STORAGE 101:
State of Play & Technology Overview

IFC International Finance Corporation
WORLD BANK GROUP

Creating Markets, Creating Opportunities

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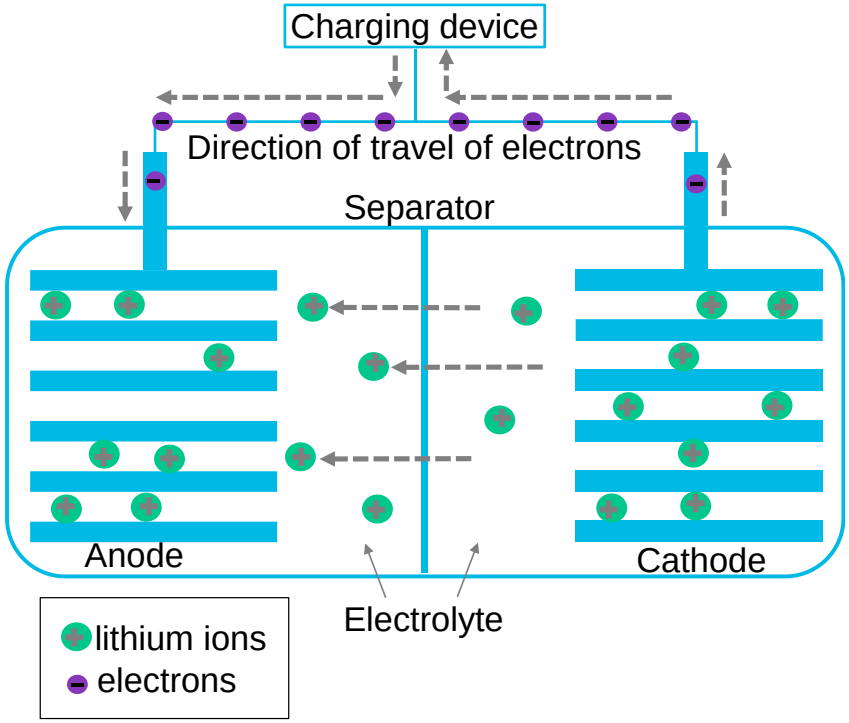
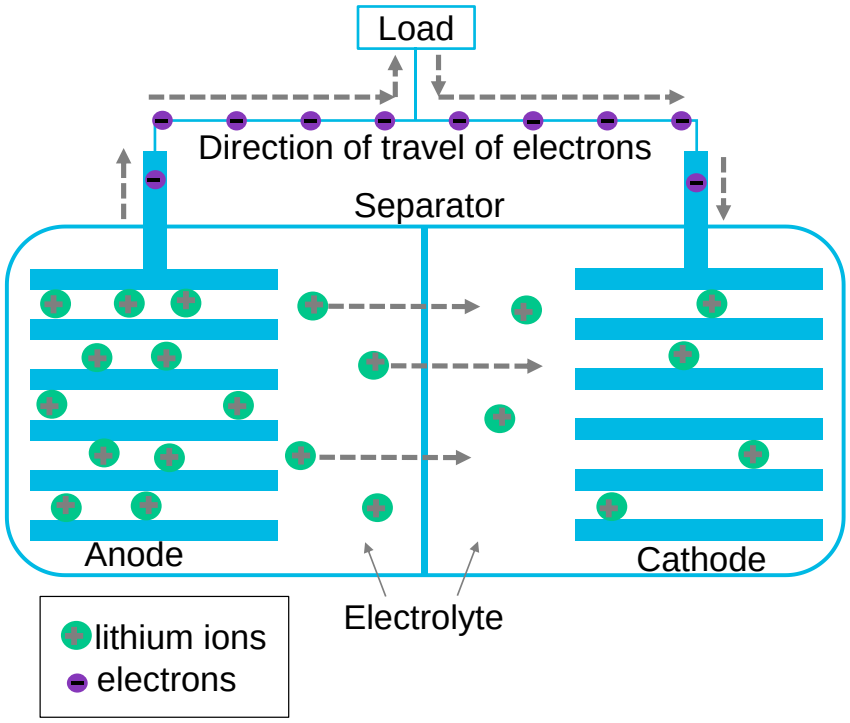
State of Play

LITHIUM-ION BATTERIES

CHARGING (BATTERY IS PLUGGED INTO ELECTRICITY MAINS)



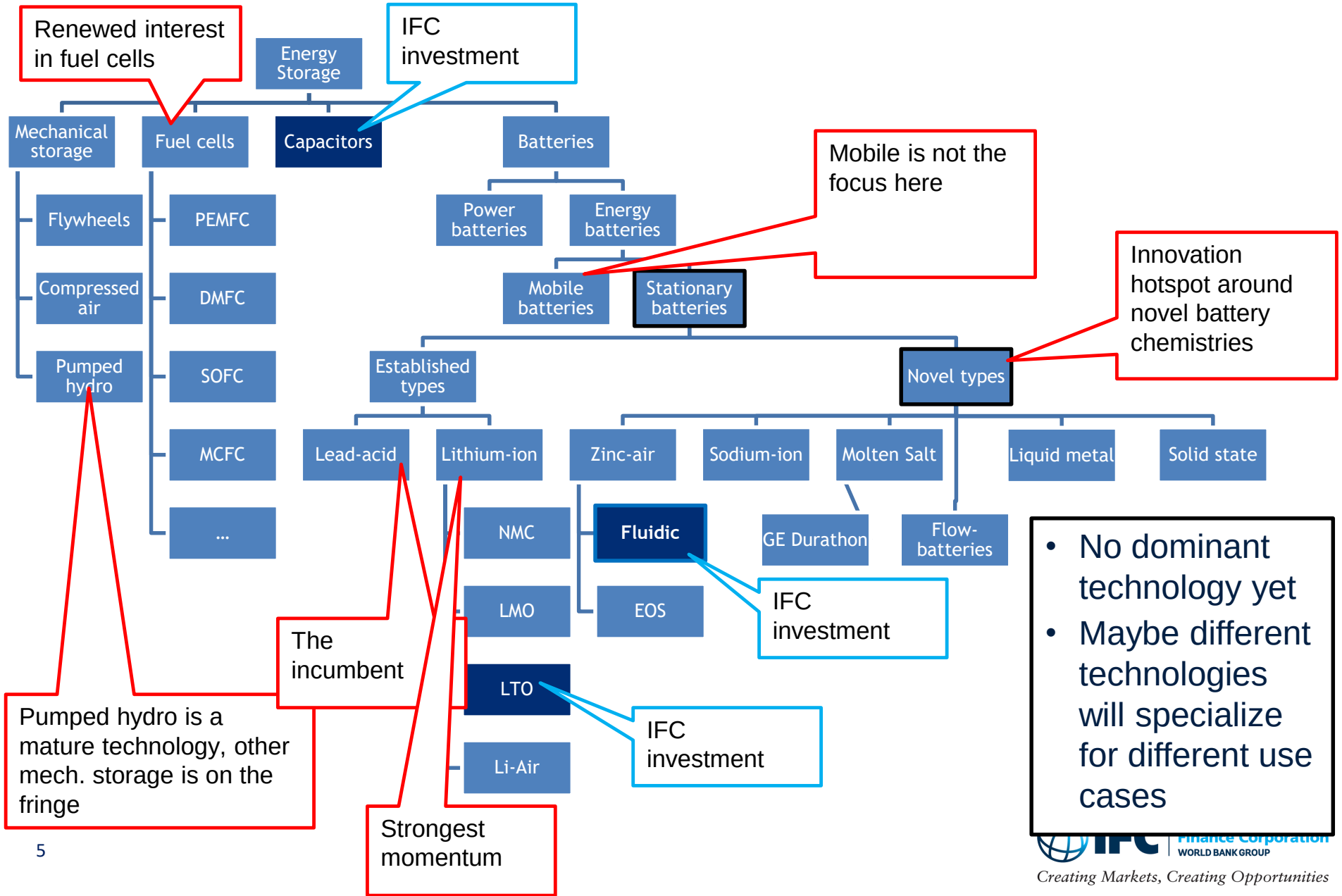
DISCHARGING (BATTERY IS GENERATING ELECTRICITY)



Battery performance criteria

- **Specific power**: Short term power surge e.g. for starter engines
- **Cycle life**: Most important where swapping cells incurs high cost, e.g. remote installations, vehicles
- **Gravimetric energy density**: EVs require low weight
- **Volumetric energy density**: Passenger cars require compact batteries
- **Ambient temperature**: High temp. tolerance required in hot climates, reduces need for active cooling
- **Charge speed**: Grid backup, when power is only temporarily on
- **Charge retention**: Infrequent discharge, e.g. UPS
- **Safety**: Risk of thermal runaway unacceptable in transportation applications
- **Round trip efficiency**: Counterintuitively, sometimes not so important, e.g. when energy is stored which would otherwise be curtailed
- **Cell cost:** Cost of individual cells, not as important as …
- **system cost**: Including packaging, remote monitoring and climate control.

Overview of major battery chemistry families



There is no single winning technology yet. Lithium-ion has best all-round performance at this time.

Made by countless local manufacturers

Incumbent – good all-around battery. Made by Samsung, LG, Tesla/Panasonic, BYD, Sony & 20+ smaller vendors

Mostly small vendors (Primus, ESS, Gildemeister …)

Nant Energy: Robust, long-duration

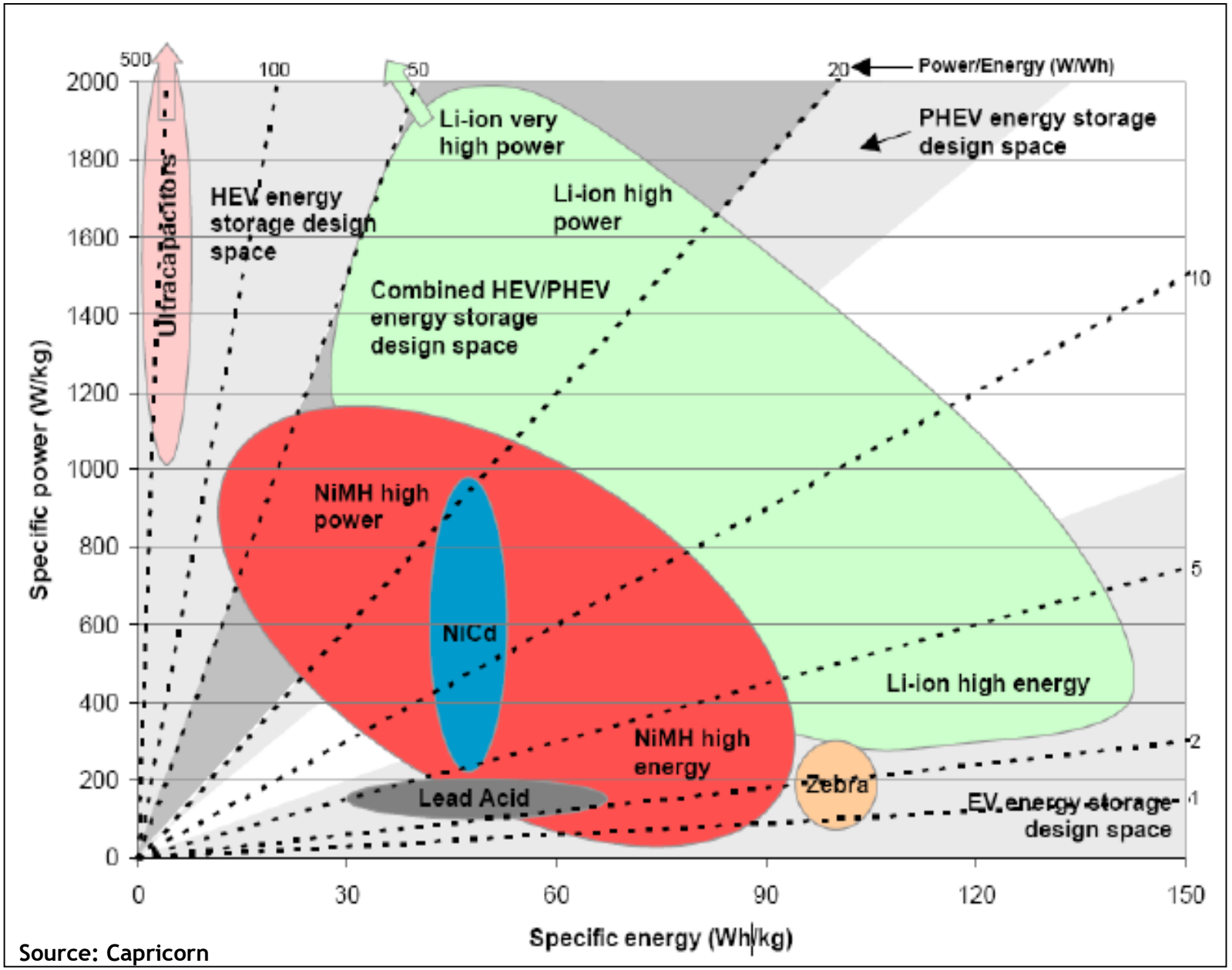
	Lead Acid	Li-ion	Flow	Zinc-air	…
Chemistries	Flooded, VLR/AGM/Gel, carbon matt	LCO, LMO, NMC, NCA, LFP, Li-S, Li Metal, LTO, Li-Si	Vanadium redox, Iron-Chromium, Zinc-Bromine	Zinc-air	… plus long tail of other battery types for specialized applications
O&M	Requires regular maintenance	Requires cooling/air conditioning	Requires electrical pump to function continuously	Low maintenance (e.g. air filter washing)	
Discharge time	Can be optimized for short or long (20h) discharge	Short (up to 4h)	Medium to long (4h-10h)	Long (7h)	
Cycle life (# of deep cycles)	200 – 800	2,000 – 8,000	10,000 – 15,000	10,000+	
Round Trip Efficiency	60%-70%	85%-98%	60%-85%	50-70% [1)]	
Density	Large and heavy	High	Medium	Medium	
Cell Price	<$100/kWh	<$250/kWh, and falling	$200-$600 per kWh	$160-250/kWh, lower at scale [2)]	
Safety	Medium, risk of gassing	Low, about 1-in-a-million chance of fire	No flammability but chemical spills possible	Risk-free	
Toxicity	Very critical	Medium	Varies, e.g. Bromine is critical	None	
Misc.	Hazardous manufacturing		Reliability issues in harsh environment	No cooling required	

1) Nant Energy is working toward 80%
2) On path to $100, roadmap to $35

Glossary: “Lithium-ion” is no single technology but a family of different combinations of anode and cathode materials

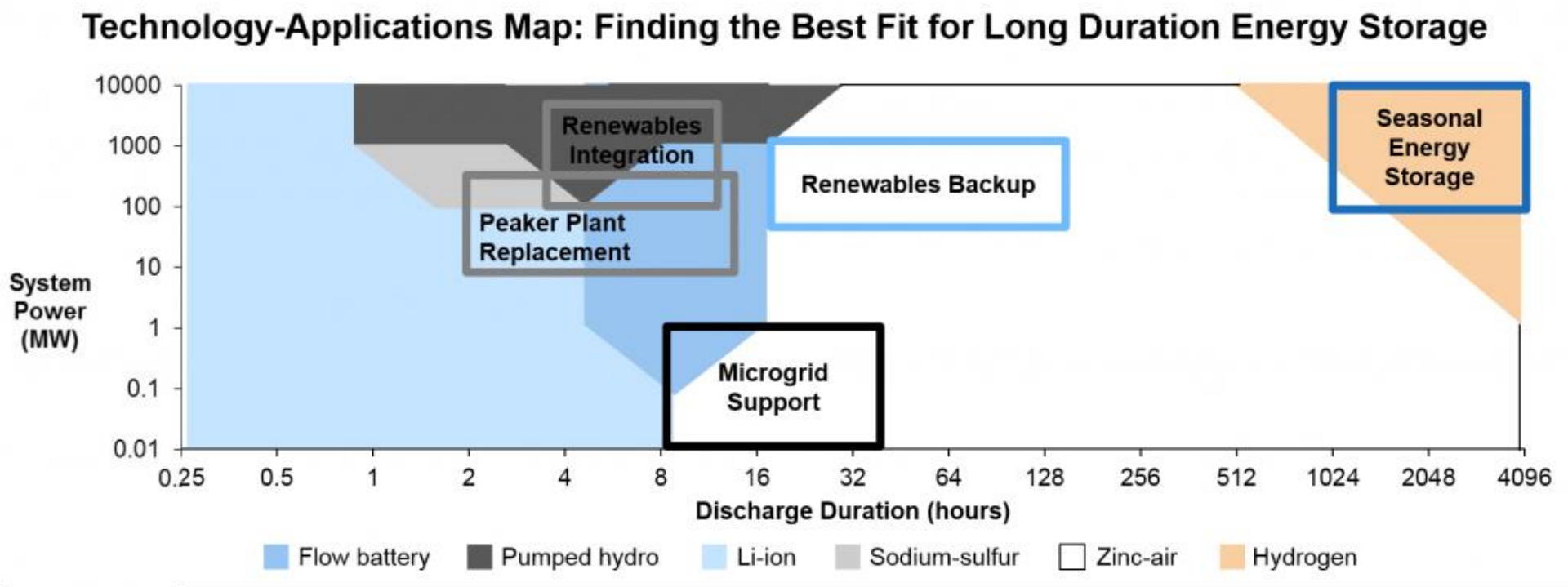
Lithium Cobalt Oxide Cathode	LCO
Lithium Manganese Oxide Spinel Cathode	LMO
Lithium Nickel Manganese Cobalt Oxide Cathode	NMC (alt. NCM)
Lithium Nickel Cobalt Aluminium Cathode	NCA
Lithium Iron Phosphate Cathode	LFP
Lithium Sulphur Cathode	Li-S
Lithium Metal Anode	Li Metal
Lithium Titanate Anode	LTO
Lithium with Nano-Structure Silicon Anode	Li-Si

ENERGY STORAGE: COMPARISON POWER AND ENERGY



Source: Capricorn

SOME APPLICATION REQUIRE LONG DURATION STORAGE



BATTERIES ARE CHANGING HOW PEOPLE AND BUSINESSES GENERATE, PURCHASE, AND CONSUME ENERGY

- **Affordable** battery-powered energy **storage** is **the missing link** between intermittent renewable energy and 24/7/365 reliability
- Energy storage will be **required to exceed 50% of renewable energy** share.
- The combination of cheap solar & storage will change the sector forever.
- Batteries can:
  - Simultaneously perform transmission and distribution functions
  - Act as generators (by charging and releasing stored energy)
  - Act as grid assets (energy shifting and peaking capacity)

THE U.S. LEADS GLOBALLY IN DEPLOYMENTS. THERE IS NOW TRACTION IN EMERGING MARKETS.

- Map shows **battery systems >10MW**, **deployed or under development**
- **U.S. leads** because of head start from ARRA projects, ahead of South Korea, Japan, the E.U. and Australia
- **Chile** was the first emerging market to deploy (2012)
- **China** has recently announced a batch of very large new projects
- **Island grids** are early adopters
- Weak interconnection in **MENA** driving interest in storage

Source: DoE

Technology & Economics

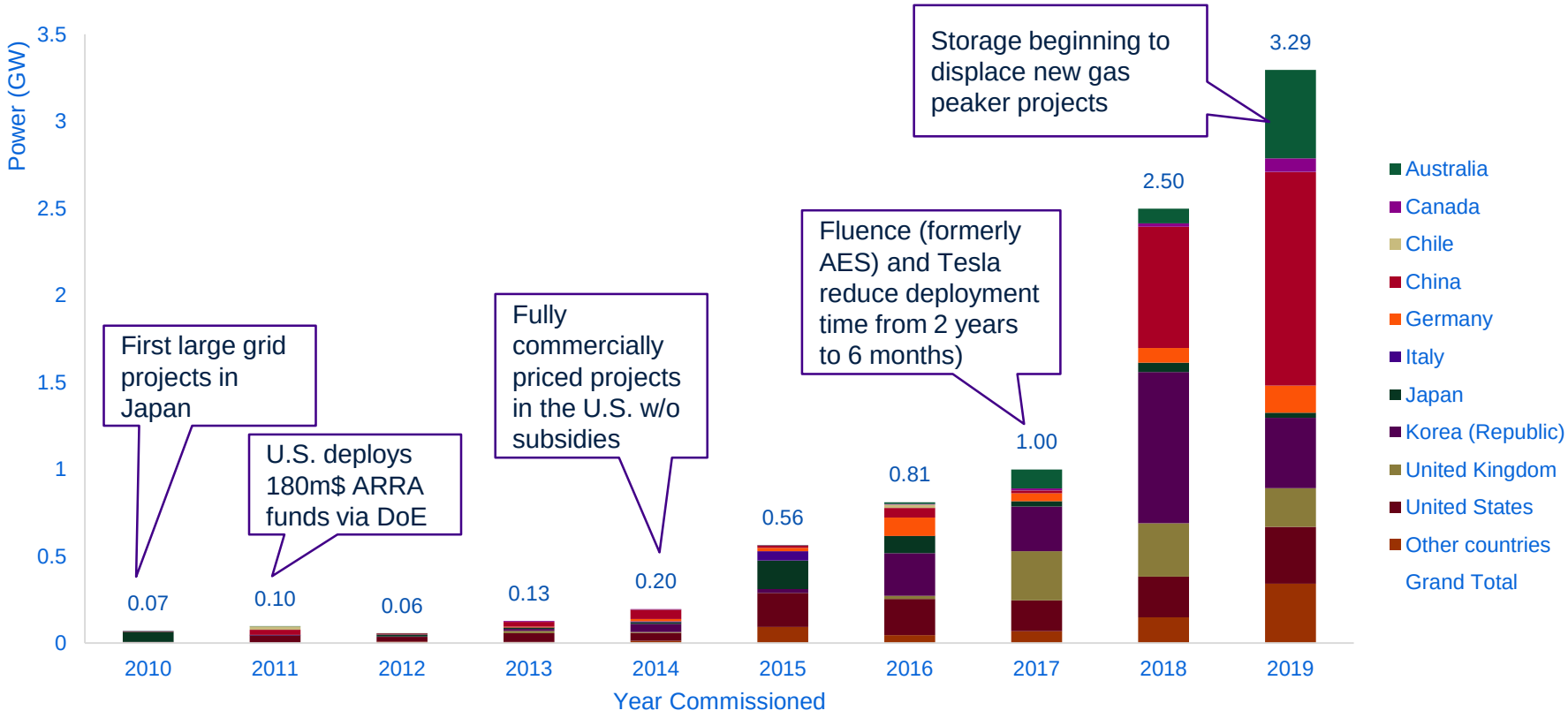
COMPONENTS OF A BATTERY ENERGY STORAGE SYSTEM

Apart from the actual battery, a stationary battery energy storage system, or BESS, requires additional components to become operational at the grid level:

- An **energy management system** (EMS) that optimizes either the battery use, or the integrated use of the battery with attached solar or wind.
- A **grid connection**
- A **transformer** for connecting to the grid and stepping up voltage.
- **Balance of plant (BoP)** (including buildings, HVAC, fire suppression, cabling, and metering)

Source: Wartsila

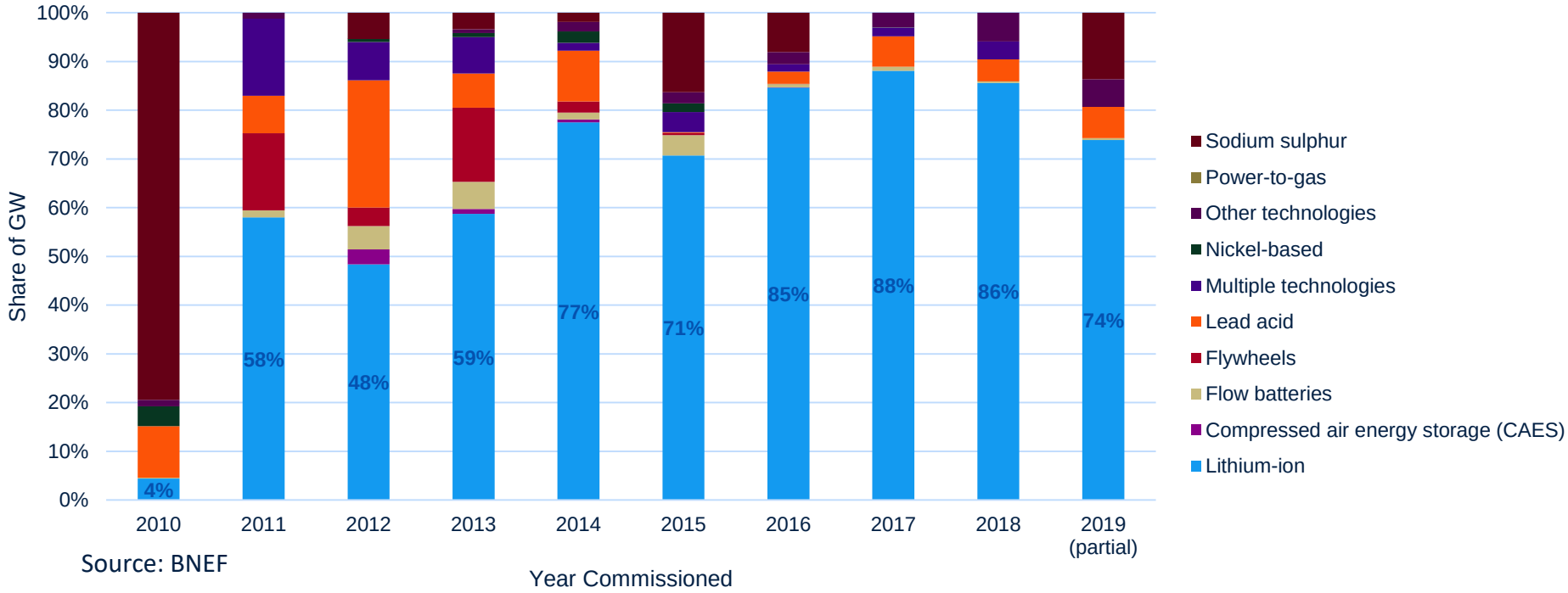
GRID-SCALE BATTERY SYSTEMS HAVE BEEN RUNNING FOR THE PAST DECADE. THE TECHNOLOGY IS DE-RISKED AND BANKABLE.



Source: BNEF Storage Assets database, retrieved 10/28/2019
Includes commissioned, financed/under construction, and announced projects using lithium ion, nickel-based, sodium sulphur, and flow batteries

MOVING BEYOND LITHIUM-ION: BRINGING OTHER BATTERY TECHNOLOGIES TO MARKET

COMMISSIONED UTILITY-SCALE STORAGE PROJECTS



Source: BNEF

- **Lithium-ion's dominance has been thanks to the auto industry driving down prices**, with energy sector reaping the benefits
- **"No battery fits all"**: Other technologies are superior for specific applications (e.g. IFC client Nant Energy for off-grid / bad grid applications)
- Optimizing technologies to applications will deliver market growth (rather than cannibalizing)

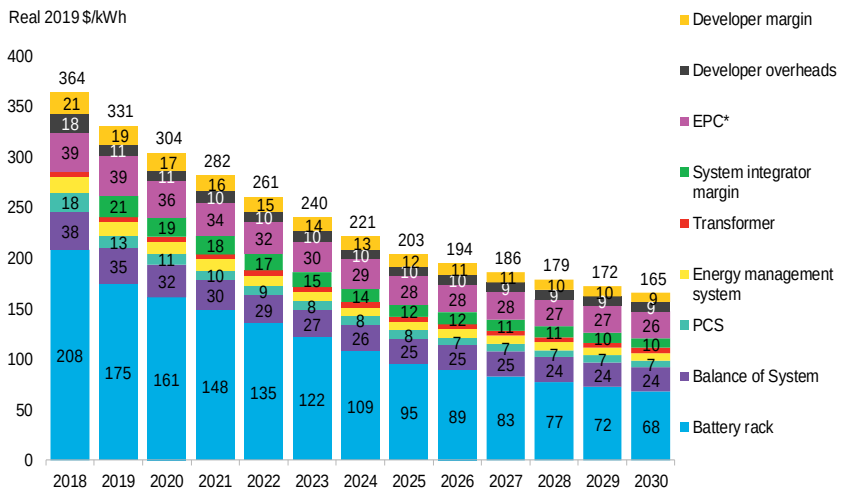
MARKET MISMATCH: EMERGING MARKETS NEED LONGER DURATION STORAGE

	OECD	Emerging markets
Needs	• **Short duration** – there's always a grid for backup • **Priority on power: Ability to quickly ramp** up and down (similar to peakers) • **Benign ambient temp** • **Multiple applications** serving complex market structures (i.e. real time bidding into ancillary services markets) • **End-of-life recycling** no issue	• **Long duration** - Power remote systems through the night and thorugh outages • **Energy over power** • **More extreme ambient** • **Low maintenance** • **End-of-life recycling** not always perfect
Appropriate technologies	Li-ion	Long-duration, robust, un-cooled, non-toxic technology

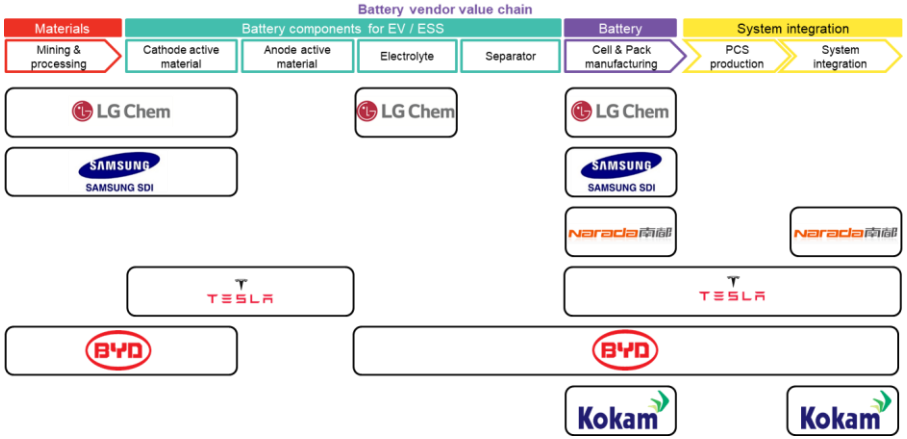
WHAT'S NEXT?

FOUR MAJOR PREDICTIONS:

INPUT COSTS FALL



VALUE CHAIN MATURES & EVOLVES



MARKET CONFIDENCE SOARS

South Africa's Eskom Preparing First Large-Scale Battery Tender

EIA: Utility-scale battery storage exceeding 10-fold growth over 10 years

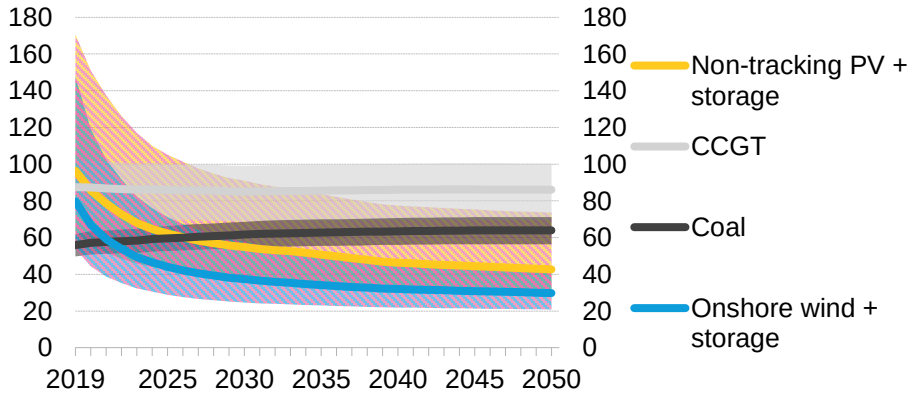
Battery Energy Storage Is A $620 Billion Opportunity As Costs Continue To Crash

Huge Battery Investments Drop Energy-Storage Costs Faster Than Expected, Threatening Natural Gas

Global Energy Storage to Hit 158 Gigawatt-Hours by 2024, Led by US and China

LCOE BECOMES MORE COMPETITIVE

$/MWh (real 2018), India



Source: BNEF

THANK YOU