

# SWIS Coal Retirement by 2021 Modelling

7<sup>th</sup> November 2016



# The Key Message

- The SWIS can close all coal and replace it with wind and solar PV with no increase in cost of electricity, resulting in 63% reduction in current electricity emissions.
- It would be feasible to close Muja ABCD and Collie power stations by 2021 (this term of government), resulting in 50% reduction in current electricity emissions for no increase in cost of electricity
- 85% reduction in emissions is feasible by 2030



# SWIS 5-year transition scenario to 60% Renewable Energy with 38% of existing carbon emissions

- Introduction
- Climate imperatives; summary of 5 year transition
- How did SEN model it? – outline SIREN; outline Powerbalance
- Coal phase-out – details – LCOE's graphs
- What would it mean for Collie:
  - **Short term 5 year**
    - Package for coal workers – options for redundancy, retraining in wind installation, mine rehabilitation, tourism
    - Installation hub – construction base for > 1000 MW of wind
    - Tower fabrication and construction
  - **Possible in the longer term (10 years)**
    - Biomass power generation and pellet industry; rail to Wagin / Katanning for biomass produced in the 400- 600 mm southern agricultural region



# 12 reasons to modernize and clean up SWIS now.

1. **REDUCE CARBON EMISSIONS.** Calls for action since 1988 but still carbon emissions rise > 400 ppm; 2016 hottest year on record above average.
2. Increasing climate disasters in a world heated by man's carbon emissions. (Examples in past 2 years - Yarloop, Northcliffe fires, Forbes floods)
3. Paris accord, 155 nations – legally binding reduction targets - Australia 28% reduction by 2030.
4. Labor's target of 50% renewable energy by 2030.
5. RET target for WA means much cheaper to install RE than pay for LGC's.
6. Wind and PV cheaper than coal and price still falling.
7. Interest rates for investors have never been lower.
8. 20 billion investment over 15 years means 'jobs and growth'!
9. SEN technical and economic modelling indicates all coal can be replaced with wind and solar in 5 years **REDUCING CARBON EMISSIONS BY 60%.**
10. Wholesale price of electricity price will be no higher than with existing coal
11. Wind PV –zero pollution zero water use
12. Stand-alone remote and edge of grid PV-wind installations will reduce distribution and TAP costs

## 90% C emissions reduction by 2030 – cost effective



# Transition from coal to renewable electricity

SEN's modelling shows that **all coal generation can be replaced with wind and of solar PV with no increase in electricity prices.**

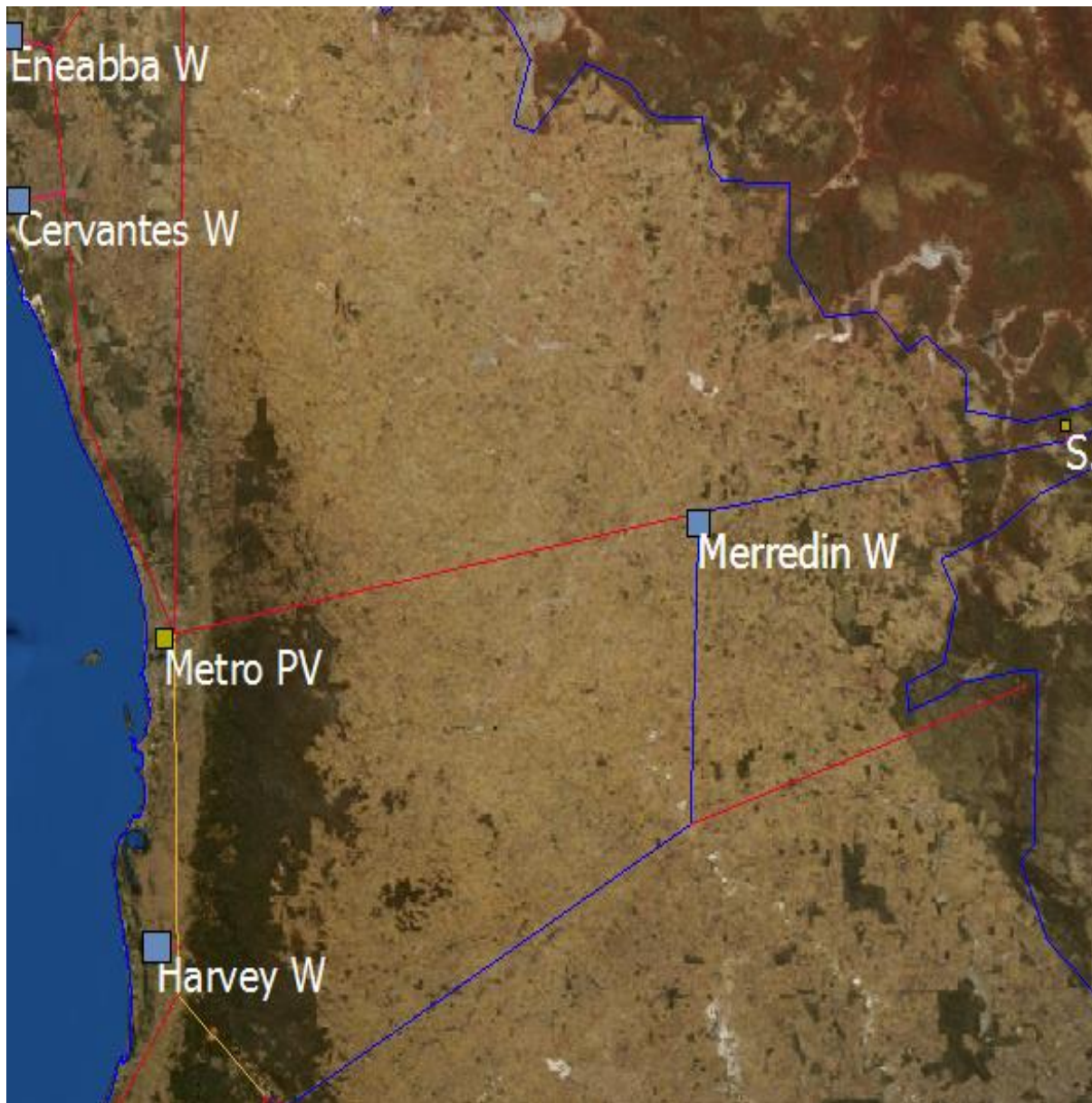
- No new gas generation capacity.
- Assumes RET LGC price \$55/MWh and zero carbon price.

## A vision for Collie in the next 5 years













- Muja ABCD and Collie closed
- 1000 – 1400 MW of Wind east and west of Collie (up to 7 Collgar windfarms)
- Up to 200 MW of utility scale PV
- CO2 emissions down by 50%, a reduction of 6.2 million tonnes per year



# SIREN modelled map of wind and PV installation to replace coal (Wind 2500 MW, PV 1700 MW)



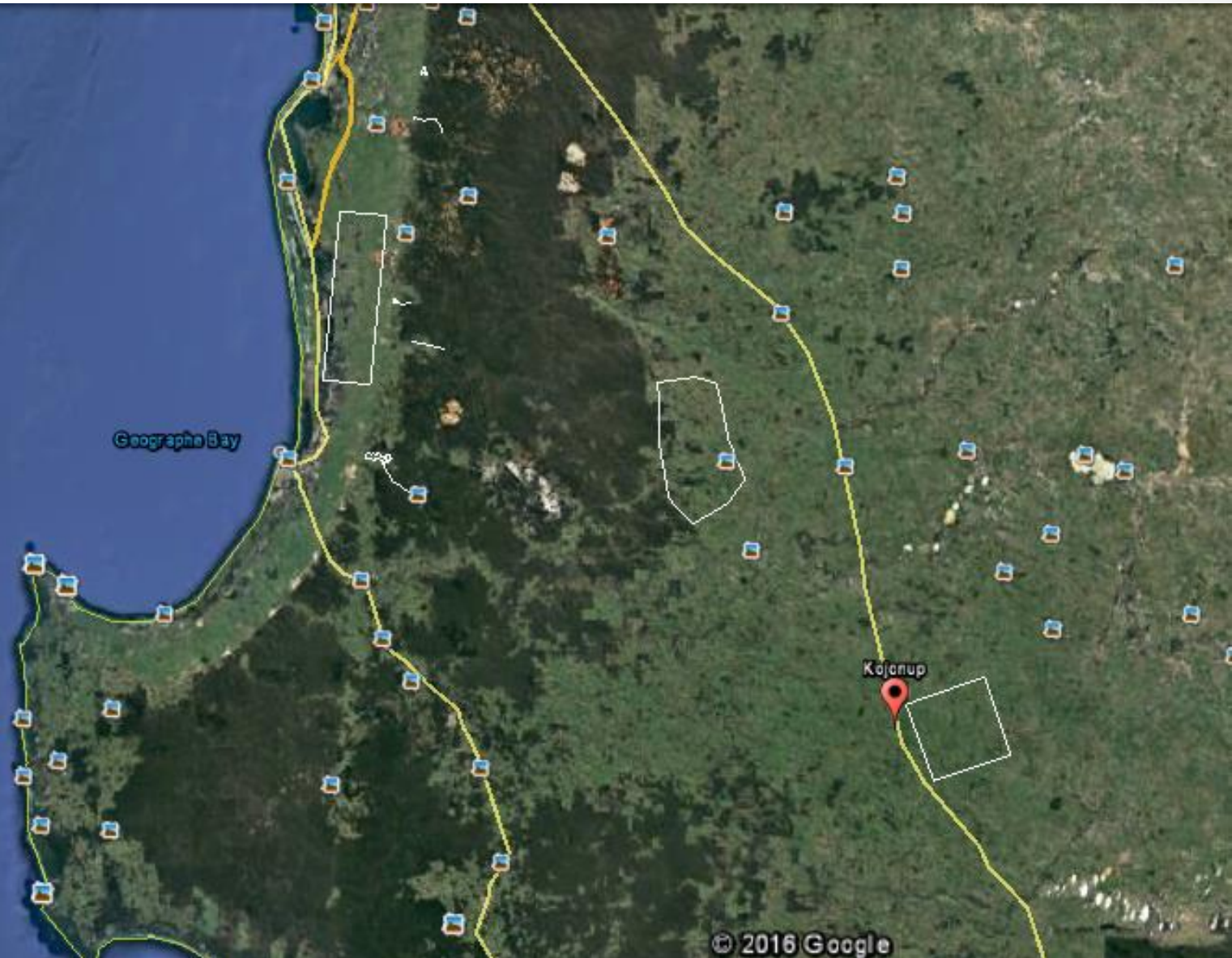
## SIREN - Display stations

 Name	Technology	Capacity (MW)	%0
Cervantes W	 Wind	400.0	
Collie East W	 Wind	400.0	
Eneabba W	 Wind	400.0	
Harvey W	 Wind	500.0	
Karara PV	 Fixed PV	350.0	
Kojonup W	 Wind	400.0	
Merredin W	 Wind	400.0	
Metro PV	 Fixed PV	1,000.0	
S. Cross PV	 Fixed PV	350.0	
	 Fixed PV	1,700.0	40.5%
	 Wind	2,500.0	59.5%
	Total	4,200.0	100.0%





# Higher agricultural land east of Collie and Kojonup and coastal plain west of Harvey; 1500 MW of wind would easily fit in these 3 areas







Collgar Wind Farm (Collgar) is a \$750 million renewable energy project consisting of 111 wind turbines located approximately 25km south east of Merredin in Western Australia, with a generation capacity of 206 Megawatts.

During the construction phase, Collgar employed up to 150 people over a period of two years..... ongoing employment for a team of 10-20 locally based staff. <http://www.collgarwindfarm.com.au/>

Landholder are paid \$4,000 to \$8,000 per turbine, \$3,000 to \$4,000 per megawatt of capacity, or 2-4% of gross revenues.

[http://www.windustry.org/how\\_much\\_do\\_farmers\\_get\\_paid\\_to\\_host\\_wind\\_turbines](http://www.windustry.org/how_much_do_farmers_get_paid_to_host_wind_turbines)

# SEN's costing assumptions

	Conservative LCOE's	Reference	Recent Power Purchase Agreement prices, Australia
Wind	\$85	BREE 2014 est. for 2025	\$77
PV, rooftop	\$65	Solar Choice, 2016	
PV, fixed, utility	\$110	BREE 2014 est. for 2025	\$100
CST with 6 hrs storage	\$165	BREE 2014 est. for 2025	
'Behind meter' Battery	\$40	nominal subsidy = SRET	
Coal	\$100	BREE 2014 est. for 2025	
Nuclear (SMR)	\$159	BREE 2014 est. for 2025	

\* 20 year fixed PPA for Hornsdale stage 2 (Renew Economy, 23-8-2016)

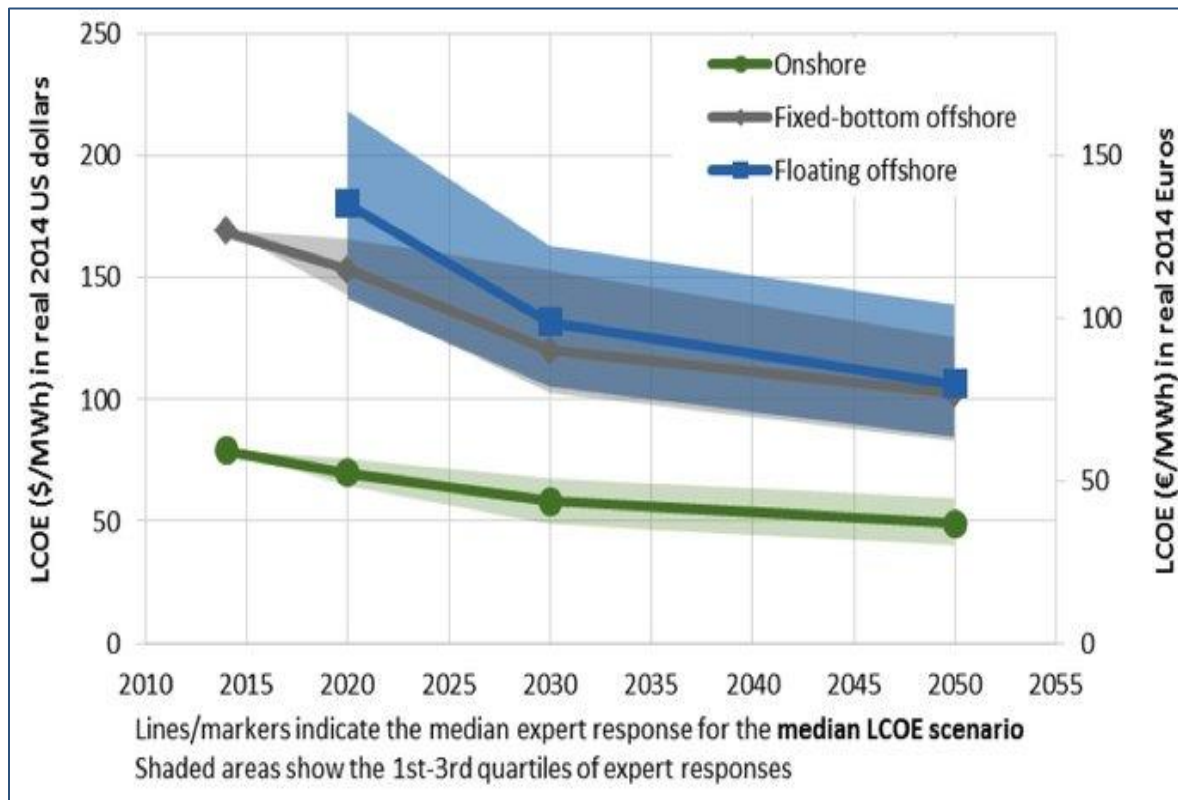
\*\* <http://reneweconomy.com.au/2016/12-large-scale-solar-projects-to-get-arena-funding-and-the-winners-are-23169>



# LCOE of Wind generation is falling

The 100MW Hornsdale wind project..... has achieved Australia's lowest known contract price for renewables at \$77/MWh.

See <http://reneweconomy.com.au/2015/sa-wind-farm-delivers-cheapest-wind-energy-ever-procured-in-australia-68843>



Ref: Wiser et al,  
2016, Berkeley Lab,  
NREL, IEA



# PV now less than AU\$35/MWh

- In September 2016 Marubeni and Jinko Solar won a reverse auction to build a 350 MW solar plant in Abu Dhabi with a price of \$US24.20/MWh (**\$A32.11/MWh**)
- The Marubeni-Jinko Solar bid is now the world's lowest, the previous low being \$US29.10/MWh for a solar plant in Chile
- The other bids for the Abu Dhabi project were:
  - \$US 25.90/MWh from Tenaga and Phelan Energy
  - \$US 29.10/MWh from RWE/Belectric
  - \$US 30.80/MWh from JGC, First Solar and Sojitz
  - \$US 36.30/MWh from Kepco, Q Cells and GSE
- The cost of solar PV in the UAE is currently around one third of the price of gas generation
- Deploying solar enables the UAE to export higher volumes of natural gas
- Ref:<http://reneweconomy.com.au/2016/how-the-jaw-dropping-fall-in-solar-prices-will-change-energy-markets-55160>





# SEN's modelled LCOE's for scenarios for reducing carbon emissions on the SWIS electricity grid

With a RET LGC price of \$55, closing all coal and replacing with wind and PV generation would not increase the wholesale electricity price, while decreasing CO2 emissions by 50%

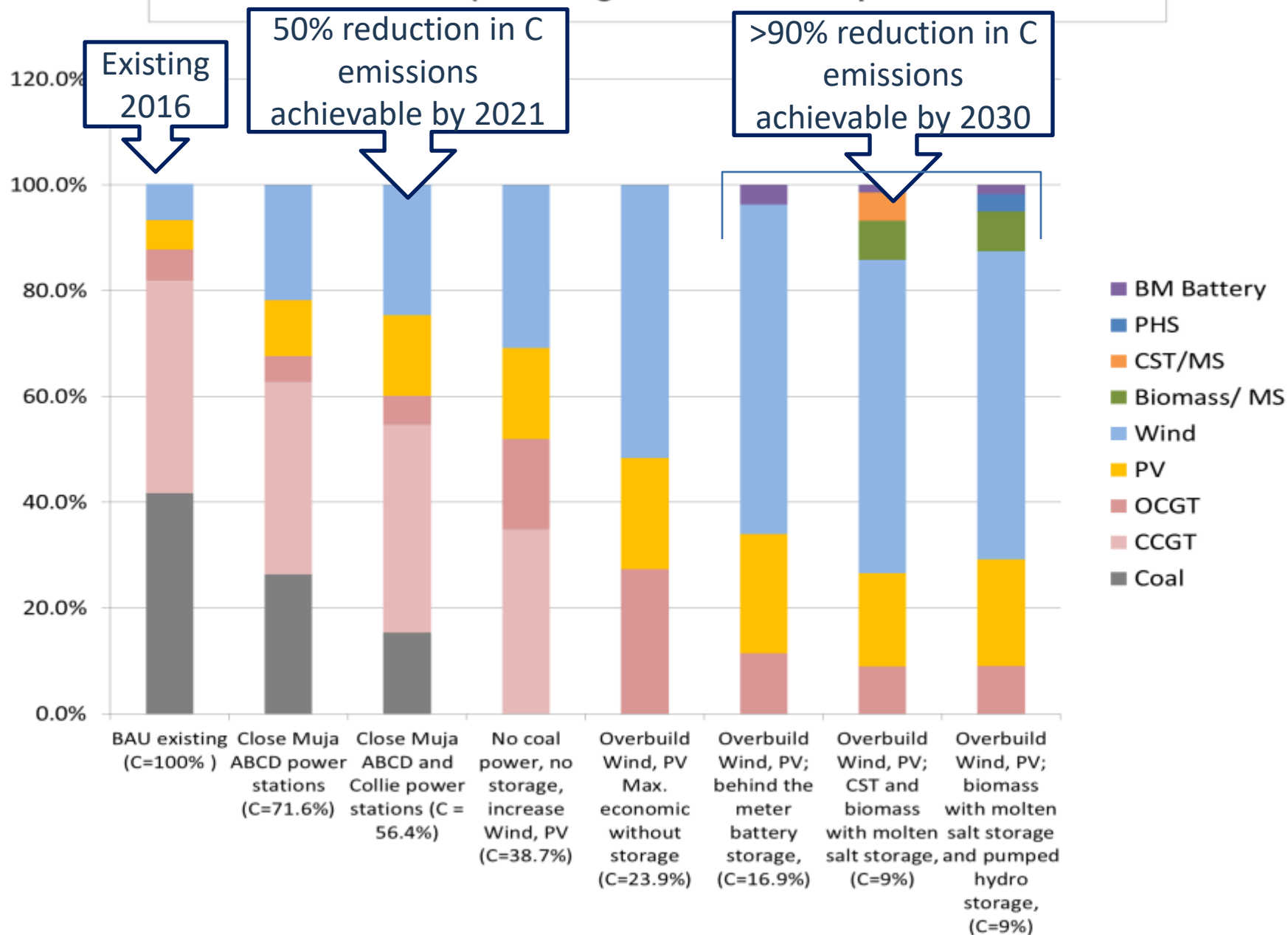
	BAU existing; C=100%	Close Muja ABCD; C=69%	Close Muja ABCD Collie; C=50.3%	Close Muja AB; CCS retrofit coal; C=38.3%	Close Muja AB; New coal retrofit C=38.3%;	No coal, no storage, incr.Wind, PV; Eq to CCS; C=37.2%	Wind, PV max. economic without storage C=24.4%
Zero C price and zero RET	\$91	\$99	<b>\$109</b>	\$106	\$132	\$109	\$117
\$30 C price	\$109	\$112	<b>\$119</b>	\$113	\$140	\$116	\$122
\$55 LGC price, 20% RET target; excess LGC's sold	\$98	\$96	<b>\$100</b>	\$113	\$140	\$98	\$90
RET as above; Recent PPA's for wind, PV in Australia	\$98	\$94	<b>\$97</b>	\$113	\$140	\$94	\$84

Note: \$100 / MWh = 10c / kWh



# Modelled scenarios for phasing out coal and gas generation on the SWIS (assuming no RET and no C price)

% of total generation





[illegible]

# Power capacity for SWIS transition scenarios

	Power Capacity MW				
Technology	Existing	Close Muja ABCD	2021 Close all Muja ABCD & Collie	Renewable Energy - equivalent C emissions to CCS	Renewable Energy - maximum economic without storage
CCGT	1475	1475	1475	1000	0
Coal	1778	752	435	0	0
OCGT	1659	1486	1486	2600	3000
Rooftop PV	500	800	1400	1200	2300
Fixed PV	10	200	500	500	400
Wind	500	1700	2300	2600	4800
TOTAL	5922	6413	7596	7900	10500

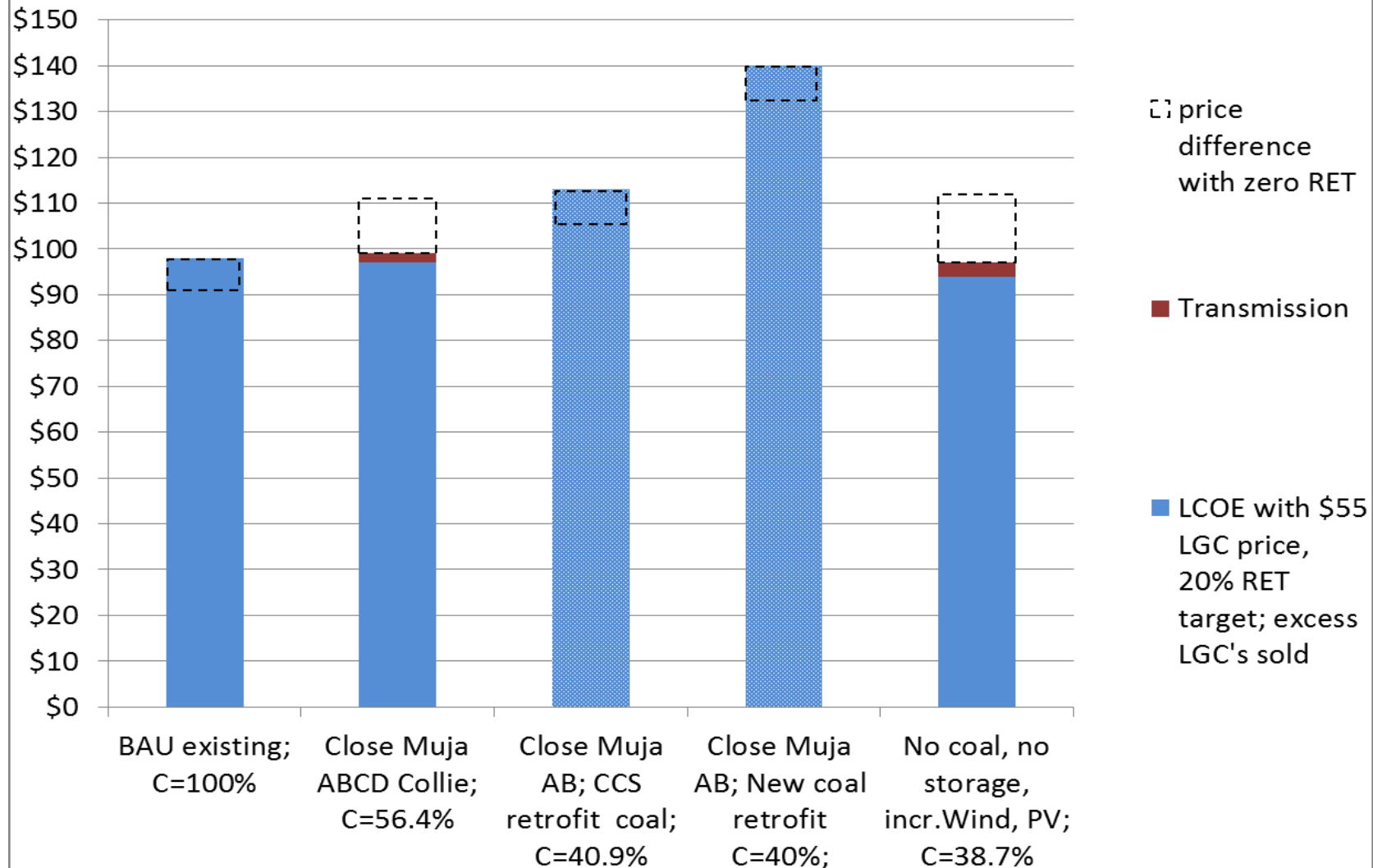


Retirement of coal fired power stations Submission 72 - Supplementary Submission								
								Overbuild Wind, PV; biomass with molten salt storage and pumped hydro storage, (C=9%)
	BAU existing (C=100%)	Close Muja ABCD power stations (C=71.6%)	Close Muja ABCD and Collie power stations -	<b>No coal power, no storage, increase Wind, PV (C=38.7%)</b>	Overbuild Wind, PV Maximum economic without storage (C=23.9%)	Overbuild Wind, PV; behind the meter battery storage, (C=16.9%)	Overbuild Wind, PV; CST and biomass with molten salt storage, (C=9%)	
	<b>Weighted average LCOE of scenarios</b>							
<b>LCOE with Zero C price and zero RET</b>	\$91	\$99	\$109	<b>\$109</b>	\$117	\$124	\$137	\$136
<b>LCOE with \$30 C price</b>	\$109	\$112	\$119	<b>\$116</b>	\$122	n/a	n/a	n/a
<b>LCOE with 20% RET target; \$55 LGC price, excess LGC's sold</b>	\$98	\$96	\$100	<b>\$98</b>	n/a	n/a	n/a	n/a
<b>LCOE with RET as above; current PPA's for wind, PV in Australia</b>	\$98	\$94	\$97	<b>\$94</b>	n/a	n/a	n/a	n/a

# Annualized cost of transmission is < \$3 / MWh (for 3200 MW of dispersed utility scale wind and PV)

Name	Peak (MW) for station	Max. line MW = 5*MW/8	Line type	Cost per km	end station	Main line distance to be costed (km)	Connector distance to be costed (km)	LINE + END STATION COSTS
Kojonup Wind	400	500	330s	\$1,000,000	\$8,000,000	111	10	\$129,000,000
Collie E Wind	400		330s	\$1,000,000	\$8,000,000	0	20	\$28,000,000
Harvey Wind	500		330s	\$1,000,000	\$8,000,000	0	10	\$18,000,000
Three Springs		1000	330d	\$1,500,000	\$0	275	0	\$412,500,000
Karara PV	350		330s	\$1,000,000	\$8,000,000	0	10	\$18,000,000
Cervantes Wind	400		330s	\$1,000,000	\$8,000,000	0	20	\$28,000,000
Eneabba Wind	400		330s	\$1,000,000	\$8,000,000	0	40	\$48,000,000
Merredin Wind	400	500	330s	\$1,000,000	\$8,000,000	228	20	\$256,000,000
Southern Cross PV	350		330s	\$1,000,000	\$8,000,000	0	10	\$18,000,000
		MW of dispersed utility scale wind and PV	3,200				Total cost of new lines plus sub-stations	\$955,500,000
							Total transmission line kilometres	754
Note: 1000 MW of PV in metro area not included as no transmission needed								Annualized cost per MWh \$ 2.94

## Modelled scenarios for reducing carbon emissions on the SWIS



## Weighted average LCOE\* of Modelled scenarios for reducing carbon emissions on the SWIS

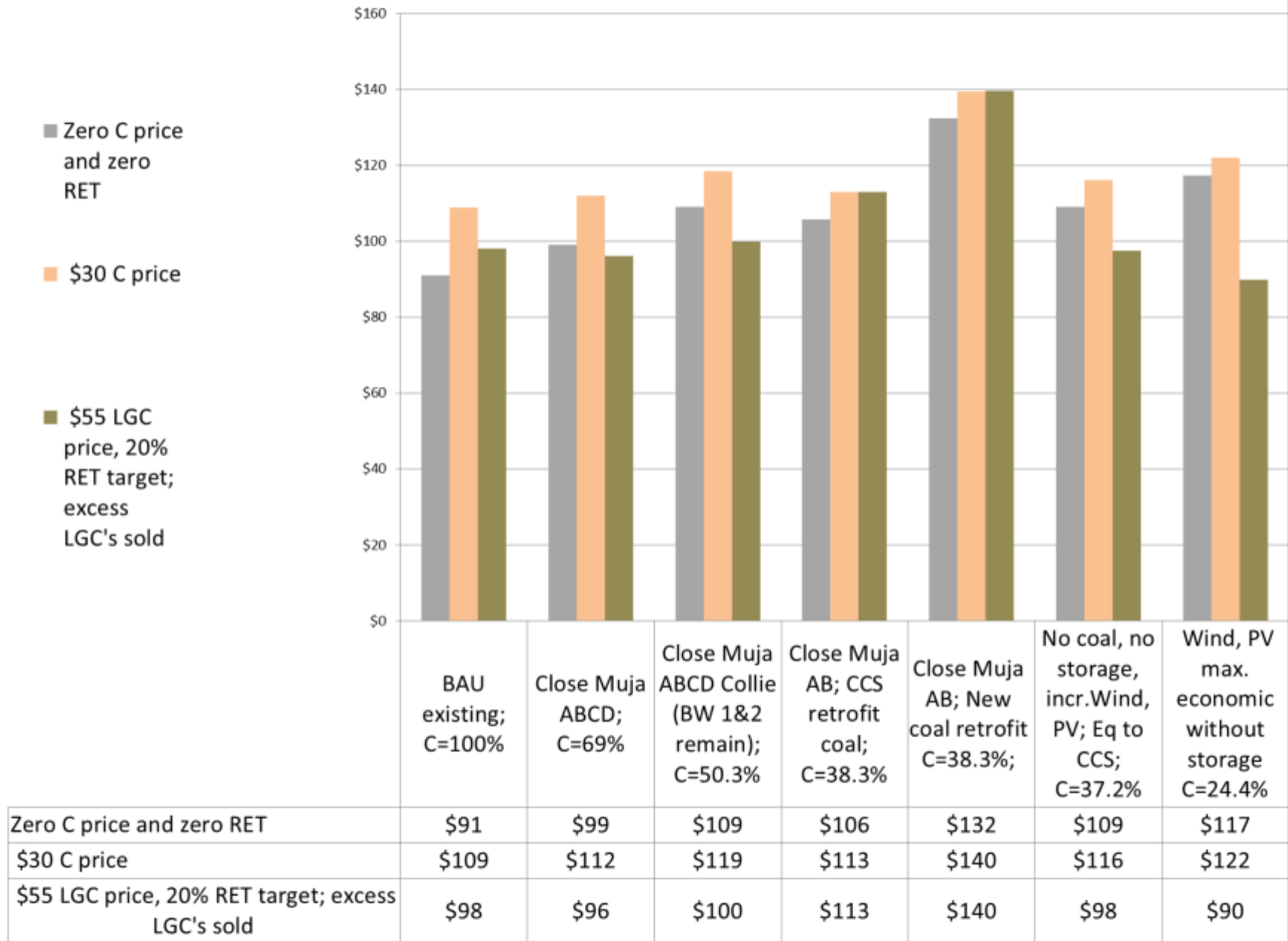
	BAU existing; C=100%	Close Muja ABCD; C=69%	Close Muja ABCD Collie (BW 1&2 remain); C=50.3%	Close Muja AB; CCS retrofit coal; C=38.3%	Close Muja AB; New coal retrofit C=38.3%;	No coal, no storage, incr.Wind, PV; Eq to CCS; C=37.2%	Wind, PV max. economic without storage C=24.4%
Zero C price and zero RET	\$91	\$99	\$109	\$106	\$132	\$109	\$117
\$30 C price	\$109	\$112	\$119	\$113	\$140	\$116	\$122
\$55 LGC price, 20% RET target; excess LGC's sold	\$98	\$96	\$100	\$113	\$140	\$98	\$90
RET as above; current PPA's for wind, PV in Australia	\$98	\$94	\$97	\$113	\$140	\$94	\$84



*\*close to wholesale price*



Retirement of coal fired power stations  
Submission 72 - Supplementary Submission  
**Cost of scenarios for decarbonizing the SWIS**



# Transitioning

WA needs a  
**RENEWABLE ENERGY  
TRANSITION** Planning  
Agency.

2030 100% :  
Wind-PV-Batt  
+CST  
+ MS storage  
+Biomass  
+ bio-oil OCGT

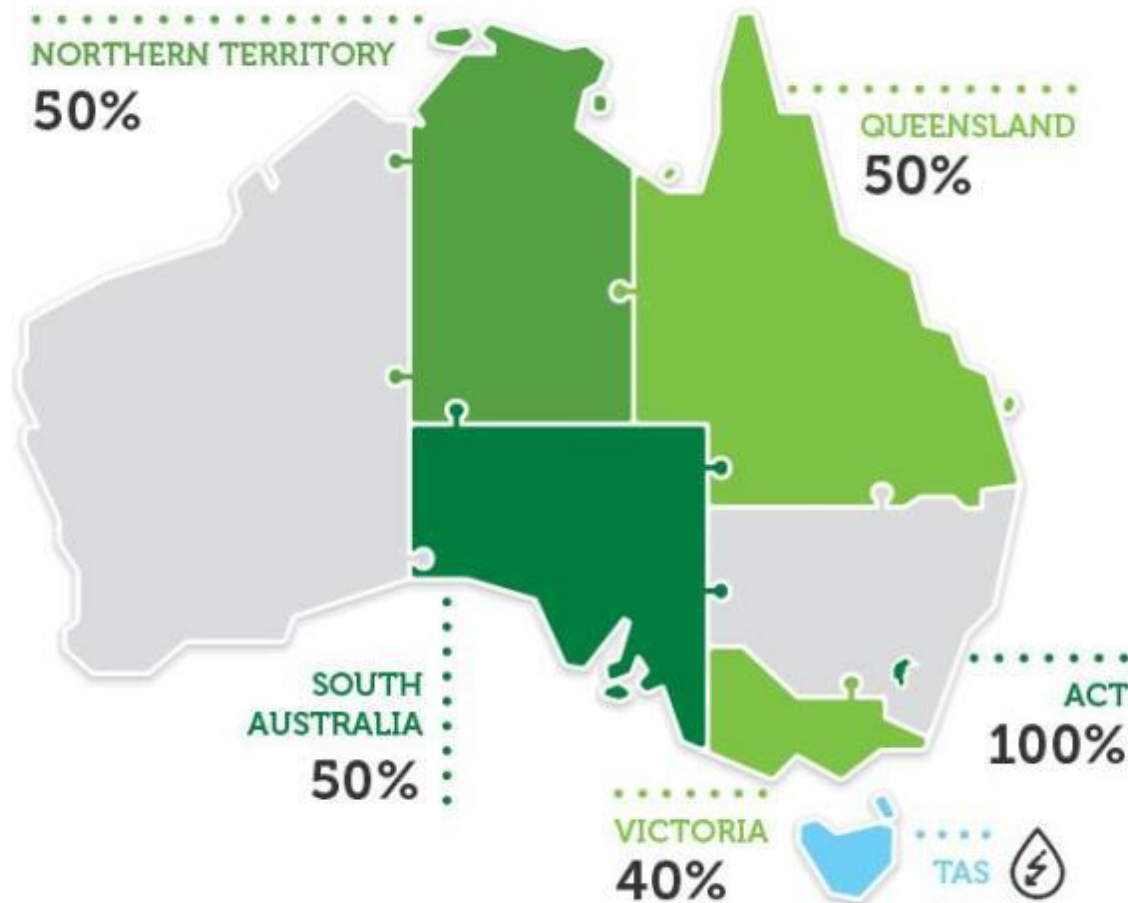
2026 > 75% RE  
Wind  
PV  
BM Battery  
Gas OCGT

2016 14% RE  
Coal  
Gas  
Starting  
Wind, PV

2030 100% RE  
Wind-PV-Batt  
+PHS  
+ Bio-oil OCGT



# MOST GOVERNMENTS ARE NOW SETTING AMBITIOUS RENEWABLES TARGETS!



# Synergy plan for Carbon Capture and Storage (CCS) for Collie coal plant

SEN's modelling shows:

- **CCS retrofit** of old plants will cost about the same as the Wind or PV option. (LCOE \$106/MWh compared to \$109)
- **With current RET** the LCOE of CCS option is higher than Wind or PV (\$113 compared to \$94)
- Increased maintenance of old plants would inevitably push the LCOE higher.
- **New coal – CCS** plants are not cost effective – LCOE \$133/MWh or \$136 with RET.
- Coal CCS is not yet 'stand alone commercial' on power station scale due to high technical and social risks and the energy is not renewable.
- Less popular politically and foregoes the employment opportunities of wind and PV.



Retirement of coal fired power stations  
Submission 72 – Supplementary Submission

# Summary of modelled carbon capture and storage (CCS) scenarios for the SWIS, compared with renewable energy scenario

## Percentage of total electricity generation

	Close Muja AB; CCS retrofit (C=40.9%))	Close Muja AB; New coal CCS (C=40%)	No coal, no storage, increase Wind, PV (C=38.7%)
Coal	41.9%	40.3%	0.0%
CCGT	40.3%	41.9%	34.9%
OCGT	5.6%	5.6%	17.1%
PV	5.6%	5.6%	17.2%
Wind	6.8%	6.8%	30.8%
Biomass/ MS	0.0%	0.0%	0.0%
CST/MS	0.0%	0.0%	0.0%
PHS	0.0%	0.0%	0.0%
BM Battery	0.0%	0.0%	0.0%
total	100.3%	100.2%	100.0%
Weighted average LCOE of scenarios			
LCOE with Zero C price and zero RET	\$106	\$132	\$109
LCOE with \$30 C price	\$113	\$140	\$116
LCOE with 20% RET target; \$55 LGC price, excess LGC's sold	\$113	\$140	\$98
LCOE with RET as above; current PPA's for wind, PV in Australia	\$113	\$140	\$94

## Carbon Capture and Storage (CCS)

### \$140 billion 140 megawatt (MW) power station in Canada

“When the coal-fired 140 megawatt (MW) Boundary Dam power station with a CCS plant was officially opened in early October 2014 .....it was touted as the world’s first “commercial scale” CCS plant.....”

In the last two weeks, SaskPower’s carefully-crafted illusion of the CCS plant as a success story has been shattered by revelations in a series of leaked internal documents. Instead of capturing 90 per cent of the carbon dioxide from the power station, the plant has captured about half that amount or less. Problems with the plant have meant that it has often been shut down.”

<http://reneweconomy.com.au/2015/the-fallout-from-saskpowers-boundary-dam-ccs-debacle-54803>





# Jobs- comparing technologies

- Permanent O&M jobs per MW in biomass, wind and PV outnumber those for coal by 2 to seven-fold.
- Construction, installation and manufacturing jobs for wind plus PV are greater than new coal as wind capacity (MW) to be constructed = 3.5\*coal; PV = 1\*coal

	construction/ installation	manufacturing	operations & maintenance Jobs/MW	Fuel
	<i>Job years/MW</i>	<i>Job years/MW</i>	<i>Jobs/ MW</i>	<i>jobs/GWh</i>
Coal	11.2	5.4	0.14	
Gas	1.3	0.93	0.14	
Biomass	14	2.9	1.5	0.108
Wind	3.2	4.7	0.3	
PV	13	6.7	0.7	



# Jobs for a 100 % RE scenario for the SWIS grid:

## >8000 permanent jobs, > 150,000 job years in construction and manufacturing

Jobs for WA							
Technology	C & I (Job Yrs../MW)	O & M (Jobs/ MW)	Manf. (Job Yrs. / MW)	Cap. (MW)	C & I Job years	O & M Jobs	Manufact -uring Job years
Roof-top PV	13.0	0.7	6.7	2,000	26,000	1,400	13,400
Fixed Solar PV Farm	13.0	0.7	6.7	1,000	13,000	700	6,700
Wind Farm	3.2	0.3	4.7	6,000	19,200	1,800	28,200
Biomass Facility	14.0	1.5	2.9	3,000	42,000	4,500	8,700
<b>TOTAL S</b>				<b>12,000</b>	<b>100,200</b>	<b>8,400</b>	<b>57,000</b>

- Based on 85% scenario, but substituting biofuel for gas in order to achieve 100% RE. This scenario includes the following mix of generation technologies and their associated capacities:
- 6,000 MW of wind; 3,000 MW of solar PV;
- 3,000 MW of gas fuelled turbines fuelled with bio-fuels.



# Jobs in Biomass industries for Collie

## 1. 2017 - 25

- Establish and expand mallee woodchip production on farms in the Great Southern region.
  - **Hundreds** of jobs growing harvesting and transporting woodchips
  - 120 km railway to Wagin / Narrogin – \$360 m project.
  - construction and maintenance jobs based in Collie.

## 2. 2020-22

- Construct 400 MW biomass with molten salt storage (MS) at Collie :
- **150 permanent jobs\*** and **8000 job years in construction and manufacturing**  
*\*(50 MW biomass plant in Vermont employs 40)*

## 3. 2021-25

- Establish wood pellet manufacturing plant in Collie and export from Bunbury port.
  - 85,000 tpa plant in NY State **employs 16; another 100 in wood supply and support industries.** \$10 million in payroll, wood purchase and other expenditures annually.
  - <http://biomassmagazine.com/articles/5579/production-begins-at-largest-wood-pellet-plant-in-northeast-u-s>



# SIREN Toolbox



# How did SEN model it?

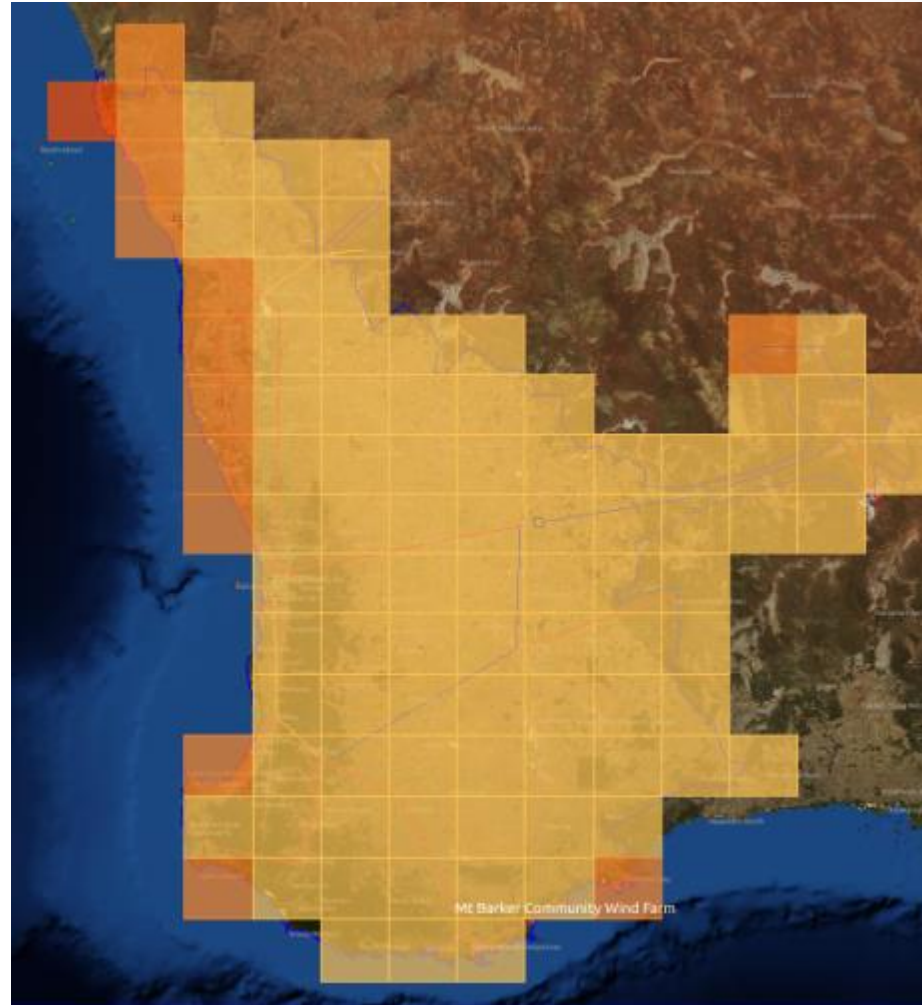
## SIREN

- Sophisticated computer model with simple user interface
- Users explore potential location and scale of renewable energy sources (stations, storage, transmission) to meet electricity demand
- Can be based upon existing network



# Weather affects generation

- Weather data that reflects actual weather conditions of the past enables any model to better map actual load demand
  - For example, hot weather increases air conditioning load
- NASA MERRA data
  - NASA reanalysed satellite data
  - Worldwide solar and wind data





# Place and size Stations



- Click to add Station
- Simple interface to specify Station details
- Save & reload Scenarios

**SIREN - Edit station**

Name:

Technology:

Lat:

Lon:

Capacity:  MW

Area:  sq. Km

Scenario:

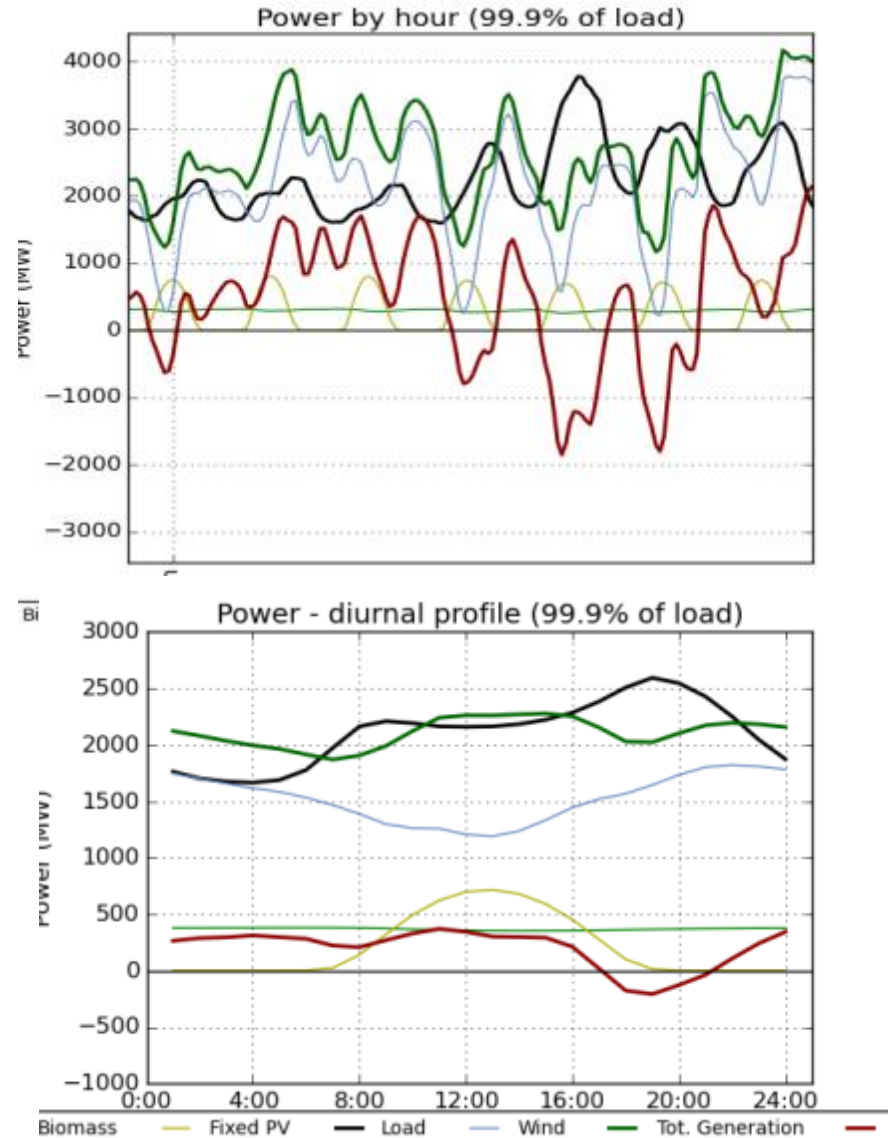
Power\_File:

Grid\_Line:



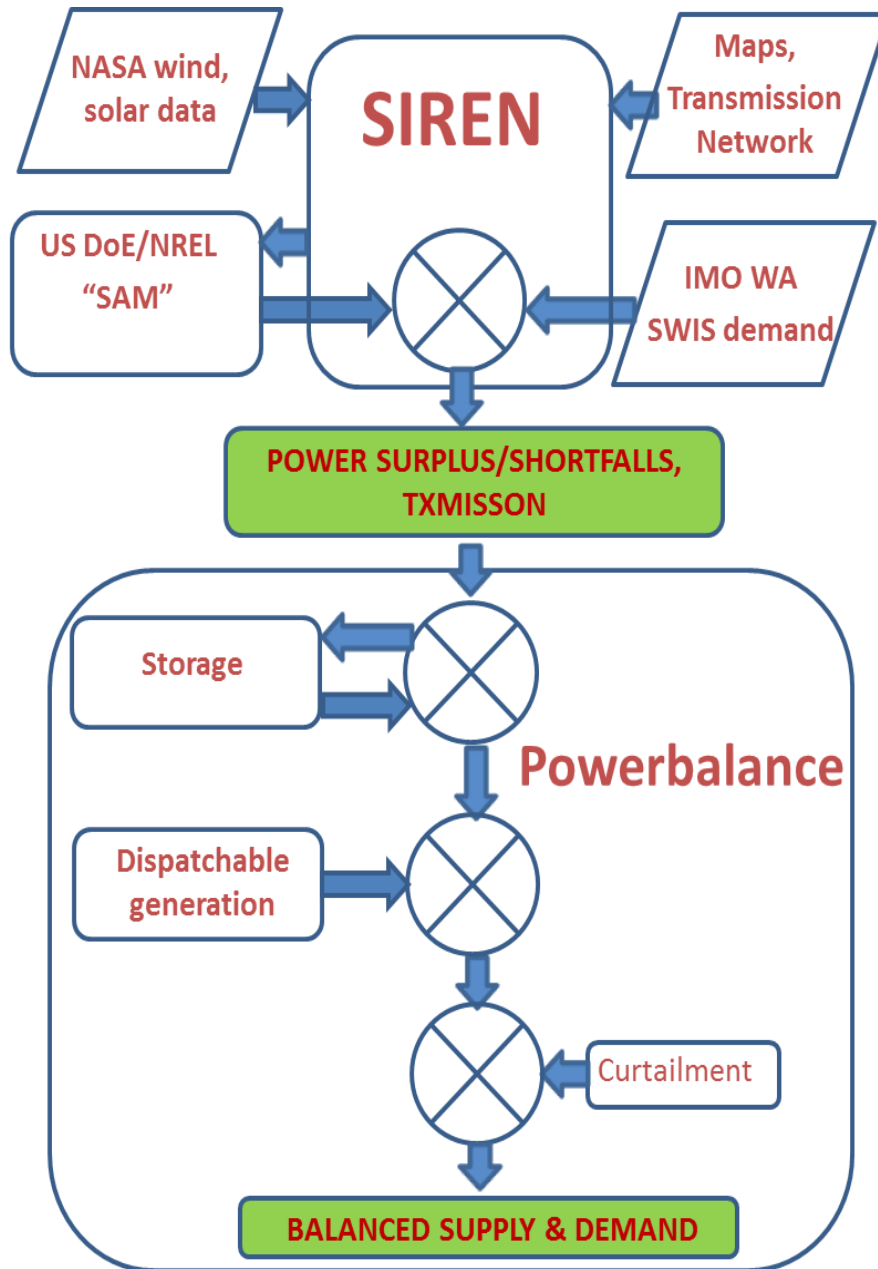
# Model Power generation

- System Advisor Model (SAM) models from US DoE National Renewable Energy Laboratory (NREL)
- Model for each station and produce combined result
- Match generation to Load
- Strong correlation (0.77) between SAM calculated generation and actual generation validates use of SAM models and MERRA data



# SIREN TOOLKIT

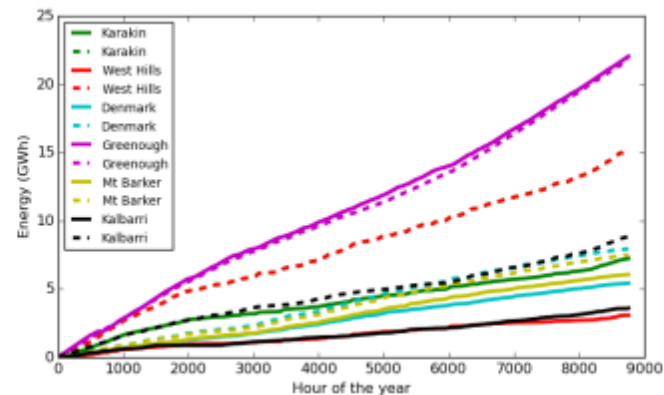
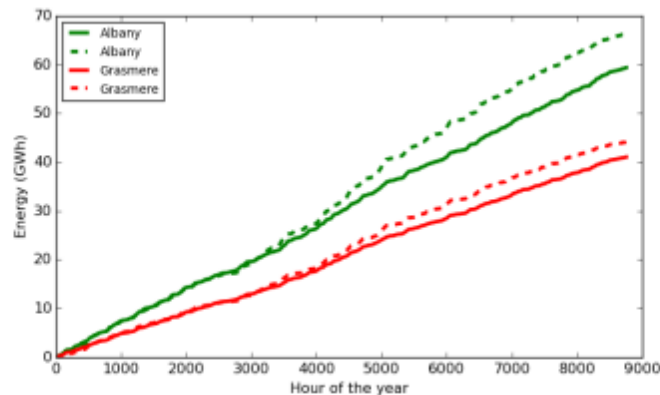
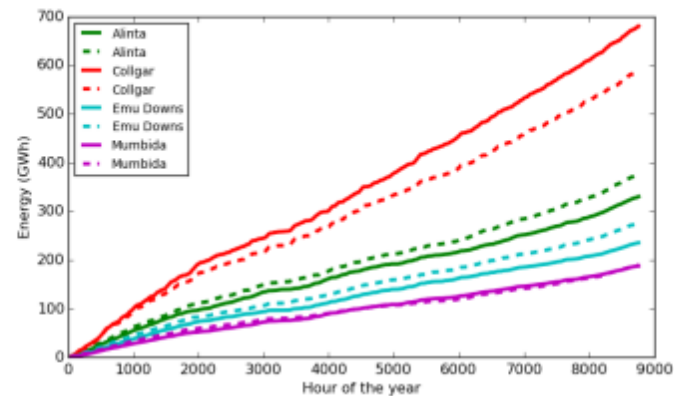
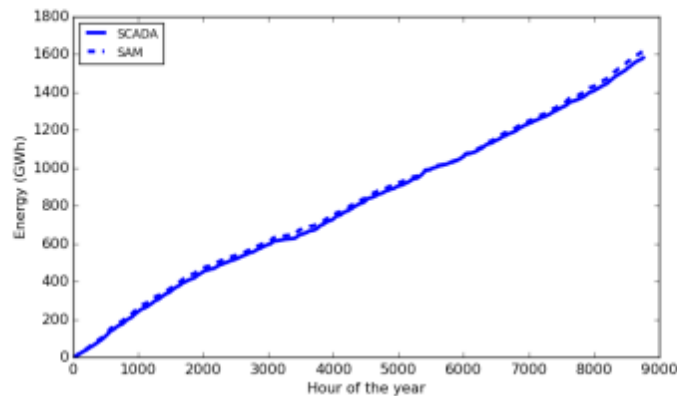
## Process Flow



# How does it compare?

- Validated SAM calculated generation with actual generation
  - Average correlation is 0.77, (0.70-0.83 for wind, 0.95 for the one utility scale PV farm)
  - Validates use of US DoE 'SAM' modules and NASA 'MERRA' data
  - Correlation of actual generation with calculated gives confidence to use this approach

SCADA versus SAM cumulative



# What is POWERBALANCE?

Programmed Excel spreadsheet templates for scenario types.

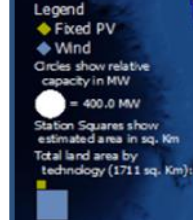
## What does it do?

- Quantifies and costs dispatchable energy generation, storage and CO2 emissions.
- Balances power with load for 8760 hours of a year.
- Enables you to complete a costed RE scenario.





Area	Technology	Capacity (MW)	CF	Generated (GWh)	Cost (\$)	Period	Shortfall
Liberty W	Wind	400.00	0.43	1,496,233	1,440,000	1 2029-01-01 00:00	11,571.00
Badgingarra W	Wind	400.00	0.33	1,163,108	1,140,026	2 2029-01-01 01:00	57,166.00
Bunbury PV	Fixed PV	200.00	0.25	443,464	435,571	3 2029-01-01 02:00	69,177.00
CLewin W	Wind	400.00	0.47	1,657,807	1,605,114	4 2029-01-01 03:00	-35,144.00
Collie E W	Wind	400.00	0.33	1,157,661	1,132,614	5 2029-01-01 04:00	-298,788.00
Collie E WIND	Wind	400.00	0.33	1,157,661	1,131,895	6 2029-01-01 05:00	-547,600.00
Gtn PV	Fixed PV	400.00	0.26	909,861	878,354	7 2029-01-01 06:00	-827,133.00
Harvey W	Wind	400.00	0.33	1,149,008	1,131,233	8 2029-01-01 07:00	-618,033.00
Kalgoorlie-Boulder PV	Fixed PV	200.00	0.26	454,905	439,749	9 2029-01-01 08:00	-103,099.00
Katanning W	Wind	500.00	0.34	1,494,960	1,453,361	10 2029-01-01 09:00	498,899.00
Kojonup Station	Wind	200.00	0.34	650,300	579,232	11 2029-01-01 10:00	1,094,233.00
Lancelin W	Wind	400.00	0.38	1,519,234	1,300,005	12 2029-01-01 11:00	1,432,600.00
Merredin W	Wind	500.00	0.33	1,319,989	1,200,000	13 2029-01-01 12:00	1,755,222.00
Morawa PV	Fixed PV	200.00	0.26	422,721	410,500	14 2029-01-01 13:00	1,887,800.00
N Metro PV	Fixed PV	1,000.00	0.26	2,285,171	2,260,000	15 2029-01-01 14:00	1,830,633.00
Oake W 2	Wind	400.00	0.38	1,337,111	1,289,190	16 2029-01-01 15:00	1,589,022.00
Oakagee W	Wind	400.00	0.38	1,337,111	1,288,515	17 2029-01-01 16:00	1,206,700.00
S Metro PV	Fixed PV	800.00	0.26	1,828,582	1,812,867	18 2029-01-01 17:00	628,277.00
Southern Cross PV	Fixed PV	200.00	0.25	438,095	424,750	19 2029-01-01 18:00	278,777.00
Walkaway W	Wind	400.00	0.42	1,456,842	1,400,000	20 2029-01-01 19:00	-230,944.00
Wellstd W	Wind	400.00	0.38	1,332,411	1,270,124	21 2029-01-01 20:00	-717,455.00
Wellstd W 2	Wind	400.00	0.38	1,332,411	1,270,000	22 2029-01-01 21:00	-1,118,299.00
	Fixed PV	1,000.00		6,782,799	6,665,276	23 2029-01-01 22:00	-1,384,950.00
	Wind	5,000.00		19,308,394	18,753,239	24 2029-01-01 23:00	-1,493,333.00
Total		9,000.00		26,091,193	25,418,515	25 2029-01-02 00:00	-1,442,633.00
						26 2029-01-02 01:00	-1,344,990.00
						27 2029-01-02 02:00	-1,254,000.00
						28 2029-01-02 03:00	-1,164,000.00



# 1 Siren

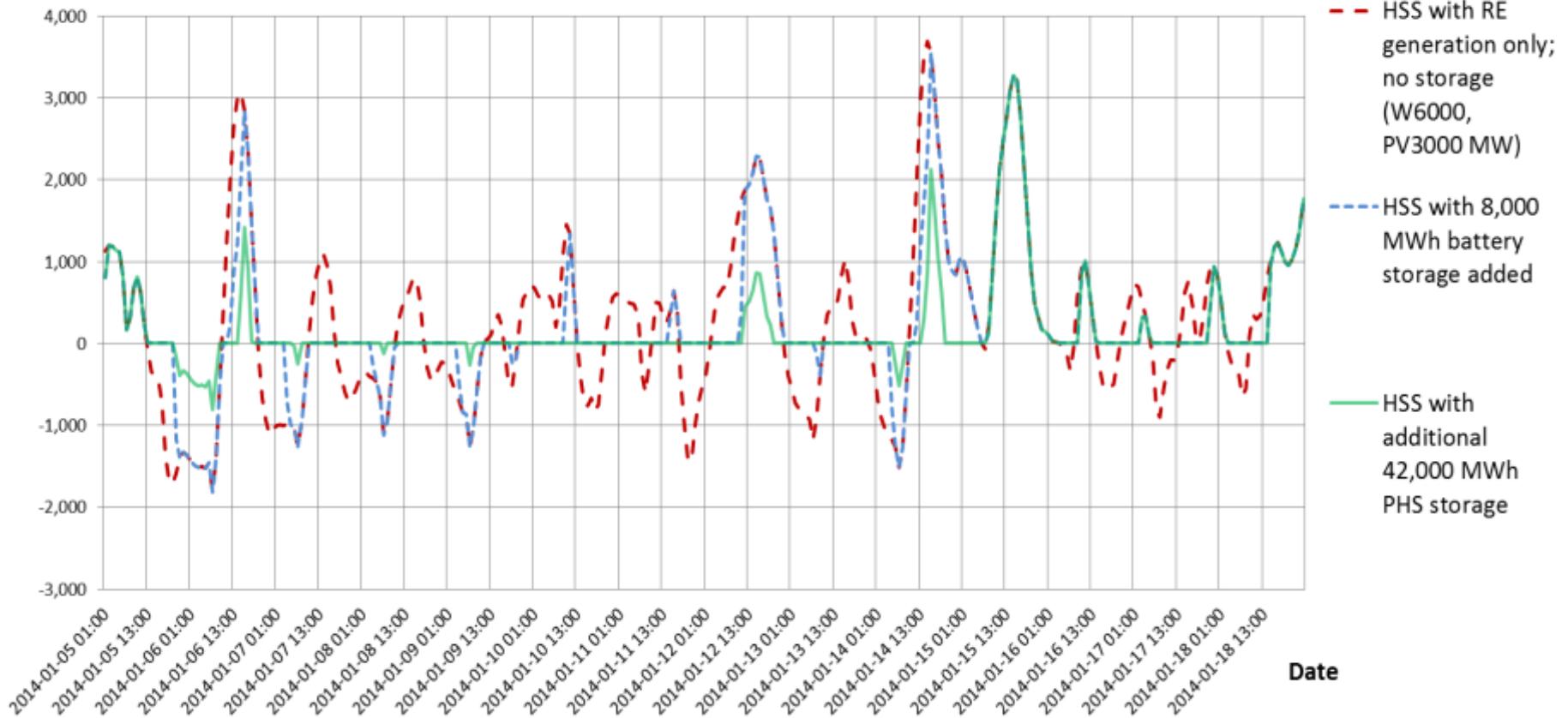
8760 hr/

[illegible]

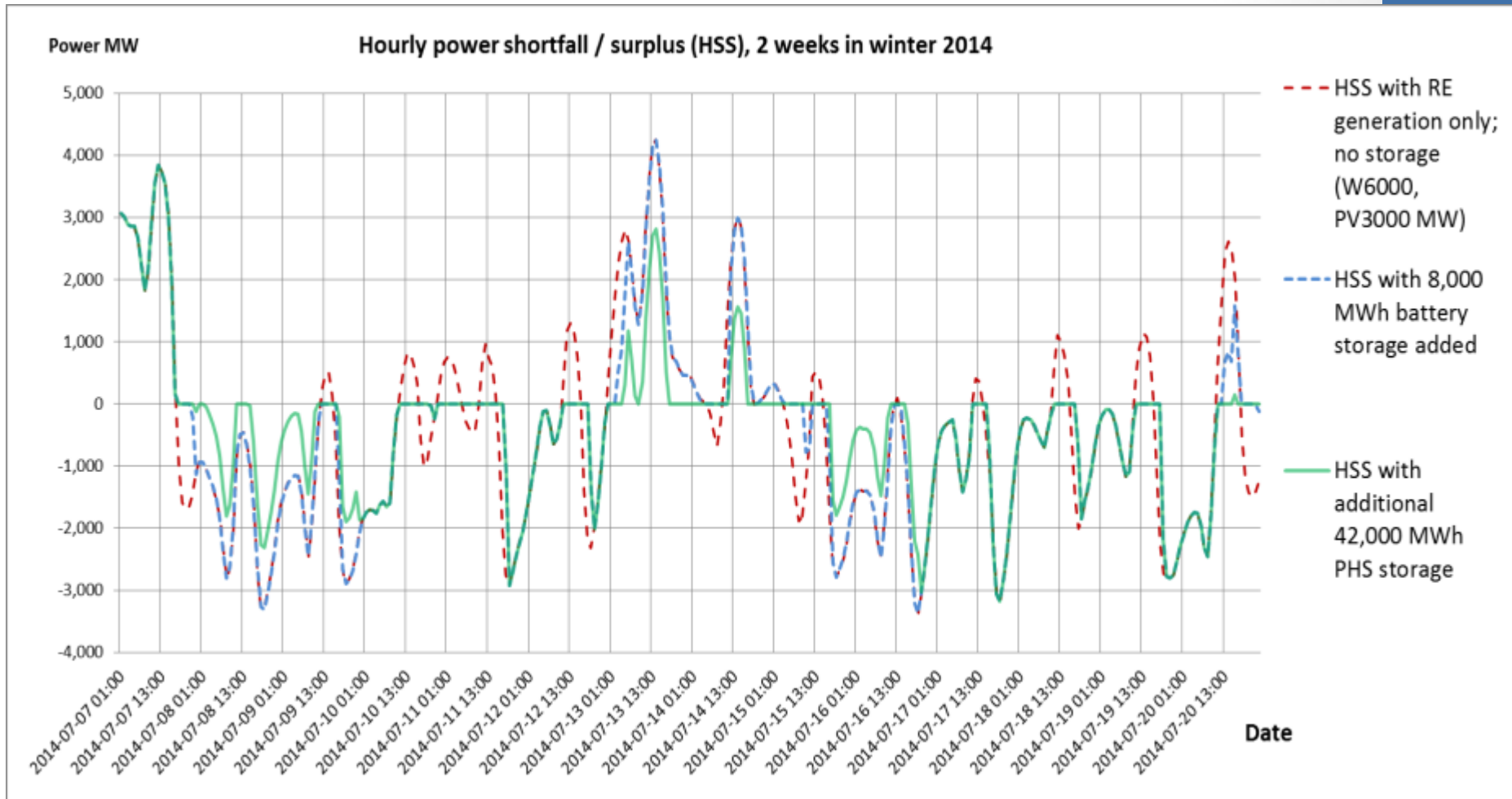


Power MW

### Hourly power shortfall / surplus (HSS), 2 weeks in summer 2014



## Deep, prolonged shortfalls in RE generation.



- To provide enough energy for all shortfall periods during winter, storage would have to be increased 100-fold, increasing LCOE to >\$500/ MWh.
- OCGT's are the most cost effective generation capacity to cover periods of low wind and sun.



# Replacement of coal with wind and solar PV generation can be achieved by 2021

SEN's modelling shows that all coal generation can be replaced with:

- 2500 MW of wind
- 1700 MW of solar PV

Competitive with current grid generation LCOE  
\$114/MWh; **\$96/MWh with RET**

## A vision for Collie in the next 5 years

- 1000 – 1400 MW of Wind east and west of Collie (5 - 7 Collgar windfarms)
- Up to 200 MW of utility scale PV
- CO2 emissions reduced to 38% of current

CO2 emissions down by >60% from 11.7 to 4.5 million tonnes (reduction of 7.2 million tonnes)



Coal is on the way out, too polluting; too carbon intensive. The aging power stations are due for replacement:

<b>COAL-FUELLED GENERATORS</b>	<b>Owner</b>	<b>Yr built</b>	<b>Retire</b>	<b>Retmt age, yrs</b>	<b>MW capacity</b>
MUJA AB (G1, G2, G3, G4)	Synergy	1965	2016	51	220
Muja C (G5, G6)	Synergy	1981	2017	36	385
Muja D G7, G8)	Synergy	1985	2019	34	422
Collie	Synergy	1990	2019	29	317
Bluewaters 1	Sumitomo	2009	2029	20	217
Bluewaters 2	Sumitomo	2009	2030	21	217

On economic grounds , even if pollution is ignored, the old coal power plants should be closed at 30 years of age (design life) or before and replaced with new wind & PV generation.



# STORAGE

**Economic to store 5 – 15% of the cheap renewable energy for use at night**

‘Behind the Meter’  
Batteries



Concentrating Solar  
Thermal with Molten Salt  
Storage



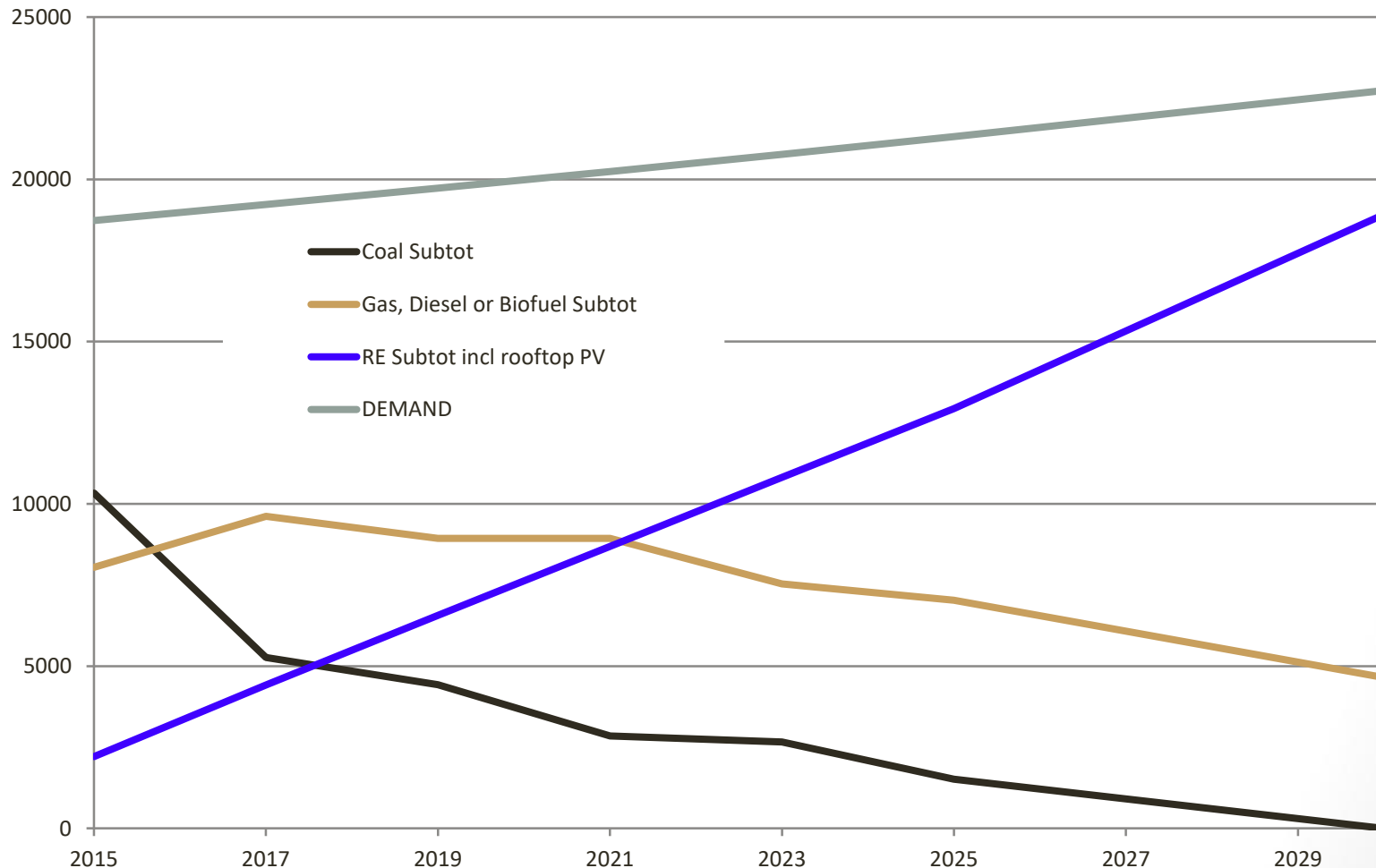
Pumped Ocean  
Hydro



# 'Roadmap' to the Future SWIS?

RETIRE COAL - REPLACE WITH RENEWABLES

## Electricity Generation & Demand, MWh





# What might a modern renewable electricity generation system for WA look like? One scenario achievable by 2030:

<b>Percent renewable energy</b>	<b>91.0%</b>
<b>CO2e million tonnes;</b>	<b>1.32</b>
<b>CO2 % of BAU</b>	<b>9.88%</b>

Energy source	% of total annual grid energy demand	LCOE \$/MWh (BREE AETA 2025)	LCOE \$/MWh (likely 2020)	MW power capacity	MWh storage capacity
Wind	59.3%	\$85	\$77	5800	n/a
PV	17.6%	\$80	\$75	2400	n/a
<i>(Surplus Wind and PV)</i>	17.1%				
CST	5.4%	\$165	\$140	500	7000
BM Battery	1.4%	\$40	\$40	n/a	2000
PHS	0.0%	\$0	\$0	0	0
<b>Biomass / MS (at Collie)</b>	<b>7.4%</b>	<b>\$249</b>	<b>\$249</b>	<b>400</b>	<b>6400</b>
OCGT	9.0%	\$219	\$219	2200	n/a
<b>Weighted average LCoE (\$/MWh) with zero C price, zero RET</b>		<b>\$137</b>	<b>\$128</b>	<b>Plus transmission \$6-7/ MWh</b>	



# Key policies for renewable electricity

1. Keep Western Power government owned.
2. Enable WP to provide grid storage to manage and facilitate RE.
3. Balancing generators (OCGT, biomass and grid storage) should all be owned by Govt. (Synergy) to prevent price gouging during shortfall periods by corporate power oligopoly.
4. Secure gas supply agreements and pipeline capacity to cover peak gas demand for electricity generation.
5. An Office and Renewable Energy answering directly to Dept. of Premier and Cabinet to plan RE transition, with WP and Synergy.
6. Supply tariff and feed-in tariff incentives for behind the meter battery storage and rooftop solar.
7. Reform electricity market - power purchase agreements with 'contracts for difference' enabling private industry to supply all wind, solar PV and solar CST generation at stable prices.
8. Incentives and assistance for biomass production and renewable fuel industries.
9. Legislation to ensure biomass for energy is not harvested from native forest.



# Biomass generation and wood pellet industry for Collie in 10 years?



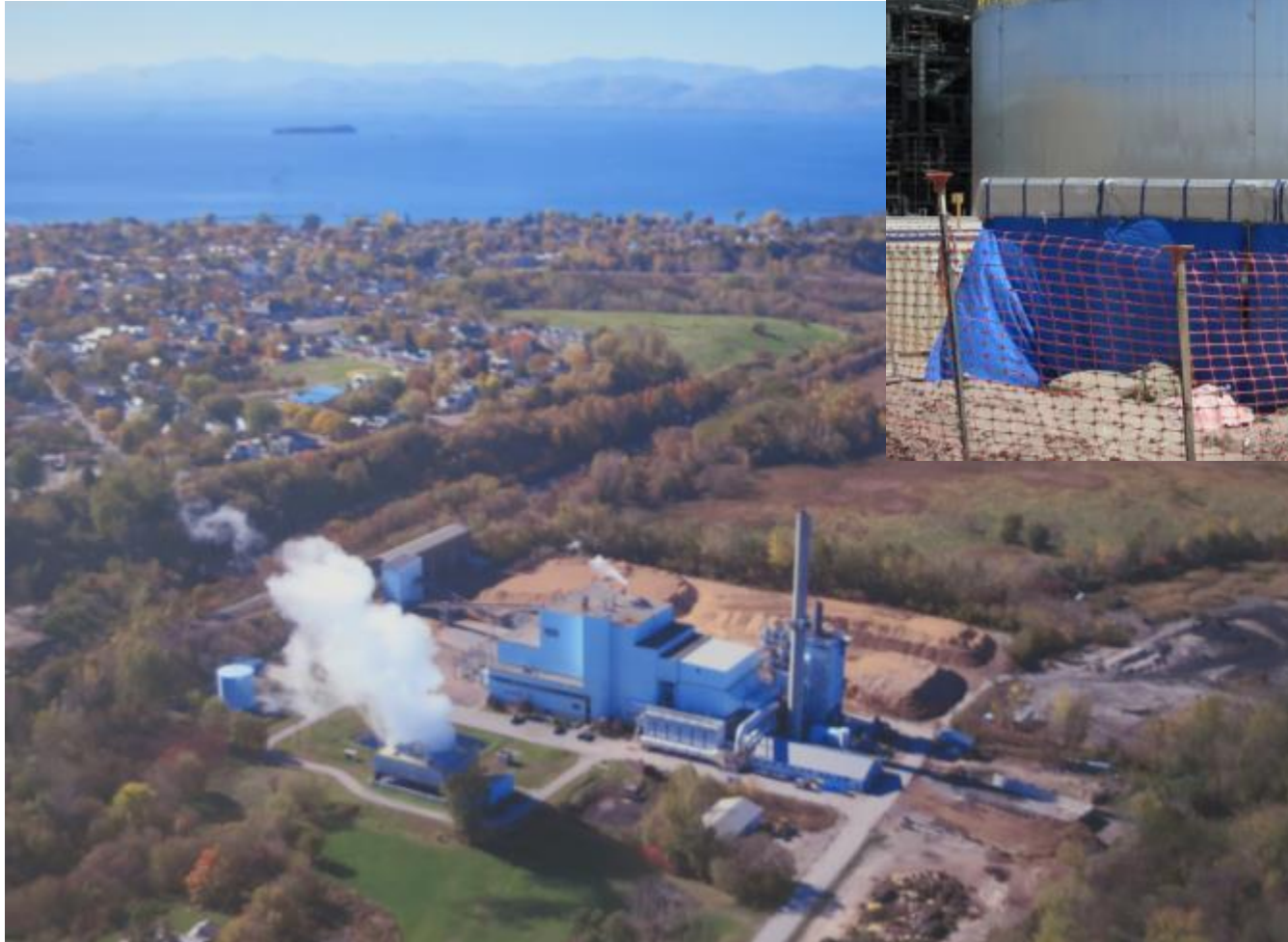
# A future for Collie

- Short term 5 year
- Package for coal workers – options for redundancy, retraining in wind installation, mine rehabilitation, tourism
- Installation hub – construction base for > 1000 MW of wind generation within 100 km of Collie
- Possible tower fabrication and construction
- Possible in the longer term (10 years)
- Biomass power generation and pellet industry; rail to Wagin / Katanning for biomass produced in the 400-600 mm southern agricultural region



# Biomass thermal power generation with Molten Salt storage. Up to 400 MW could be located at Collie *(using plantation and waste biomass only)*

50 MW McNeil Biomass  
Power station Vermont, US



Molten salt tank  
at 110 MW  
Concentrating  
Solar Thermal  
power station in  
Nevada



## WA Biomass resources (*Mt = million dry tonnes*)



Biomass from Oil Mallee “Alleys”  
on 10 % of dryland farms 3.6 Mt  
10% of the Gt Southern Region  
alone would produce enough (1.2  
Mt) to generate 10% of projected  
2029 electricity demand.

*Note: need to legislate no biomass harvest  
from state forests*



Wood waste - pine and blue gum  
plantations, and municipal  
combustible waste – >1 Mt

Cereal straw – up to 1  
Mt (wheat belt )





## Oil mallee - a coppicing crop for biomass energy: electricity generation and wood pellets for export



120 -140 km of new rail  
Collie to Wagin or  
Katanning. Cost \$360 –  
400 million. To transport  
1.2 million tonnes\* of  
woodchips for a 400 MW  
power station plus 0.2  
million tonnes for wood  
pellet exports. (*\*seven  
5,000 tonne trains per day*)



Harvester cuts coppiced trees  
at ground level, chops  
biomass to size, and chutes it  
into a mobile hopper, which  
conveys it to road trucks.  
(*Photo: courtesy John Bartle*)



# Additional slides (to illustrate FAQ's)



[http://www.sen.asn.au/modelling\\_overview](http://www.sen.asn.au/modelling_overview)

click [download here at SourceForge](#).

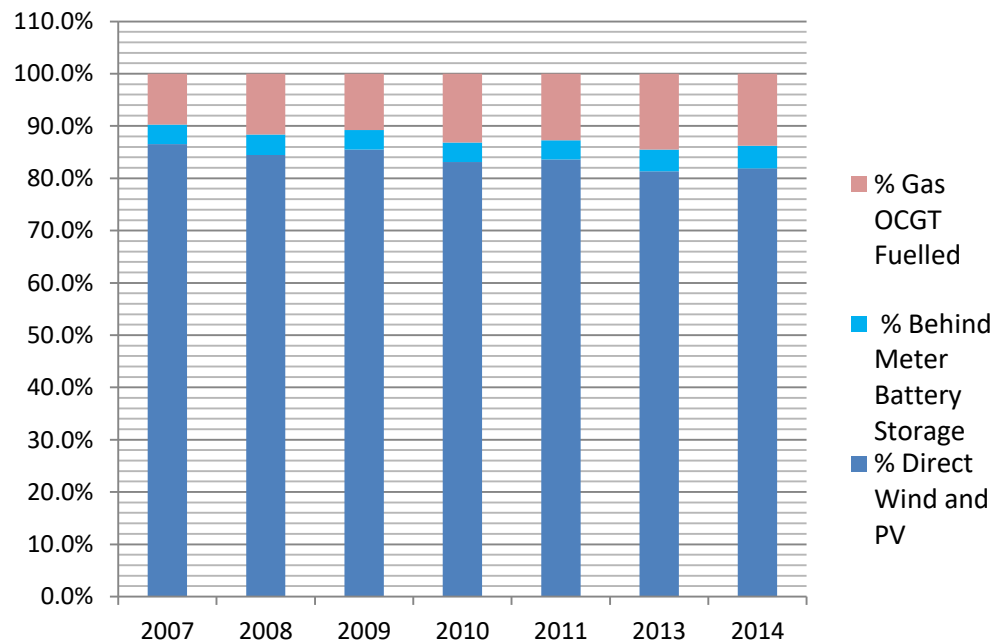
[http://www.sen.asn.au/modelling\\_findings](http://www.sen.asn.au/modelling_findings)

We can do hands-on SIREN Toolkit training workshops



**Table 8. Variation in renewable energy generation and weighted average LCOE over 7 years (Scenario Wind 6000 PV 3000 with 8000 MWh of storage)**

Year	% Direct Wind and PV	% Behind Meter Battery Storage	% Gas OCGT Fuelled	% Renewable Energy	Weighted average LCOE
2007	86.5%	3.8%	9.7%	90.3%	\$122
2008	84.5%	3.9%	11.7%	88.3%	\$125
2009	85.5%	3.7%	10.8%	89.2%	\$127
2010	83.1%	3.7%	13.1%	86.9%	\$127
2011	83.6%	3.7%	12.7%	87.3%	\$124
2013	81.4%	4.1%	14.5%	85.5%	\$129
2014	81.9%	4.4%	13.7%	86.3%	\$128



# DISPATCHABLE POWER AND STORAGE COSTING

TECHNOLOGY	STORAGE Fixed costs: \$ per MWh storage capacity per year	GENERATION Fixed costs: \$ per MW power capacity per year	\$Variable (Fuel +VOM) per MWh sent out
Behind Meter Battery Storage	168,356		0
Behind Meter Battery Storage (nominal subsidy)			40
Battery Storage On Grid (Li-ion, 1 MW scale)	217,498		6
CST MS (Molten Salt storage component)	6,741		0
PHS (Storage component)	5,111		0
Concentrated Solar Thermal (CST) without storage		529,138	6
Pumped Hydro (PHS) without storage		240,995	5
Open Cycle Gas Turbine (OCGT) using Gas		87,121	128
OCGT using bio-oil fuel		87,121	371
Gas co-firing added to MS Storage		112,795	128
Biomass Waste co-firing added to MS Storage		374,928	30
Biomass Oil Mallee co-firing added to MS (CS)		374,928	66
Waste fired Thermal		749,856	20

‘Disp. Power Costs’  
tab

Biomass co-firing CO2e: cost/t tCO2e/MWh	Max shortfall after CST / MS	Bio-oil fuelled OCGT balancing generation	Bio-oil OCGT CO2e: cost/t tCO2e/MWh
30	-2,343		30
0.13			0.28
		1800	30
		875,957	
11,561,266		481,798,030	7,358,040
		550	8.4
		0.06	
Shortfall /surplus 3	OCGT bio-oil-fuelled balancing	Suplus /shortfall 4 remaining	Shortfalls to be load curtailed

‘RE LCOE; EF's tables’  
tab

Carbon Price \$/tCO2e	30	
Commercial Technologies	Median Carbon g CO2el kWh	Reference
Coal	820	IPCC Annex iii (median)
Coal sub-critical SWIS (Blue Water)	920	Griffin Power, 2008
Gas - combined cycle	490	IPCC Annex iii (median)
Gas - OCGT	515	IPCC Annex iii (median)
Bio-oil - OCGT	280	Steele et al, 2012
Biomass - dedicated	130	IPCC Annex iii (low)
Solar PV utility	48	IPCC Annex iii (median)
Solar PV rooftop	41	IPCC Annex iii (median)
Conc. Solar thermal	27	IPCC Annex iii (median)
Hydropower	24	IPCC Annex iii (median)
Wind onshore	11	IPCC Annex iii (median)
Wind offshore	12	IPCC Annex iii (median)
Nuclear	12	IPCC Annex iii (median)
Pre-commercial technologies		IPCC Annex iii (median)
Coal oxyfuel CCS	160	IPCC Annex iii (median)
Coal CCS	220	IPCC Annex iii (median)
Coal IGCC	200	IPCC Annex iii (median)
Gas CC, CCS	170	IPCC Annex iii (median)



## Dispatch order – most to least capital intensive

1. Wind and solar PV
2. BM battery will be used first by consumers regardless of grid dispatch orders.
3. Thermal biomass generation (\$750,000/MW/yr.
4. Solar CST with MS (500,000/MW/yr.)
5. Additional MS storage (\$7,000/MWh/yr.)
6. Co-firing of MS storage (\$350,000 – \$400,000 per MW/yr.)
7. PHS (\$241,000/MW/yr.)
8. Additional PHS (\$5,000/MWh/yr.)
9. OCGT generation is always dispatched last ( \$90,000 per MW capacity) Highest fuel cost (\$128/MWh for gas and \$371/MWh for bio-oil
10. Load reduction by demand side management (DSM)





# Potential Biomass Resources in WA

Dry biomass (oil mallee) from 10% of WA grain belt (0.1*14 million ha * 2.6t / ha/ yr.)*	3,640,000 tons/yr.
Straw and wood (plantation) waste**	2,000,000 tons/yr.
Annual BIOMASS FUELED ELECTRICITY that could be generated @ (1.7 MWh/dry ton)	9600 GWh
Total annual generation WA South West Grid 2029	23,000 GWh
Potential TOTAL BIOMASS FUELED ELECTRICITY % of total energy sent out in 2029	42%



# Thermal generation – fuel cost comparison

Resource	delivered cost / dry tonne	Energy content GJ/dry tonne*	Energy content MWh/ dry tonne	Fuel cost \$ / MWh electricity generated at 33% efficiency
Oil mallee	\$98	19.5	5.4	6.0
Straw	\$104	15.1	4.2	8.3
Plantation wood waste	\$30	16	4.4	2.3
(Coal - Collie)	\$45	21	5.8	2.5
(Gas - WA domestic) **	\$223	53.6	14.9	5.0
(Gas - LNG export price 2011)	\$523	54.6	15.2	11.5

\* Dry tonne is 10% moisture

\*\* BREE, 2012. Gas Market Report





## Open Cycle Gas Turbines

5- 15% of energy

- Energy cost \$200 - \$550 / MWh.
- Dual fuel – gas cheaper than diesel or bio-oil. (Industry for Collie?)
- OCGT 'Fleet' of 30 – 60
- In Metro and industrial areas.
- 1 in 6 equipped to run as synchronous compensators.



# KEY FINDINGS

- 1. A modernized SWIS renewable electricity generation system would cost no more than renewing the existing coal & gas system.**

## 85-90% renewable energy

- 55-65% wind 20-30% PV
- Storage – 5 - 10%; surplus wind, PV.
- Molten Salt or Pumped hydro; some BM battery
- 10 - 15% gas OCGT
- CO2 emissions 10-15% of BAU

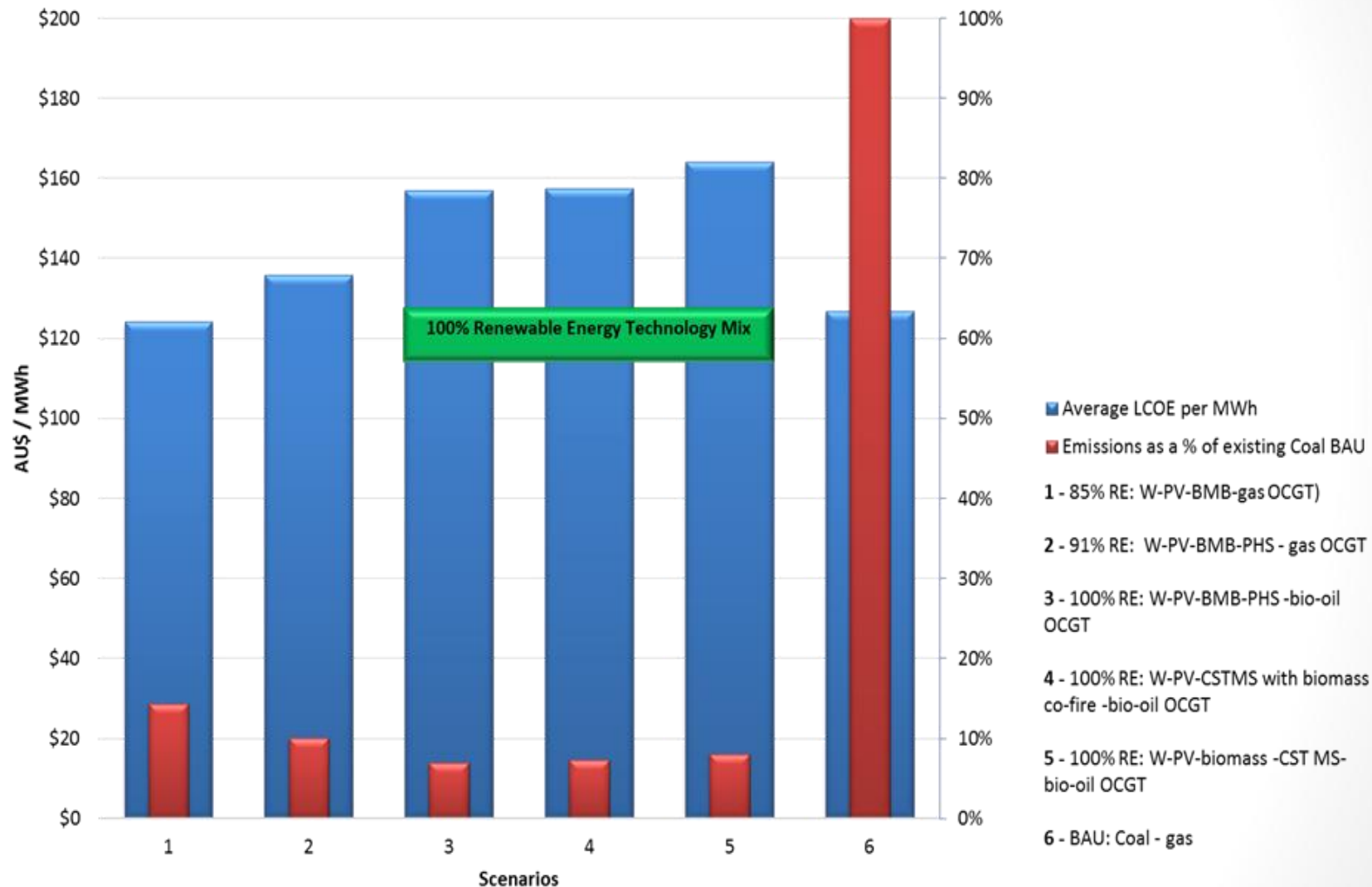


## 2. 100% Renewable Electricity is achievable

- 3 scenarios (3-5 in Study) presented as examples.
- About 50-65% wind, 15-25% PV for primary energy source.
- CO2 Emissions – 7 – 8 % of BAU.
- Cost \$155 – 165 / MWh; 3-4c/kWh more than renewing the existing coal – gas system.
- Have large scale grid storage – CST MS or PHS – 5- 8% of energy goes through storage.
- Bio – fuelled OCGTs for dispatchable generation.



# Scenarios – Cost and Emissions Comparison



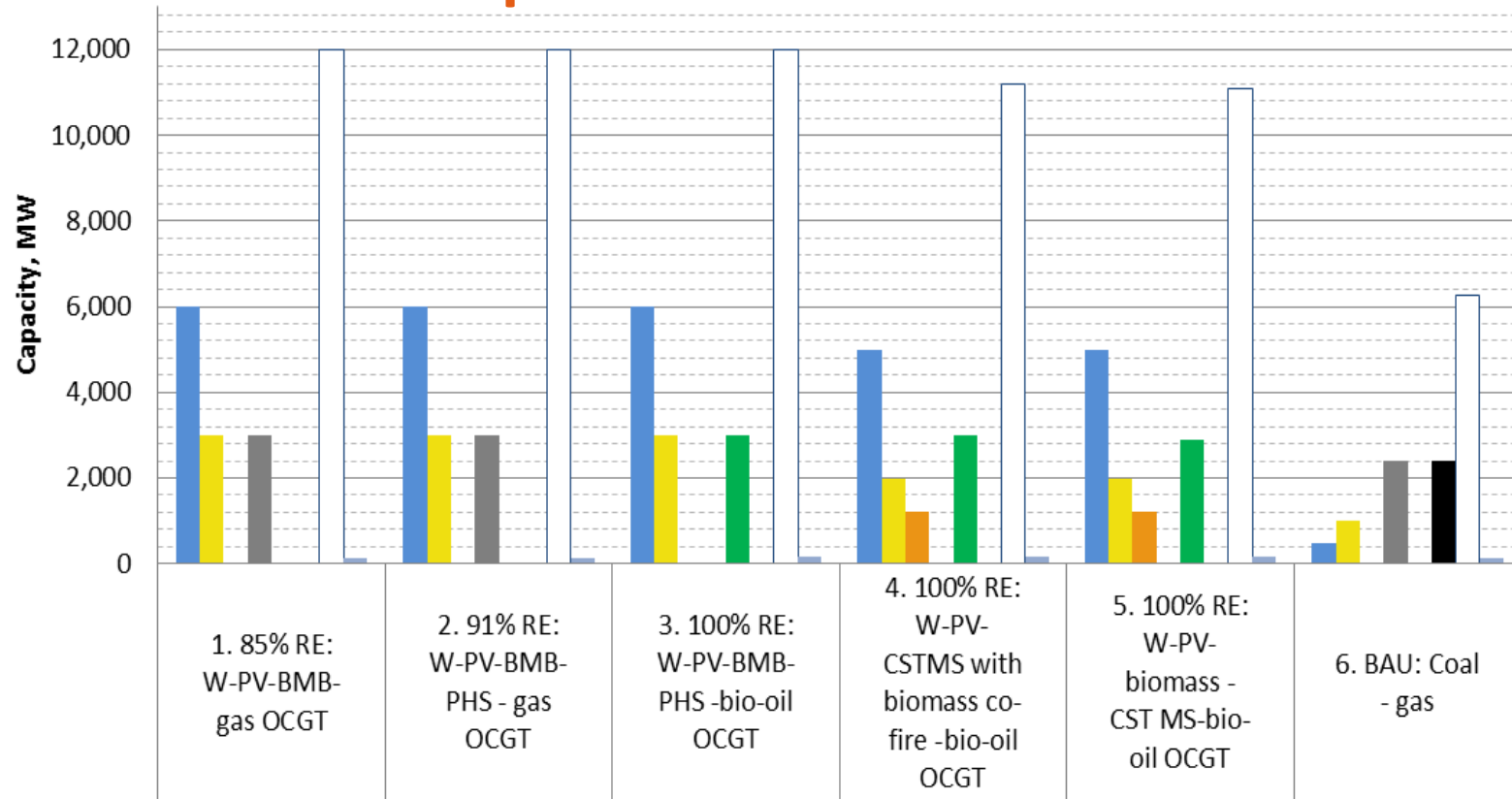


*Table 10. Summary of scenario costs and carbon emissions.*

Scenario	Average LCoE (\$/MWh)	Emissions (% of BAU Scenario 6)	Total Emissions (ktCO <sub>2</sub> e)	Cost of emissions reduction from BAU (\$/tCO <sub>2</sub> e)	% surplus generation	Annual energy cost (\$m)	LC of new transmission lines (\$/MWh)
Scenario 1: 85% RE	\$128	16.9%	2,266	-\$6	21.8%	\$2,977	\$7 – 9
Scenario 2: 91% RE	\$138	11.9%	1,595	\$17	14.0%	\$3,248	\$7 – 9
Scenario 3: 100% RE	\$159	8.2%	1,095	\$57	14.0%	\$3,749	\$7 – 9
Scenario 4: 100% RE	\$160	8.6%	1,158	\$59	20.7%	\$3,763	\$7 – 9
Scenario 5: 100% RE	\$165	9.4%	1,256	\$70	23.6%	\$3,902	\$7 – 9
Scenario6: BAU	\$129	100.0%	13,391	\$30	0.0%	\$3,056	\$0



# Scenario Comparisons



Wind	6,000	6,000	6,000	5,000	5,000	480
Solar PV	3,000	3,000	3,000	2,000	2,000	1,000
Solar CST	0	0	0	1,200	1,200	0
Gas (OCGT)	3,000	3,000	0	0	0	2,400
Biomass (OCGT &/or Co-fired)	0	0	3,000	3,000	2,900	0
Coal	0	0	0	0	0	2,400
TOTAL	12,000	12,000	12,000	11,200	11,100	6,280
Weighted average LCOE \$/MWh	\$124	\$136	\$157	\$158	\$164	\$127

# Other costs and benefits

## Renewable options

- Transmission costs \$7 - 9/MWh (< 1c/kWh).
- If surplus energy from high wind scenarios were sold at \$30/MWh it would reduce cost by \$6/MWh.

## Coal

- **Carbon cost risk.** Scenario was modelled with carbon price of \$30/tCO<sub>2</sub>. If increased to real cost (about \$60/ t CO<sub>2</sub>e) **would increase** LCOE by \$25/ MWh (2.5c/unit).
- CCS not economic; not currently commercial.



# Pumped hydro ocean storage sites in WA



- 1 of 4 potential sites 40 – 70 km north of Geraldton: 230 ha, 110 – 120 m elevation, on farm land 1.2 km from ocean
- More potential sites 100 – 120 km east of Albany





# Pumped-Hydro examples



- Ludington reservoir, Lake Michigan
- 34 m deep with 110 M head, 4 km long (350 ha)
- 6 turbines, can generate 1872 MW for over 13 hours



## 170 m CST tower at Solar Reserve's 110 MW plant in Nevada





# Carbon emissions by sector: WA and Australia

2013 CARBON EMISSIONS BY SECTOR	WA emissions		Australia emissions	
	Mt CO2e	%	Mt CO2e	%
Agriculture forestry and fishing	24	39.6%	100.7	18.3%
Mining	5.3	8.7%	63.8	11.6%
Manufacturing	10	16.5%	70.7	12.9%
Electricity gas and water	10.8	17.8%	191.8	34.9%
Services construction and Transport	6.5	10.7%	65.4	11.9%
Residential	4	6.6%	57.1	10.4%
<b>TOTAL</b>	<b>60.6</b>	<b>100.0%</b>	<b>549.4</b>	<b>100.0%</b>

*Source: National Inventory by Economic Sector 2013 Australia's National Greenhouse Accounts*

*Commercial services and construction*

