BATTERY STORAGE

ACCELERATING THE ENERGY TRANSITION

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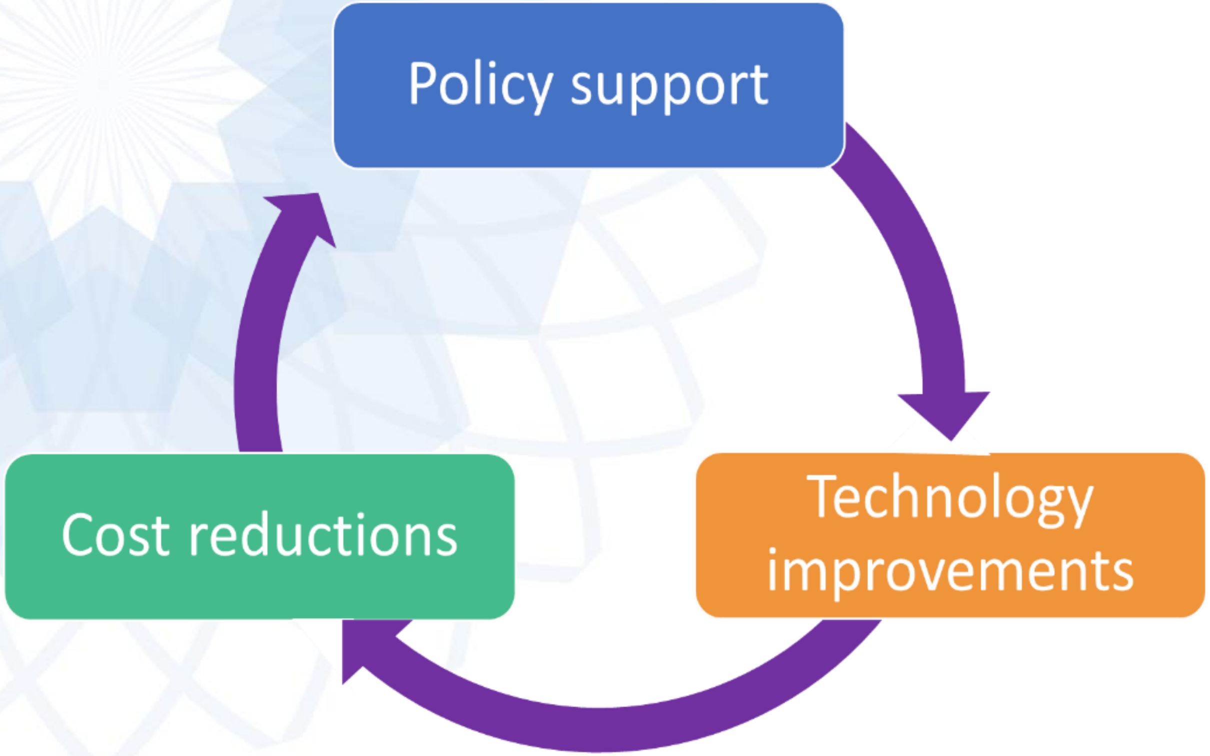
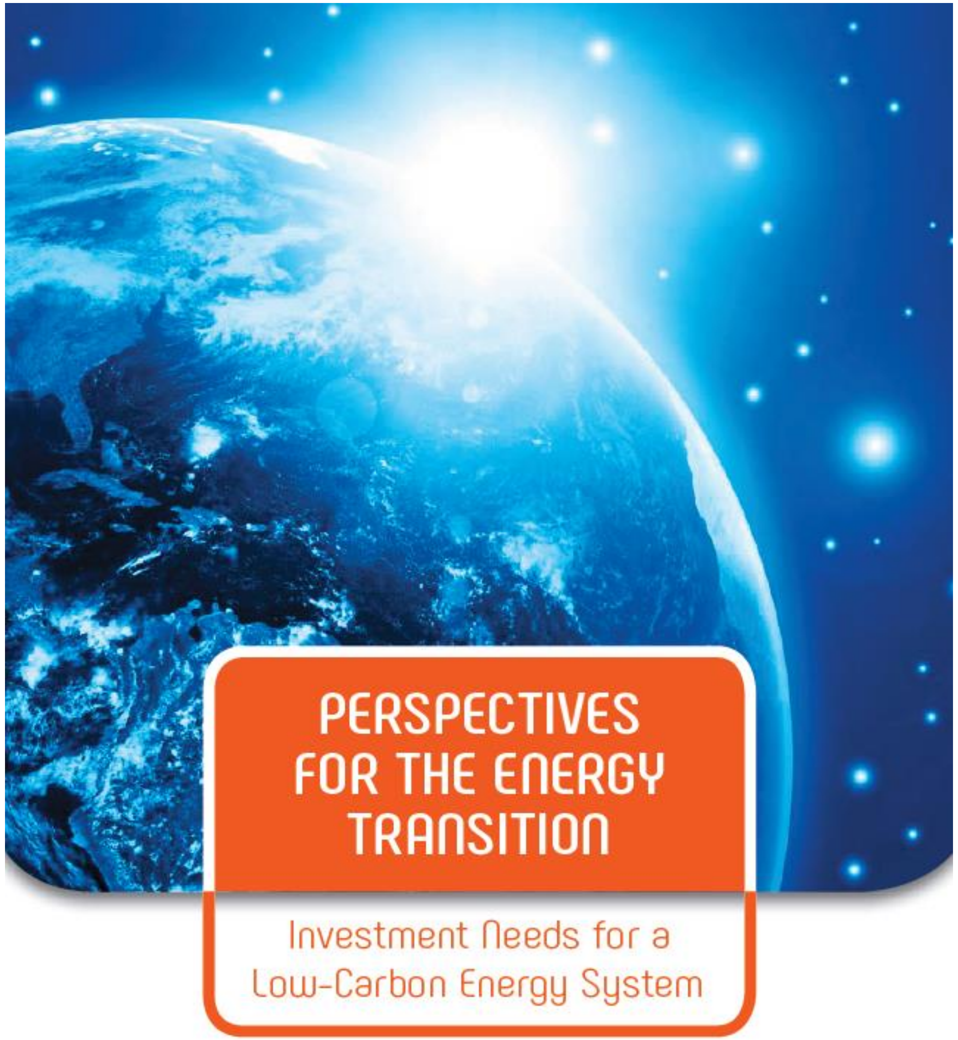
23 MAY 2017

Renewable Energy Costs, Technologies and Markets

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 CO_2 emissions by sector

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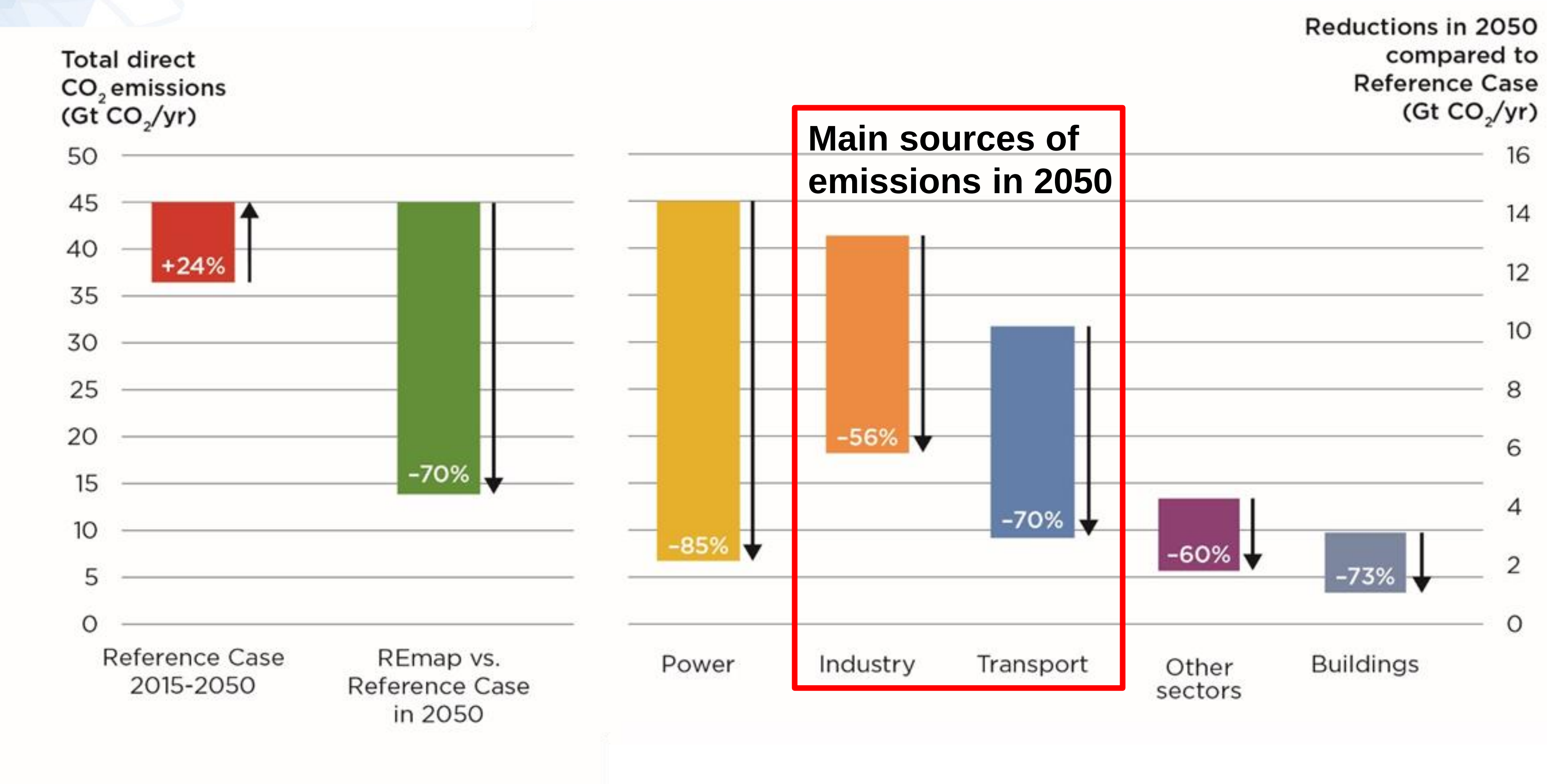
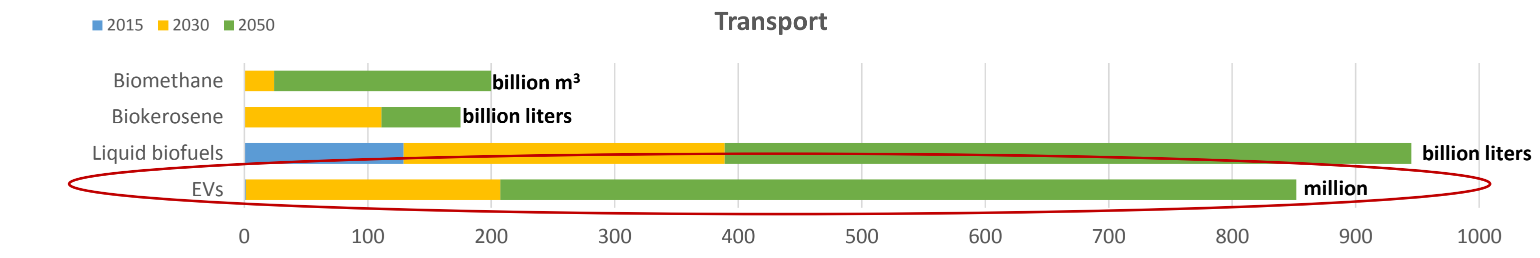
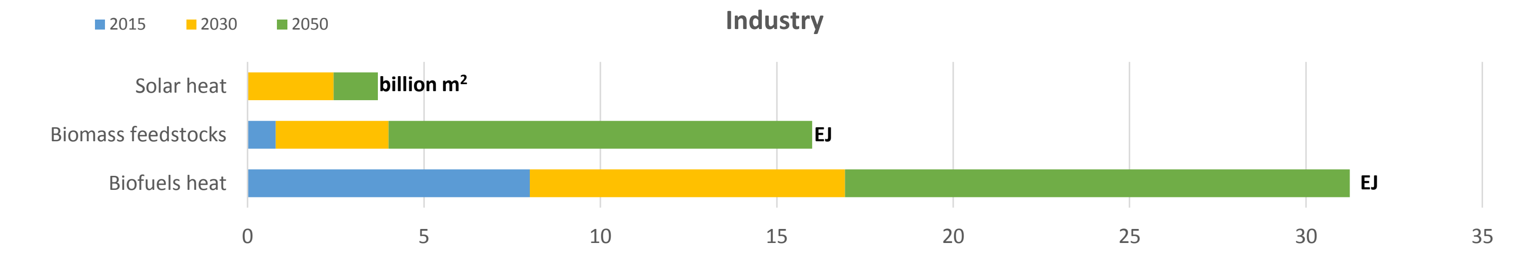


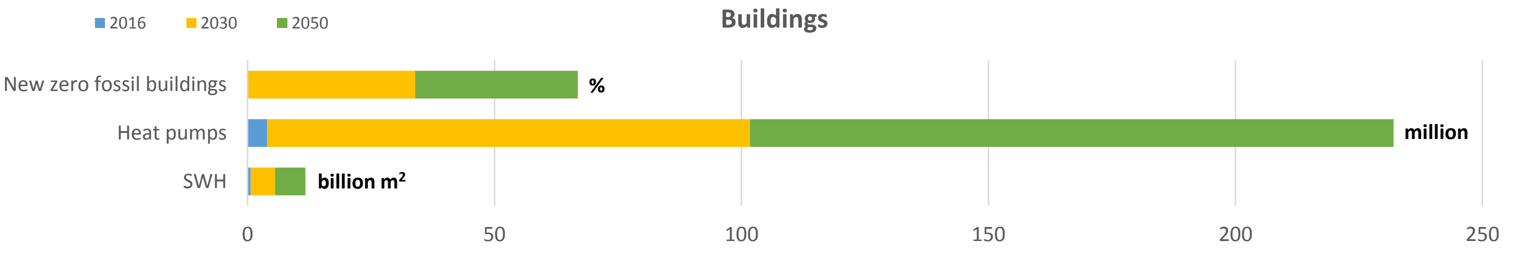
By 2050, total energy-related CO_2 emissions will need to decrease to below 10 Gt/yr

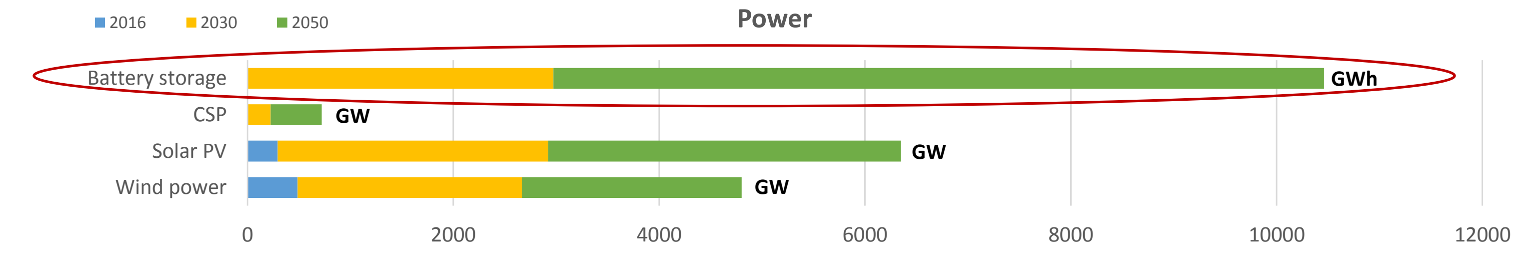
CO_2 emissions from the power and buildings sectors will be almost eliminated

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)

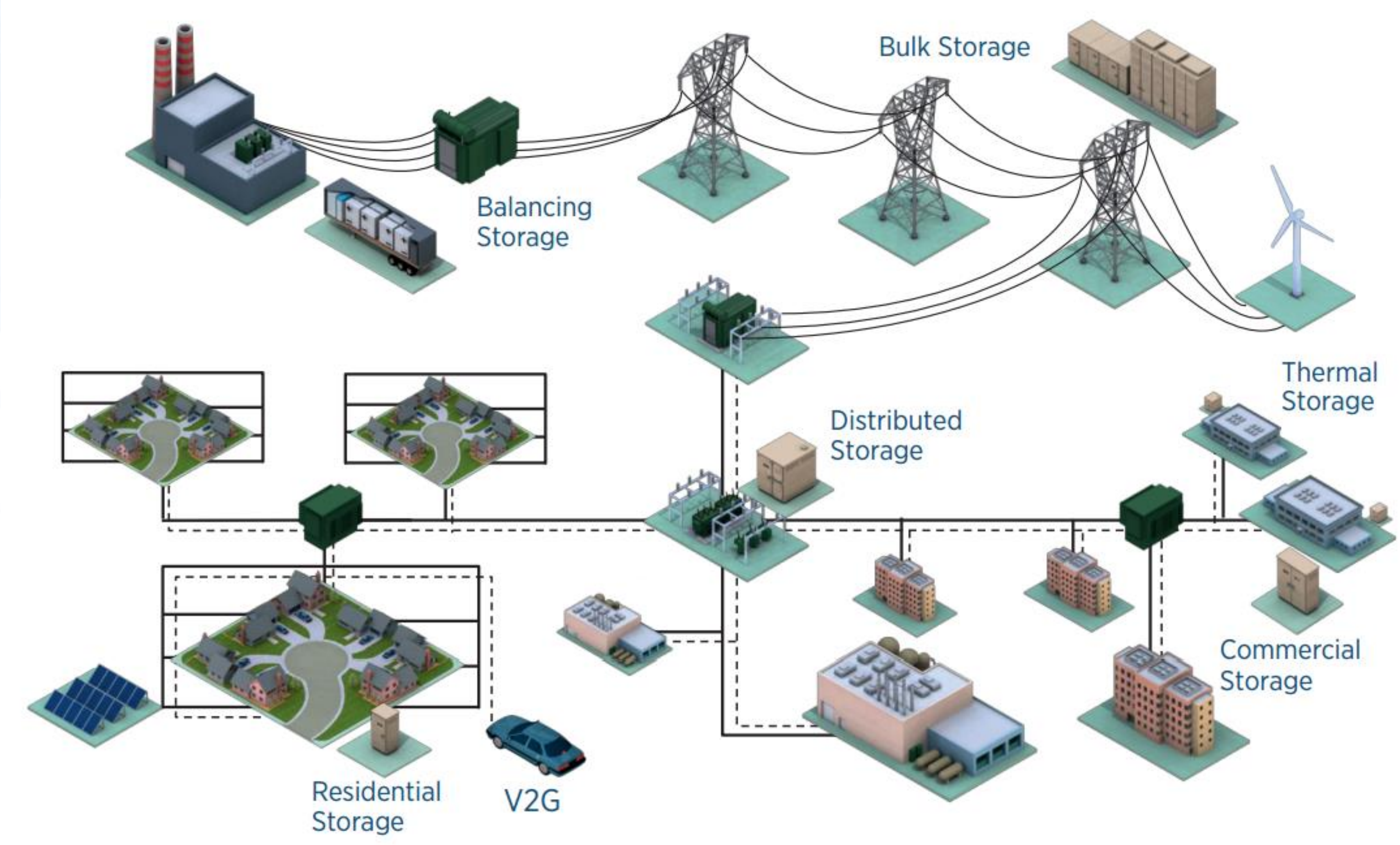
Storage

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 integrating v high share of VRE)
- In the next 3-5 years, the storage industry is positioned to scale and echo the stark growth seen in the solar PV industry.
- 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 as well as increased RE penetration on islands/mini-grids and off-grid

Power systems

Potential locations and applications of electricity storage



BATTERY ELECTRICITY STORAGE FOR STATIONARY APPLICATIONS

REPORT SCOPE AND PROGRESS

Context

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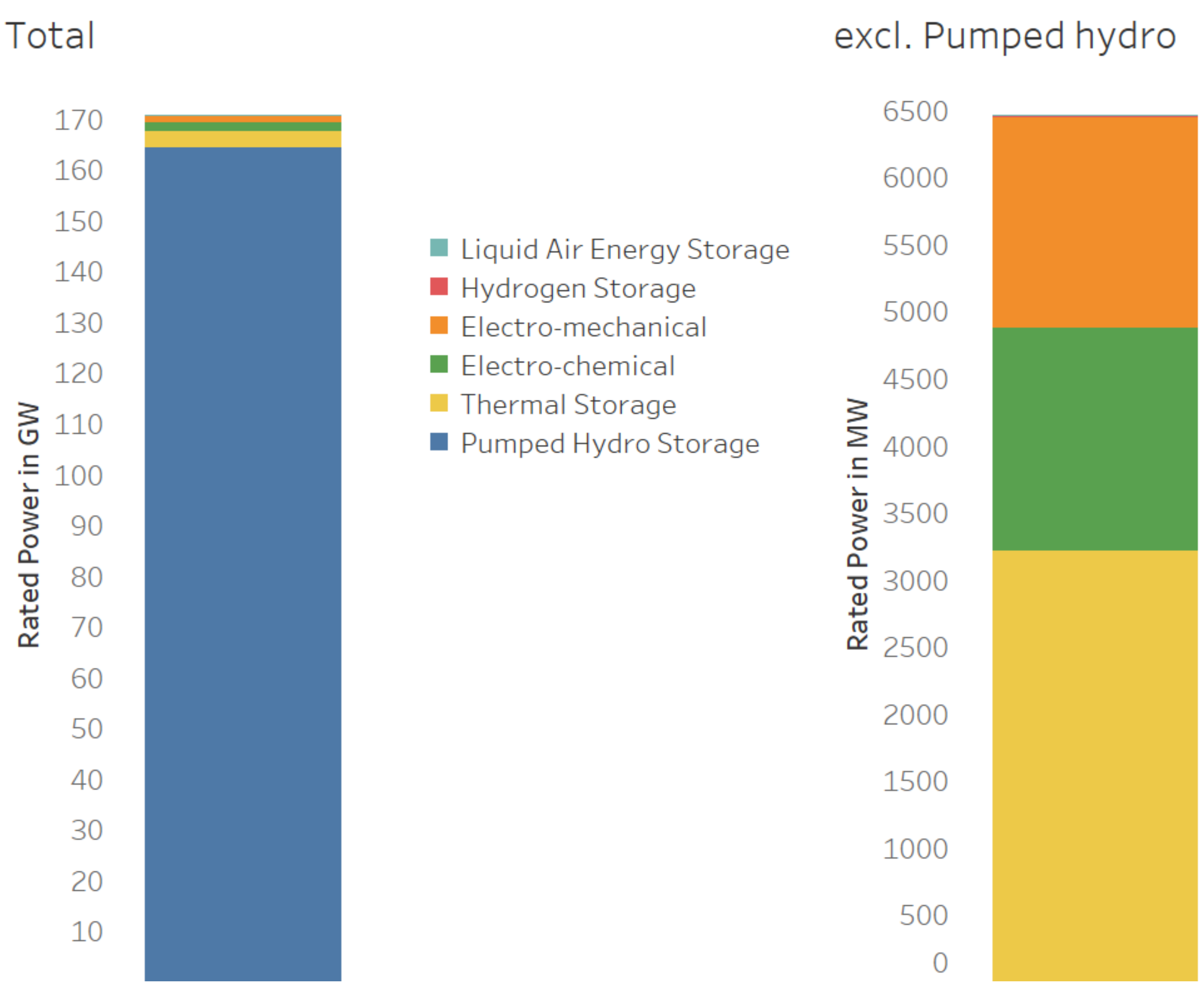
IRENA's RE costs and markets team is preparing a study to analyze and discuss stationary battery electricity options and costs

- 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, competiveness of battery storage for different services and market growth in detail for electricity storage devices, focusing on batteries to 2030

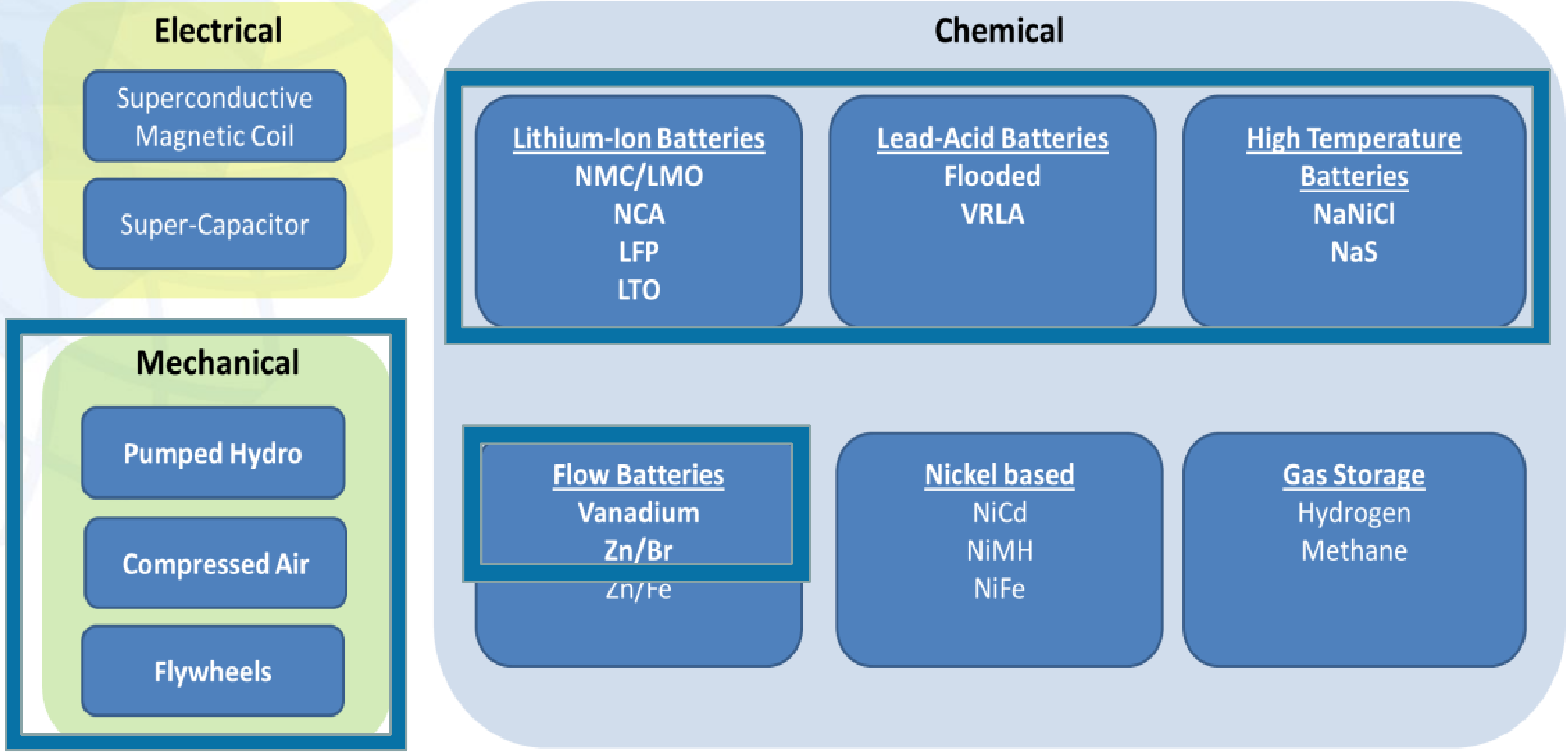
Stationary storage today



- Source: DOE

Technology overview

Scope of analysis

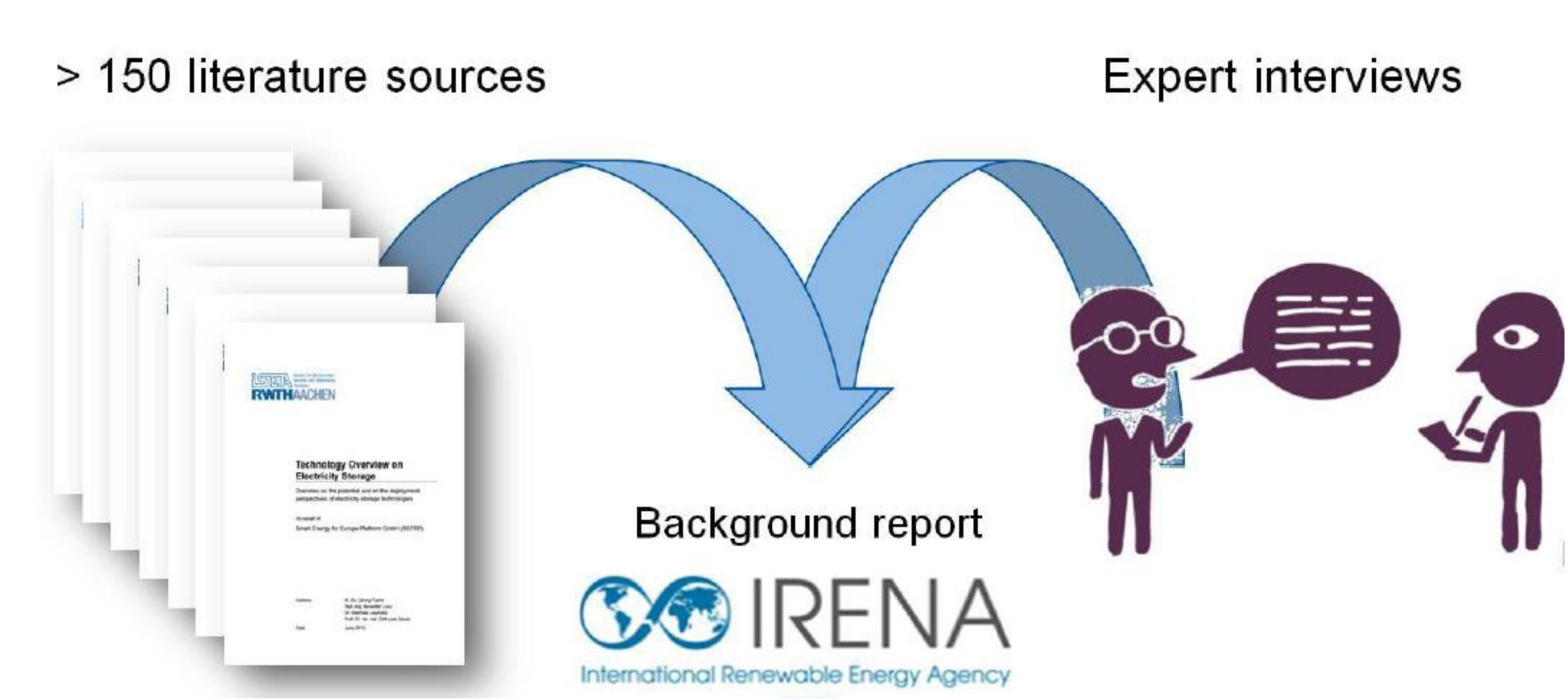


Electricity Storage

Current and future cost of battery electric storage for electric power

- Detailed descriptions of 13 storage technologies including their required balance of system
- Strengths and weaknesses of each technology are highlighted, possible development paths including opportunities and threats are discussed
- One of the most comprehensive technology overviews for stationary storage systems available on the market today
- Typical system designs for 12 typical storage applications
- Excel Tool to calculate the Cost of Service of all storage technologies in different applications

Methodology



COST AND TECHNOLOGY STATUS

Small-scale: rapidly falling prices

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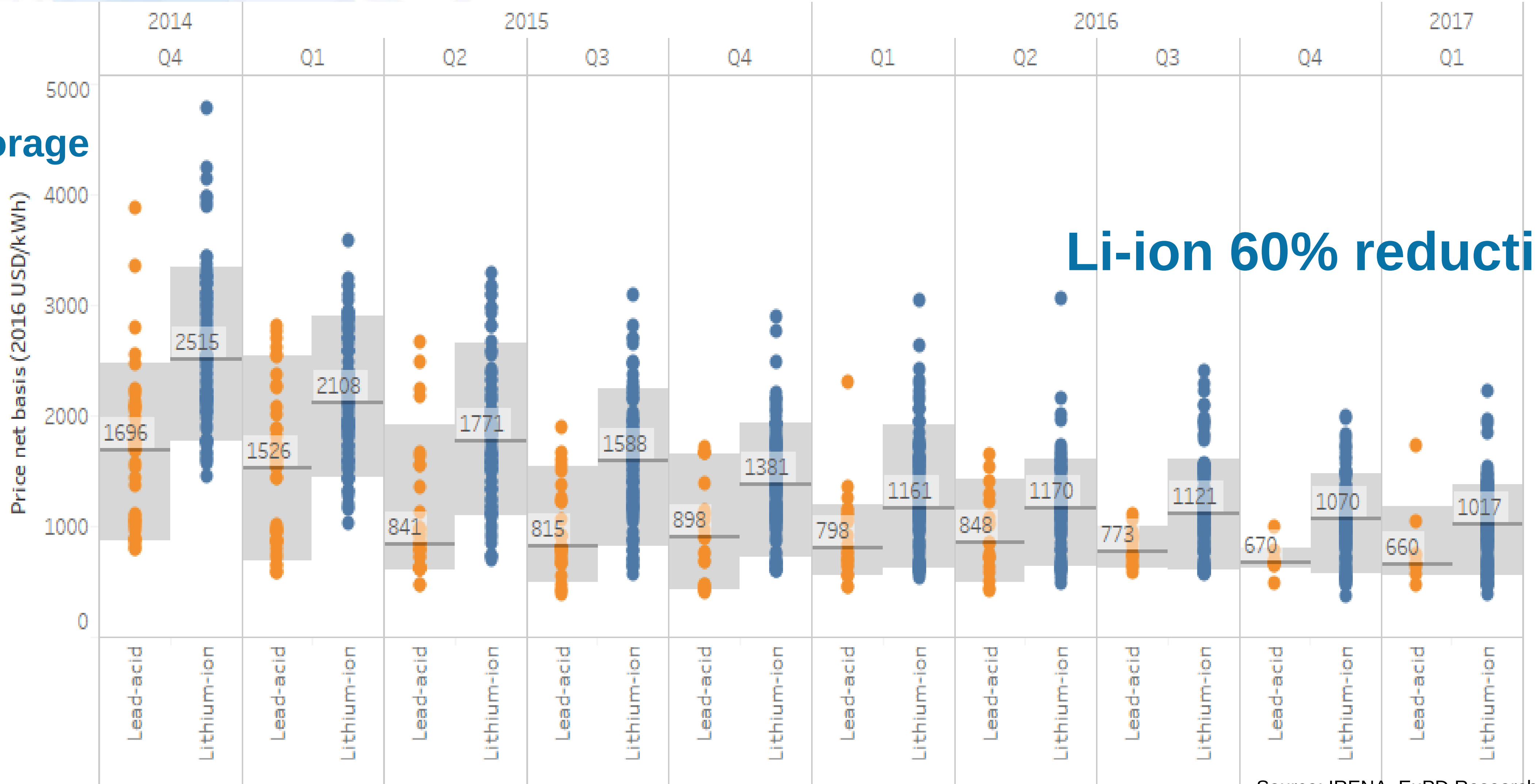
Home storage

Li-ion 60% reduction!



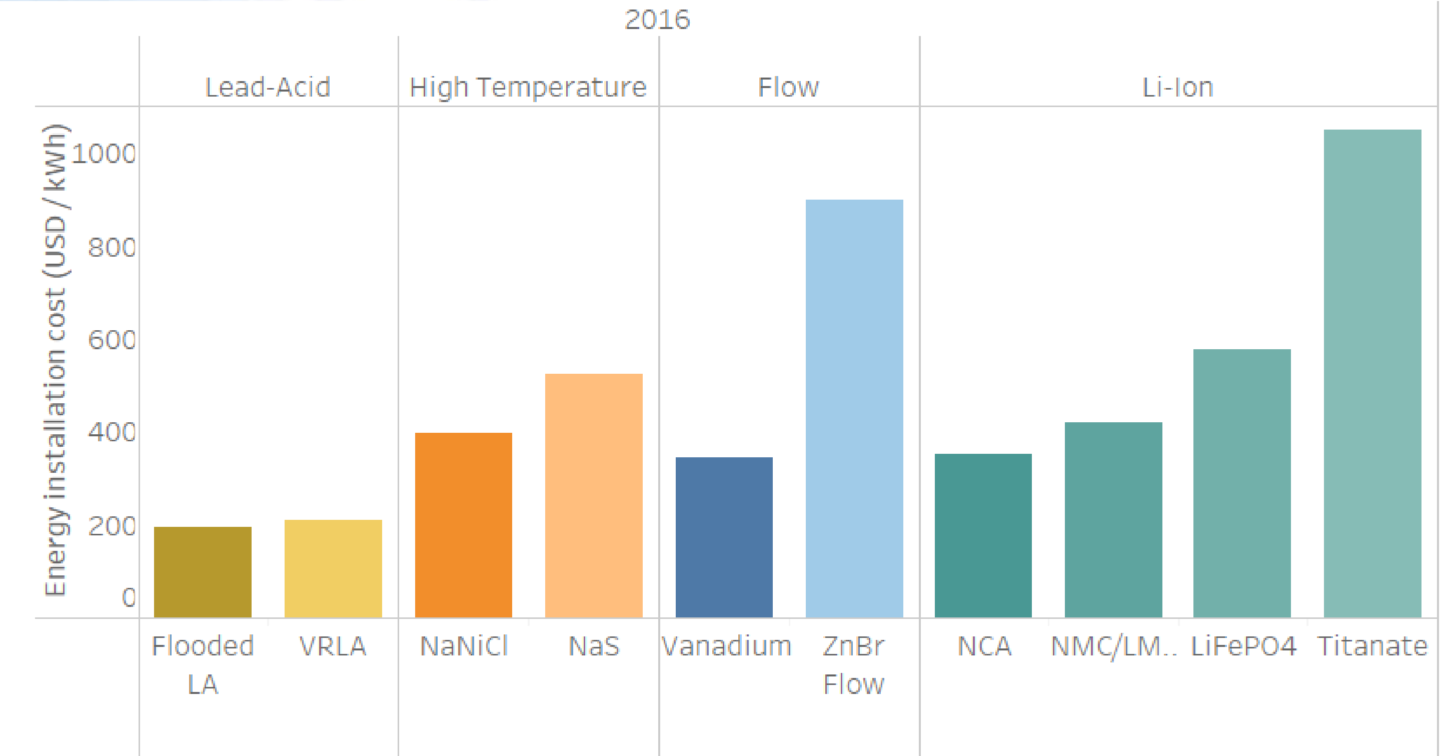
Source: IRENA, EuPD Research

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.

Current prices of different storage technologies

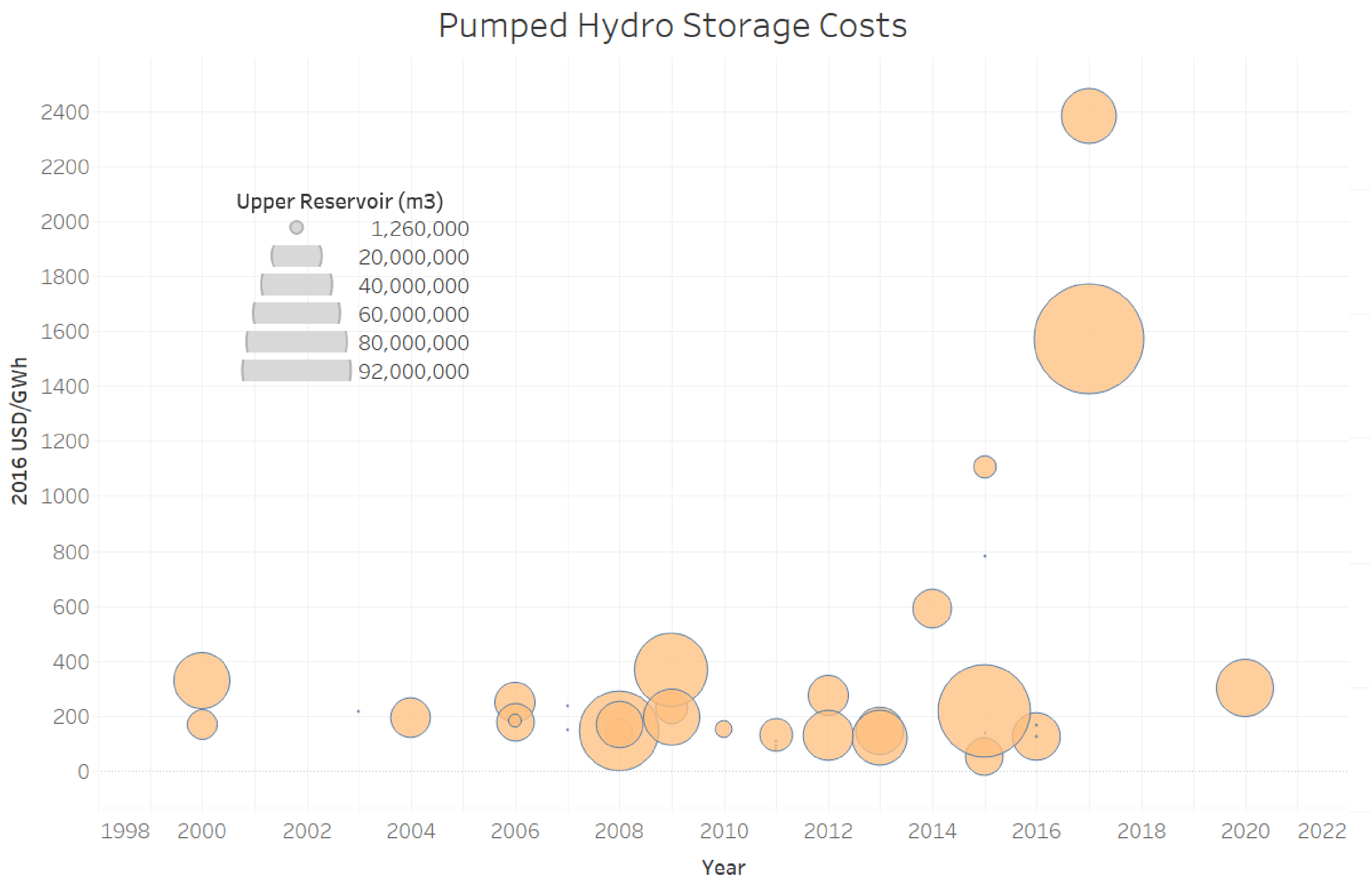
Current energy installations costs (USD/kWh of storage) Reference case 2016



- High temperature ranging USD 400/kWh to USD 525/kWh
- Vanadium currently at USD 350/kWh and ZnBr at USD 900/kWh
- Current Li-ion costs ranging USD 350/kWh to USD 1050/kWh

Note: prices shown are for stationary applications and EV or specific residential applications could differ

Current prices: Pumped Hydro Storage



Potential cost evolution

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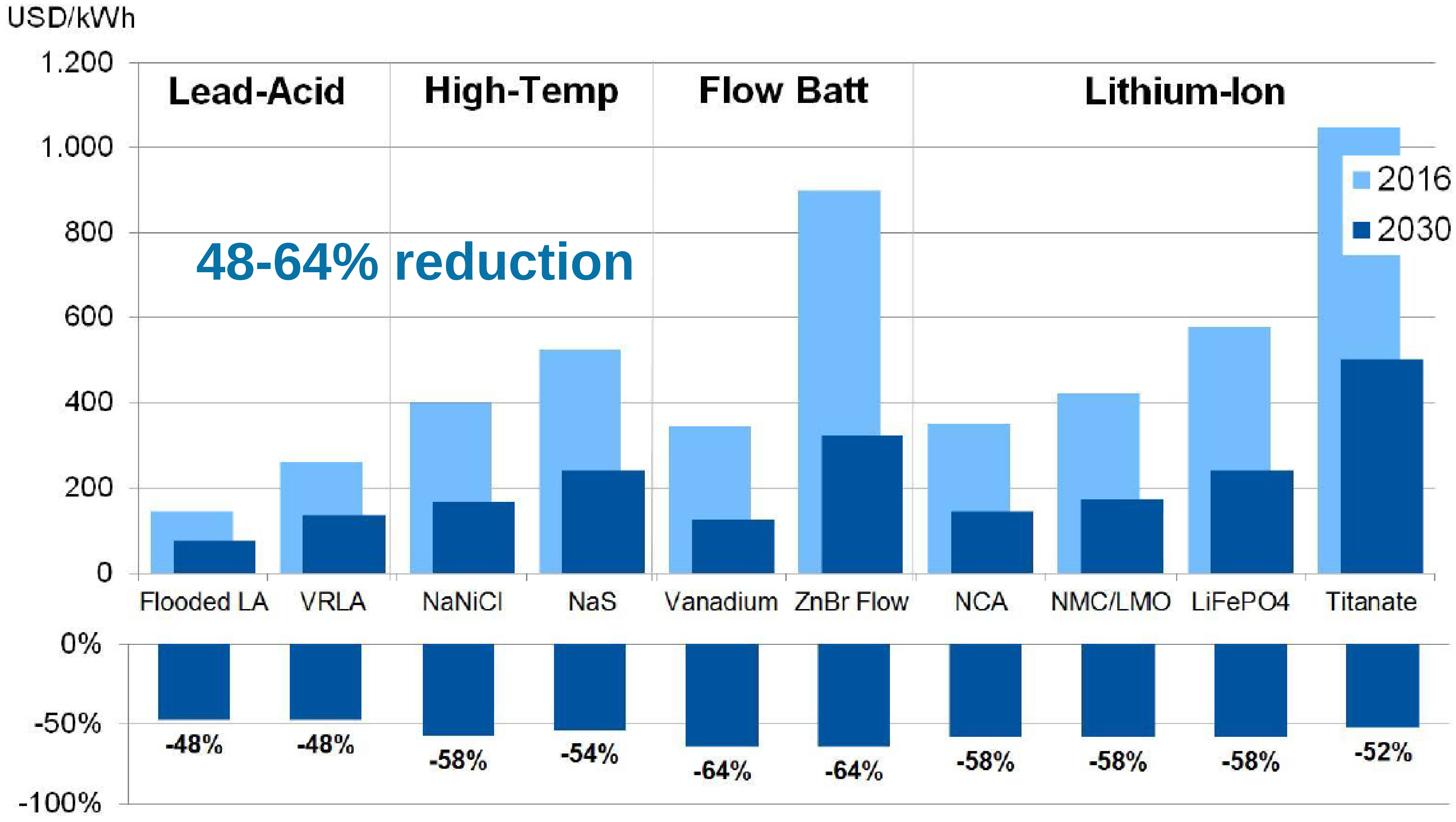

Prices in 2030
USD 80 - 400/kWh

Compared to 2016
USD 190 - 1050/kWh

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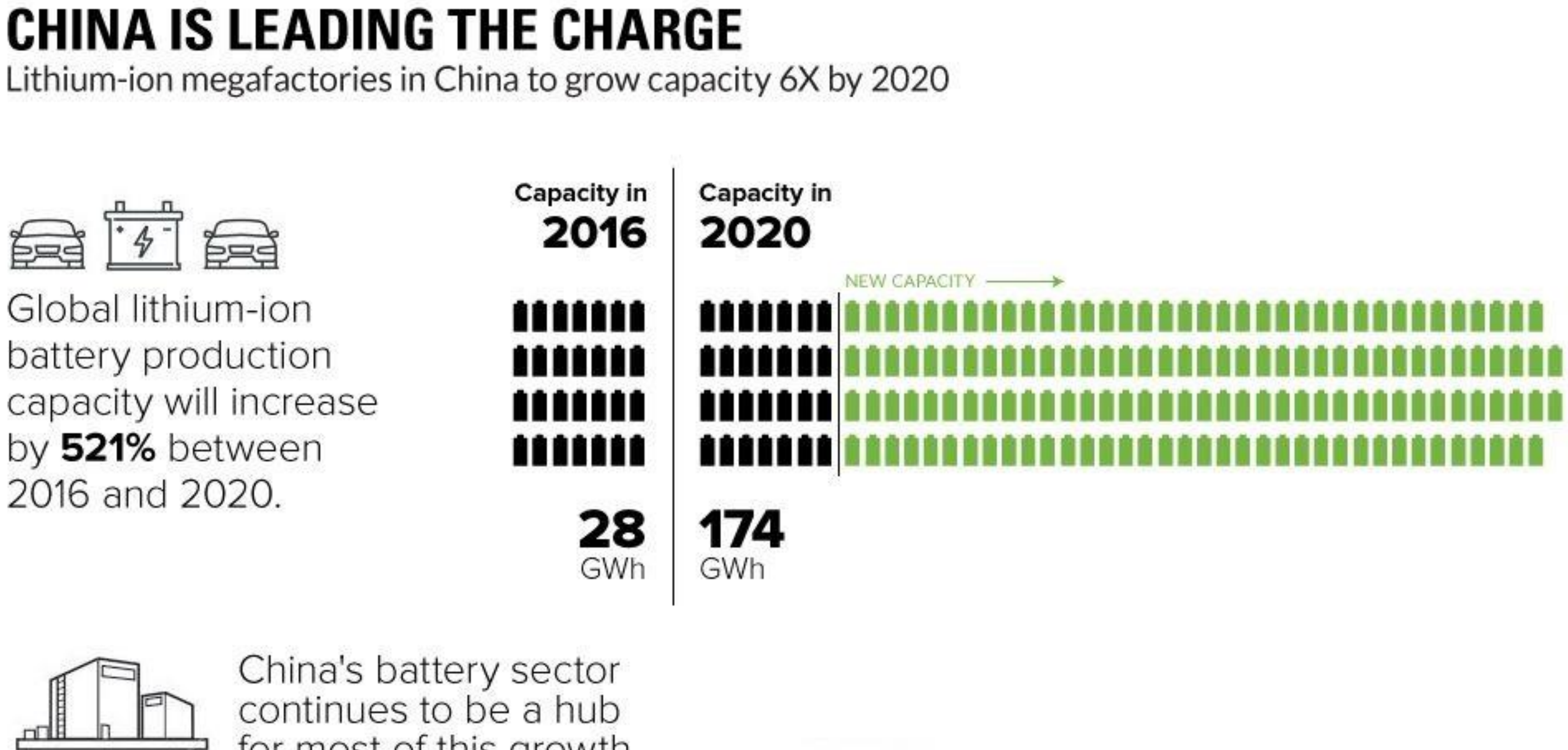

Source: http://www.visualcapitalist.com/china-leading-charge-lithium-ion-megafactories/

	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%**

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

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- 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

[10]

	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	-	-	-	-	-

Main drivers: High-temp Batteries (NaS and ZEBRA)

- Sodium Sulfur (NaS)
  - Potential for very low cost active materials
  - Corrosion needs to be controlled

- "Low temperature" electrolytes (~150 °C) can
  - Reduce corrosion / Increase lifetime
  - Reduce thermal self-discharge
  - But low max. power, only stationary applications

- Innovative developments
  - Larger cell stacks promise cheaper production costs
  - Development of low cost corrosion resistant materials (e.g. coatings, joints, ...)

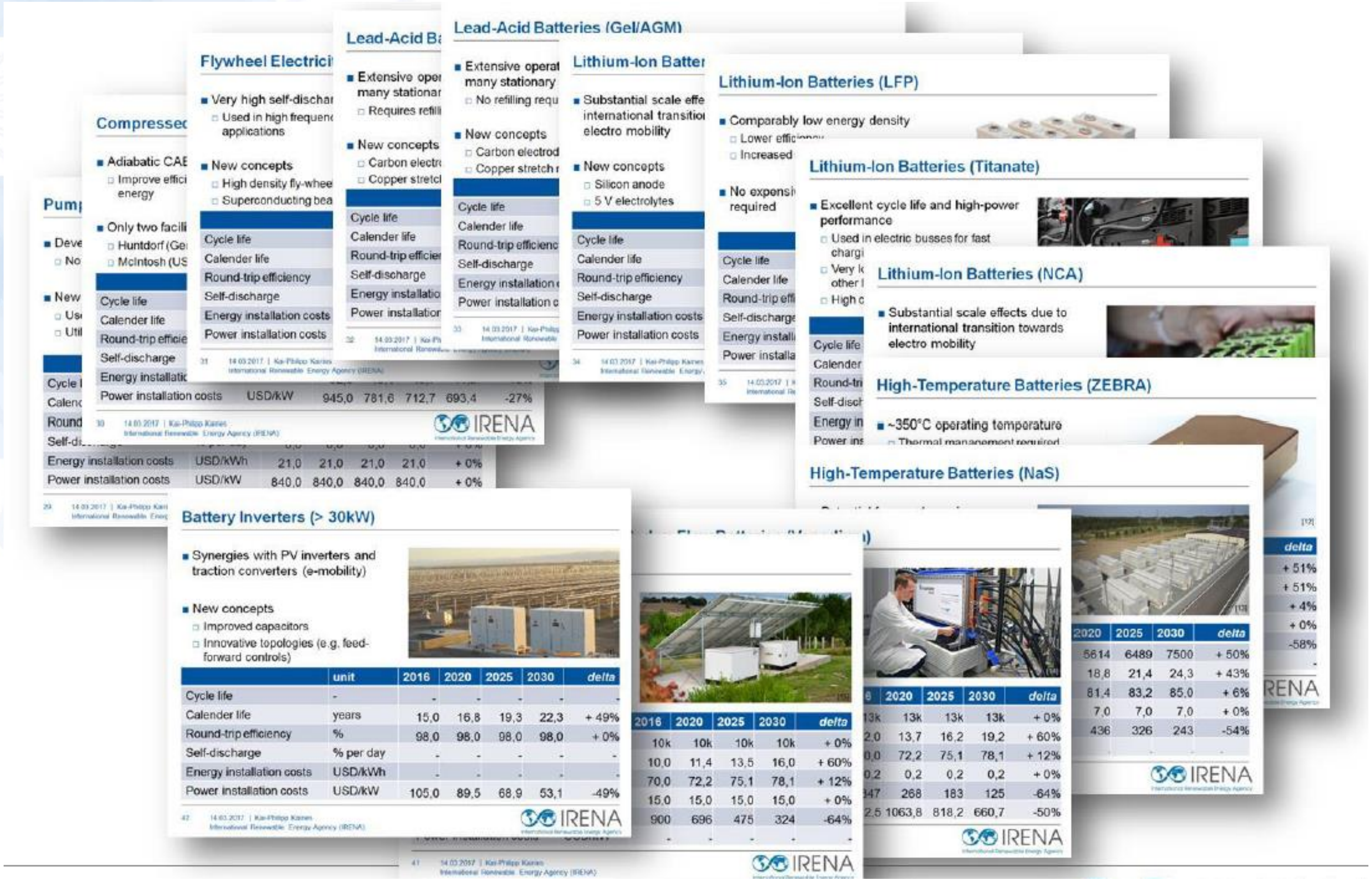
Example: High-temp NaS

- Potential for very low prices
  - Sodium and sulfur abundantly available
  - High corrosion requires expensive components

[13]

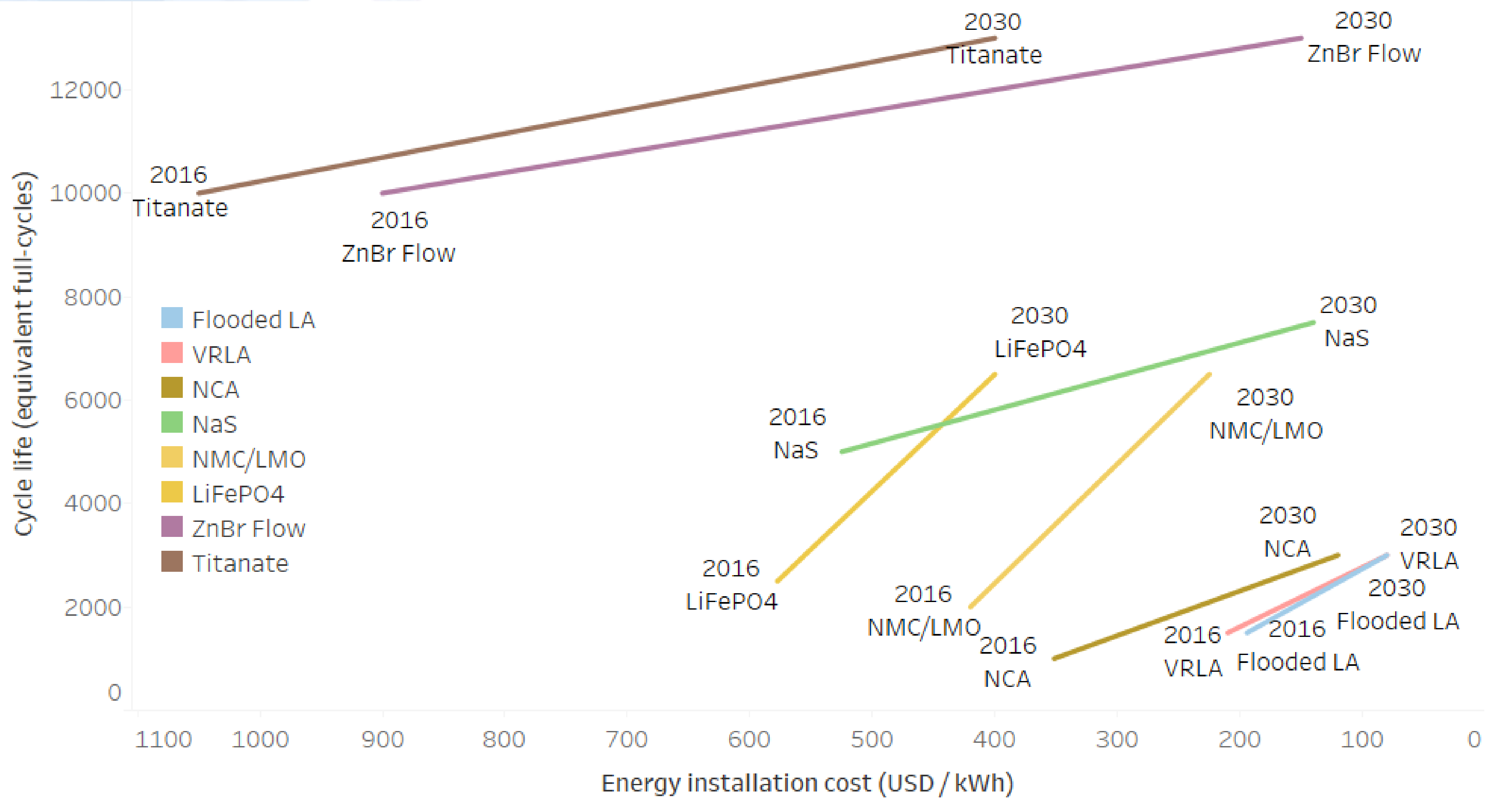
	unit	2016	2020	2025	2030	*delta*
Cycle life	-	5000	5614	6489	7500	+ 50%
Calender life	years	17,0	18,8	21,4	24,3	+ 43%
Round-trip efficiency	%	80,0	81,4	83,2	85,0	+ 6%
Self-discharge	% per day	7,0	7,0	7,0	7,0	+ 0%
Energy installation costs	USD/kWh	525	436	326	243	-54%
Power installation costs	USD/kW	-	-	-	-	-

Tech sheets for 15 technologies



Performance

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



COST OF SERVICE MODELS

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-Ise

- Off-grid
  - Nano-grid
  - Village Electrification
  - Island Grid

Cost of service calculations: Industrial peak shaving

Application

- Industrial peak shaving
  - 200 kW rated power
  - 5 kWh nomical capacity
  - 0,6 cycles per day

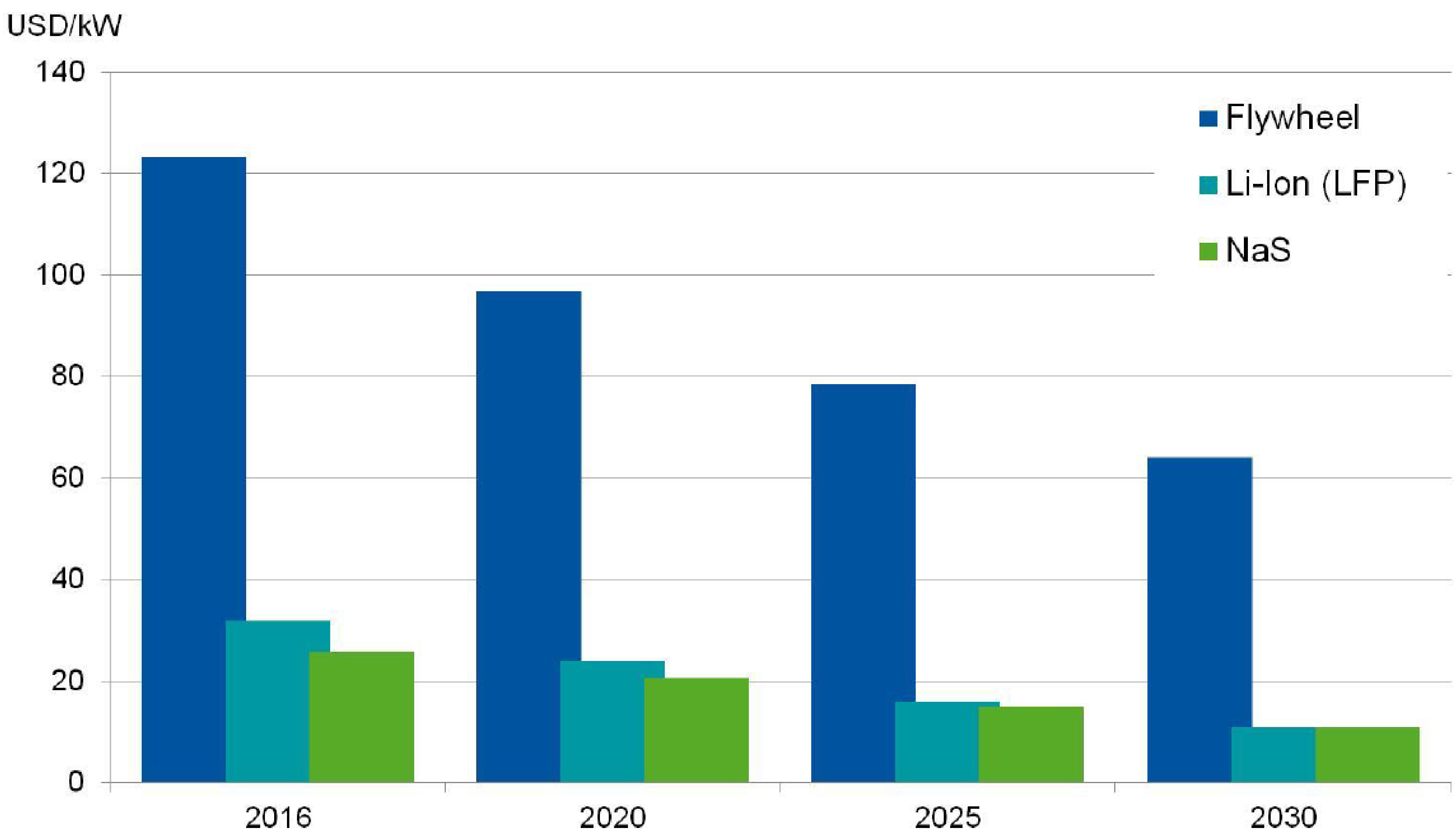
Storage Technologies

- Li-Ion (LFP)
- Li-Ion (Titanate)
- Redox-Flow (ZbBr)

Results

- Cost of power per year [USD/kW]

Cost of service calculations: Industrial peak shaving



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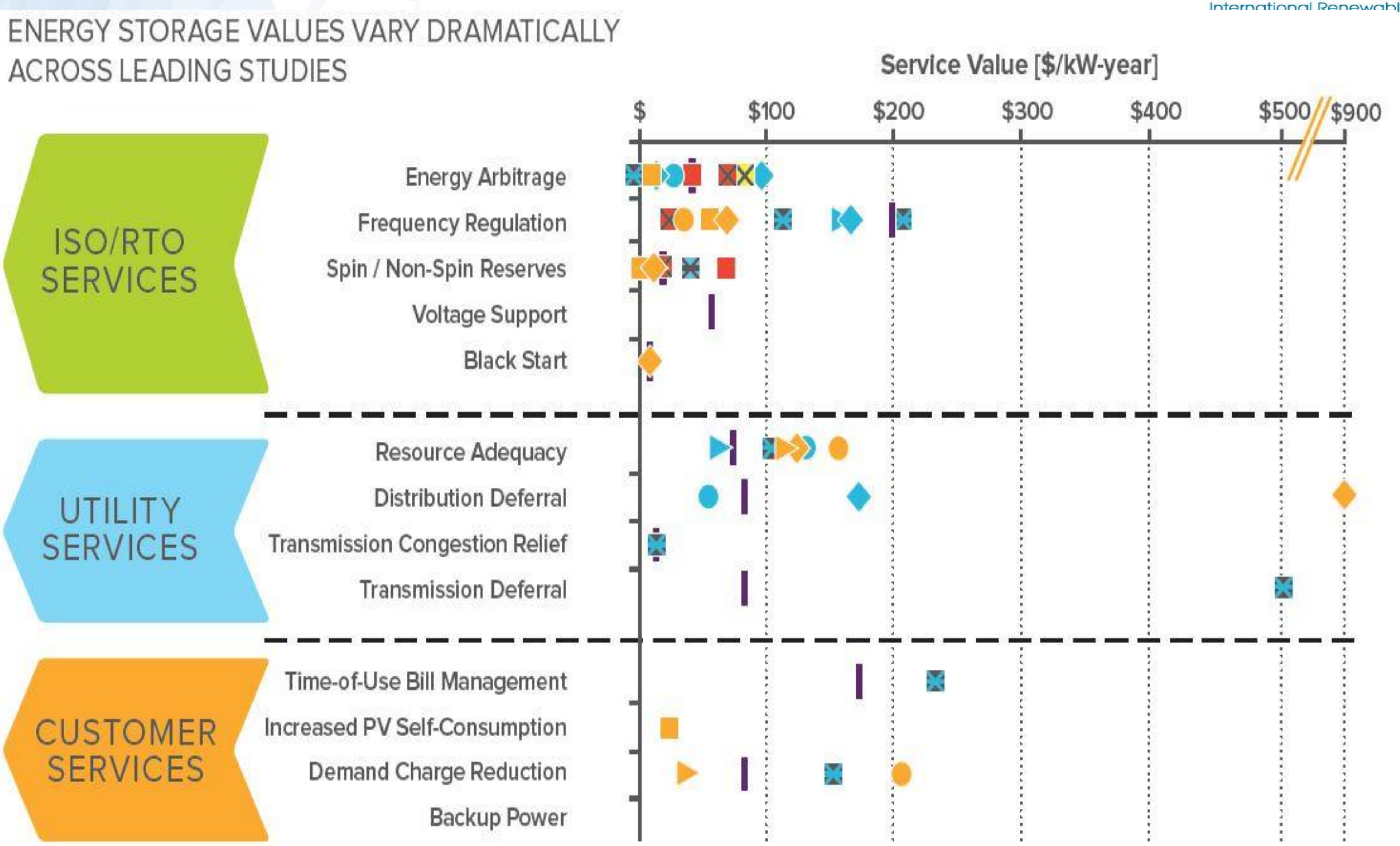

Source: Rocky Mountain Institute

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 with restrictions	Technically feasible with restrictions
	Primary Reserve Control	Technically not feasible	Technically not feasible	Technically feasible with restrictions	Technically feasible with restrictions	Technically feasible, economic operation possible	Technically feasible with restrictions	Technically feasible with restrictions
	Secondary Reserve Control	Technically feasible, economic operation possible	Technically feasible, economic operation possible	Technically feasible, economically not advisable	Technically feasible, economically not advisable	Technically feasible, economically not advisable	Technically feasible, economically not advisable	Technically feasible, economically not advisable
	Minute Reserve	Technically feasible, economic operation possible	Technically feasible, economic operation possible	Technically feasible, economically not advisable	Technically feasible, economically not advisable	Technically feasible, economically not advisable	Technically feasible, economically not advisable	Technically feasible, economically not advisable
	Long-time Storage	Technically feasible with restrictions	Technically feasible with restrictions	Technically feasible, economically not advisable	Technically feasible, economically not advisable	Technically feasible, economically not advisable	Technically feasible, economically not advisable	Technically feasible, economically not advisable
	Ramping	Technically feasible with restrictions	Technically feasible with restrictions	Technically feasible, economically not advisable	Technically feasible, economic operation possible	Technically feasible, economic operation possible	Technically feasible, economic operation possible	Technically feasible, economic operation possible
	Avoid Redispatch	Technically feasible, economically not advisable	Technically feasible, economically not advisable	Technically feasible, economically not advisable	Technically feasible, economically not advisable	Technically feasible, economically not advisable	Technically feasible, economically not advisable	Technically feasible, economically not advisable
	Black start capability	Technically feasible, economically not advisable	Technically feasible, economically not advisable	Technically feasible, economically not advisable	Technically feasible, economically not advisable	Technically feasible, economically not advisable	Technically feasible, economically not advisable	Technically feasible, economically not advisable
Private usage	**Increase Self-Consumption**	Technically not feasible	Technically not feasible	Technically feasible, economically not advisable	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, economically not advisable	Technically feasible, economically not advisable	Technically feasible, economically not advisable	Technically feasible, economically not advisable	Technically feasible, economically not advisable
	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, 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 with restrictions

Technically not feasible

Technically feasible, economically not advisable

Highlights

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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

Timeline

Report conceptulisation is underway, consultants work being finalised

- Stakeholder meetings during Energy Storage Europe (Düsseldorf) / Intersolar and others events and meetings to present draft results
- Drafting of report: June-August 2017
- Peer review: September 2017
- Final report: October 2017

Thank you!

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Questions

What areas of analysis should we focus on?

What are the questions you face domestically?

What aspects should we target for follow-up work? Self-consumption, grid-services, etc.