Institute for Sustainable Futures

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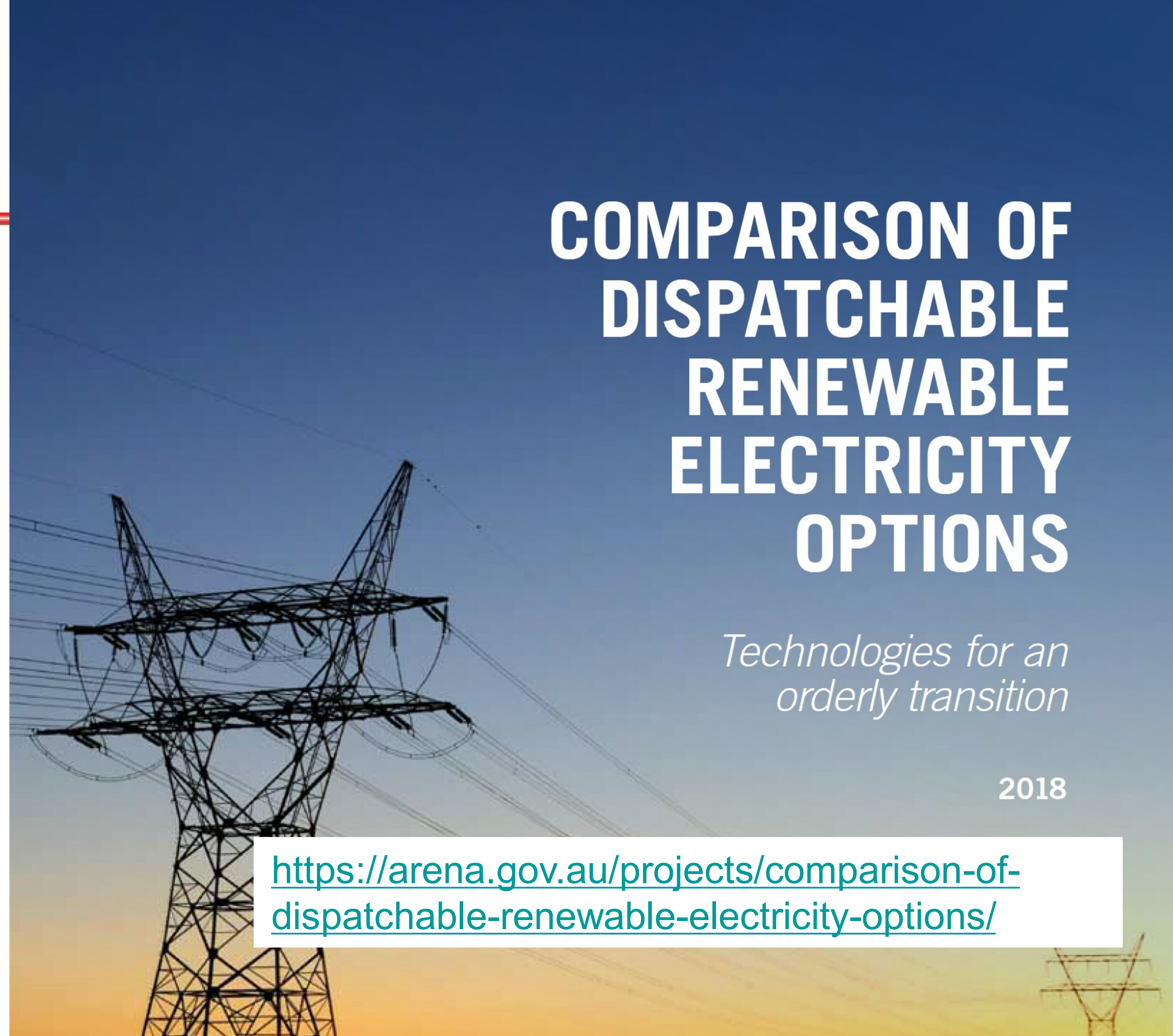
Prepared for

ARENA

Australian Government
Australian Renewable Energy Agency



https://arena.gov.au/projects/comparison-of-dispatchable-renewable-electricity-options/

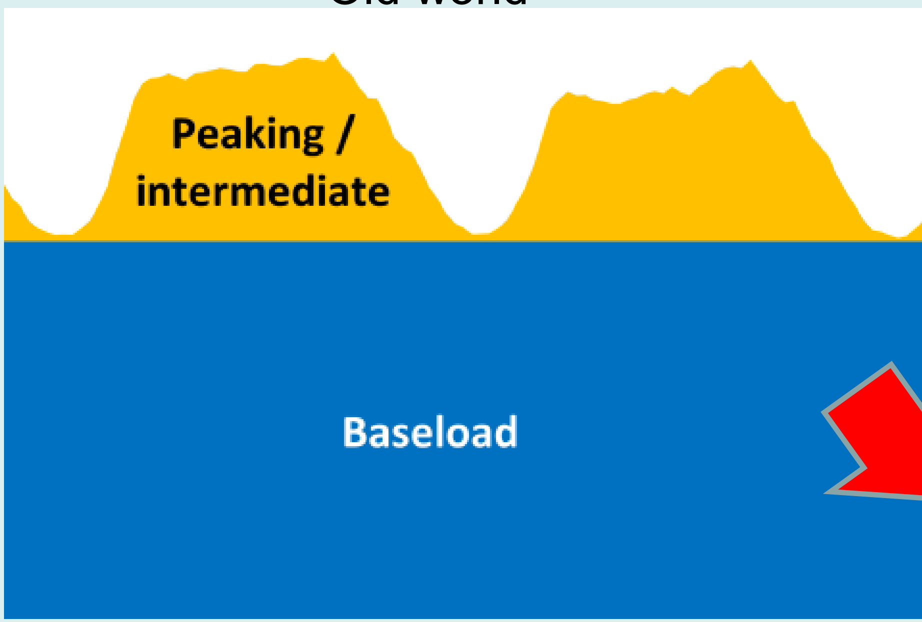
Summary of results
Australian Institute of Energy presentation, Sydney 30 October 2018

Keith Lovegrove (ITP), Muriel Watt (ITP), Jay Rutovitz (ISF), Geoff James (ISF), David Leitch (ITK), Adam Milczarek (ITP), Joe Wyder (ITP), Annie Ngo (ITP)

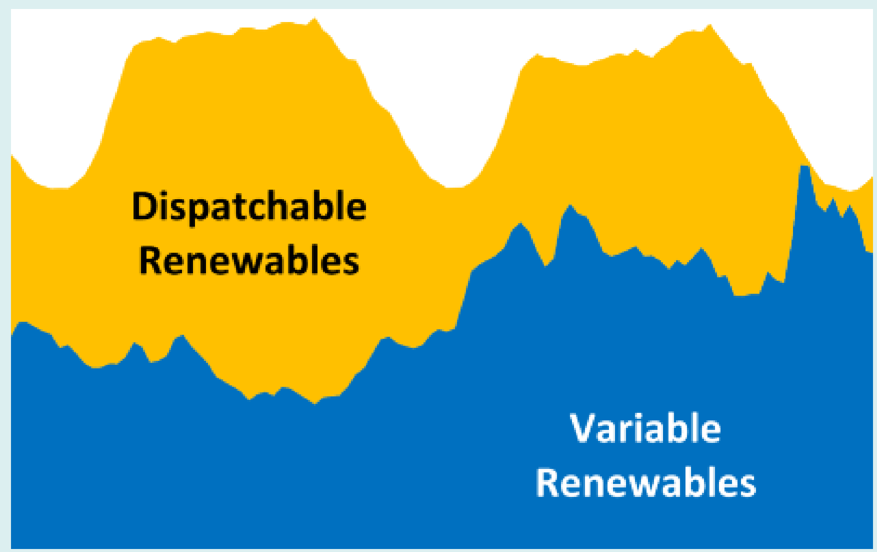
http://itpau.com.au/

Planning for a changing electricity mix

Old world



New world



We need the least cost mix

This study

- Looks at technology combinations from a whole of system viewpoint
- Examining individual technologies and combinations, to classify their characteristics, appropriate uses, costs and sensitivities in a transparent and consistent way
- Not a grid integration / NEM modelling exercise
- Not picking winners – identifying choices.
- The results should inform future grid integration studies.
- The results should help inform rational debate and policy development

Previewing Conclusions

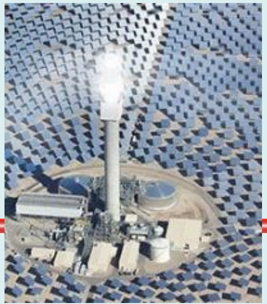
- We have multiple affordable options for firm dispatchable renewable generation over all time scales at 1.5 - 2 x cost of VRE
- Likely least cost is a mix of technologies, durations and locations
- Achievable growth rates could keep pace with coal retirements and see a large share of dispatchable RE by 2050
- Pursuing dispatchable RE options now maximises chance of least cost orderly transition.

Technologies evaluated


- Utility scale Wind or PV generation or a grid sourced mix of two in combination with:
  - Large network connected batteries
  - Pumped hydro storage
  - Hydrogen storage (electrolysers, fuel cells, and combustion)

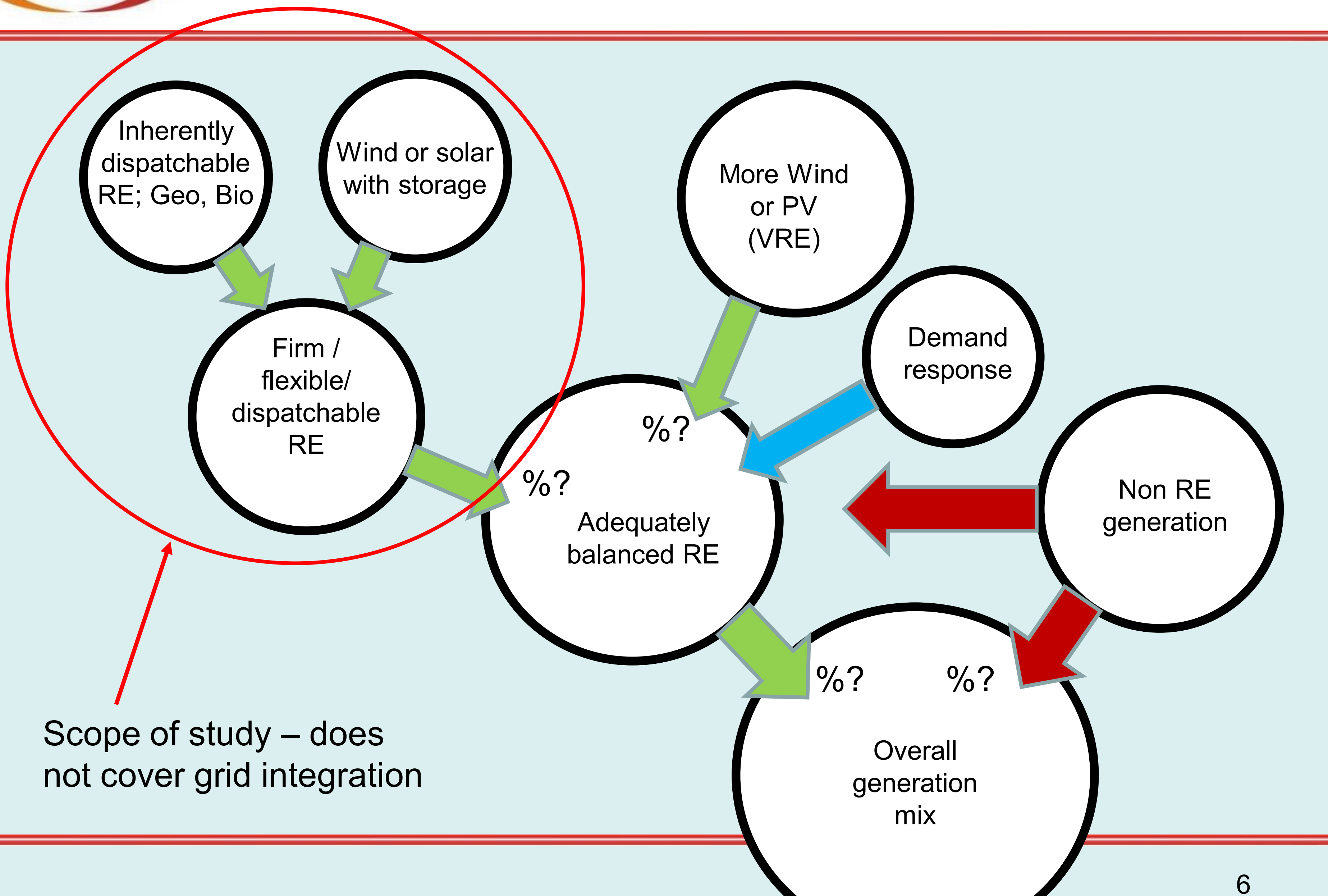

- Behind the meter PV generation and batteries
- Bio Energy
  - Anaerobic Digestion plus gas engine
  - Combustion boiler plus steam turbine


- Concentrating solar power (CSP) with thermal storage
- Geothermal generation



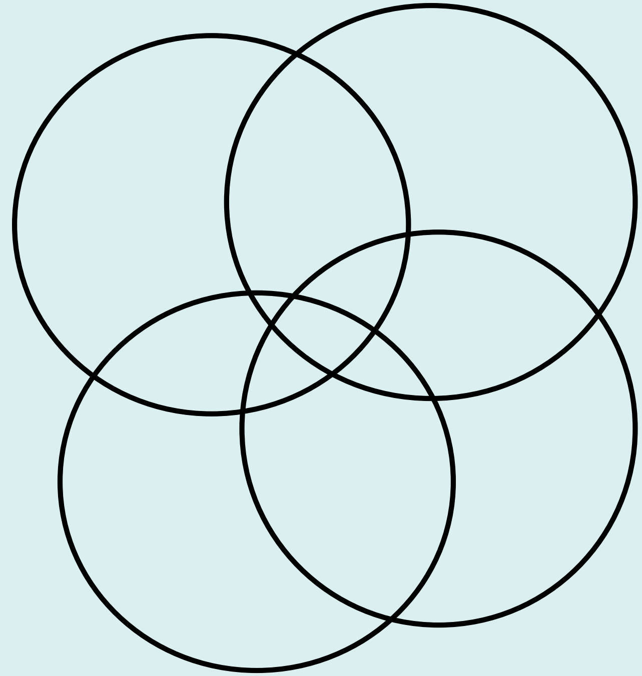
Representative technologies that are ready to be installed at utility scale

Categories of electricity generation



Some key terms used rather loosely

- Dispatchable
  - Can generate and raise or lower output on command from system operator
- Firm
  - Can guarantee a level of reliable generation for a certain period
- Scheduled
  - "A generator with an aggregate nameplate capacity of 30 MW or more is usually classified as scheduled if it has appropriate equipment to participate in the central dispatch process managed by AEMO"
- Flexible
  - Can be called on whenever needed to respond to demand changes 'rapidly'



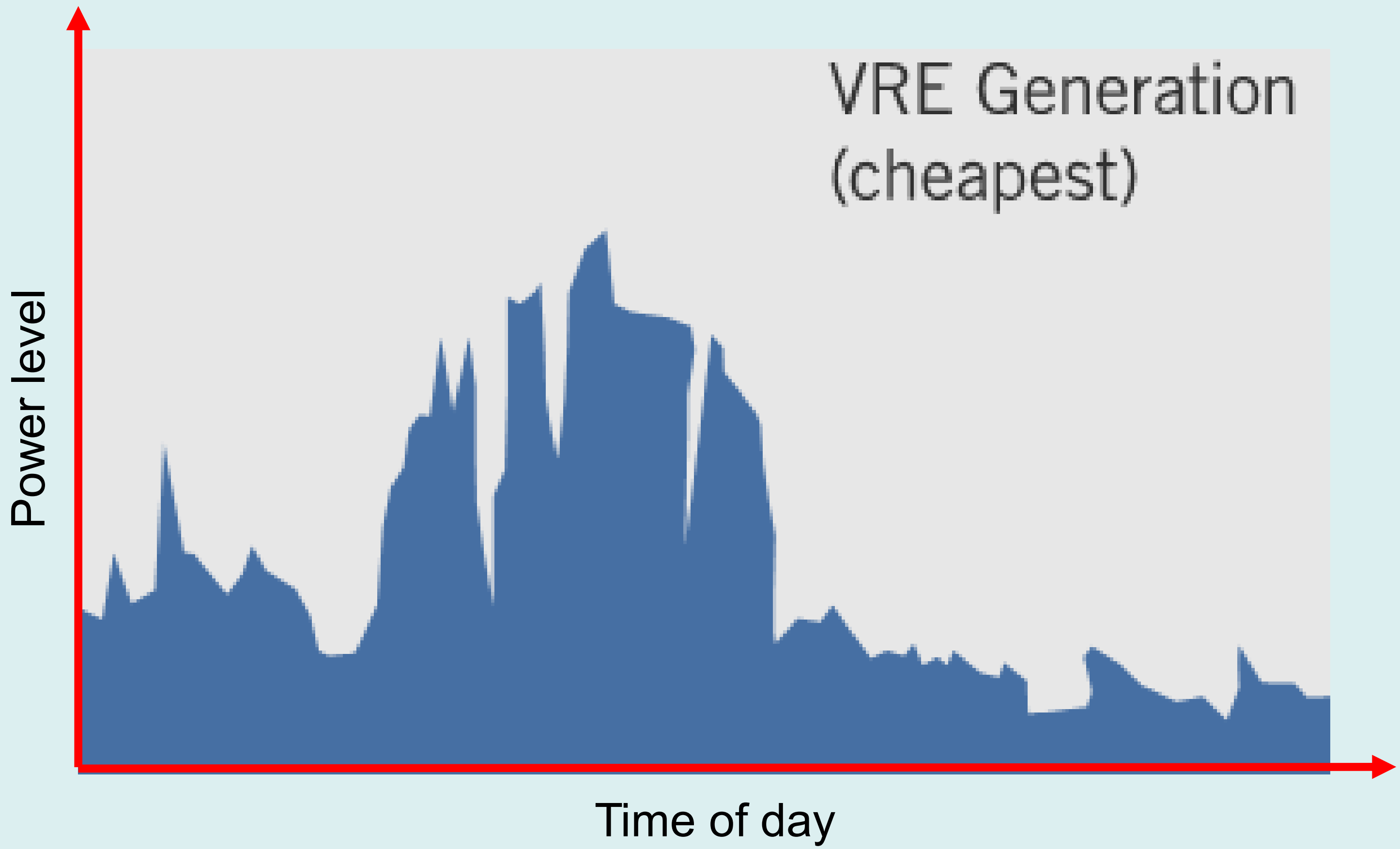
And the latest;
"Firming" really means "Balancing" in many cases of use – it doesn't mean all generation is then firm

Services from dispatchable generators

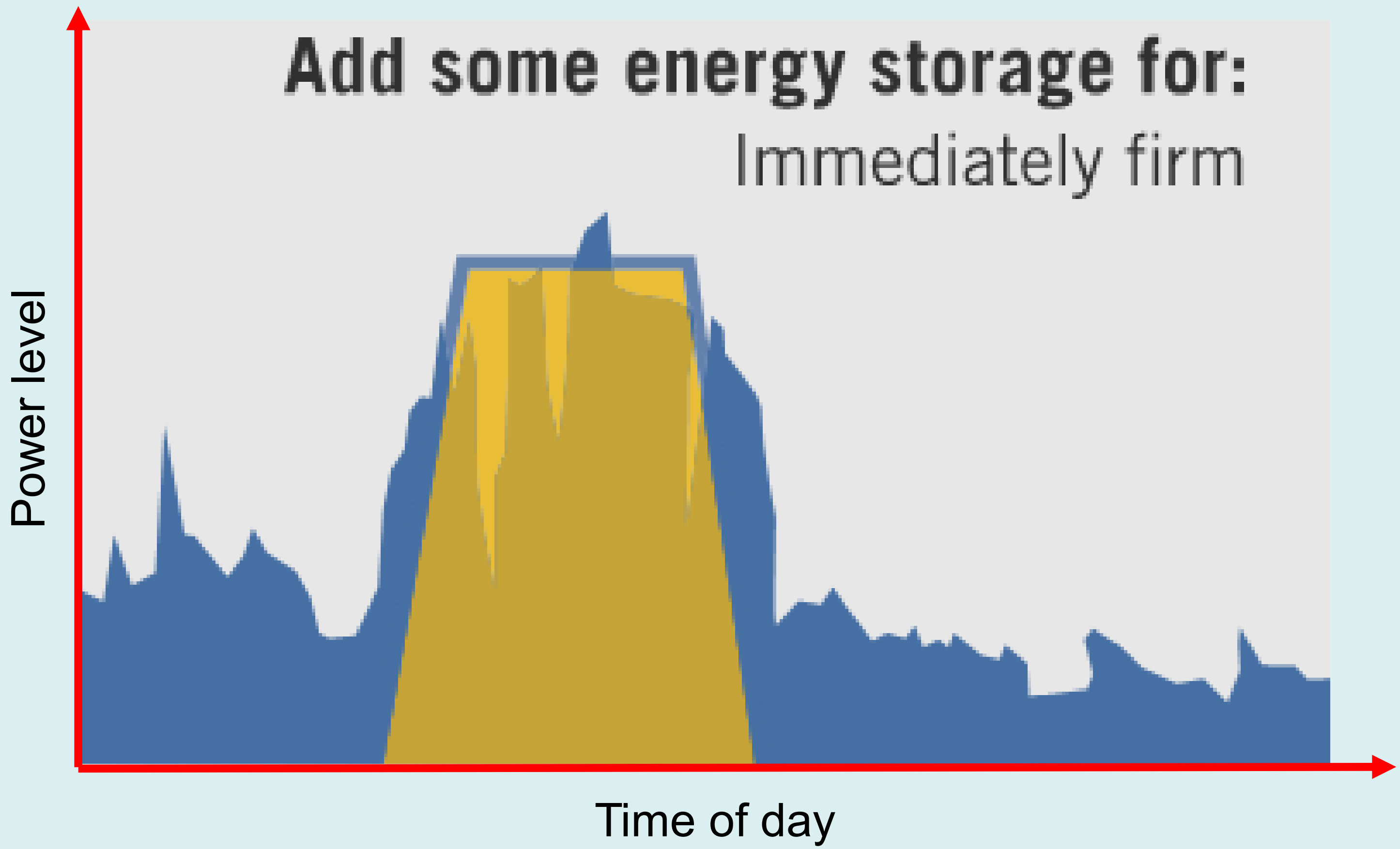
Many different classifications and levels of detail..

- **Sending out electricity when most needed**
  - **Short term smoothing of wind and PV**
  - **Longer term firming and extending wind and solar**
  - **Targeting peak demand periods**
  - **Providing long term energy reserve**
- Providing ancillary services (frequency, blackstart etc)
- Supporting system security (inertia, fault current)
- Supporting transmission and distribution networks

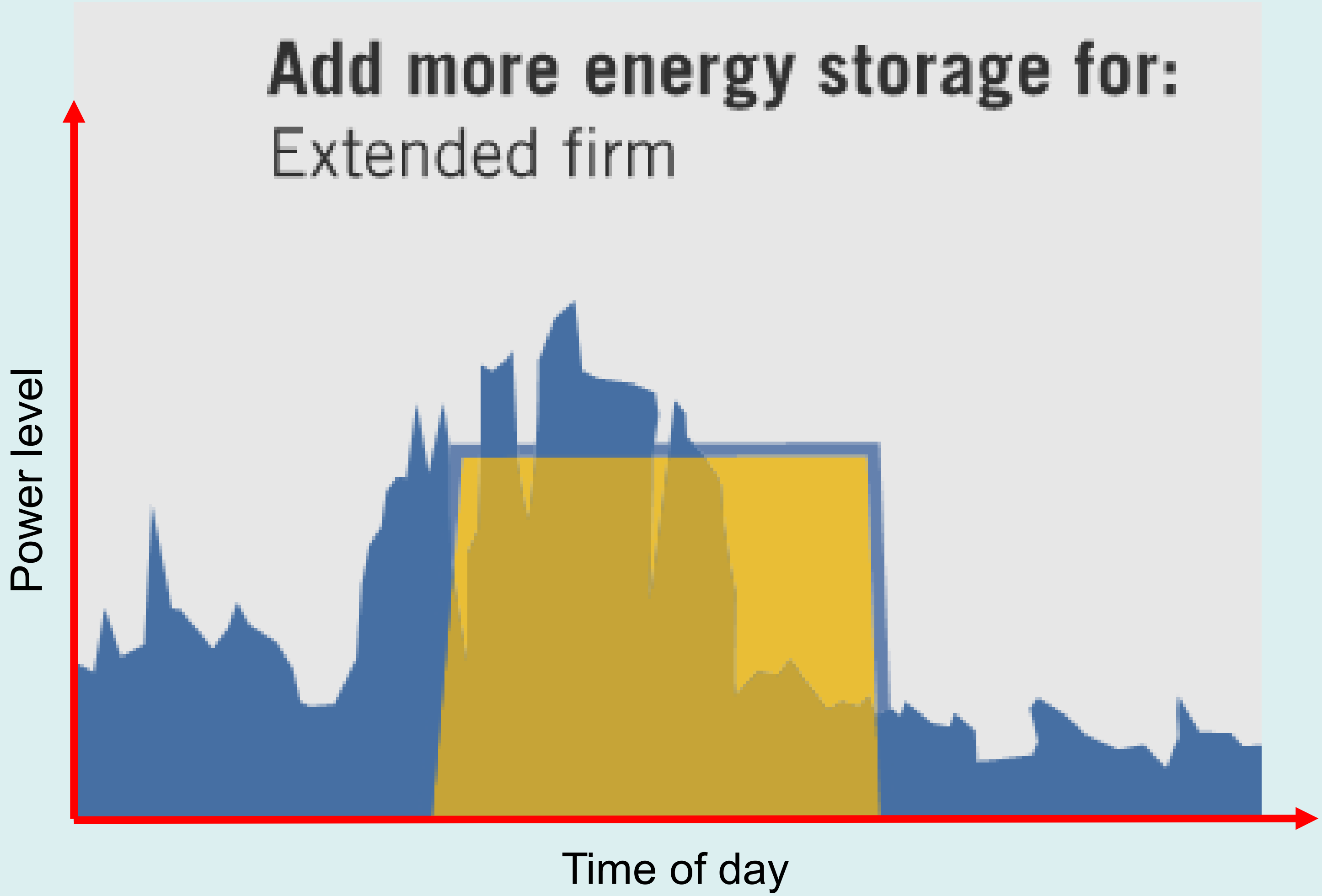
Wind or solar based Generation



Wind or solar based Generation



Wind or solar based Generation



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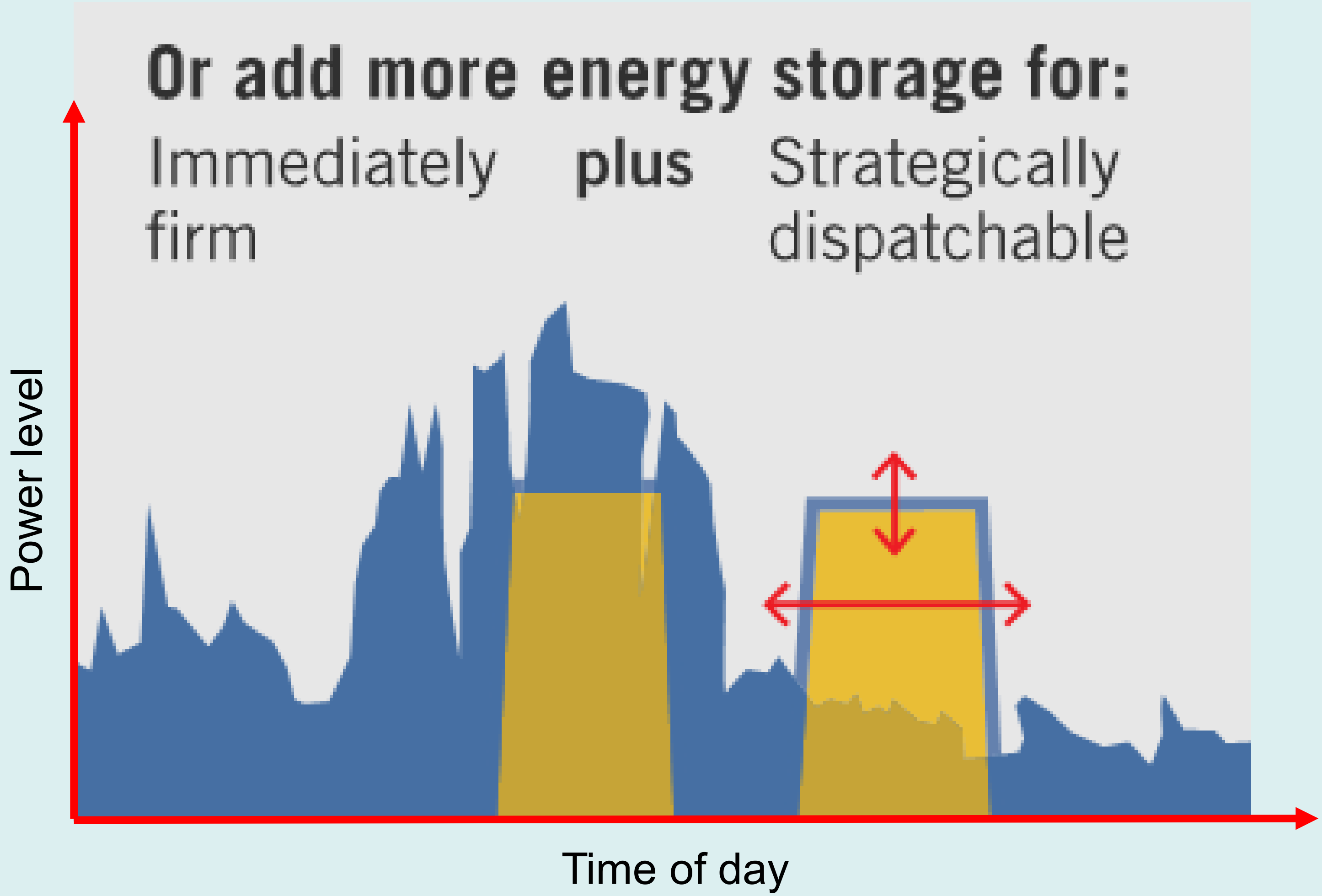
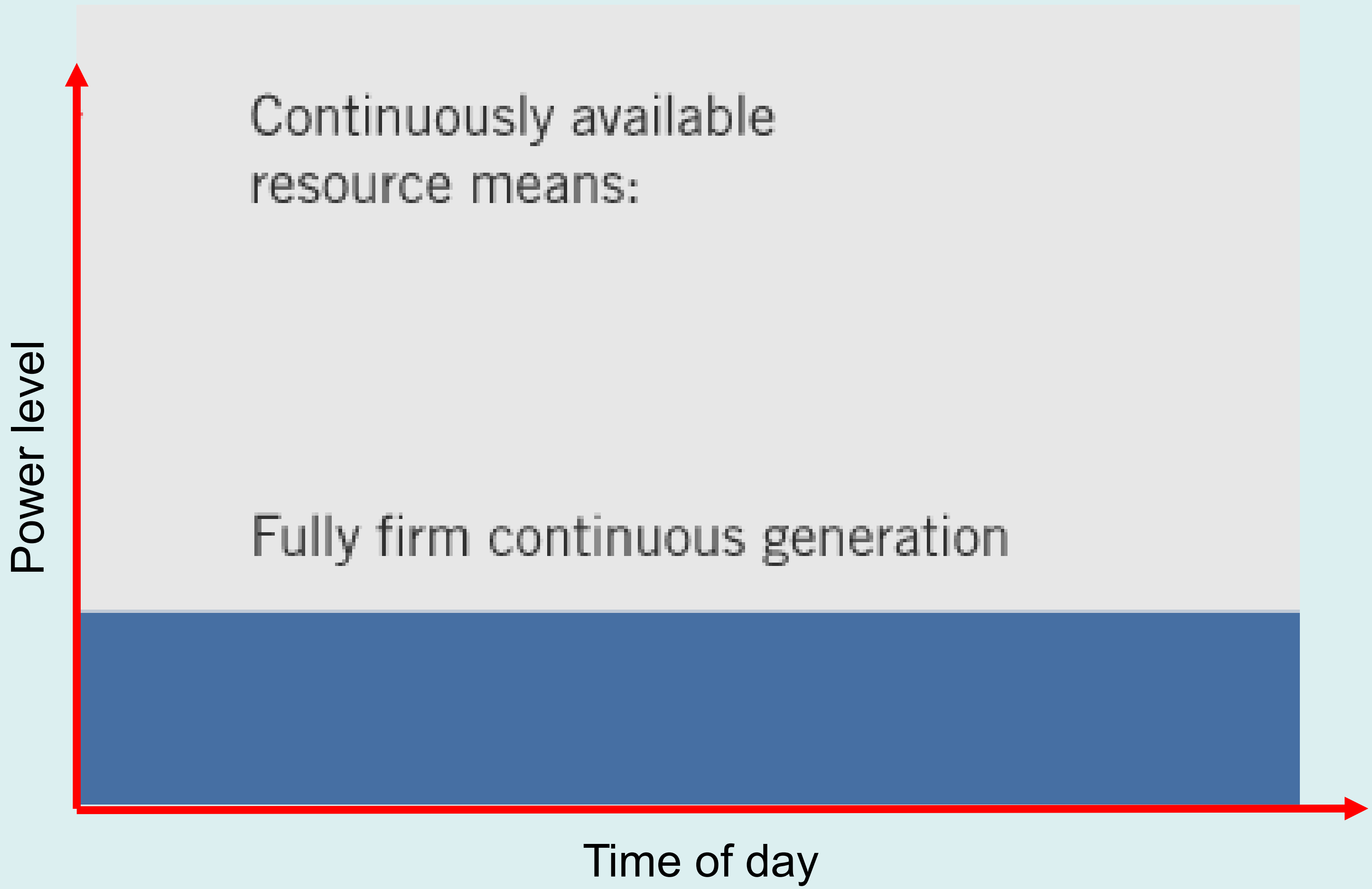
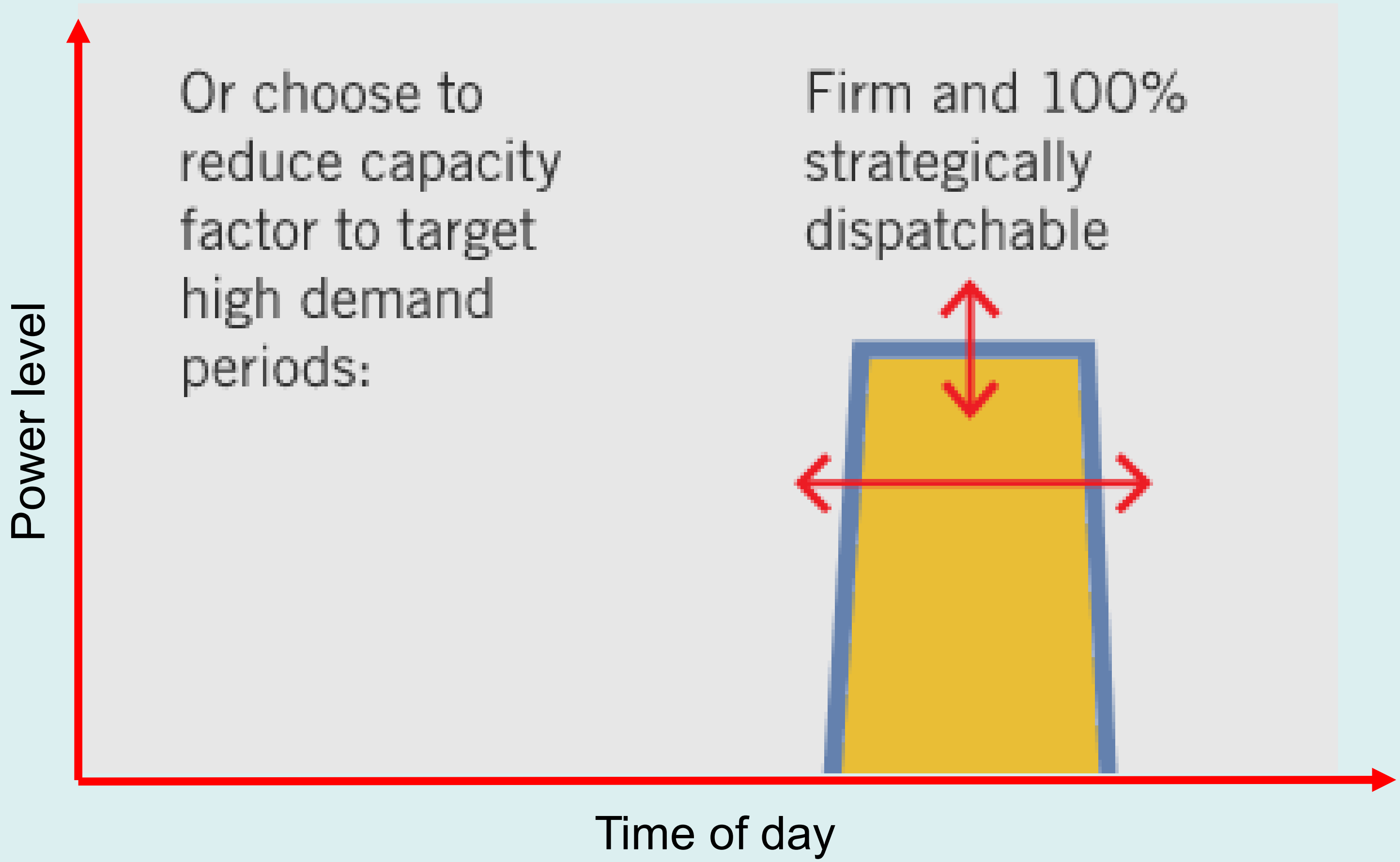


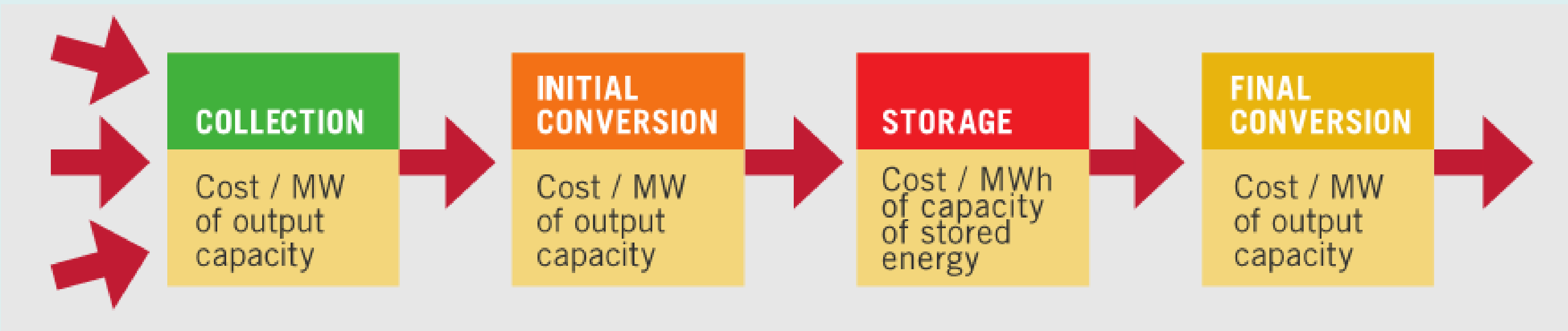
Bio / Geo Energy based Generation



Bio / Geo Energy based Generation



Our installed cost model combines subsystems



- Cost is sum of collection, initial conversion, storage and final conversion contribution
- Size dependence of cost for each subsystem:
- $Cost(capacity\ x) = Cost(capacity\ y) \left[\frac{x}{y}\right]^n$

Where: *x* - plant capacity of interest

y - base case plant capacity

n - between 1 (modular) and 0.7 (strong economy of scale)

Installed cost models

	Collection				Initial conversion				Storage				Final conversion			
COST MODEL PARAMETERS	Baseline size	Unit	Cost per unit at baseline $m	Power law exponent	Baseline size	Unit	Cost per unit at baseline $m	Power law exponent	Baseline size	Unit	Cost per unit at baseline	Power law exponent	Baseline size	Unit	Cost per unit at baseline $m	Power law exponent
PV	100.00	MW AC	$ 1.87	0.89	na	na	na	na	na	na	na	na	na	na	na	na
Wind	100.00	MW	$ 2.18	0.90	na	na	na	na	na	na	na	na	na	na	na	na
Battery	na	na	na	na	na	na	na	na	1	MWh	$687,735	1.00	1.00	MW	$ 0.39	0.74
PHES	na	na	na	na	na	na	na	na	1,200	MWh	$ 37,000	0.70	200.00	MW	$ 1.50	0.70
Digestor Biomas	na	na	na	na	7.26	MWth	$1.42	0.70	11	MWht	$ 12,391	0.80	2.50	MW	$ 0.91	0.70
Combustion Biomass	na	na	na	na	na	na	na	na	44,384	MWhth	$ 6.7	1.00	15.00	MW	$ 4.89	0.70
Hydrogen	na	na	na	na	20.00	MW	$1.09	0.70	20,000	MWhf	$ 655	0.70	20.00	MW	$ 1.64	0.70
Concentrated Solar Thermal	600.00	MWth	$ 0.46	0.90	na	na	na	na	1,429	MWht	$ 26,000	0.80	100.00	MW	$ 2.40	0.70
Engineered Geothermal	na	na	na	na	na	na	na	na	na	na	na	na	50.00	MW	$ 14.00	0.80
Hot sedimentary geothermal	na	na	na	na	na	na	na	na	na	na	na	na	50.00	MW	$ 6.27	0.70

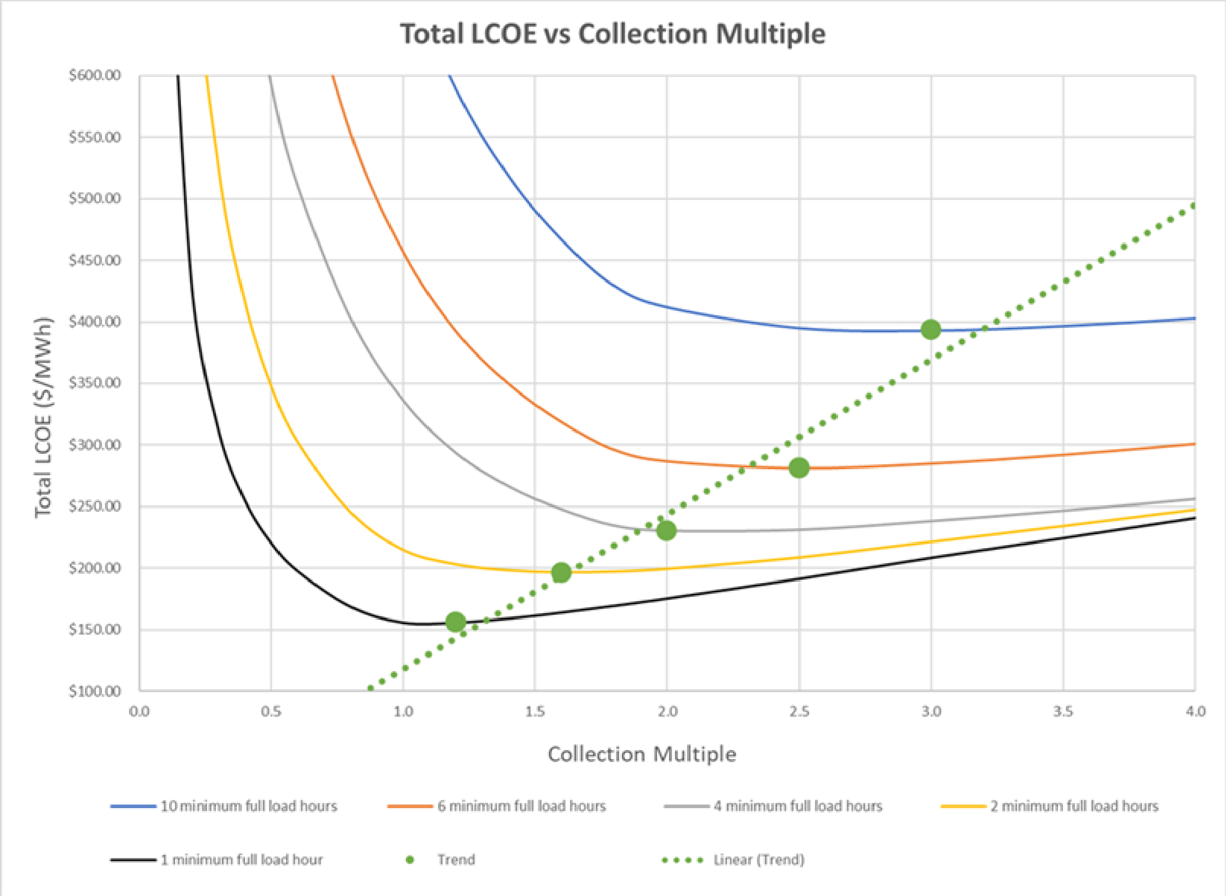
Values from 2017 data. Public information, confidential briefings (including current Aus. project activity), then least square fitting to subsystem based cost model

Modelling ‘firm and extend’

- Simple dispatch model with real hour by hour resource profile
- Use LCOE as a function of configuration

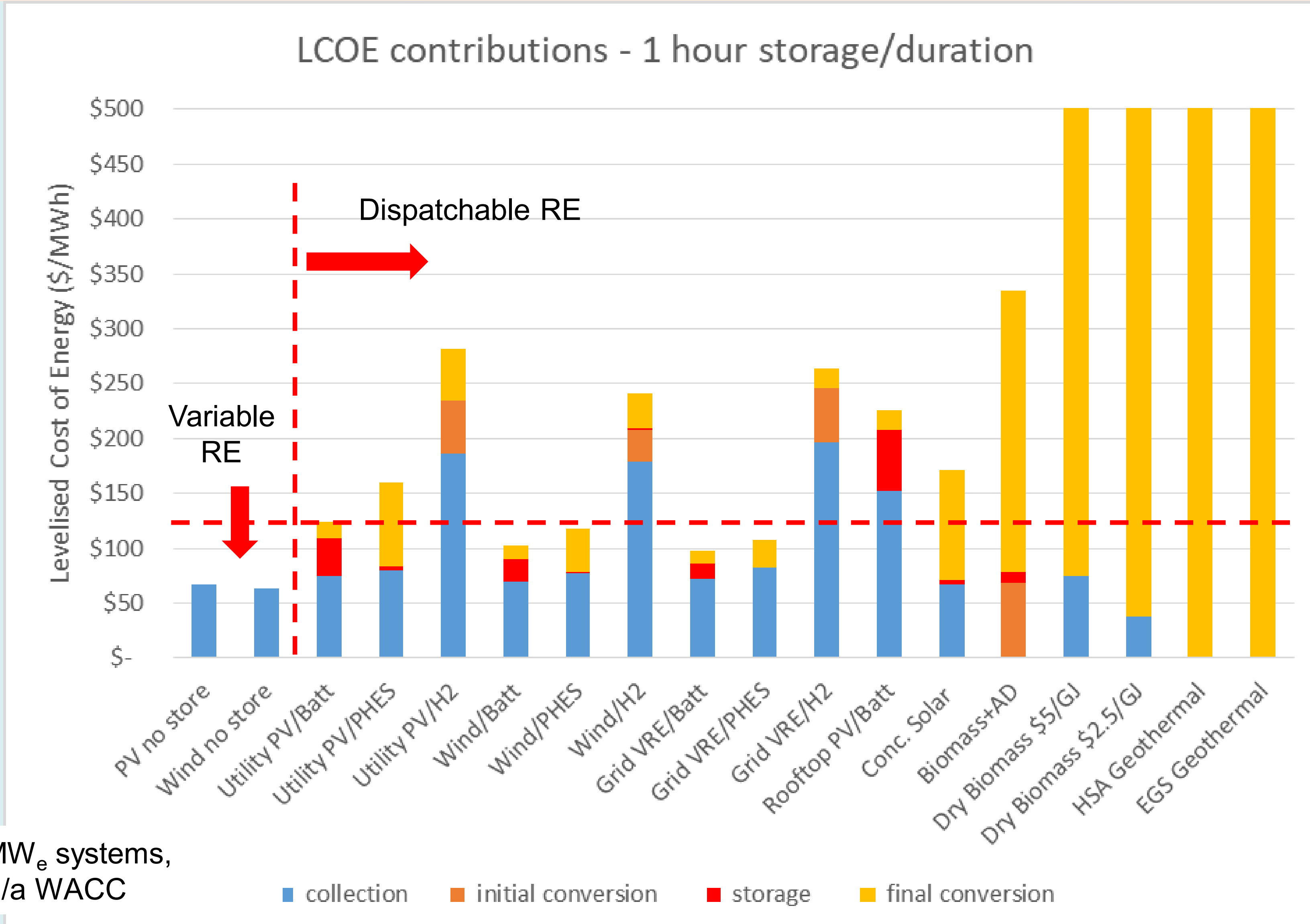
$$LCOE = \frac{(F_R + \mathrm{OM}_{fixed})C_0}{PF_c} + OM_{variable} + \frac{c_{in}}{\eta}$$

- Systems optimised for min LCOE for each level of storage



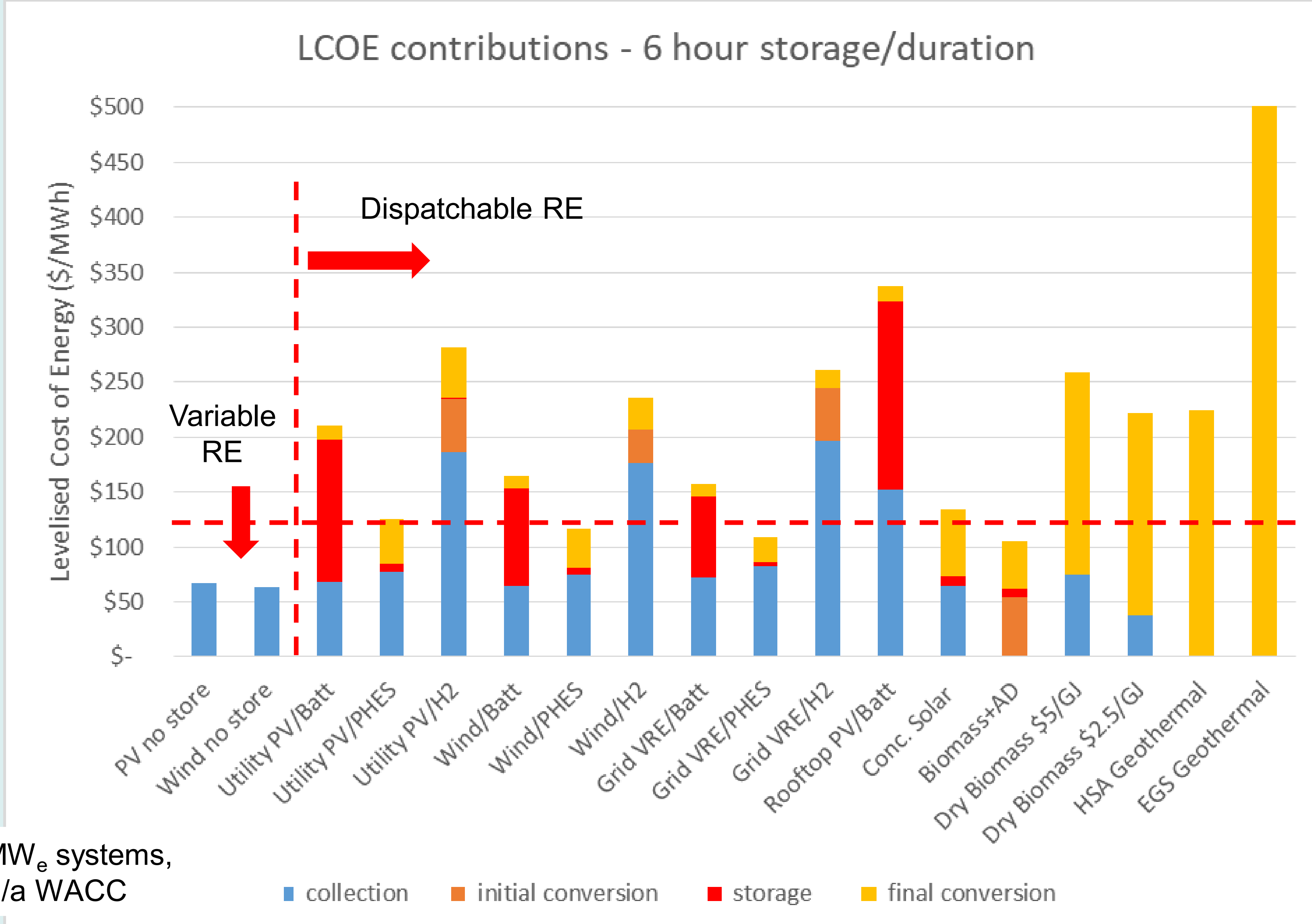
PV plus batteries example

Configurations depend on duration



$100MW_e$ systems, 6.5%/a WACC

Configurations depend on duration



$100MW_e$ systems,
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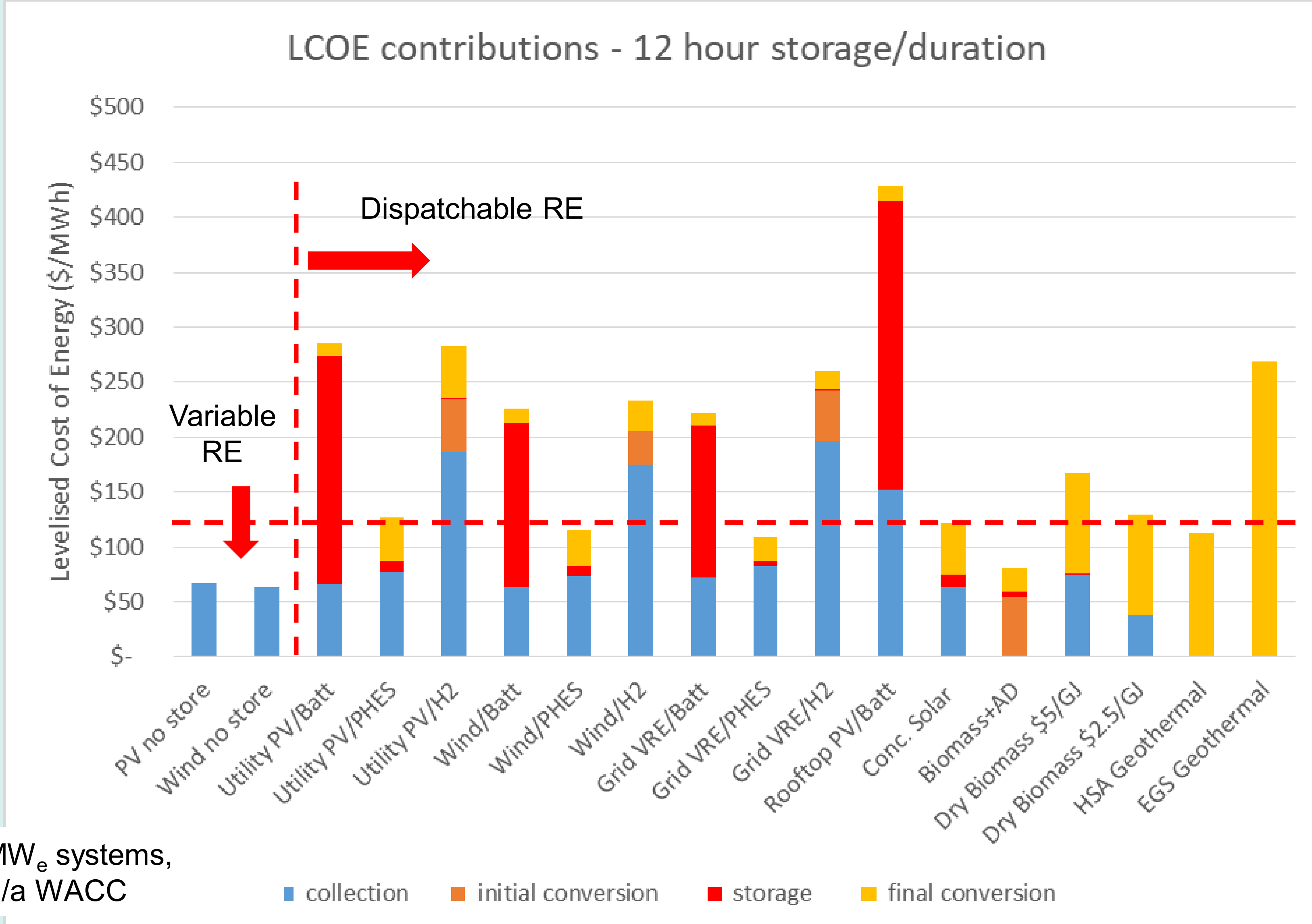
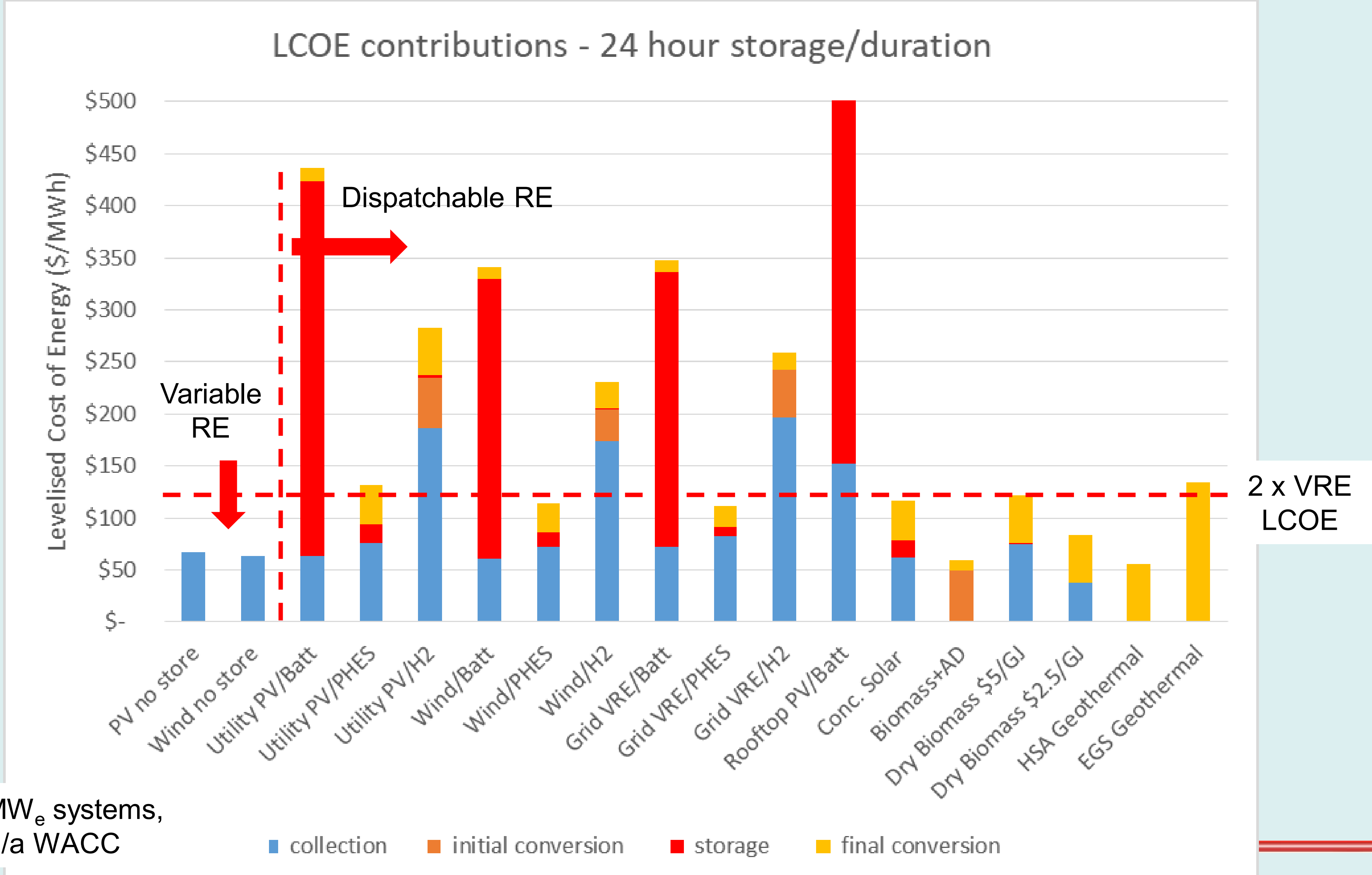
Configurations depend on duration



2 x VRE LCOE

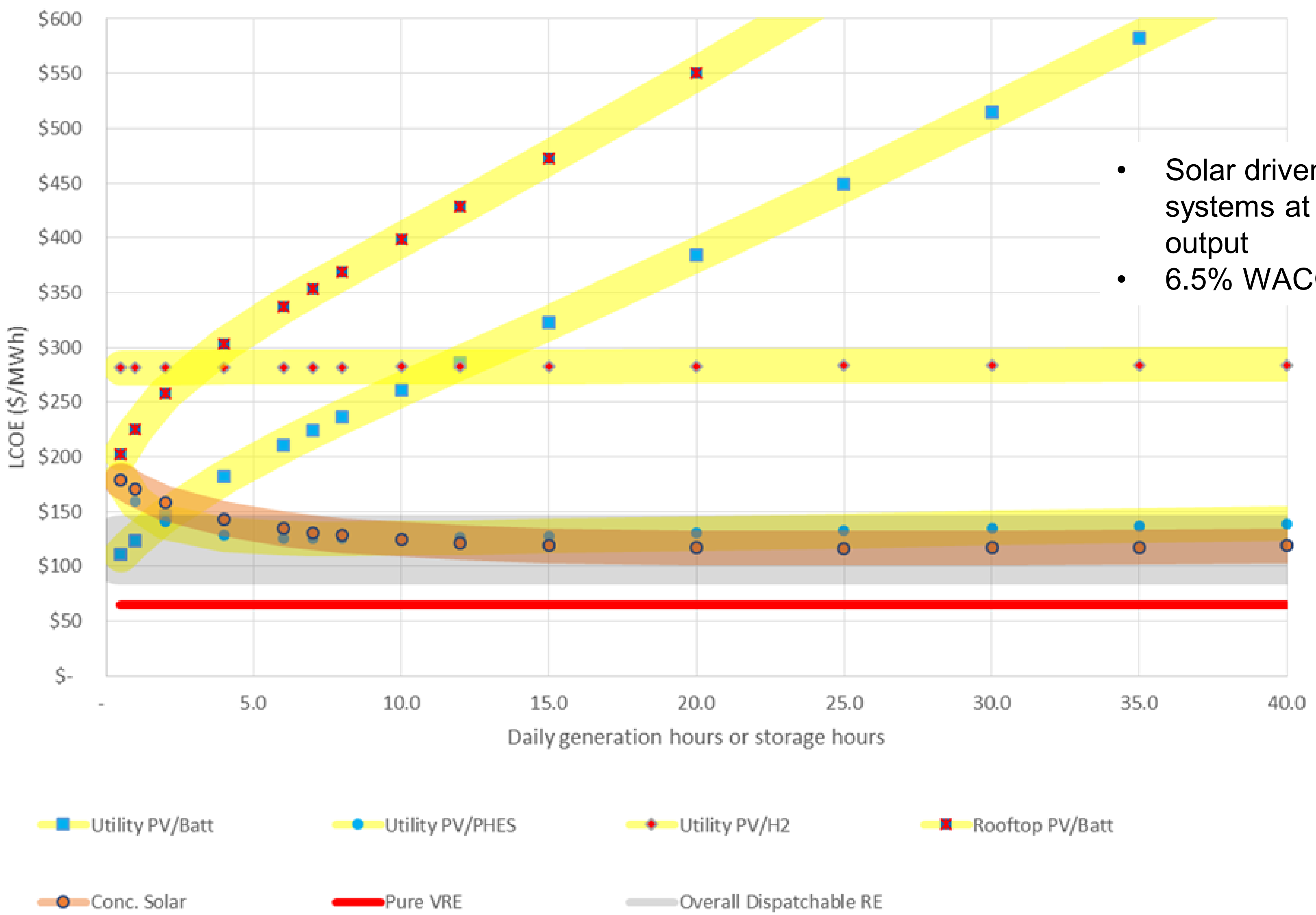
100MW$_e$ systems, 6.5%/a WACC

Configurations depend on duration



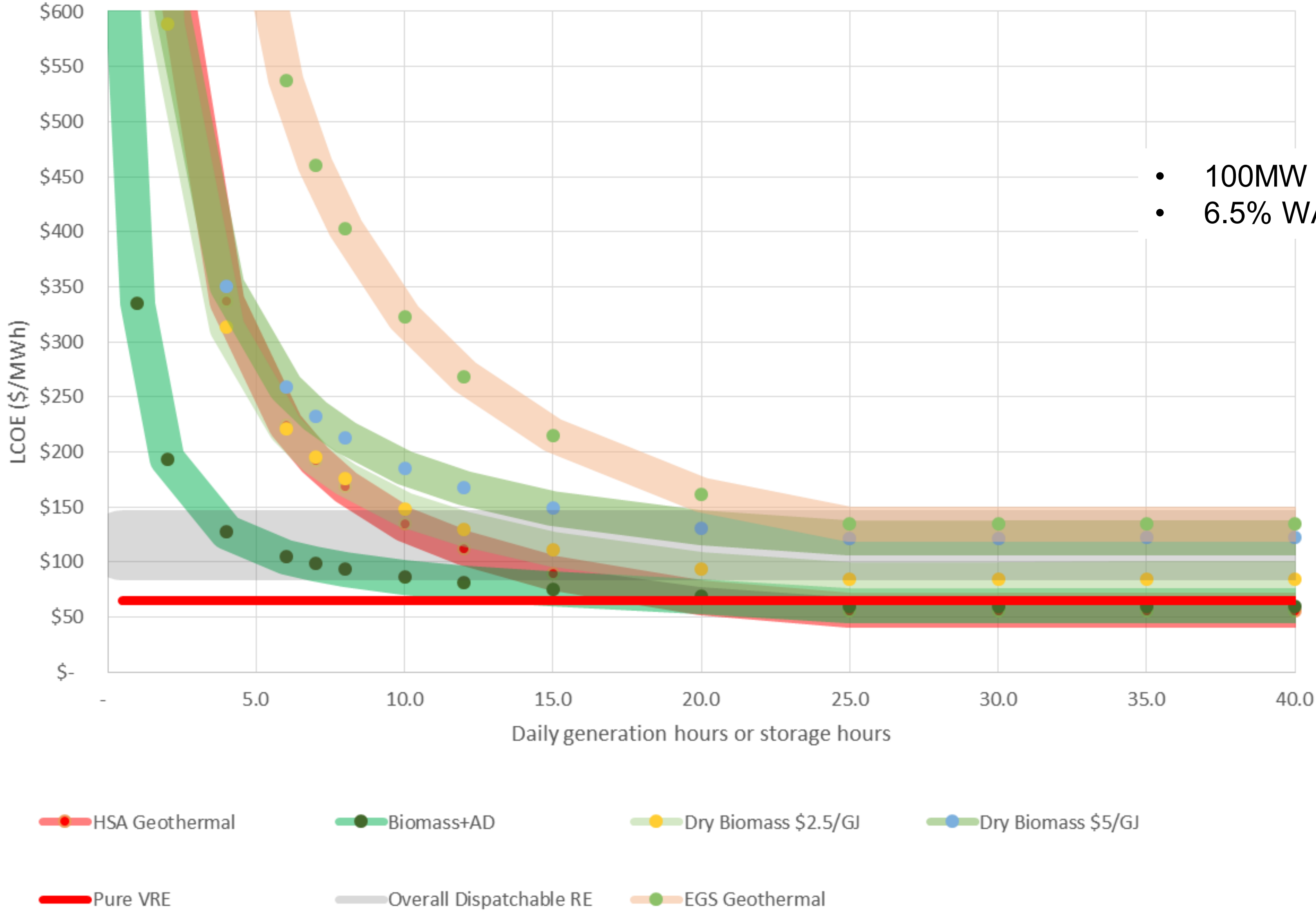
$100MW_e$ systems, 6.5%/a WACC

Solar driven options



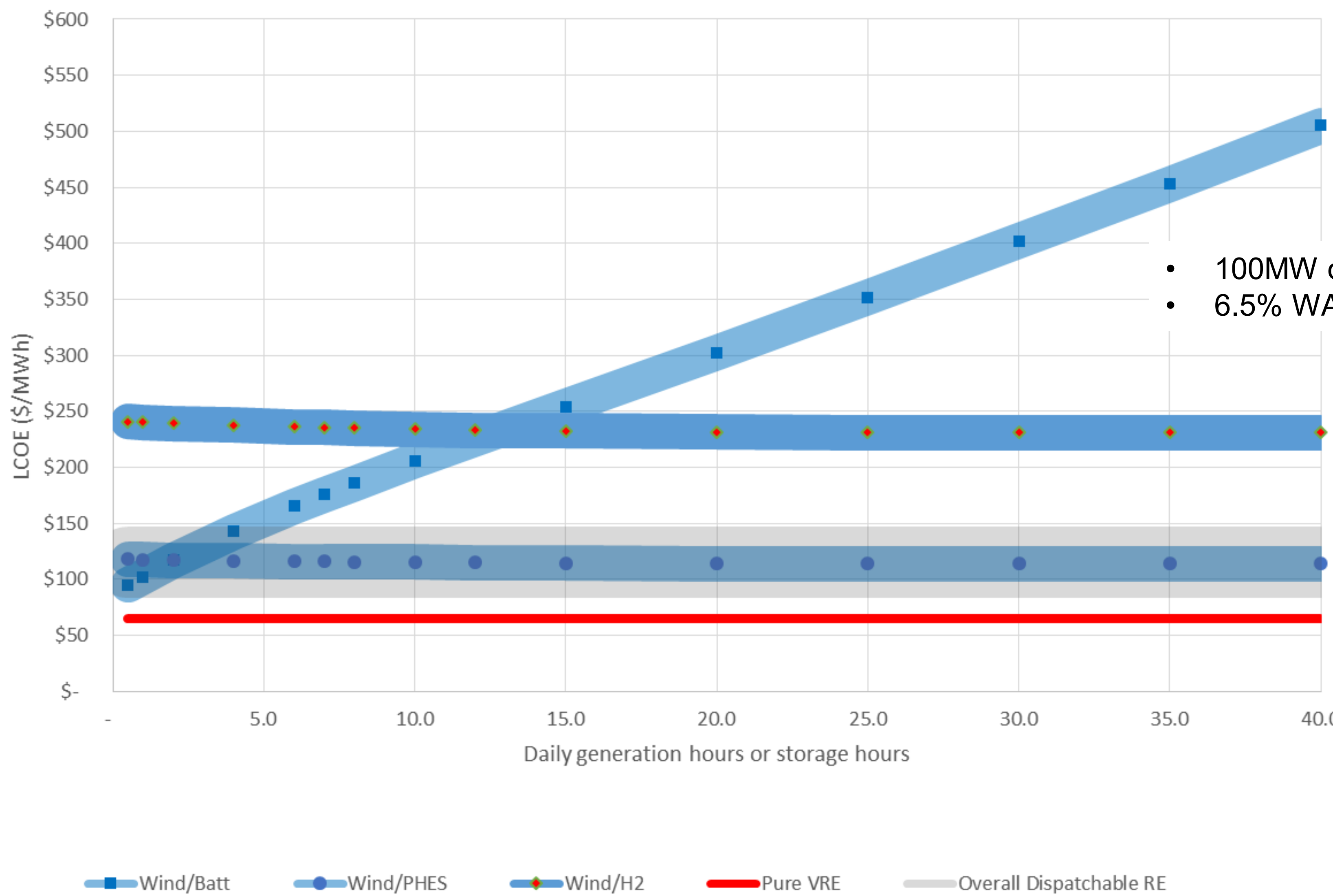
- Solar driven systems at 100MW output
- 6.5% WACC

Bio, Geo driven options



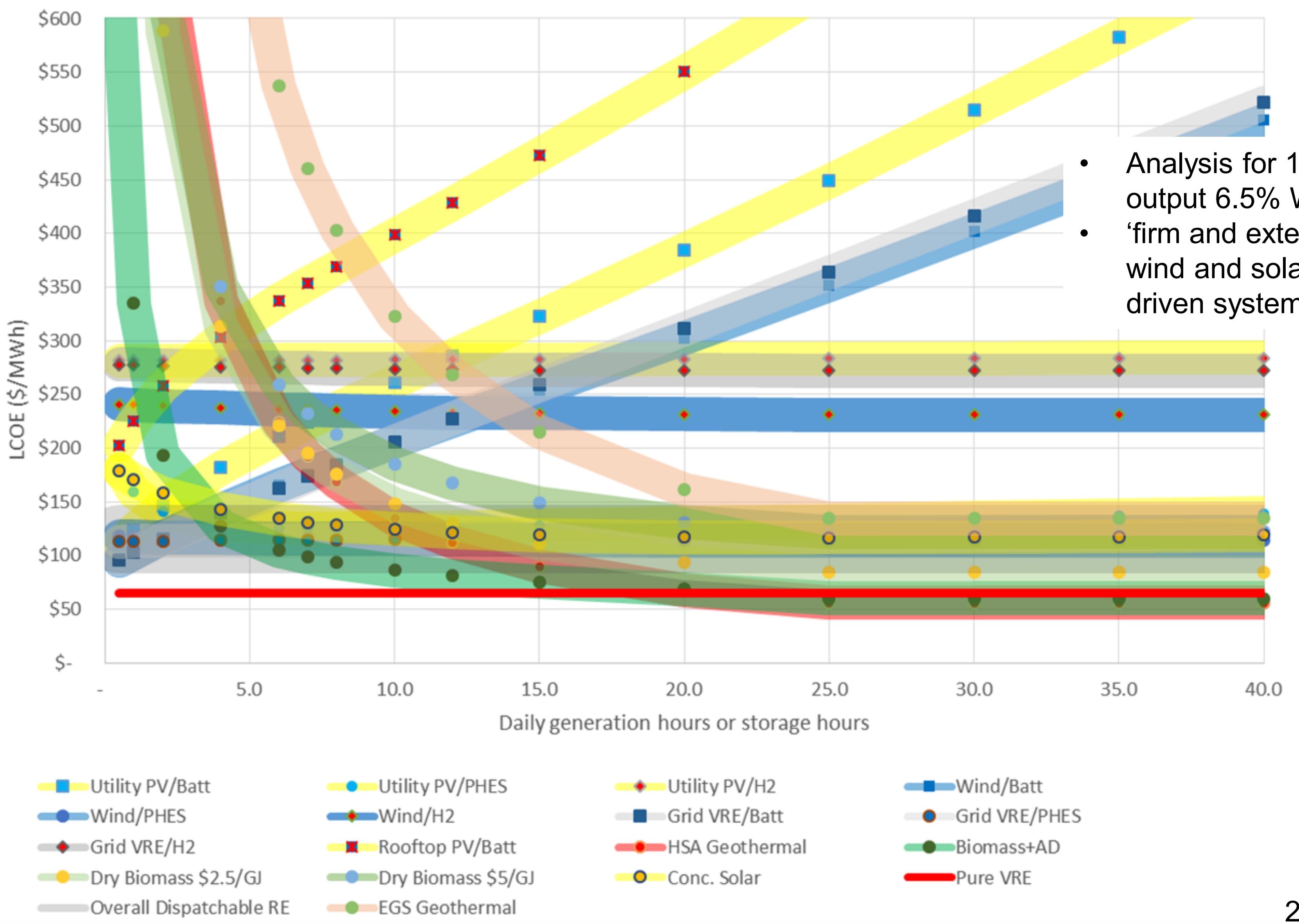
- 100MW output
- 6.5% WACC

Wind driven options



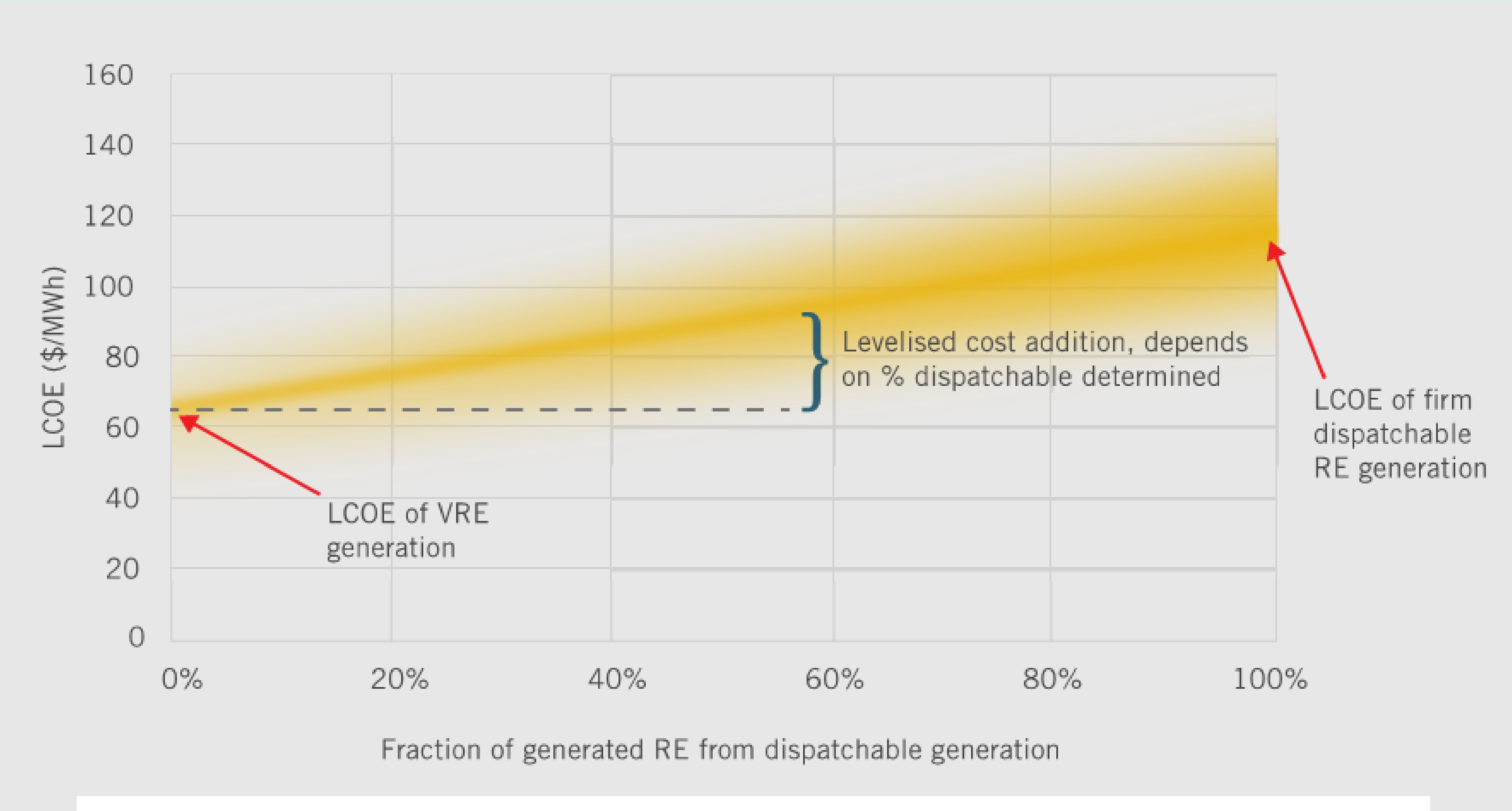
- 100MW output
- 6.5% WACC

Spoilt for choice



- Analysis for 100MW output 6.5% WACC
- ‘firm and extend’ wind and solar driven systems

Average cost of RE generation



- Note this is separate to question of overall % of RE in total generation
- In a 100% RE system the average cost will fall somewhere between the VRE cost and the Dispatchable RE cost

Incremental cost of adding long term energy reserves

Energy Storage technology	Specific Installed cost per equivalent stored electricity	Annualised cost of capital and O&M	Addition to LCOE at 1% utilisation
	$\$/MWh_e$	$\$/MWh_e/year$	**$\$/MWh_e$**
Biomass Depot	$29	$3	**$0.04**
Hydrogen	$1,768	$276	**$3**
Hydro Dam	$46,250	$4,467	**$51**
Bio Gas accumulator	$36,444	$5,698	**$65**
Molten Salt	$61,905	$5,979	**$68**
Batteries	$764,150	$94,260	**$1,076**

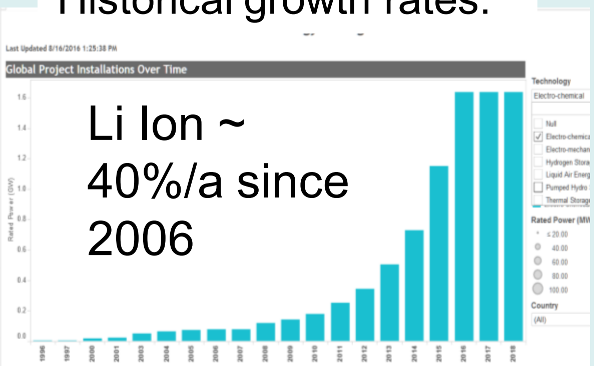
Add to the underlying LCOE of dispatchable RE: <$200/MWh

Final conversion characteristics

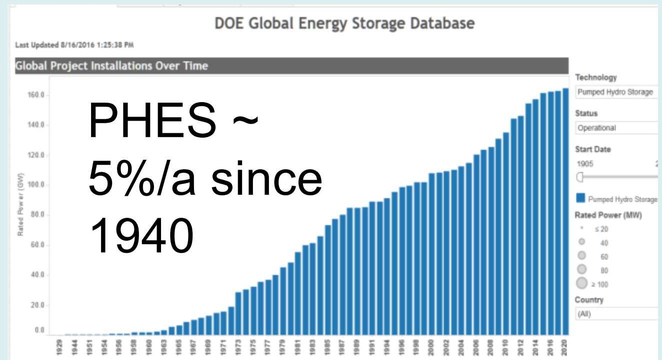
	Very fast response possible synthetic inertia	Synchronous generator with Inertia	Synchronous generator	Possible use as synchronous condensor
Inverter (for batteries or fuel cell)	Yes	No	No	No
Steam turbo generator (bio or CST)	No	Yes	Yes	Yes
Gas turbine generator (H2 or bio)	No	Yes	Yes	Yes
Gas engine	No	Yes	Yes	No
Hydro turbo generator (PHES)	No	Yes	Yes	Yes

No regrets growth and cost reduction go together

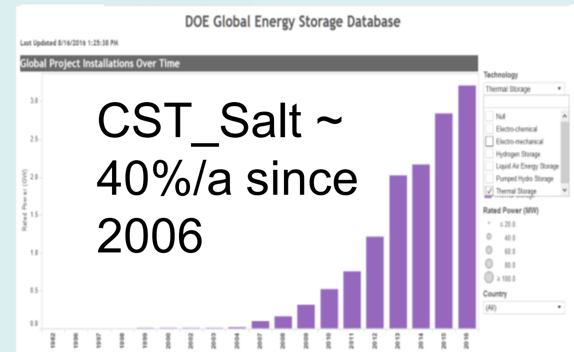
Historical growth rates:



Li Ion ~ 40%/a since 2006

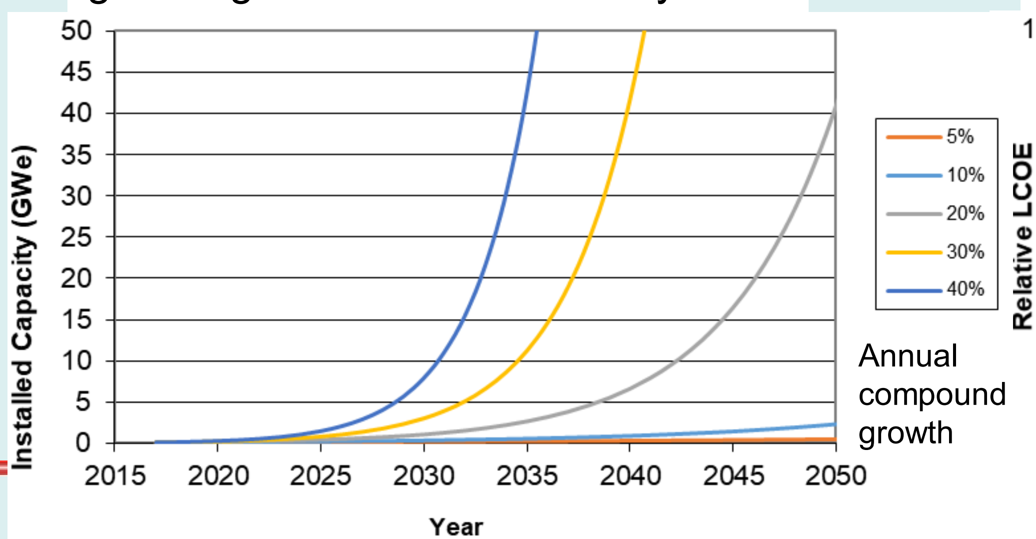


PHES ~ 5%/a since 1940



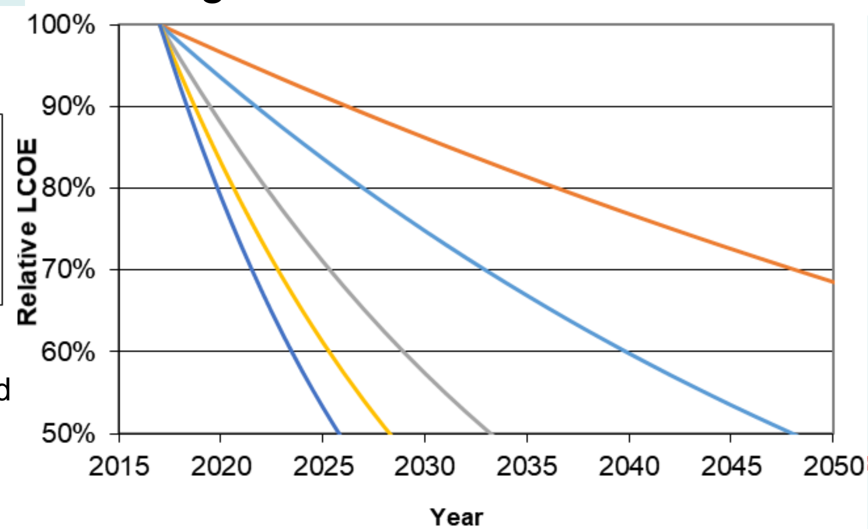
CST_Salt ~ 40%/a since 2006

Compound growth >20%/a in any tech or mix from a 200MW base gives significant contribution by 2050

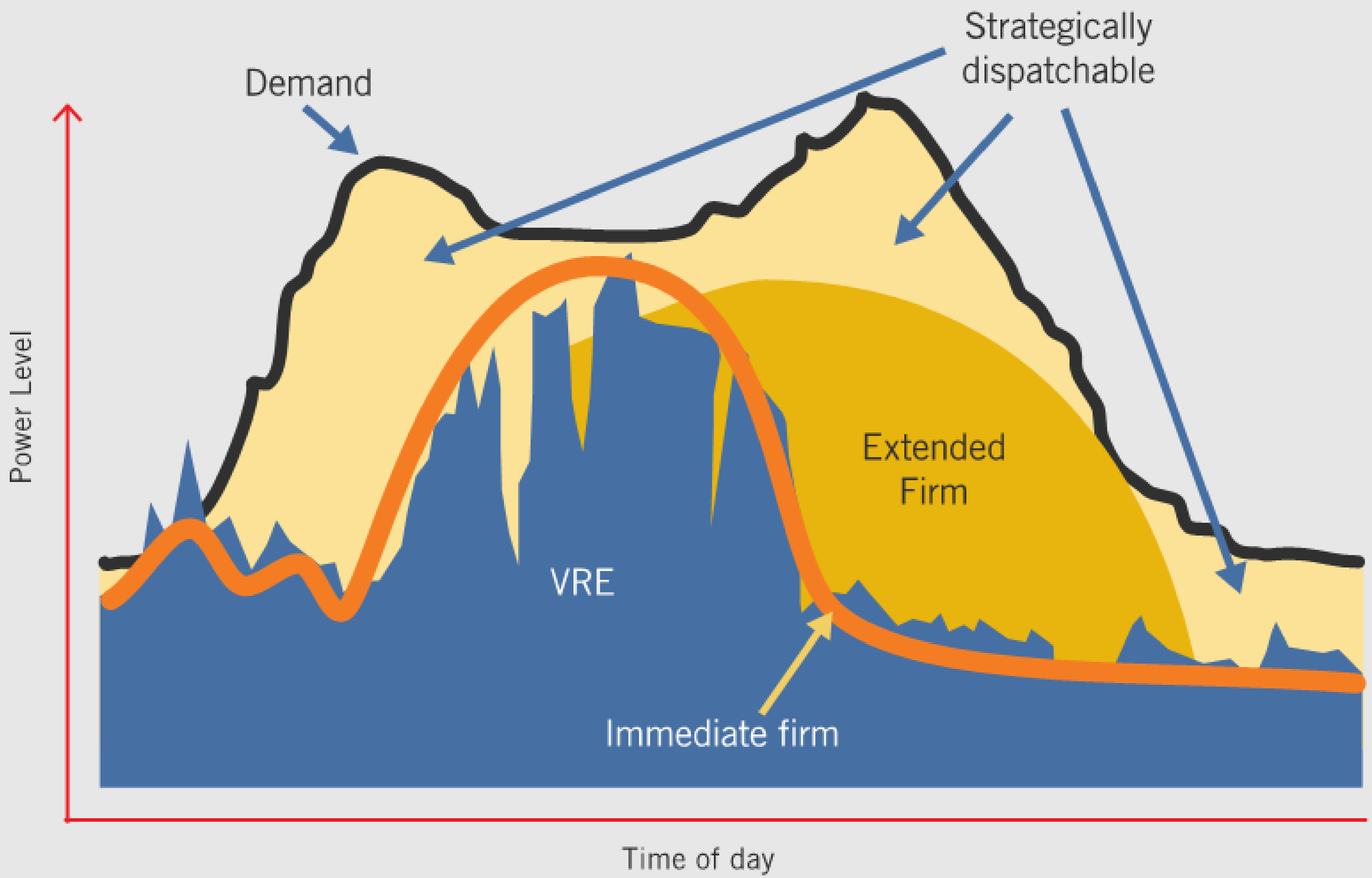


Annual compound growth

Energy technologies all manage approx. 15% cost reduction per doubling until mature



Assembling a least cost mix



Conclusions

- We have multiple affordable options for firm dispatchable renewable generation over all time scales at 1.5 - 2 x cost of VRE
- Long term energy reserves possible at 2 - 3 x VRE cost
- Cost reductions will inevitably track with global and local deployment
- Likely least cost is a mix of technologies, durations and locations
- Achievable growth rates could keep pace with coal retirements and see a large share of dispatchable RE by 2050
- Pursuing dispatchable RE options now maximises chance of least cost orderly transition.

HAVING SOME DISPATCHABLE ELECTRICITY IS ESSENTIAL

MIX OF

Technologies
Locations
Durations

=

EQUALS

Least cost ✓

Least risk ✓

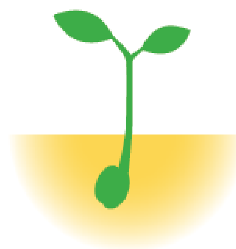
Orderly transition ✓

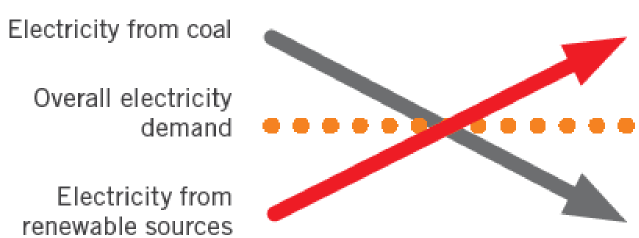
COST VS VALUE

Dispatchable renewable energy costs more than variable renewable energy but is considerably more valuable.

ACHIEVABLE GROWTH

Achievable growth rates could keep pace with coal retirements and enable an orderly transition to a large share of Renewable Energy.





LONG TERM

In parallel, long term energy reserves can be added to ensure generation in critical periods.