Imperial College London

Future cost of electricity storage in power system applications

Oliver Schmidt, Sylvain Melchior, Iain Staffell

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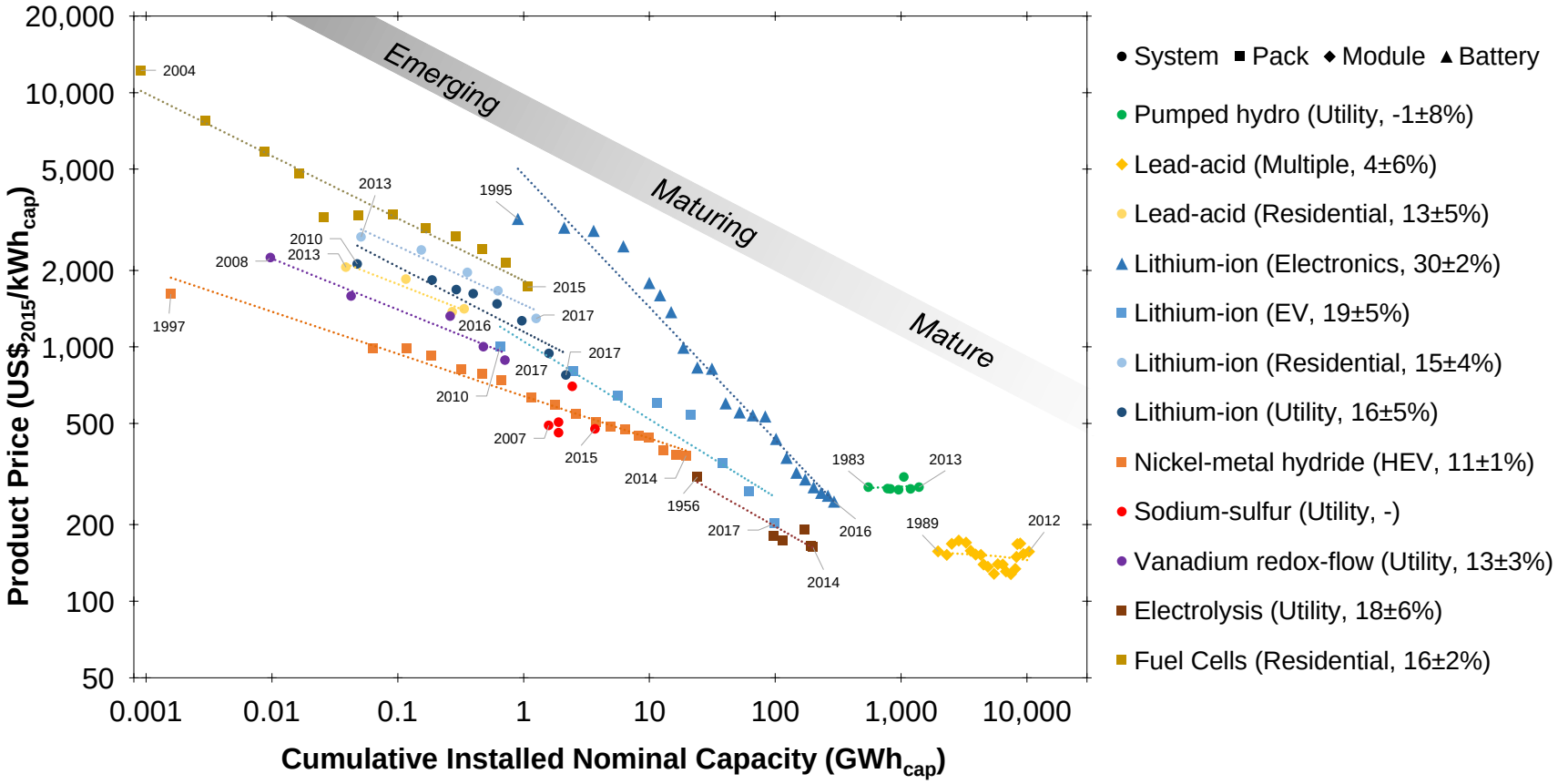
Grantham Institute

Experience curve dataset for storage technologies can predict investment cost

Experience Curve Dataset



Source: Updated from O. Schmidt, A. Hawkes, A. Gambhir & I. Staffell. The future cost of electrical energy storage based on experience rates. Nat. Energy 2, 17110 (2017)

But, comparison of technologies must be based on levelised cost of storage (LCOS)

LCOS Formula

- Investment cost
- Construction time
- Replacement cost / interval

- Charging cost
- O&M cost

$$LCOS\left[\frac{\$}{MWh}\right] = \frac{Investment\ cost\ +\ Operating\ cost\ +\ Disposal\ cost}{Electricity\ discharged}$$

- Round-trip efficiency
- Depth-of-discharge
- Annual cycles
- Cycle life
- Calendar life
- Degradation

- End-of-life cost or residual value

▶ The discounted cost of a "MWh" discharged from the storage device

We model LCOS of 9 storage technologies in 12 power system applications up to 2050

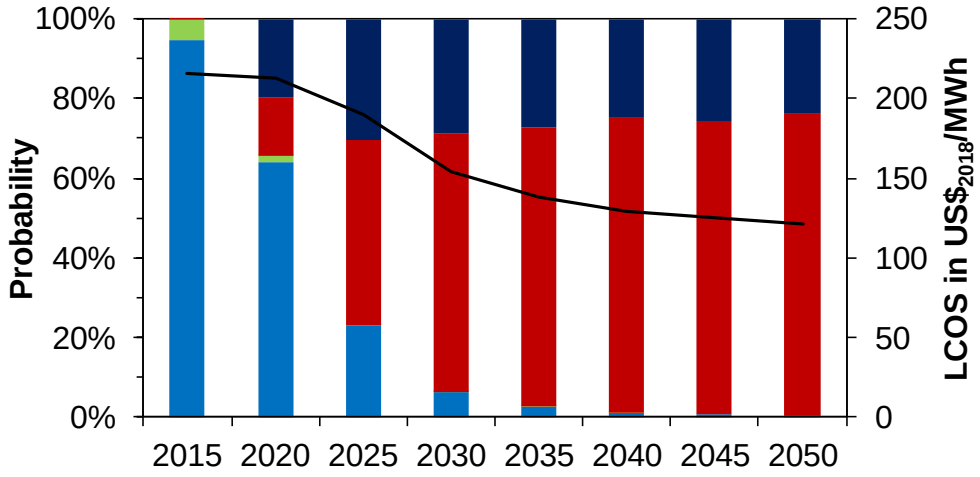
Applications vs Technologies

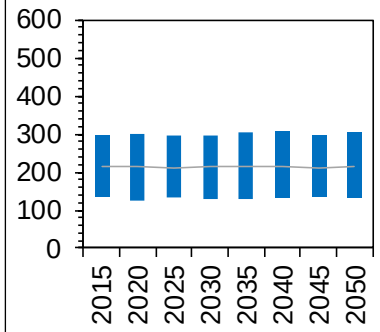
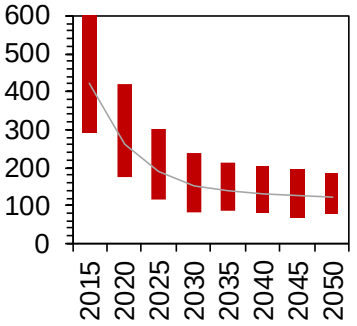
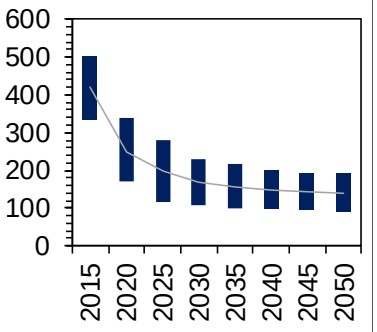
Role	Application	Pumped hydro	CAES	Fly-wheel	Li-ion	Sodium-sulfur	Lead-acid	VRFB	Hydro-gen	Super-cap.
	1. Energy arbitrage	✓	✓		✓	✓	✓	✓	✓	
System operation	2. Primary response			✓	✓	✓	✓	✓	✓	✓
	3. Secondary response	✓	✓	✓	✓	✓	✓	✓	✓	✓
	4. Tertiary response	✓	✓		✓	✓	✓	✓	✓	
	5. Peaker replacement	✓	✓		✓	✓	✓	✓	✓	
	6. Black start	✓	✓	✓	✓	✓	✓	✓	✓	✓
	7. Seasonal storage	✓	✓					✓	✓	
Network operation	8. T&D upgrade deferral	✓	✓		✓	✓	✓	✓	✓	
	9. Congestion mgmt	✓	✓		✓	✓	✓	✓	✓	
Consumption	10. Bill management				✓	✓	✓	✓	✓	
	11. Power quality			✓	✓	✓	✓	✓	✓	✓
	12. Power reliability				✓	✓	✓	✓	✓	

Lithium-ion and vanadium redox-flow will compete for secondary response

③ Secondary Response

Power Capacity	100 MW
Discharge duration	1 hour
Annual cycles	1000
Charging cost	50 $/MWh

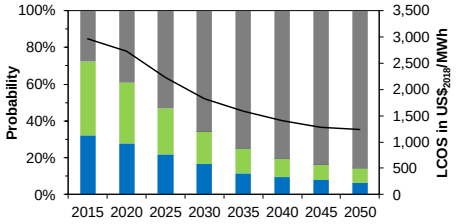


	Pumped hydro	Compressed air	Lithium-ion	Vanadium redox-flow
LCOS in US$2018/MWh				

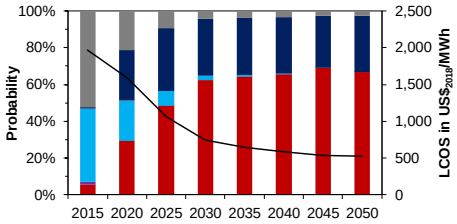
Lithium-ion becomes dominant technology in most applications by 2030

Application overview

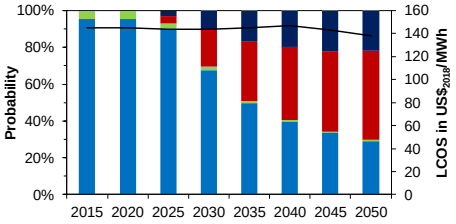
7 Seasonal storage



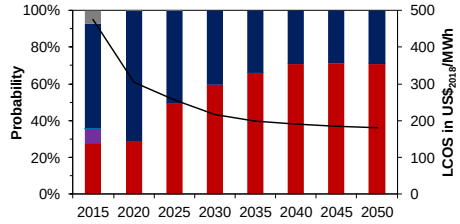
12 Power reliability



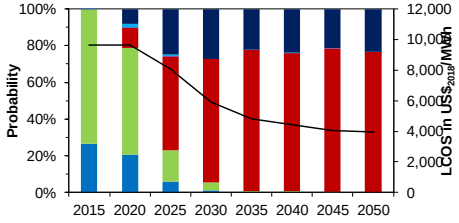
8 T&D deferral



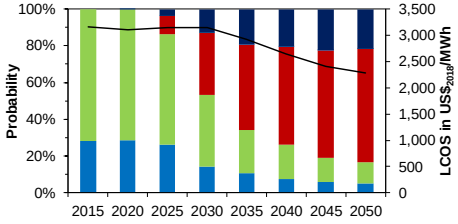
10 Bill management



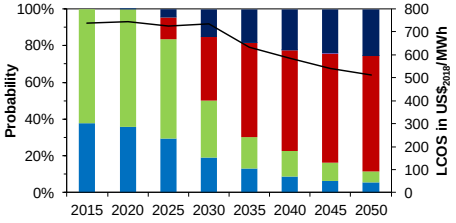
6 Black start



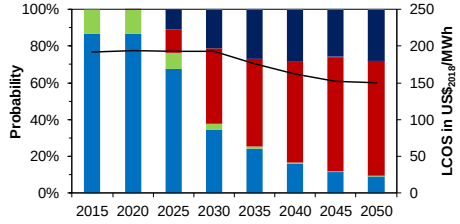
4 Tertiary response



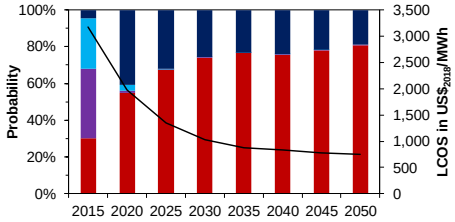
5 Peaker replacement



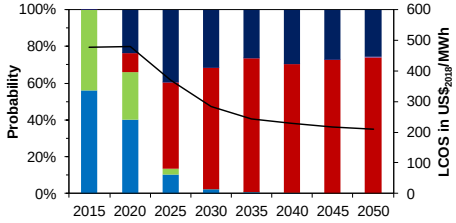
1 Energy arbitrage



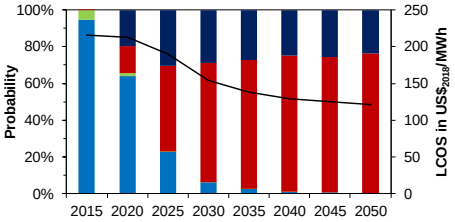
11 Power quality



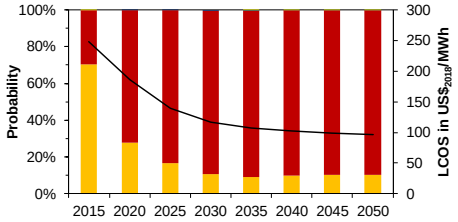
9 Congestion management



3 Secondary response

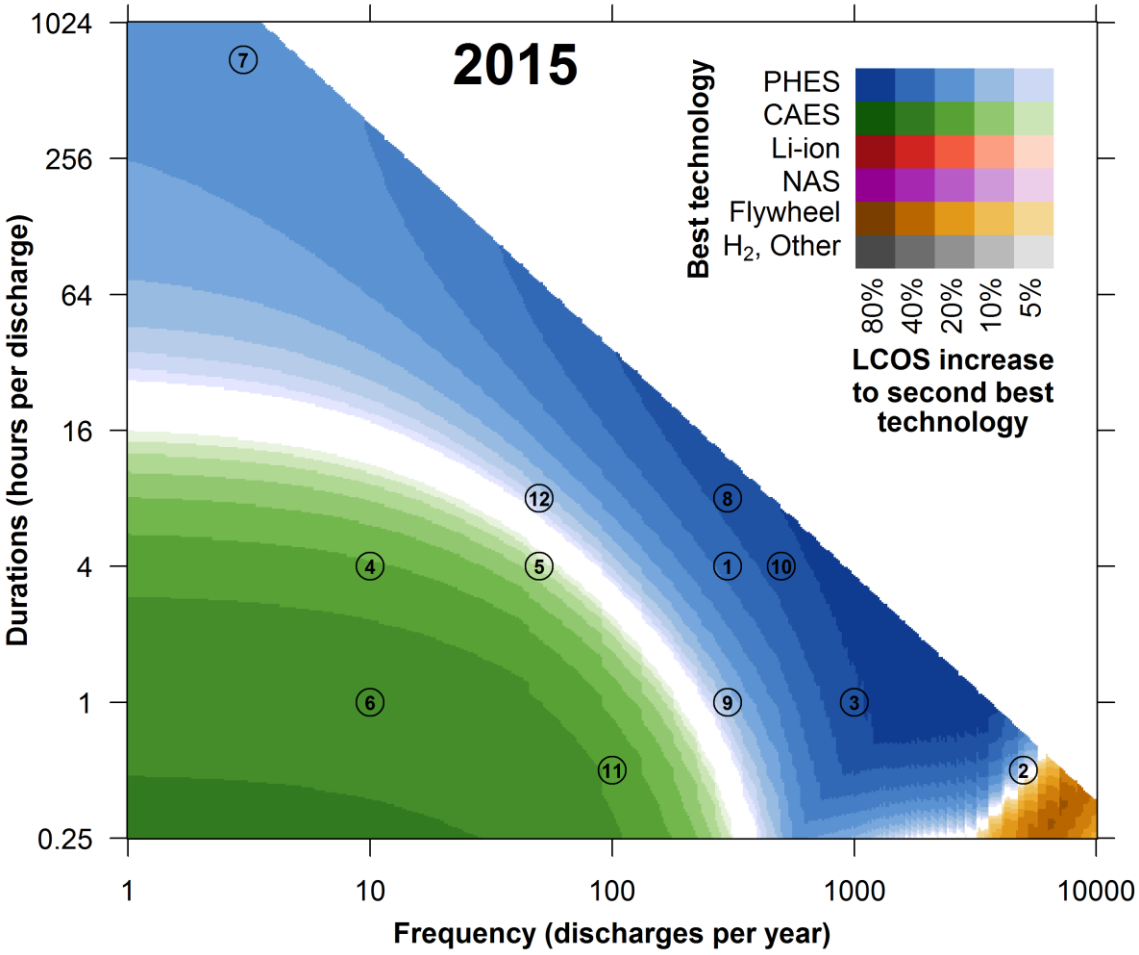


2 Primary response



Overall, pumped hydro and compressed air give way to lithium-ion and hydrogen

General overview



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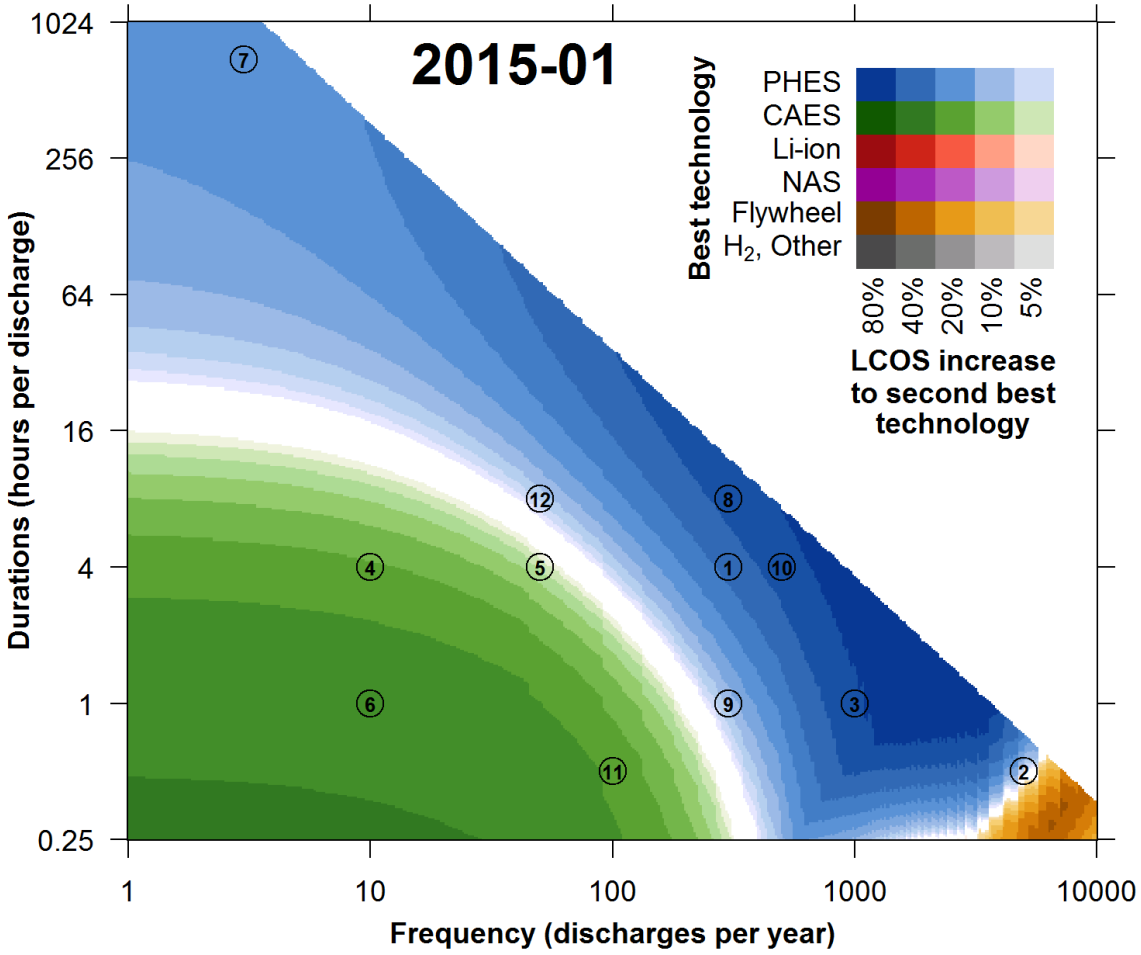
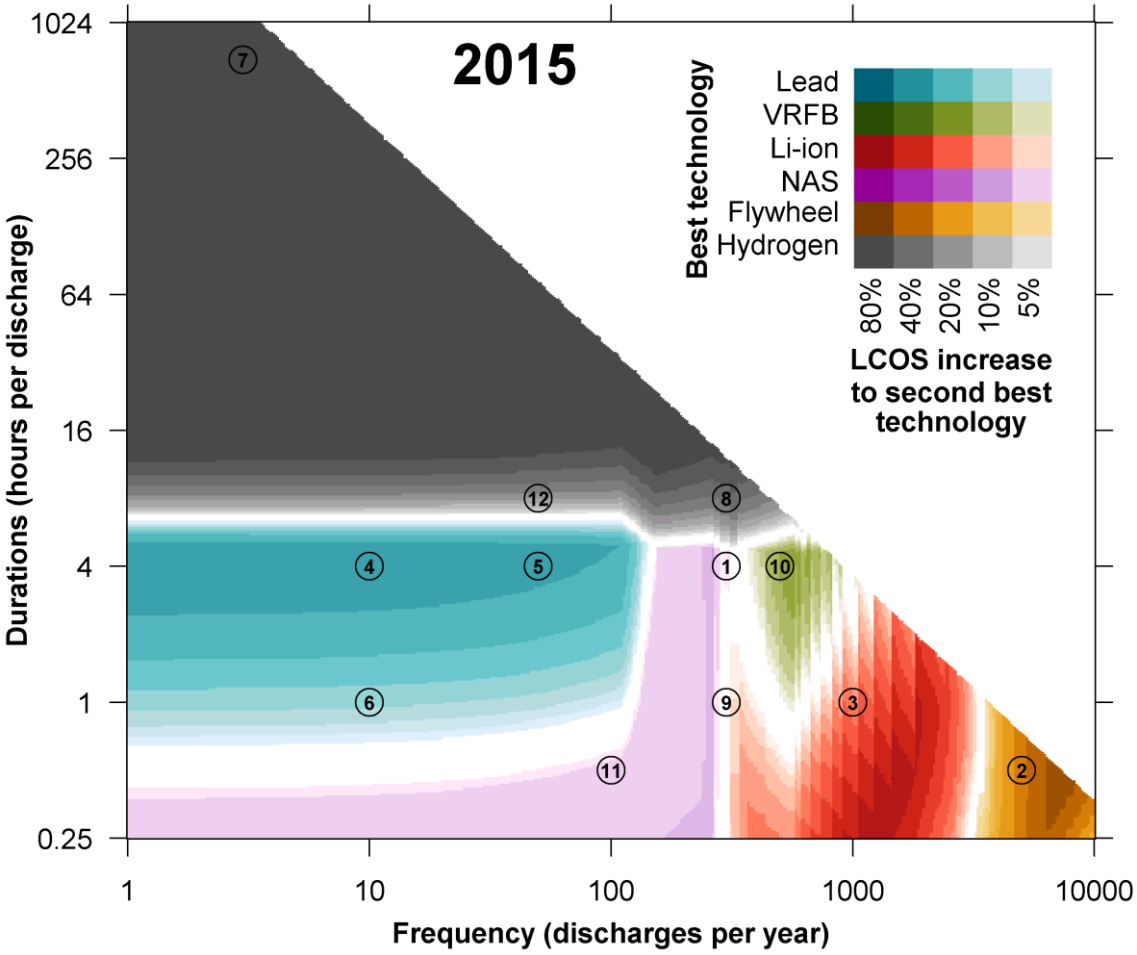


Lithium-ion more competitive than all other battery technologies by 2030

General overview – excl PHS, CAES



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NERC SCIENCE OF THE ENVIRONMENT

Discussion

Methodology:

Results:

Oliver Schmidt | PhD Researcher in Energy Storage
Grantham Institute - Climate Change and the Environment
Imperial College London, Exhibition Road, London SW7 2AZ
Tel: +44 (0) 7934548736
Email: o.schmidt15@imperial.ac.uk
Website: www.storage-lab.com

Grantham Institute