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Network implications of a 100% renewably powered Australian National Electricity Market

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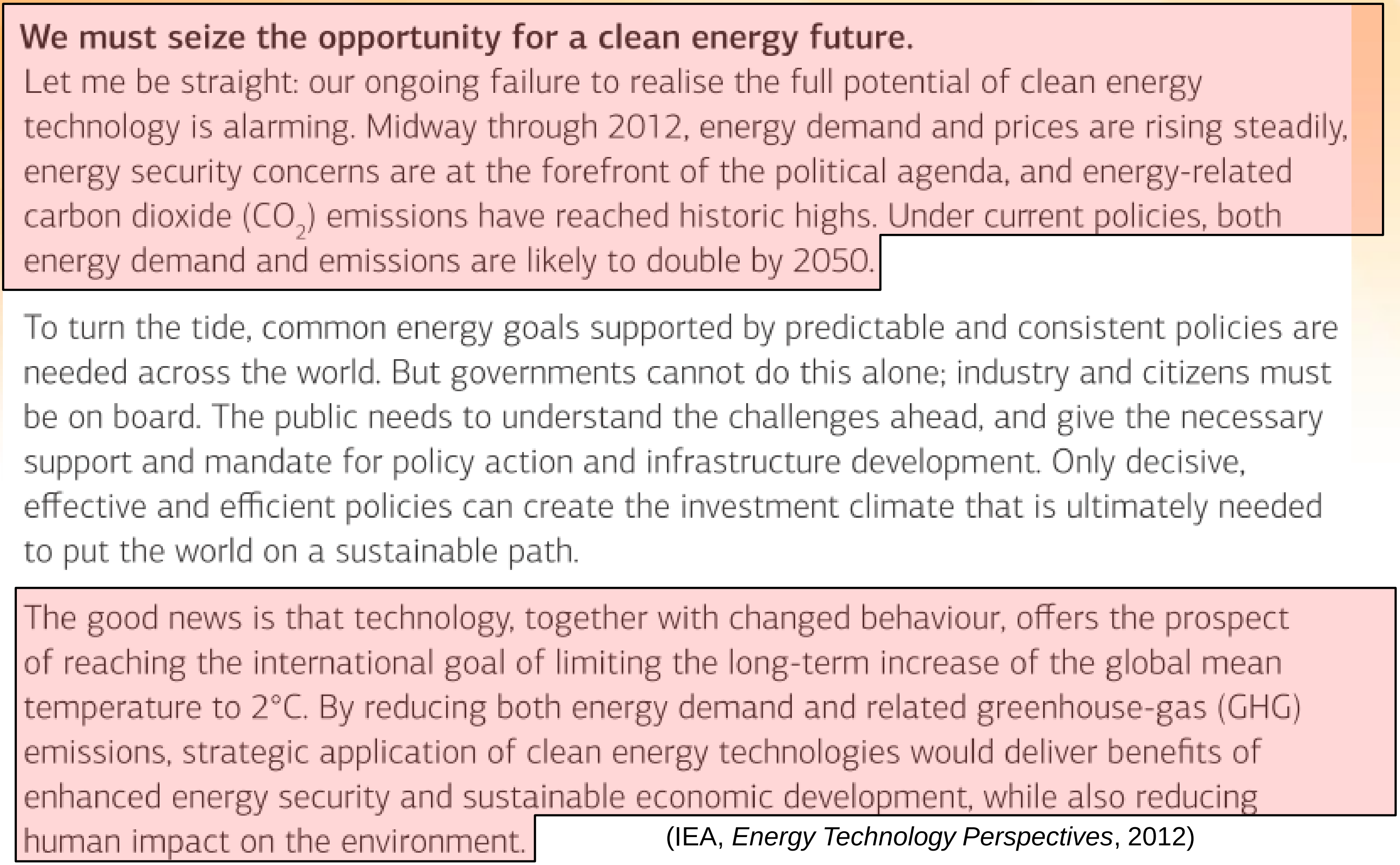
Future Networks Technical Seminar
DIgSILENT/University of Sydney
Sydney, September 2013

The challenge + opportunity for a clean energy future



We must seize the opportunity for a clean energy future.

Let me be straight: our ongoing failure to realise the full potential of clean energy technology is alarming. Midway through 2012, energy demand and prices are rising steadily, energy security concerns are at the forefront of the political agenda, and energy-related carbon dioxide (CO_2) emissions have reached historic highs. Under current policies, both energy demand and emissions are likely to double by 2050.

To turn the tide, common energy goals supported by predictable and consistent policies are needed across the world. But governments cannot do this alone; industry and citizens must be on board. The public needs to understand the challenges ahead, and give the necessary support and mandate for policy action and infrastructure development. Only decisive, effective and efficient policies can create the investment climate that is ultimately needed to put the world on a sustainable path.

The good news is that technology, together with changed behaviour, offers the prospect of reaching the international goal of limiting the long-term increase of the global mean temperature to 2°C. By reducing both energy demand and related greenhouse-gas (GHG) emissions, strategic application of clean energy technologies would deliver benefits of enhanced energy security and sustainable economic development, while also reducing human impact on the environment.

(IEA, *Energy Technology Perspectives*, 2012)

Growing interest in future 100% renewable electricity

- Many drivers including
  - climate change (and given poor progress of other low carbon options)
  - energy security (most countries see fossil fuel $ as economic liabilities)
  - falling renewable technology costs
  -
- Some key questions
  - *Technical feasibility?* – can 100% renewables mixes utilizing highly variable and somewhat unpredictable solar and wind reliably meet demand at all times and locations
  - **If yes,** *Economic feasibility?* – is 100% renewables economically worth doing given likely costs vs costs of inaction, other options
  - **If yes, how do we get there**

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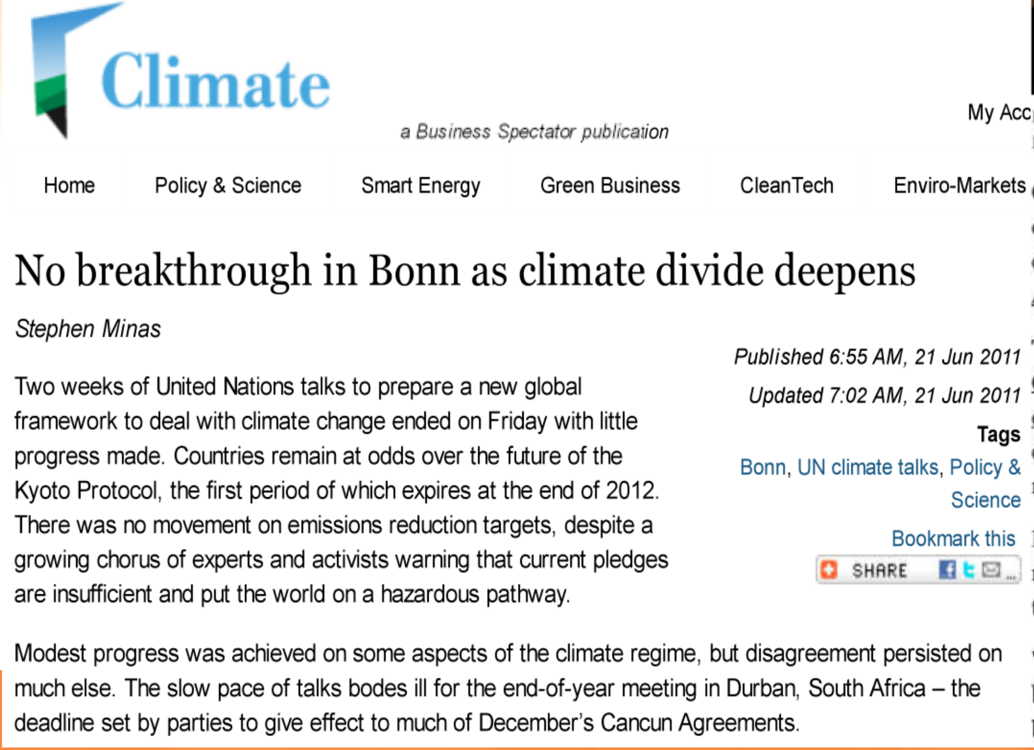
Climate change context

- Generally worsening scientific prognosis for warming, impacts
- Increasing global emissions
- An evident weakening international response



Climate

a Business Spectator publication

My Acc

Home Policy & Science Smart Energy Green Business CleanTech Enviro-Markets

No breakthrough in Bonn as climate divide deepens

Stephen Minas

Published 6:55 AM, 21 Jun 2011

Updated 7:02 AM, 21 Jun 2011

Tags

Bonn, UN climate talks, Policy & Science

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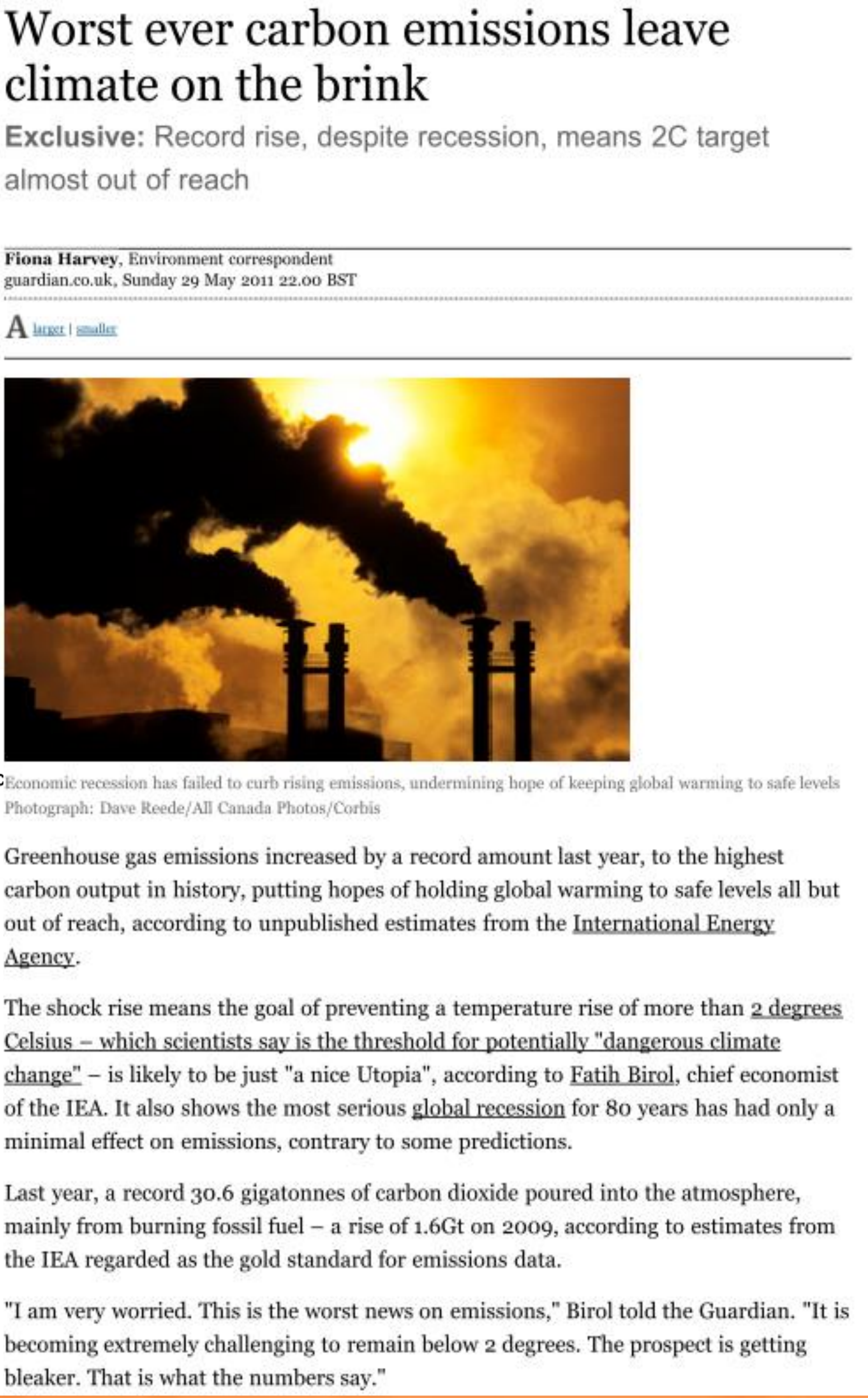
Two weeks of United Nations talks to prepare a new global framework to deal with climate change ended on Friday with little progress made. Countries remain at odds over the future of the Kyoto Protocol, the first period of which expires at the end of 2012. There was no movement on emissions reduction targets, despite a growing chorus of experts and activists warning that current pledges are insufficient and put the world on a hazardous pathway.

Modest progress was achieved on some aspects of the climate regime, but disagreement persisted on much else. The slow pace of talks bodes ill for the end-of-year meeting in Durban, South Africa – the deadline set by parties to give effect to much of December's Cancun Agreements.



Worst ever carbon emissions leave climate on the brink

Exclusive: Record rise, despite recession, means 2C target almost out of reach

Fiona Harvey, Environment correspondent
guardian.co.uk, Sunday 29 May 2011 22.00 BST

A larger | smaller

Economic recession has failed to curb rising emissions, undermining hope of keeping global warming to safe levels Photograph: Dave Reede/All Canada Photos/Corbis

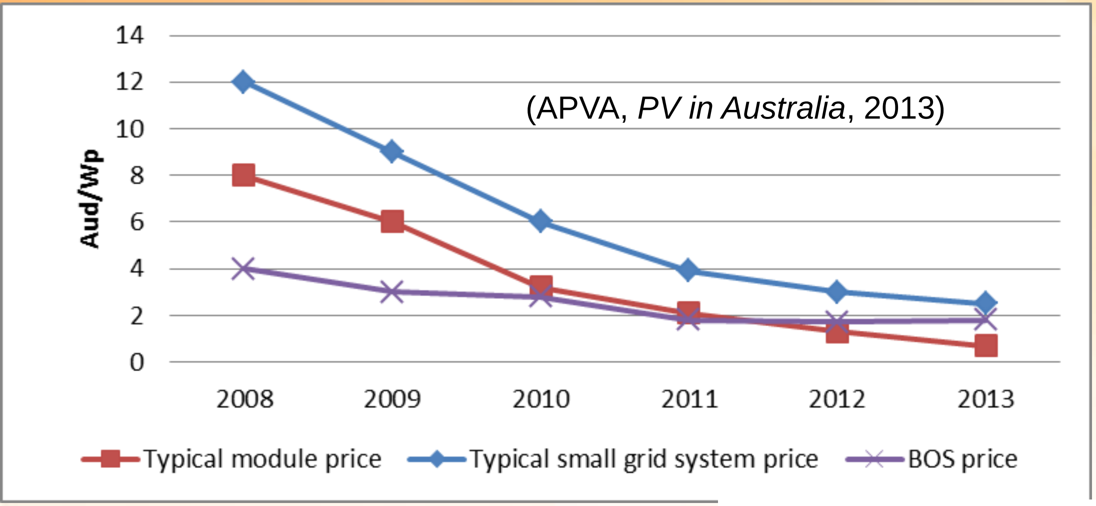
Greenhouse gas emissions increased by a record amount last year, to the highest carbon output in history, putting hopes of holding global warming to safe levels all but out of reach, according to unpublished estimates from the International Energy Agency.

The shock rise means the goal of preventing a temperature rise of more than 2 degrees Celsius – which scientists say is the threshold for potentially "dangerous climate change" – is likely to be just "a nice Utopia", according to Fatih Birol, chief economist of the IEA. It also shows the most serious global recession for 80 years has had only a minimal effect on emissions, contrary to some predictions.

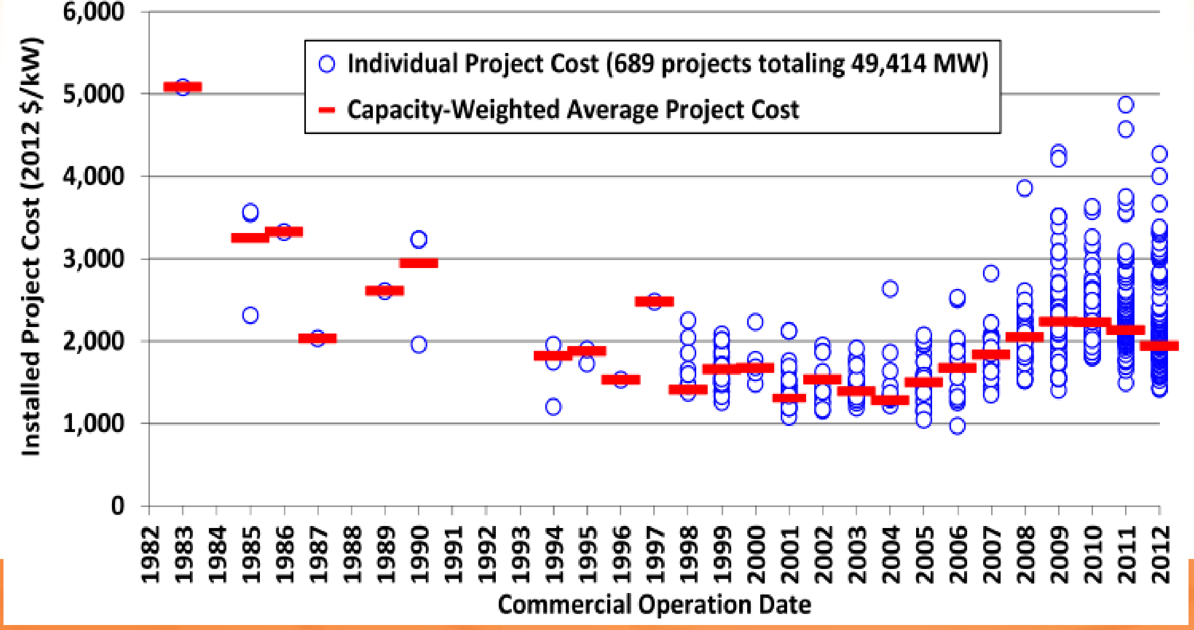
Last year, a record 30.6 gigatonnes of carbon dioxide poured into the atmosphere, mainly from burning fossil fuel – a rise of 1.6Gt on 2009, according to estimates from the IEA regarded as the gold standard for emissions data.

"I am very worried. This is the worst news on emissions," Birol told the Guardian. "It is becoming extremely challenging to remain below 2 degrees. The prospect is getting bleaker. That is what the numbers say."

Some (but not all) key RE technology costs falling

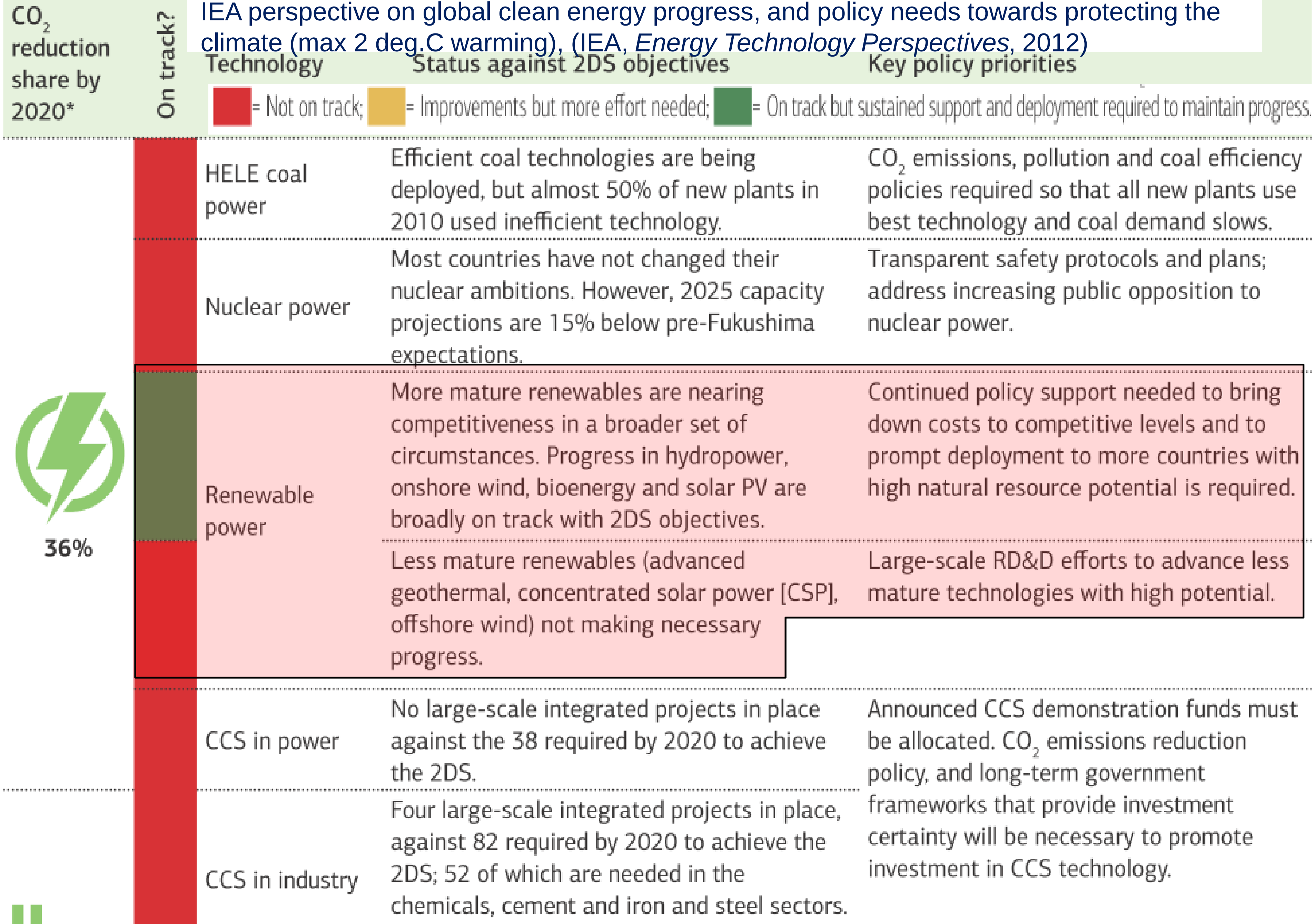

(APVA, *PV in Australia*, 2013)

(LBL, *Wind Energy Report*, 2013)



How are other options progressing

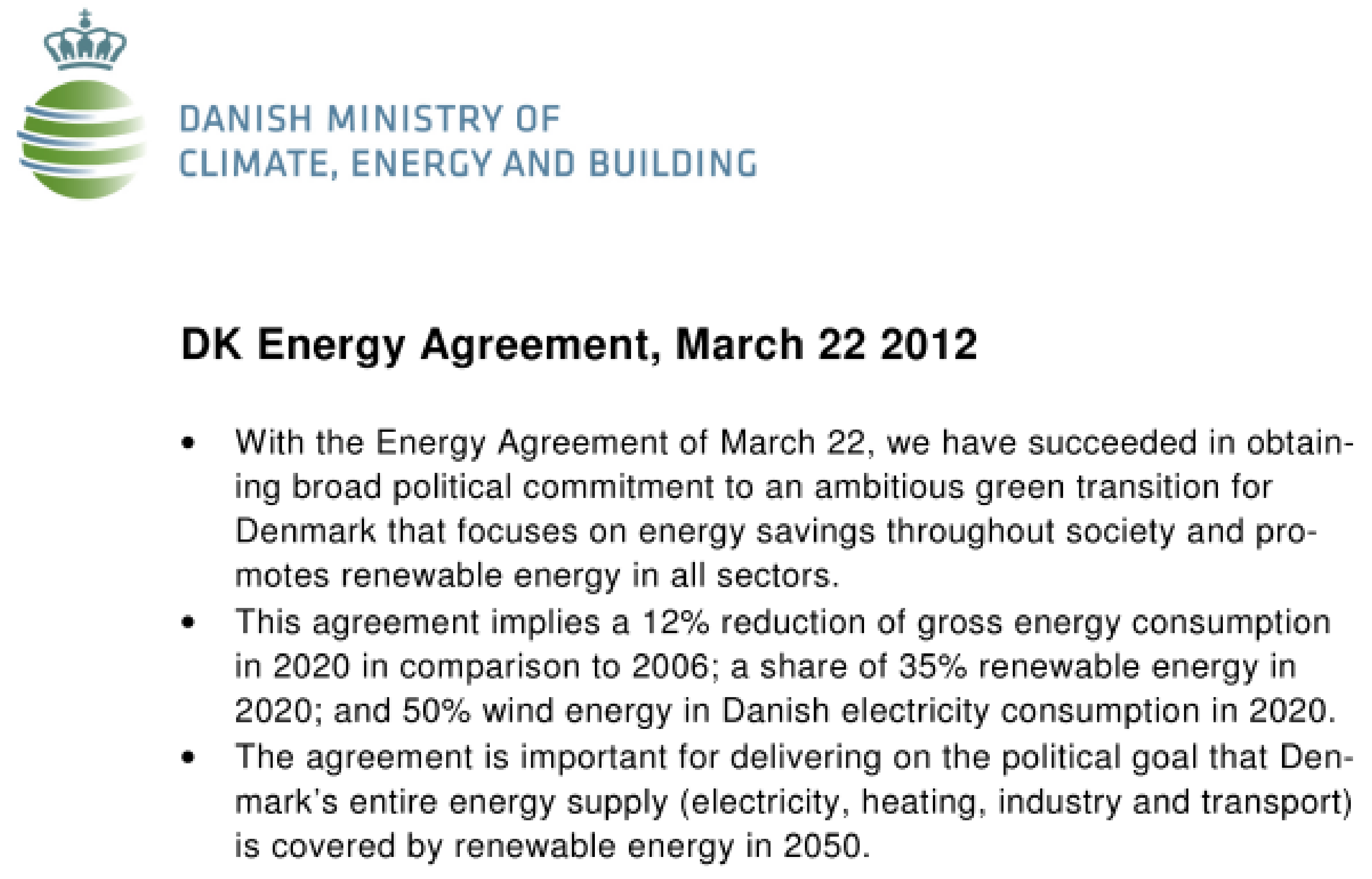
IEA perspective on global clean energy progress, and policy needs towards protecting the climate (max 2 deg.C warming), (IEA, *Energy Technology Perspectives*, 2012)



🟥 = Not on track; 🟨 = Improvements but more effort needed; 🟩 = On track but sustained support and deployment required to maintain progress.

CO_2 reduction share by 2020*	On track?	Technology	Status against 2DS objectives	Key policy priorities
	🟥	HELE coal power	Efficient coal technologies are being deployed, but almost 50% of new plants in 2010 used inefficient technology.	CO_2 emissions, pollution and coal efficiency policies required so that all new plants use best technology and coal demand slows.
	🟥	Nuclear power	Most countries have not changed their nuclear ambitions. However, 2025 capacity projections are 15% below pre-Fukushima expectations.	Transparent safety protocols and plans; address increasing public opposition to nuclear power.
36%	🟩	Renewable power	More mature renewables are nearing competitiveness in a broader set of circumstances. Progress in hydropower, onshore wind, bioenergy and solar PV are broadly on track with 2DS objectives.	Continued policy support needed to bring down costs to competitive levels and to prompt deployment to more countries with high natural resource potential is required.
	🟥		Less mature renewables (advanced geothermal, concentrated solar power [CSP], offshore wind) not making necessary progress.	Large-scale RD&D efforts to advance less mature technologies with high potential.
	🟥	CCS in power	No large-scale integrated projects in place against the 38 required by 2020 to achieve the 2DS.	Announced CCS demonstration funds must be allocated. CO_2 emissions reduction policy, and long-term government frameworks that provide investment certainty will be necessary to promote investment in CCS technology.
	🟥	CCS in industry	Four large-scale integrated projects in place, against 82 required by 2020 to achieve the 2DS; 52 of which are needed in the chemicals, cement and iron and steel sectors.	

Growing plans on transition pathways



DANISH MINISTRY OF CLIMATE, ENERGY AND BUILDING

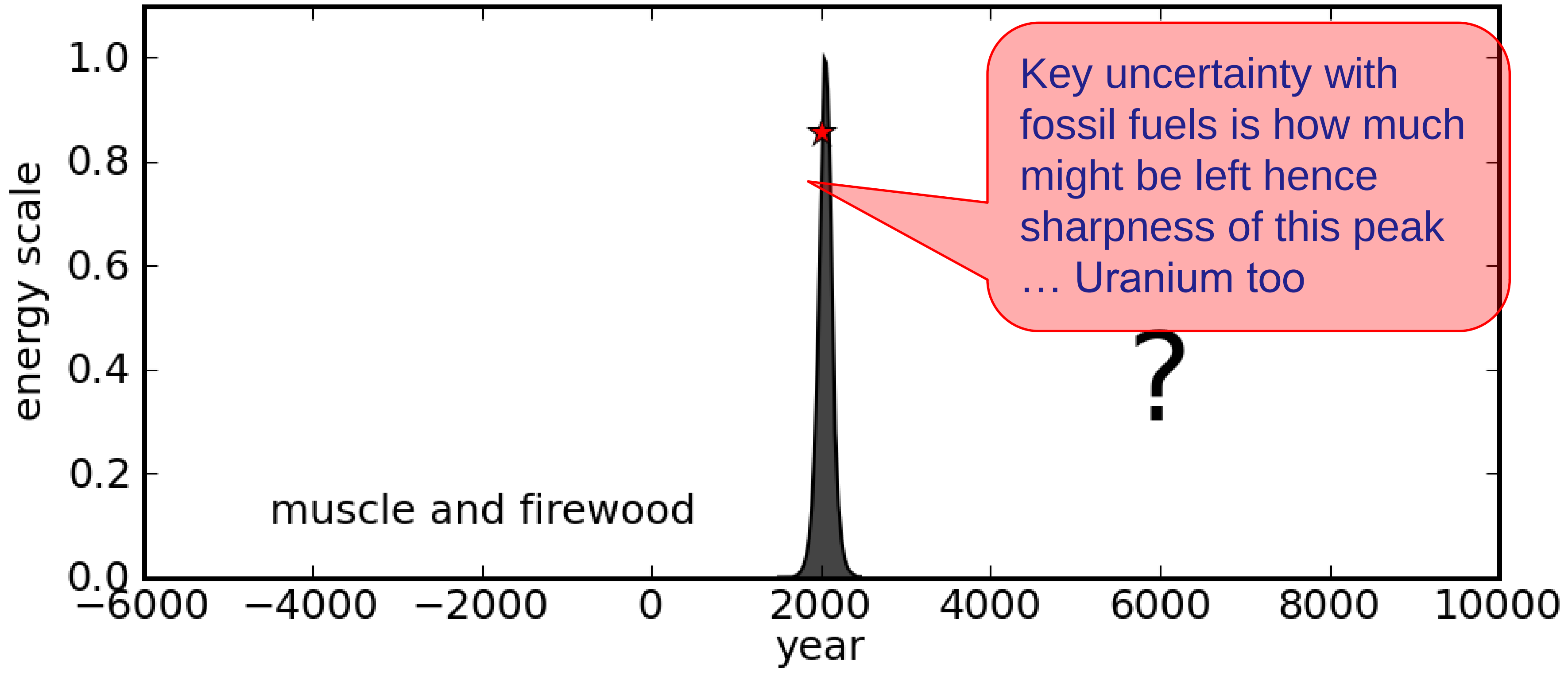
DK Energy Agreement, March 22 2012

- With the Energy Agreement of March 22, we have succeeded in obtaining broad political commitment to an ambitious green transition for Denmark that focuses on energy savings throughout society and promotes renewable energy in all sectors.
- This agreement implies a 12% reduction of gross energy consumption in 2020 in comparison to 2006; a share of 35% renewable energy in 2020; and 50% wind energy in Danish electricity consumption in 2020.
- The agreement is important for delivering on the political goal that Denmark's entire energy supply (electricity, heating, industry and transport) is covered by renewable energy in 2050.

Taking a longer-term perspective, 100% renewables a question of when.. and how

- *Our only technically feasible option*
- *Wind and PV seem well placed to play major role*

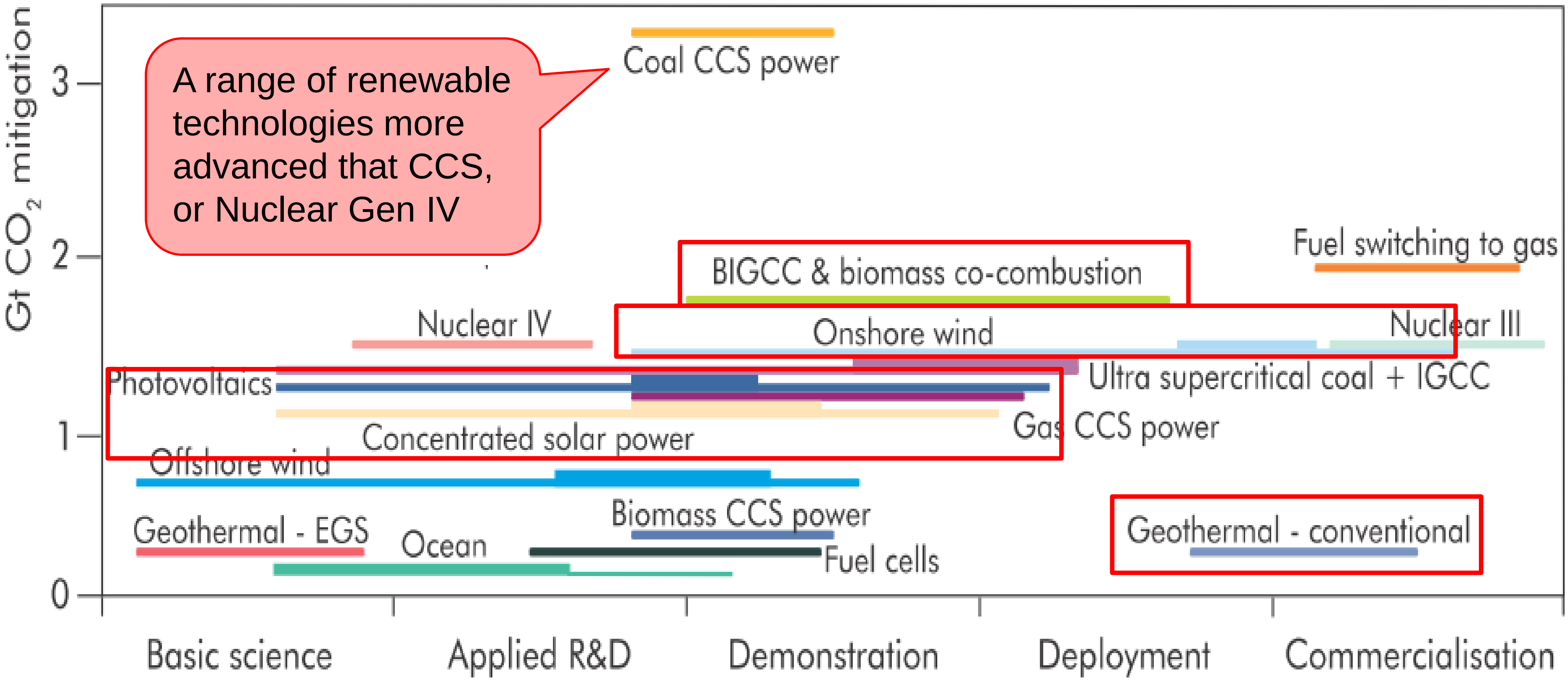
(Murphy, *http://physics.ucsd.edu/do-the-math/*, 2012)



Key uncertainty with fossil fuels is how much might be left hence sharpness of this peak … Uranium too

Technical feasibility: range of proven renewables

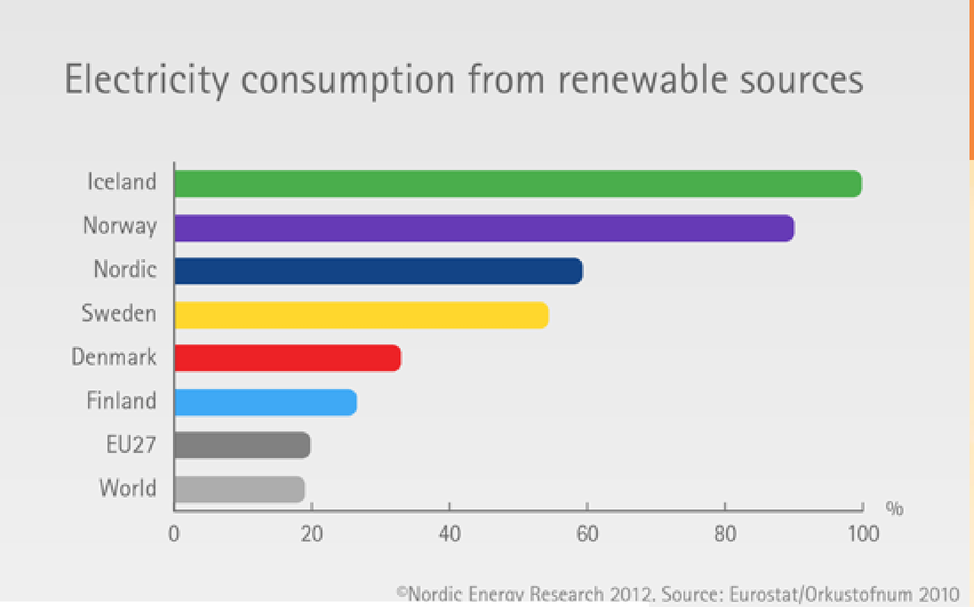
Figure 4.6 ▶ Near-term technology development priorities and CO_2 mitigation for power generation technologies (IEA, *Energy Technology Perspectives*, 2010)



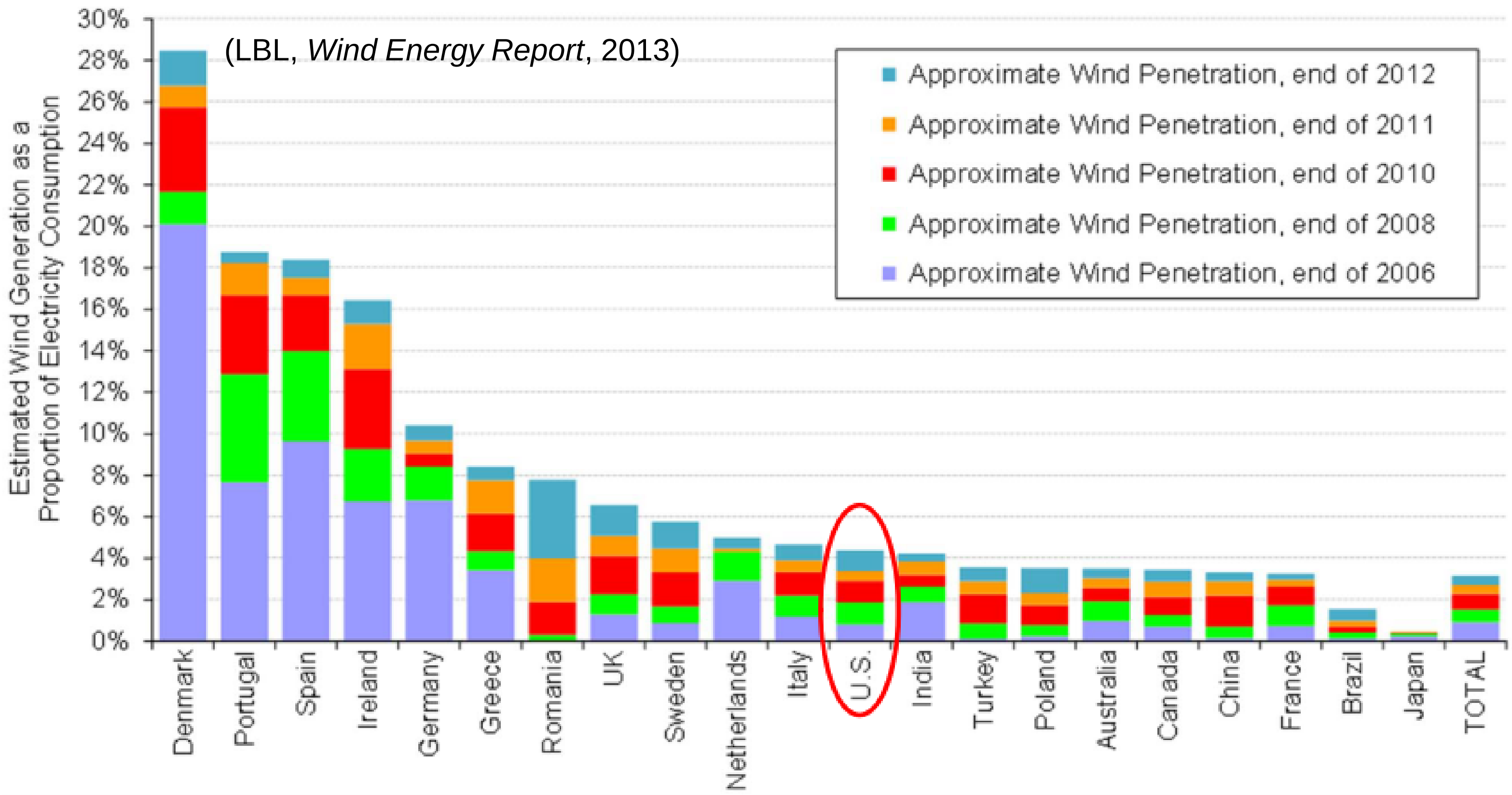
A range of renewable technologies more advanced that CCS, or Nuclear Gen IV

Technical feasibility: ‘what exists is possible’

wind a significant contributor in growing number of electricity industries around the world



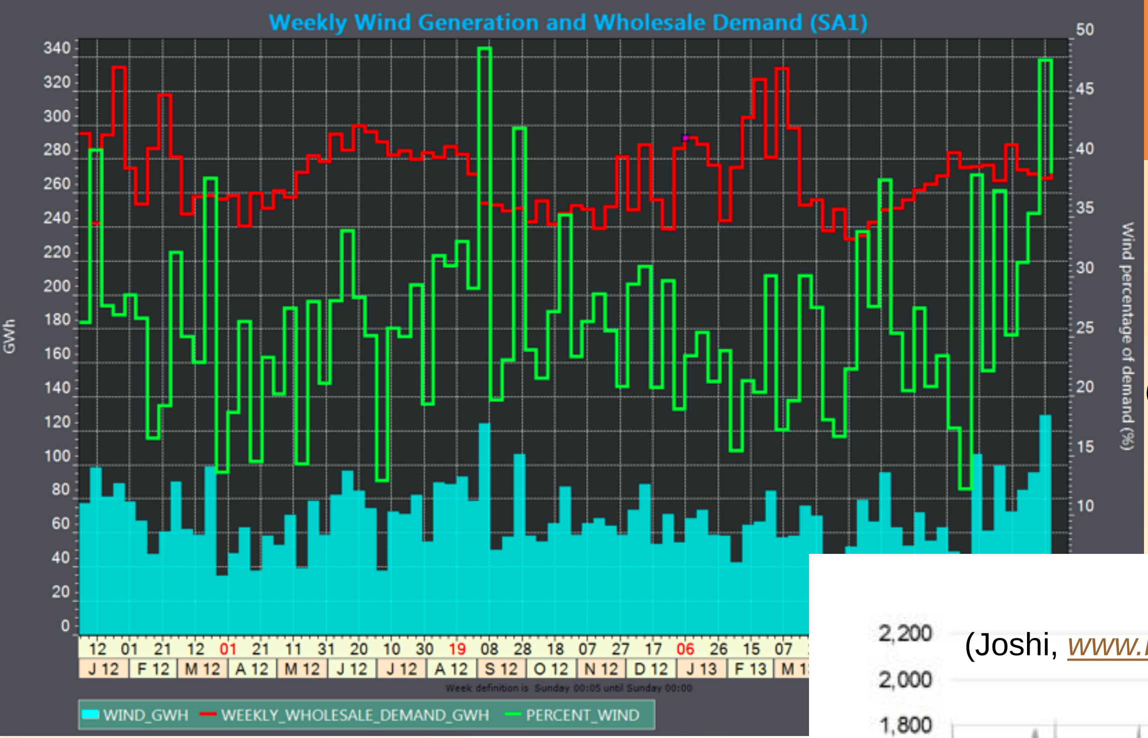
©Nordic Energy Research 2012. Source: Eurostat/Orkustofnum 2010



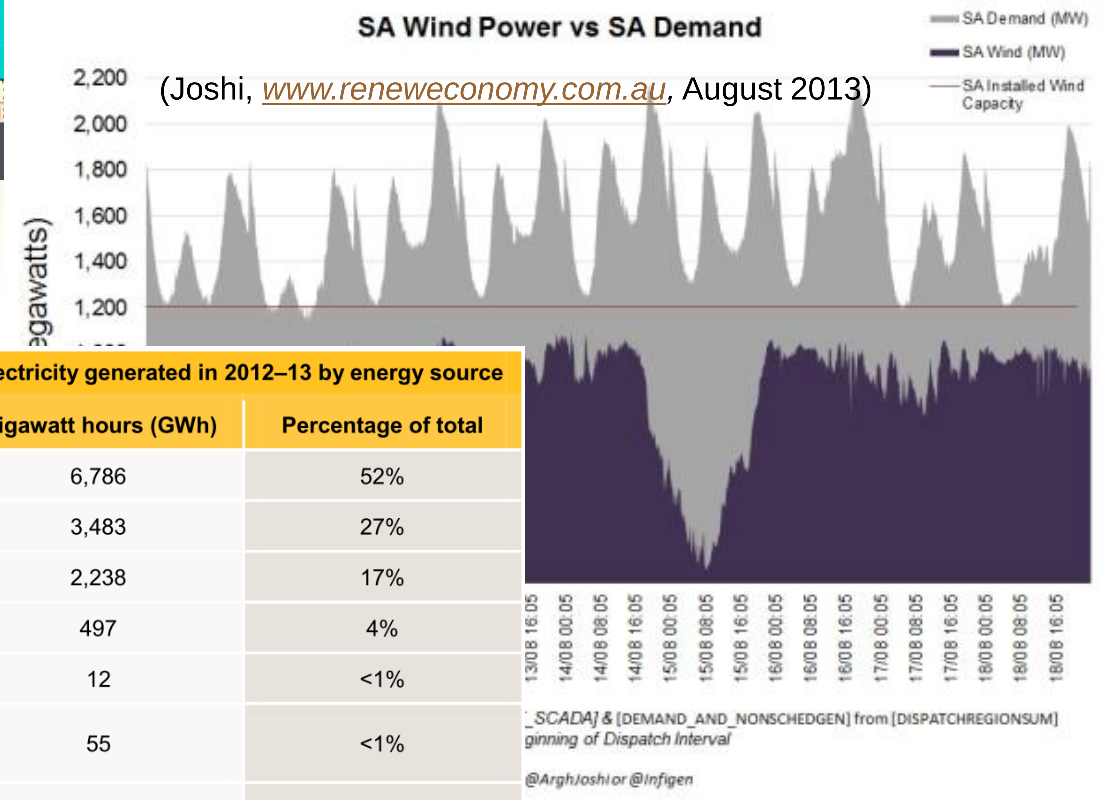
(LBL, *Wind Energy Report*, 2013)

)

Perhaps "The future is here. It's just not widely distributed yet."



(*www.reneweconomy.com.au*, September 2013)

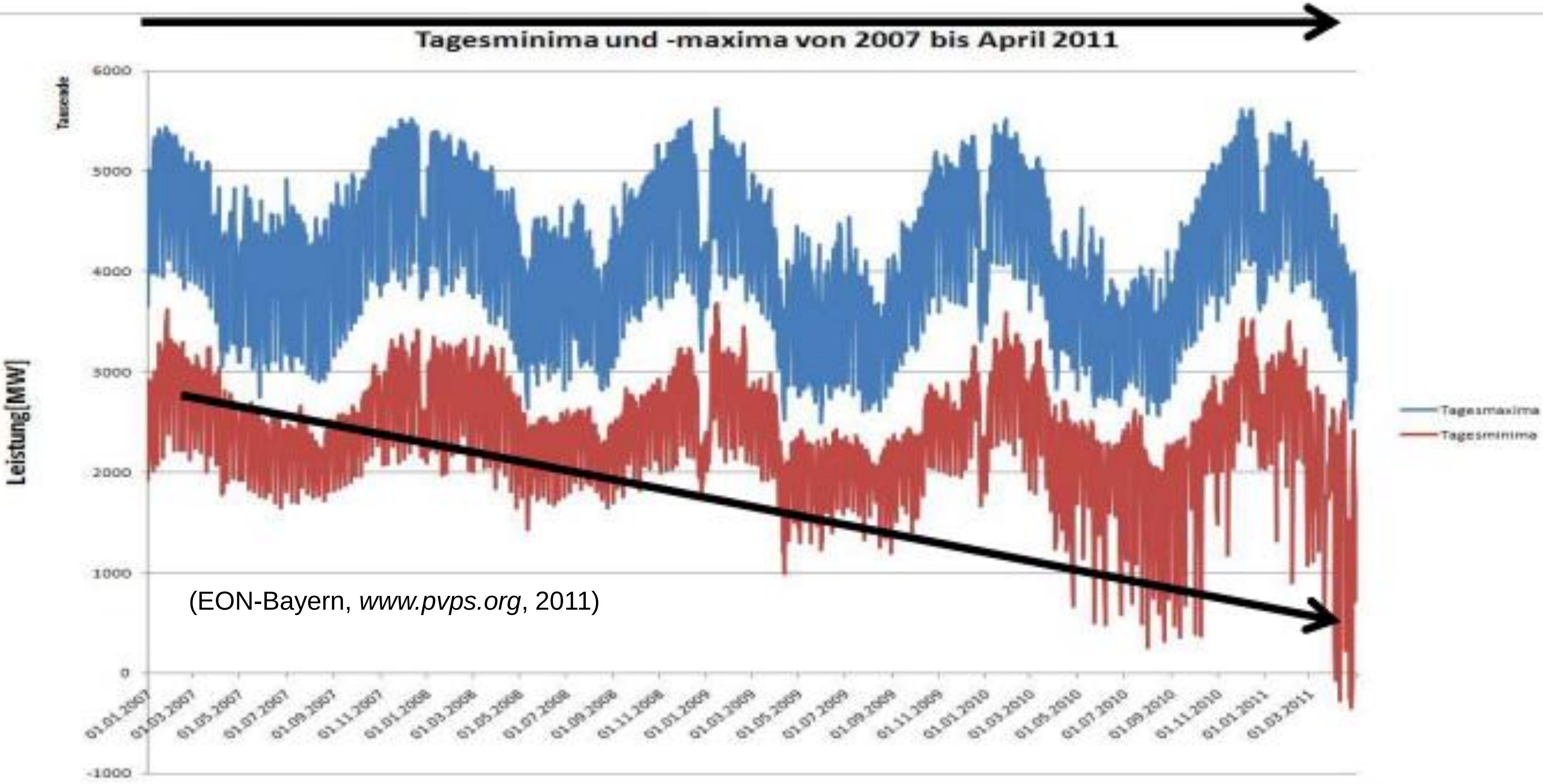


(Joshi, *www.reneweconomy.com.au*, August 2013)

(AEMO, *South Australia Electricity Report*, 2013)

Energy source	South Australia registered generation capacity		Electricity generated in 2012–13 by energy source	
	Megawatts (MW)	Percentage of total	Gigawatt hours (GWh)	Percentage of total
Gas	2,672	50%	6,786	52%
Wind	1,203	23%	3,483	27%
Coal	770	14%	2,238	17%
Rooftop PV[a]	400	7%	497	4%
Diesel	270	5%	12	<1%
Landfill methane/ landfill gas	16	<1%	55	<1%
Hydro	3	<1%	6	<1%
Total	**5,334**	**100%**	**13,077**	**100%**

Load profile of E.ON Bavaria against upstream grid operator (E.ON Netz)



(EON-Bayern, *www.pvps.org*, 2011)

→ **In spring and summer reduction of received power**

→ **In winter low impact of PV's**

100% renewables for the NEM?

A significant change from current mix with some hydro, modest wind

Note missing PV, other non-registered renewables

Figure 1.4
Registered capacity in regions, by fuel source, 2011

(AER, *2012*)

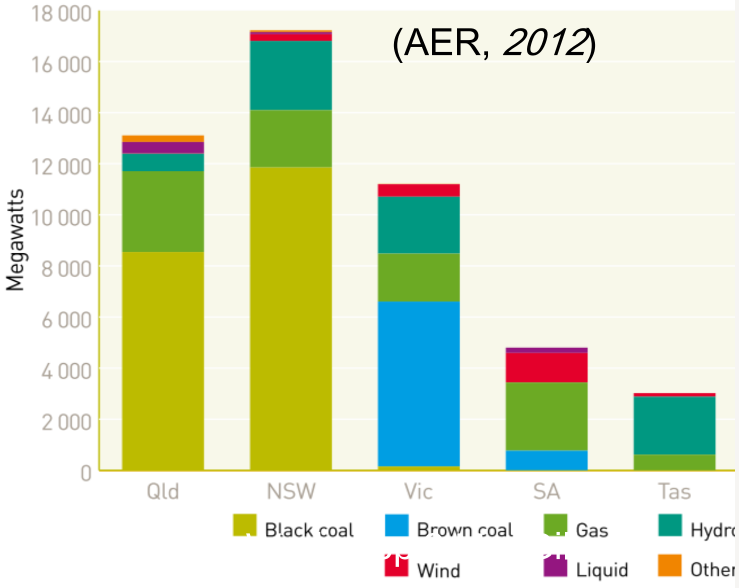
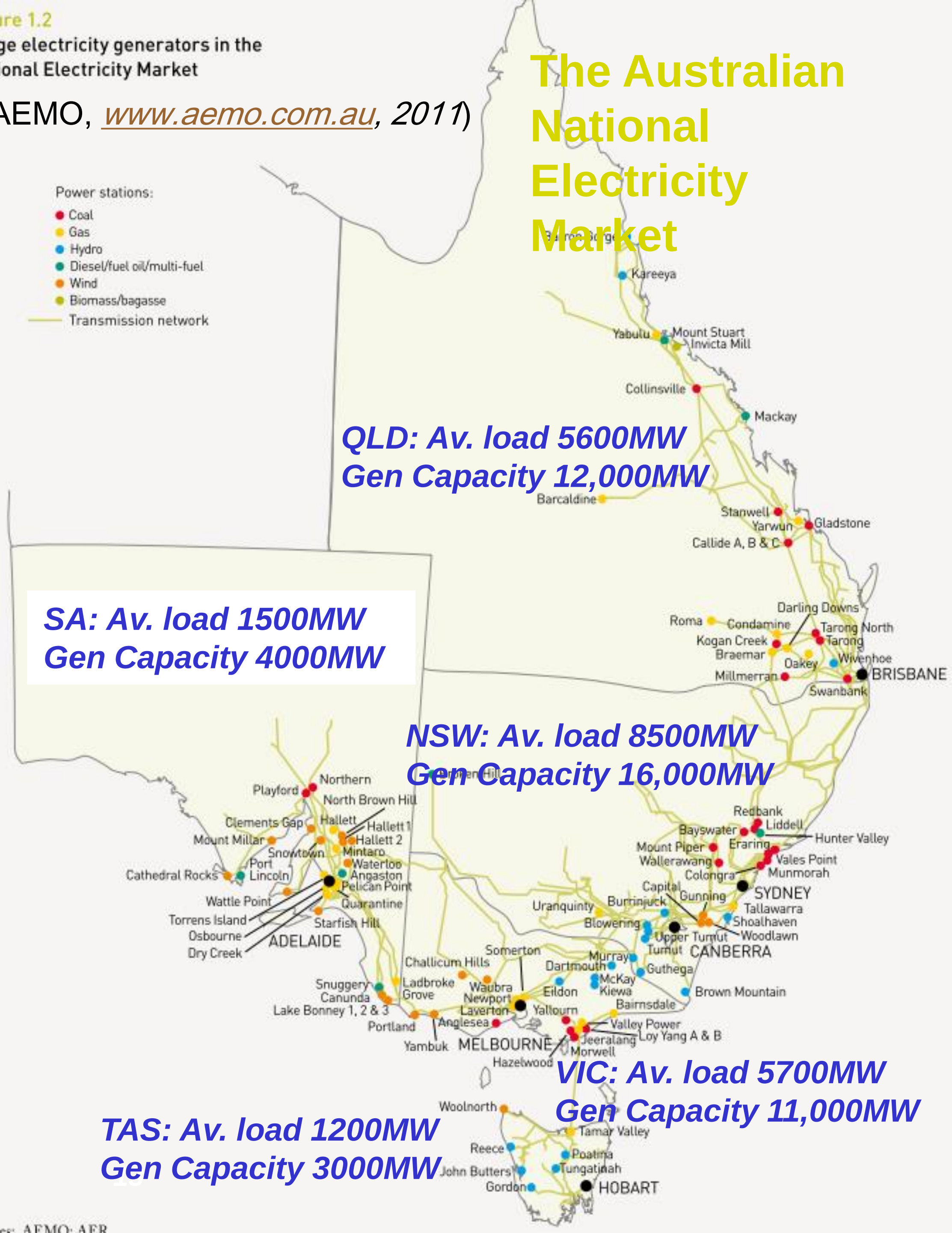


Figure 1.2
Large electricity generators in the National Electricity Market

(AEMO, *www.aemo.com.au*, *2011*)

The Australian National Electricity Market



QLD: Av. load 5600MW
Gen Capacity 12,000MW

SA: Av. load 1500MW
Gen Capacity 4000MW

NSW: Av. load 8500MW
Gen Capacity 16,000MW

VIC: Av. load 5700MW
Gen Capacity 11,000MW

TAS: Av. load 1200MW
Gen Capacity 3000MW

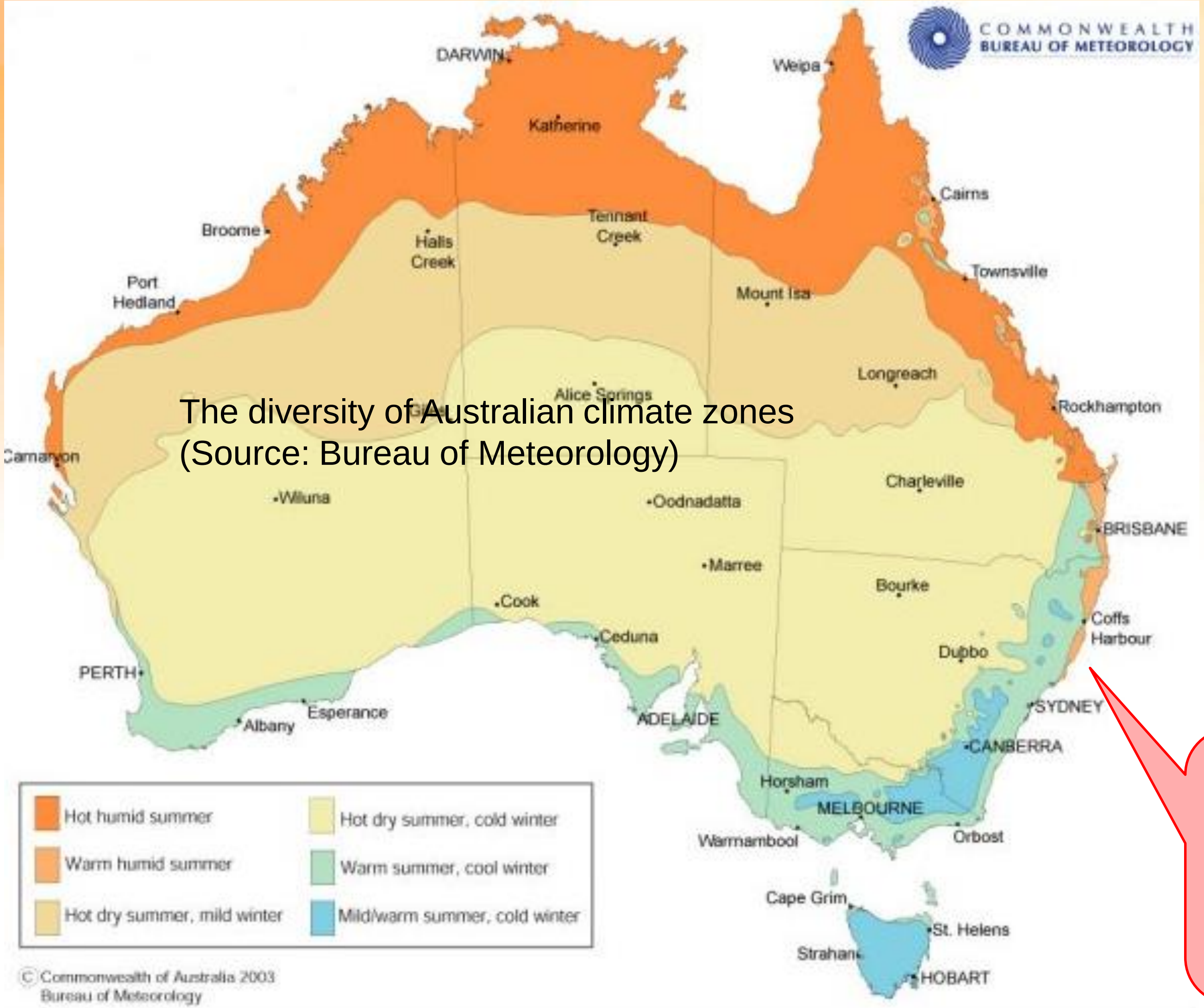
Sources: AEMO; AER

Some potential network issues, implications

- Likely more a Q of economic & commercial, rather than technical feasibility
- Key questions
  - Which technologies
  - Where? *In particular, more centralised or decentralised*
  - Under what types of operational arrangements

- RE integration implications for Tx and Dx
  - Local - ‘more of the same’ and more
  - Regional – going beyond current valuable lessons, System – Some important new challenges

Some new NEM regions to consider

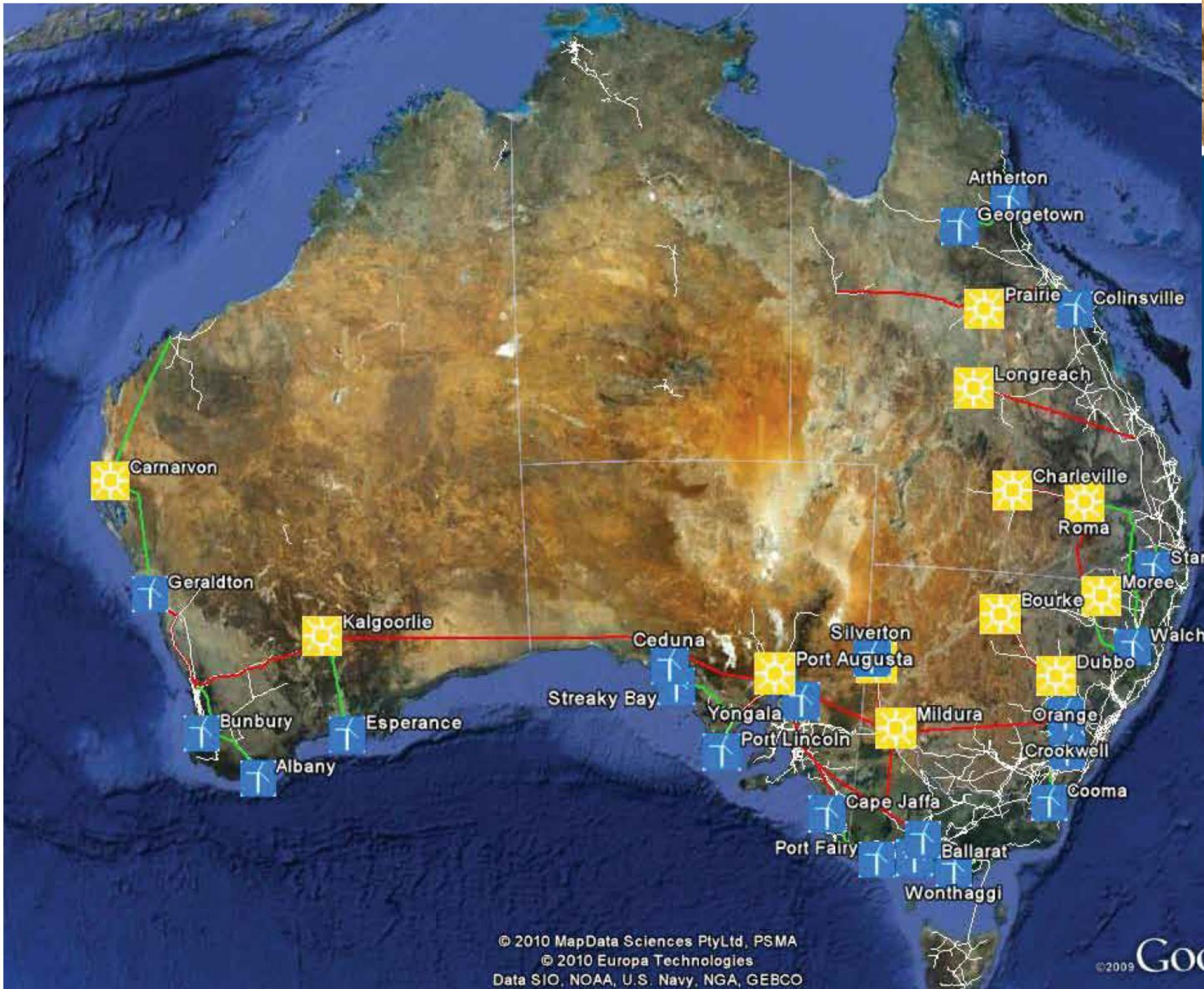


The diversity of Australian climate zones
(Source: Bureau of Meteorology)

Considerable 'integration' value in having diverse climate regions across the NEM

Beyond Zero Emissions, 2010

Proposed Power Grid for 100% Renewable Electricity



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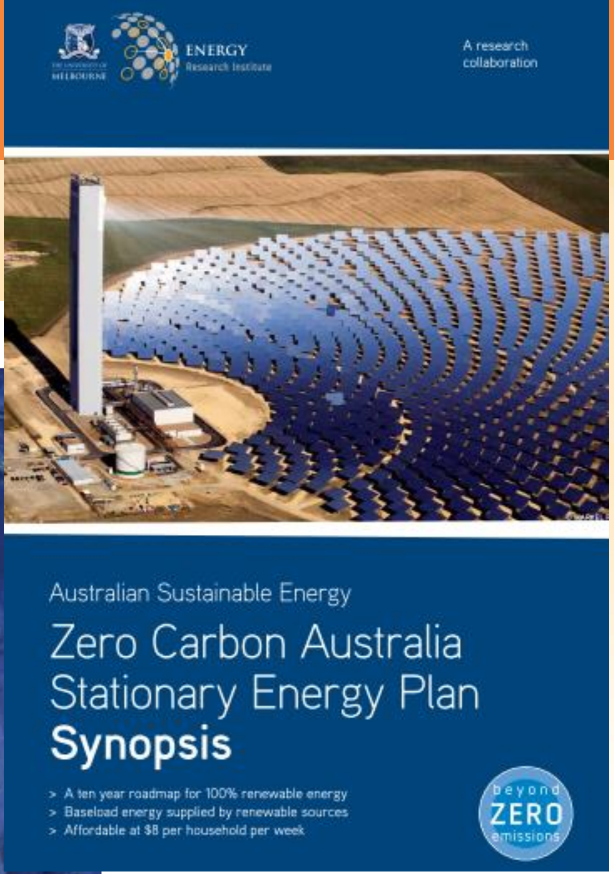
Data SIO, NOAA, U.S. Navy, NGA, GEBCO



ENERGY Research Institute

A research collaboration

Australian Sustainable Energy

Zero Carbon Australia Stationary Energy Plan

Synopsis

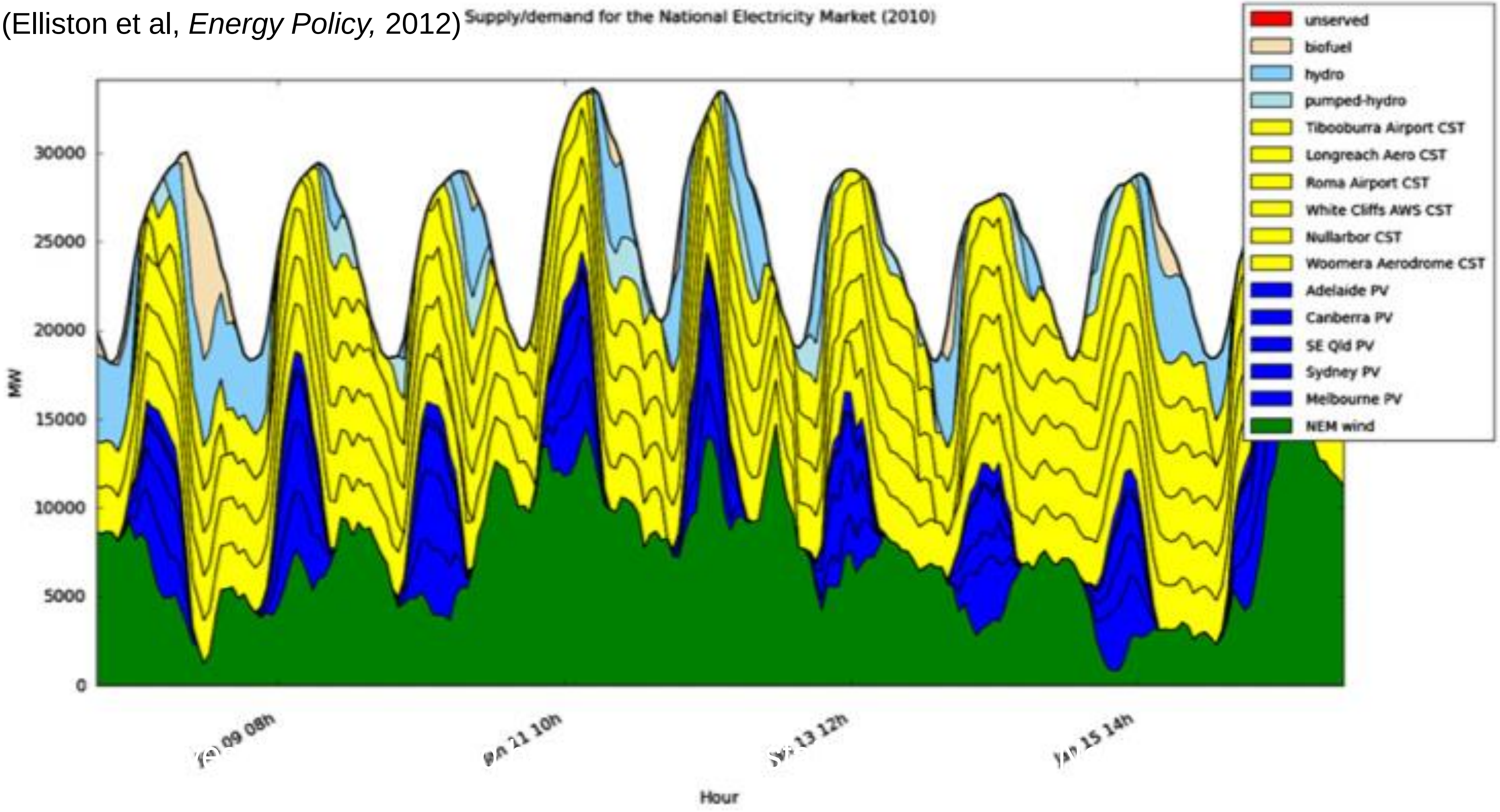
- A ten year roadmap for 100% renewable energy
- Baseload energy supplied by renewable sources
- Affordable at $8 per household per week

beyond ZERO emissions

UNSW – Elliston, Diesendorf & MacGill, 2011…

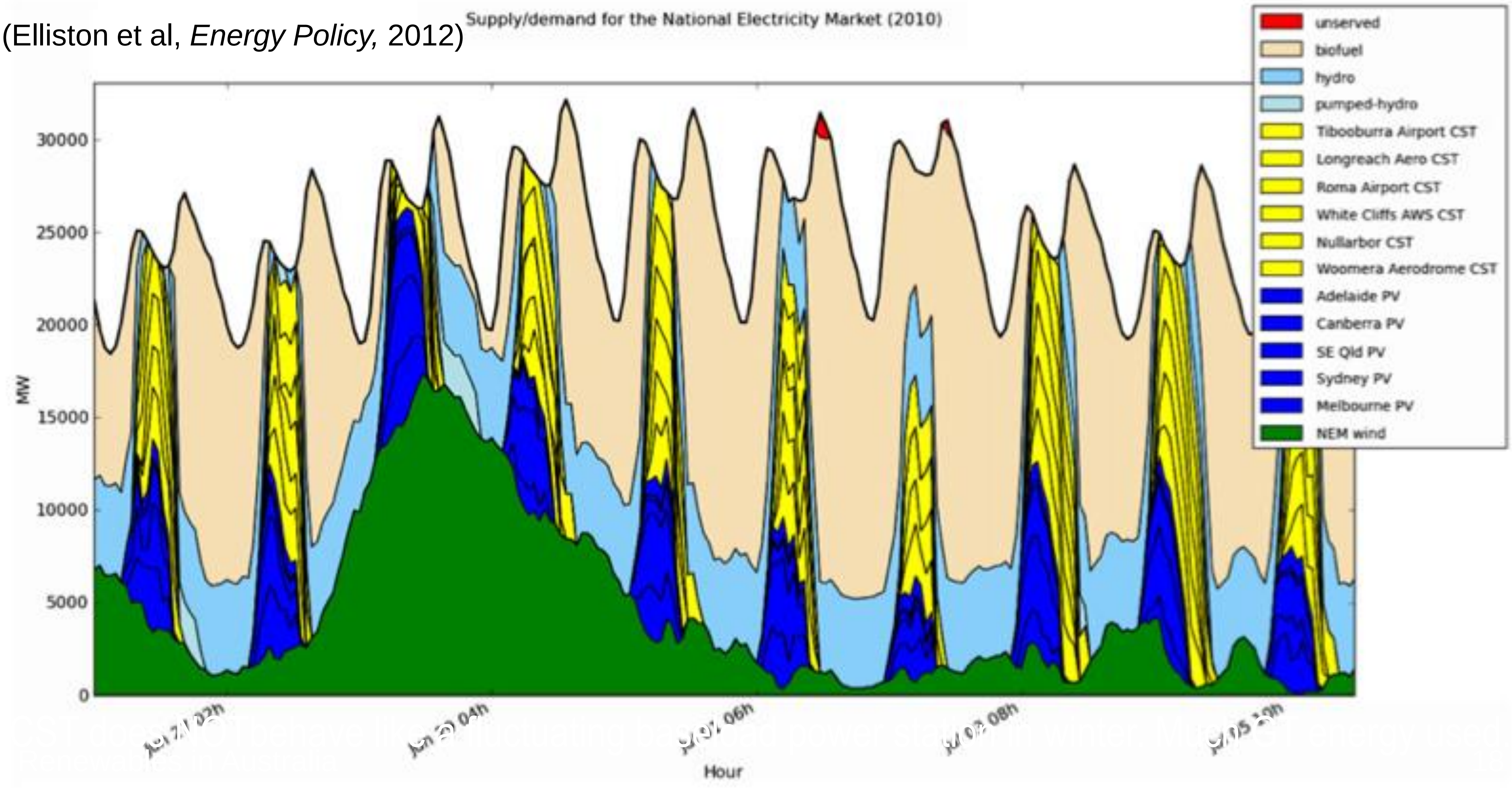
Custom Simulation Tool: eg. upply and Demand for a Typical Week in Summer 2010 – Baseline Simulation

(Elliston et al, *Energy Policy,* 2012)



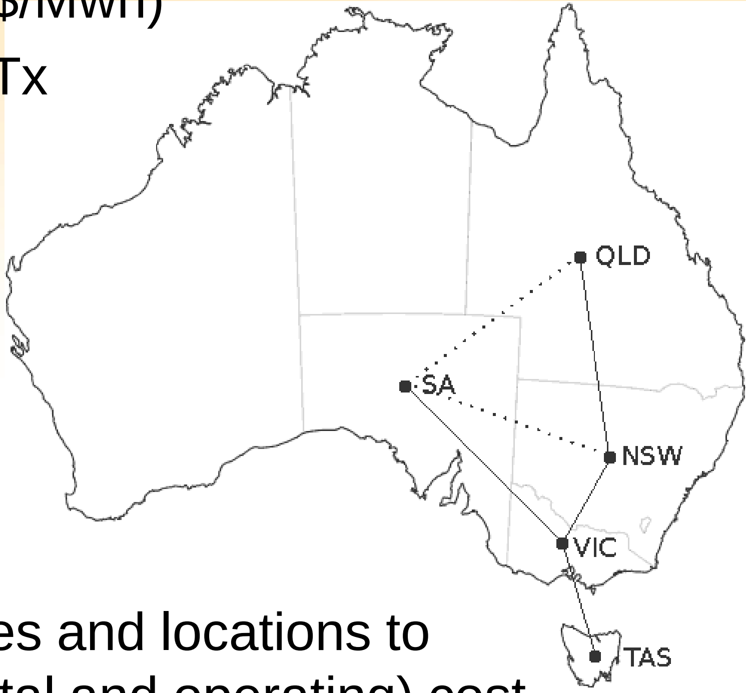
Technical feasibility?: Supply and Demand for a Challenging Week in Winter 2010 – Baseline Simulation

(Elliston et al, *Energy Policy,* 2012)



Economic feasibility? Simulation extensions &*Search*

- Cost model – using AETA (BREE, 2012)
  - 2030 projected annualised capital cost ($/kW/yr)
  - Fixed O&M ($/kW/yr) and Variable O&M ($/Mwh)
  - Optionally including 'high level' indicative Tx
- Regional model
  - Each "generator" assigned to a region
  - Dispatch algorithm region-aware
  - Tracks hourly energy exchanges between regions
- *Search* algorithm
  - genetic algorithm seeks mix of technologies and locations to minimise overall industry annualised (capital and operating) cost *(including cost of USE)*

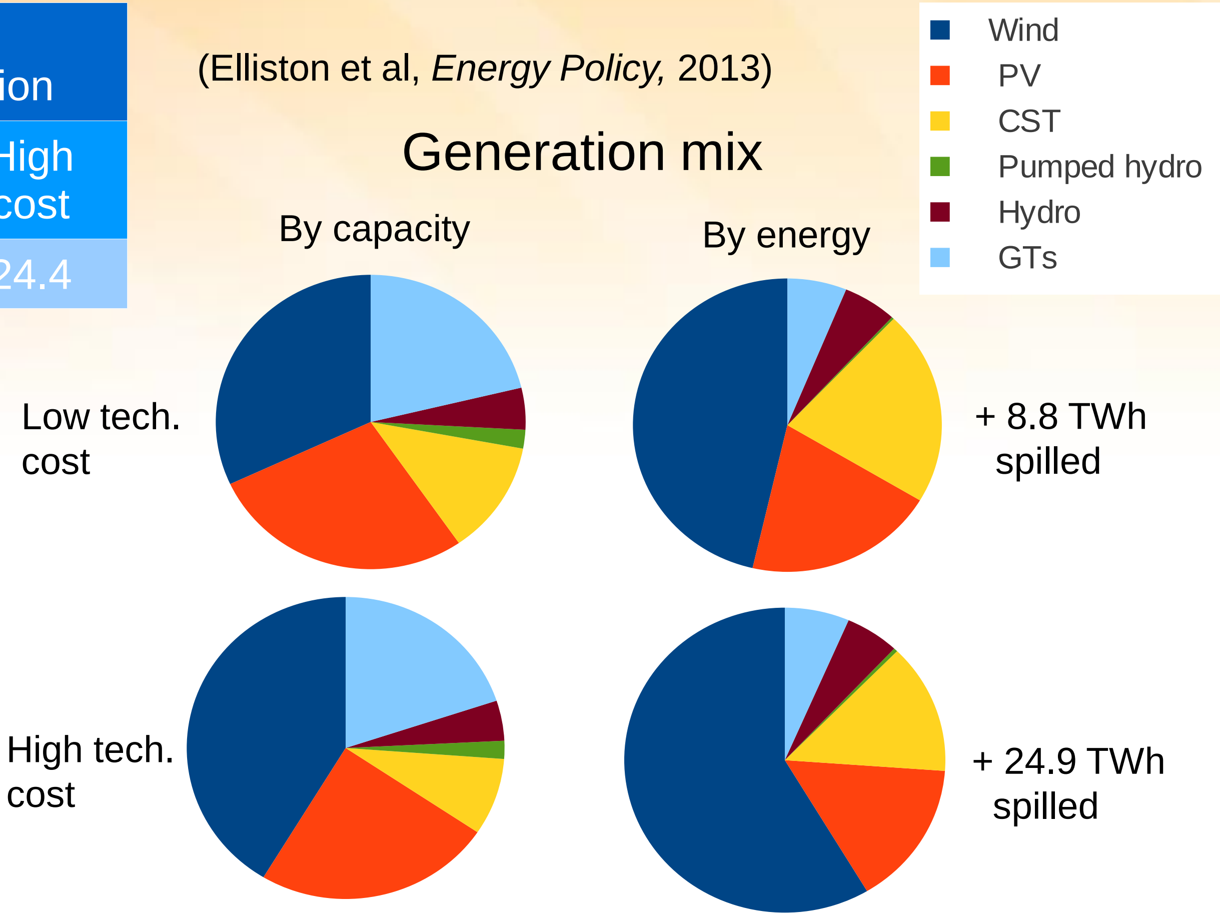


Preliminary findings

A$b/yr for AETA *high* and *low* technology cost scenarios

Without transmission		With transmission	
Low cost	High cost	Low cost	High cost
19.6	22.1	21.2	24.4

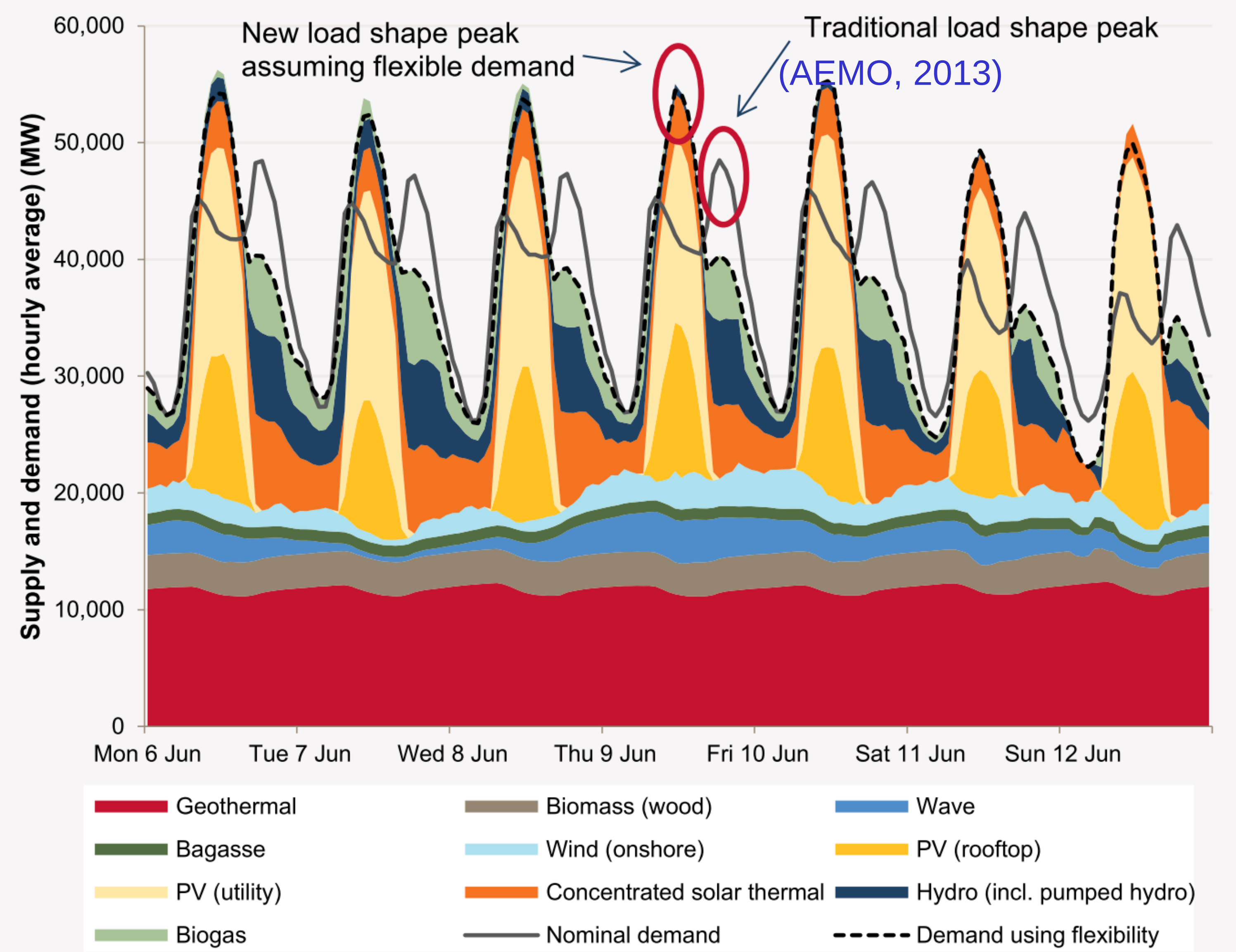
Current NEM costs approx. $10b/year. At carbon prices of $50-100/tCO2 100% renewables costs can be lower cost than ‘replacement’ scenario



(Elliston et al, *Energy Policy,* 2013)

Generation mix

AEMO 100% Renewables Study, 2012-13

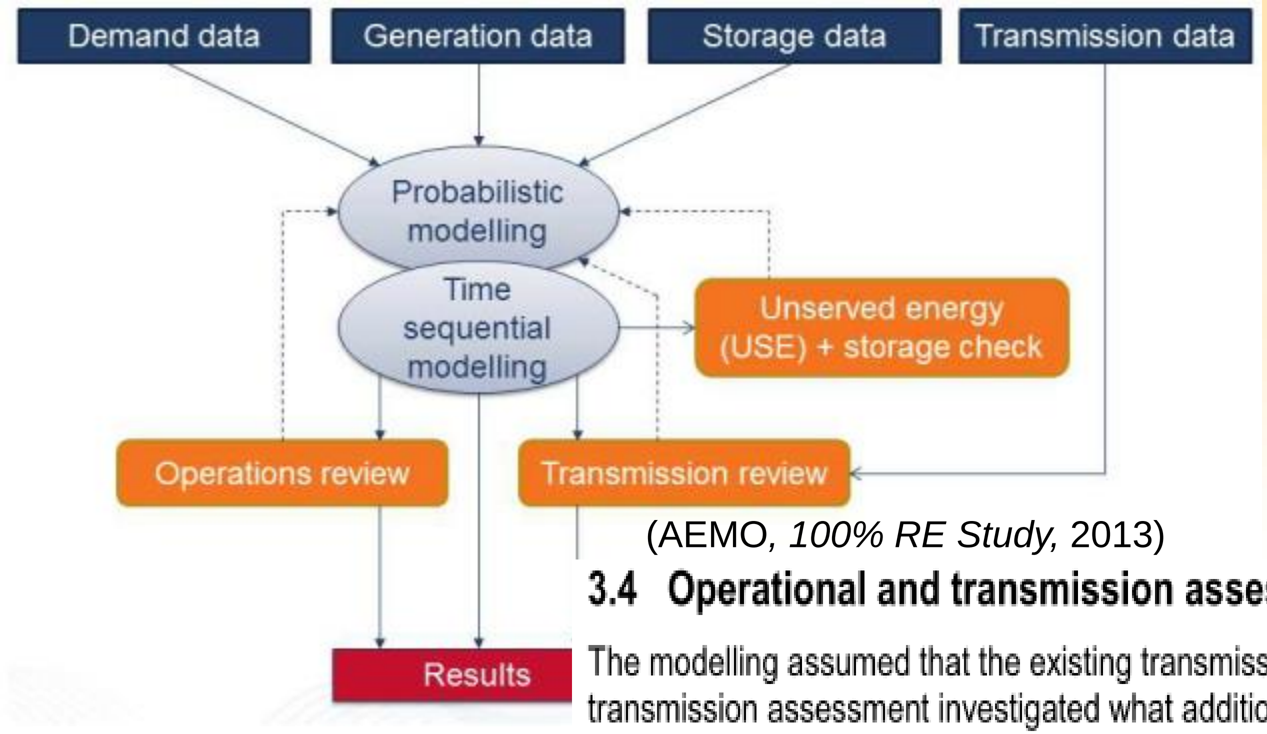


New load shape peak assuming flexible demand

Traditional load shape peak

(AEMO, 2013)

AEMO Network considerations



Demand data
Generation data
Storage data
Transmission data
Probabilistic modelling
Time sequential modelling
Unserved energy (USE) + storage check
Operations review
Transmission review
Results

(AEMO, *100% RE Study,* 2013)

3.4 Operational and transmission assessments

The modelling assumed that the existing transmission system was available in all four cases. The transmission assessment investigated what additional transmission assets would be required to transport the modelled generation from where it is produced to the load centres at the lowest overall cost. This investigation explored both new transmission lines as well as upgrades to the existing transmission system.

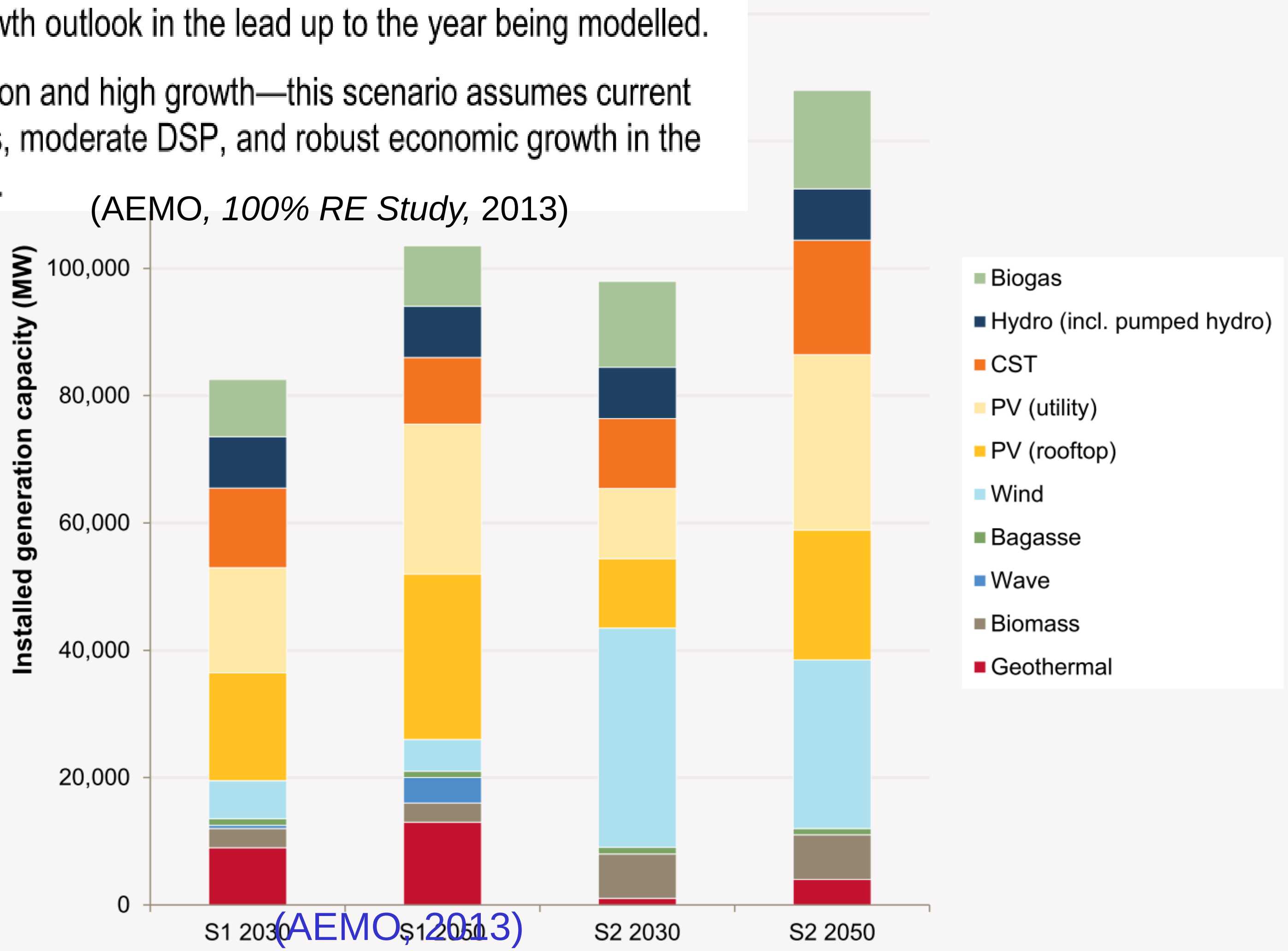
The operational assessment considered a range of technical issues including frequency control and system inertia. Operational assessments also aimed to identify any generation mix adjustments likely to be required for system security purposes.

AEMO 100% RE – least cost capacity mix

Scenario 1: Rapid transformation and moderate growth—this scenario assumes strong progress on lowering technology costs, improving demand side participation (DSP), and a conservative average demand growth outlook in the lead up to the year being modelled.

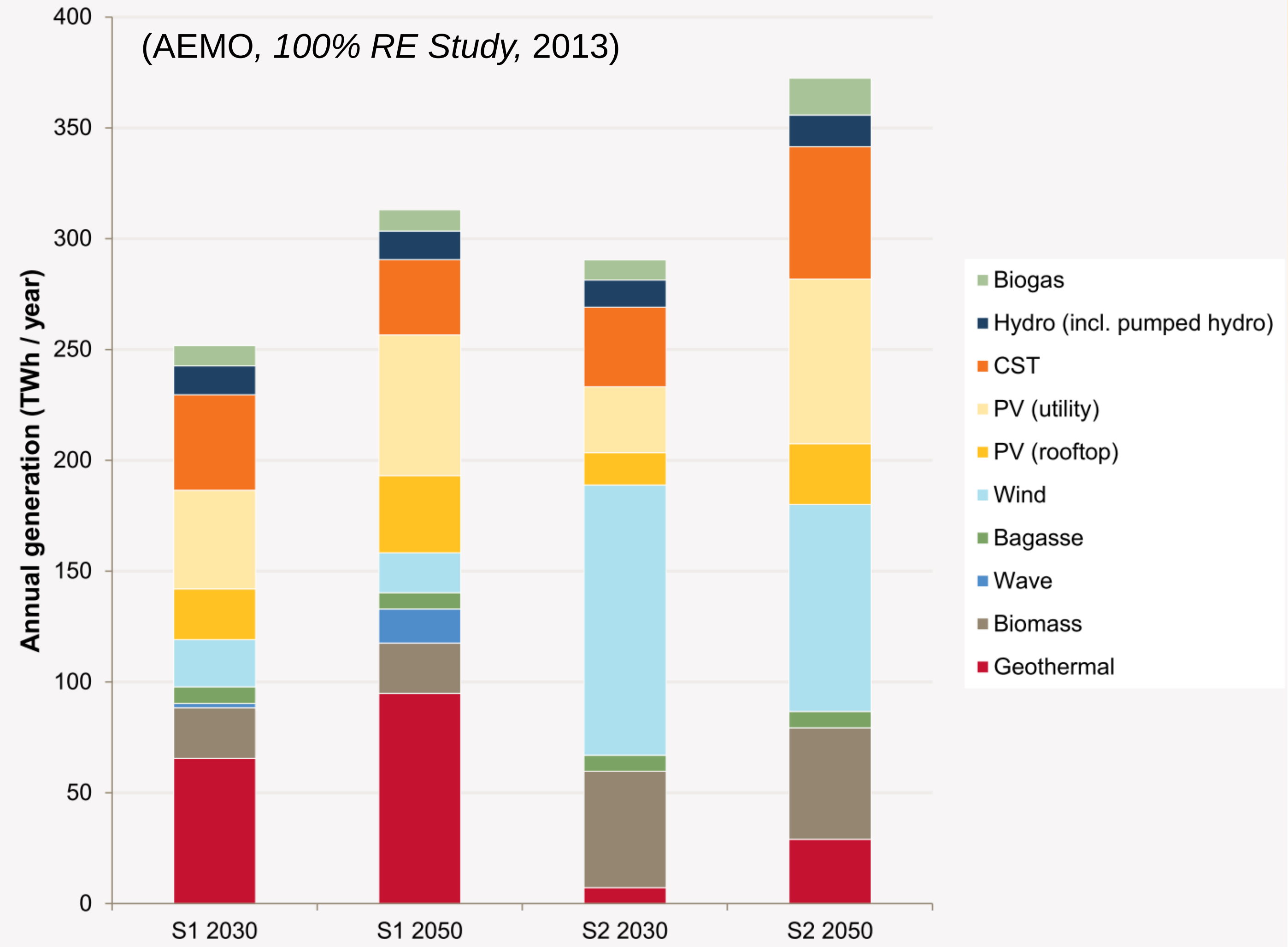
Scenario 2: Moderate transformation and high growth—this scenario assumes current trends in lowering technology costs, moderate DSP, and robust economic growth in the lead up to the year being modelled.

(AEMO, *100% RE Study,* 2013)



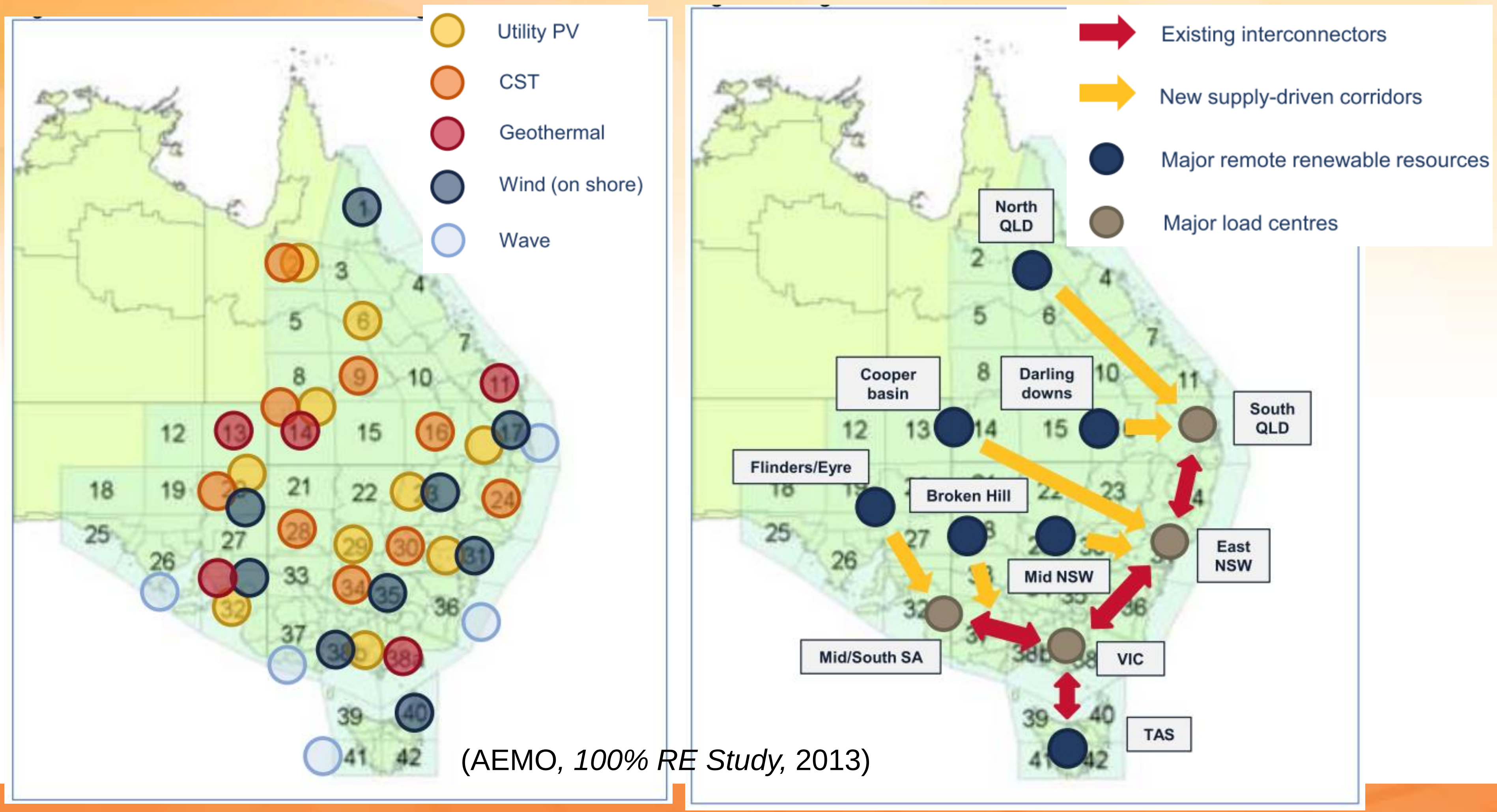
(AEMO, 2013)

AEMO 100% RE – least cost generation mix



(AEMO, 2013)

RE locational options, chosen Tx build



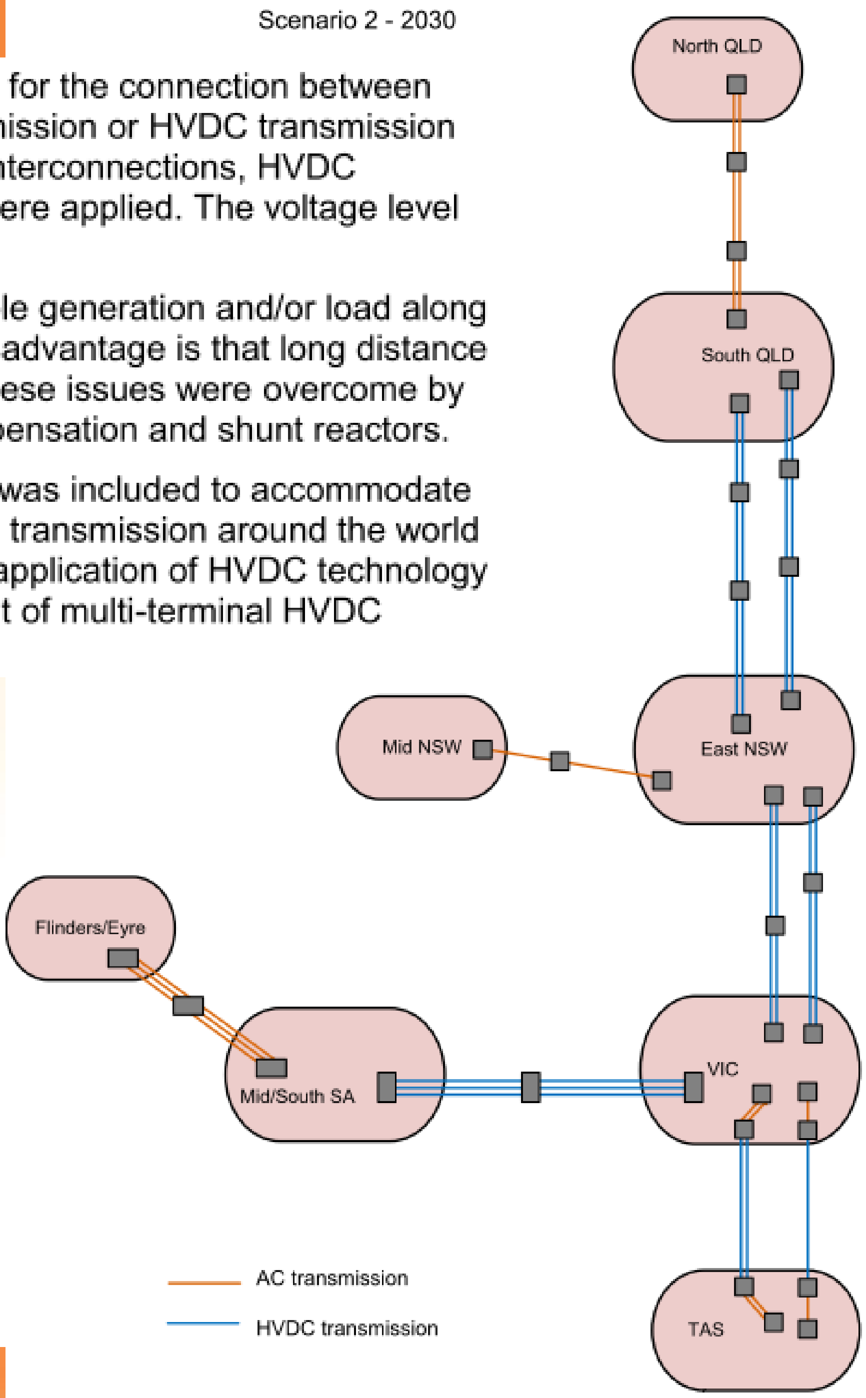
(AEMO, *100% RE Study*, 2013)

Both AC and HVDC transmission options were considered. Except for the connection between Victoria and Tasmania, all options were based on either AC transmission or HVDC transmission exclusively. In the case of Victoria and Tasmania, additional new interconnections, HVDC submarine cables and short connection of AC transmission lines were applied. The voltage level included for AC options was 500 kV and for HVDC, +/-500 kV.

The advantage of AC transmission is its ability to connect renewable generation and/or load along the transmission route with relatively low connection costs. The disadvantage is that long distance AC transmission lines pose system and voltage stability issues. These issues were overcome by introducing additional, intermediate switching stations, series compensation and shunt reactors.

For HVDC transmission, at least one intermediate terminal station was included to accommodate new renewable energy sources along the route. Most of the HVDC transmission around the world is either point-to-point or back-to-back HVDC systems. Presently, application of HVDC technology with one intermediate terminal station is available and development of multi-terminal HVDC technology is undergoing further advancement in this area.

(AEMO, *100% RE Study,* 2013)



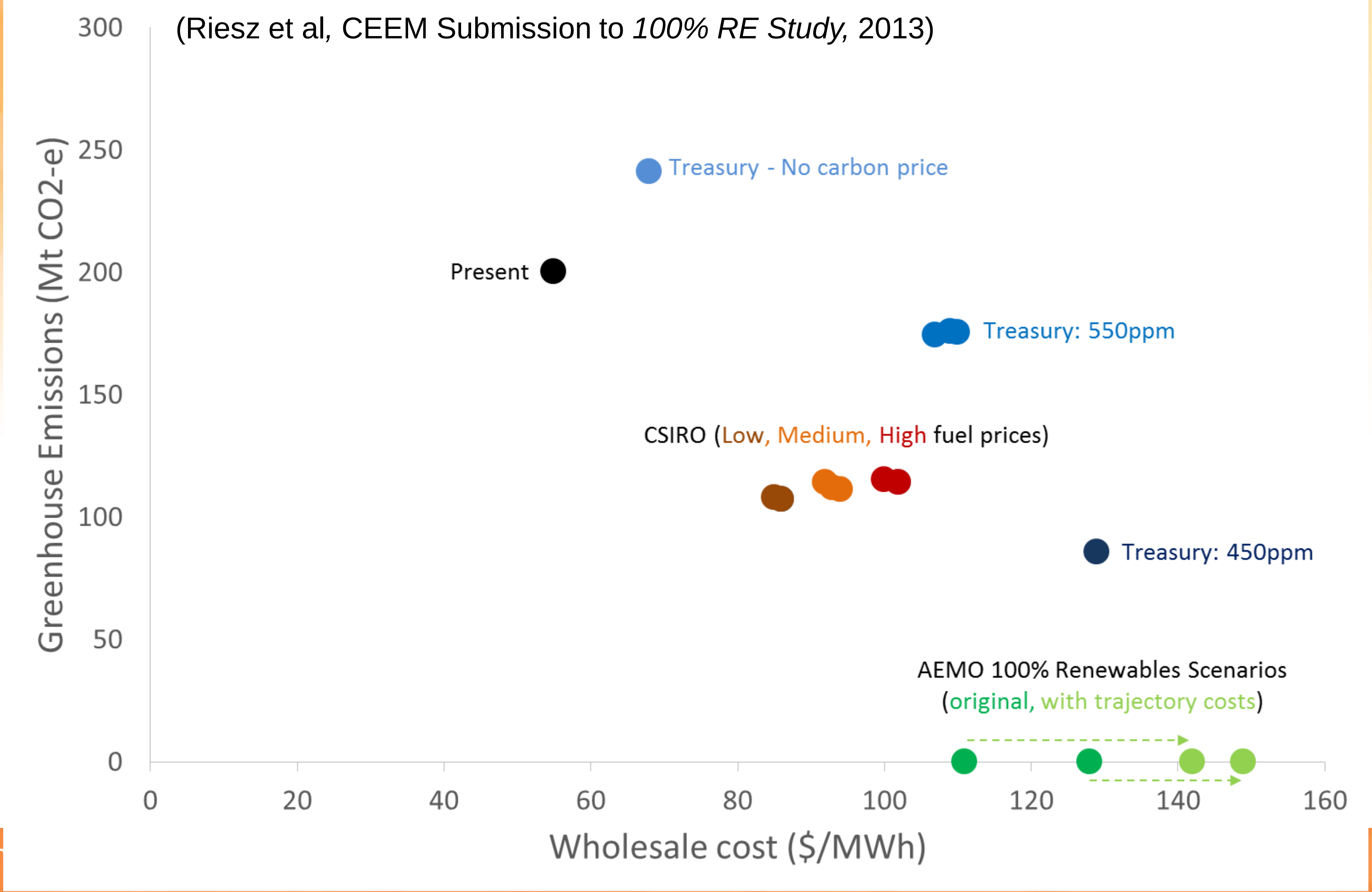
AEMO Findings

	Scenario 1 2030*	Scenario 1 2050*	Scenario 2 2030*	Scenario 2 2050*
Rooftop PV	$18 billion	$36 billion	$17 billion	$23 billion
Generation (excluding rooftop PV)	$171 billion	$209 billion	$208 billion	$276 billion
New generation connection	$8 billion	$11 billion	$10 billion	$13 billion
New transmission corridors	$22 billion	$28 billion	$17 billion	$21 billion
Total	**$219 billion**	**$285 billion**	**$252 billion**	**$332 billion**

(AEMO, *100% RE Study*, 2013)

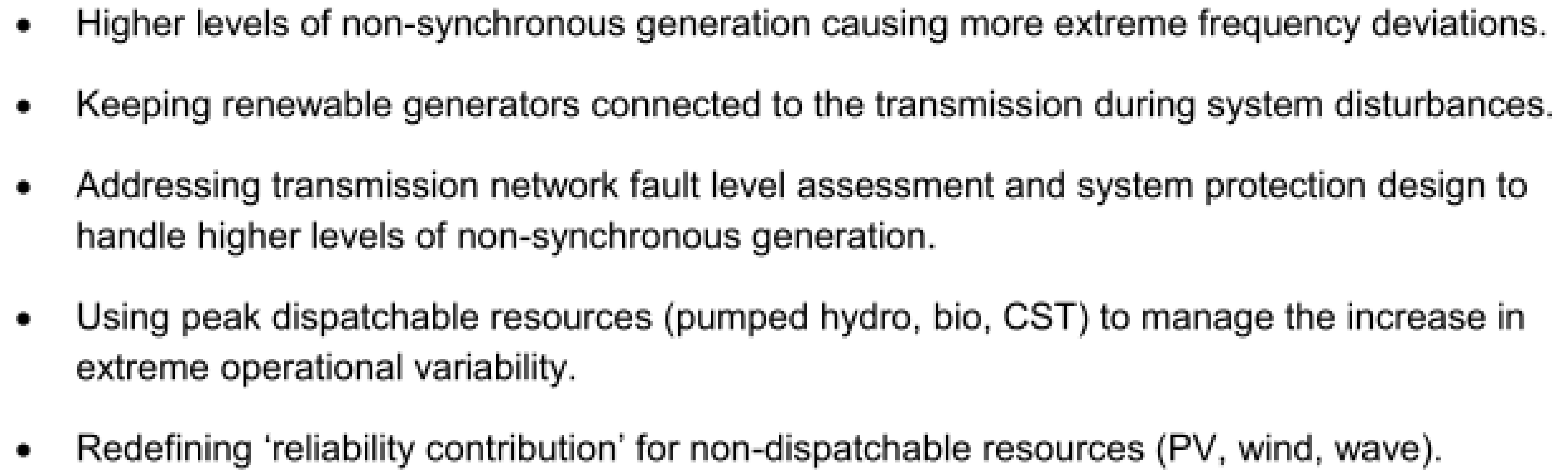
	Scenario 1 2030 ($/MWh)	Scenario 1 2050 ($/MWh)	Scenario 2 2030 ($/MWh)	Scenario 2 2050 ($/MWh)
Total wholesale	111	112	128	133
Current wholesale (2012 estimate)	55	55	55	55
Additional wholesale	56	57	73	78
Additional transmission	10	10	6	6

How do estimated costs compare?



(Riesz et al, CEEM Submission to *100% RE Study,* 2013)

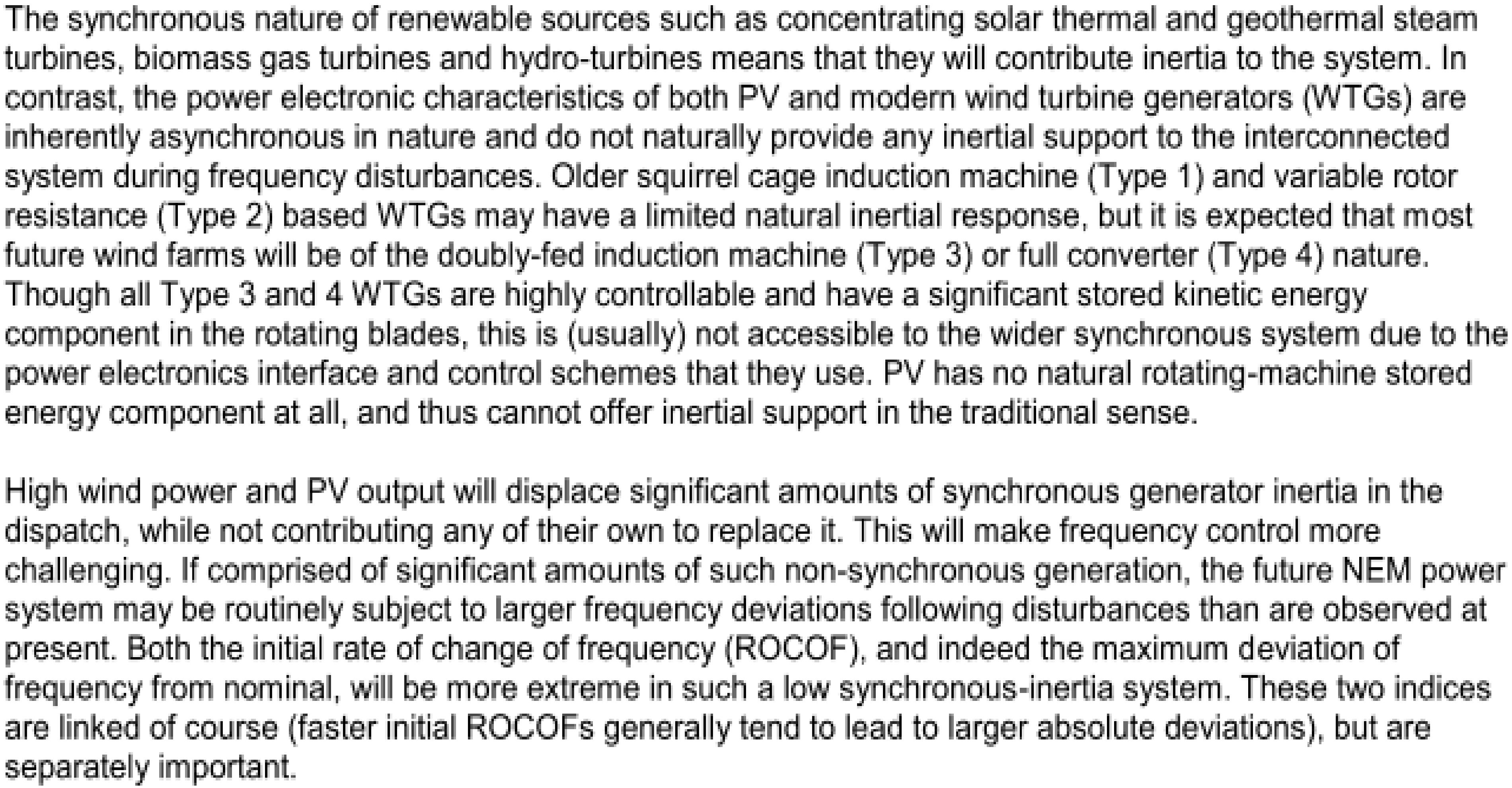
Key Qs for AEMO operational review



- Higher levels of non-synchronous generation causing more extreme frequency deviations.
- Keeping renewable generators connected to the transmission during system disturbances.
- Addressing transmission network fault level assessment and system protection design to handle higher levels of non-synchronous generation.
- Using peak dispatchable resources (pumped hydro, bio, CST) to manage the increase in extreme operational variability.
- Redefining ‘reliability contribution’ for non-dispatchable resources (PV, wind, wave).

(AEMO, *100% RE Study,* 2013)

Operational review – *eg. Inertia*



The synchronous nature of renewable sources such as concentrating solar thermal and geothermal steam turbines, biomass gas turbines and hydro-turbines means that they will contribute inertia to the system. In contrast, the power electronic characteristics of both PV and modern wind turbine generators (WTGs) are inherently asynchronous in nature and do not naturally provide any inertial support to the interconnected system during frequency disturbances. Older squirrel cage induction machine (Type 1) and variable rotor resistance (Type 2) based WTGs may have a limited natural inertial response, but it is expected that most future wind farms will be of the doubly-fed induction machine (Type 3) or full converter (Type 4) nature. Though all Type 3 and 4 WTGs are highly controllable and have a significant stored kinetic energy component in the rotating blades, this is (usually) not accessible to the wider synchronous system due to the power electronics interface and control schemes that they use. PV has no natural rotating-machine stored energy component at all, and thus cannot offer inertial support in the traditional sense.

High wind power and PV output will displace significant amounts of synchronous generator inertia in the dispatch, while not contributing any of their own to replace it. This will make frequency control more challenging. If comprised of significant amounts of such non-synchronous generation, the future NEM power system may be routinely subject to larger frequency deviations following disturbances than are observed at present. Both the initial rate of change of frequency (ROCOF), and indeed the maximum deviation of frequency from nominal, will be more extreme in such a low synchronous-inertia system. These two indices are linked of course (faster initial ROCOFs generally tend to lead to larger absolute deviations), but are separately important.

(AEMO, *100% RE Study*, 2013)

Where next?

"The best way to predict your future is to create it!"

Abraham Lincoln

An alternative, more engineering oriented, answer

-- “That depends…”