energy & resources | economic analysis & strategy | commercial & policy advice

CAPE OTWAY ASSOCIATES

The Effect of Nuclear Energy on Total System Electricity Costs

Stephen Wilson

ANA Conference

Sydney | 6th October 2023

Various 'HATS'

au.linkedin.com/in/energyeconomist

Advisory	**Managing Director** CAPEOTWAY ASSOCIATES
Advocacy	nuclear energy focused
Research	**Visiting Fellow** *Centre for Energy Security*
	Adjunct Professor *Mechanical & Mining Engineering* The University Of Queensland Australia
Development	**Director** an energy technology start-up

Without nuclear power generation in the system

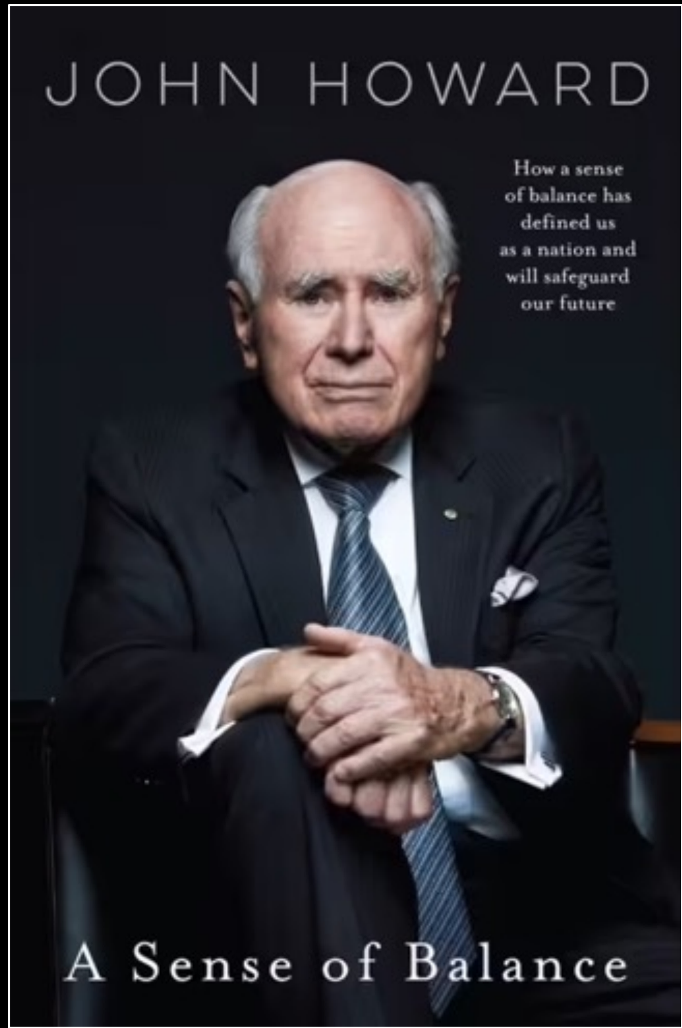
I believe we will find it is close to impossible to

deeply decarbonise the Australian economy

…but it would be a mistake to think that nuclear power in Australia is inevitable as a result

Australia’s energy policy

2000 – present




IF RENEWABLES GET ANY CHEAPER WE'RE STUFFED.
POWER BILL
TAP TAP
JOHANNES LEAK

What is the **Power Cost Paradox**?

CAPEOTWAY ASSOCIATES

Levelised Cost of Energy

- Wind and solar

$50 /MWh

- Nuclear (First-of-a-Kind)

$100 /MWh

Question

How much of each should we build to get the lowest

TOTAL SYSTEM COST

?

Two main messages delivered to governments, oppositions and to the nation

The problem

- The Power Cost Paradox
- The Power System Paradox
- The Power Market Paradox
- **Saturation**
- Balancing

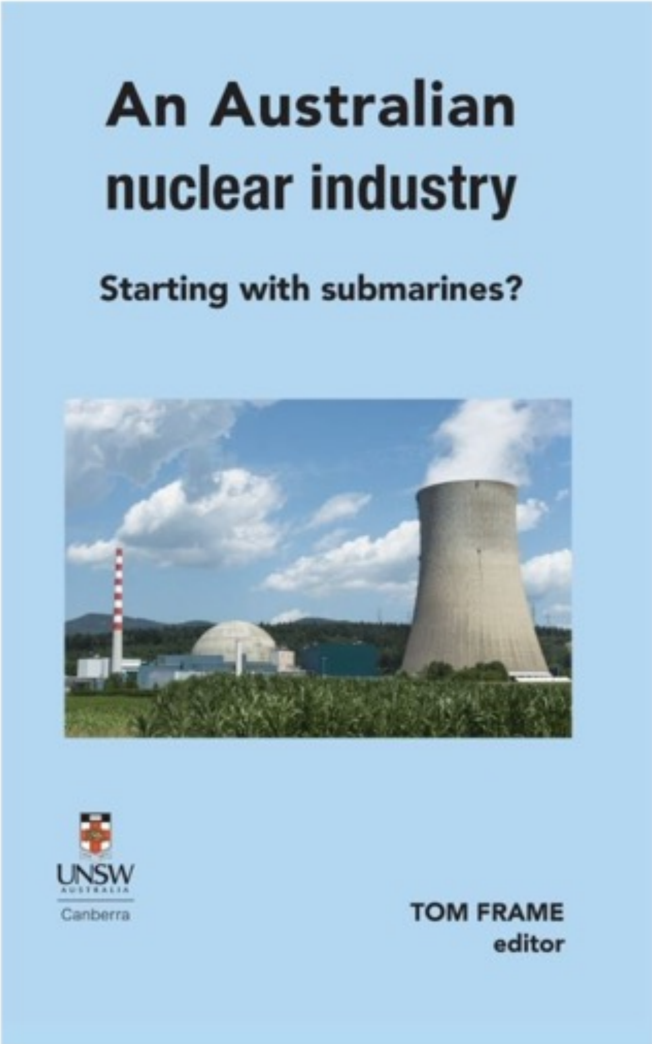
'PLAN B'

Main finding:

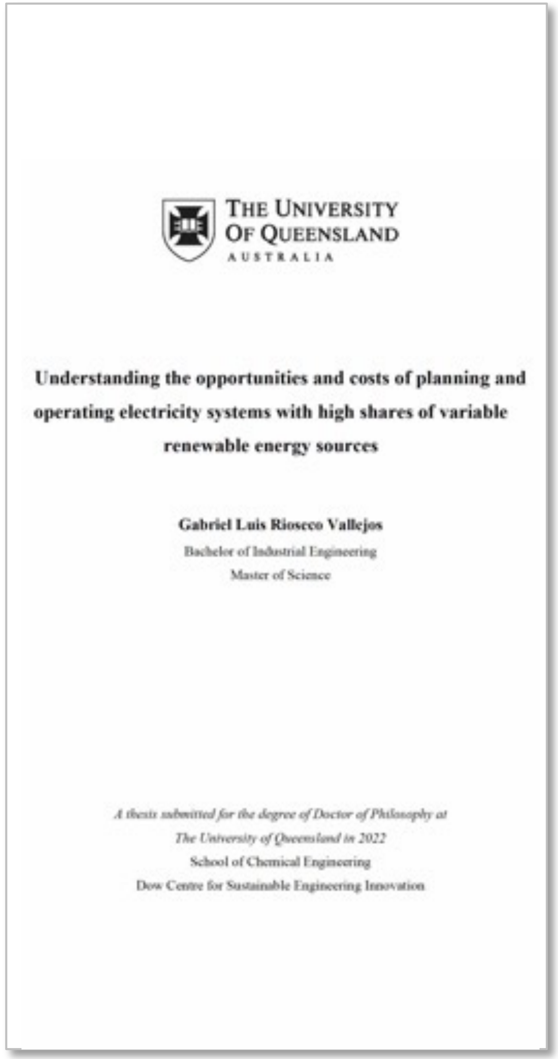
- Australia *is* **capable**

Main recommendation:

- Create **real options** starting *NOW*


An Australian nuclear industry
Starting with submarines?
UNSW
Canberra
TOM FRAME
editor


What would be required
for nuclear energy plants to be operating in Australia from the 2030s
Stephen Wilson
A Preliminary Concept Study by The University of Queensland generously supported by the Barry Murphy Travel & Research Bursary in Nuclear Energy
The University Of Queensland
Australia
Engineering, Architecture and Information Technology


The University Of Queensland
Australia
Understanding the opportunities and costs of planning and operating electricity systems with high shares of variable renewable energy sources
Gabriel Luis Rioseco Vallejos
Bachelor of Industrial Engineering
Master of Science
A thesis submitted for the degree of Doctor of Philosophy at The University of Queensland in 2022
School of Chemical Engineering
Dow Centre for Sustainable Engineering Innovation

An Australian nuclear industry

Starting with submarines?

UNSW Australia
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TOM FRAME
editor

LCoE worked examples

		CSIRO GenCost (2019) inputs (high cost case)		*for illustration (low cost case)*		*UPDATED (low cost case)*	
Reactor module capacity, thermal		133		200		250	*MWth*
Thermal efficiency		*45%*		*30%*		*31%*	
Reactor module capacity, electrical-gross		60		60		77	*MWe*
Nº modules and plant capacity	**12**	**720**	**12**	**720**	**12**	**924**	*MWe*
Plant capacity on a sent-out basis		**683**		**683**		**875**	*MWe*
Series Nº & CapEx on a per unit capacity basis	***Nth***	16.000	***Nth***	4.800	***Nth***	3.740	*AU$M /MW*
CapEx on a total plant overnight cost basis		**11,520**		**3,456**		**3,456**	***AU$M***
Construction period	**5 years**	**60**	**3 years**	**36**	**3 years**	**36**	*months*
Interest During Construction (IDC) approximate		1,728		275		275	*AU$M*
CapEx including capitalised IDC @WACC		**13,248**		**3,731**		**3,731**	***AU$M***
Project Contingency	30%	3974	10%	373	10%	373	*AU$M*
Process Contingency (technology maturity)	10%	1325	0%	0	0%	0	*AU$M*
CapEx including IDC and Contingencies		**18,547**		**4,104**		**4,104**	***AU$M***
Technical service life		60		60		60	*years*
Weighted Average Cost of Capital		**6.00%**		**5.30%**		**5.30%**	
Capital recovery period		30		60		60	*years*
Fixed operation & maintenance per unit of capacity		$200,000		$100,000		$100,000	*/MW*
Capacity charge as an annuity		$1,871,436		$316,359		$246,524	*/MW /y*
Plant Capacity Factor		80%		90%		90%	of capacity x 24h/d x 365d/y
Annual generation sent out		6,648		7,479		7,466	*MWh /y per MWe of gross generating capacity*
Capital recovery charge		**$281.51**		**$42.30**		**$33.02**	*/MWh*
Annual fixed O&M		**$30.08**		**$13.37**		**$13.39**	*/MWh*
Fuel + variable operation & maintenance		**$20.00**		**$10.00**		**$10.00**	*/MWh*
Long-Run Average Cost over capital recovery period		**$331.59**		**$65.67**		**$56.41**	***/MWh***

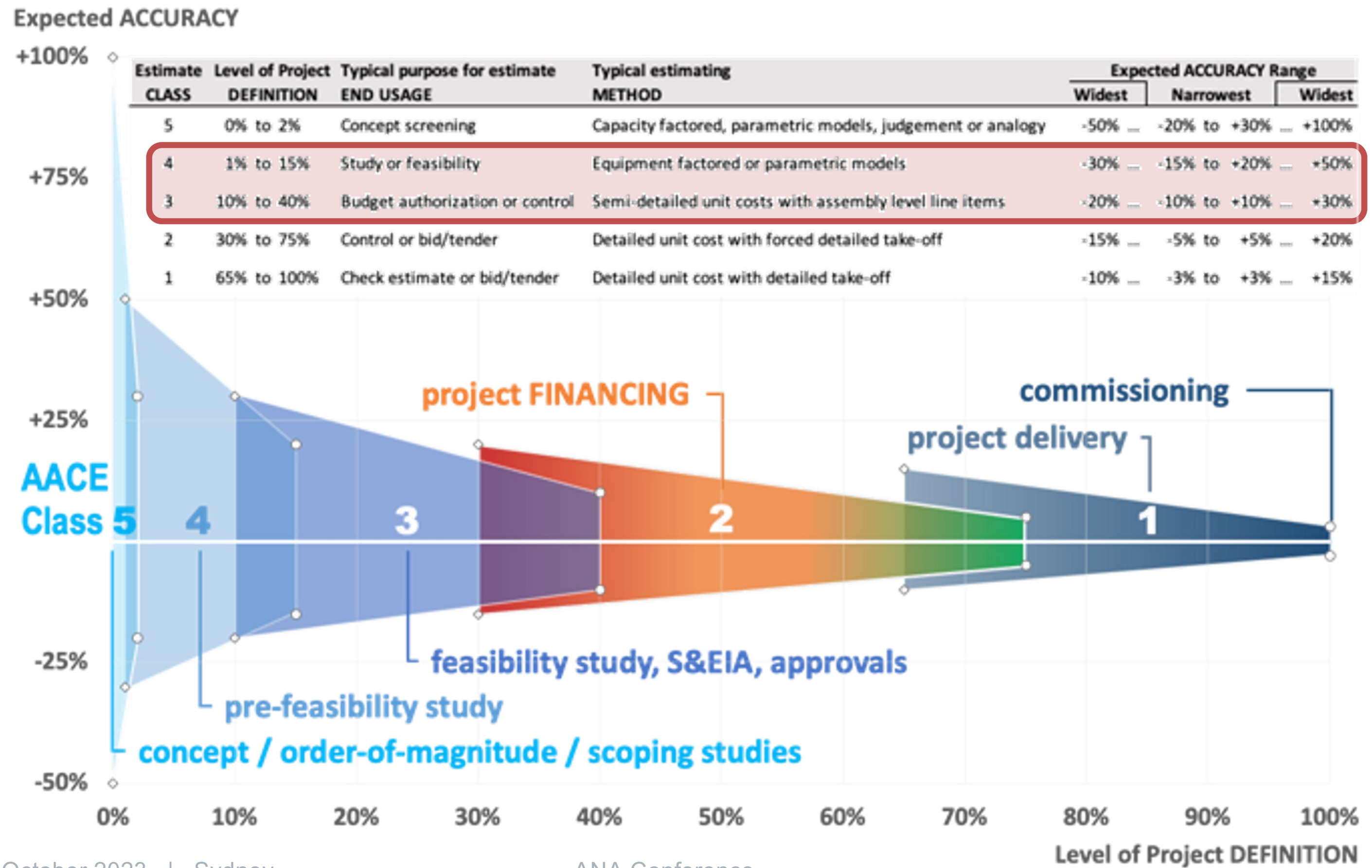
LCoE is ***<u>not</u>*** an investment-grade metric

MANAGEMENT

Preliminary concept

The engineering project lifecycle

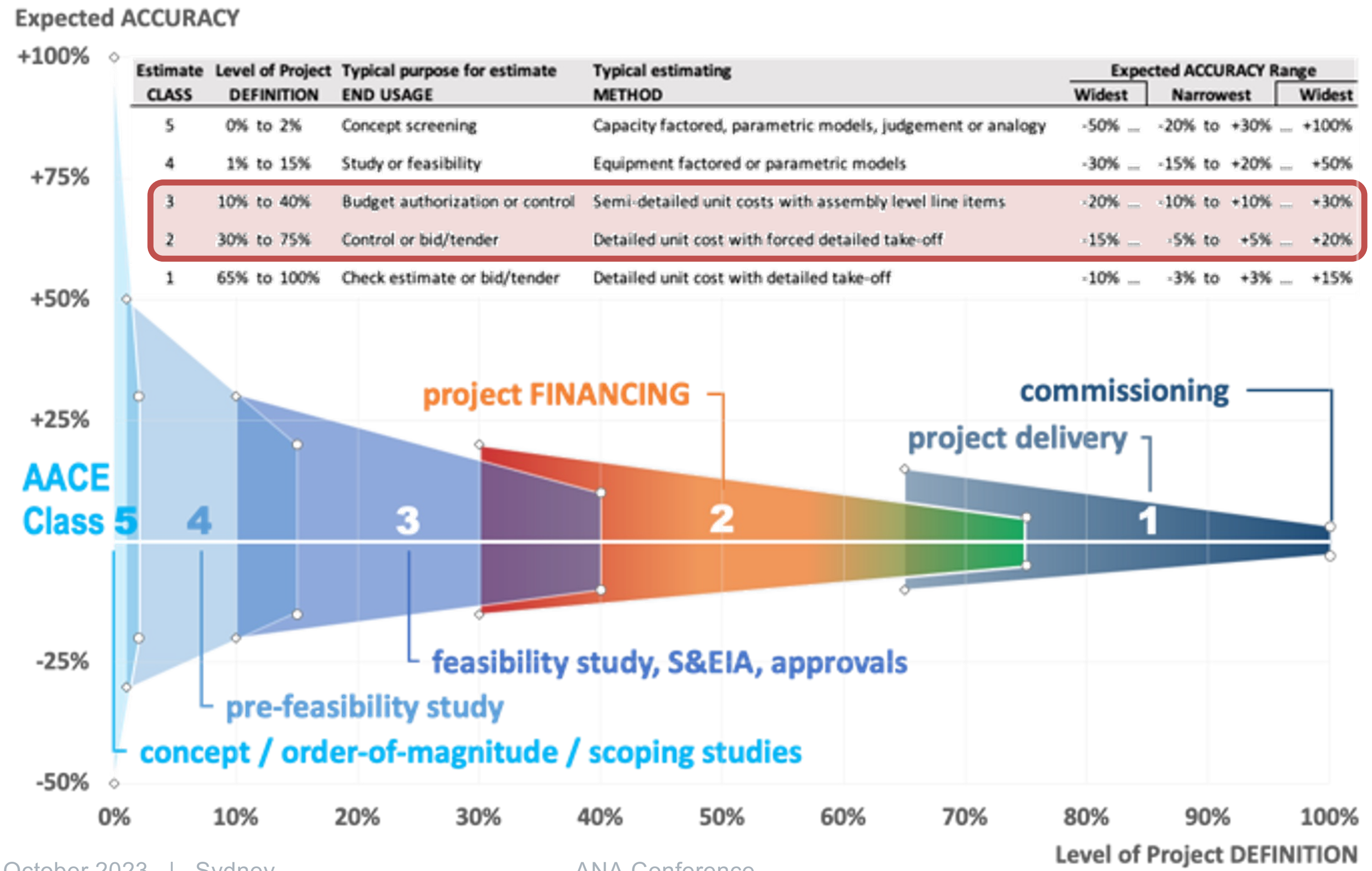
Cost estimate classification matrix and expected accuracy versus project maturity



Estimate CLASS	Level of Project DEFINITION	Typical purpose for estimate END USAGE	Typical estimating METHOD	Expected ACCURACY Range Widest	Narrowest	Widest
5	0% to 2%	Concept screening	Capacity factored, parametric models, judgement or analogy	-50% …	-20% to +30% …	+100%
4	1% to 15%	Study or feasibility	Equipment factored or parametric models	-30% …	-15% to +20% …	+50%
3	10% to 40%	Budget authorization or control	Semi-detailed unit costs with assembly level line items	-20% …	-10% to +10% …	+30%
2	30% to 75%	Control or bid/tender	Detailed unit cost with forced detailed take-off	-15% …	-5% to +5% …	+20%
1	65% to 100%	Check estimate or bid/tender	Detailed unit cost with detailed take-off	-10% …	-3% to +3% …	+15%

NuScale SMR development was here

Cost estimate classification matrix and expected accuracy versus project maturity



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4	1% to 15%	Study or feasibility	Equipment factored or parametric models	-30%	-15% to +20%	+50%
3	10% to 40%	Budget authorization or control	Semi-detailed unit costs with assembly level line items	-20%	-10% to +10%	+30%
2	30% to 75%	Control or bid/tender	Detailed unit cost with forced detailed take-off	-15%	-5% to +5%	+20%
1	65% to 100%	Check estimate or bid/tender	Detailed unit cost with detailed take-off	-10%	-3% to +3%	+15%

NuScale SMR development is or will soon be here

Cost cannot be considered simplistically or in a vacuum

5. Energy **SECURITY**	considerations at the national-level
4. The **VALUE**	to the system, including real option value
3. The **SYSTEM**	What is the effect on system costs of 1, 2, 3 … N plants ?
2. The **FLEET**	How would that cost come down from 1st to Nth-of-a-Kind ?
1. The **ASSETS**	What would it actually cost to build a nuclear plant in Australia ?

SCOPE of the study

THE UNIVERSITY OF QUEENSLAND AUSTRALIA

TABLE 5 Illustrative build-up of capital charge and financing structure, showing average energy unit costs

NuScale/Fluor central estimate [77] (AACE class 3-4, U.S. ref. unit cost basis)	AACE lower	2 850	AACE upper	2017US$ /kWe gross
Overnight capital cost on a per unit capacity basis (2017US$ to 2020 AU$)	2 893	3 993	5 613	2020AU$ / kWe gross
CapEx on a total plant overnight cost basis	**2 757**	**3 690**	**5 187**	**AU$M**
Owners' costs: AU$2015, adjusted to AU$2020	203	393	765	AU$M
CapEx: overnight costs plus owners' costs	**2 959**	**4 083**	**5 952**	**AU$M**
Construction period (authors' conservative assumptions)	36	48	60	months
Interest During Construction (IDC) approximate	235	433	789	AU$M
CapEx including owners' costs, IDC capitalised @WACC	**3 195**	**4 516**	**6 740**	**AU$M**
Project Contingency 30%	958	1 355	2 022	AU$M
CapEx including IDC and Contingencies authors' estimate	**4 153**	**5 871**	**8 762**	**AU$M**
10% Government finance		yield 1.0%		
20% Special purpose bonds		yield 3.0%		
40% Commercial debt plus ECA finance		yield 6.1%		
30% Equity portion		yield 7.2%		
Illustrative WACC with the above assumptions		**5.3%**		
Capital recovery period		30		years
Fixed operation & maintenance per unit of capacity		100		AU$ /kW
Capacity charge as an annuity	316	447	667	AU$ /kW /y
Plant Capacity Factor		95%		of capacity x 24h/d x 365d/y
Operating hours per year		8 322		h /y
Capital recovery charge expressed per unit of output	**38**	**54**	**80**	AU$ /MWh
Annual fixed O&M expressed per unit of output		12		AU$ /MWh
Fuel + variable operation & maintenance		10		AU$ /MWh
Long-run average cost of energy, levelised over 30 y capital recovery	**60**	**76**	**102**	**AU$ /MWh**

Sources: Authors' estimates and calculations, using key inputs from NuScale as cited and described in chapter 2: references [77,78,177]; and Table 6.1 from report for ref. [14]: WSP Parson's Brinkerhoff (Feb 2016) *Quantitative Analysis and Initial Business Case – Establishing a Nuclear Power Plant and Systems in South Australia*.

FINANCING

Table 5 Illustrative build-up of capital charge and financing structure, showing average energy unit costs

AACE case^	Lowest	Lower	CENTRAL‡	Higher	Highest	
Overnight CapEx	*2 983*	*3 488*	***3 993***	*4 604*	*5 613*	*2020AU$ /kWe gross*
TOTAL CapEx *	**4 153**	**5 002**	**5 871**	**7 032**	**8 762**	*AU$M*
…-of a-Kind	*'Best' Nth*	*'Worst' Nth*	*5th-of-a-Kind*	*'Best 1st*	*'Worst 1st*	*Learning*
Assumed build	*36*	*42*	***48***	*54*	*60*	*months*
LRACE	*60*	*68*	***76***	*86*	*102*	*AU$ /MWh*

^ Based on the mix of class 3 and class 4 components
‡ Based on NuScale US$**2850**/$kW_e$ gross in 2017 US dollars
* for a **12**-module plant x **77** MW_e in a generic location

Discounted at ***5.3%*** per annum with capital recovered over **30** years
annual fixed O&M of **$100** /kW and variable O&M of **$10** /MWh
plant capacity factor of 95% giving 8322 hours per year at full load

Cost cannot be considered simplistically or in a vacuum

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5. Energy **SECURITY**	considerations at the national-level
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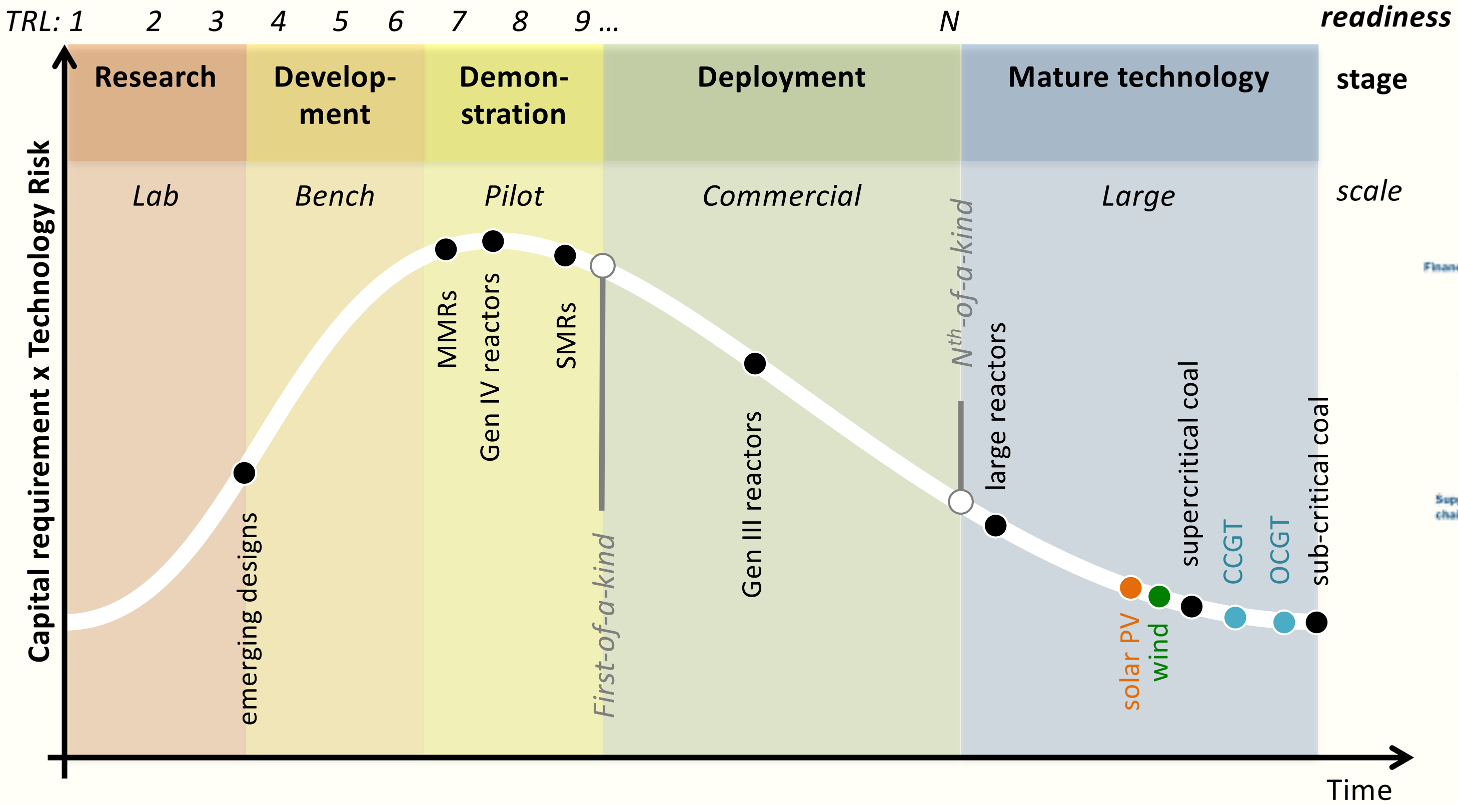
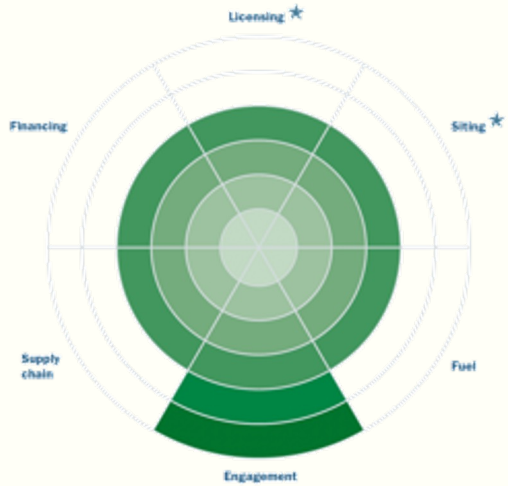
Technology Learning
—the Grubb Curve





The NEA Small Modular Reactor Dashboard Volume II **more info:** https://doi.org/10.1787/e586e483-en

W. weapons

A. accidents

R. radiation

N. nuclear ‘waste’

1. costs

2. time

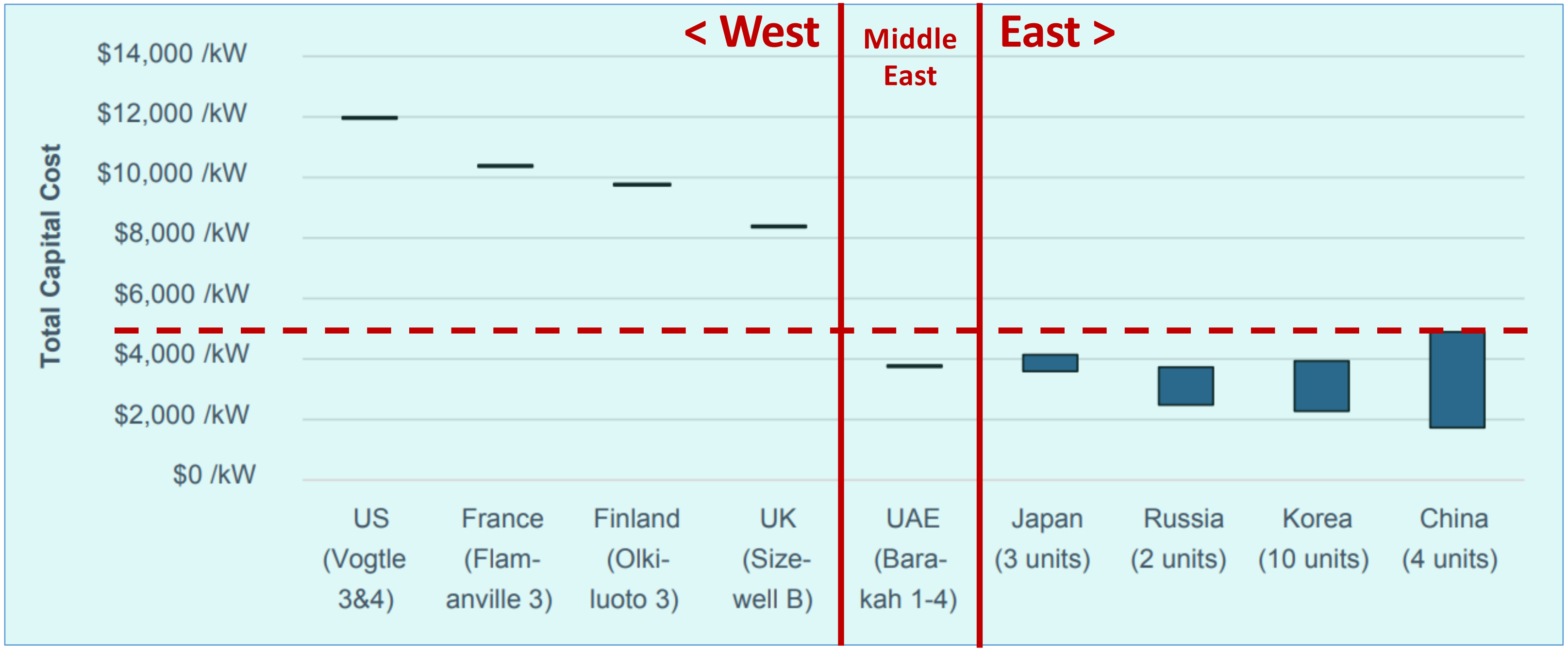
3. ‘waste’ *

* this is actually:

Slightly Used Nuclear Fuel

Does nuclear energy **cost too much?**

…or are Westerners stupid?

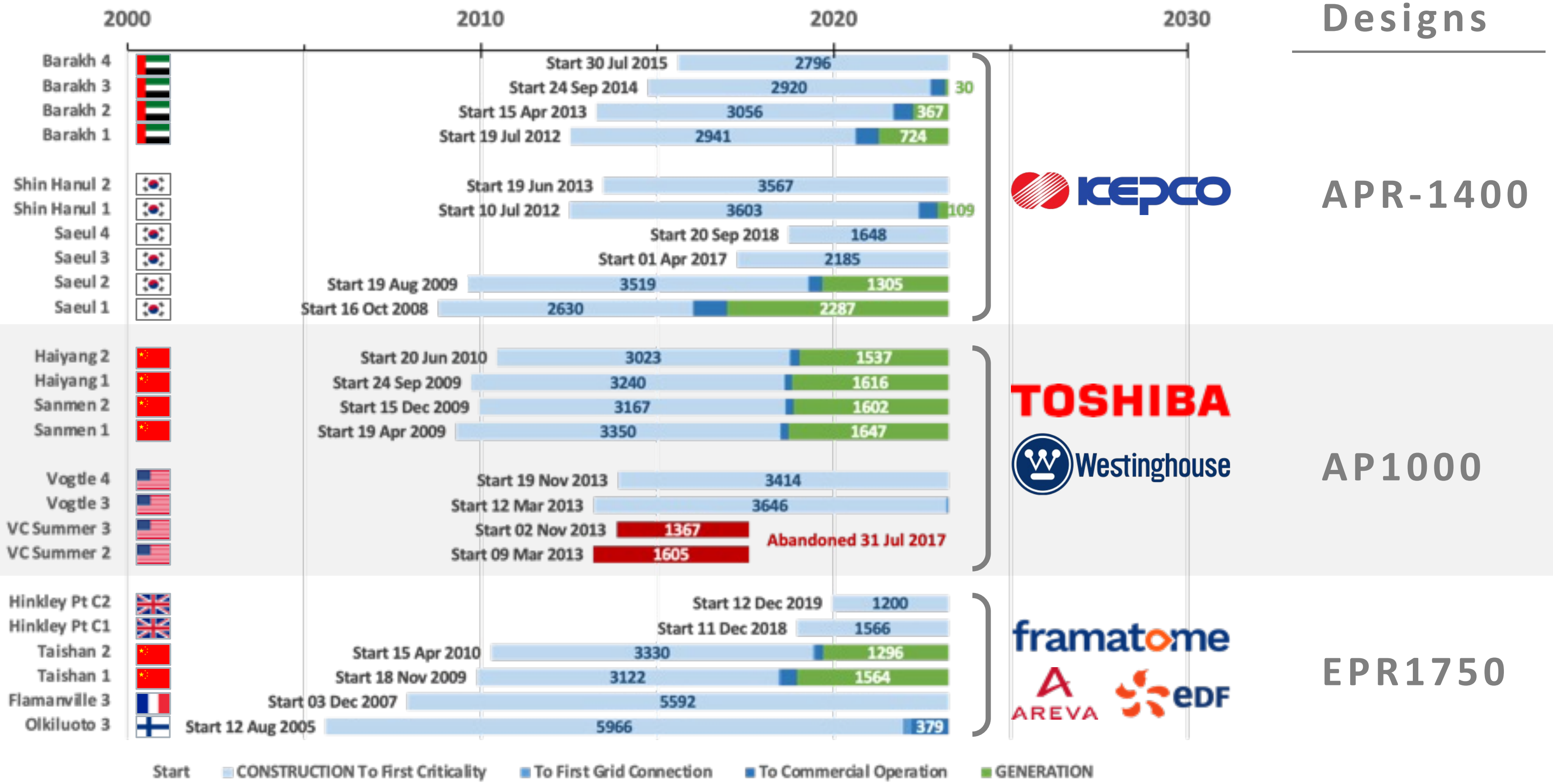


Total capital costs ($US/kW) of recent nuclear projects

Source: reproduced with kind permission of Dr Dave Collins Synergetics Pty Ltd: ***Report on the International Congress on Advances in Nuclear Power Plants (ICAPP23) held in Gyeongju, South Korea, on 23 to 27 May 2023 and Implications for Australia***

Does nuclear energy **take too long?** *…or are Westerners just a bit slow?*

Construction times of large 21st century PWRs



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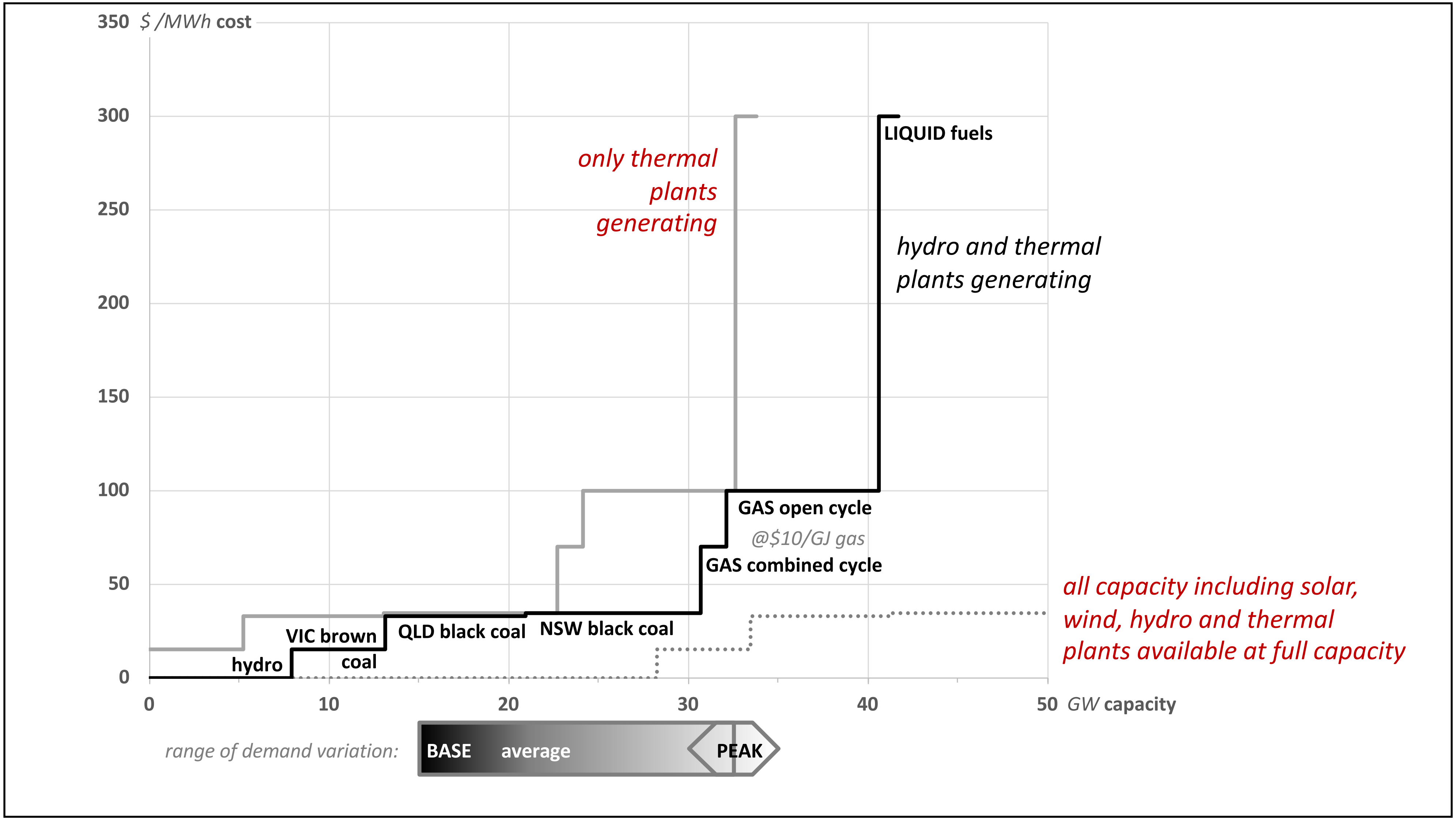
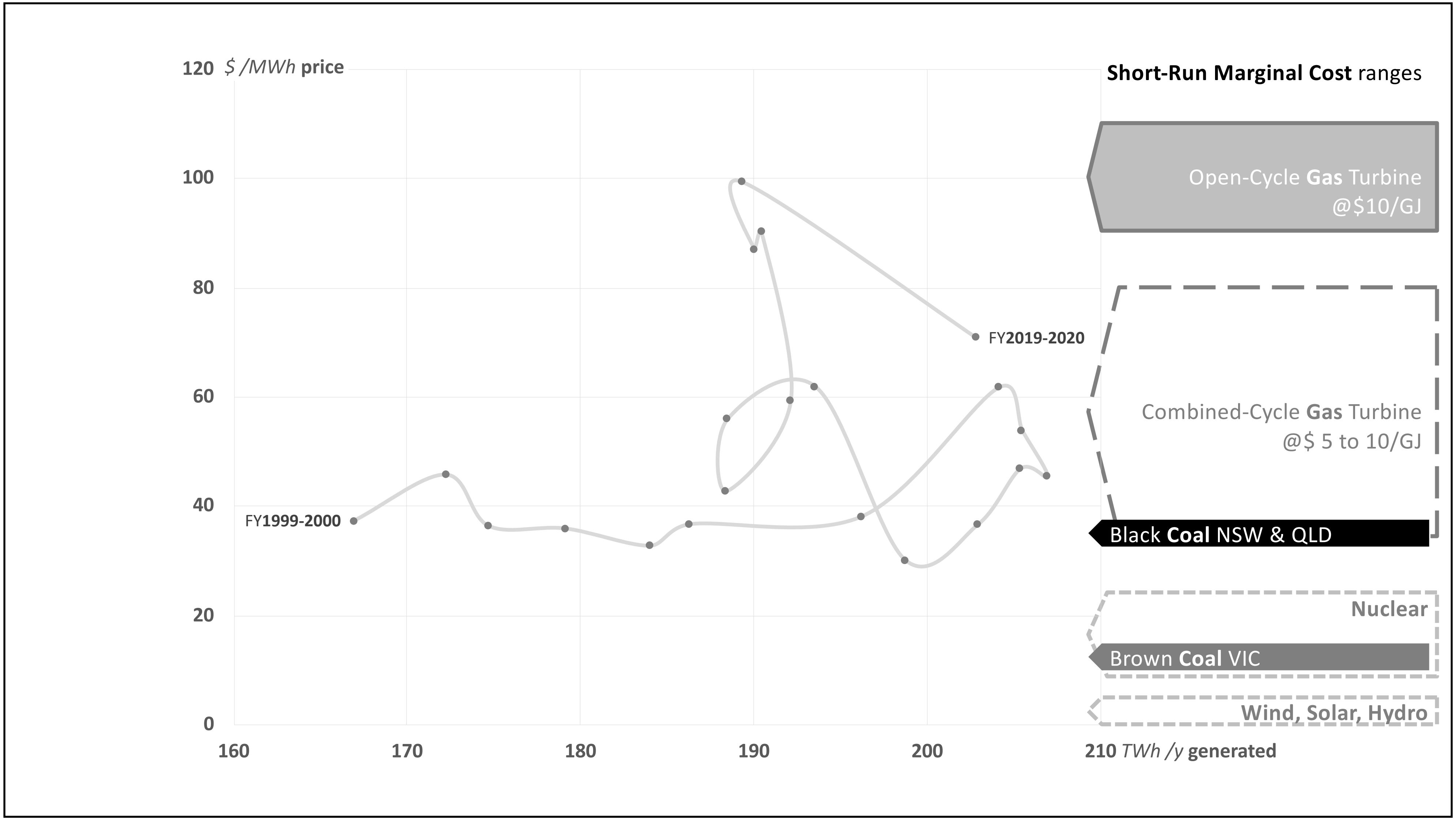
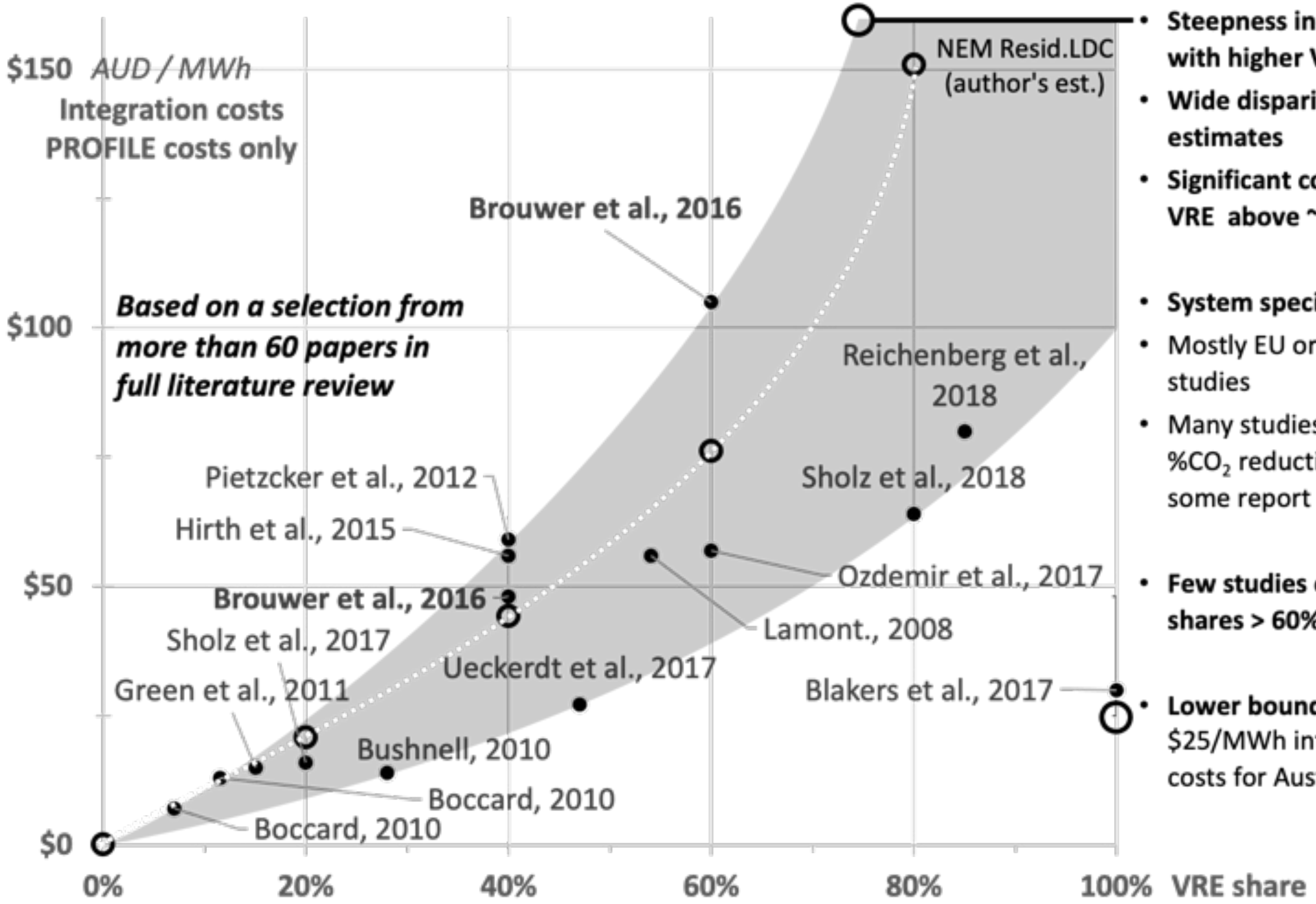


350 $ /MWh cost
300
250
200
150
100
50
0
0
10
20
30
40
50 GW capacity
only thermal plants generating
LIQUID fuels
hydro and thermal plants generating
GAS open cycle
@$10/GJ gas
GAS combined cycle
all capacity including solar, wind, hydro and thermal plants available at full capacity
VIC brown coal
QLD black coal
NSW black coal
hydro
range of demand variation:
BASE
average
PEAK



120 $ /MWh price
100
80
60
40
20
0
160
170
180
190
200
210 TWh /y generated
FY1999-2000
FY2019-2020
Short-Run Marginal Cost ranges
Open-Cycle Gas Turbine @$10/GJ
Combined-Cycle Gas Turbine @$ 5 to 10/GJ
Black Coal NSW & QLD
Nuclear
Brown Coal VIC
Wind, Solar, Hydro



- **Steepness increases with higher VRE shares**
- **Wide disparity of estimates**
- **Significant costs for VRE above ~ 25% share**

- **System specific**
- Mostly EU or USA studies
- Many studies report %CO_2 reduction: only some report VRE share

- **Few studies explore shares > 60%**

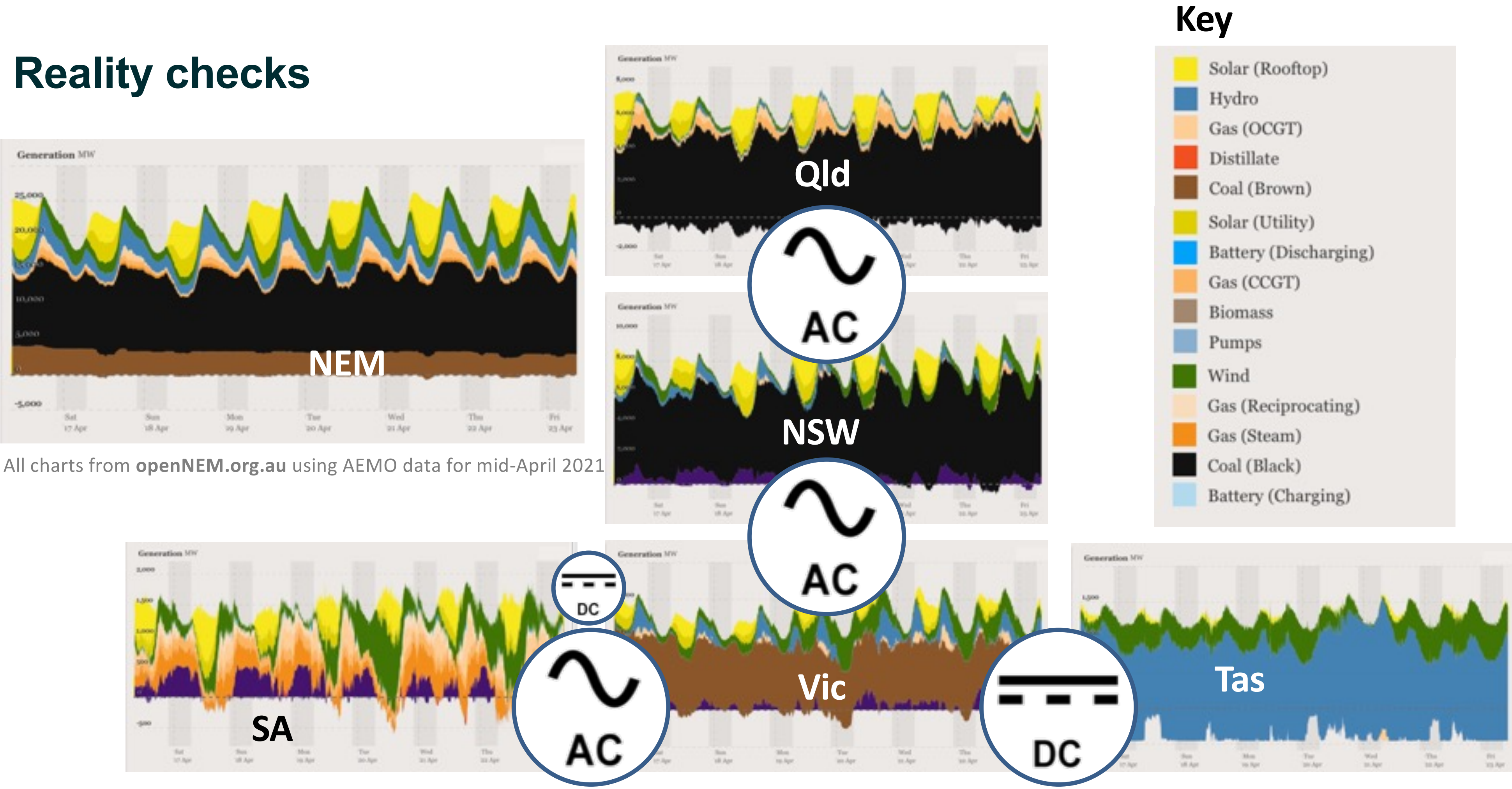
- **Lower bound** estimate: $25/MWh integration costs for Australia

“There is no single full-fidelity model of a power system.”

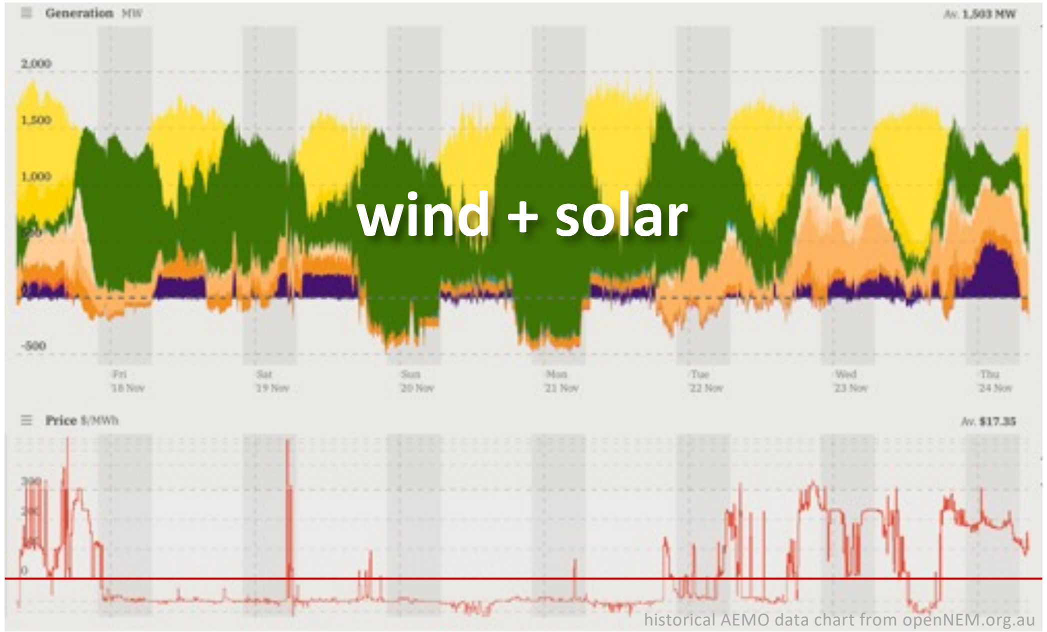
… but there are plenty of useful models

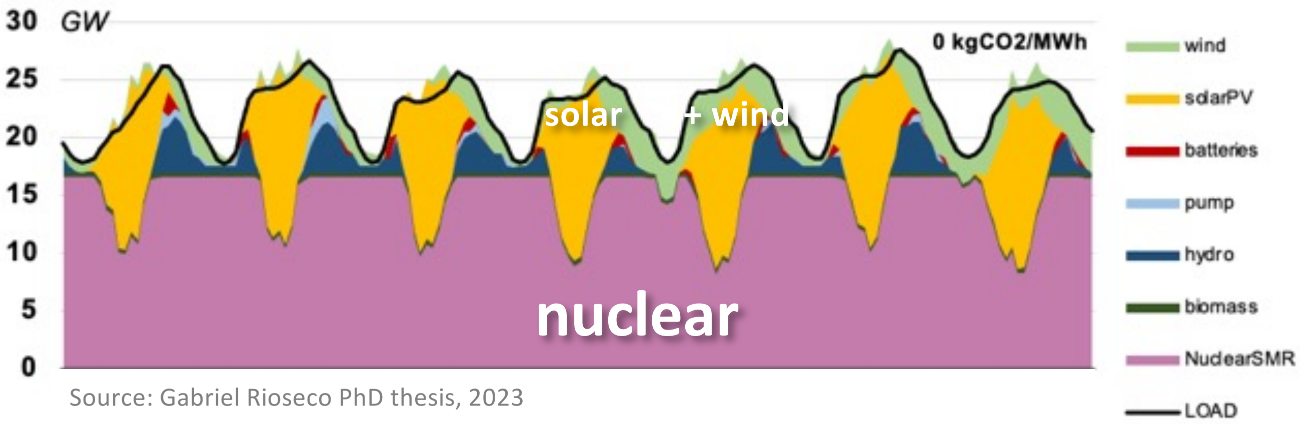
Dr Archie Chapman, University of Queensland

Reality checks



All charts from **openNEM.org.au** using AEMO data for mid-April 2021





Source: Gabriel Rioseco PhD thesis, 2023

South Australia:

Wind + solar driven (subsidised)

Gas dependent (and **import**/export)

Nuclear is excluded

System cost minimisation

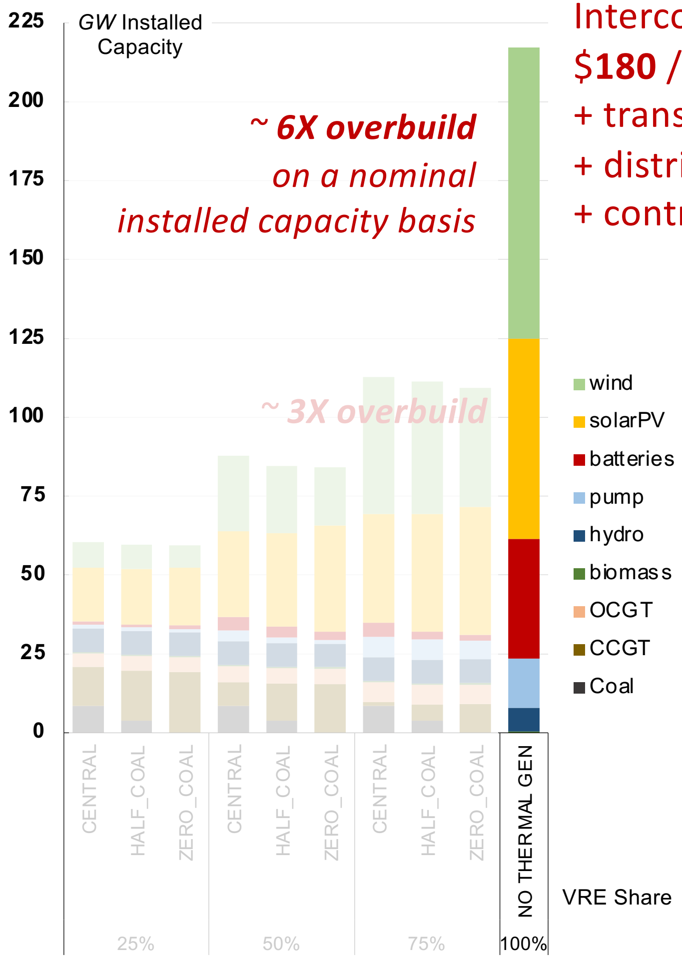
- 5-region NEM with interconnector constraints and investment
- unit commitment constraints

simultaneously optimising for a given generation mix:

- long-run investment AND 24x365 hourly dispatch
- emissions constraint (shown)
- OR wind + solar share

- low sensitivity to SMR CapEx
- high flexibility gains entry
- optimisation drives utilisation

Generation costs in the interconnected system



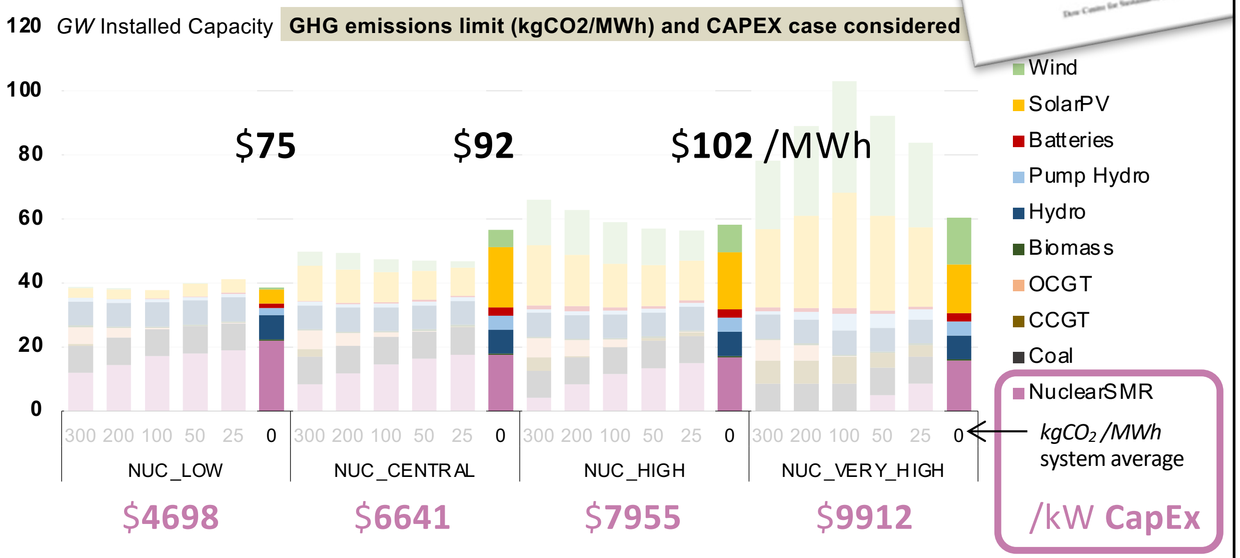
Interconnected generation system cost:

$180 /MWh

+ transmission for Rewiring the Nation

+ distribution for two-way flows

+ control systems



Generation costs in the interconnected system


THE UNIVERSITY OF QUEENSLAND
AUSTRALIA

Understanding the opportunities and costs of planning and operating electricity systems with high shares of variable renewable energy sources

Gabriel Luis Riesco Vallejos
Bachelor of Industrial Engineering
Master of Science

A thesis submitted for the degree of Doctor of Philosophy at
The University of Queensland in 2022
School of Chemical Engineering
Dow Centre for Sustainable Engineering Innovation

Renewables-based WITHOUT nuclear	No emissions WITH nuclear
$**180** /MWh + + +	$**90** /MWh – – –
+ **transmission** on a huge scale	• use existing transmission
+ **distribution** for two-way flows	• avoid distribution upgrades
+ **control** systems …	• avoid system balancing problems

Cost cannot be considered simplistically or in a vacuum

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Here is what has happened to **PRICES**

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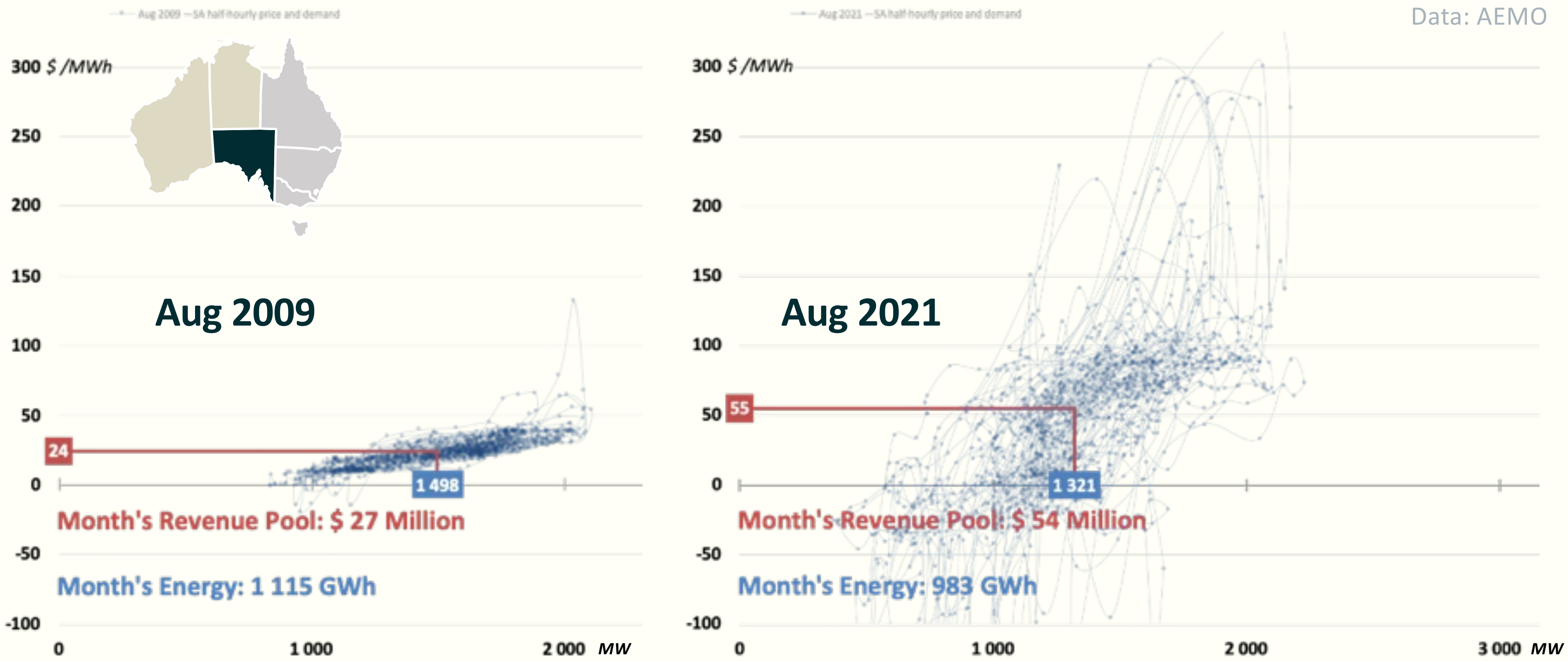
Data: AEMO



a SYSTEM ≠ *a market*

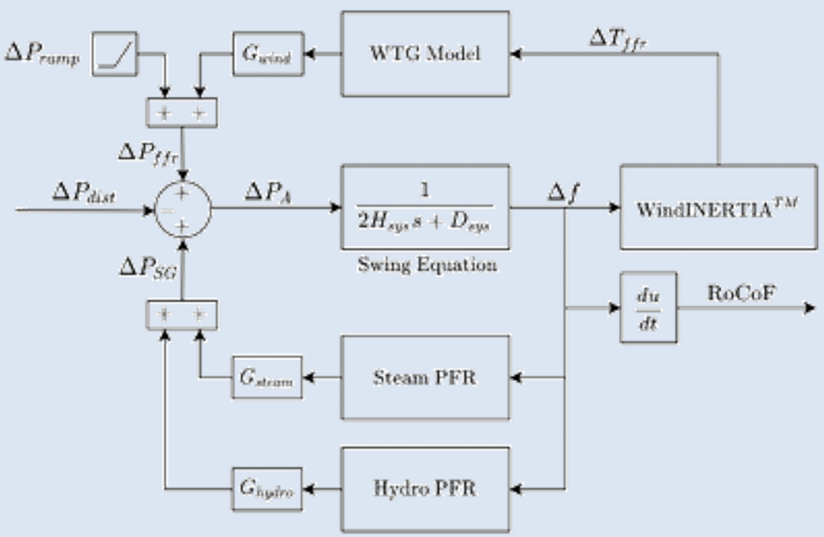
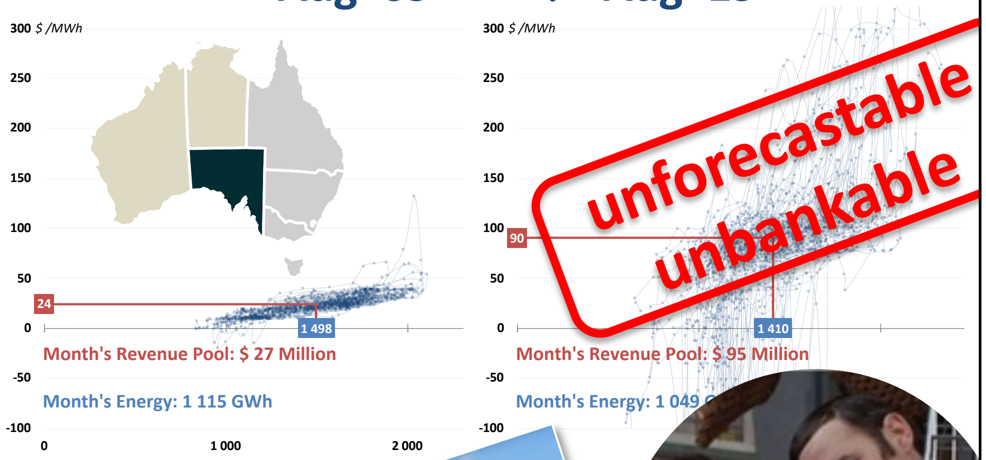


Fig. 1. **Complete system block diagram.** This figure is a representative model of the actual system built in Simulink. The main input is a power system disturbance and the output of interest is the frequency nadir and RoCoF.

Aug '09 ⟶ Aug '19



Finding and observation
from earlier research

CAPEOTWAY ASSOCIATES

"No-one can produce a bankable price forecast of the Australian electricity market today"

—a senior banker with 25 years of experience financing the Australian energy sector

Our research in mid-2017 found that this view is **universally held** by the major Australian banks and the major international banks present in Australia

ECONOMICS

Applicability

SMRs are designed to be used for:

- **Electricity**
- **Balancing** renewable energy
- **Hydrogen** production
- **eFuel** synthesis
- **Desalination** of seawater
- **Heat** for industry

Proceedings of ICAPP 2015
May 03-06, 2015 – Nice (France)
Paper 15555

Can Nuclear Power and Renewables be Friends?

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Abstract – *The increasing penetration of renewables, especially wind generation, have dramatically changed the economics and realities of grid management in ways that now encourage some level of load-following capabilities for historically baseload plants, including nuclear. The NuScale small modular reactor design currently under development in the United States is well suited for integration with renewables because of several design features related to the nuclear steam supply system, the power conversion system, and the overall plant architecture. The multi-module nature of a NuScale plant allows the plant output to be varied in three ways spanning a wide range of different time frames: (1) taking one or more modules offline for extended periods of sustained wind output, (2) adjusting reactor power for one or more modules for intermediate periods to compensate for hourly changes in wind generation, or (3) bypassing the steam turbine for rapid responses to wind generation variations. Results are presented from a recent analysis of nuclear-wind integration that utilized historical wind generation data from the Horse Butte wind farm in Idaho. Also discussed is the experience of Energy Northwest in their implementation of limited load-shaping at the Columbia Generating Station.*

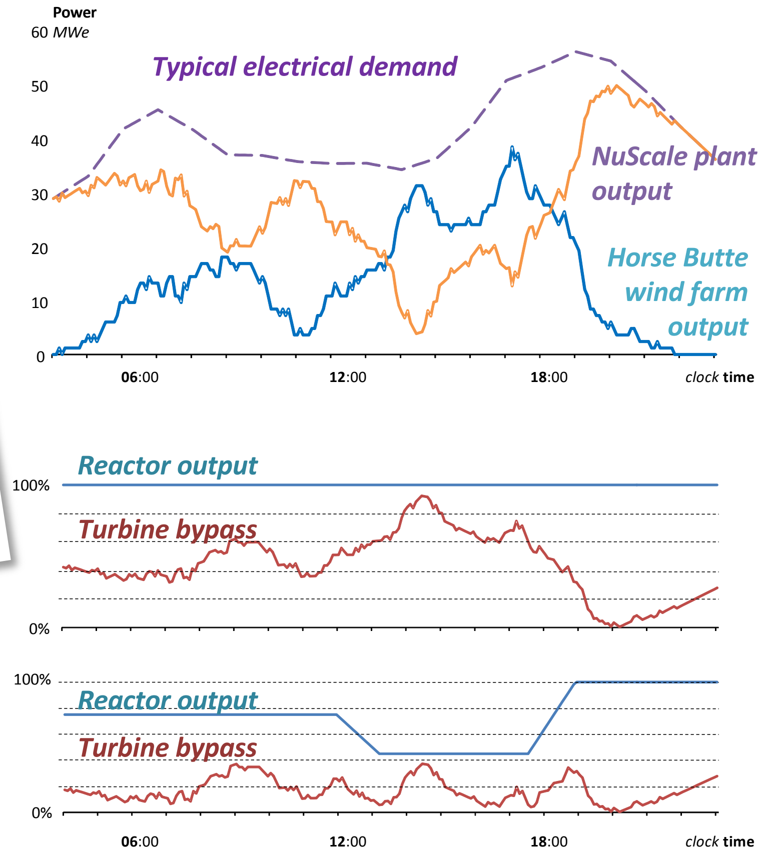
I. INTRODUCTION

Competition for constrained federal funding and ideological biases have tended to pit various energy technologies against each other, especially between renewable sources, typically wind and solar, and traditional sources, including hydro, coal, natural gas, and nuclear. Of the traditional sources, only hydro and nuclear offer abundant power with virtually no emission of greenhouse gases (GHG). However, new sites for large hydroelectric plants are very limited and have their own environmental issues. As such, nuclear appears to be the only resource that has the potential to not only add to the "clean" energy provided by wind and solar technologies, but actually enable larger contributions of these renewable sources without jeopardizing grid stability or risking unmet electricity demand. However, doing so may require nuclear plant designs to incorporate features that enhance their load-following capabilities.

Conventional wisdom suggests that nuclear power plants should be operated continuously at full capacity and that natural gas plants are best suited to provide "peaking" capability to meet excess demand. This historical strategy has been driven mostly by economic considerations since nuclear plants have relatively high capital cost and low fuel cost compared to natural gas plants. Because of the low fuel cost in a nuclear plant, running the plant at 50% power has minimal impact on operations costs but reduces revenue by one-half. The increasing penetration of renewable sources, especially wind, has altered this economic argument since wind turbines are also capital-intensive (per unit of power produced) and their fuel cost is zero. Also, wind generation tax credits encourage their full-out operation. Finally, some regional policies require grid dispatchers to preferentially use renewable energy first, which exacerbates the economic challenges of operating base-load plants and are driving plant owners to change their concepts of economic dispatch.

Many nuclear plants currently operating were designed to load-follow and were originally outfitted with automatic grid control (AGC) features. However, the U.S. Nuclear Regulatory Commission established a policy that precluded the use of automatic dispatching for true load following, although they allow manual load-shaping if conducted by a licensed reactor operator. Globally, France's pressurized water reactors routinely load-follow due to the high

Figure 16 SMR turbine bypass load following



Value

Real options to build nuclear plants with small modular reactors have substantial value arising from decarbonisation and deep uncertainty in grids

Ingersoll et al, *Can Nuclear Power and Renewables be Friends?* Proceedings of ICAPP 2015
May 03-06, 2015 – Nice (France)
Paper 15555

Some Perspectives on costs

remarks on insights from recent research

THE UNIVERSITY OF QUEENSLAND

Bachelor of Engineering Thesis

Hydrogen or Electrons: the Engineering and Economics of HVDC and Green Hydrogen—a Study of the Viability of Clean Energy Exports from Northern Australia to Southeast Asia

Student Name: Jarrod ALLEN
Course Code: MECH4500
Supervisor: Professor Stephen Wilson
Submission Date: 29 October 2020

A thesis submitted in partial fulfilment of the requirements of the Bachelor of Engineering Degree in Mechanical Engineering

UQ Engineering

Faculty of Engineering, Architecture and Information Technology

1 **Green HYDROGEN**
(& ammonia)

2 **Frequency STABILITY**

Emerging Frequency Control Mechanisms in IBR Dominated Power Systems

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Brisbane, Queensland 4072

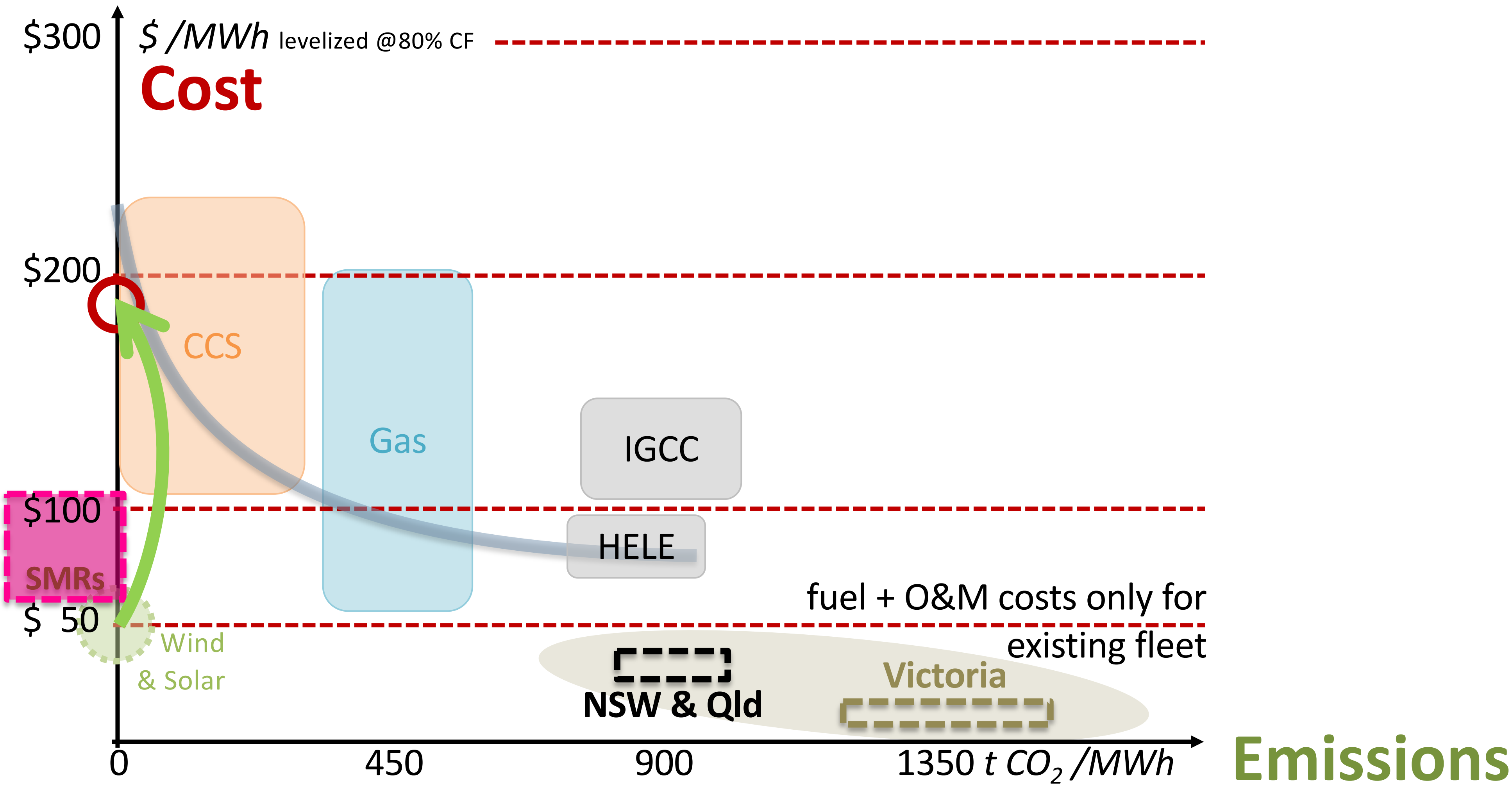
***Abstract*—As inverter-based resource (IBR) penetration increases, system inertia levels are decreasing and the type of frequency response available is changing. This paper explores the adequacy of emerging technologies in providing post-contingency frequency control in the absence of traditional synchronous generators (SGs). The three technologies considered are (1) the fast frequency response (FFR) of a wind turbine generator, (2) the FFR of grid-scale battery systems and (3) the inertial contribution of synchronous condensers (SCs). The model incorporating these technologies is built around the aggregated swing equation and also includes the primary responses of steam and hydro generators.**

The findings indicate that although no individual technology can adequately improve the frequency response, combinations of them can. For example, SCs and batteries were seen to maintain the rate of change of frequency (RoCoF) and nadir within safe operating levels. This suggests that a more granular set of grid services is required to maintain system stability and that these services can be offered by a range of new technologies.

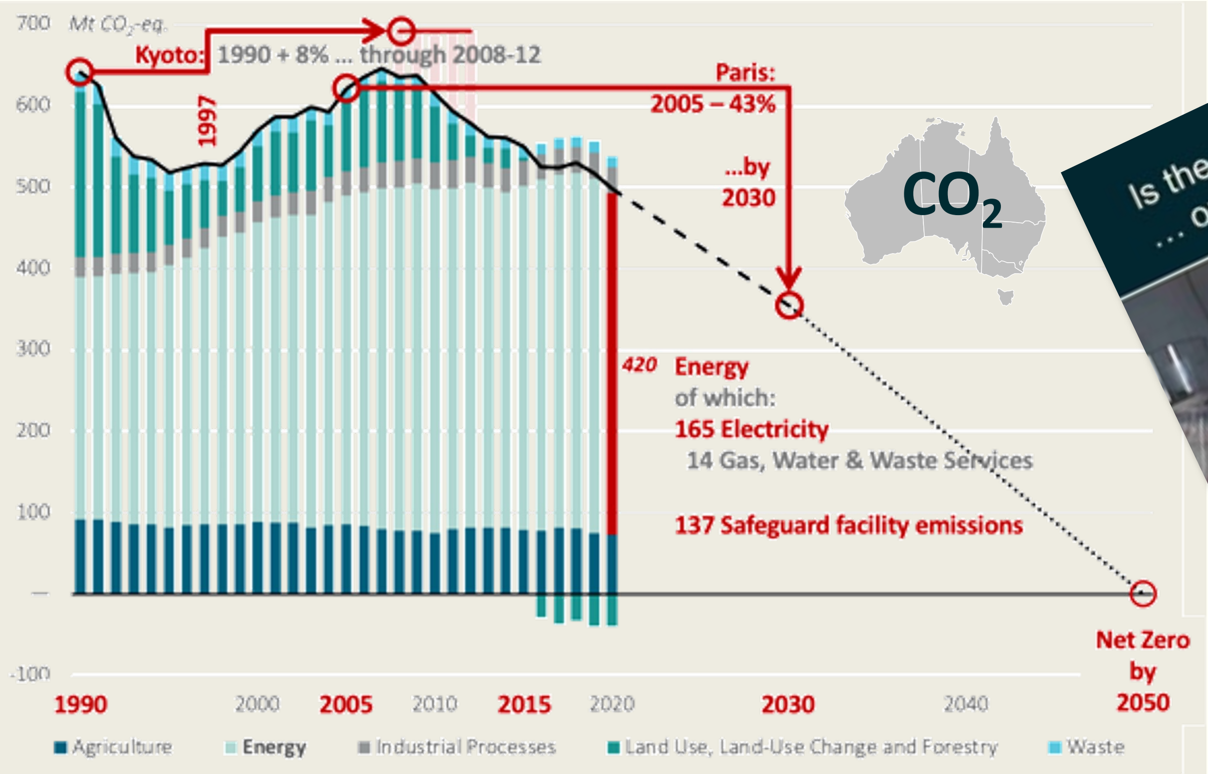
1) The *fast frequency response* (FFR) of a wind turbine generator (WTG),
2) the FFR of a battery energy storage system (BESS) and
3) the inertial contribution of synchronous condensers (SCs).

Each of these technologies has received individual attention in literature, wind FFR in [2], ramp FFR in [3] and synchronous condensers in [4]. This research adds to this work by studying a reduced-form system where the effects of each technology can be studied together.

In July of this year, AEMO CEO announced plans to "engineer grids that are capable of running at 100% instantaneous penetration of renewable energy" by the year 2025 [5]. This announcement extended AEMO's previous target of 75% penetration outlined in their Integrated System Plan [6]. As Australia prepares to enter operating regions heretofore unseen


$300
$ /MWh levelized @80% CF
Cost
$200
CCS
Gas
IGCC
$100
HELE
SMRs
fuel + O&M costs only for
existing fleet
$ 50
Wind
& Solar
Victoria
NSW & Qld
0
450
900
1350 t CO_2 /MWh
Emissions

CLIMATE
what about carbon costs?



Source: National Greenhouse Gas accounts: https://greenhouseaccounts.climatechange.gov.au, + annotations


G7
Cornwall
12 Jun 2021
G7
United Kingdom 2021
1 x 210 MW_{th} reactor
driving 2 x 30 MW_e turbines
UNITED KINGDOM
UNITED STATES
AUSTRALIA
AUKUS
15 Sep 2021
COP26
GLASGOW
2 Nov 2021
700
600
500
400
300
200
100
-100
Mt CO_2-eq.
Kyoto: 1990 + 8% ... through 2008-12
1997
Paris:
2005 – 43%
...by
2030
420 Energy
of which:
165 Electricity
14 Gas, Water & Waste Services
137 Safeguard facility emissions
Net Zero
by
2050
1990
2000
2005
2010
2015
2020
2030
2040
2050
Agriculture
Energy
Industrial Processes
Land Use, Land-Use Change and Forestry
Waste

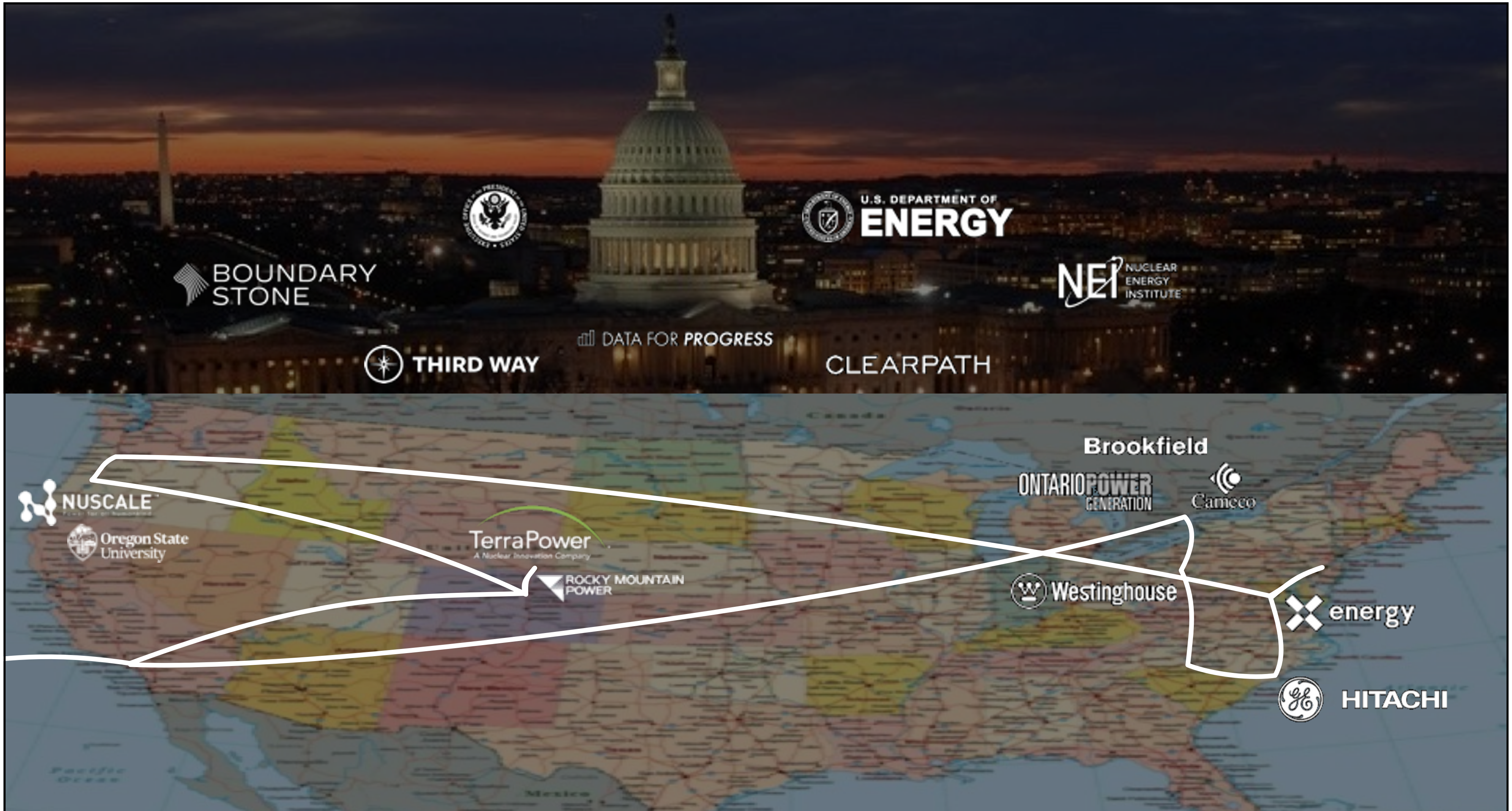
Cost cannot be considered simplistically or in a vacuum

CAPEOTWAY ASSOCIATES

5. Energy **SECURITY**	considerations at the national-level
4. The **VALUE**	to the system, including real option value
3. The **SYSTEM**	What is the effect on system costs of 1, 2, 3 … N plants ?
2. The **FLEET**	How would that cost come down from 1^{st} to N^{th}-of-a-Kind ?
1. The **ASSETS**	What would it actually cost to build a nuclear plant in Australia ?

Point Loma Naval Base
San Diego, California
13th March 2023

https://www.forces.net/china/sunak-and-biden-discuss-chinas-increased-assertiveness-and-agree-visits



nuclear energy due diligence study tour Jan-Feb 2023 with the shadow minister for climate change and energy


"Energy security *IS* national security."

What is ‘**energy security**’ ?

definition:

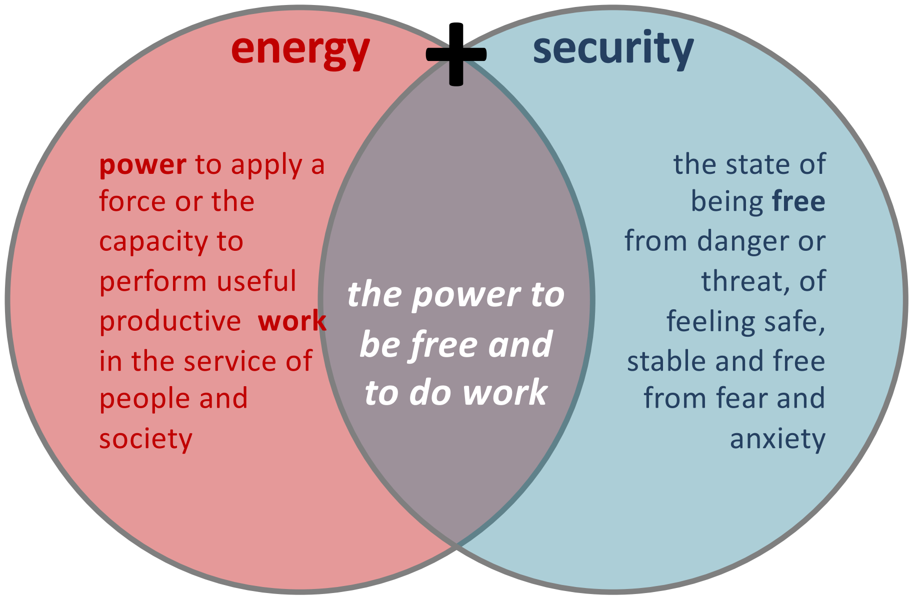
the power to be free and to do work

Institute of Public Affairs

The Canberra definition

first put forth at the IPA Retreat the in May 2023 at the Hotel Canberra

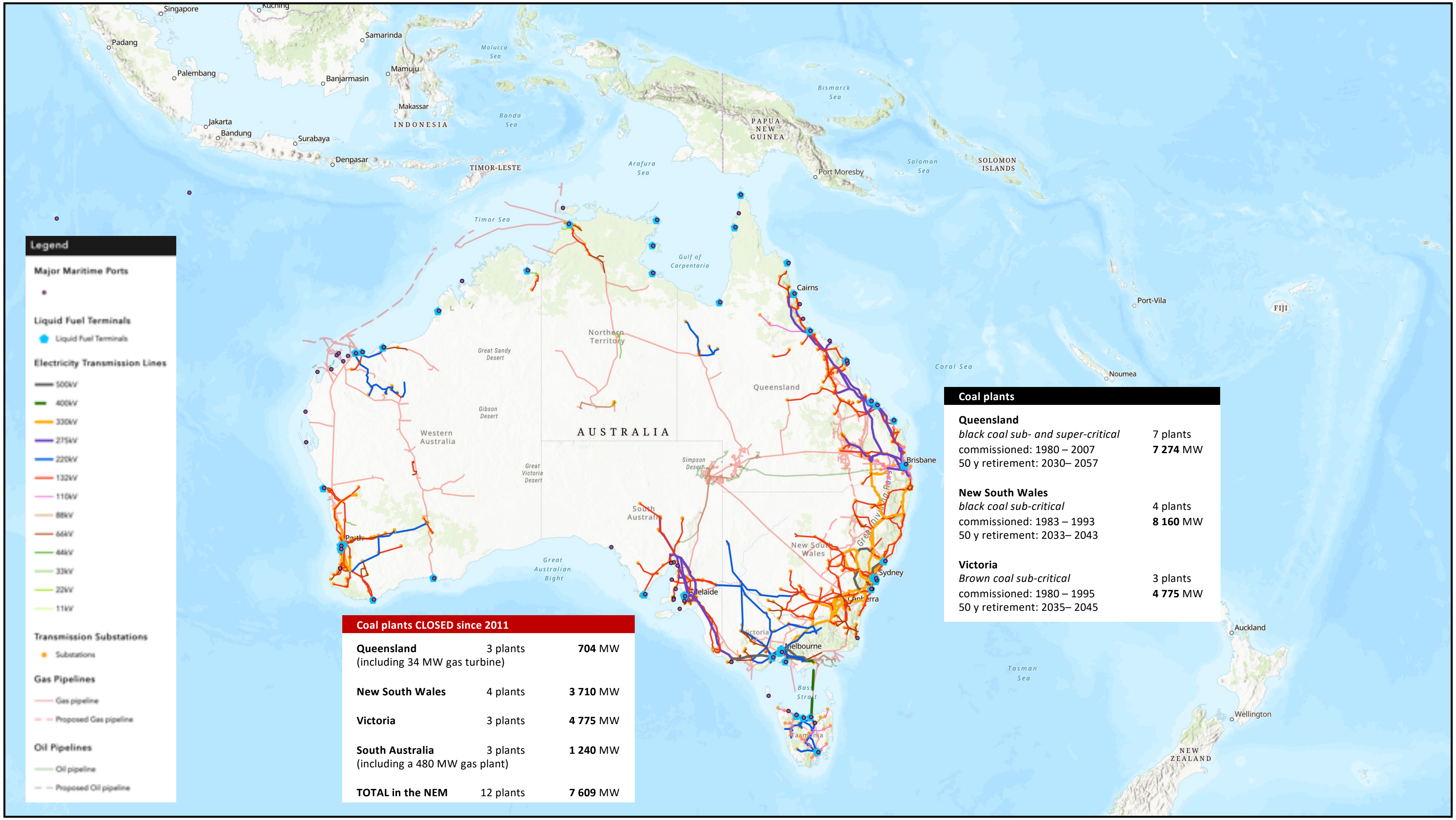
What is ‘**energy security**’ ?



energy security

*and **national security***

are inseparable

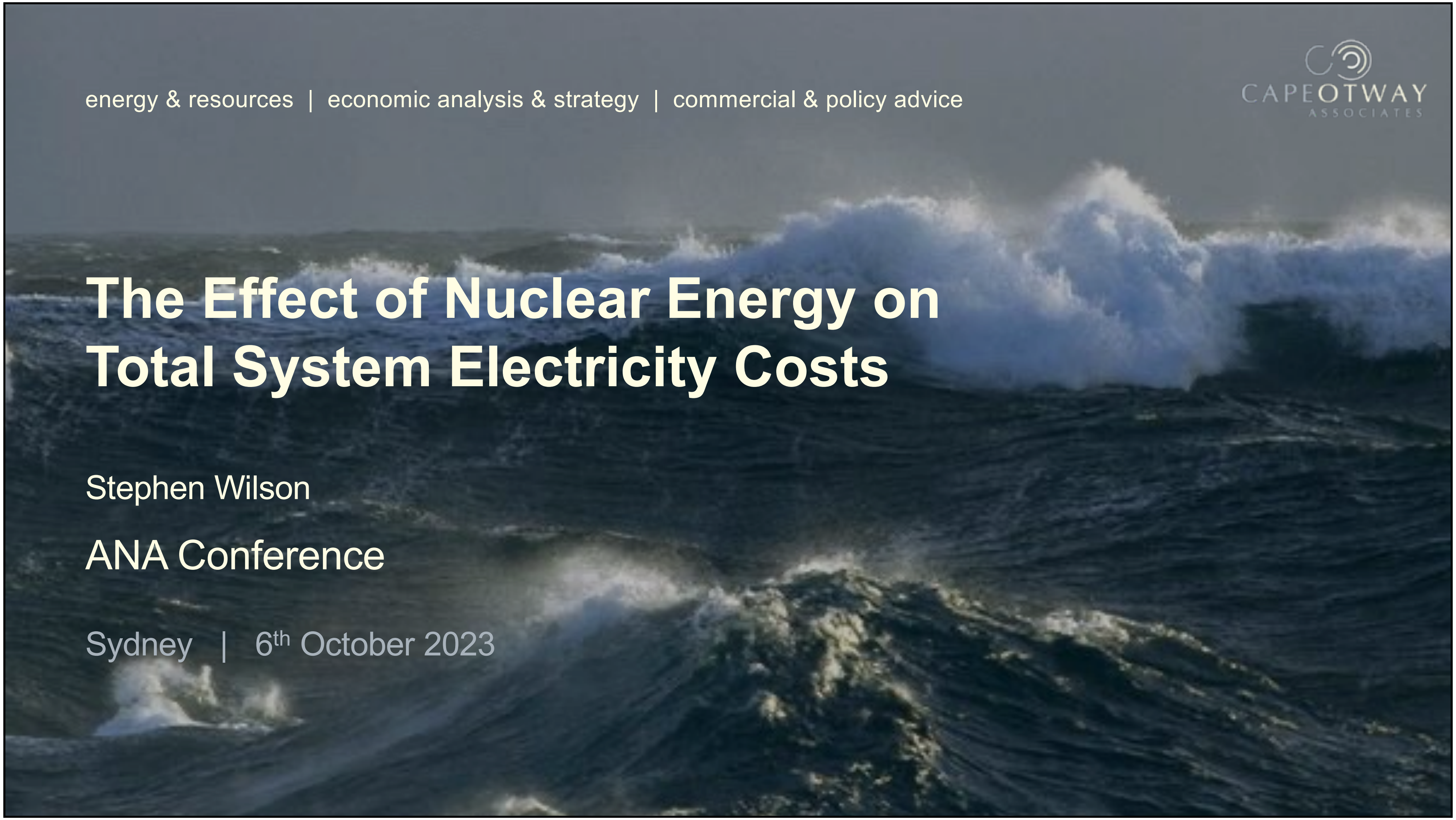


Coal plants CLOSED since 2011

Queensland (including 34 MW gas turbine)	3 plants	**704** MW
New South Wales	4 plants	**3 710** MW
Victoria	3 plants	**4 775** MW
South Australia (including a 480 MW gas plant)	3 plants	**1 240** MW
TOTAL in the NEM	12 plants	**7 609** MW

Coal plants

Queensland	
black coal sub- and super-critical	7 plants
commissioned: 1980 – 2007	**7 274** MW
50 y retirement: 2030– 2057	
New South Wales	
black coal sub-critical	4 plants
commissioned: 1983 – 1993	**8 160** MW
50 y retirement: 2033– 2043	
Victoria	
Brown coal sub-critical	3 plants
commissioned: 1980 – 1995	**4 775** MW
50 y retirement: 2035– 2045	



energy & resources | economic analysis & strategy | commercial & policy advice

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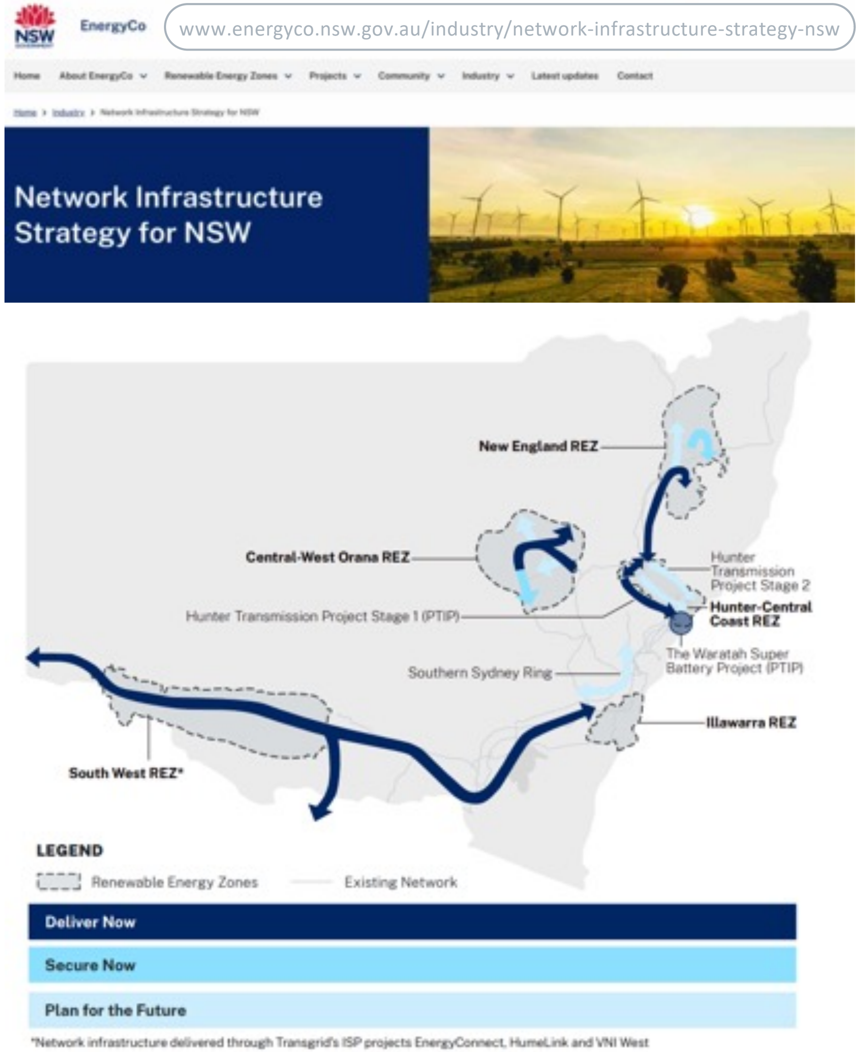
The Effect of Nuclear Energy on Total System Electricity Costs

Stephen Wilson

ANA Conference

Sydney | 6th October 2023

Backups



REZ development – 2029-30 in the Step Change scenario

2022 Integrated System Plan
June 2022

AEMO

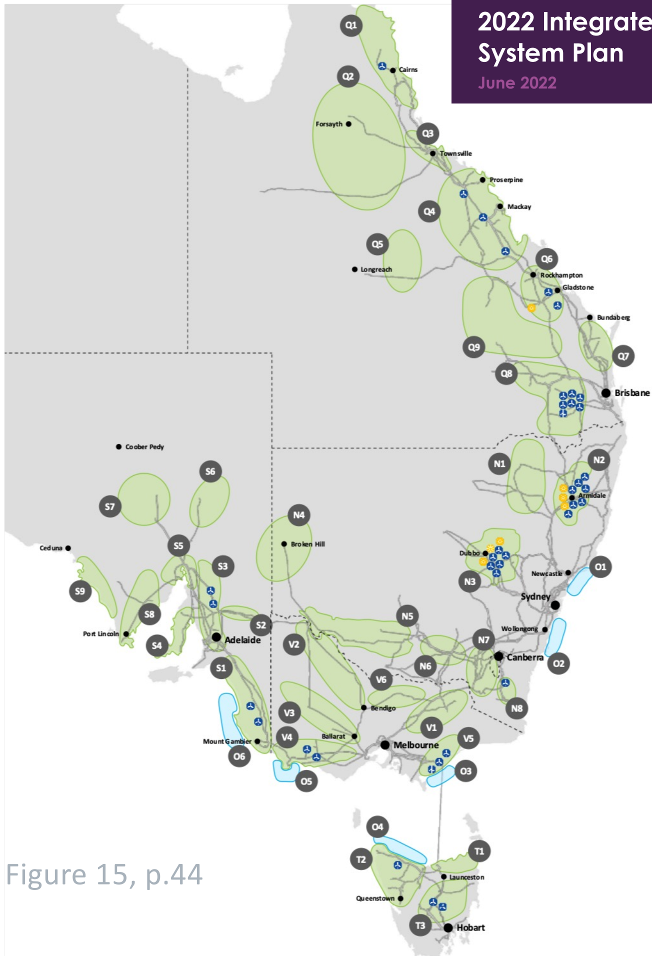


Figure 15, p.44

WHAT'S GAMBLING REALLY COSTING YOU?

For free and confidential support call 1800 858 858 or visit gamblinghelpline.org.au

What are we thinking?

We are betting the power system

Best case: odds of **150:1**

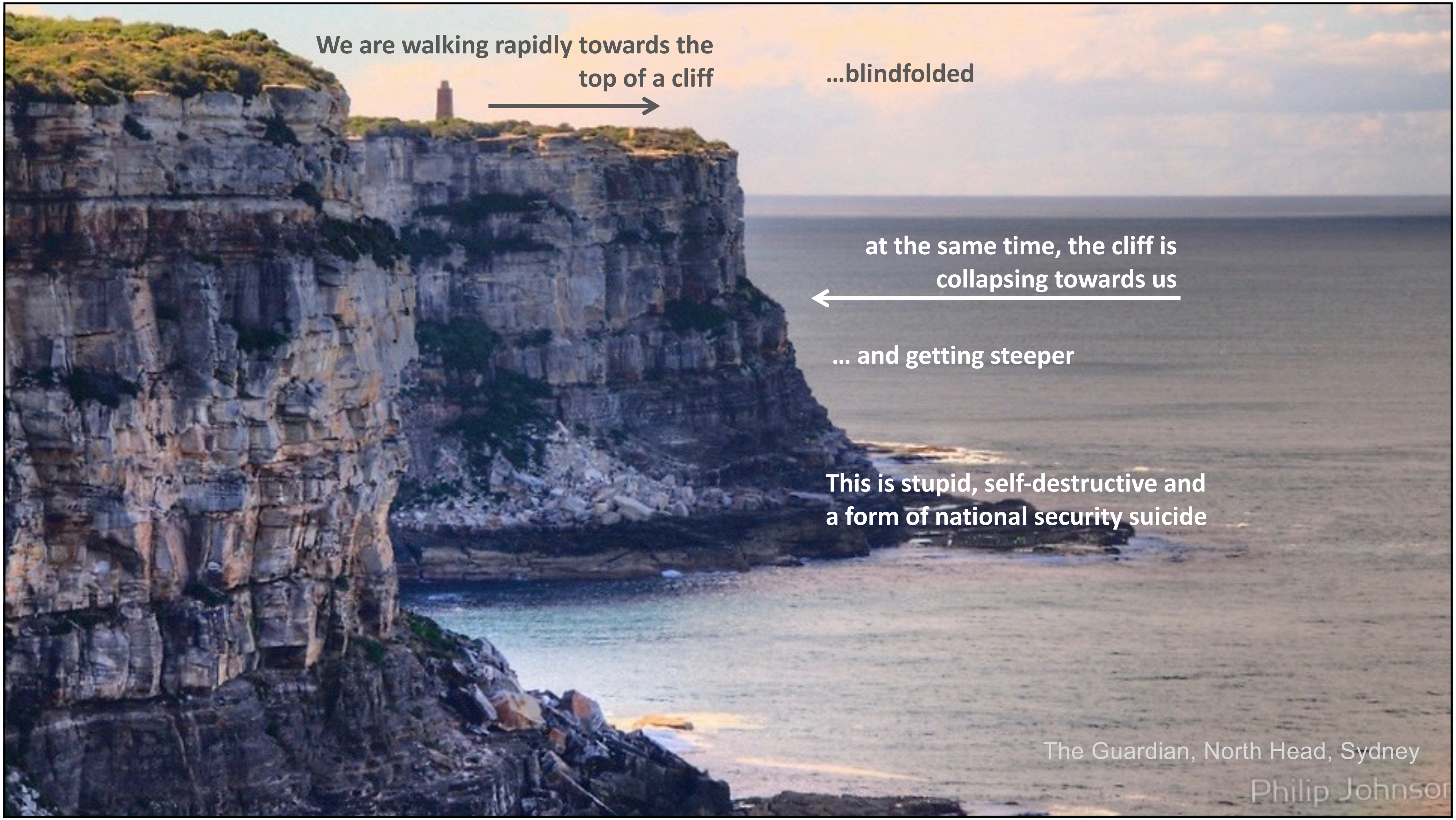
Worst case: odds of **500:1**
…or longer

…and hence the economy

Since the power system is our civilizational support structure

The current official plan is a perpetual recession machine

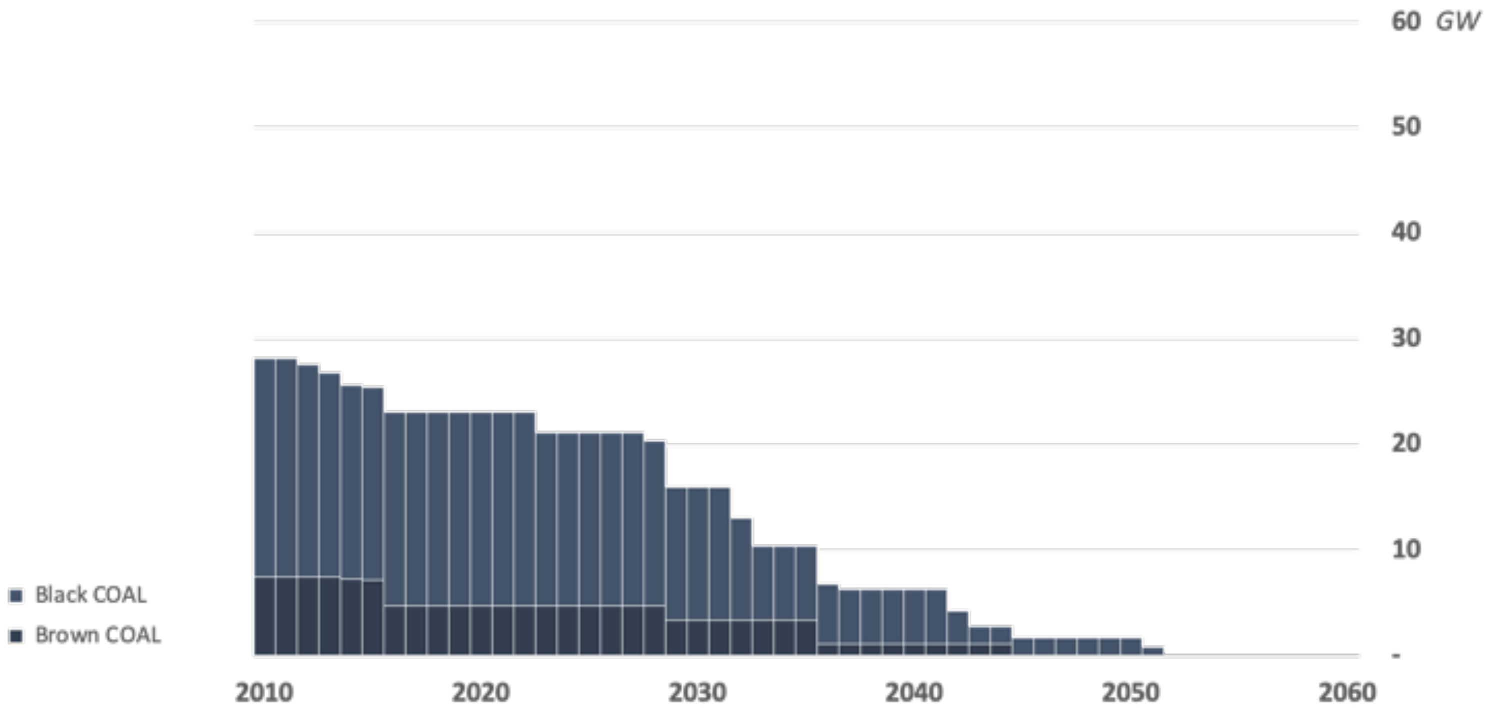

NEI NUCLEAR ENERGY INSTITUTE
Maria, what would be your advice for Australia?
"Well! First: stop blowing up your coal plants — you're not ready to live without them yet!"
— Maria Korsnick, CEO of NEI, highly experienced engineer


We are walking rapidly towards the top of a cliff
...blindfolded
at the same time, the cliff is collapsing towards us
... and getting steeper
This is stupid, self-destructive and a form of national security suicide
The Guardian, North Head, Sydney
Philip Johnson

CONTEXT

Oct 2021

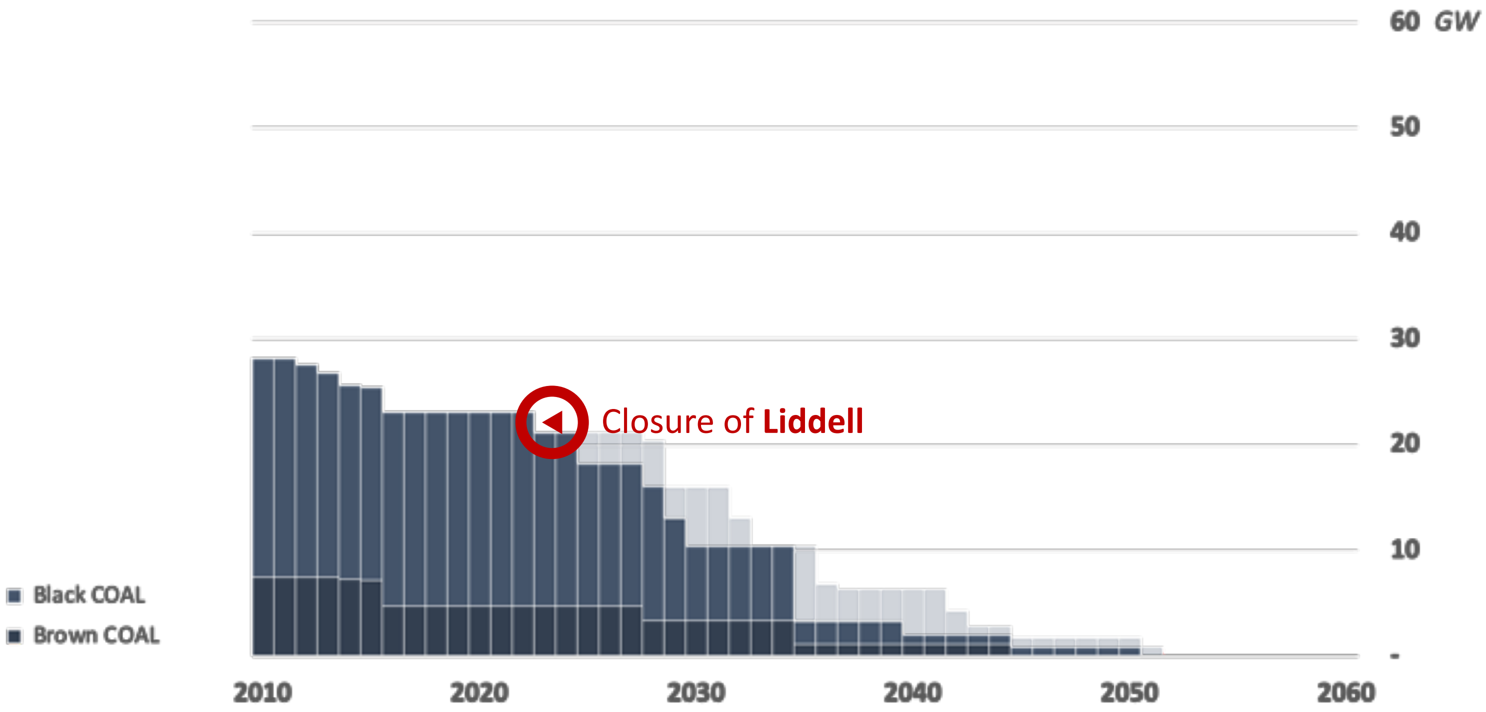
THE UNIVERSITY OF QUEENSLAND AUSTRALIA

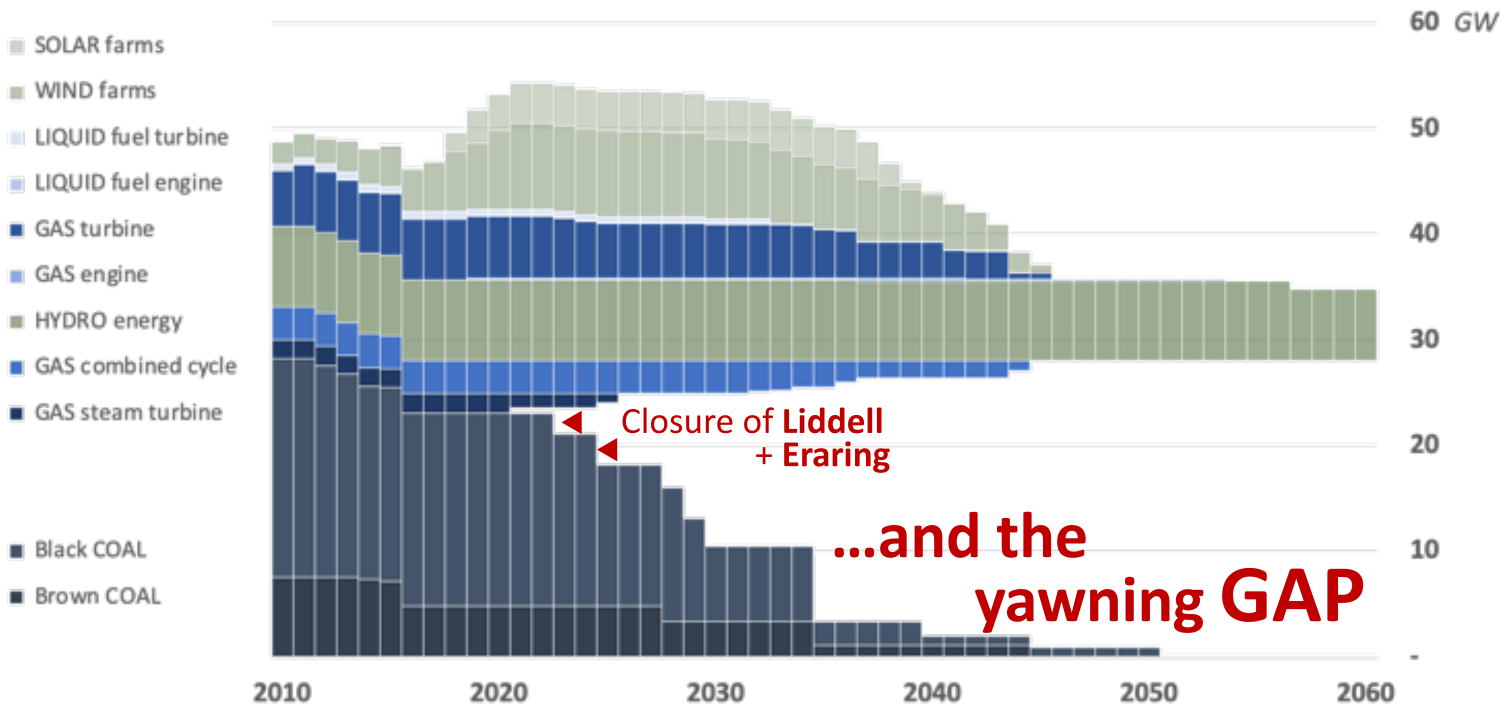


CONTEXT

Jan 2023

The University of Queensland
Australia

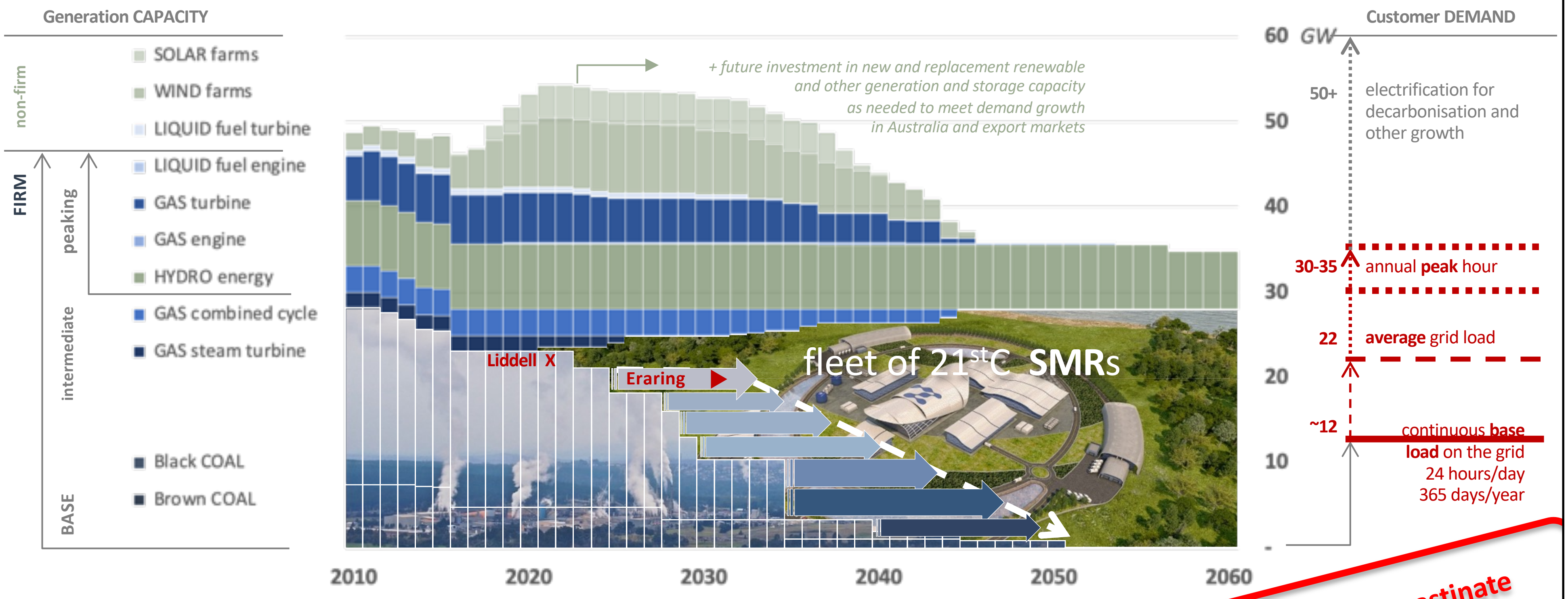




SOLAR farms
WIND farms
LIQUID fuel turbine
LIQUID fuel engine
GAS turbine
GAS engine
HYDRO energy
GAS combined cycle
GAS steam turbine
Black COAL
Brown COAL
60 GW
50
40
30
20
10
-
2010
2020
2030
2040
2050
2060
Closure of Liddell
+ Eraring
...and the
yawning GAP

CONTEXT

The interconnected power system in Eastern Australia



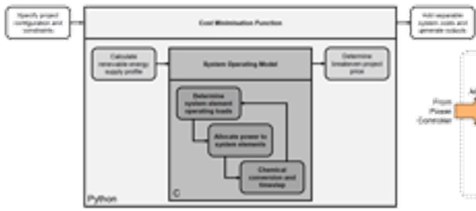
DON'T procrastinate ...and DON'T rush

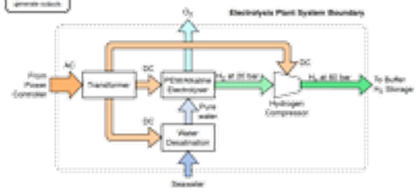
Source: adapted from *What would be required*, Figure 1, with updated data

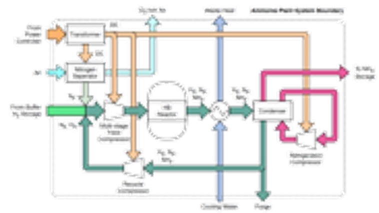

Newcastle
Portland
Tomago
Gladstone
Victoria
New South Wales
Queensland

Green H_2 or NH_3

production and export



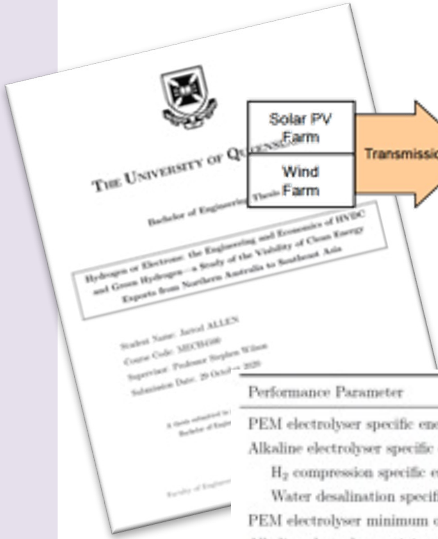


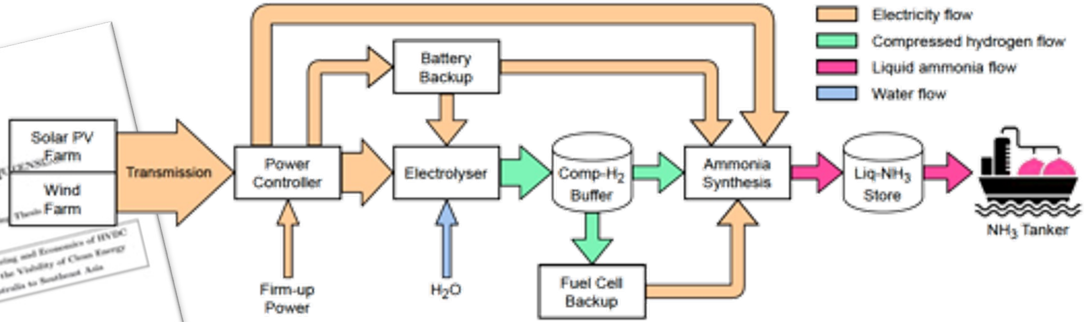


Realisation:

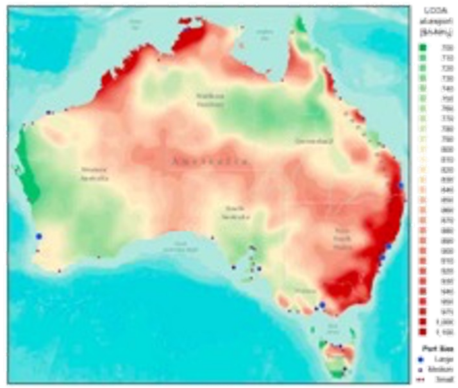
This long, complex, high-loss, low-utilisation, capital-inefficient, and weather-dependent value chain…

…will never be able to deliver below the cost of production of 'pink' H_2 in the destination markets





Performance Parameter		Value	Reference
PEM electrolyser specific energy consumption	x_{el}^{EY}	51 MWh/t_{H_2}	[99, 100]
Alkaline electrolyser specific energy consumption	x_{el}^{EY}	45 MWh/t_{H_2}	[23, 99]
H_2 compression specific energy consumption		1.6 MWh/t_{H_2}	[66, 101]
Water desalination specific energy consumption		4 $kWh/m^3_{H_2O}$	[102]
PEM electrolyser minimum operating load	x_{ramp}^{EL}	0 %	[99, 100]
Alkaline electrolyser minimum operating load	x_{ramp}^{EL}	20 %	[99]
Hydrogen fuel cell efficiency	x_{el}^{FC}	17 MWh/t_{H_2}	[103]
NH_3 synthesis loop specific energy consumption	x_{el}^{HB}	0.55 MWh/t_{NH_3}	[58, 28]
N_2 separation unit specific energy consumption		0.11 MWh/t_{NH_3}	[47, 58]
NH_3 Synthesis plant minimum operating load	r_{min}^{HB}	20 %	[57, 58]
NH_3 Synthesis plant maximum ramp rate	r_{ramp}^{HB}	30 %/h	[57]
NH_3 and H_2 stoichiometric ratio	$x_{NH_3}^{HB}$	0.1776 kg_{H_2}/kg_{NH_3}	
Battery storage round-trip efficiency	$\eta_{el}^{ST_{el}}$	85 %	[80]



System stability

focus on frequency response

Key issue: challenge of **BALANCING** the system

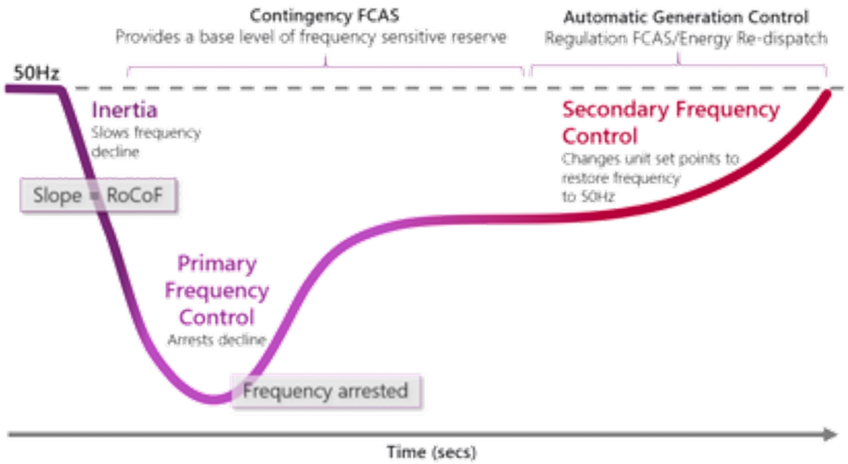
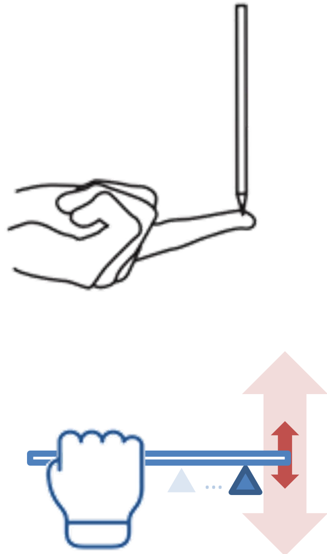


Figure 2.2: **The frequency response of a power system [26].** The overall dynamics are controlled by three major components, the inertial, primary, secondary responses. The secondary response, as mentioned in Table 1.1, is not considered in this research.



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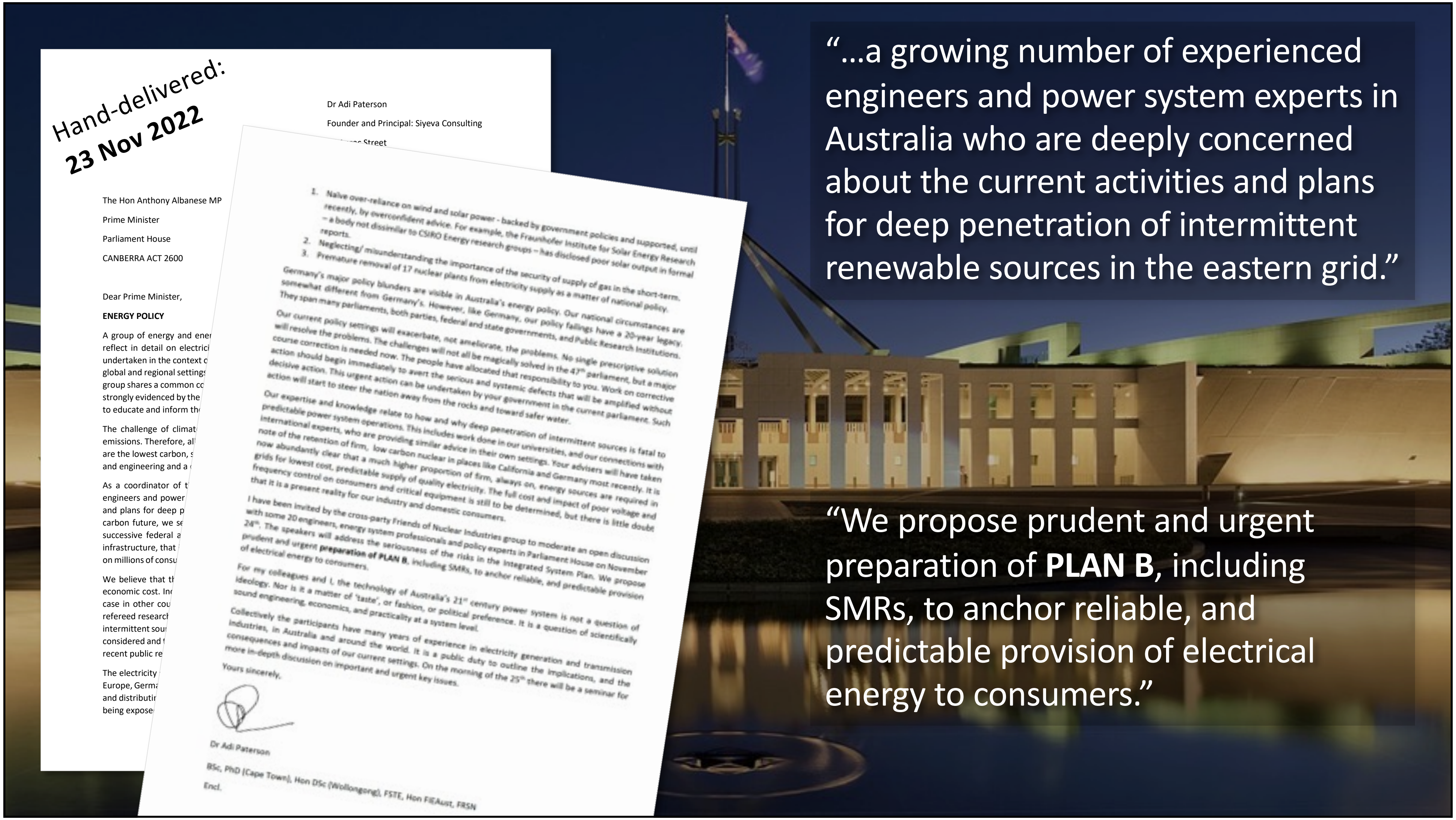
Hand-delivered:
23 Nov 2022
Dr Adi Paterson
Founder and Principal: Siyeva Consulting
The Hon Anthony Albanese MP
Prime Minister
Parliament House
CANBERRA ACT 2600
Dear Prime Minister,
ENERGY POLICY
Yours sincerely,
Dr Adi Paterson
BSc, PhD (Cape Town), Hon DSc (Wollongong), FSTE, Hon FIEAust, FRSN
Encl.
"…a growing number of experienced engineers and power system experts in Australia who are deeply concerned about the current activities and plans for deep penetration of intermittent renewable sources in the eastern grid."
"We propose prudent and urgent preparation of PLAN B, including SMRs, to anchor reliable, and predictable provision of electrical energy to consumers."