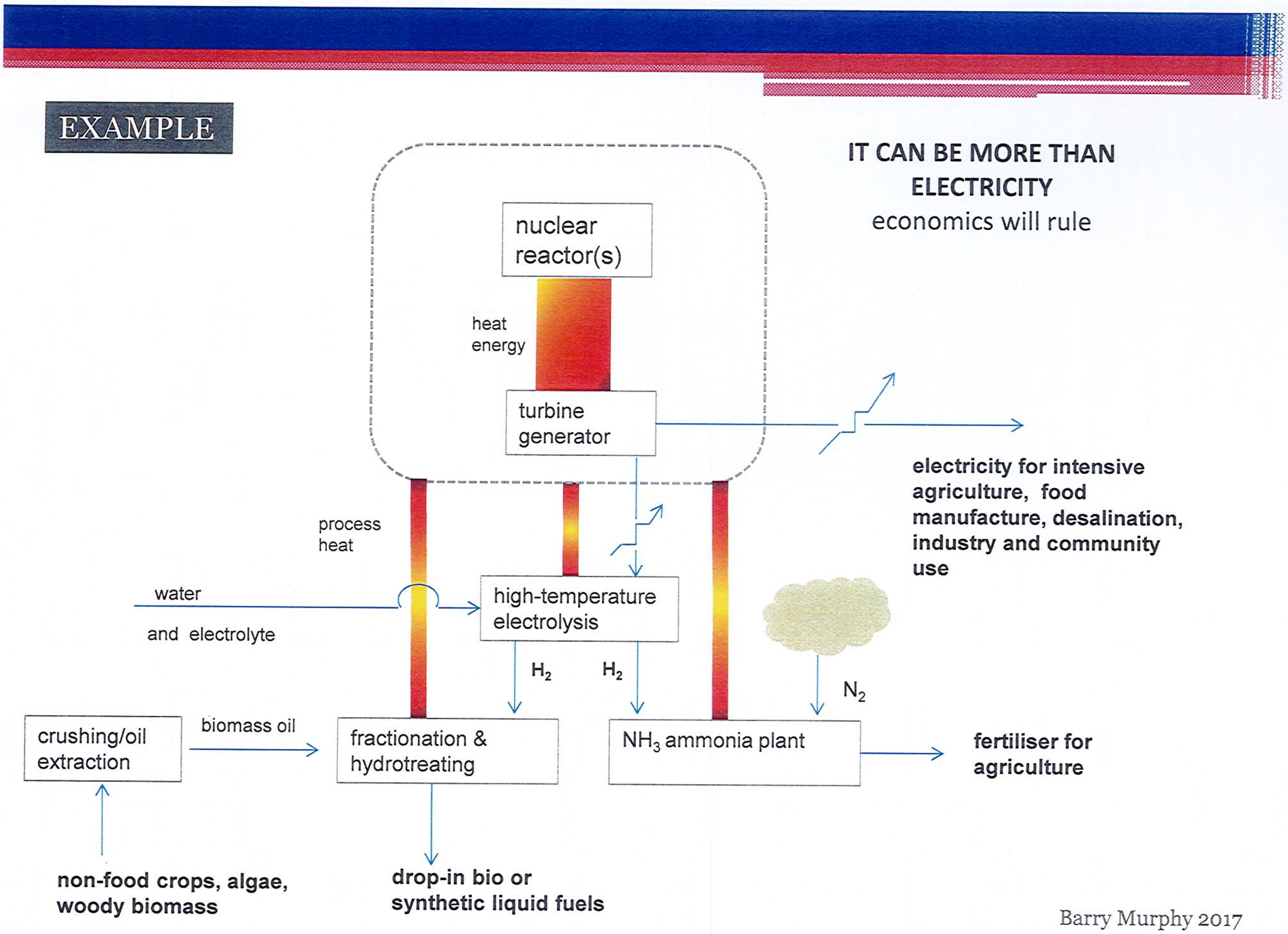

Modelled Comparison of a Range of NEM Electricity Generation Cases
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Emissions T/MWh
1. Base Case - Existing NEM approximation
2. Replace Brown Coal Generation with Nuclear
3. Replace all Coal Generation with Nuclear
4. AEMO Neutral case Fig. 9 - 2040 approximation - ISP 2018
5. Replace all Coal Generation with Combined Cycle Gas
6. 100% Renewables Solar PV, Wind and Hydro with storage
$0
$20
$40
$60
$80
$100
$120
$140
$160
$180
$200
$220
$240
$260
$280
$300
$320
$340
$360
$380
$400
$420
$440
System Levelised Cost of Energy (SLCOE) $/MWh
© Electric Power Consulting Pty Ltd 2018

FIG 5



EXAMPLE
IT CAN BE MORE THAN ELECTRICITY
economics will rule
nuclear reactor(s)
heat energy
turbine generator
electricity for intensive agriculture, food manufacture, desalination, industry and community use
process heat
water
and electrolyte
high-temperature electrolysis
H_2
H_2
N_2
crushing/oil extraction
biomass oil
fractionation & hydrotreating
NH_3 ammonia plant
fertiliser for agriculture
non-food crops, algae, woody biomass
drop-in bio or synthetic liquid fuels
Barry Murphy 2017

How does Australia feel about nuclear?

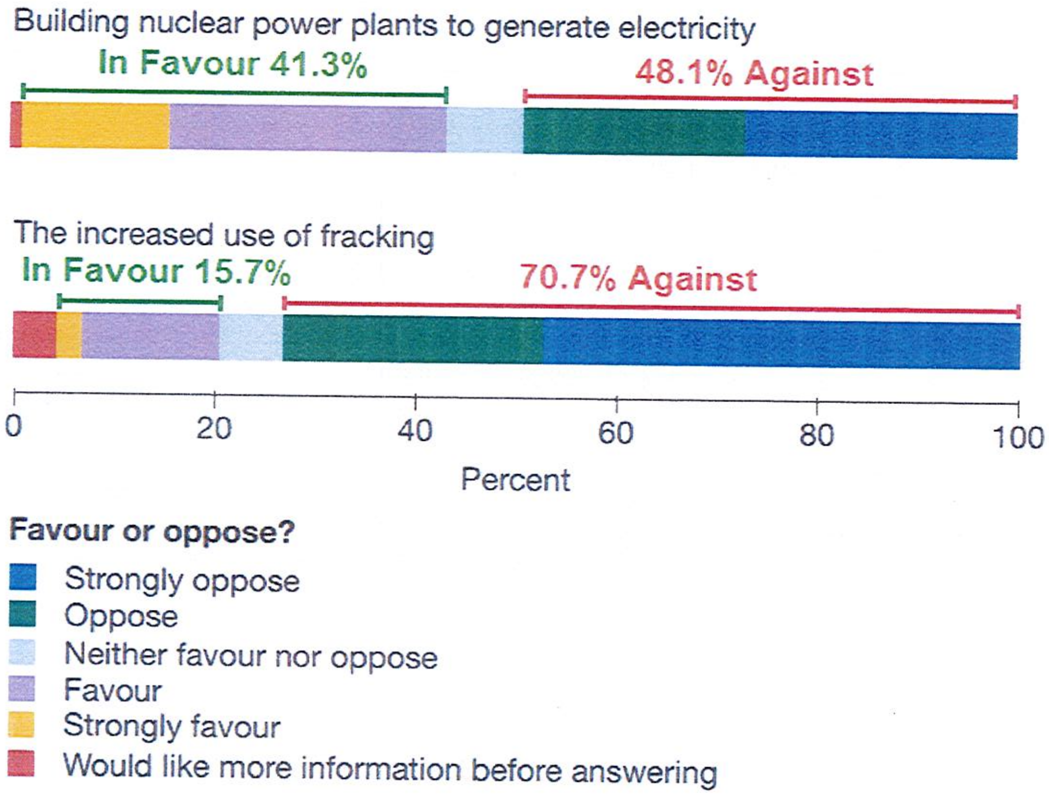


Figure 11: Support for scientific advances

Source: ANU, The Australian Beliefs and Attitudes Towards Science Survey 2017