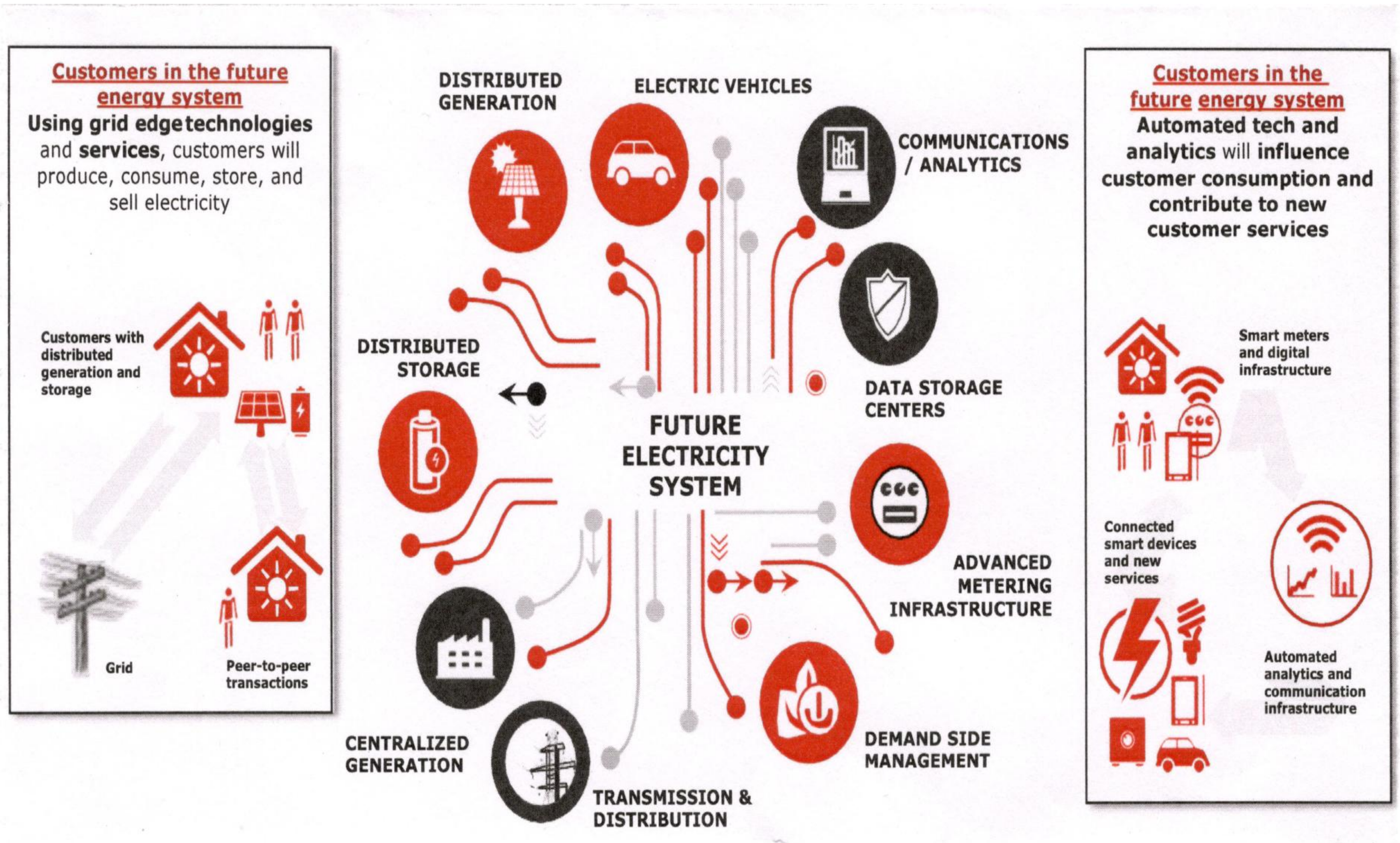
Innovative Technologies for Storage for Future Business

Major energy storage technologies

- Batteries
- Pumped Hydro
- Flywheels
- Compressed air energy systems

Future Energy System



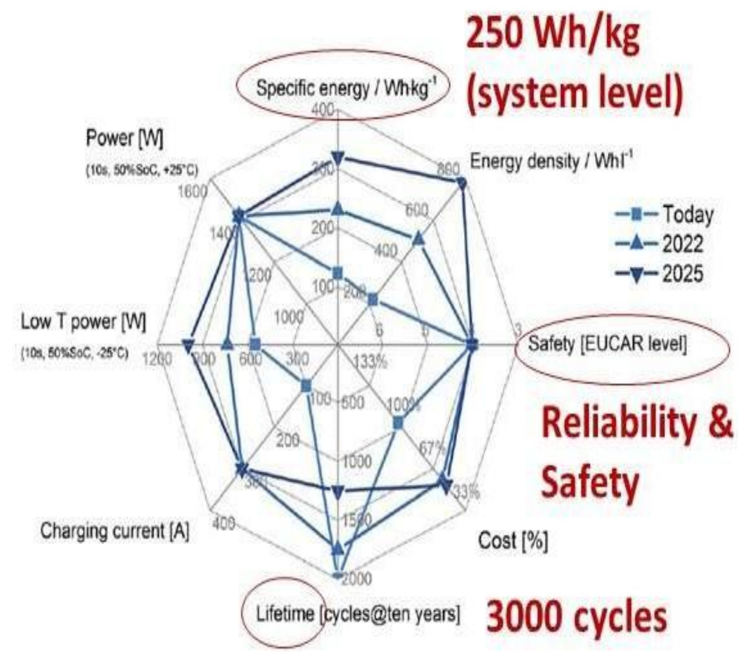
Source : World Economic Forum

ENERGY STORAGE FOR xEV

Battery storage for electrified vehicles

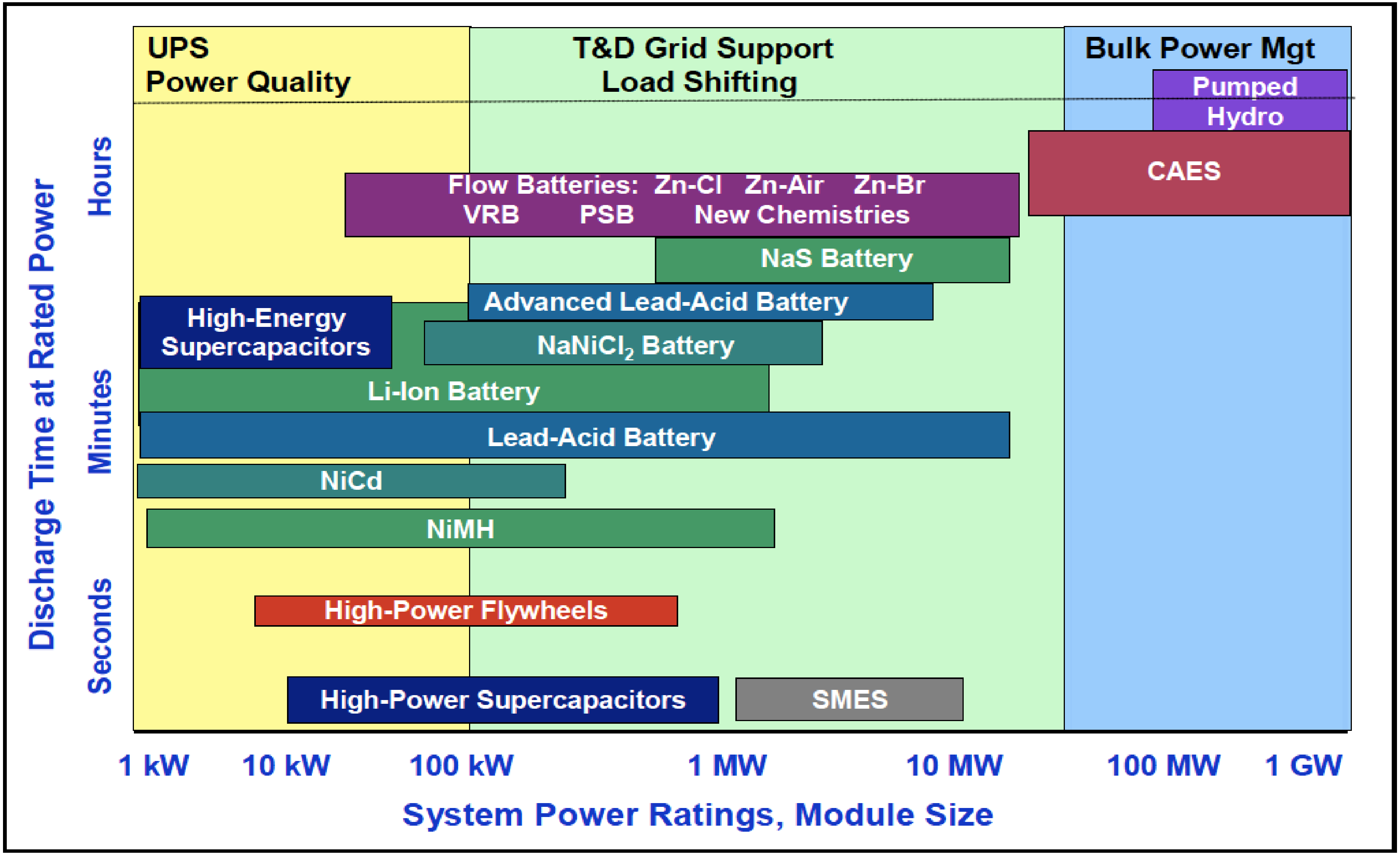
- Boost with Li-ion batteries introduction
- Still limiting parameters for large scale commercialization
  - Lifetime
  - Driving range
  - Quality & safety
  - Cost
- Affordable economical business plan for OEMs strongly depending on storage

- **Understanding and control of battery ageing mechanisms is the key**
  - Extending battery lifetime
  - "Smart" BMS and charging modalities implementation

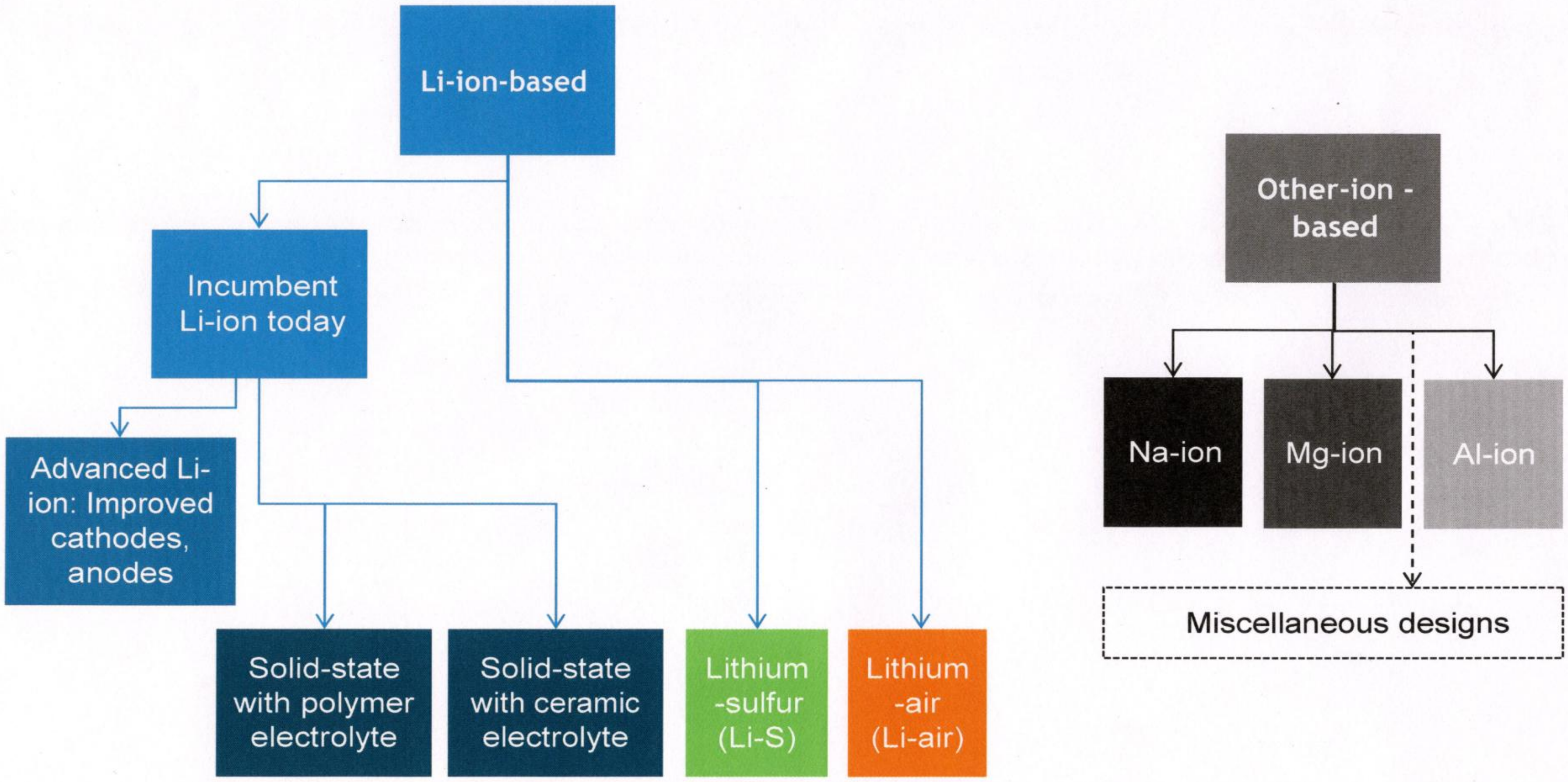


D. Andre et al., Future generations of cathode materials: an automotive industry perspective, *J. Mater. Chem. A.* 3 (2015) 6709–6732

Mapping Storage Technologies



Beyond today's incumbent Li-ion and advancing Li-ion, there are many next-generation battery options

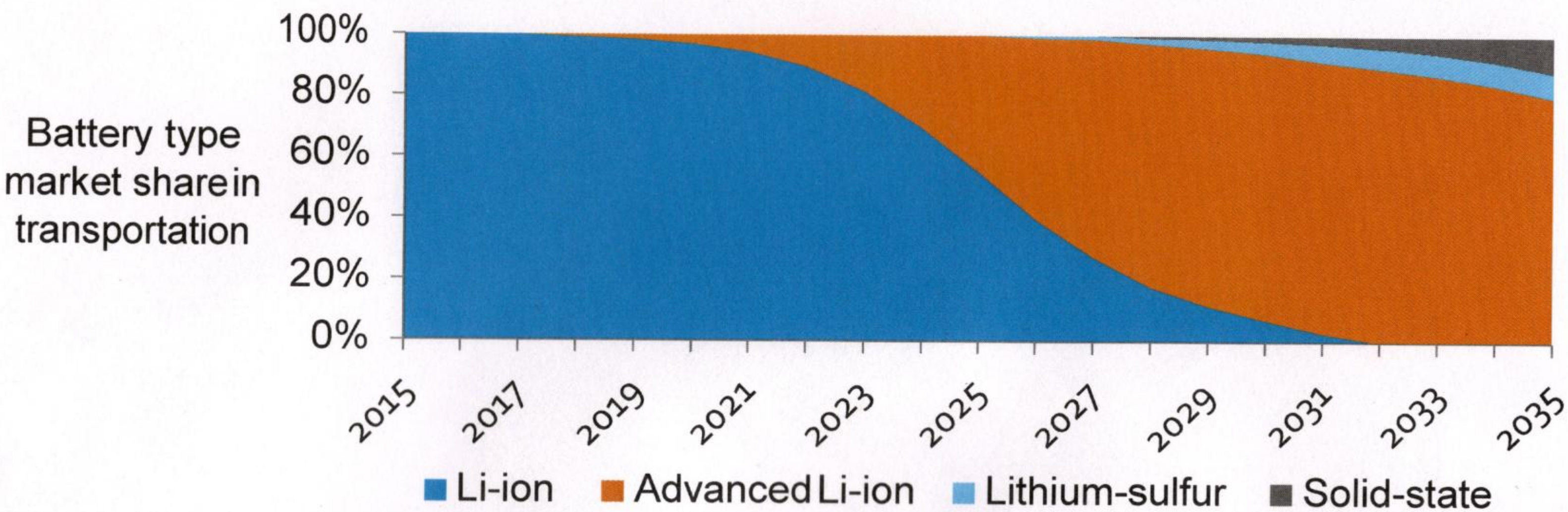


Source : Lux Research

› The biggest growth in batteries will actually come from gradually evolving Li-ion batteries, through incremental innovations like higher-voltage cathodes and electrolytes, paired with higher-capacity active materials like silicon-containing composites

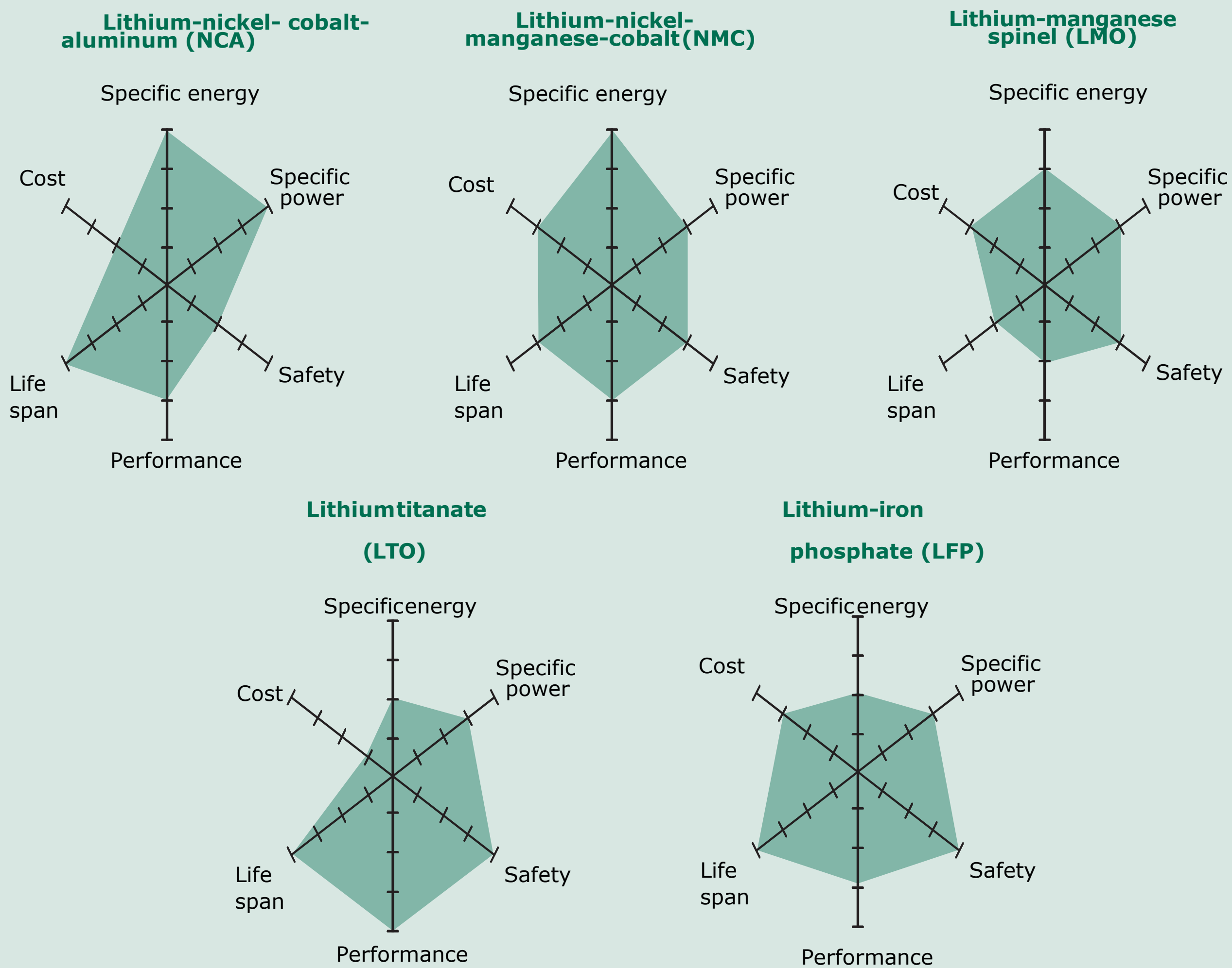
› Next-generation batteries must wait until nearly 2030 to gain noteworthy market share – around then, solid-state batteries will win about $3 billion in transportation and $2 billion in electronics; lithium-sulfur will capture market share, too, though its growth will be slower

› Early adopter markets will be key – military, wearables, IoT



Source : Lux Research

Tradeoffs Among the Five Principal Lithium-Ion Battery Technologies



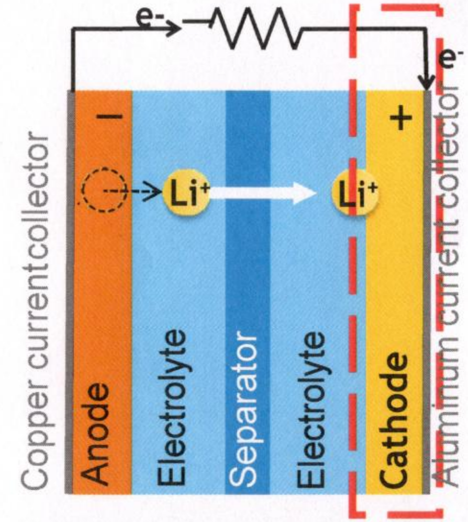
Source: BCG research.

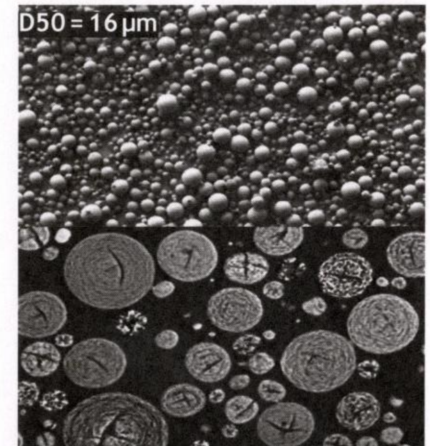
Note: The farther the colored shape extends along a given axis, the better the performance along that dimension.

Li-ion will remain a moving target, with one of key improvements being better cathodes

- Today's Li-ion batteries still enjoy incremental improvements every year, boosting performance within established design and manufacturing process, via better cathodes (this slide) and anodes, electrolytes, separators (next slides)
- **Major Li-ion cathodes**: Li-containing transition metal oxides, at < 4.1 V: Lithium
    - cobalt oxide ($LiCoO_2$, LCO)
    - Lithium nickel manganese cobalt oxide ($Li(Ni_xMn_yCo_{1-x-y})O_2$, NMC)
    - Lithium manganese oxide ($LiMn_2O_4$, LMO; spinel-type)
    - Lithium iron phosphate ($LiFePO_4$, LFP)
- **Advanced Li-ion cathodes**:
    - Higher-voltage and higher-capacity materials, including:
        - "Layered-layered" oxide materials, such as BASF's high-energy NMC (see the report "The Li-ion NMC Patent Lawsuit and Its Fallout: Waging Billion-dollar War over Crystal Phases")
        - Spinel-type oxides (such as $LiNi_{0.5}Mn_{1.5}O_4$)
        - Polyanion materials (such as $LiCoPO_4$)
    - **Advantages**: Greater volumetric and gravimetric energy density, potentially reaching or exceeding the 300 Wh/kg to 350 Wh/kg level
    - **Challenges**: Low cycle life due to material degradation upon cycling (commonly less than 100 cycles), capacity fade, safety concerns

Source : Lux Research



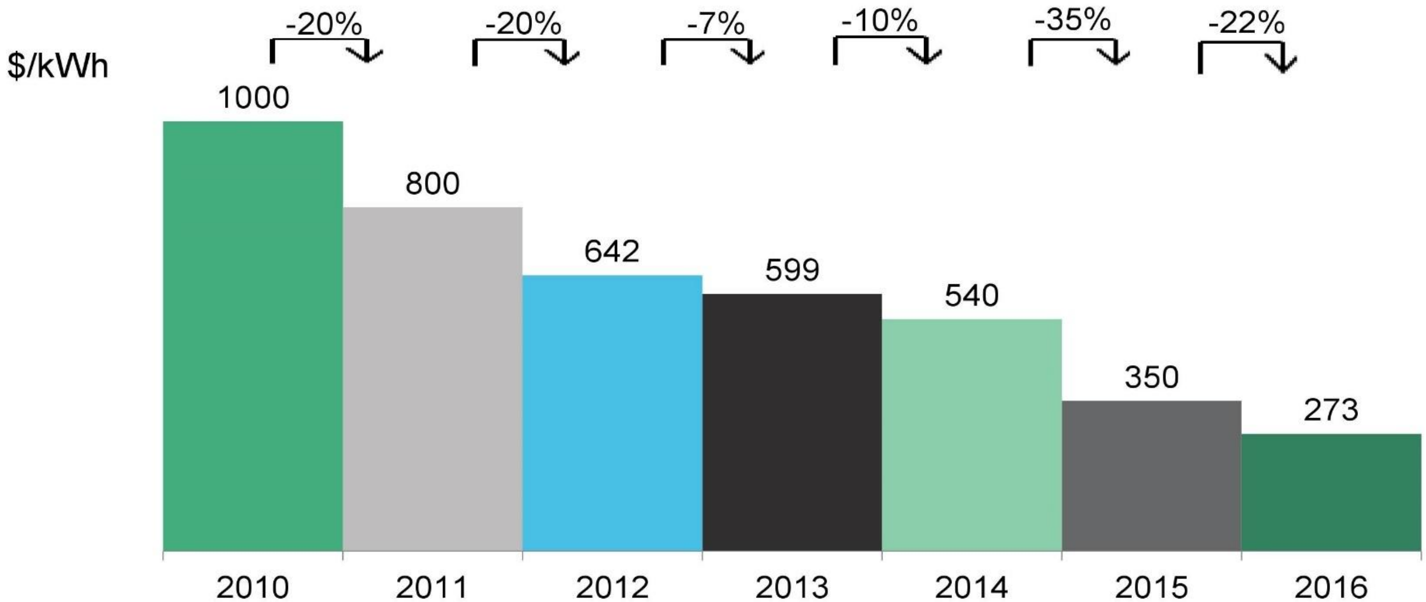


High-energy NMC cathode material from BASF

The price of lithium-ion batteries in 2016 was $273/kWh – a drop of 73% since 2010.

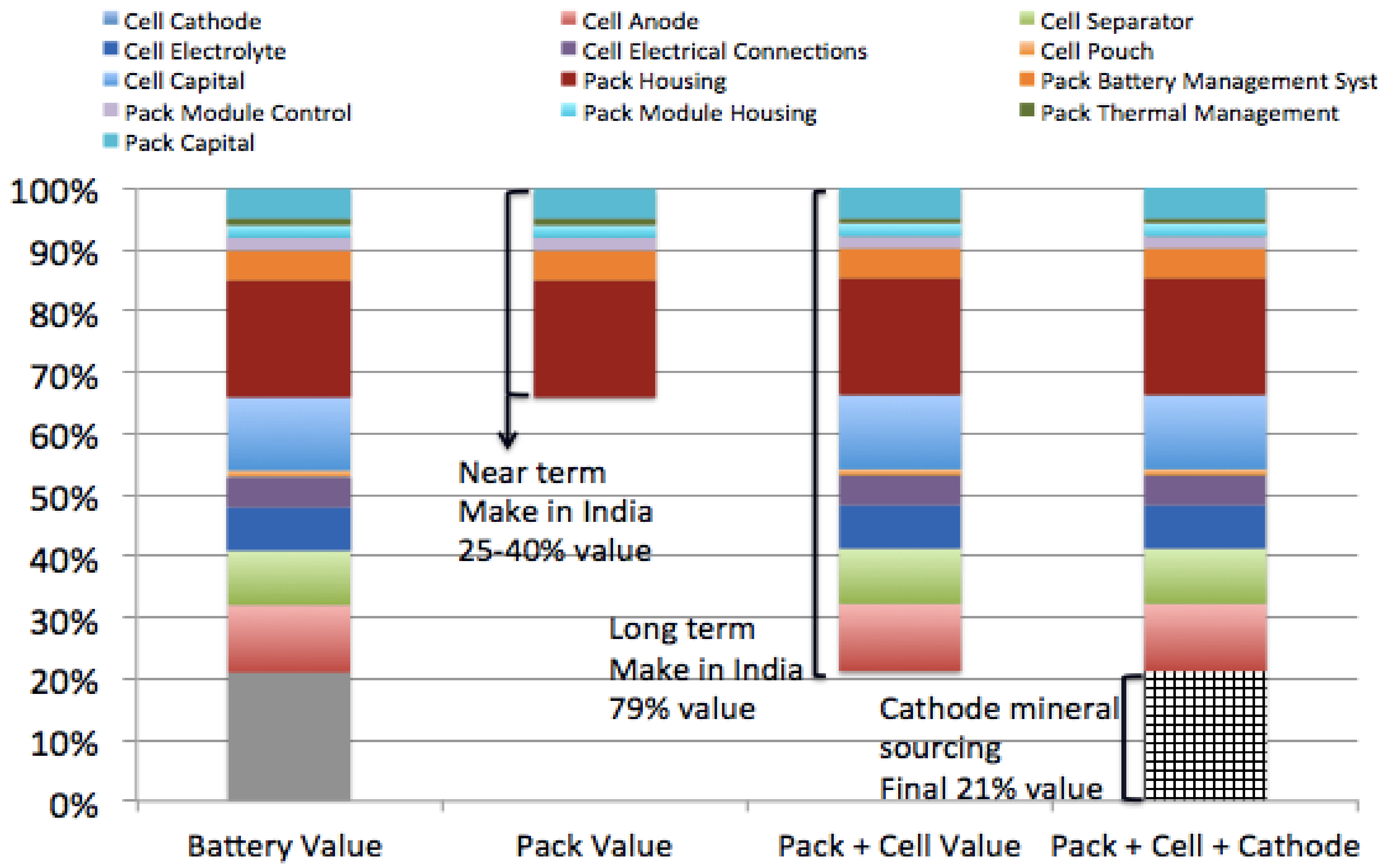
- The steep decrease in prices in the past few years is in part due to technology improvements and economies of scale.
- However, fierce competition between the major manufacturers has been instrumental in bringing down prices.

BNEF lithium-ion battery price survey, 2010-16 ($/kWh)

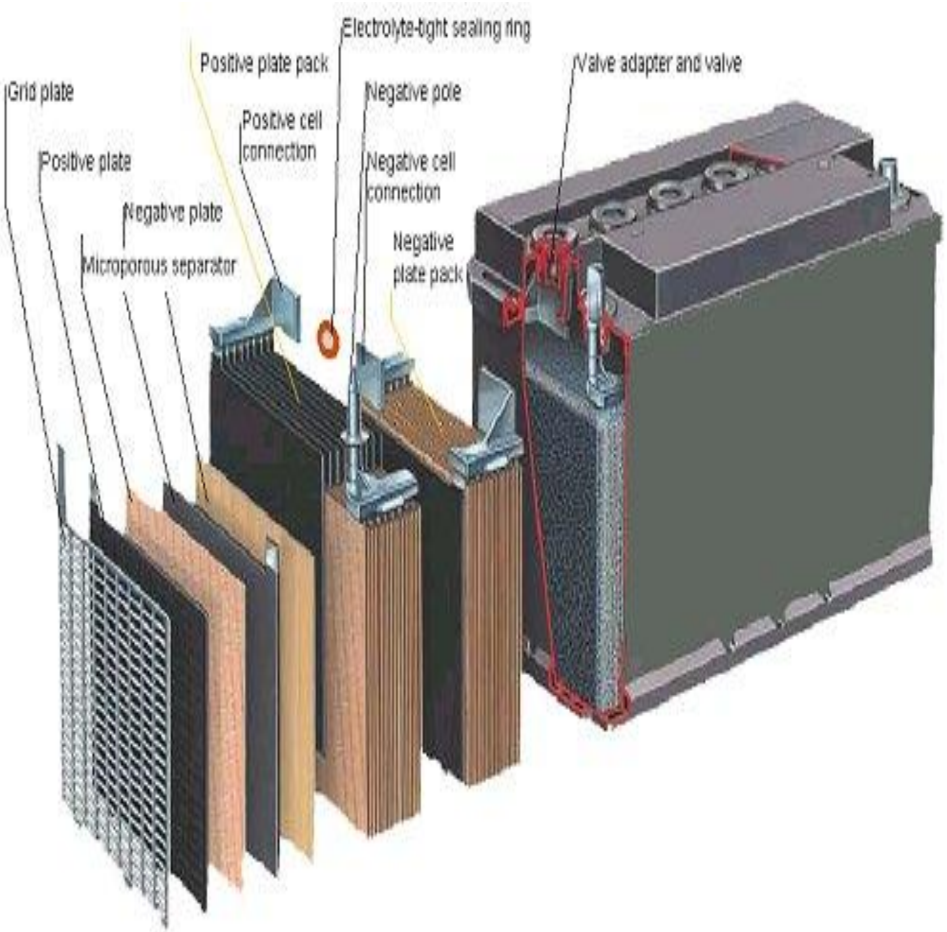


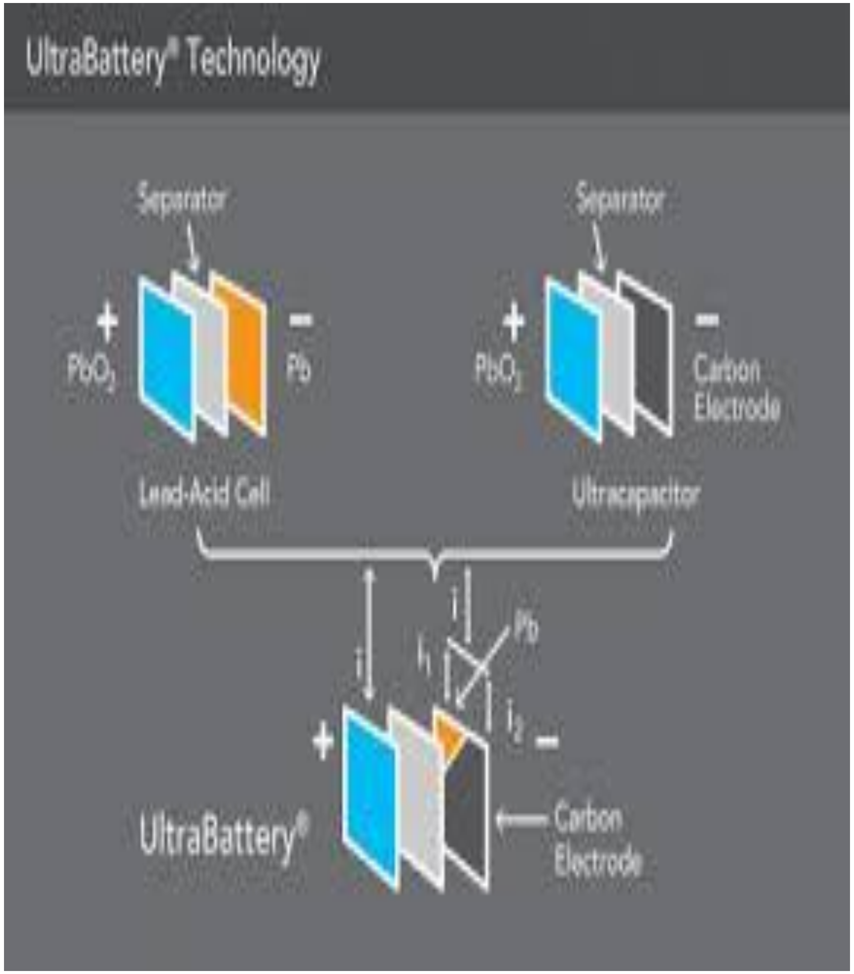
Notes: This includes cells plus pack prices. For years where there were two surveys, the data in this chart is an average for the year.

BATTERY COST BREAKDOWN AND OPPORTUNITIES FOR VALUE CAPTURE



Advanced Lead acid battery





Challenges and Enablers

Challenges

- Lack of core technology and manufacturing of advanced chemistries
- Lack of mineral resources
- Tackling cost and complexity of battery management electronics
- Cost of oil

Enablers

- Market potential (800 – 900 GWhr capacity required for full conversion to EVs by 2030)
- As per projections, by 2025, mid segment pre tax price of EVs would be similar to ICEs
- Stable long term government policies facilitating advanced technology battery manufacturing and development of ecosystem
- Incentives in the short to mid term (recoverable due to lower oil import bill)

Drivers for growth of battery based energy storage in India

Policy objectives

- Master plans for most cities in India target **60-80 per cent public transport** ridership by 2025-2030 (Center for Science and Environment)

Market size

- India is the **2nd** largest two-wheeler market (**80 million** in 2010) in the world after China
- Two-wheelers will continue to remain mode of choice in 2035 (UNEP, DTU and IIM-A)

Environmental

- **Thirteen** out of 20 cities in the world with **highest air pollution** are in India
- Low carbon scenario with 'highest' EV penetration shows 50 percent drop in PM by 2035 (UNEP, DTU and IIM-A)

Allied opportunities

- With the Government of India targeting **100 GW of solar by 2022**, electric vehicles can improve reliability and utilization of renewable by acting as storage


Thank You