
Large-scale electricity storage

THE ROYAL SOCIETY

Designing Energy Storage Systems for 2050 to meet net-zero

Medium Duration Energy Storage 2024 - London

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Energy Storage Technologies for 2050 net zero

Different storage economics - drive the choice of technologies - ‘horses for courses’

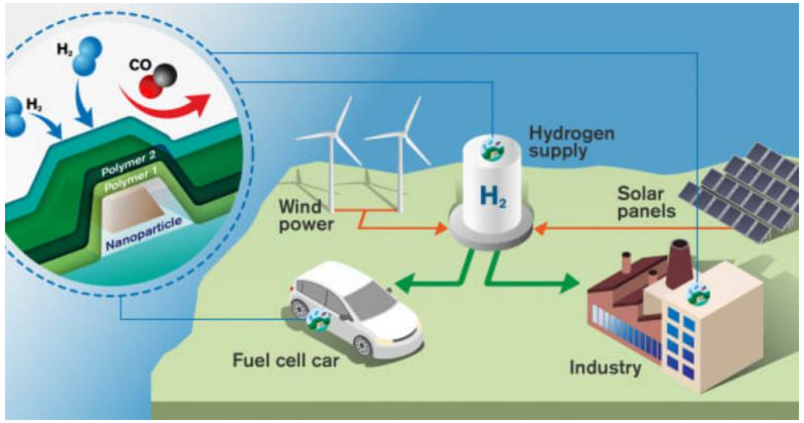
Short-term

Hornsdale, S Australia: Li-Ion battery - 150 MWh

Mid-term

McIntosh, USA: CAES
- 110 MW, 2,640 MWh

Long-term



Hydrogen energy storage concept
- NorthH2 project, 1 GW

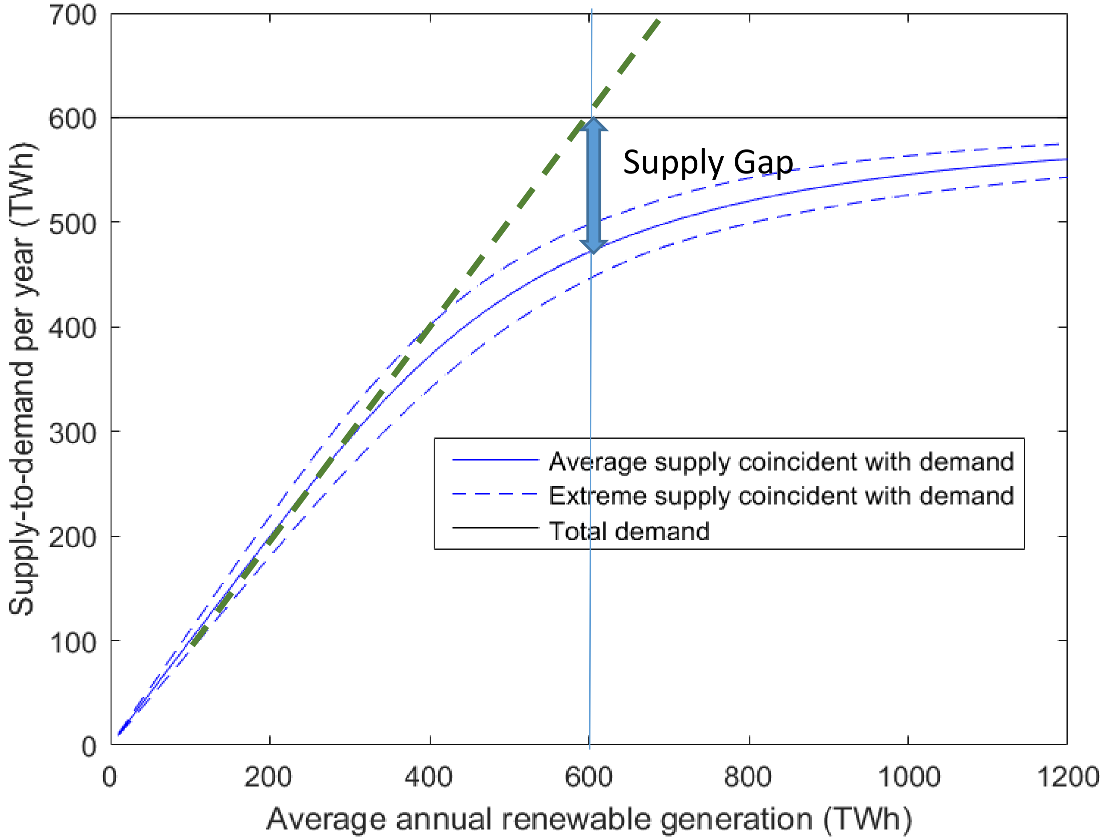
Principle	Type	Future Storage	Future Power	Efficiency	Requirements P : V : N pa
Electro-chemical	Batteries – Li-Ion, Flow etc.	**\$100/kWh**	**\$180/kW**	90%+	**10 -20 GW: 30-50GWh: >100**
Physical	Compressed Air, Liquid Air, Thermal Energy, Gravity etc.	**\$9/kWh**	**\$200 + \$200/kW**	50% (CAES)- 70% (AACAES)	**20 GW: >2 TWh: 10+**
Chemical	Hydrogen, Ammonia, Hydrocarbons.	**\$0.8/kWh**	**\$858 + \$429/kW**	40% Hydrogen 25% Ammonia	**90 GW: 70 TWh: <1**

[Roulstone (2022) Storage Costing WP]

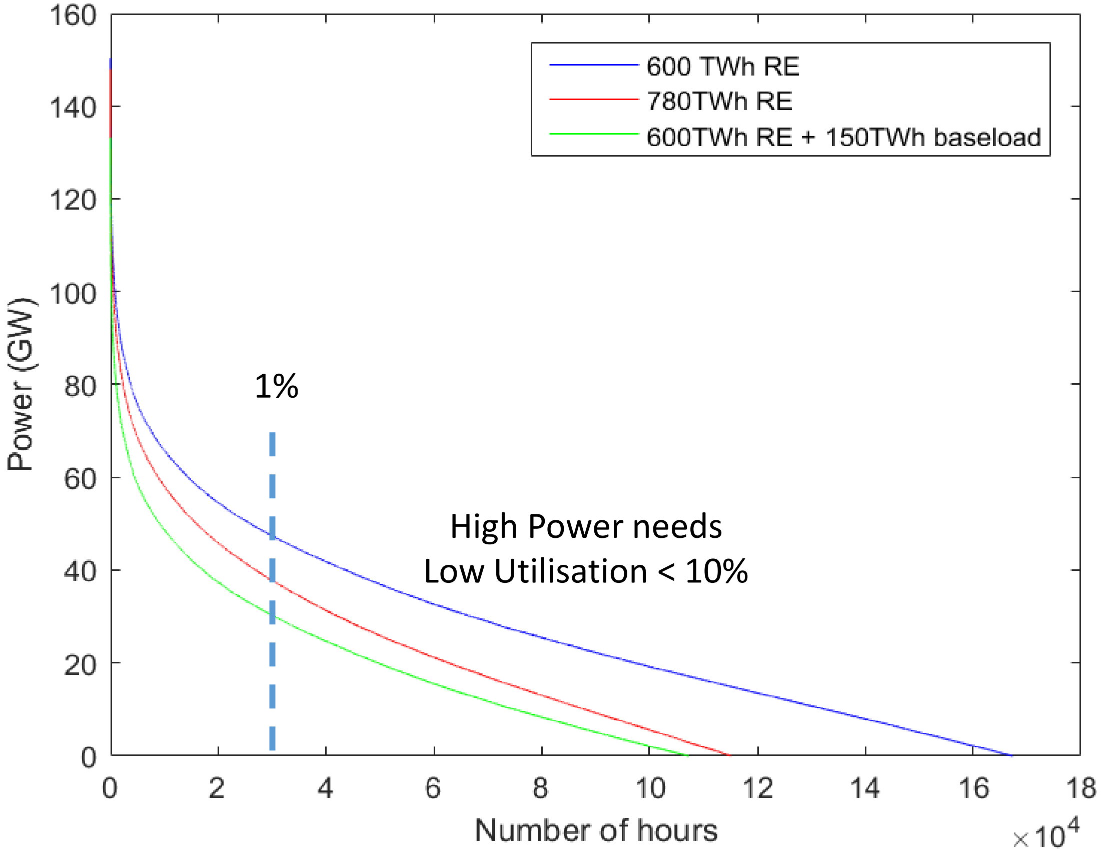
Cosgrove (2022)

Miss-timing of Renewable Supply v Demand

600 TWh
Solar/Wind: 20/80
On/Offshore: 30/70



Supply Gap



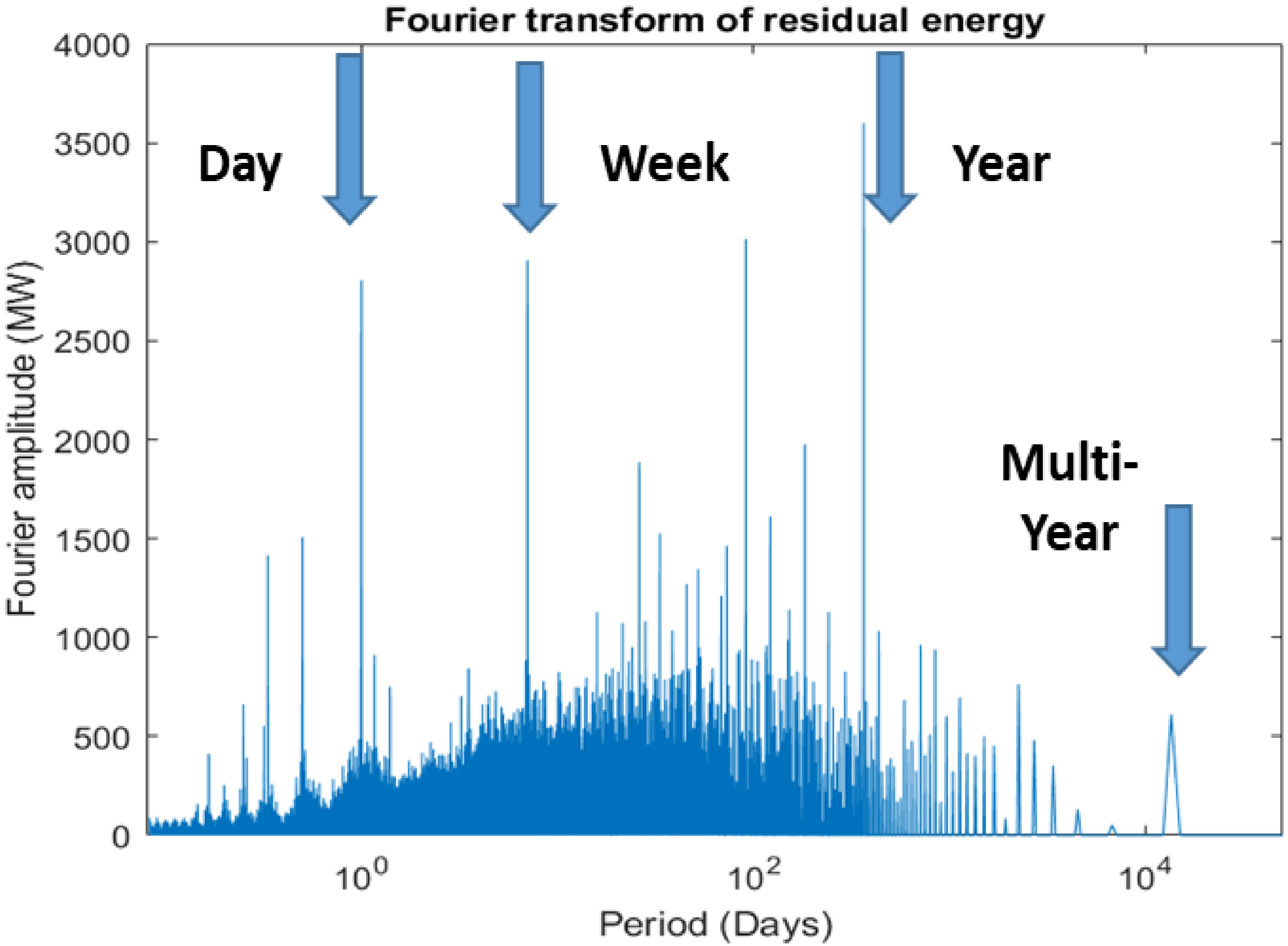
1%

High Power needs
Low Utilisation < 10%

- When average supply equals demand >120 TWh is miss-timed – not available for supply and is surplus;
- High power requirements - above 100 GW - for complementary power – for very few hours in 37 years.

Fourier analysis of residual power

37 years of UK 2050 demand & renewable supply: 20/80 solar/wind



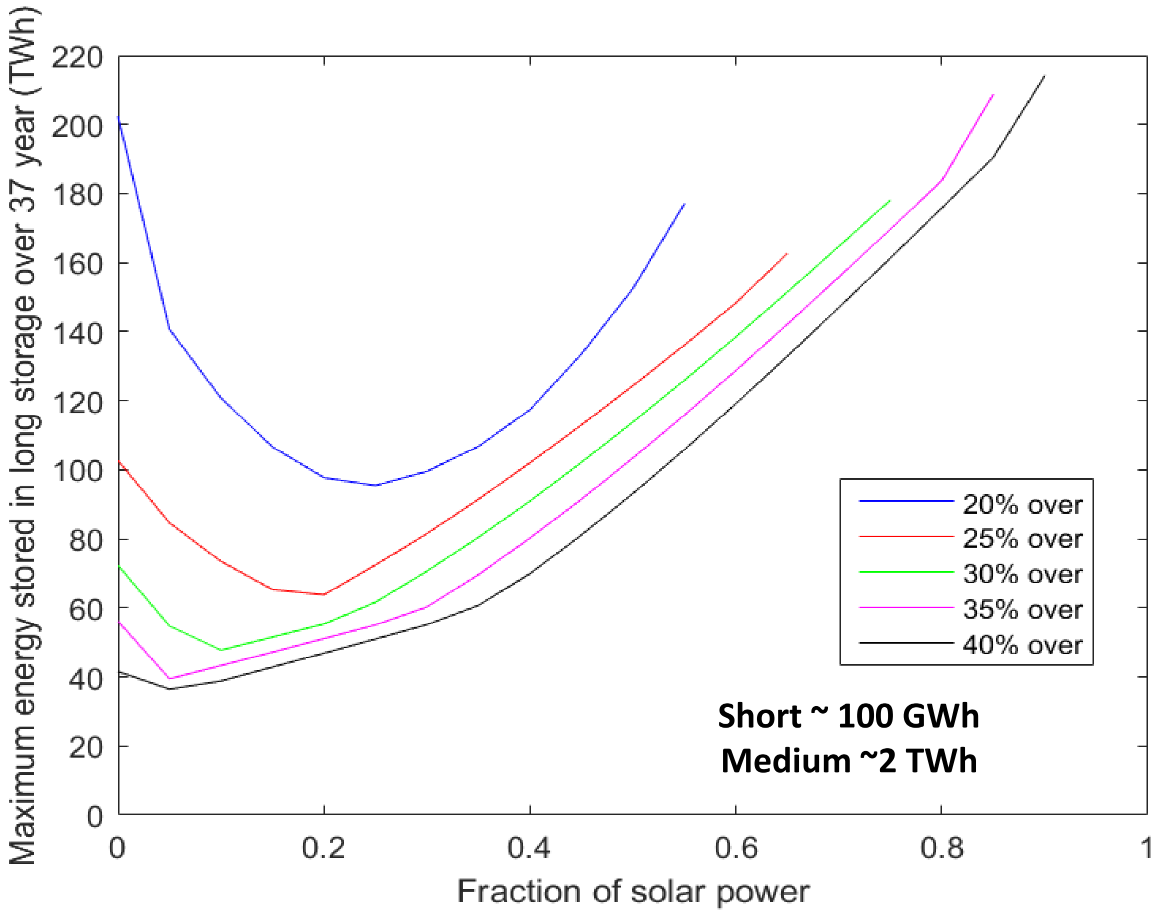
Volume of Storage needed ∞

Power * Duration

Longer term fluctuations are much more significant.

Weather periodicity - sizing stores & overcapacity

Stores: **Short 6 hours** >90%; **Medium 168 hours** 70%; **Long** 40% (typical of hydrogen)
Solar/wind mix is important - ~20% optimal at 30% overcapacity - size and energy release – Long ~60 TWh
Requires at least 18% overcapacity to ensure supply always meets demand – diminishing returns above 30%

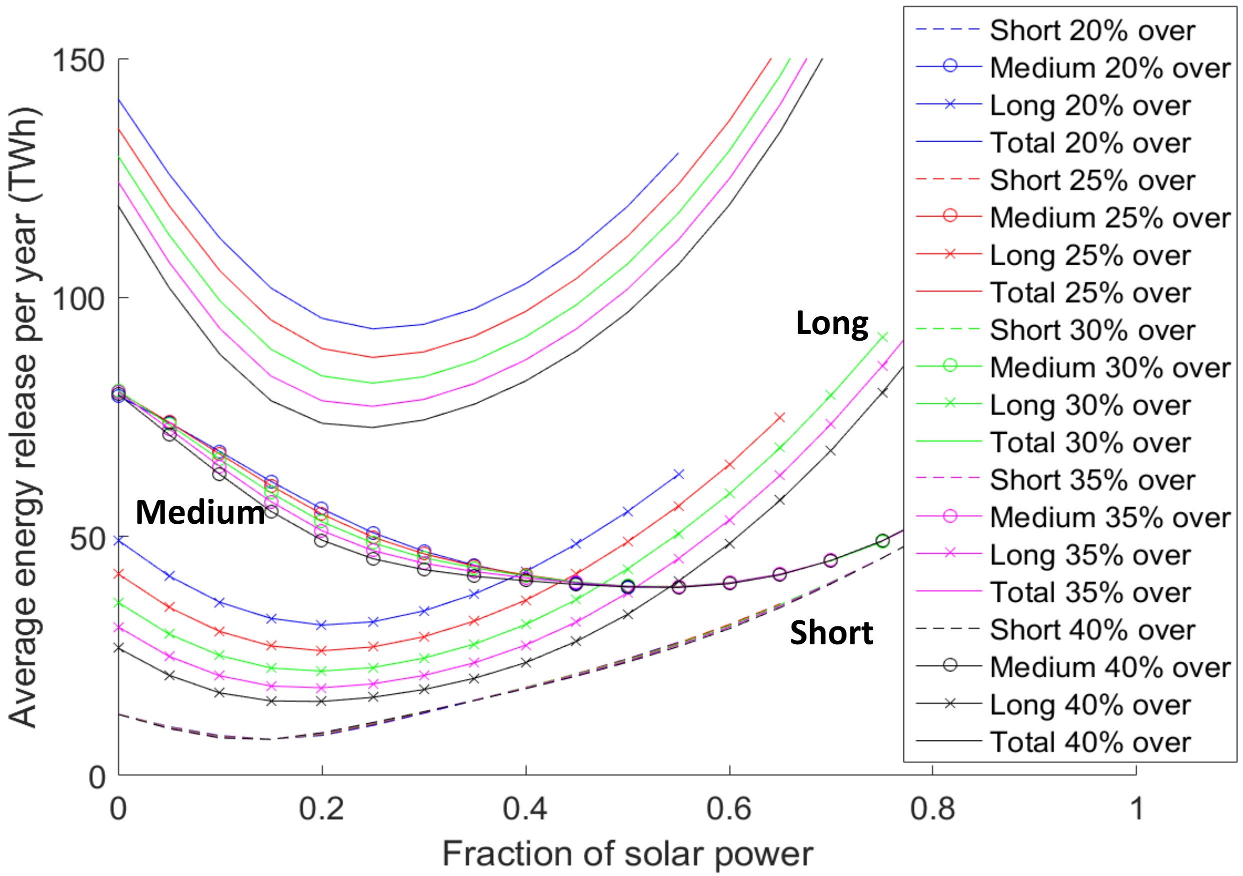


Short ~ 100 GWh
Medium ~2 TWh

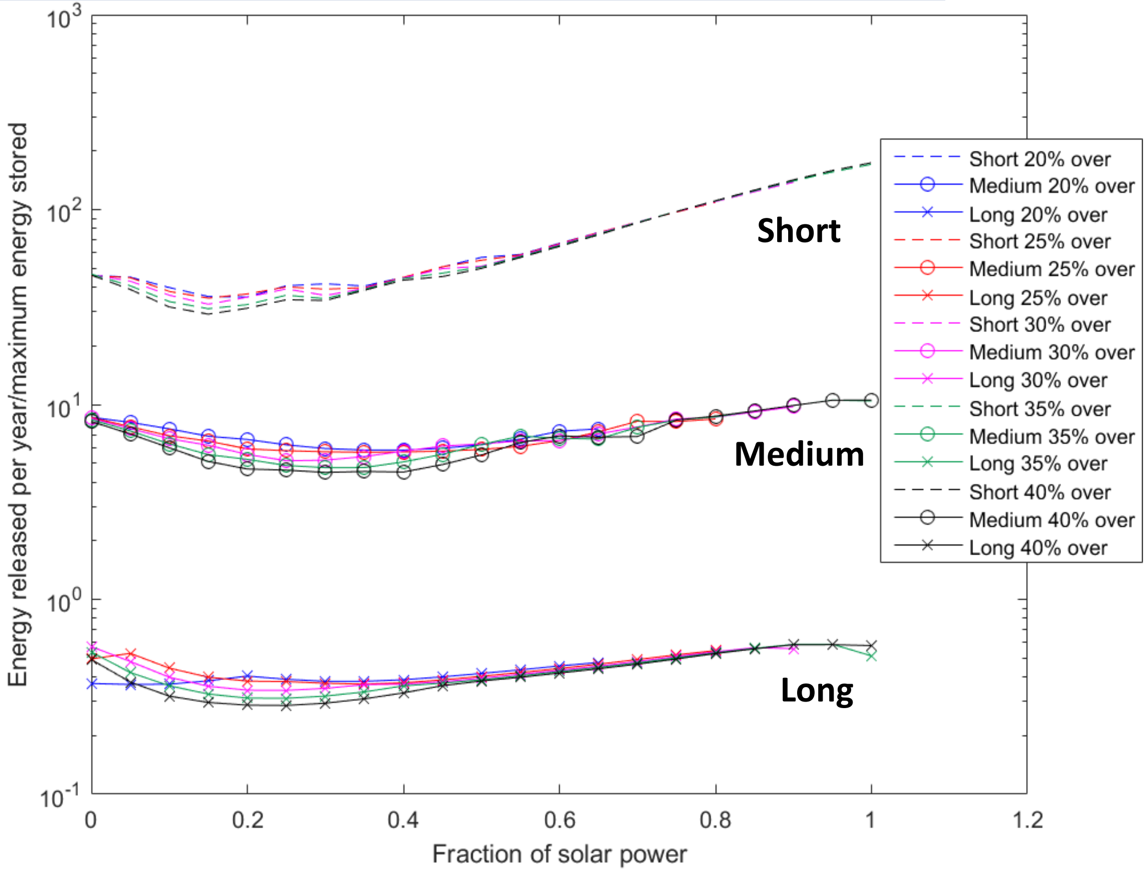
Long period Store
Size v Mix

Weather periodicity - multiple stores behaviour

Stores: **Short 6 hours** 100GWh **Medium 168 hours** ~2 TWh; **Long** ~60 TWh
Energy release (~100 TWh pa) dominated by cycling of Medium duration store - unless very high solar shares.
Very different cycling rates - <1 to 30 per year for different types of (unconstrained) stores.



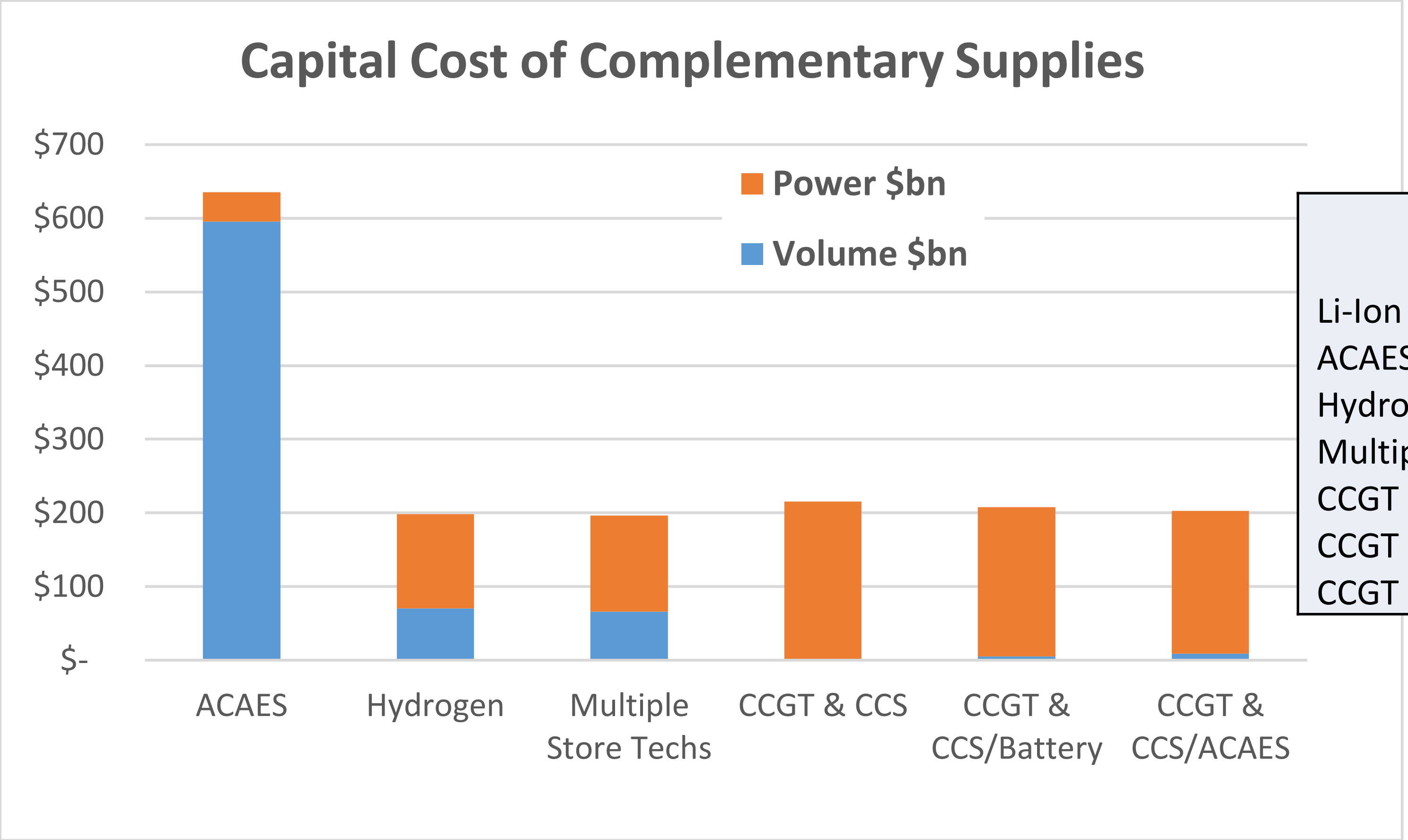
Energy Release pa v Mix - 100% renewables



Store Cycles pa v Mix - 25% Baseload

Capex Options - 2050 Renewable Systems

Storage technology & CCGT & CCS examples for Complementary supplies



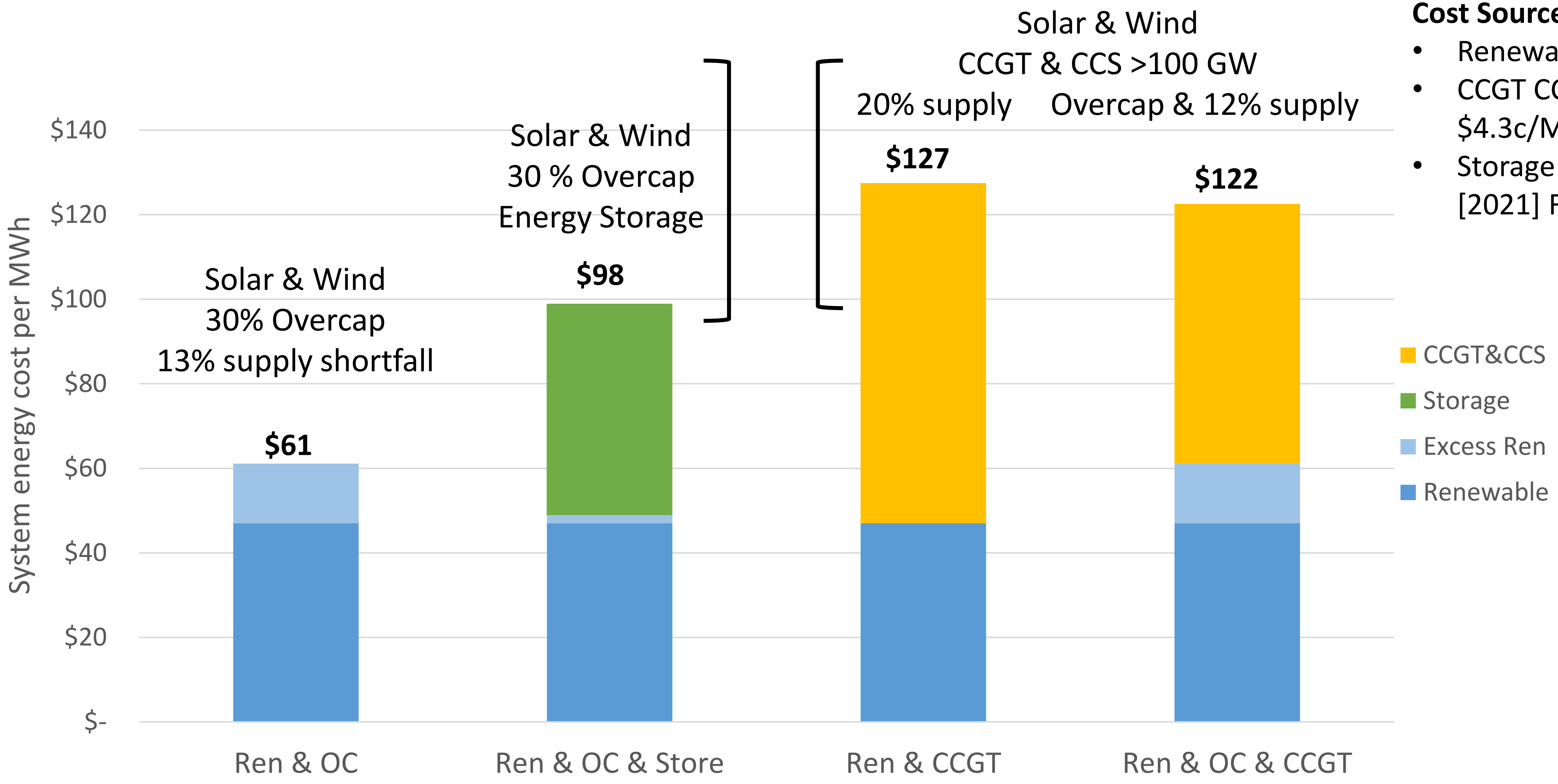
Case	RTE	Volume TWh	Power GW		$bn
Li-Ion Batteries	90%	58	100	$	**5,855**
ACAES	70%	66	100	$	**636**
Hydrogen	40%	88	100	$	**198**
Multiple Store Techs	56%	74	120	$	**196**
CCGT & CCS	-	-	100	$	**215**
CCGT & CCS/Battery	-	0.05	50/90	$	**208**
CCGT & CCS/ACAES	-	1	20/90	$	**203**

Cost Sources:

- CCGT CCS – Wood (2018)
- Storage cost – Roulstone [2021] Future.

System energy cost comparisons

Renewables plus storage & CCGT & CCS system energy costs are similar



Solar & Wind
30% Overcap
13% supply shortfall

Solar & Wind
30 % Overcap
Energy Storage

Solar & Wind
CCGT & CCS >100 GW
20% supply Overcap & 12% supply

Cost Sources:

- Renewables - WEO 2021]
- CCGT CCS – Wood, Fuel $4.3c/MMBTU
- Storage cost – Roulstone [2021] Future.

References

1. **UK Committee on Climate Change (May 2019).** Net Zero - The UK's contribution to stopping global warming.
2. **Imperial College (2019).** Supporting data for CCC. https://www.theccc.org.uk/publication/net-zero-the-uks-contribution-to-stopping-global-warming/
3. **IEA (2021) World Energy Outlook** Renewables - Analysis and forecasts.
4. **Shaner M et al. (2018)** Geophysical constraints on the reliability of solar and wind power in US. Energy & Env. Science 2018.
5. **Renewables.ninja** GB https://www.renewables.ninja/
6. **Roulstone et al (2021).** The Need for Energy Storage. Draft Chapter RS WG Energy Storage. DOI 10.13140 Jan 2021
7. **Cosgrove, Roulstone & Zachary (2023)**. Intermittency and Periodicity in Net-zero Renewable Energy Systems with Storage. Journal of Renewable Energy. Vol. 212 August 2023. https://doi.org/10.1016/j.renene.2023.04.135
8. **Roulstone (2022).** UK Multi-year Renewable Energy Systems with Storage - Cost Investigation. University of Cambridge, April 2022. https://doi.org/10.13140/rg.2.2.33695.43689
9. **Staffell & Pfenninger (2016**). Using bias-corrected reanalysis to simulate current and future wind power output. Energy 114. 1224-39 Nov 2016.
10. **Strbac (2018).** An analysis of alternative UK heat de-carbonisation pathways – for the Committee on Climate Change. Imperial College.
11. **MIT (2022).** Future of Energy Storage. MIT Energy Initiative 2022.
12. **Royal Society (2023).** Long Duration Energy Storage. September 2023.
13. **Wood (2018) for BEIS.** Assessing the Cost Reduction Potential and Competitiveness of Novel (Next Generation) UK CCCS Benchmarking State-of-the-art and Next Generation Technologies Document Number: 13333-8820-RP-001