

BATTERY STORAGE

ACCELERATING THE ENERGY TRANSITION

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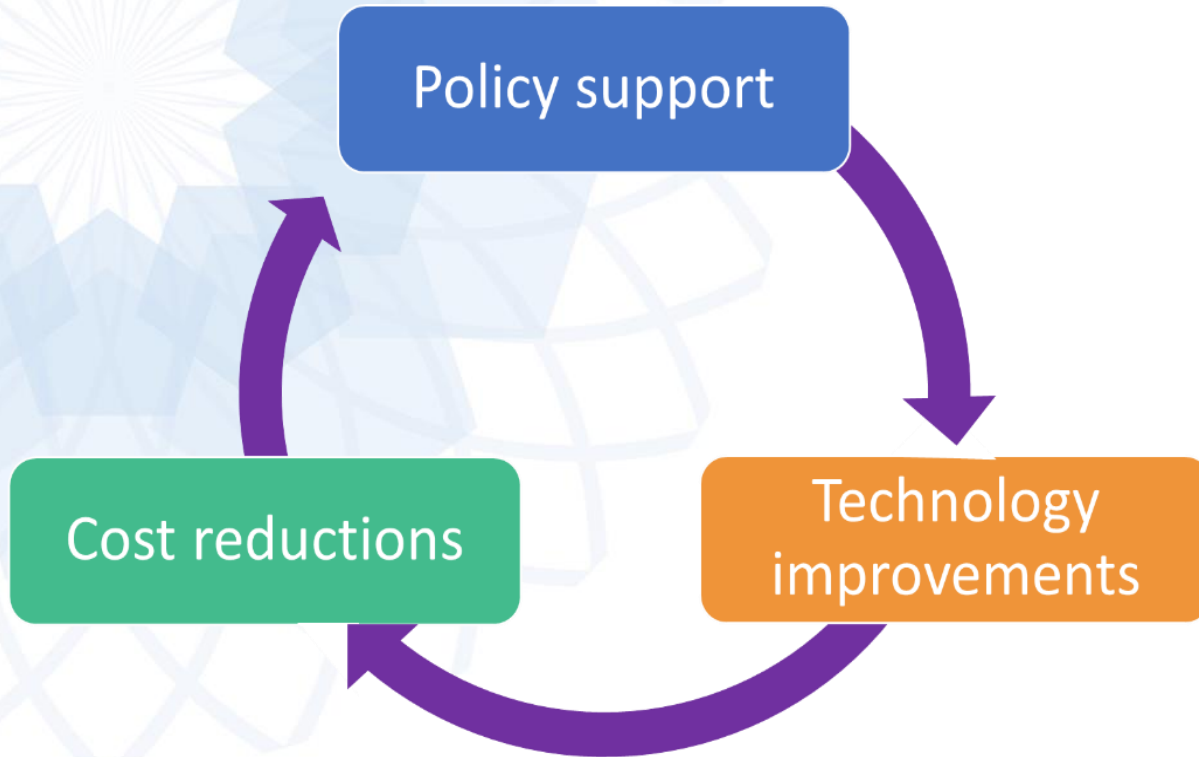
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WHY BATTERY STORAGE IS IMPORTANT

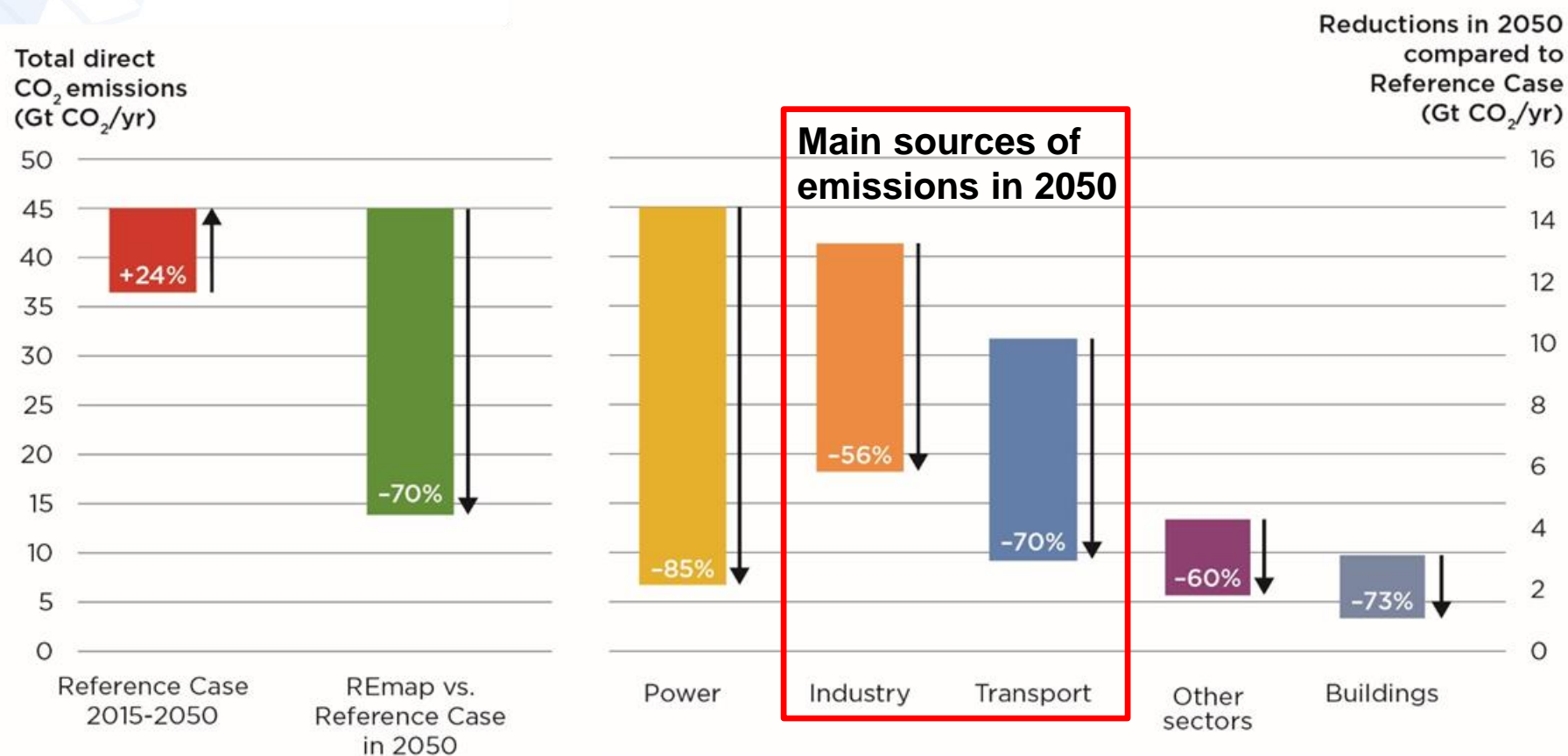
The Energy Sector is Being Transformed



A *virtuous cycle* is unlocking the **economic**, **social** and **environmental** benefits of renewables

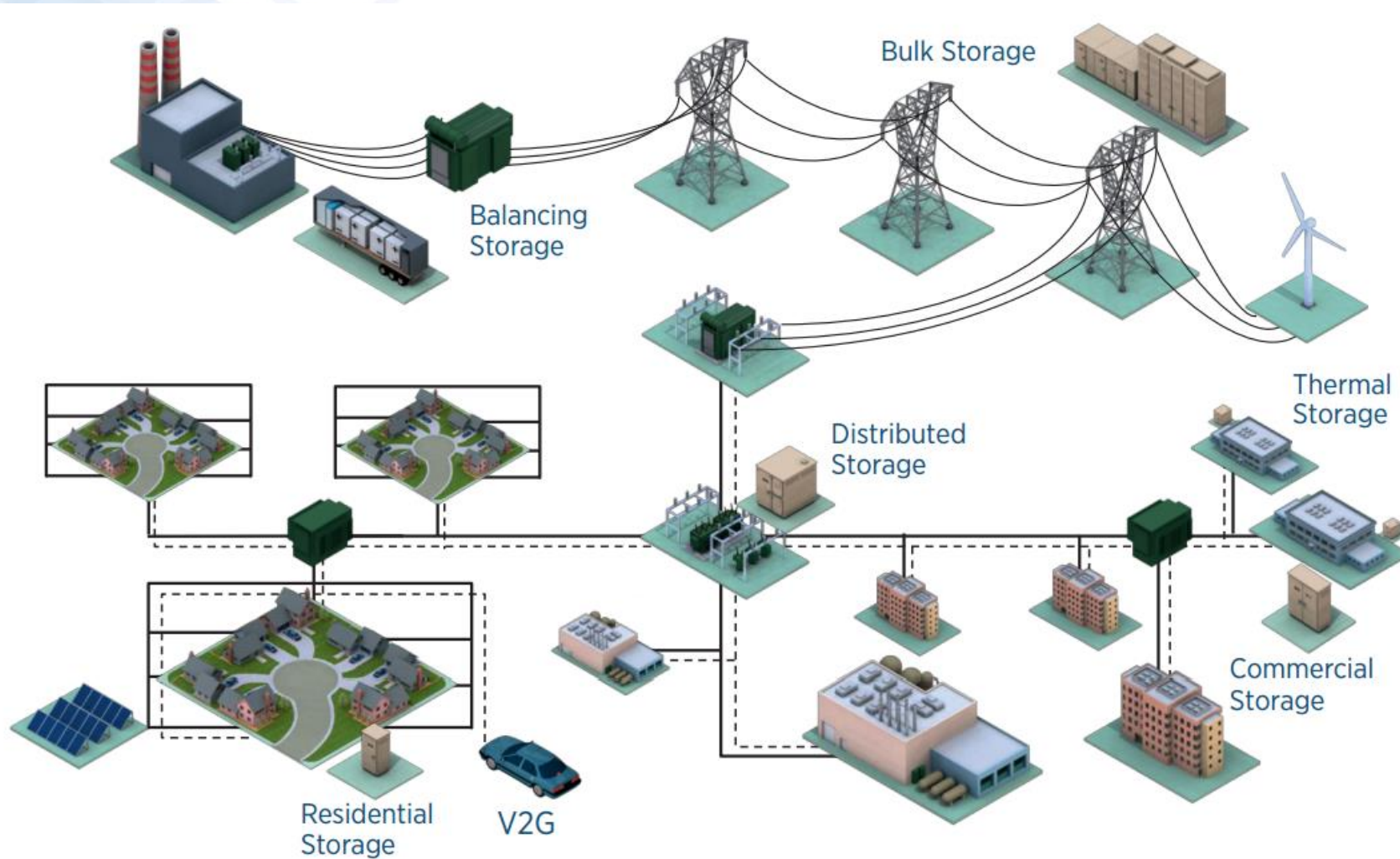


Development in CO₂ emissions by sector

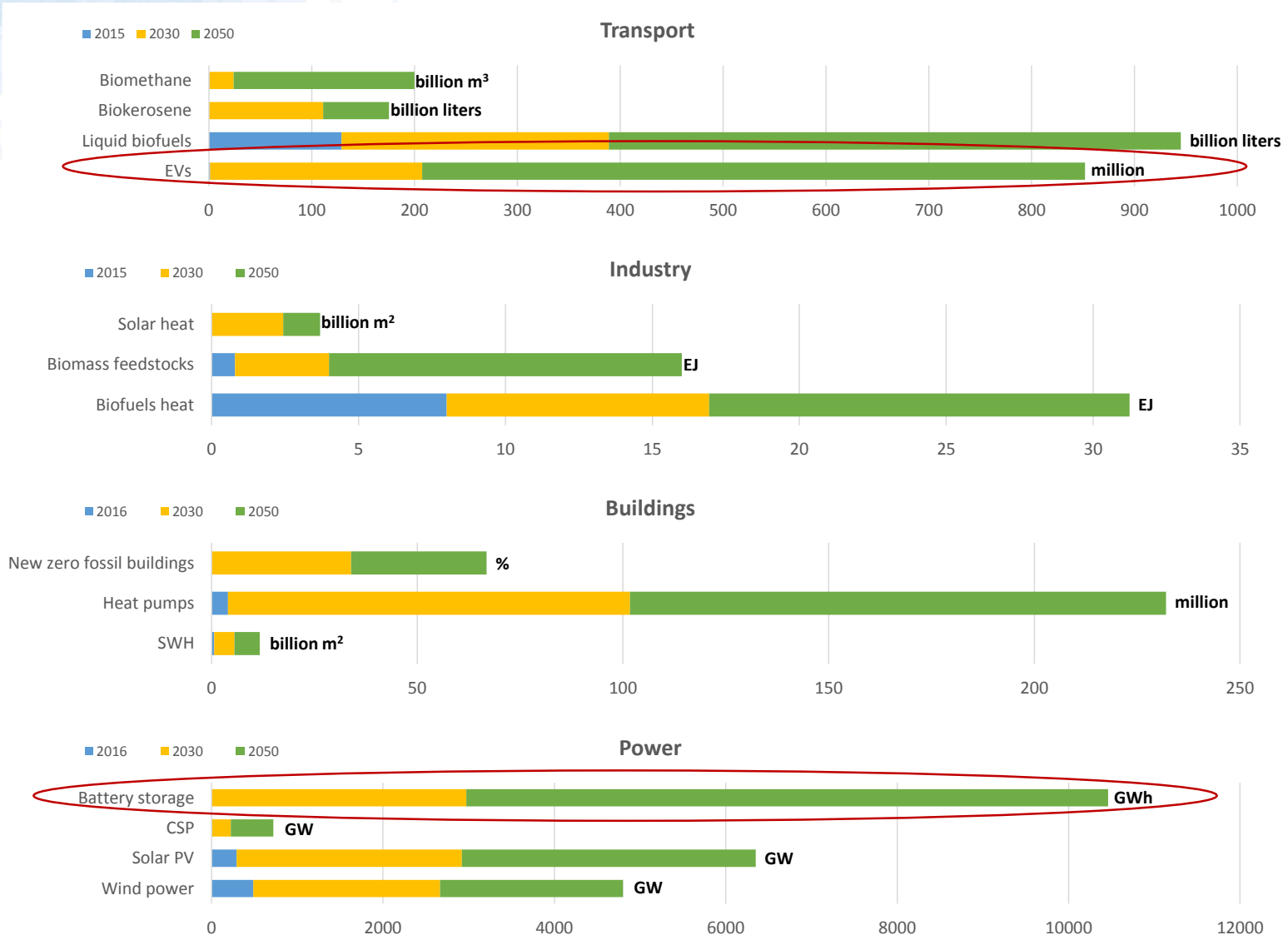


By 2050, total energy-related CO₂ emissions will need to decrease to below 10 Gt/yr
CO₂ emissions from the power and buildings sectors will be almost eliminated

Potential locations and applications of electricity storage



The end-use sectors transition: untapped area



Transport

- Will traditional car makers able to catch up?
- Significant biofuel trade
- Materials needs (e.g. rare earth for EVs)

Industry

- Industry is the most challenging sector

Buildings

- Significant acceleration of buildings renovation

Power

- Growing equipment industries
- Materials needs (e.g. for batteries, inverters)

Storage

The importance of battery storage and roles

- Battery storage important part of transition now to medium-term (e.g. SHS, islands, frequency response and EVs)
- Long term to integrate v high share of VRE)
- In the next 3-5 years, the storage industry is positioned to scale
- Incremental improvements in energy storage technologies, developments in regional regulatory and market drivers, and emerging business models are poised to make energy storage a growing and viable part of the electricity grid
- In the stationary sector, increased economic applications due to cost declines are expected for grid services

BATTERY ELECTRICITY STORAGE FOR STATIONARY APPLICATIONS

Context

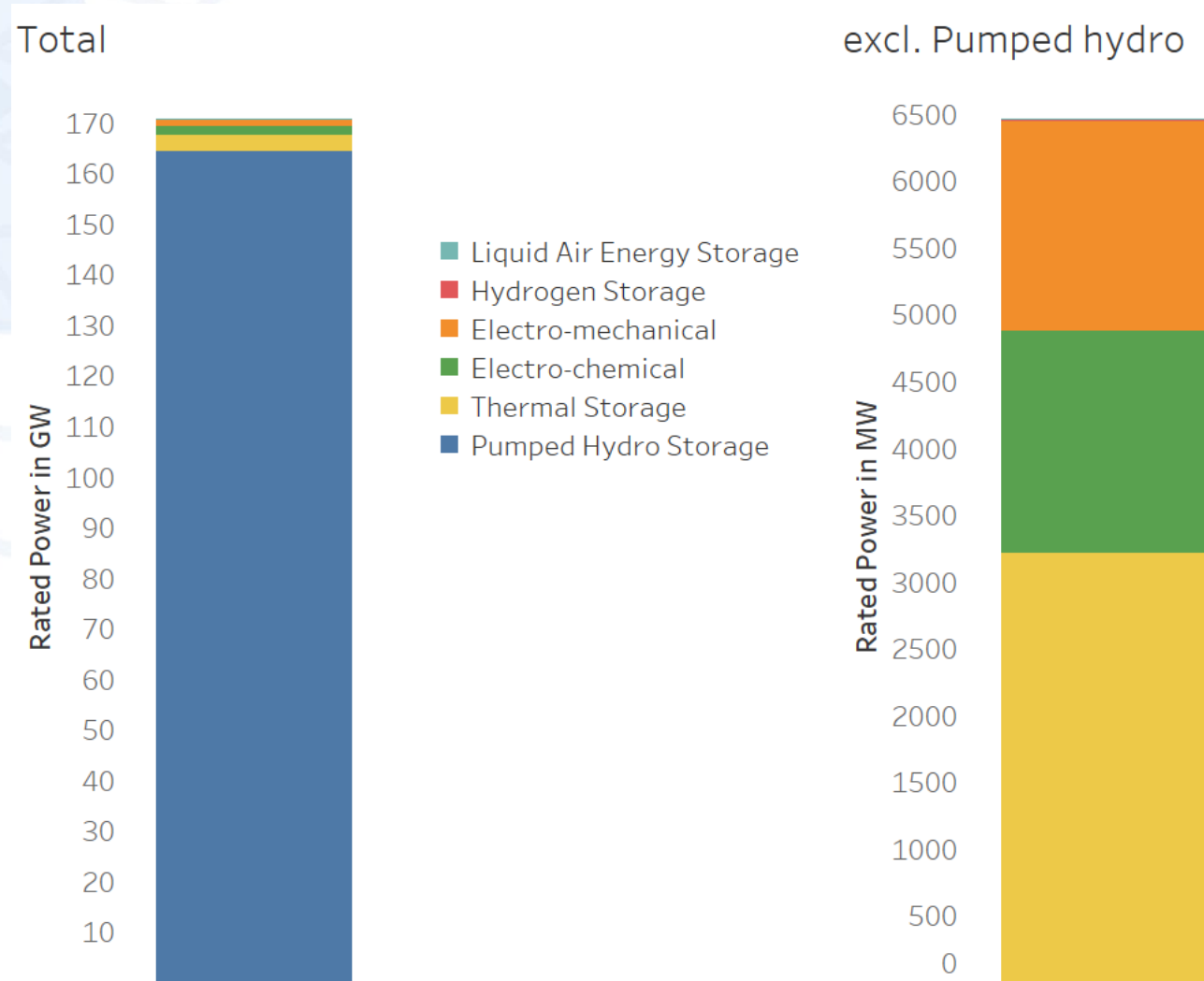
IRENA's RE costs and markets team is preparing a study to analyze and discuss stationary battery electricity options and costs

Existing market and technology options

Latest performance and cost data (and the breakdown of costs into components) for electricity storage technologies in different geographic markets and market segments/applications.

Cost reduction potential, competitiveness of battery storage for different services and market growth in detail for electricity storage devices, focusing on batteries to 2030

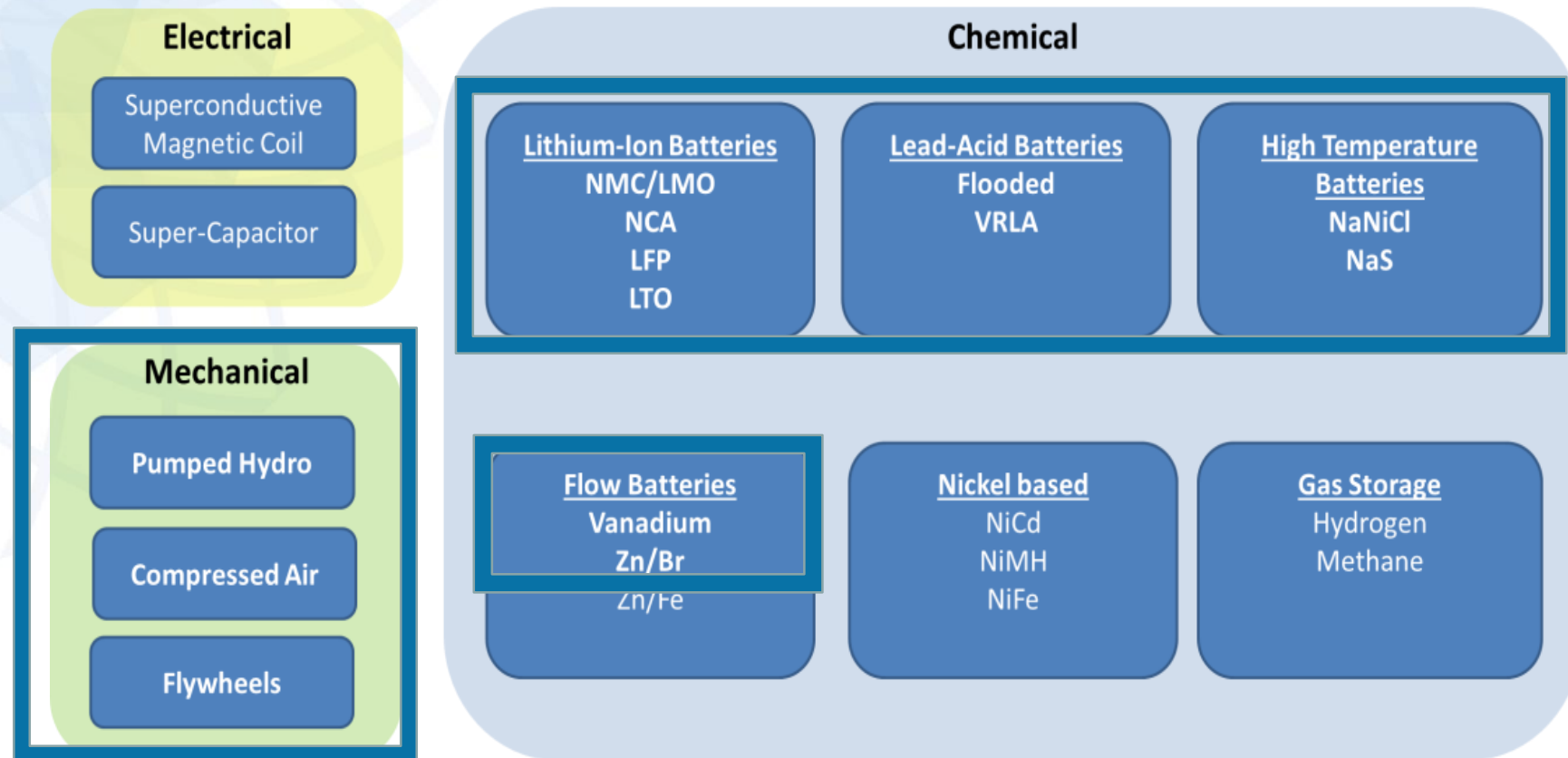
Stationary storage today



• Source: DOE

Technology overview

Scope of analysis



> 150 literature sources

Expert interviews

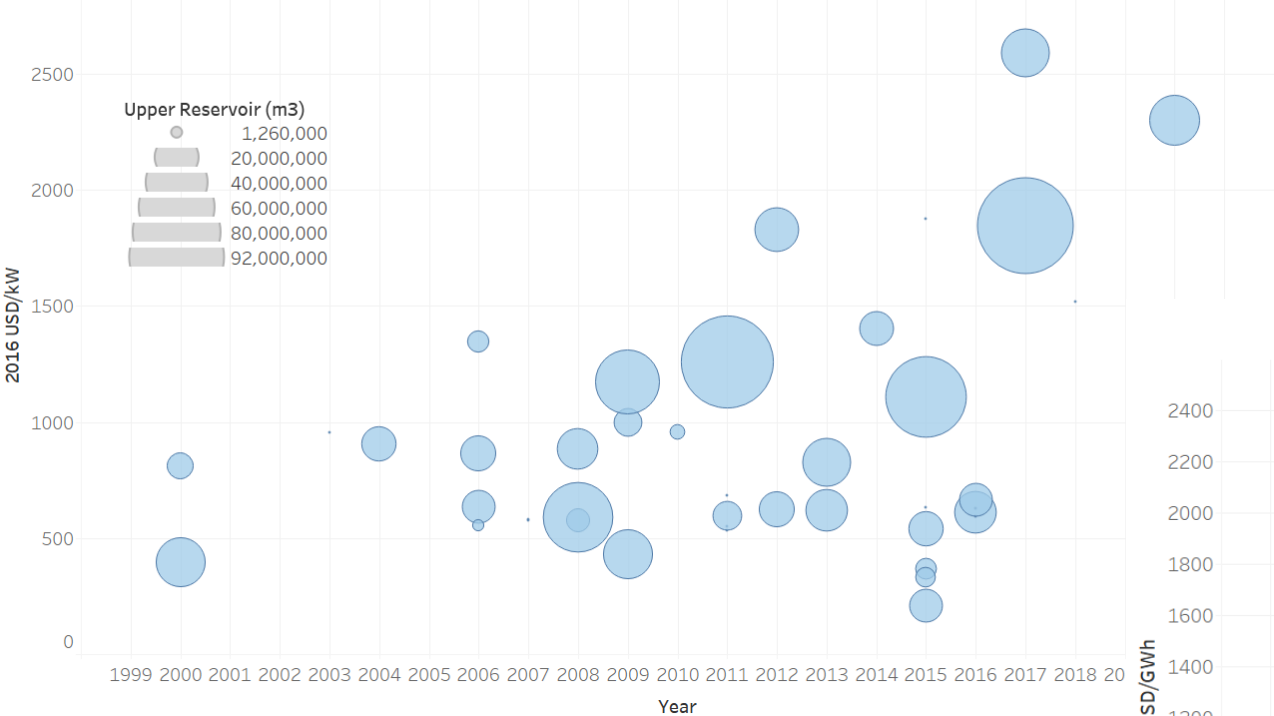




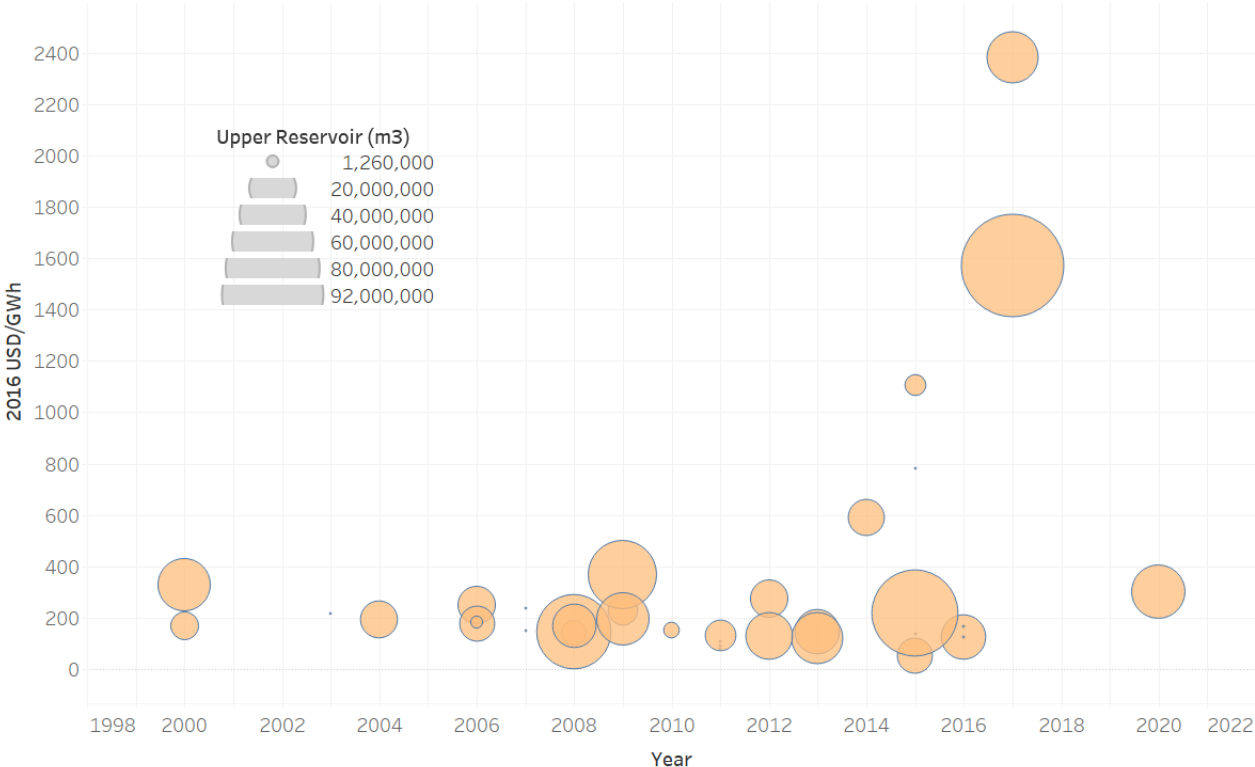
COST AND TECHNOLOGY STATUS

Current prices: Pumped Hydro Storage

Pumped Hydro Storage Costs

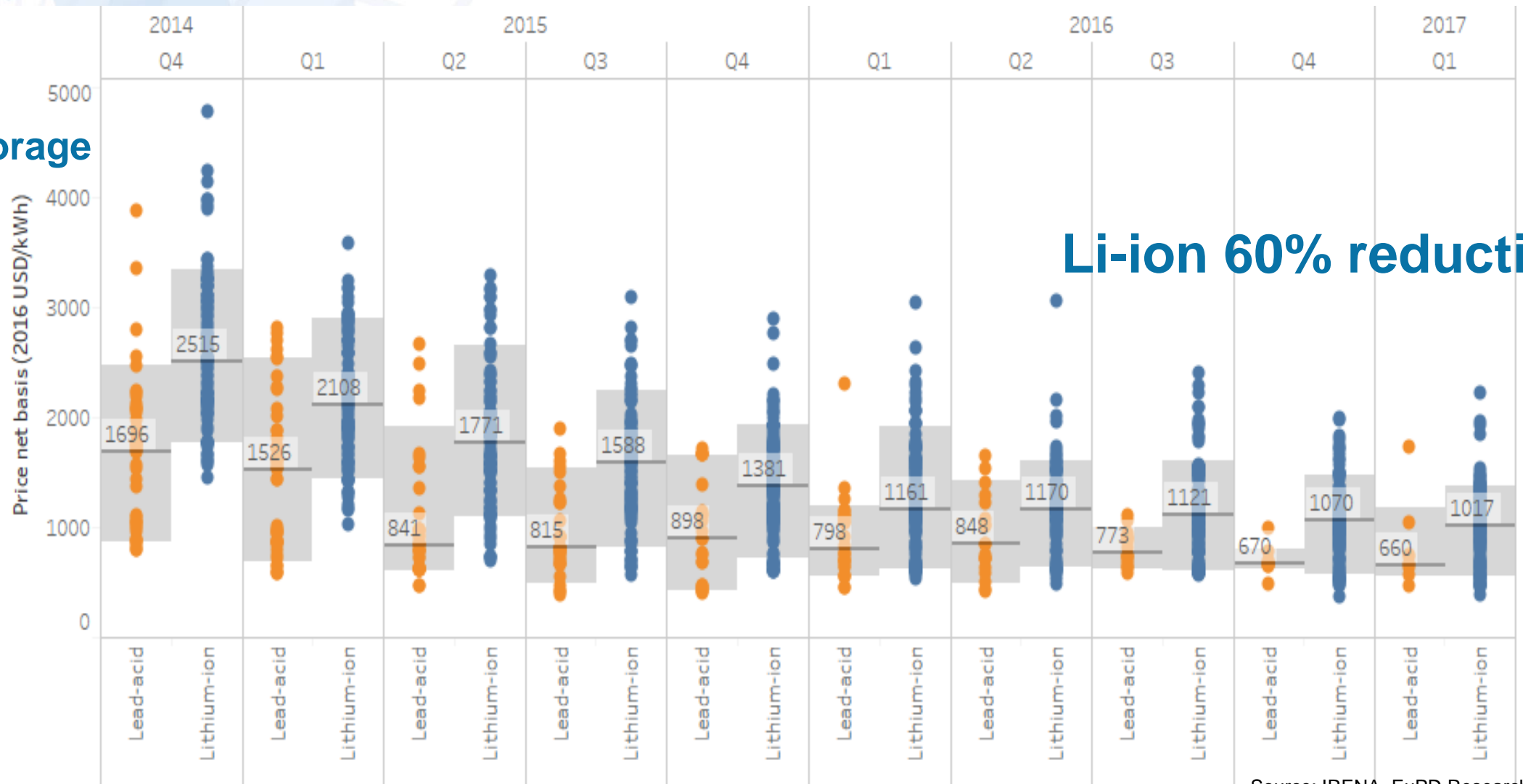


Pumped Hydro Storage Costs



Small-scale: rapidly falling prices

Home storage



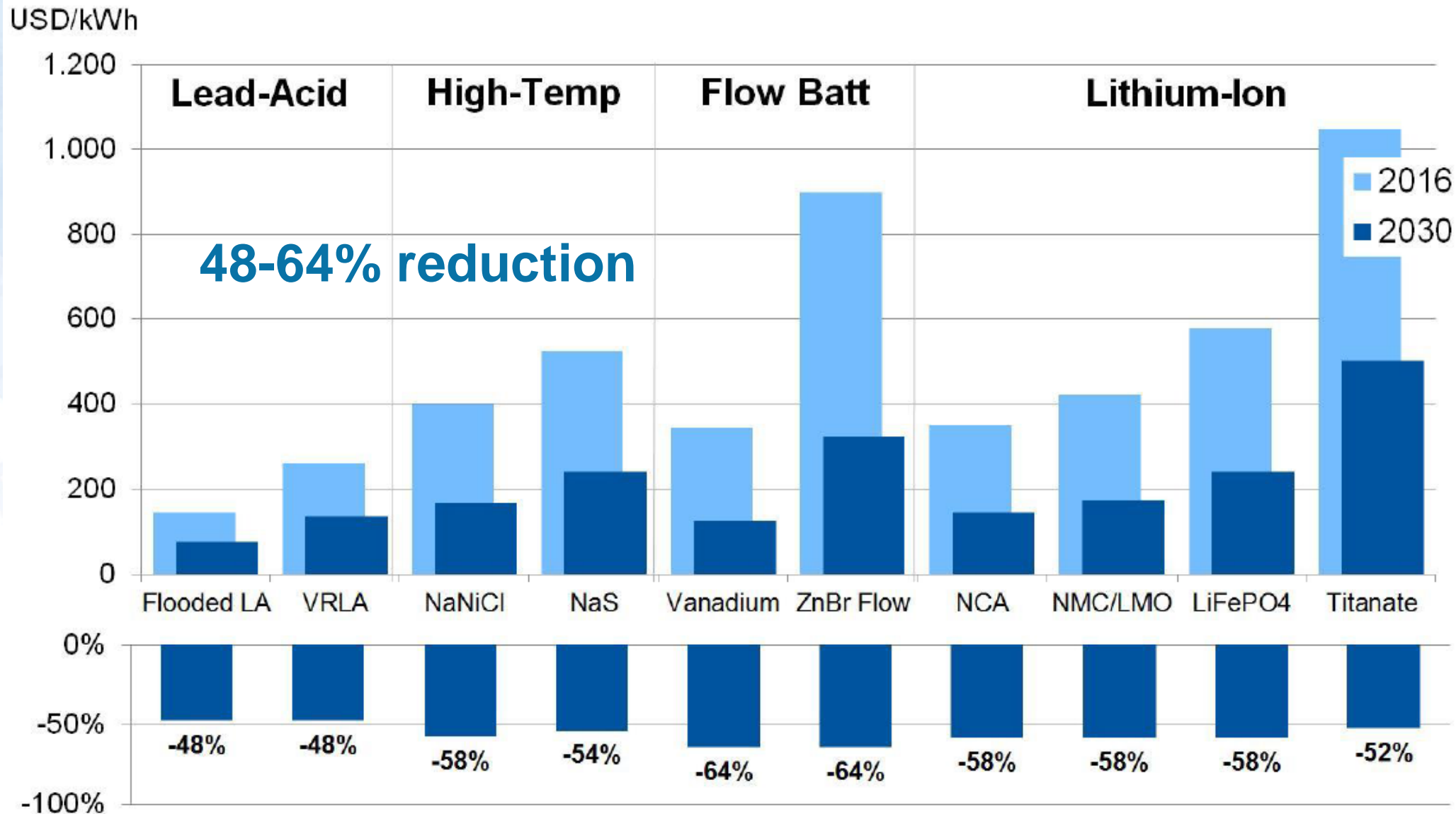
Li-ion 60% reduction!

Source: IRENA, EuPD Research

Median prices for lithium-ion based residential storage system offers in **Germany** have declined roughly 60% Q4 2014 to Q1 2017

Note: Horizontal bar shows median offer price, grey range 10th and 90th percentile.

Potential cost evolution



Prices in 2030
USD 80 - 400/kWh

Compared to 2016
USD 190 - 1050/kWh

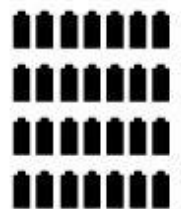
CHINA IS LEADING THE CHARGE

Lithium-ion megafactories in China to grow capacity 6X by 2020



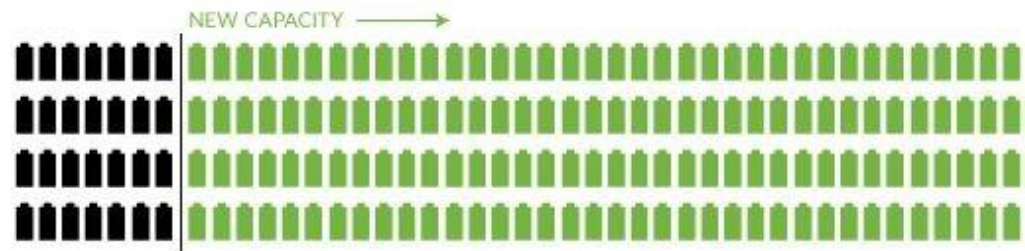
Global lithium-ion battery production capacity will increase by **521%** between 2016 and 2020.

Capacity in
2016

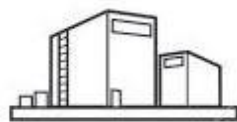


28
GWh

Capacity in
2020



174
GWh



China's battery sector continues to be a hub for most of this growth.

Source: <http://www.visualcapitalist.com/china-leading-charge-lithium-ion-megafactories/>

	2016 Capacity (GWh)	2020 Capacity (GWh)	% of Global Total (2020)
United States	1.0	38.0	22%
China	16.4	107.5	62%
Korea	10.5	23.0	13%
Poland	0.0	5.0	3%
Total	27.9	173.5	100%

Tech sheets for 15 technologies

Compressor

- Adiabatic CAE
 - Improve efficiency
- Only two facilities
 - Huntorf (Germany)
 - McIntosh (USA)

Flywheel Electricity

- Very high self-discharge
 - Used in high frequency applications
- New concepts
 - High density fly-wheel
 - Superconducting bearings

Lead-Acid Batteries (Gel/AGM)

- Extensive operation in many stationary applications
 - No refilling required
- New concepts
 - Carbon electrodes
 - Copper stretchers

Lithium-Ion Batteries (LFP)

- Substantial scale effects in international transition towards electro mobility
- New concepts
 - Silicon anode
 - 5 V electrolytes

Lithium-Ion Batteries (LFP)

- Comparably low energy density
 - Lower efficiency
 - Increased self-discharge
- No expensive materials required

Lithium-Ion Batteries (Titanate)

- Excellent cycle life and high-power performance
 - Used in electric buses for fast charging
 - Very low self-discharge
 - High cycle life

Lithium-Ion Batteries (NCA)

- Substantial scale effects due to international transition towards electro mobility

High-Temperature Batteries (ZEBRA)

- ~350°C operating temperature
- Thermal management required

High-Temperature Batteries (NaS)

Battery Inverters (> 30kW)

- Synergies with PV inverters and traction converters (e-mobility)
- New concepts
 - Improved capacitors
 - Innovative topologies (e.g. feed-forward controls)

	unit	2016	2020	2025	2030	delta
Cycle life	-	-	-	-	-	-
Calendar life	years	15,0	16,8	19,3	22,3	+ 49%
Round-trip efficiency	%	98,0	98,0	98,0	98,0	+ 0%
Self-discharge	% per day	-	-	-	-	-
Energy installation costs	USD/kWh	-	-	-	-	-
Power installation costs	USD/kW	105,0	89,5	68,9	53,1	-49%

Table 1: Power installation costs (USD/kW)

Technology	2016	2020	2025	2030	delta
Compressor	945,0	781,6	712,7	693,4	-27%
Flywheel Electricity	21,0	21,0	21,0	21,0	+ 0%
Lead-Acid Batteries (Gel/AGM)	840,0	840,0	840,0	840,0	+ 0%

Table 2: Energy installation costs (USD/kWh)

Technology	2016	2020	2025	2030	delta
Flywheel Electricity	21,0	21,0	21,0	21,0	+ 0%
Lead-Acid Batteries (Gel/AGM)	840,0	840,0	840,0	840,0	+ 0%

Table 3: Battery Inverters (> 30kW) - Energy and Power Installation Costs

Capacity	2016	2020	2025	2030	delta
10k	10k	10k	10k	10k	+ 0%
100k	10,0	11,4	13,5	16,0	+ 60%
1000k	70,0	72,2	75,1	78,1	+ 12%
10000k	15,0	15,0	15,0	15,0	+ 0%
100000k	900	696	475	324	-64%

Table 4: High-Temperature Batteries (NaS) - Energy and Power Installation Costs

Capacity	2020	2025	2030	delta	
13k	13k	13k	13k	+ 0%	
20k	13,7	16,2	19,2	+ 60%	
100k	72,2	75,1	78,1	+ 12%	
1000k	0,2	0,2	0,2	+ 0%	
10000k	147	268	183	125	-64%
100000k	2,5	1063,8	818,2	660,7	-50%

Table 5: High-Temperature Batteries (NaS) - Energy and Power Installation Costs (continued)

Capacity	2020	2025	2030	delta
5814	6489	7500	+ 50%	
18,8	21,4	24,3	+ 43%	
81,4	83,2	85,0	+ 6%	
7,0	7,0	7,0	+ 0%	
436	326	243	-54%	

Main drivers: Lithium-ion

- Differentiation between 4 different technologies
 - NMC/LMO, NCA, LFePO₄ and Titanate
- International transition towards electro mobility leads to substantial scale effects (NCA NMC/LMO)
 - 70% price reduction since 2012
- > 170 GWh / year production capacities projected for 2020
 - Tesla Gigafactory / BYD / CALB / ...
 - LG Chem / Foxconn / CATL / ...



- Innovative developments
 - Mass production
 - Utilize silicon in anode
 - Durable LMO cathodes
 - 5 V electrolytes
 - Lithium-Sulphur
 - Lithium-Air

Example: Li-ion titanate

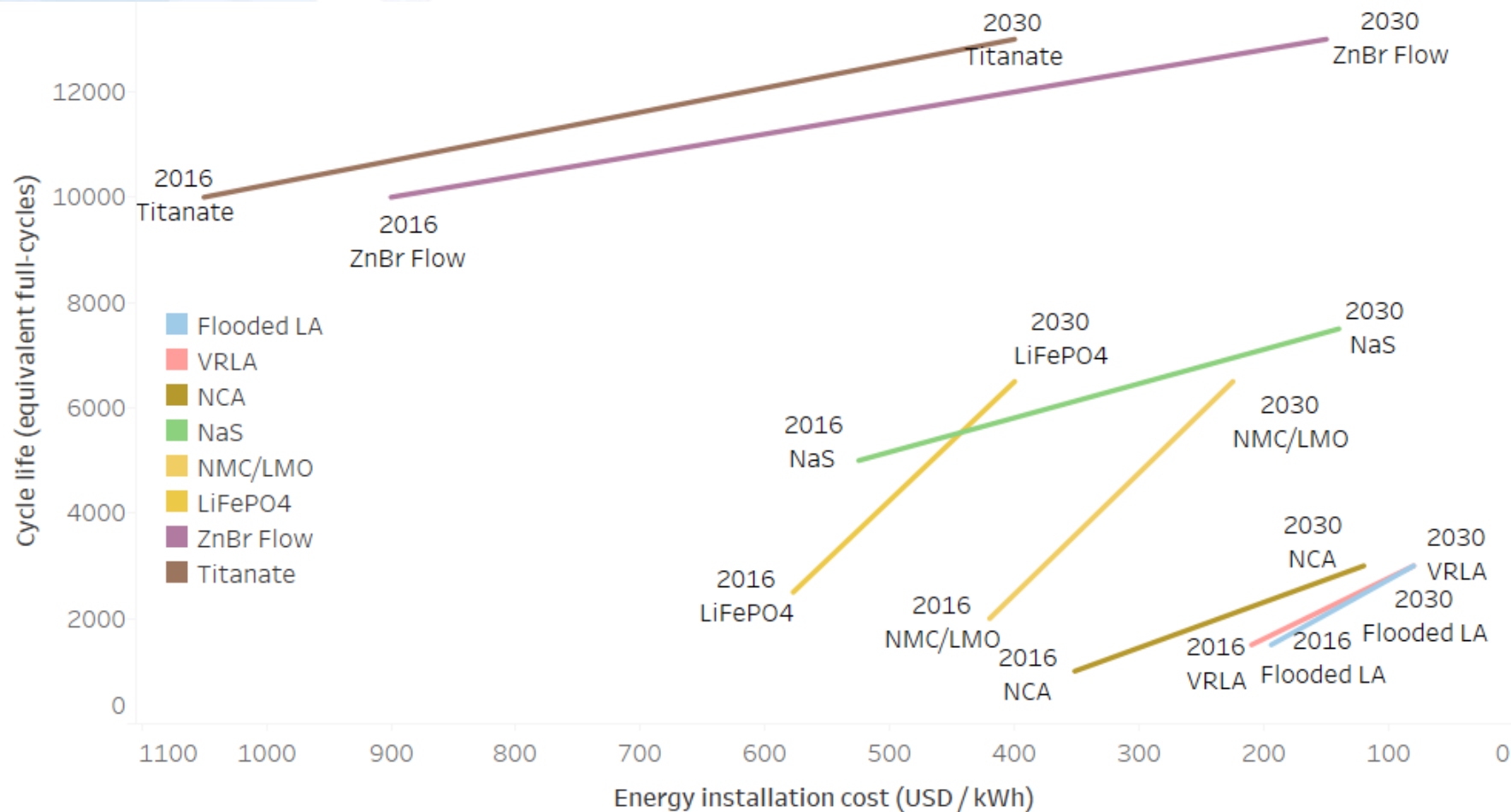
- Excellent cycle life and high-power performance
 - Used in electric busses for fast charging
 - Very low energy density compared to other lithium-ion batteries
 - High costs due to low scales



	unit	2016	2020	2025	2030	delta
Cycle life	-	10k	12k	15k	19k	+ 91%
Calender life	years	15,0	16,9	19,7	23,0	+ 53%
Round-trip efficiency	%	96,0	96,5	97,1	97,8	+ 2%
Self-discharge	% per day	0,1	0,1	0,1	0,1	+ 0%
Energy installation costs	USD/kWh	1050	880	665	502	-52%
Power installation costs	USD/kW	-	-	-	-	-

Performance

Opportunities arise also from the combined effect of higher lifetimes and lower energy installation costs





COST VS VALUE: A COMPLEX SUBJECT

Cost of service calculations: Potential market segments to examine

■ Grid Services

- Enhanced Frequency Response
- Frequency Containment Reserve
- Frequency Restoration Reserve
- Energy Shifting

■ Behind-the-meter

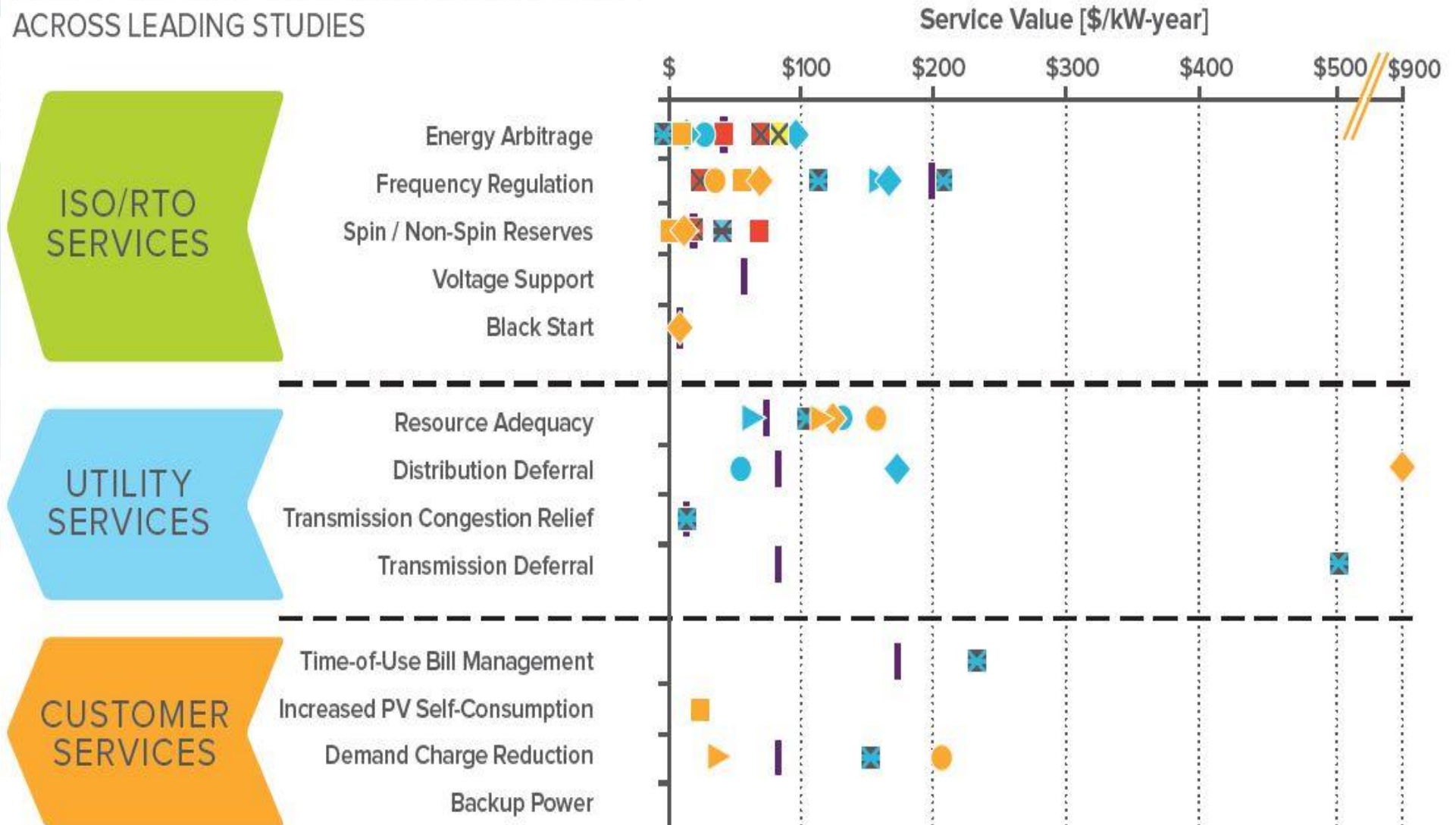
- Solar Self consumption
- Community Storage
- Increased Power Quality
- Peak Shaving
- Time-of-Use



■ Off-grid

- Nano-grid
- Village Electrification
- Island Grid

ENERGY STORAGE VALUES VARY DRAMATICALLY
ACROSS LEADING STUDIES







Source: Rocky Mountain Institute

Feasibility

Applications examples

		Pumped Hydro	CAES	Flywheel	Lead-Acid Batteries	Li-Ion Batteries	High Temperature	Flow Batteries
Grid services	Ultra fast response	Technically not feasible	Technically not feasible	Technically feasible with restrictions	Technically feasible with restrictions	Technically feasible, economic operation possible	Technically feasible, economic operation possible	Technically feasible, economic operation possible
	Primary Reserve Control	Technically not feasible	Technically not feasible	Technically feasible with restrictions	Technically feasible with restrictions	Technically feasible, economic operation possible	Technically feasible, economic operation possible	Technically feasible, economic operation possible
	Secondary Reserve Control	Technically feasible, economic operation possible	Technically feasible, economic operation possible	Technically feasible, economic operation possible	Technically feasible, economic operation possible	Technically feasible, economic operation possible	Technically feasible, economic operation possible	Technically feasible, economic operation possible
	Minute Reserve	Technically feasible, economic operation possible	Technically feasible, economic operation possible	Technically feasible, economic operation possible	Technically feasible, economic operation possible	Technically feasible, economic operation possible	Technically feasible, economic operation possible	Technically feasible, economic operation possible
	Long-time Storage	Technically feasible with restrictions	Technically feasible with restrictions	Technically feasible, economic operation possible	Technically feasible, economic operation possible	Technically feasible, economic operation possible	Technically feasible, economic operation possible	Technically feasible, economic operation possible
	Ramping	Technically feasible with restrictions	Technically feasible with restrictions	Technically feasible, economic operation possible	Technically feasible, economic operation possible	Technically feasible, economic operation possible	Technically feasible, economic operation possible	Technically feasible, economic operation possible
	Avoid Redispatch	Technically feasible, economic operation possible	Technically feasible, economic operation possible	Technically feasible, economic operation possible	Technically feasible, economic operation possible	Technically feasible, economic operation possible	Technically feasible, economic operation possible	Technically feasible, economic operation possible
Black start capability	Technically feasible, economic operation possible	Technically feasible, economic operation possible	Technically feasible, economic operation possible	Technically feasible, economic operation possible	Technically feasible, economic operation possible	Technically feasible, economic operation possible	Technically feasible, economic operation possible	
Private usage	Increase Self-Consumption	Technically not feasible	Technically not feasible	Technically feasible with restrictions	Technically feasible, economic operation possible	Technically feasible, economic operation possible	Technically feasible, economic operation possible	Technically feasible, economic operation possible
	Trade Energy (Spotmarket)	Technically feasible, economic operation possible	Technically feasible, economic operation possible	Technically feasible, economic operation possible	Technically feasible, economic operation possible	Technically feasible, economic operation possible	Technically feasible, economic operation possible	Technically feasible, economic operation possible
	Peak shifting	Technically not feasible	Technically not feasible	Technically feasible with restrictions	Technically feasible, economic operation possible	Technically feasible, economic operation possible	Technically feasible, economic operation possible	Technically feasible, economic operation possible
	Increase Power quality	Technically not feasible	Technically not feasible	Technically feasible with restrictions	Technically feasible, economic operation possible	Technically feasible, economic operation possible	Technically feasible, economic operation possible	Technically feasible, economic operation possible
	UPS functionality	Technically not feasible	Technically not feasible	Technically feasible with restrictions	Technically feasible, economic operation possible	Technically feasible, economic operation possible	Technically feasible, economic operation possible	Technically feasible, economic operation possible

 Technically feasible, economic operation possible
 Technically feasible with restrictions
 Technically not feasible

 Technically feasible, economically not advisable

Highlights

Rapid recent cost reductions

Technology and performance improvements will continue

Economies of scale and cost innovation key also very important



Scale and cost reductions will open up new markets

Batteries facilitate a renewable future!



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