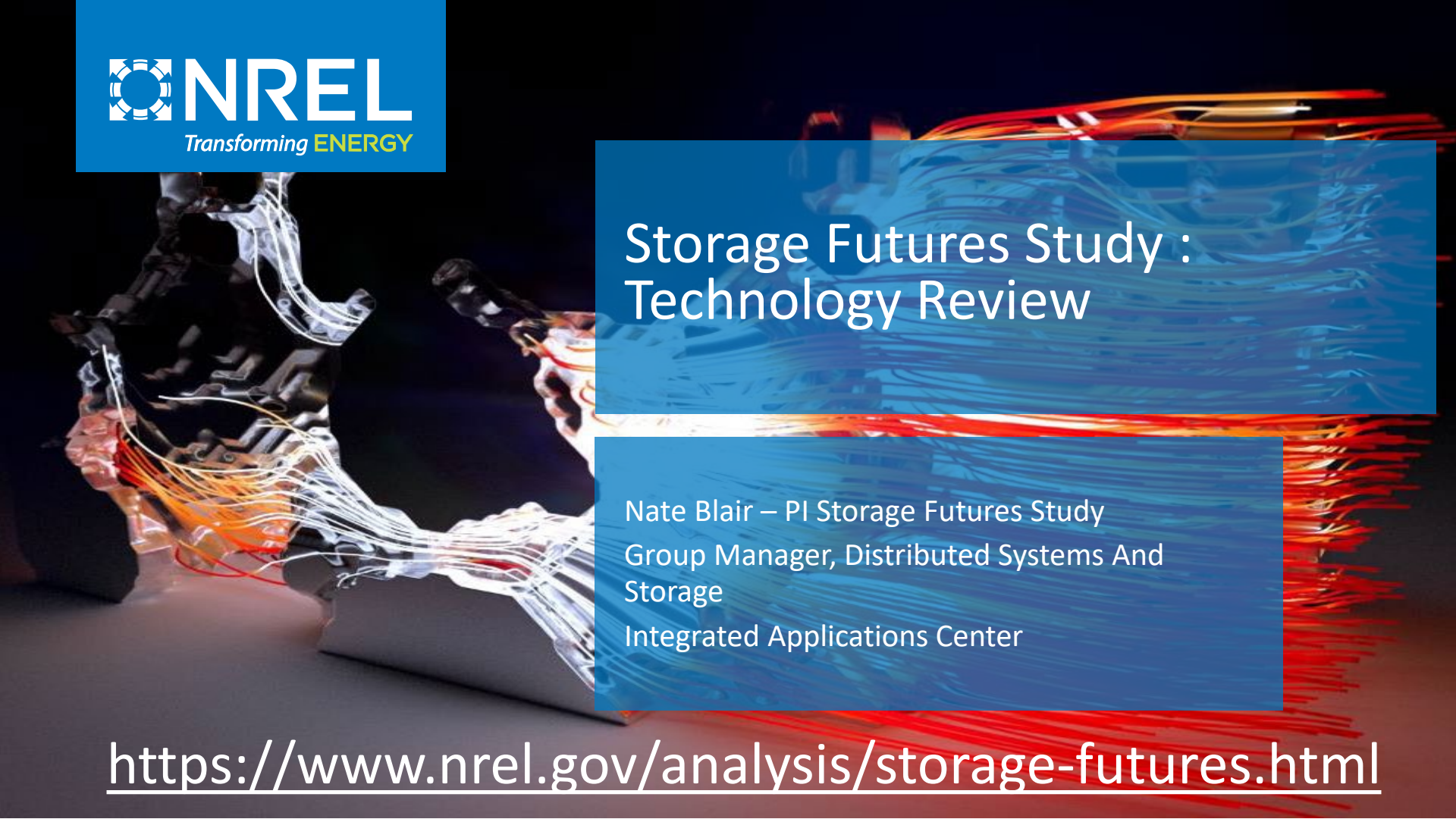

NREL
Transforming ENERGY

Storage Futures Study : Technology Review

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Integrated Applications Center

https://www.nrel.gov/analysis/storage-futures.html

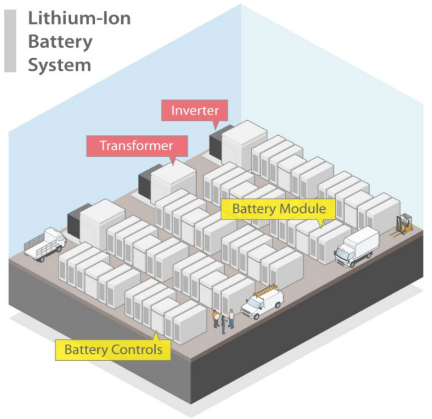
The Four Phases of Storage Deployment

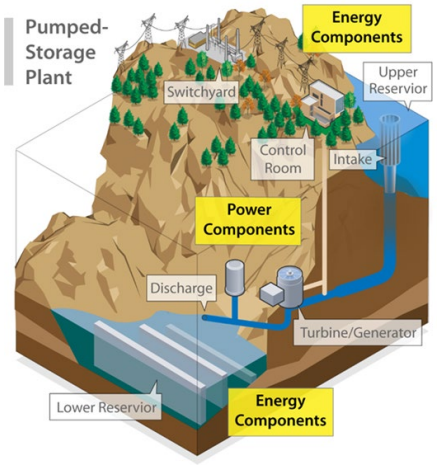
Phase	Primary Service	National Potential in Each Phase	Duration	Response Speed
Deployment prior to 2010	Peaking capacity, energy time shifting and operating reserves	23 GW of pumped hydro storage	Mostly 8–12 hr	Varies
1	Operating reserves	<30 GW	<1 hr	Milliseconds to seconds
2	Peaking capacity	30–100 GW, strongly linked to PV deployment	2–6 hr	Minutes
3	Diurnal capacity and energy time shifting	100+ GW. Depends on both on Phase 2 and deployment of variable generation resources	4–12 hr	Minutes
4	Multiday to seasonal capacity and energy time shifting	Zero to more than 250 GW	Days to months	Minutes

While the Phases are roughly sequential there is considerable overlap and uncertainty!

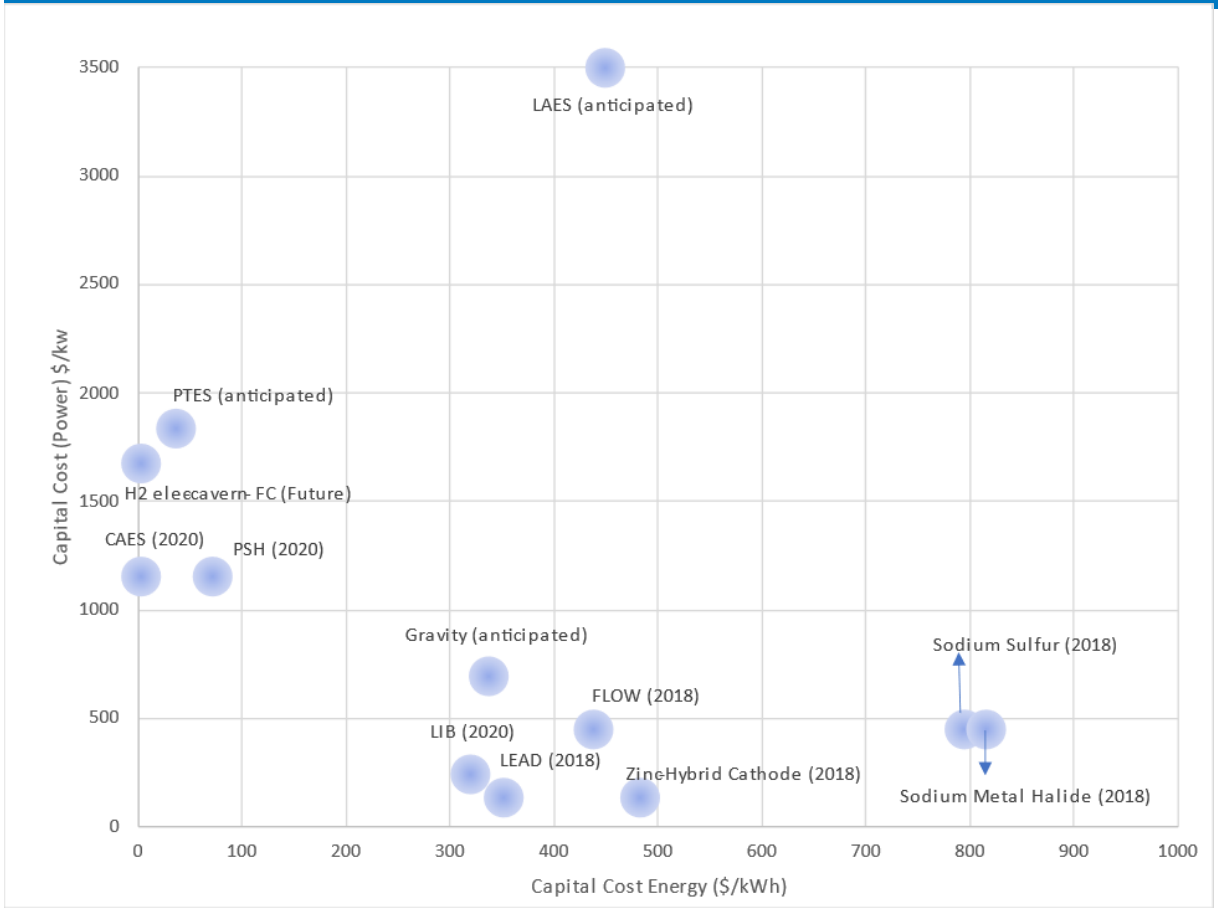
Storage Futures Study collected data on a wide variety of storage technologies

Storage Type/Technology	Primary Data Source
Thermal Storage	
Pumped thermal energy storage (PTES)	(McTigue et al. In Press)
Electrochemical Storage	
Lithium-ion battery (LIB)	Multiple sources; see References (p. 58)
Lead-acid battery	Mongird et al. 2020
Redox flow battery (flow batteries)	Mongird et al. 2020
Sodium sulfur battery	Mongird et al. 2019
Sodium metal halide battery	Mongird et al. 2019
Zinc-hybrid cathode battery	Mongird et al. 2019
Ultracapacitors	Mongird et al. 2019
Hydrogen storage (using electrolyzers, salt caverns, and stationary fuel cells)	Hunter et al. 2021
Electromechanical Storage	
Compressed air energy storage (CAES)	Mongird et al. 2020
Liquid air energy storage (LAES)	Olympios et al. In Press
Pumped-storage hydropower (PSH)	Mongird et al. 2020
Flywheel	Mongird et al. 2019
Gravity	Schmidt 2018





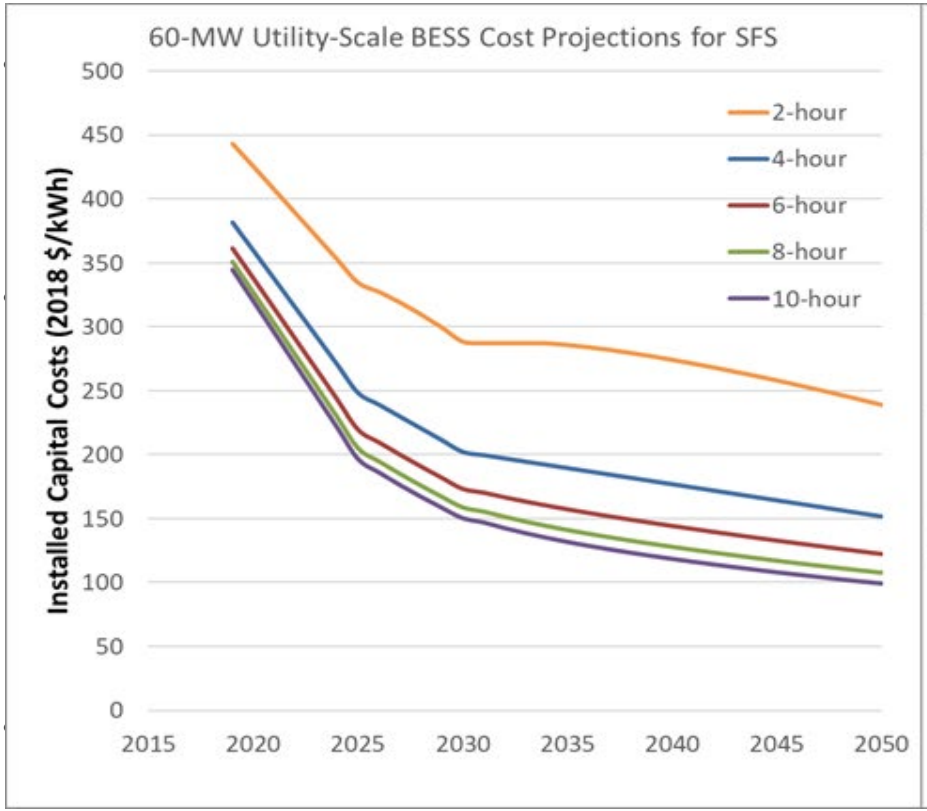
Some technologies scale better with duration

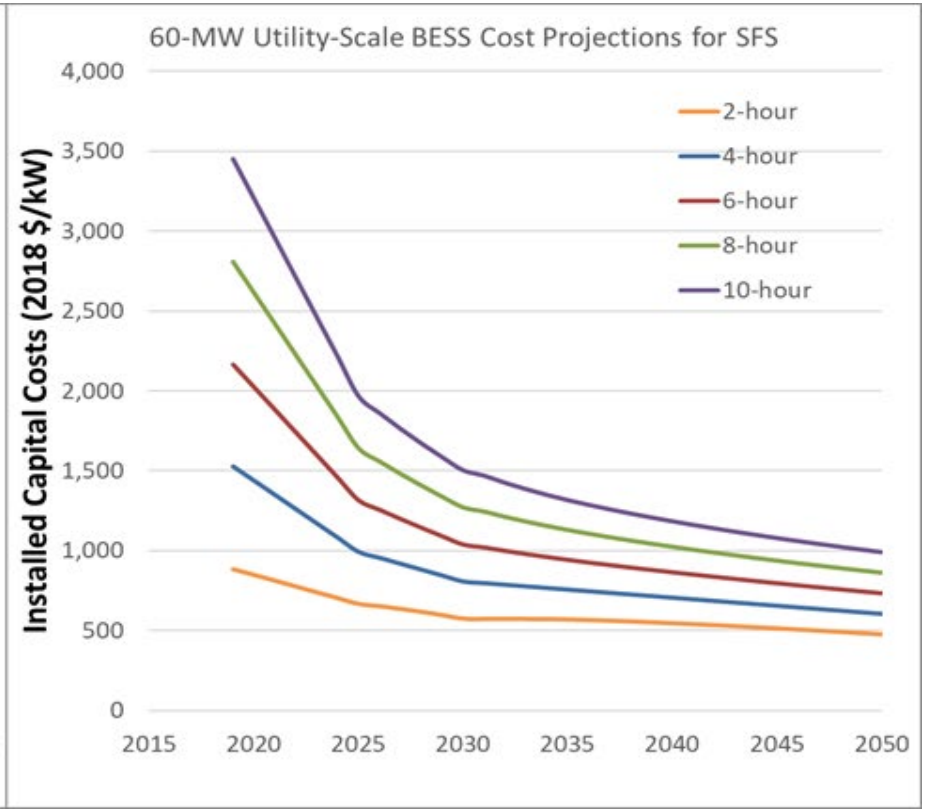


- Total cost is combination of both axis
- Low cost per duration ($/kwh) better for long-duration
- Low $/kW cost better for short-duration use cases
- Difficult to determine for emerging technologies

Capital cost for energy ($/kWh) versus capital cost for capacity ($/kW) for various technologies

Future Battery Costs by Cost Scenario - Moderate





Capital Cost vs. Duration for Storage Technologies