Industry perspective: battery energy storage

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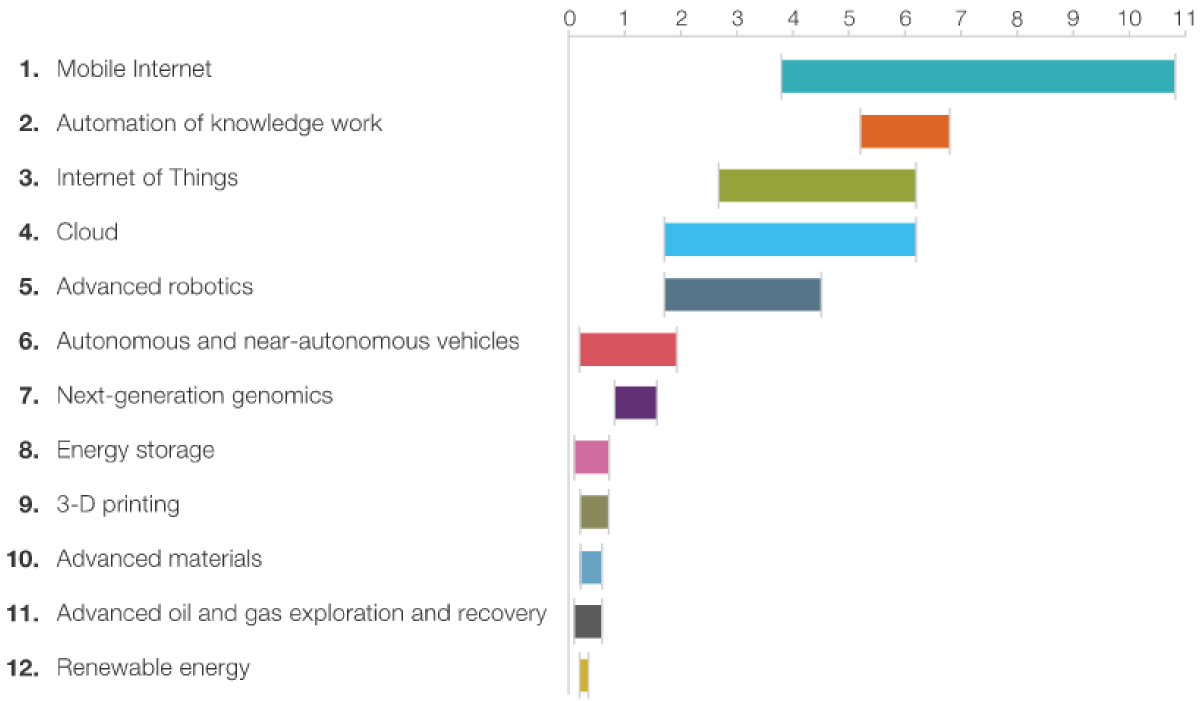
Disruptive technology

A gallery of **disruptive technologies**

Estimated potential economic impact of technologies across sized applications in 2025, $ trillion, annual



SOURCE: McKinsey Global Institute

#8 **Energy storage**

Devices or physical systems that store energy for later use

Potential economic impact in 2025 across sized applications of **~$0.1 trillion–$0.6 trillion**

40–100% of new vehicles sold in 2025 could be electric or hybrid

#12 **Renewable electricity— solar and wind**

Generation of electricity from renewable sources with reduced harmful climate impact

Potential economic impact in 2025 across sized applications of **$0.2 trillion–$0.3 trillion**

Potential to avoid emissions of **1,000 million–1,200 million tons of CO_2** annually by 2025

Component technologies

- Photovoltaic cells
- Wind turbines
- Concentrated solar power
- Hydroelectric and ocean-wave power
- Geothermal energy

Key applications

- Electricity generation
- Reduction in CO_2 emissions
- Distributed generation

Energy storage determines human civilization

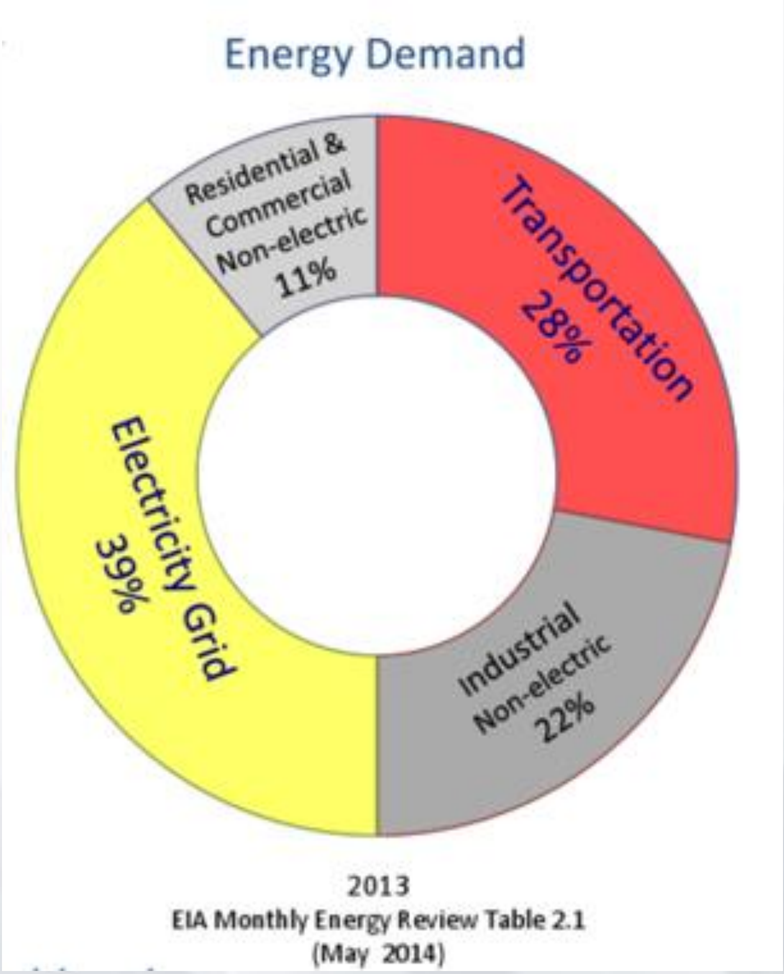
- Save the unstable/vulnerable energy and use it whenever we want
  - Primitive society: limited storage/usage
  - Feudal society: use agriculture to store/use
  - Industrial society: fossil energy and mass development
  - Decarbonized society: renewable + storage
  - Space age: laser energy storage, antimatter storage technology, etc.
- It's about cultural continuity and inheritance

Renewable energy needs storage

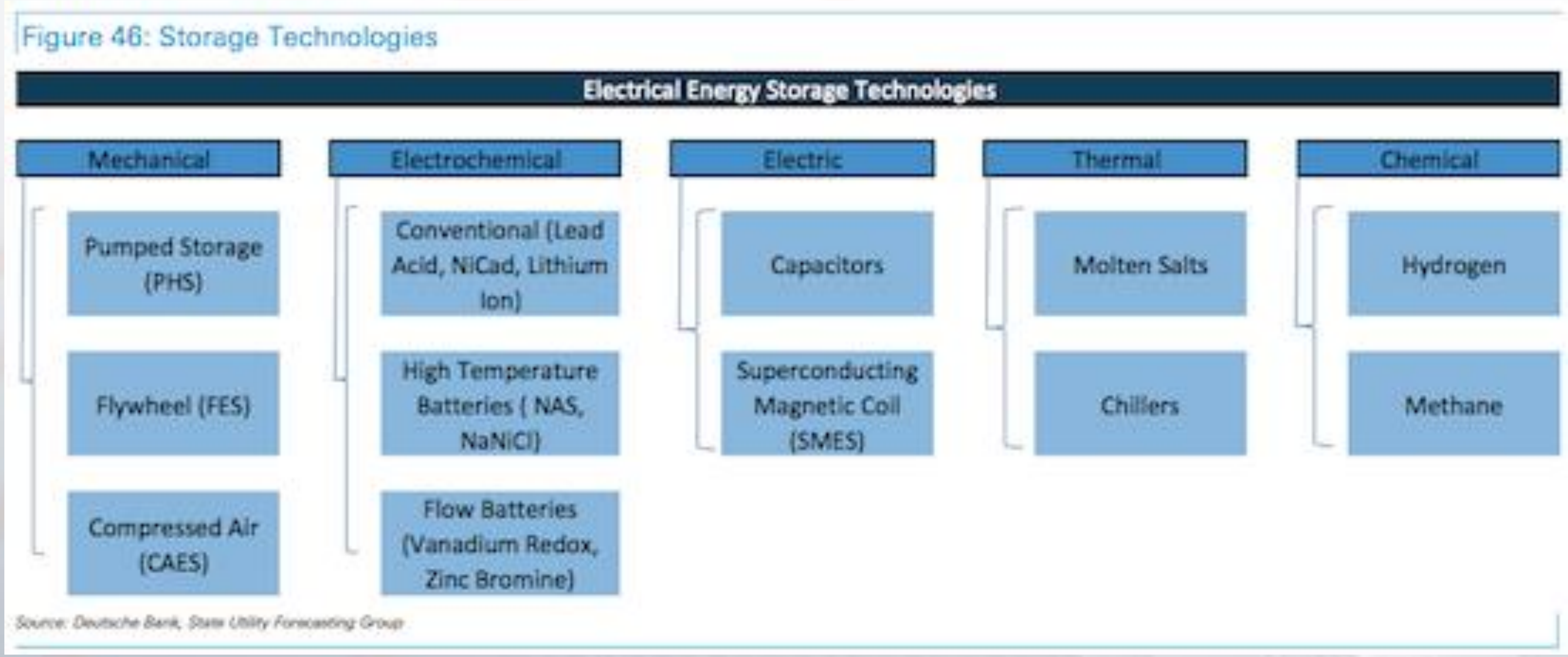
- Affected by solar and earth movement
  - Abundant, compared with limited oil & gas
    - Wind energy: 253GW, until 2012 reached 282GW, close to saturation
    - Solar energy: 800,000GW, 40-min solar = world annual energy consumption, installation now ~100GW, huge potential
  - Low energy density, meaning large space
  - Low-carbon or zero emissions
  - Widespread, would enable distributed usage
  - Intermittency and fluctuation
  - Apart from water, high cost compared with fossil energy

Energy storage challenges

- Transportation 28% **Location**
  - Foreign oil → domestic electricity
  - Reduce energy use and carbon emissions
- Power generation 39% **Time**
  - Coal → Gas → Wind/Solar
  - Greater reliability/flexibility
  - Lower cost by deferring infrastructure
- Bottleneck is high-performance/low cost storage



Major energy storage methods



Major energy storage methods

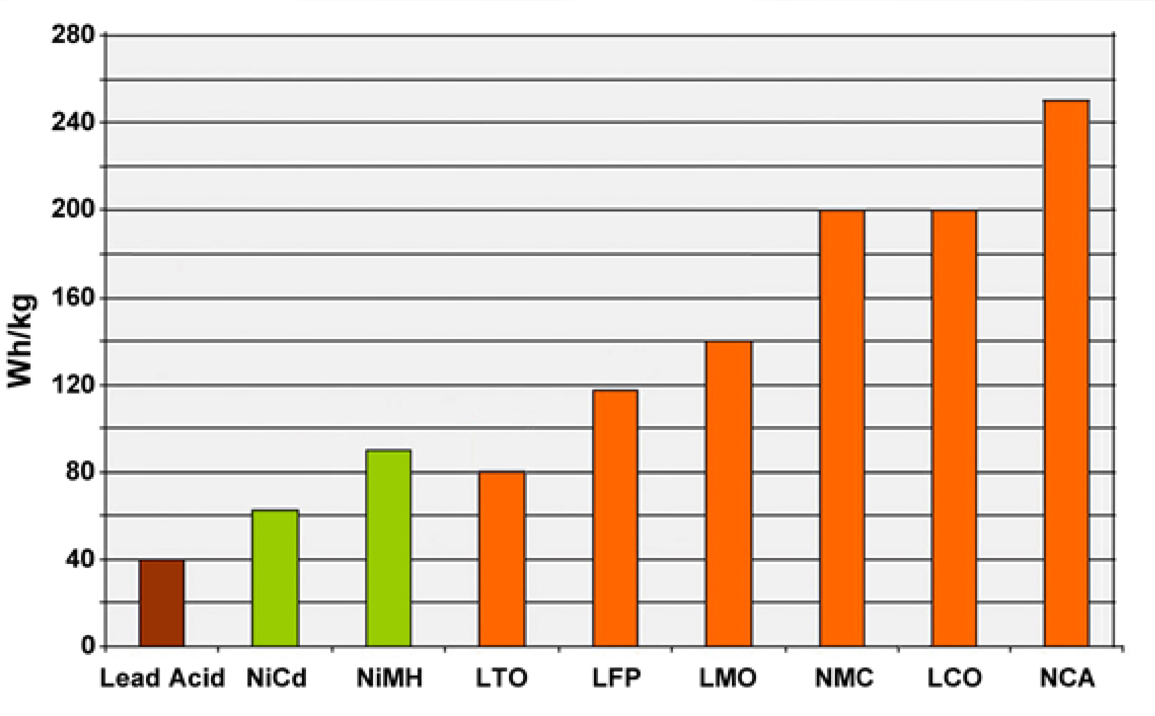
Figure 40: Overview of Storage Techniques

Technology	Maturity	Cost ($/kW)	Cost ($/kWh)	Efficiency	Cycle Limited	Response Time
Pumped Hydro	Mature	1,500-2,700	138 - 338	80-82%	No	Seconds to Minutes
Compressed Air (underground	Demo to Mature	960-1,250	60 - 150	60-70%	No	Seconds to Minutes
Compressed Air (Aboveground)	Demo to Deploy	1,950-2,150	390 - 430	60-70%	No	Seconds to Minutes
Flywheels	Demo to Mature	1,950-2,200	7,800 - 8,800	85-87%	>100,000	Instantaneous
Lead Acid Batteries	Demo to Mature	950-5,800	350 - 3,800	75-90%	2,200 - >100,000	Milliseconds
Lithium-Ion	Demo to Mature	1,085-4,100	900 - 6,200	87-94%	4,500 - >100,000	Milliseconds
Flow Batteries (Vanadium Redox)	Develop to Demo	3,000-3,700	620 - 830	65-75%	>10,000	Milliseconds
Flow Batteries (Zinc Bromide)	Demo to Deploy	1,450-2,420	290 - 1,350	60-65%	>10,000	Milliseconds
Sodium Sulfur	Demo to Deploy	3,100-4,000	445 - 555	75%	4500	Milliseconds
Power to Gas	Demo	1,370-2,740	NA	30-45%	No	10 Minutes
Capacitors	Develop to Demo			90-94%	No	Milliseconds
SMES	Develop to Demo			95%	No	Instantaneous

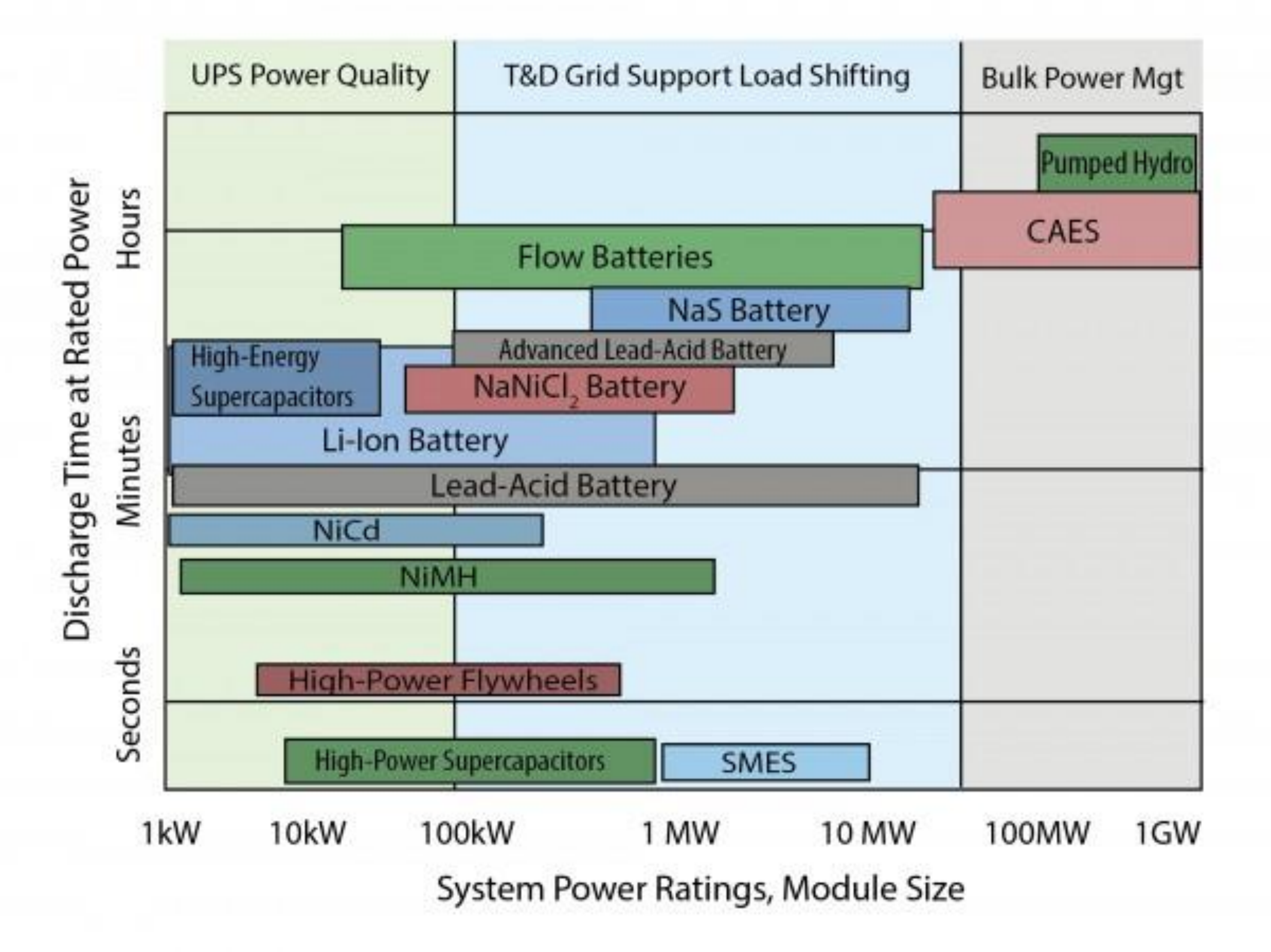
Source: State Utility Forecasting Group

Batteries for the future

- Assuming 5 standards to select batteries:
  - Energy/power density
  - Cycle and calendar life
  - Safety
  - Cost
  - Simple technology/manufacturing



Different battery applications



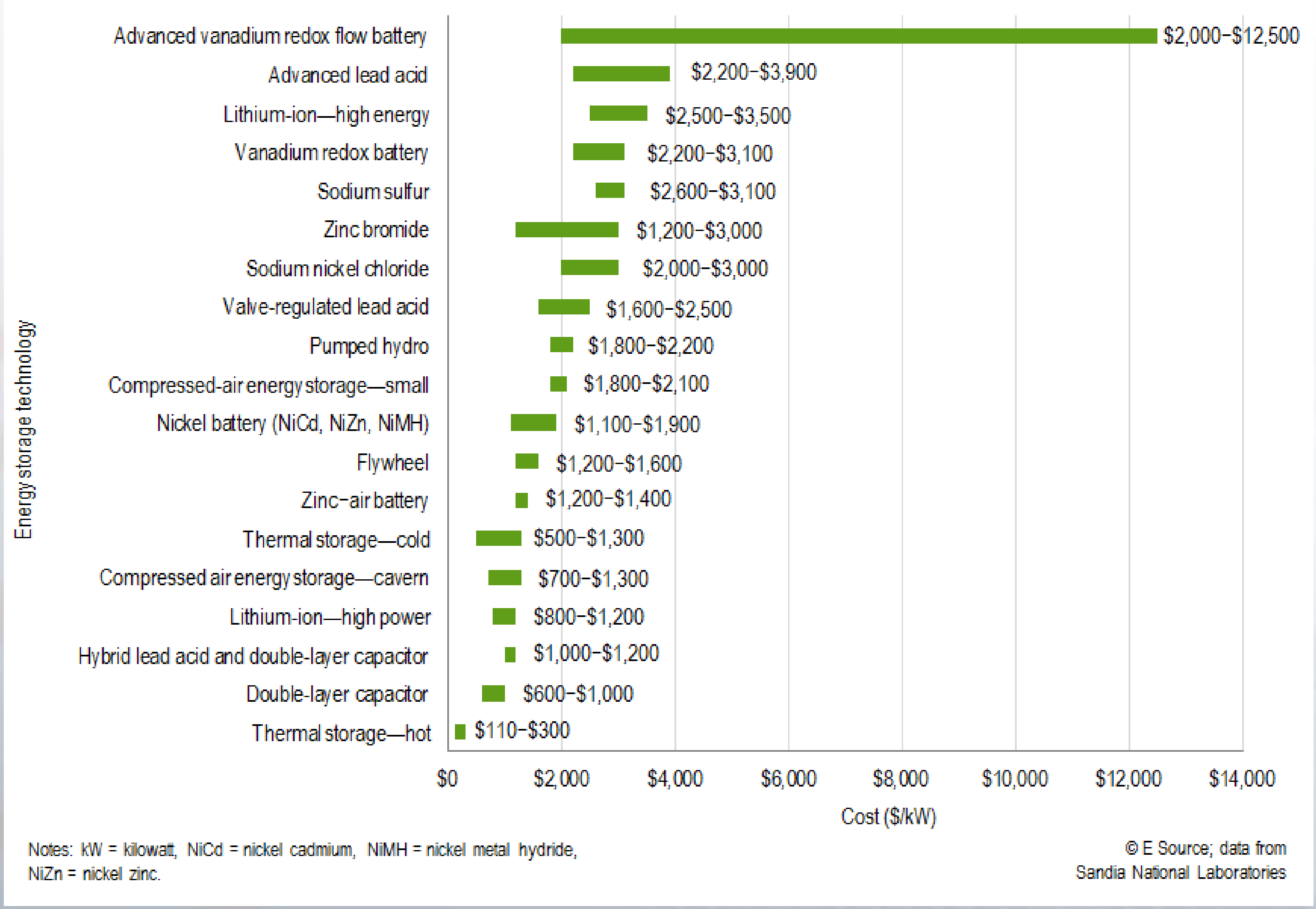
- Electricity quality and reliability are important
  - Coal, water, nuclear vs. solar and wind
  - UPS (uninterrupted power supply)
- Electricity transfer
  - Demand charge
  - Smoothing
- Energy management
  - Reduce electricity bills

Battery technology comparison

Specifications	Lead-Acid	NiCd	NiMH	Li-Ion Cobalt	Li-Ion Manganese	Li-Ion Phosphate
Specific energy density (Wh/kg)	30 – 50	45 – 80	60 – 120	150 – 190	100 – 135	90 – 120
Internal resistance (mΩ/V)	<8.3	17 – 33	33 – 50	21 – 42	6.6 – 20	7.6 – 15.0
Cycle life (80% discharge)	200 – 300	1,000	300 – 500	500 – 1,000	500 – 1,000	1,000 – 2,000
Fast-charge time (hrs.)	8 – 16	1 typical	2 – 4	2 – 4	1 or less	1 or less
Overcharge tolerance	High	Moderate	Low	Low	Low	Low
Self-discharge/month (room temp.)	5 – 15%	20%	30%	<5%	<5%	<5%
Cell voltage	2.0	1.2	1.2	3.6	3.8	3.3
Charge cutoff voltage (V/cell)	2.40 (2.25 float)	Full charge indicated by voltage signature	Full charge indicated by voltage signature	4.2	4.2	3.6
Discharge cutoff volts (V/cell, 1C*)	1.75	1	1	2.5 – 3.0	2.5 – 3.0	2.8
Peak load current**	5C	20C	5C	> 3C	> 30C	> 30C
Peak load current* (best result)	0.2C	1C	0.5C	<1C	< 10C	< 10C
Charge temperature	-20 – 50°C	0 – 45°C	0 – 45°C	0 – 45°C	0 – 45°C	0 – 45°C
Discharge temperature	-20 – 50°C	-20 – 65°C	-20 – 65°C	-20 – 60°C	-20 – 60°C	-20 – 60°C
Maintenance requirement	3 – 6 months (equalization)	30 – 60 days (discharge)	60 – 90 days (discharge)	None	None	None
Safety requirements	Thermally stable	Thermally stable, fuses common		Protection circuit mandatory		
Time durability				>10 years	>10 years	>10 years
In use since	1881	1950	1990	1991	1996	1999
Toxicity	High	High	Low	Low	Low	Low

Source: batteryuniversity.com. The table values are generic, specific batteries may differ.

Battery cost comparison

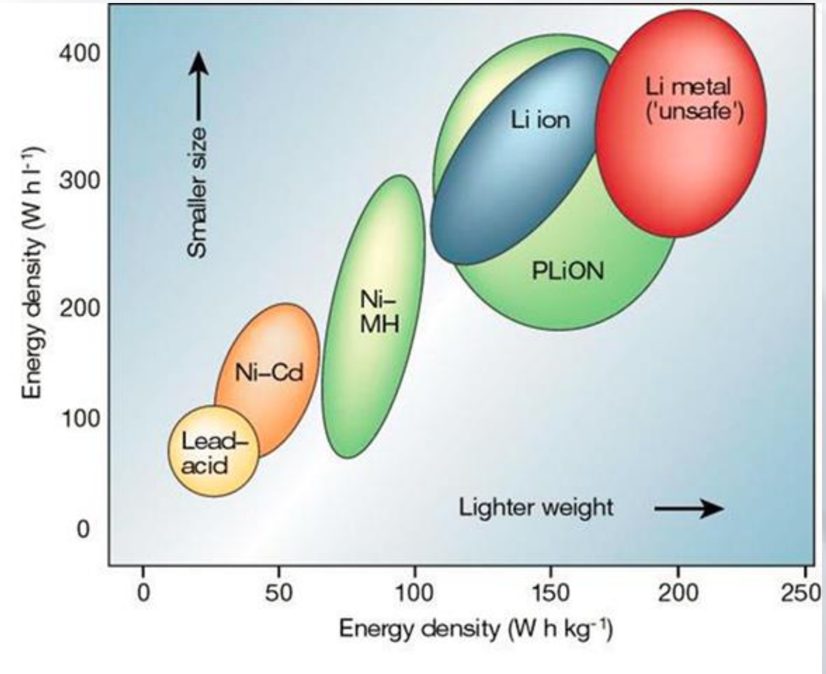


Current trend of battery types

- LFP to replace some lead-acid market
- LTO and NMC/NCA are emerging
- Later: Li metal batteries including LiS, NaS etc.

Chemical Name	Material	Abbreviation	Applications
Lithium cobalt oxide	$LiCoO_2$	LCO	Cell phones, laptops, cameras
Lithium manganese oxide	$LiMn_2O_4$	LMO	Power tools, EVs, medical, hobbyist
Lithium iron phosphate	$LiFePO_4$	LFP	Power tools, EVs, medical, hobbyist
Lithium nickel manganese cobalt oxide	$LiNiMnCo0_2$	NMC	Power tools, EVs, medical, hobbyist
Lithium nickel cobalt aluminum oxide	$LiNiCoAlO_2$	NCA	EVs, grid storage
Lithium titanate	$Li_4Ti_5O_{12}$	LTO	EVs, grid storage

Source: batteryuniversity.com



Why lithium stands out now?

- How to store electrons?
  - $e^- + M^+ \rightarrow M$
  - $e^- + M^+ + Host \rightarrow MHost$

M atomic weight	M max voltage	M cost ($/kg)
$Pb^{2+/4+}$ (207)	Li^+ (<4.5V)	Li^+ (40)
Zn^{2+} (65)	Na^+ (<4.2V)	Na^+ (1)
Al^{3+} (27)	Mg^{2+} (<~3.8V)	Mg^{2+} (2)
Mg^{2+} (25)	Al^{3+} (<~3.1V)	Al^{3+} (2)
Na^+ (23)	Zn^{2+} (<~2.2V)	Zn^{2+} (2)
Li^+ (7)	$Pb^{2+/4+}$ (<2.1V)	$Pb^{2+/4+}$ (2)
H^+ (1)	H^+ (<~1.5V)	H^+ (nearly free)

The cost of Li in Li-ion battery is only <3%

Reference: Yi Cui, Stanford

Future for lithium-ion battery cells

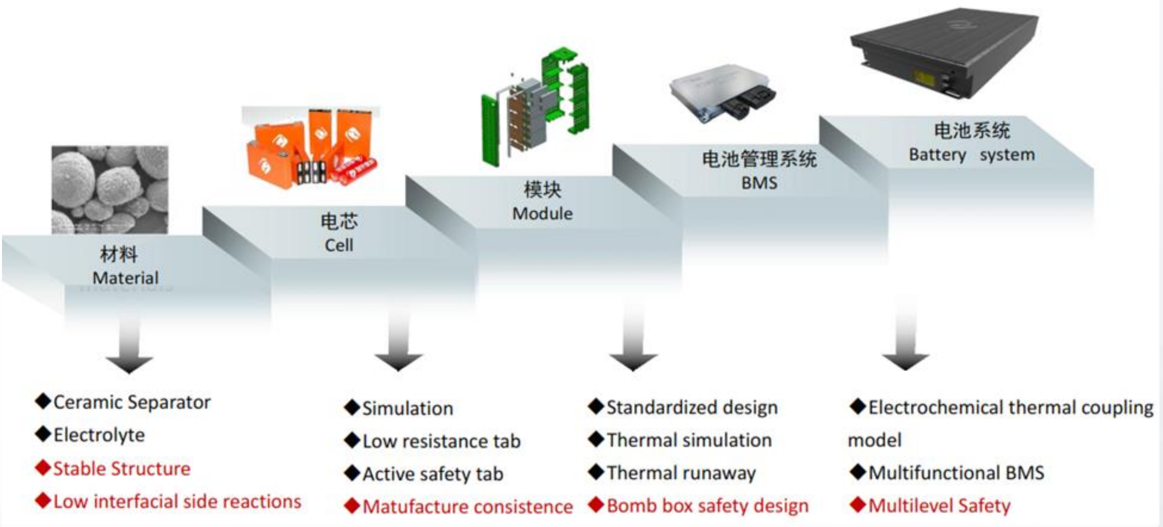
	Now	Transportation	Grid
Specific energy (Wh/kg)	~200	600	XXX
Cost ($/kWh)	250	100	100
Safety	Important	Important	Important
Calendar life	5-10	15	20

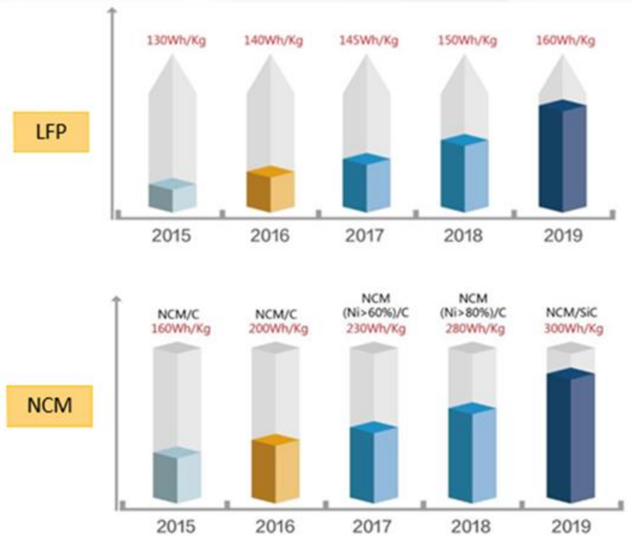
My personal prediction of li-ion battery technology trend

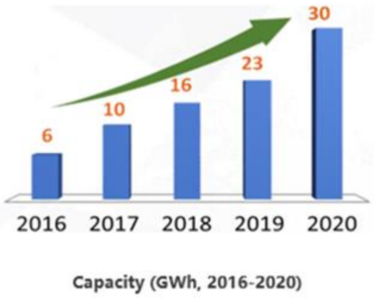
- 2015-2030, climbing to the max
  - Li-ion energy density increases at 5%/yr
  - Decrease cost 8%/yr
- After 2025, solid state battery introduction with change of price
- Until 2030, concurrent paths including LiS, NaS, Zn/Mg etc.

What we can do?

Hefei Guoxuan High-tech Power Energy Co.







Founded in May 2006 and based in Hefei, Anhui Province, China

6 Wholly-owned subsidiaries and 7 manufacturing bases in China, to reach 30 GWh by 2020.

6 R&D Institutes in Hefei, Shanghai, Silicon Valley, Cleveland, Tsukuba and Europe

In transportation

In June 2016, Hefei received the prestigious Asia-Pacific E-Visionary Award at the 29th Electric Vehicle Symposium & Ehibition in Montreal, for its outstanding efforts in the field of E-Mobility. Guoxuan's power battery technology is the major contributors to Hefei's achievement in E-Mobility.

Hefei No.18 public transit bus started its operation on 23th January, 2010, and earned many No.1 titles globally, including

- World first EV-only commercial bus route
- World No.1 total operating mileage (10 million km)
- World No.1 operating mileage of a single bus (420, 000 km)
- World No.1 operating time (more than 7 years)

Passenger vehicles

Guoxuan batteries are used in EVs for BAIC, SAIC, JAC (iEV series), Chery, Zotye, Geely, etc.

- In January 2011, 585 JAC EVs equipped with Guoxuan batteries were put into market, initiating first series application of EVs in China market.

Guoxuan batteries are also widely used in commuter vehicles, delivery vehicles, special purpose vehicles, etc.

- The SAIC EV80 equipped with Guoxuan batteries showed up at the Auto show in Birmingham, UK in April 2016, indicating a successful debut on European market.

Commercial vehicles

- Guoxuan batteries are equipped in commercial buses manufactured by Yutong, Zhongtong, Nanjing King Long, Ankai, Shanghai Sunwin, etc.

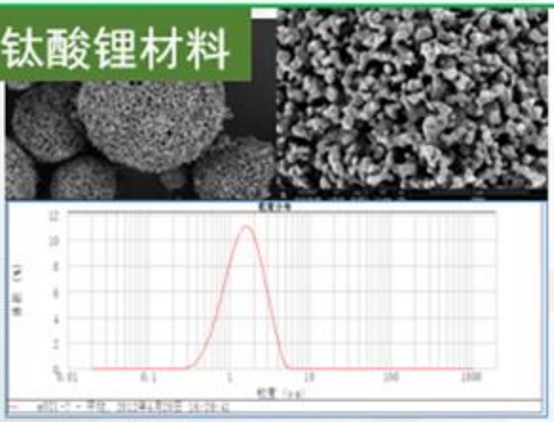
Guoxuan battery has become a standard component for majority of China's domestic buses.

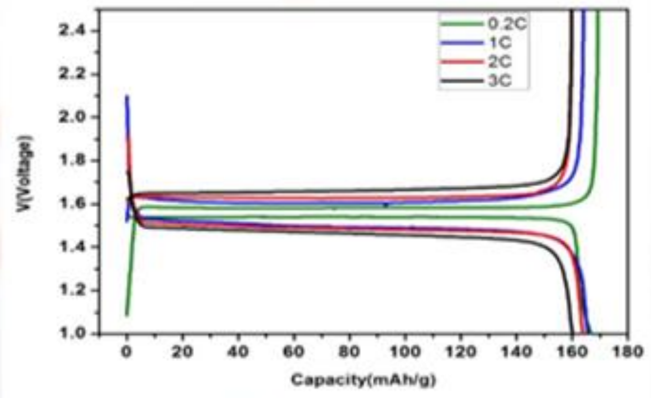
Until the end of 2016, the total shipment of Guoxuan batteries exceeds 4GWh, equipped over 26,000 passenger cars and 28,000 buses. By the end of 2017, the production capacity will achieve 10 GWh.

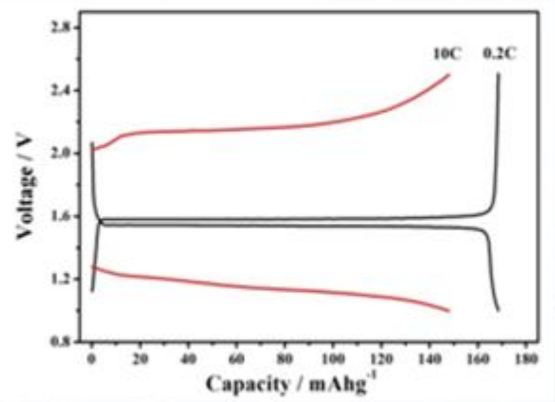
In electricity energy storage

上海电气
SHANGHAI ELECTRIC

钛酸锂材料



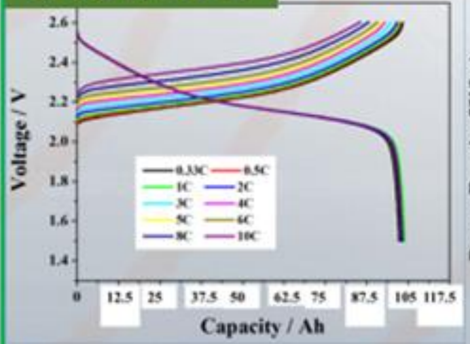


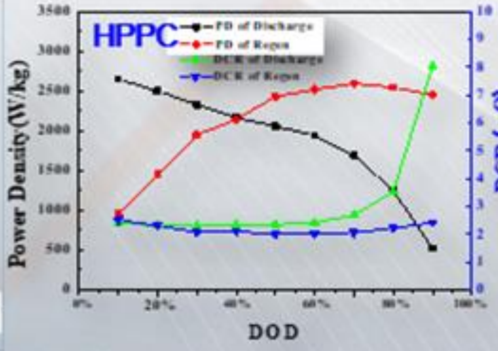


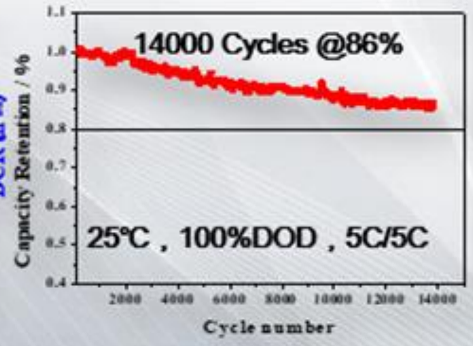
产品粒度呈现非常好的正态分布

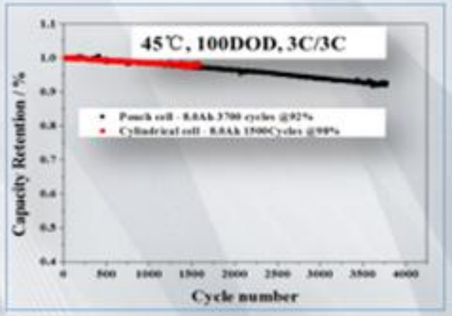
3C充放≥155mAh/g，10C充放≥148 mAh/g

钛酸锂电芯









LTO(G2)/NMC-32131Cylindrical/Pouch Cell-8Ah: >85 Wh/Kg/2300 W/Kg;25°C, >14000cls@ 5C/5C, 100%DOD;
45°C, 3700 cls@3C/3C, 92% capacity retention, 100%DOD

To be continued…

- In the past ~200 years, the slowest development in storage
  - We cannot store energy just as we hold the water in portable bottles
- Saving night energy and power the world!

Thank you!

- Welcome to join our upcoming event!

- **2017 US-China New Energy Economy Forum**

  Clean Energy: Open, Creativity, Transition
- November 16-18, Thursday to Saturday
- Santa Clara, CA

BAIC BJEV 北汽新能源

Gotion