TESTA
Thailand Energy Storage
Technology Association

ENERGY STORAGE: EMERGING TECHNOLOGIES

สภาวิศวกร

พิมพา ลิ้มทองกุล

สมาคมเทคโนโลยีกักเก็บพลังงานไทย

27 ตุลาคม 2566

THAILAND has been ranked No. 10th in the world for the country at risk from Climate Change

WHO SUFFERS MOST FROM **EXTREME WEATHER** EVENTS?

Six of Asia's countries are ranked among the world's top 10 countries most affected by climate risk based on frequency, death tolls and economic losses, according to the Global Climate Risk Index by think-tank Germanwatch.

Compiled by: ANN/DataLEADS

https://www.insightsonindia.com/2021/11/19/insights-into-editorial-wide-fault-lines-within-the-global-climate-risk-index/

AVERAGE PM 2.5 > 40 μg/m3

HIGHER RISK OF LUNG CANCER 7 TIMES

The international journal of science / 6 April 2023

nature

TUMOUR PROMOTION

Air pollution drives lung cancer in non-smokers

Treatment boost
The push to create a new generation of Alzheimer's therapies

Warming waters
Define marine heatwaves to help coastal communities

Dark of the Moon
Lunar eclipse records shed light on medieval volcanic activity

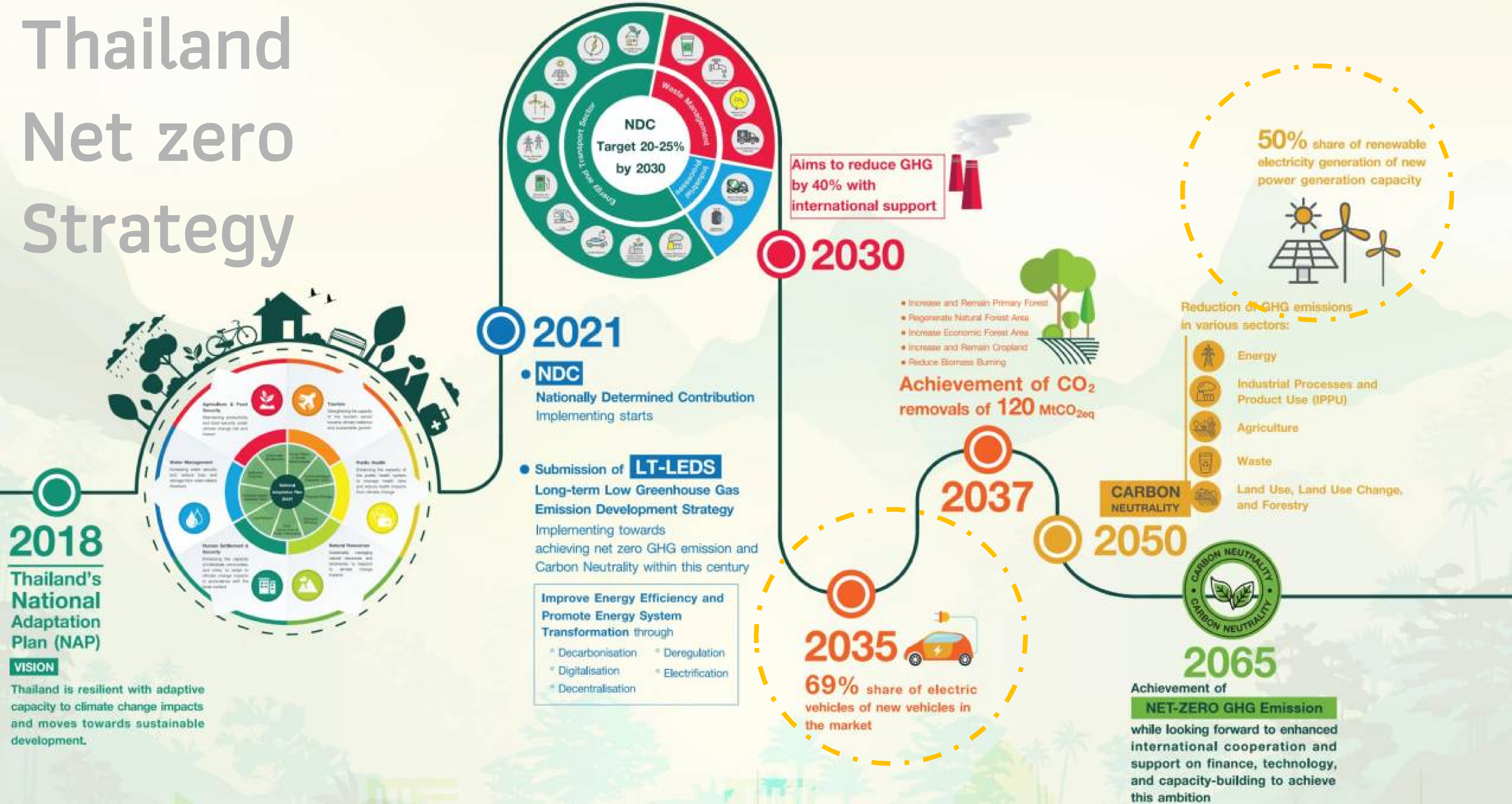
COP26

Thailand NDC will be 40% by 2030

Carbon neutrality by 2050

Net GHG emissions by 2065

Thailand Net zero Strategy



2018

Thailand's National Adaptation Plan (NAP)

VISION

Thailand is resilient with adaptive capacity to climate change impacts and moves towards sustainable development.

2021

- **NDC**

Nationally Determined Contribution

Implementing starts

- **Submission of LT-LEDS**

Long-term Low Greenhouse Gas Emission Development Strategy

Implementing towards achieving net zero GHG emission and Carbon Neutrality within this century

Improve Energy Efficiency and Promote Energy System Transformation through

- Decarbonisation
- Deregulation
- Digitalisation
- Electrification
- Decentralisation

2030

Aims to reduce GHG by 40% with international support

2035

69% share of electric vehicles of new vehicles in the market

2037

- Increase and Remain Primary Forest
- Regenerate Natural Forest Area
- Increase Economic Forest Area
- Increase and Remain Cropland
- Reduce Biomass Burning

Achievement of CO_2 removals of 120 $MtCO_{2eq}$

2050

CARBON NEUTRALITY

50% share of renewable electricity generation of new power generation capacity

Reduction of GHG emissions in various sectors:

- Energy
- Industrial Processes and Product Use (IPPU)
- Agriculture
- Waste
- Land Use, Land Use Change, and Forestry

2065

Achievement of **NET-ZERO GHG Emission** while looking forward to enhanced international cooperation and support on finance, technology, and capacity-building to achieve this ambition

Source: Thailand Greenhouse Gas Organization – www.tgo.orth

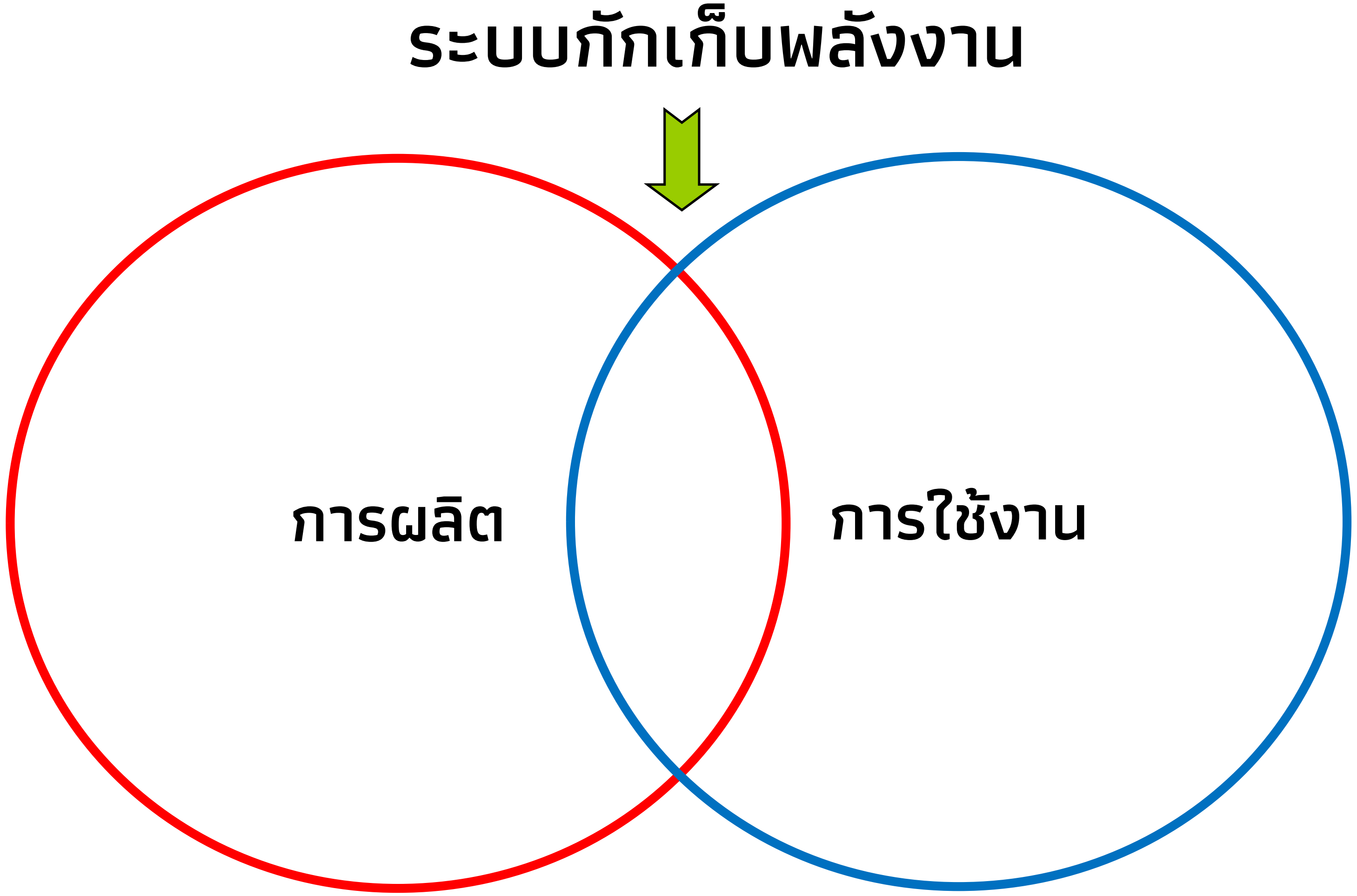
Baker McKenzie.

Battery Storage - a global enabler of the Energy Transition

2022

Energy Transition
Transform, powerfully

ENERGY STORAGE AS A KEY ENABLING TECH



ระบบกักเก็บพลังงาน

การผลิต

การใช้งาน

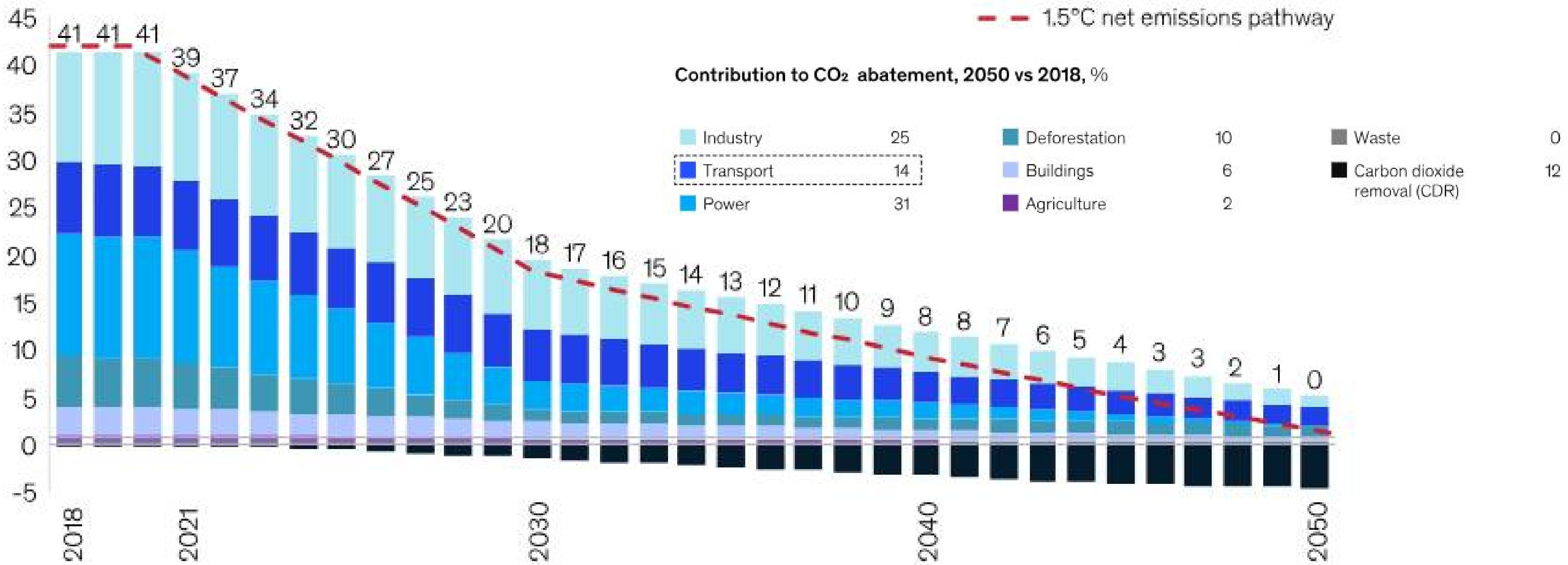
ENERGY STORAGE AS A KEY ENABLING TECH

ENERGY STORAGE

ENABLE FOR RE, EV AND EE

TRANSPORTATION SECTOR CAN RED. CO_2 ~ 14% BY 2050

CO_2 emissions per sector¹, Gigatons of carbon dioxide

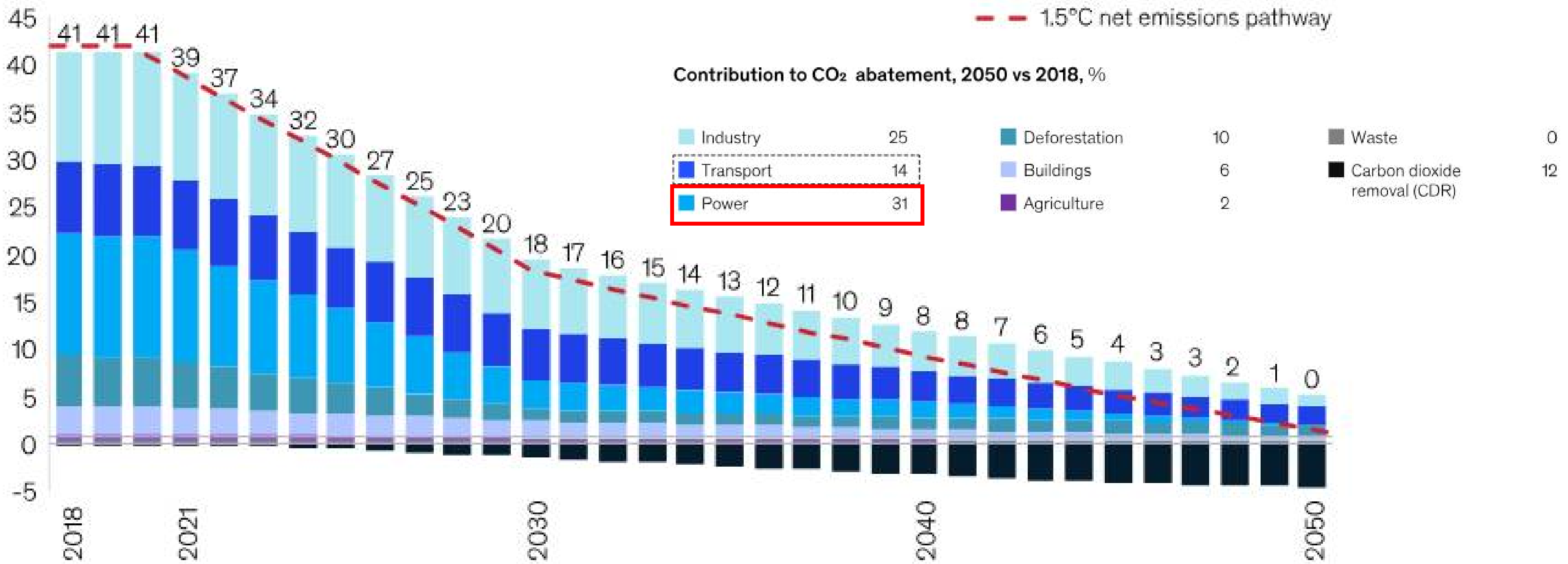


¹Emissions for 2021–29 and 2031–49 based on McKinsey 1.5°C scenario analysis, estimated using linear interpolation.
Source: McKinsey Global Energy Perspective 2019, McKinsey 1.5°C scenario analysis (scenario A)

McKinsey Report:Capturing growth in Asia's emerging EV ecosystem June 2022

POWER SECTOR CAN RED. CO$_2$ ~ 31% BY 2050 (VS. 2018)

CO₂ emissions per sector¹, Gigatons of carbon dioxide



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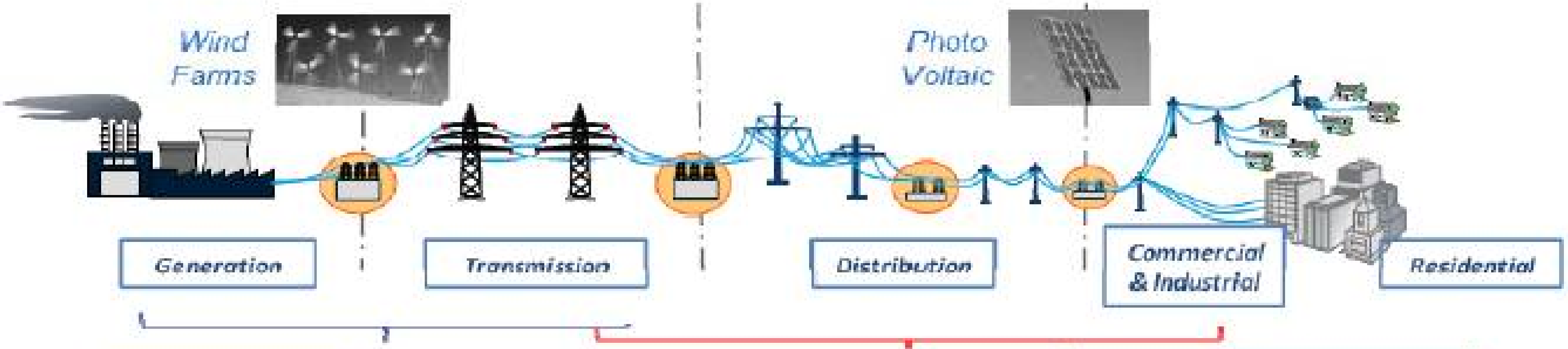
ROLE OF ES TECH IN ENERGY TRANSITION



Bulk Storage

- Electric Energy Time-Shift (Arbitrage)
- Electric Supply Capacity
- Renewable Integration

Ele

- Regulation
- Spinning & Non-Spinning reserve
- Voltage Support
- Black Start
- Load Following

Grid Operations

Aggregated Utility Scale

- Transmission Upgrade Deferral
- Transmission Congestion Relief

Transmission Infrastructure

Utility Scale

- Distribution Upgrade Deferral
- Voltage Support

Distribution Infrastructure

Community Scale

- Power Quality
- Retail Electric Energy Time-Shift
- Power Reliability
- Demand Charge Management

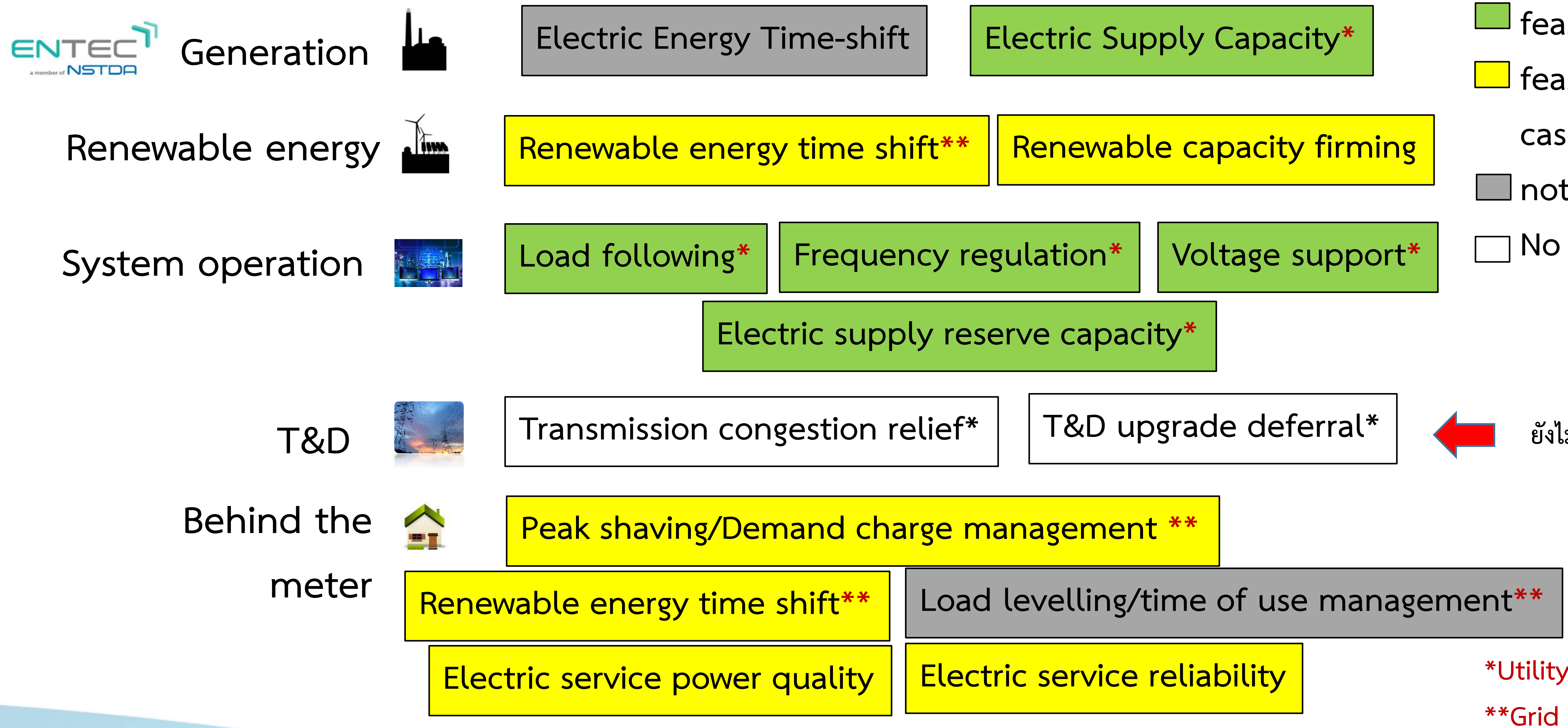
End User

Adapted from DOE Grid Energy Storage December 2013

ROLE OF ES TECH IN ENERGY TRANSITION

1. ประหยัดและเพิ่มประสิทธิภาพด้านการผลิตและส่ง
    - ชะลอการสร้างโรงไฟฟ้าใหม่ (Capacity value)
    - ช่วยรองรับปริมาณของ Renewable power system ในระบบ ให้มากขึ้นและมีประสิทธิภาพยิ่งขึ้น (Renewable Integration)
    - ชะลอการเพิ่มขนาดสายส่ง (T&D deferral)
2. สร้างเสถียรภาพทางการจ่ายไฟฟ้า ทั้งด้าน
    1. ปริมาณ (energy capacity – demand vs. supply)
    2. คุณภาพ (voltage support, frequency regulations)
3. เพิ่มประสิทธิภาพการใช้งาน/ประหยัดค่าไฟ
    - Peak shaving
    - Demand charge management

ROLE OF ES TECH IN ENERGY TRANSITION



Generation

Electric Energy Time-shift

Electric Supply Capacity*

Renewable energy

Renewable energy time shift**

Renewable capacity firming

System operation

Load following*

Frequency regulation*

Voltage support*

Electric supply reserve capacity*

T&D

Transmission congestion relief*

T&D upgrade deferral*

ยังไม่มีข้อมูล

Behind the meter

Peak shaving/Demand charge management **

Renewable energy time shift**

Load levelling/time of use management**

Electric service power quality

Electric service reliability

🟩 feasible

🟨 feasible for some case

▨ not feasible

☐ No information

*Utility-Owned services

**Grid code

Source: - Jiravan Mongkonthanatas, นำเสนอใน The Future Energy Show Thailand 2019, 27 Nov 2019 รวบรวมจาก:
- สถาบันวิจัยเพื่อการพัฒนาประเทศไทย (TDRI), โครงการศึกษาความเหมาะสมและแนะแนวทางในการส่งเสริมอุตสาหกรรมสารองไฟฟ้าสาหรับโครงข่ายไฟฟ้าของประเทศ (Grid Energy Storage), 2019
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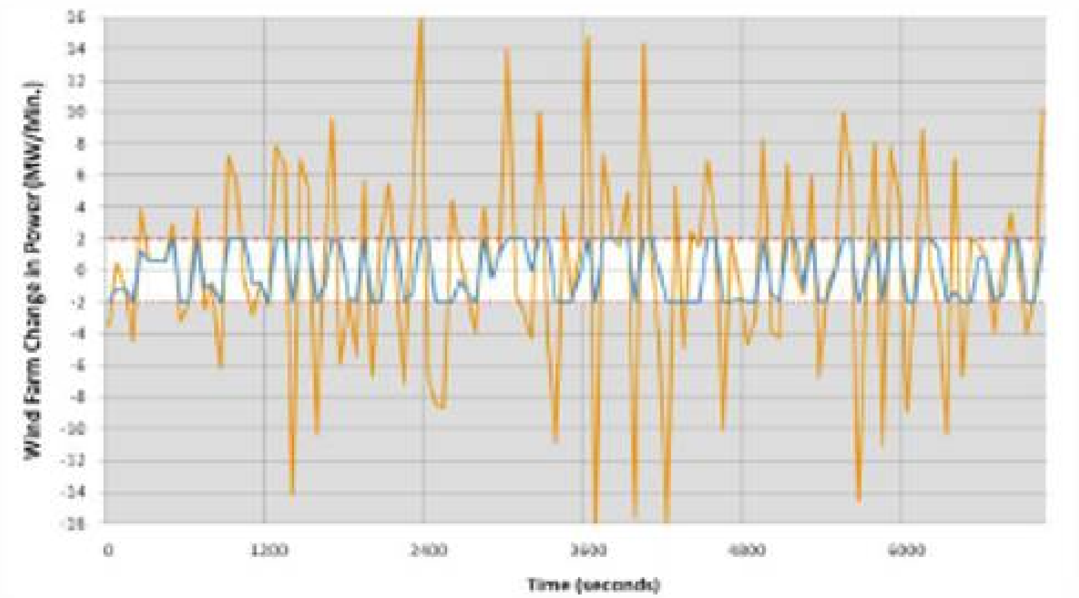
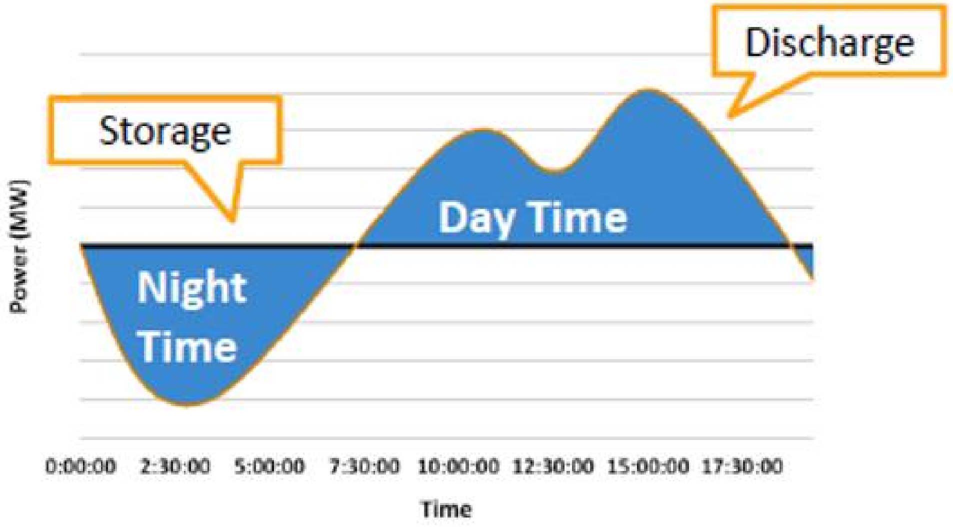
TYPE OF ENERGY STORAGE

Power



- Short duration (< 1 hr)
- Very high charge/discharge rate
- Many cycle (100/day)
- Continuous use

Energy



- Long duration (1+ hr)
- 1-2 cycle/day

ENERGY STORAGE VALUE IN THAILAND

ESS application	Value
Energy arbitrage	-0.5 to 2.5 Baht/kWh
Load following	0.07 to 0.09 Baht/kWh
Spinning reserve	0.023 to 0.028 Baht/kWh
SPP Hybrid firm (Renewable capacity firming)	2.212 to 4.062 Baht/kWh
Electric bill management (no demand charge)	Approx. 1.6 Baht/kWh
Peak Shaving	1,500 to 2,800 Baht/kW.year
Frequency regulation	3,000 to 5,500 Baht/kW.year

Energy type

Power type

- BESS cost in energy application -> 400USD/kWh = 12,000Baht/kWh (for 3000 cycles) -> **4 Baht/kWh.cycle**
- BESS cost in power application -> 600USD/kWh = 18,000Baht/kW (for 10 years) -> **1,800 Baht/kW.year**

Source: - Jiravan Mongkonthanatas, นำเสนอใน The Future Energy Show Thailand 2019, 27 Nov 2019 รวบรวมจาก:
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ENERGY STORAGE VALUE IN THAILAND

ESS application	Value	$100/kWh
Energy arbitrage	-0.5 to 2.5 Baht/kWh	✓
Load following	0.07 to 0.09 Baht/kWh	
Spinning reserve	0.023 to 0.028 Baht/kWh	
SPP Hybrid firm (Renewable capacity firming)	2.212 to 4.062 Baht/kWh	✓
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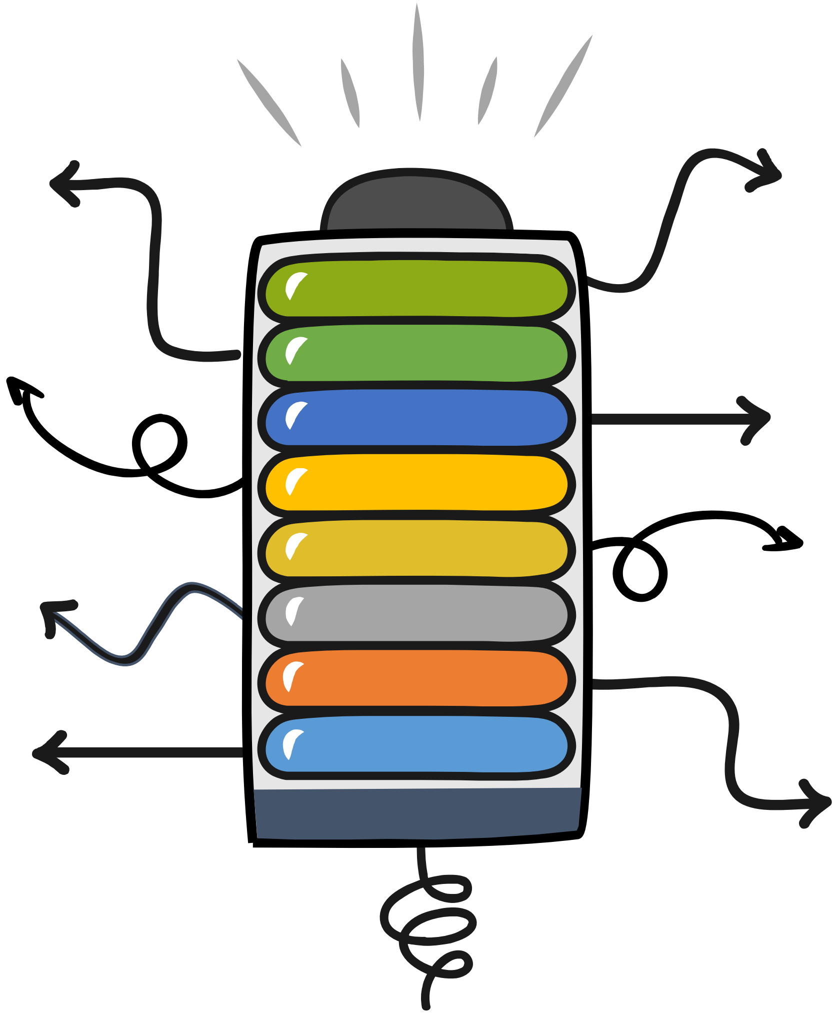
- BESS cost in energy application -> 100USD/kWh = 3,000Baht/kWh (for 3000 cycles) -> **1 Baht/kWh.cycle**
- BESS cost in energy application -> 60USD/kWh = 1,800Baht/kWh (for 3000 cycles) -> **0.6 Baht/kWh.cycle**

FUTURE OF ENREGY STORAGE



1 ถูก

2 เล็ก

3 เบา

4 ปลอดภัย

แรง 5

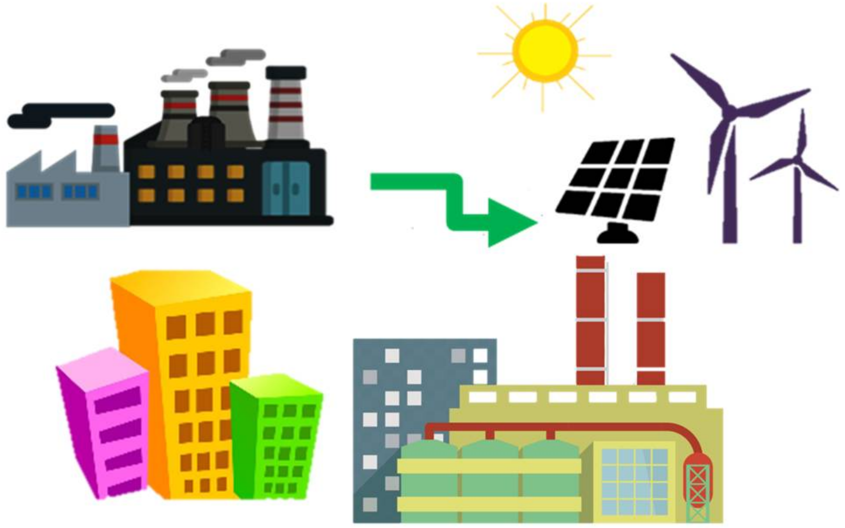
ชาร์จเร็ว 6

ใช้ได้นาน 7

? 8, 9, 10...

FUTURE OF ENREGY STORAGE: COST REDUCTION

90% ⇩



44% ⇩

0.05$/kWh.cycle (~$60/kWh @ 3000 cycles)

(~1.5 baht/kWh.cycle)

ปัจจุบันอยู่ที่ ~ 4-6 baht/kWh.cycle (Li-ion batt)

$80/kWh

(pack for 300 miles EV)

Source: US DOE Energy Storage Grand Challenge Roadmap December 2020. Web [20 May, 2022

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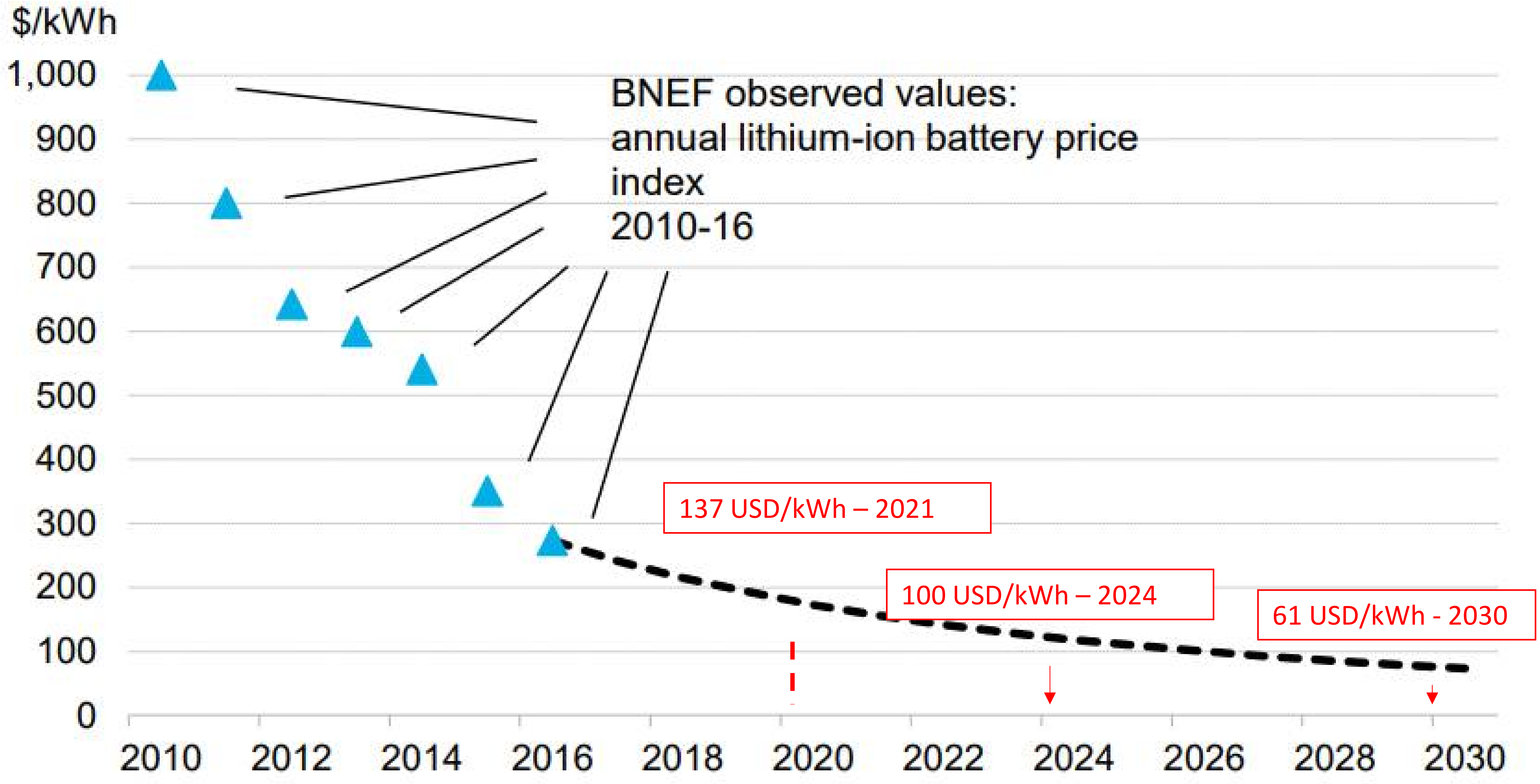
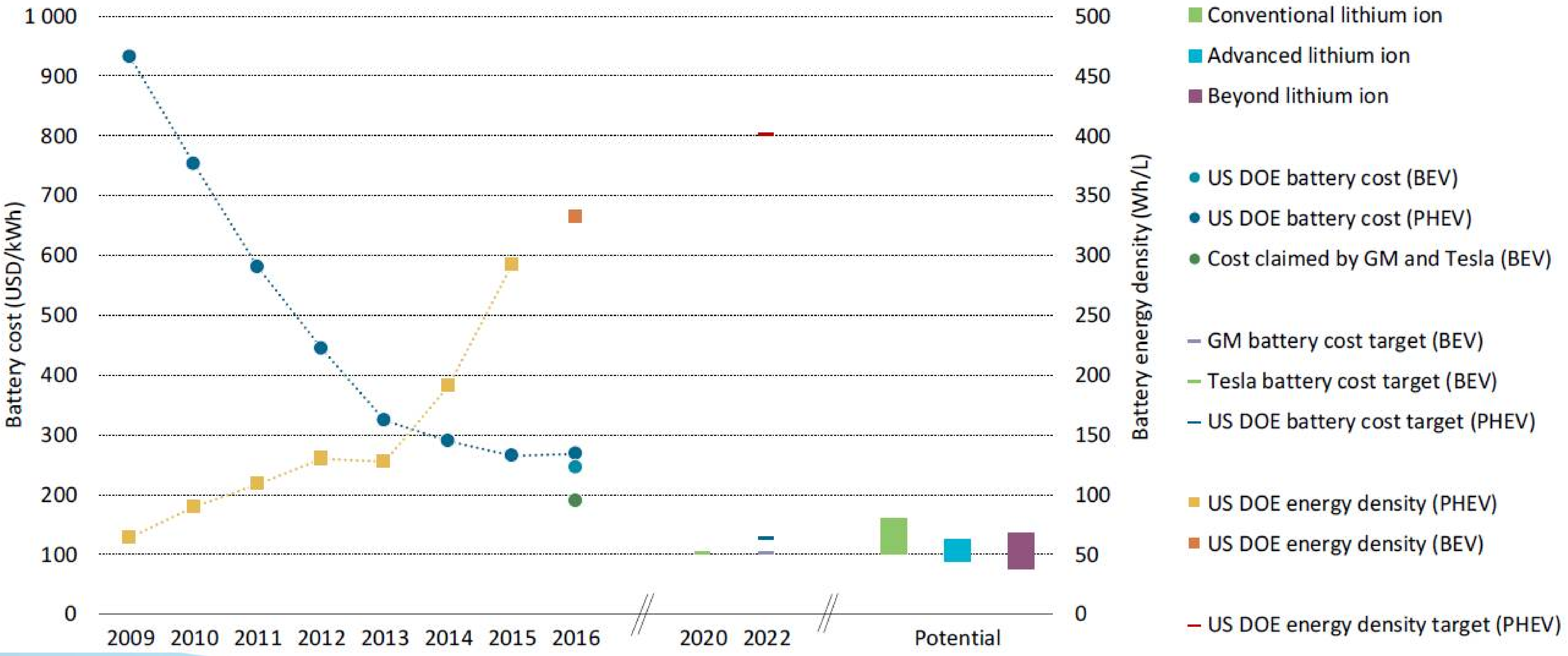


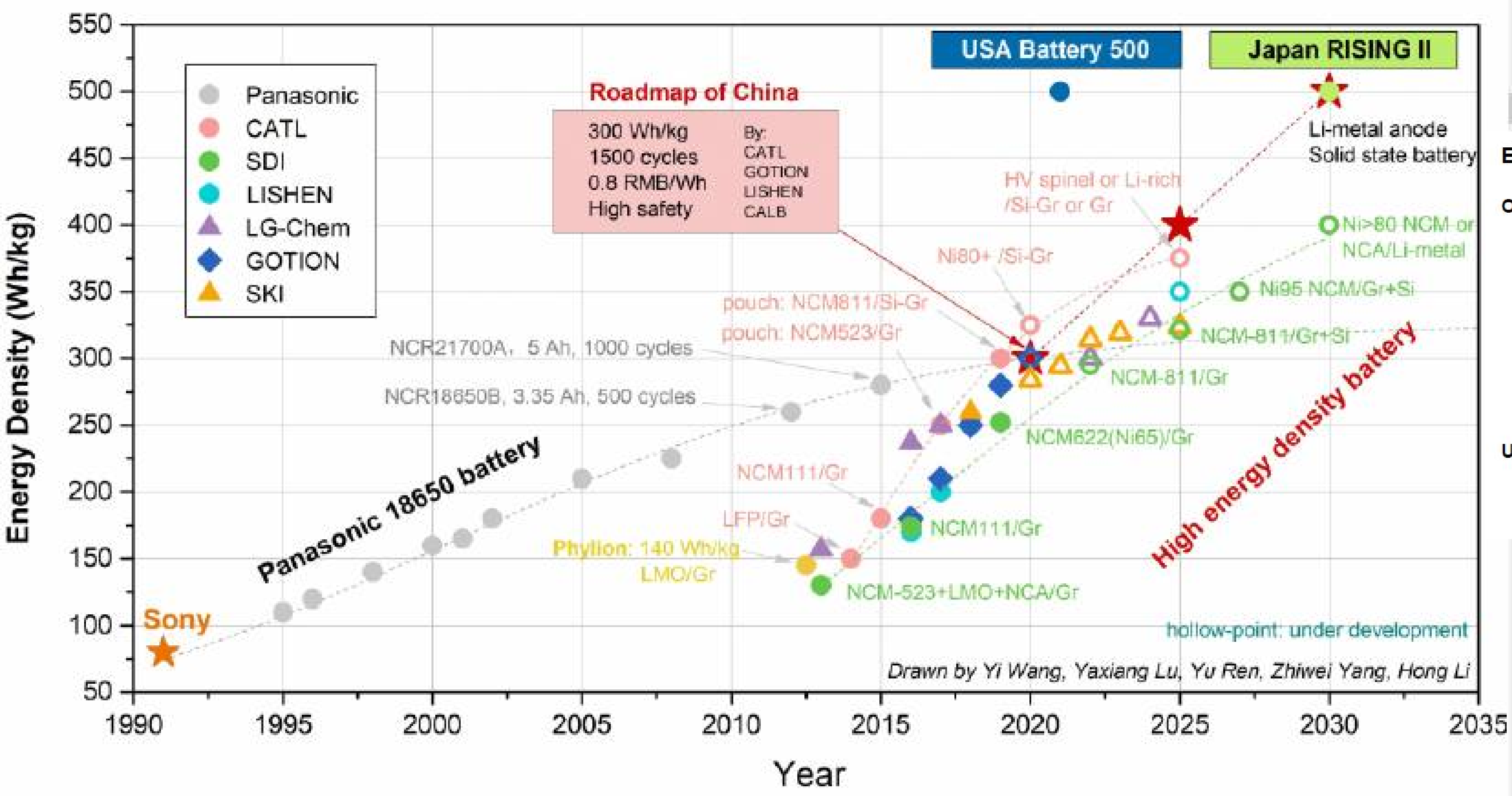
Source: Bloomberg New Energy Finance June 2017

FUTURE OF ENREGY STORAGE: COST REDUCTION



Source: Bloomberg New Energy Finance June 2017

COST REDUCTION by Li Tech



Energy Density Achieved:

On the road:

CATL: 279.56 Wh/kg
(Leap Motor T03)

SKI: 269.44 Wh/kg
(Arcfox Alpha-T)

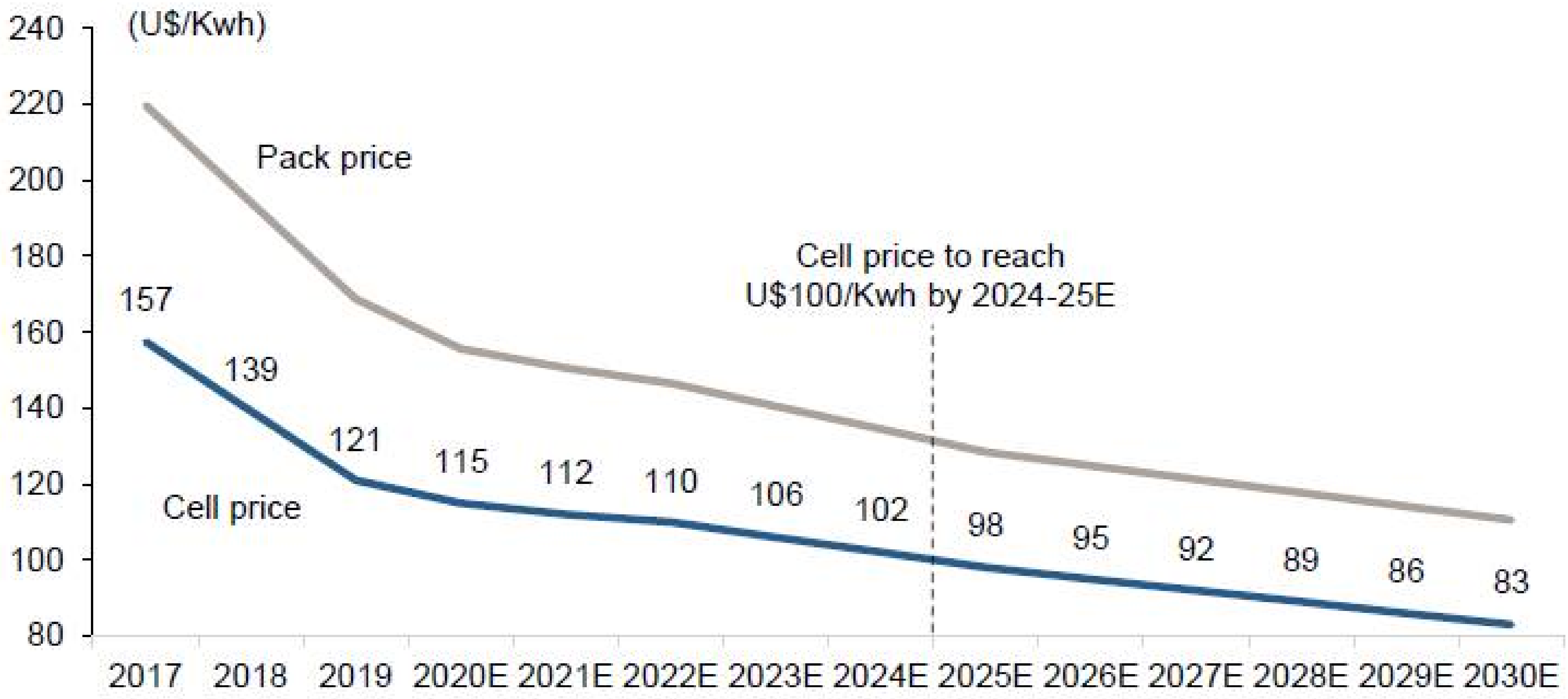
LG-Chem: 257.10 Wh/kg
(Tesla Model 3)

USA Battery 500:

350 Wh/kg, 350 cycles
(Li/NMC 622 Pouch Cell)

Source: Battery 2030+ Roadmap; Redrawn from Li, et al, cited from Figure 1 in Energy Storage Materials, 23(2019) 144-153;
State of Battery 2020 Report by BatteryBits published on Jan 16, 2021

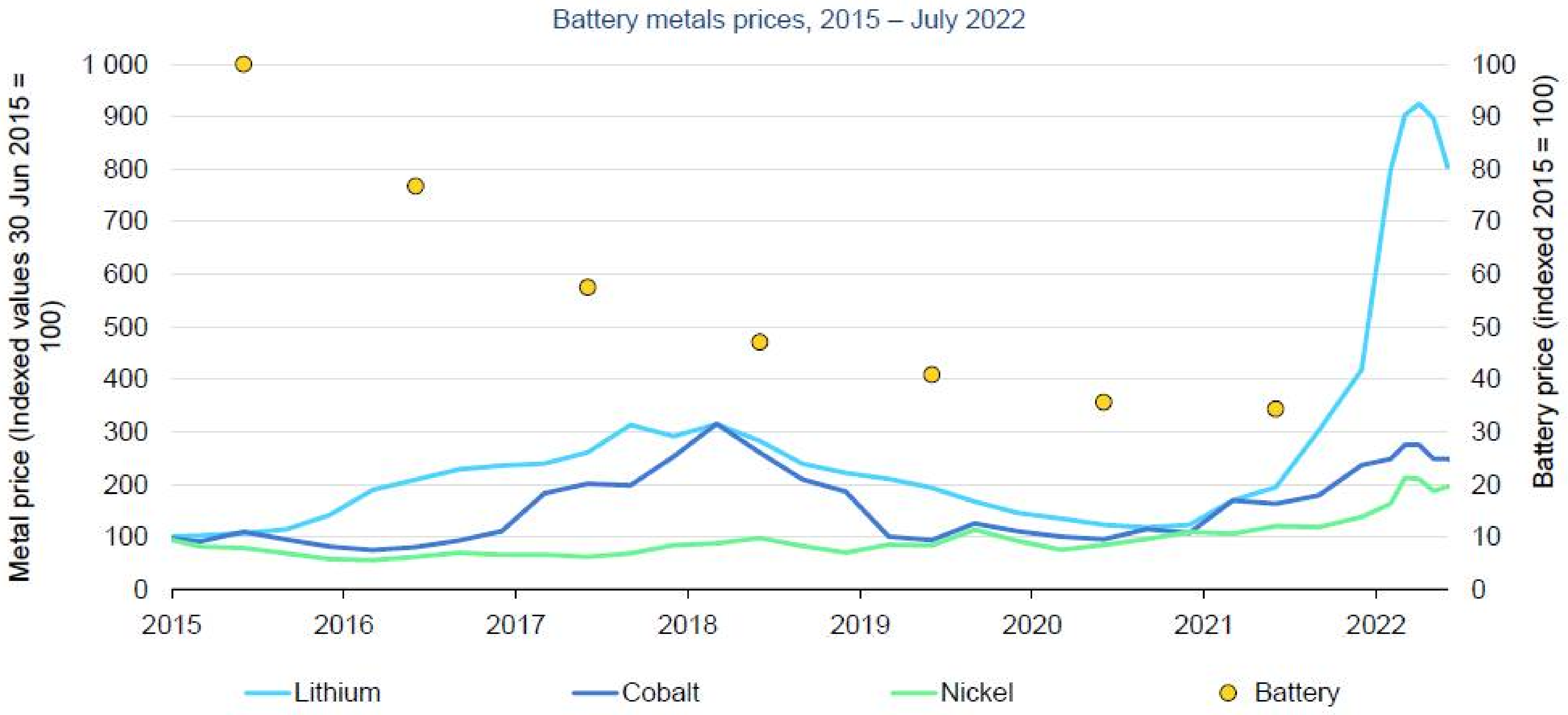
FUTURE OF ENREGY STORAGE: COST REDUCTION



Source: Credit Suisse 2020 xEV battery supply chain 17 Nov 2020

FUTURE OF ENREGY STORAGE: SUPPLY CHAIN SUSTAINABLITY

Battery metal prices increased dramatically in early 2022, posing a significant challenge to the EV industry


Battery metals prices, 2015 – July 2022

IEA. All rights reserved

Sources: IEA analysis based on S&P Global
Notes: Lithium prices are from June 2022. Cobalt and Nickel from July 2022

Source: IEA Report 2022 “Global Supply Chiang of EV Batteries”

FUTURE OF ENREGY STORAGE: SUPPLY CHAIN SUSTAINABLITY

● Environmental ● Social ● Governance

Challenges

Land pollution

Radioactive pollution

Need to protect biodiversity

Deforestation, land degradation

Resource drainage

Need to ensure health and safety

Child or forced labor

Need to ensure fair working conditions and wages

Discrimination and harassment

Need to protect indigenous rights and local communities

Warlords or terrorists

Corruption and bribery

Need for sustainable supplier management

Anticompetitive practices

Tax evasion

Information management

Customer health and safety

Transparency and reporting

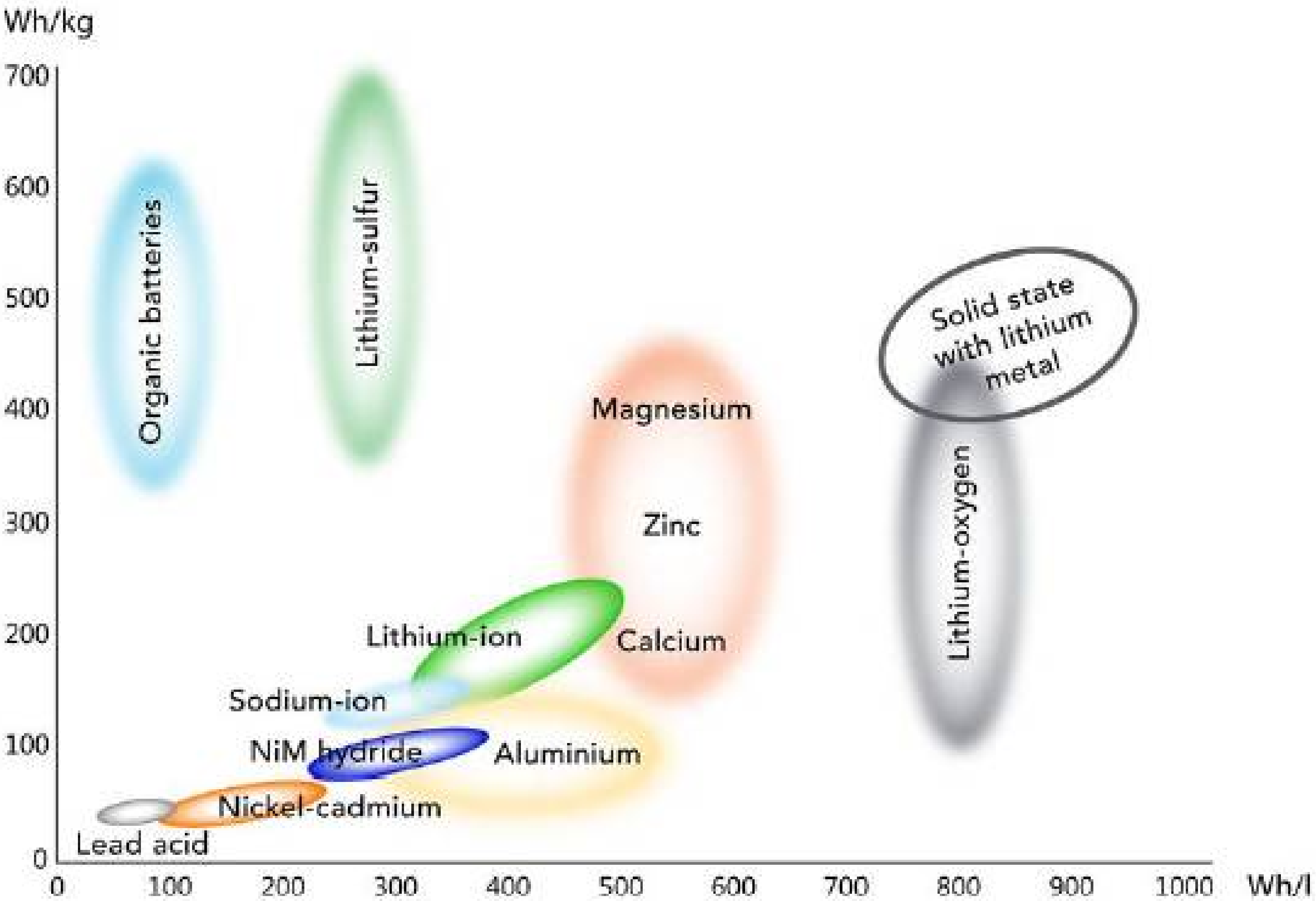
Greenhouse-gas emissions

Air pollution

Water pollution

Source: Global Battery Alliance, Battery 2030: Resilient, sustainable, and circular

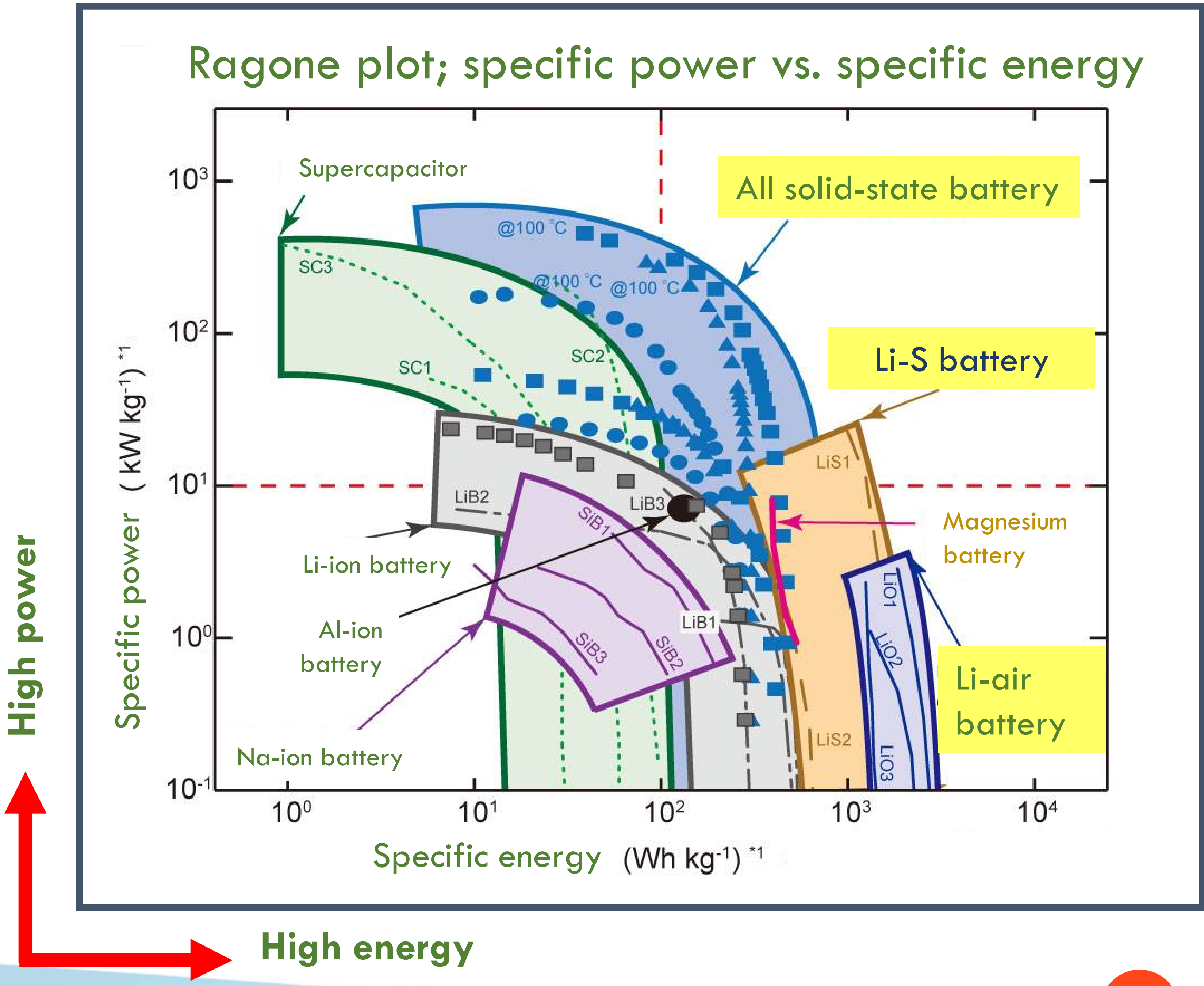
COST REDUCTION by Alternative Metal-ion Battery



Source: EU Battery 2030+ Roadmap

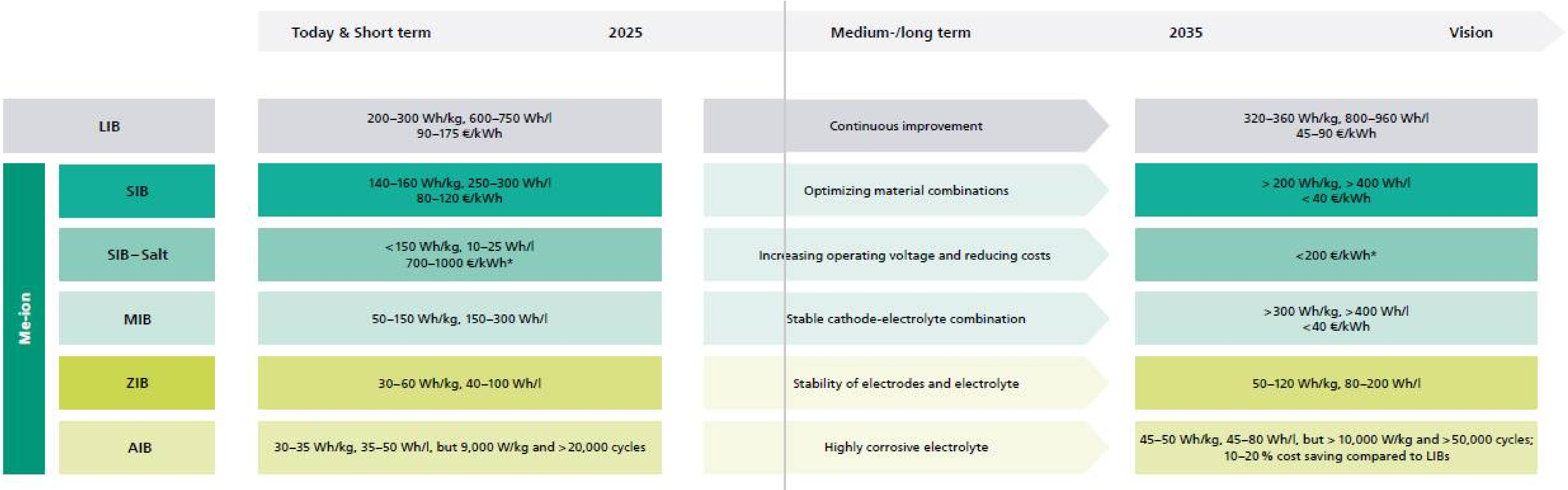
TECHNOLOGY DEV. TREND: SOLID STATE BATT

- New materials and system will be developed
- For high energy density applications e.g. EV → similar cell format and material processing are expected with evolving chemistry for the cost reason.



Source: *Kanno Ryoji, 次世代電池を牽引する、全固体電池開発, Nature Energy, 2016*

COST REDUCTION by Alternative Metal-ion Battery

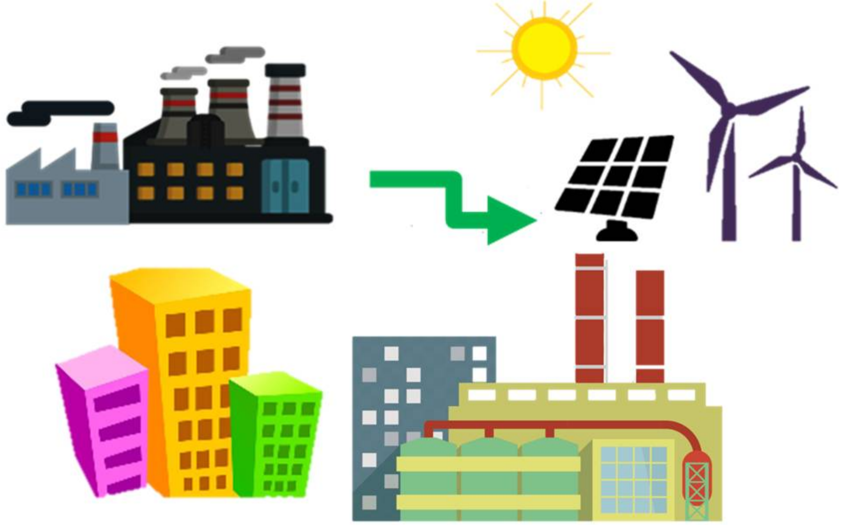


		Today & Short term 2025	Medium-/long term	2035 Vision
LIB		200–300 Wh/kg, 600–750 Wh/l 90–175 €/kWh	Continuous improvement	320–360 Wh/kg, 800–960 Wh/l 45–90 €/kWh
Me-ion	SIB	140–160 Wh/kg, 250–300 Wh/l 80–120 €/kWh	Optimizing material combinations	> 200 Wh/kg, > 400 Wh/l < 40 €/kWh
	SIB – Salt	< 150 Wh/kg, 10–25 Wh/l 700–1000 €/kWh*	Increasing operating voltage and reducing costs	< 200 €/kWh*
	MIB	50–150 Wh/kg, 150–300 Wh/l	Stable cathode-electrolyte combination	> 300 Wh/kg, > 400 Wh/l < 40 €/kWh
	ZIB	30–60 Wh/kg, 40–100 Wh/l	Stability of electrodes and electrolyte	50–120 Wh/kg, 80–200 Wh/l
	AIB	30–35 Wh/kg, 35–50 Wh/l, but 9,000 W/kg and > 20,000 cycles	Highly corrosive electrolyte	45–50 Wh/kg, 45–80 Wh/l, but > 10,000 W/kg and > 50,000 cycles; 10–20 % cost saving compared to LIBs

Source: EU Battery 2030+ Roadmap

FUTURE OF ENREGY STORAGE: COST REDUCTION

90% ⇩



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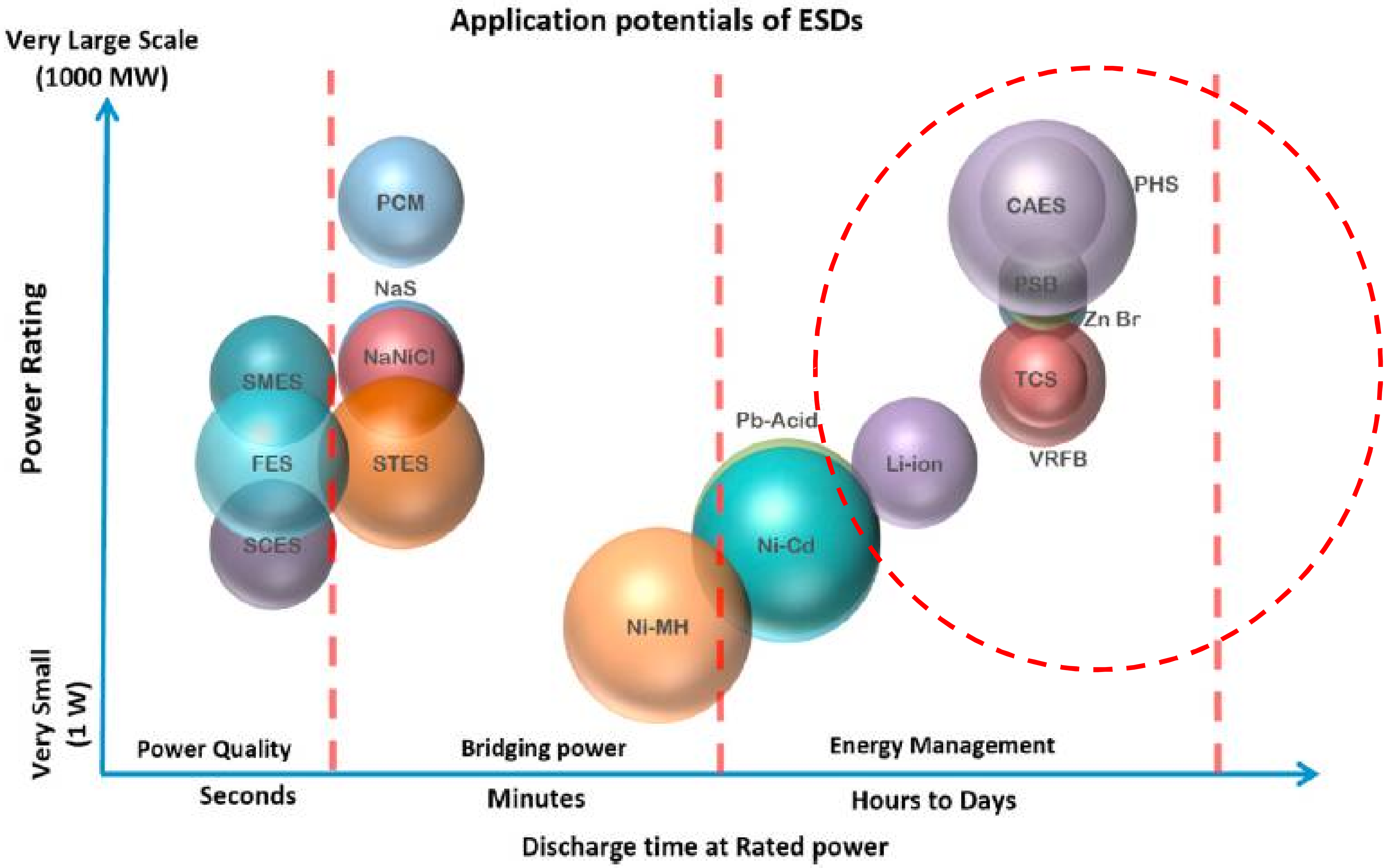
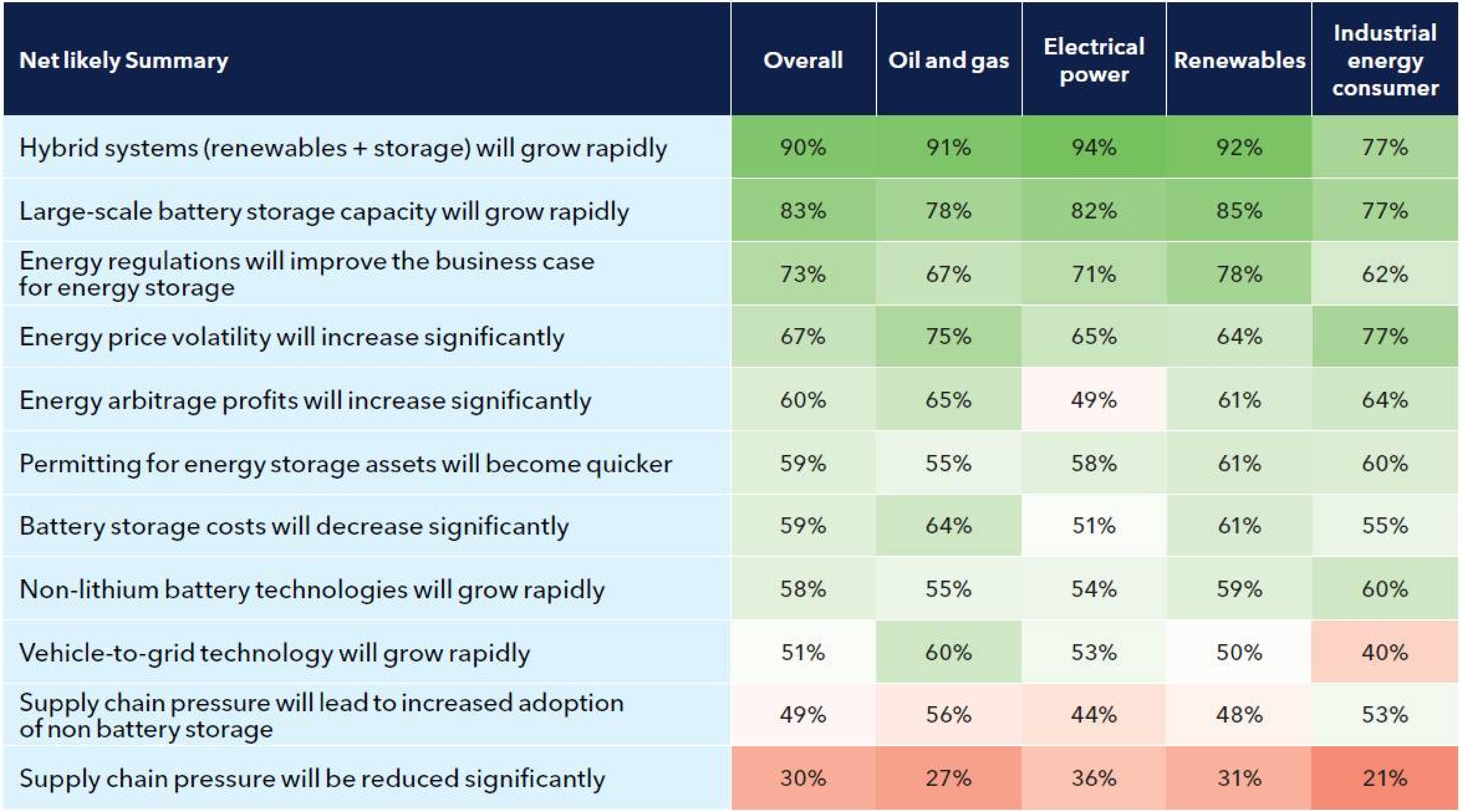
TYPE OF ENERGY STORAGE



Cheap & Long duration storage needed

Source: A A. Kebede, et. Al. A comprehensive review of stationary energy storage devices for large scale renewable energy sources grid integration, Renewable and Sustainable Energy Reviews 159 (2022) 112213

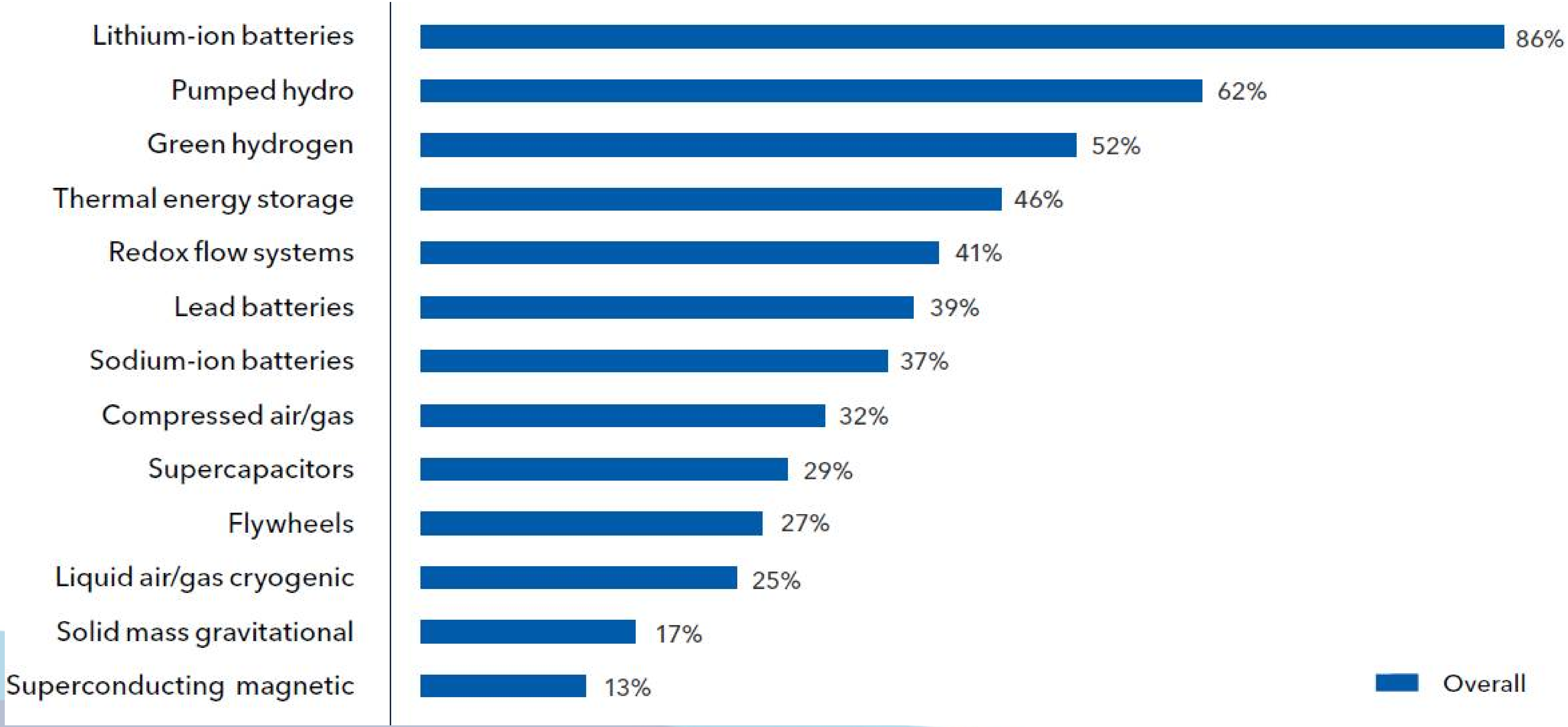
FUTURE OF ENREGY STORAGE



Net likely Summary	Overall	Oil and gas	Electrical power	Renewables	Industrial energy consumer
* Hybrid systems (renewables + storage) will grow rapidly	90%	91%	94%	92%	77%
* Large-scale battery storage capacity will grow rapidly	83%	78%	82%	85%	77%
Energy regulations will improve the business case for energy storage	73%	67%	71%	78%	62%
Energy price volatility will increase significantly	67%	75%	65%	64%	77%
Energy arbitrage profits will increase significantly	60%	65%	49%	61%	64%
Permitting for energy storage assets will become quicker	59%	55%	58%	61%	60%
* Battery storage costs will decrease significantly	59%	64%	51%	61%	55%
* Non-lithium battery technologies will grow rapidly	58%	55%	54%	59%	60%
Vehicle-to-grid technology will grow rapidly	51%	60%	53%	50%	40%
Supply chain pressure will lead to increased adoption of non battery storage	49%	56%	44%	48%	53%
Supply chain pressure will be reduced significantly	30%	27%	36%	31%	21%

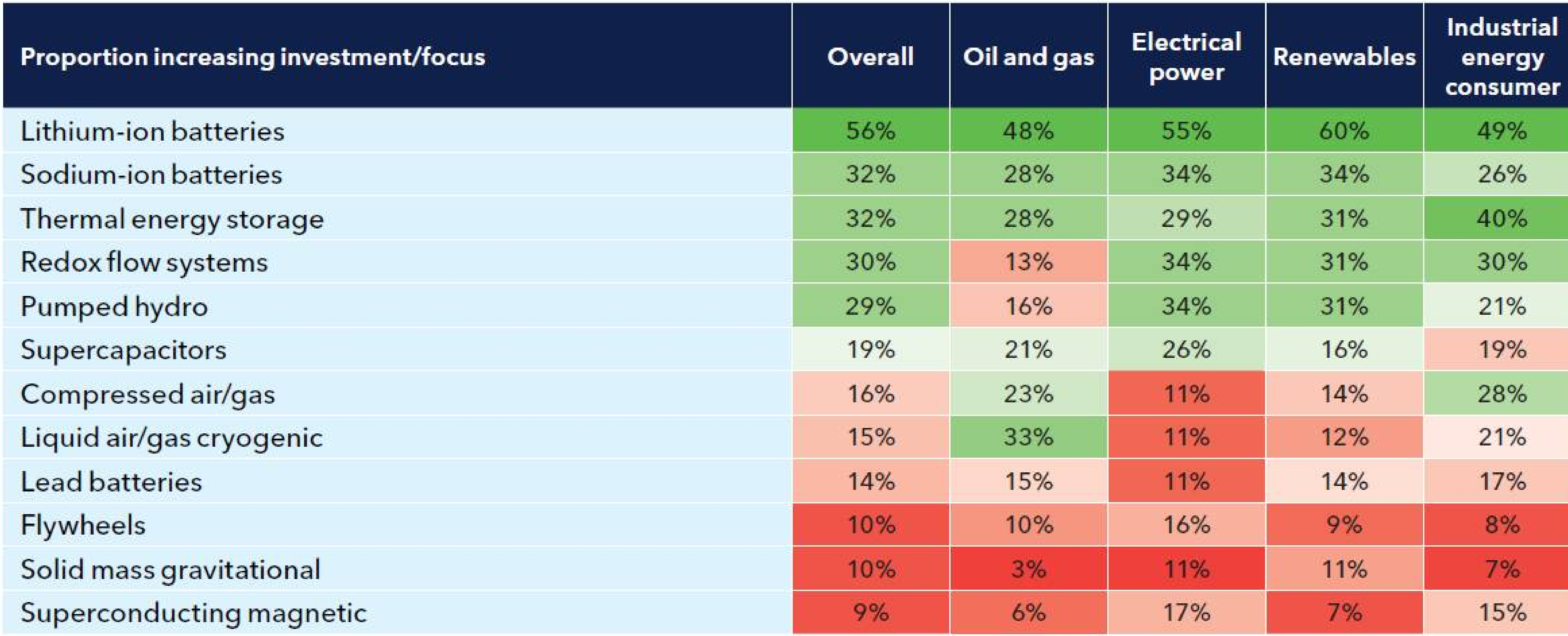
Source: DNV Energy Industry Insights 2023 “Closing the Energy Storage Gap”

ENREGY STORAGE TECH. LIKELY DEV. IN NEXT 3 YEARS



Source: DNV Energy Industry Insights 2023 “Closing the Energy Storage Gap”

ENREGY STORAGE INV. IN NEXT COMING YEAR



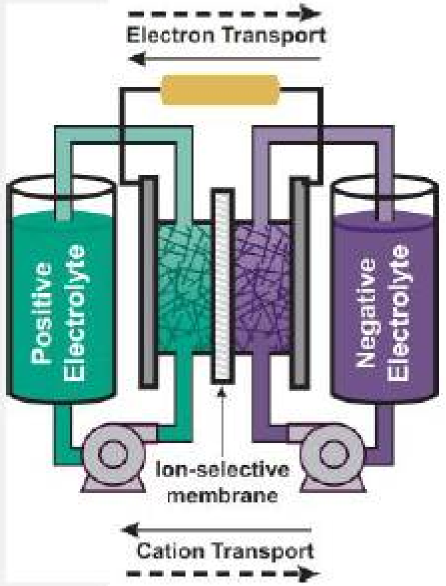
Proportion increasing investment/focus	Overall	Oil and gas	Electrical power	Renewables	Industrial energy consumer
Lithium-ion batteries	56%	48%	55%	60%	49%
Sodium-ion batteries	32%	28%	34%	34%	26%
Thermal energy storage	32%	28%	29%	31%	40%
Redox flow systems	30%	13%	34%	31%	30%
Pumped hydro	29%	16%	34%	31%	21%
Supercapacitors	19%	21%	26%	16%	19%
Compressed air/gas	16%	23%	11%	14%	28%
Liquid air/gas cryogenic	15%	33%	11%	12%	21%
Lead batteries	14%	15%	11%	14%	17%
Flywheels	10%	10%	16%	9%	8%
Solid mass gravitational	10%	3%	11%	11%	7%
Superconducting magnetic	9%	6%	17%	7%	15%

Source: DNV Energy Industry Insights 2023 “Closing the Energy Storage Gap”

CHEAP ENERGY TYPE STORAGE TECH.

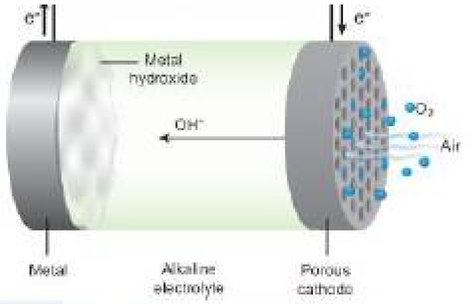
Redox Flow Batteries

- Independent scaling of power (stack) and energy (tanks) makes RFBs tunable for storage duration
- Vanadium redox is most technically advanced but cost and supply challenged
- Awaiting lower-cost highly stable chemistries for long-duration applications



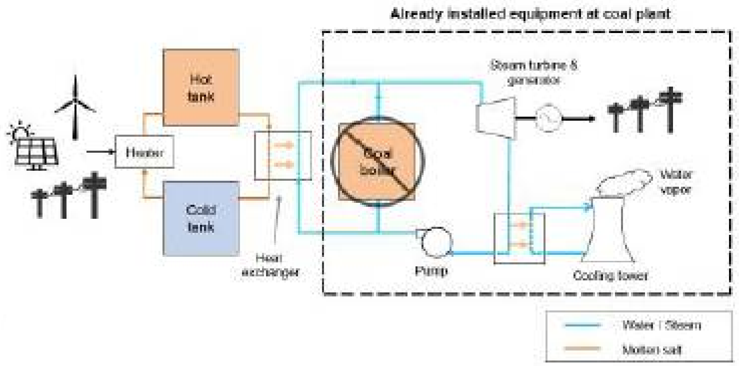
Metal-Air Batteries

- Very low energy cost makes metal-air attractive despite high power cost and low round-trip efficiency
- Best suited for long-duration storage applications
- Can use low-cost earth-abundant elements such as Zn and Fe with large existing supply chains



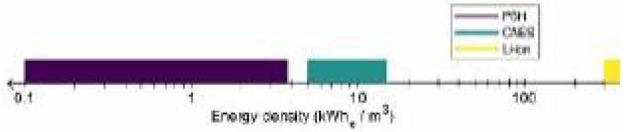
Thermal Energy Storage

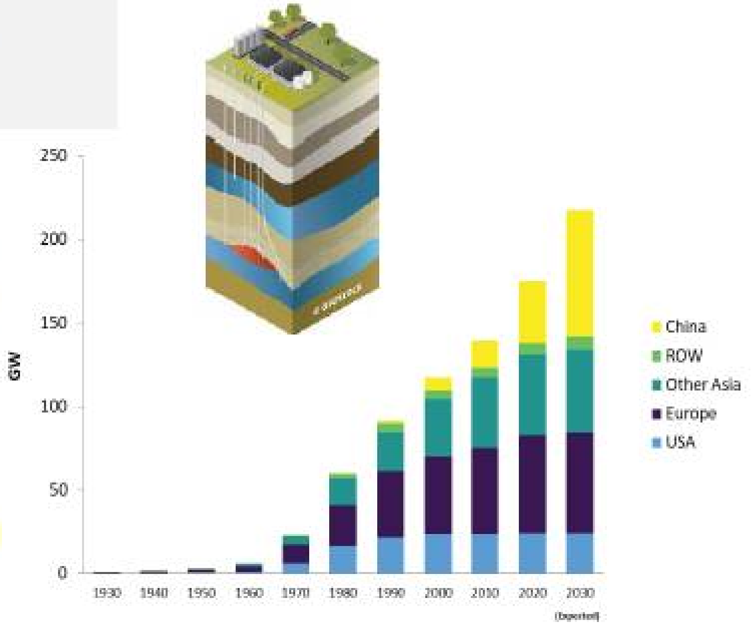
- Key challenge: conversion of heat to electricity
- Identified a new low-cost option: Steam turbine retrofit with TES at existing coal plants



Mechanical Energy Storage

- Constrained by low energy density, geology
- Pumped storage hydropower is expanding rapidly in China but not U.S.



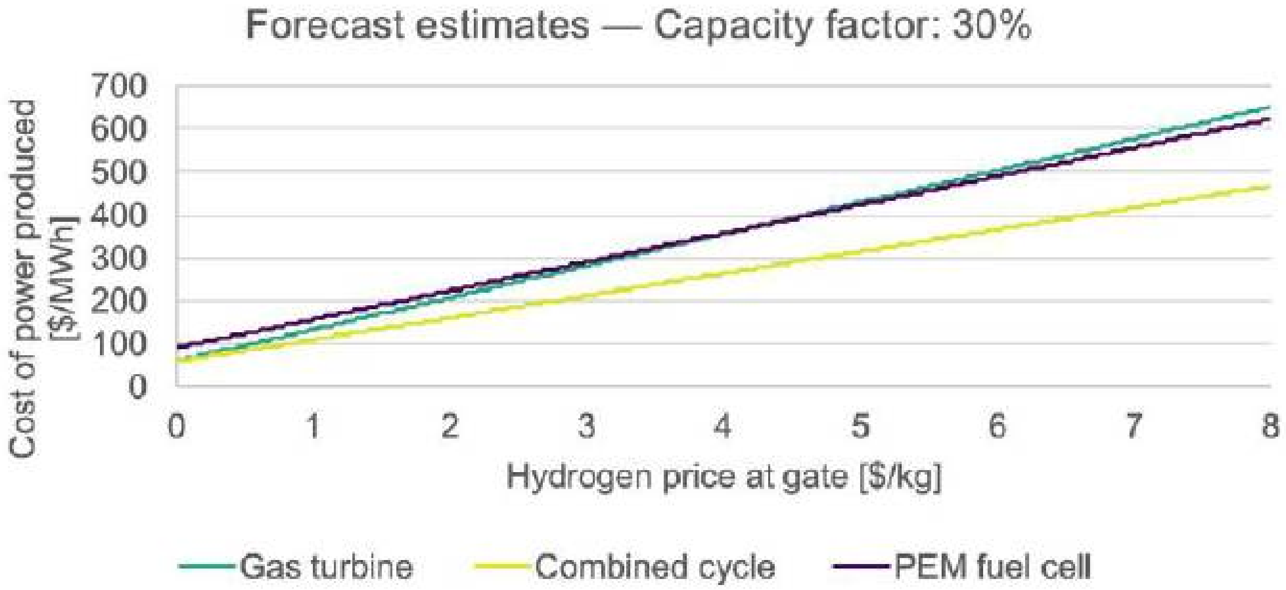


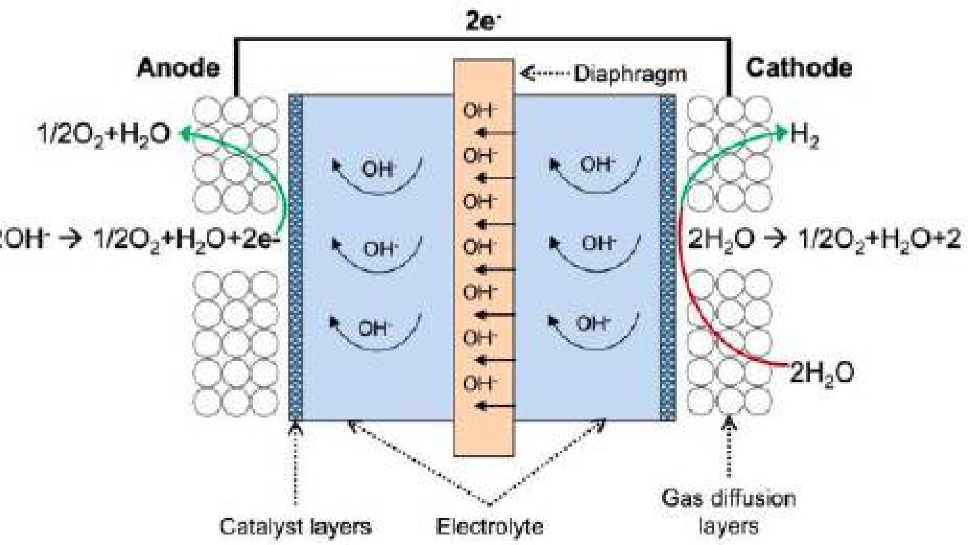
Source: MIT "The Future of Energy Storage Report" 2022

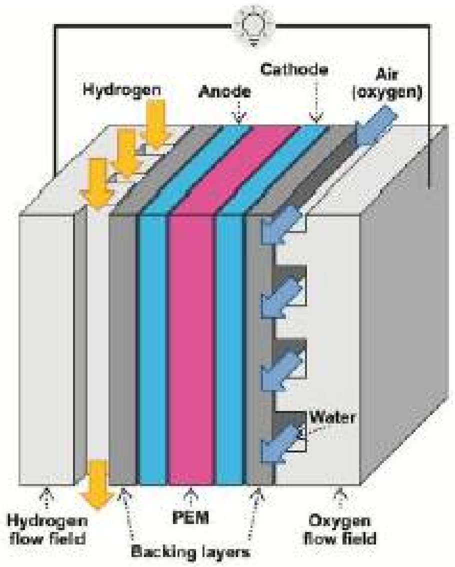
CHEAP ENERGY TYPE STORAGE TECH.

Chemical Type (Hydrogen)

- Commercially proven technologies exist for all aspects of the hydrogen value chain except for electricity production via hydrogen.
- Hydrogen is currently produced, transported, and sold to industry as a feedstock for numerous industrial processes. There is no significant consumer market.



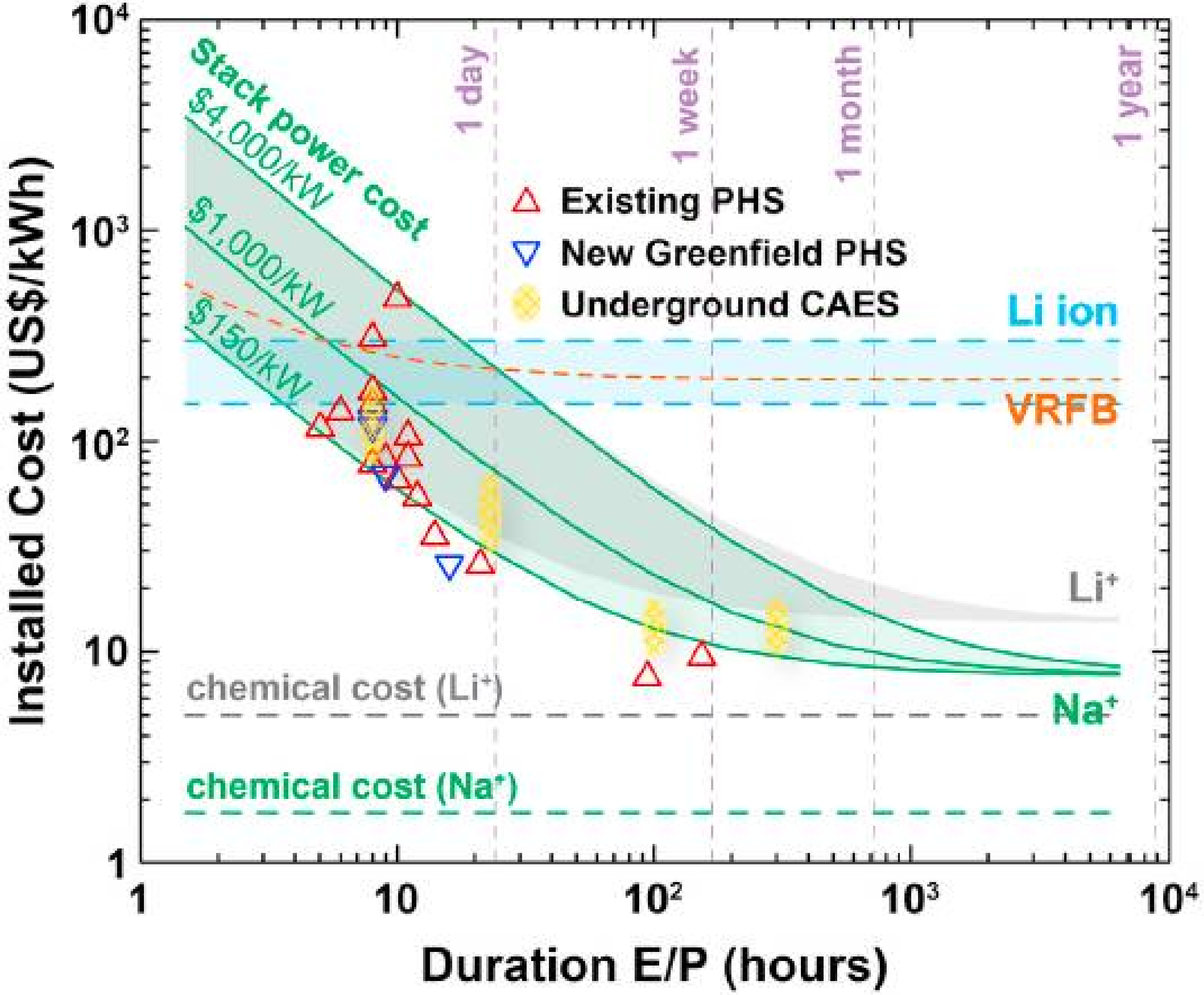




- While low costs to store hydrogen make hydrogen an appealing energy storage medium for long-duration applications, using hydrogen as a fuel to produce power is very expensive relative to similarly positioned thermal power generation assets.
- Long-duration energy storage will likely not be the main driver of hydrogen demand in a future decarbonized energy system for the simple reason that hydrogen will be more valuable as a way to indirectly electrify otherwise difficult-to-electrify energy end uses.

Source: MIT “The Future of Energy Storage Report” 2022

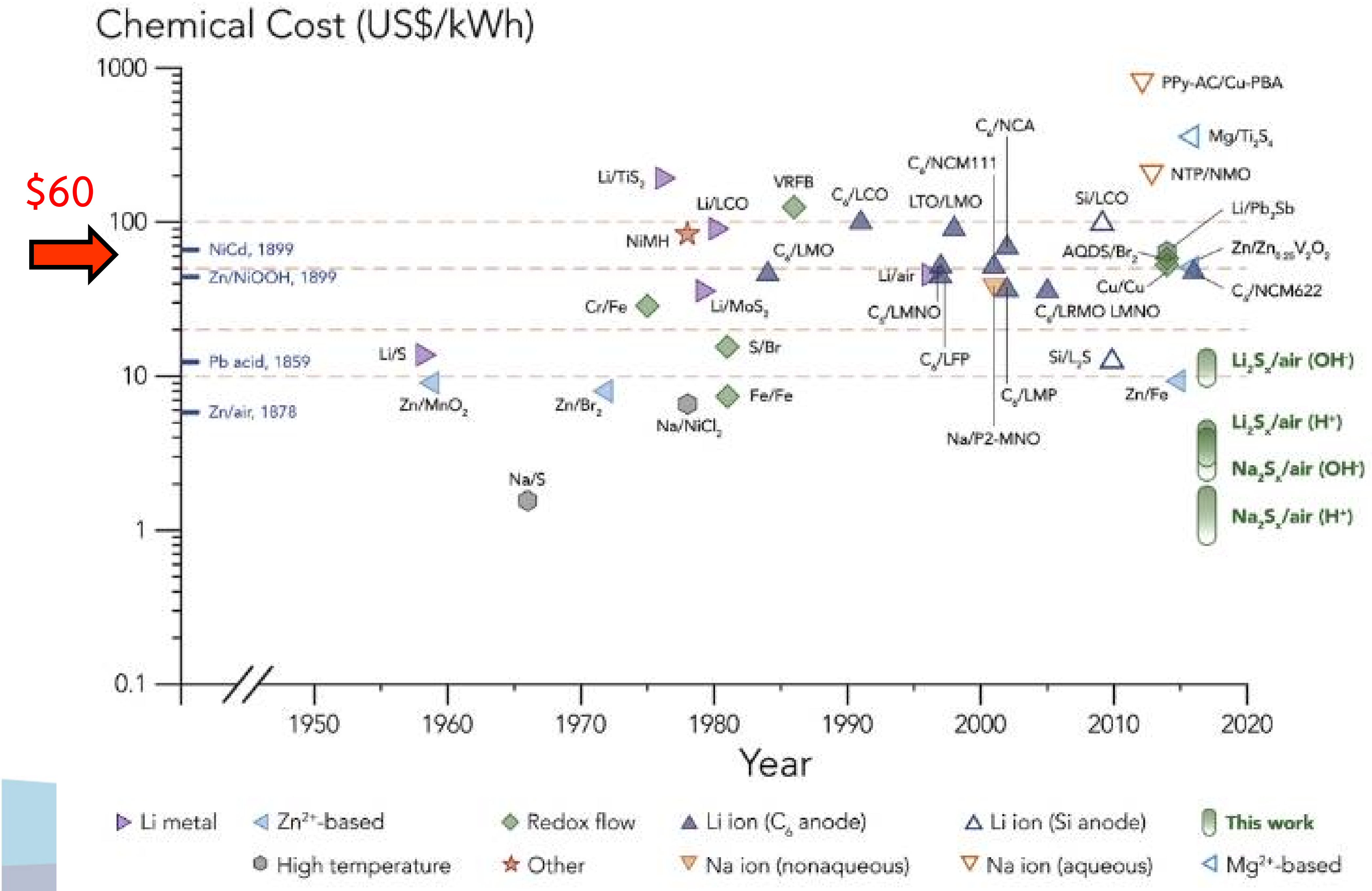
CHEAP ENERGY TYPE STORAGE TECH. VS. PHS



- Pump Hydro storage is still the cheapest and will totally get explored extenstively first
- Underground CAES will be nexted
- Other technologies development are still needed to get there.

Source: Li et al. Air-Breathing Aqueous Sulfur Flow Battery for Ultralow-Cost Long-Duration Electrical Storage, Joule 1, 212–219, October 11, 2017

CHEAP ENERGY TYPE STORAGE TECH. VS. PHS

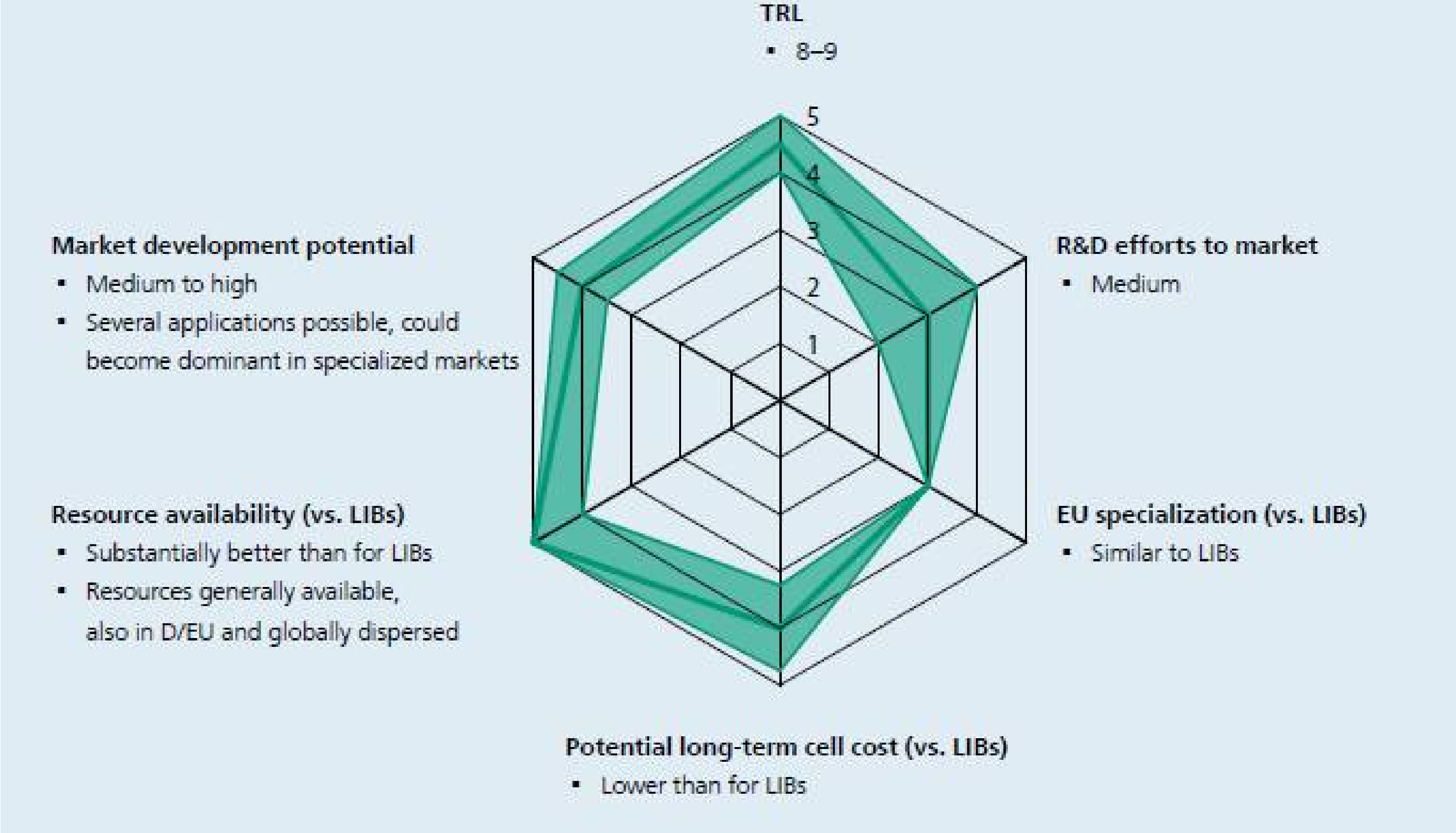


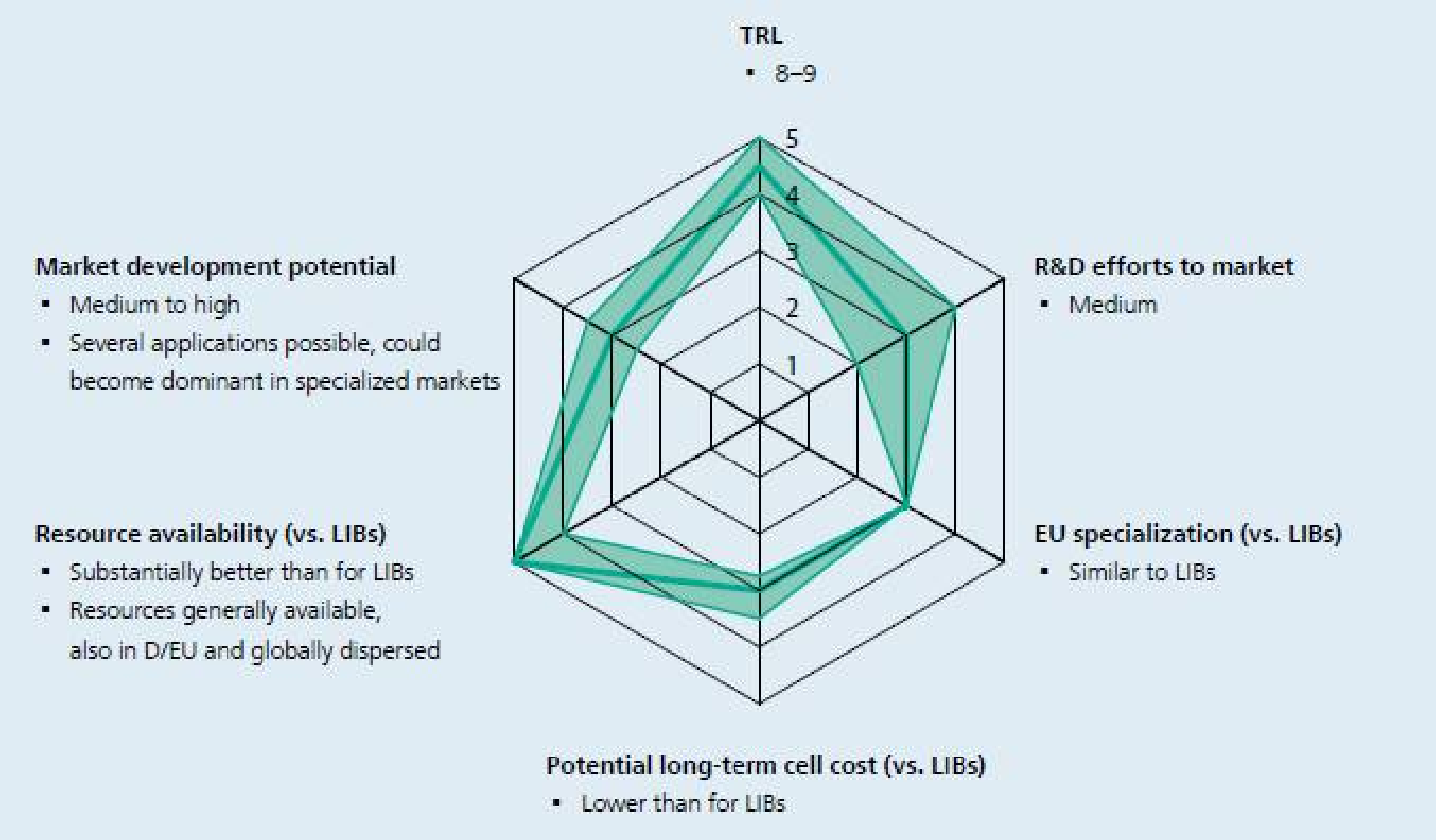
- Few combined chemistry of chemical storage maybe able to get there

Source: Li et al. Air-Breathing Aqueous Sulfur Flow Battery for Ultralow-Cost Long-Duration Electrical Storage, Joule 1, 212–219, October 11, 2017

CHEAP ENERGY TYPE STORAGE TECH. VS. PHS

Sodium-ion

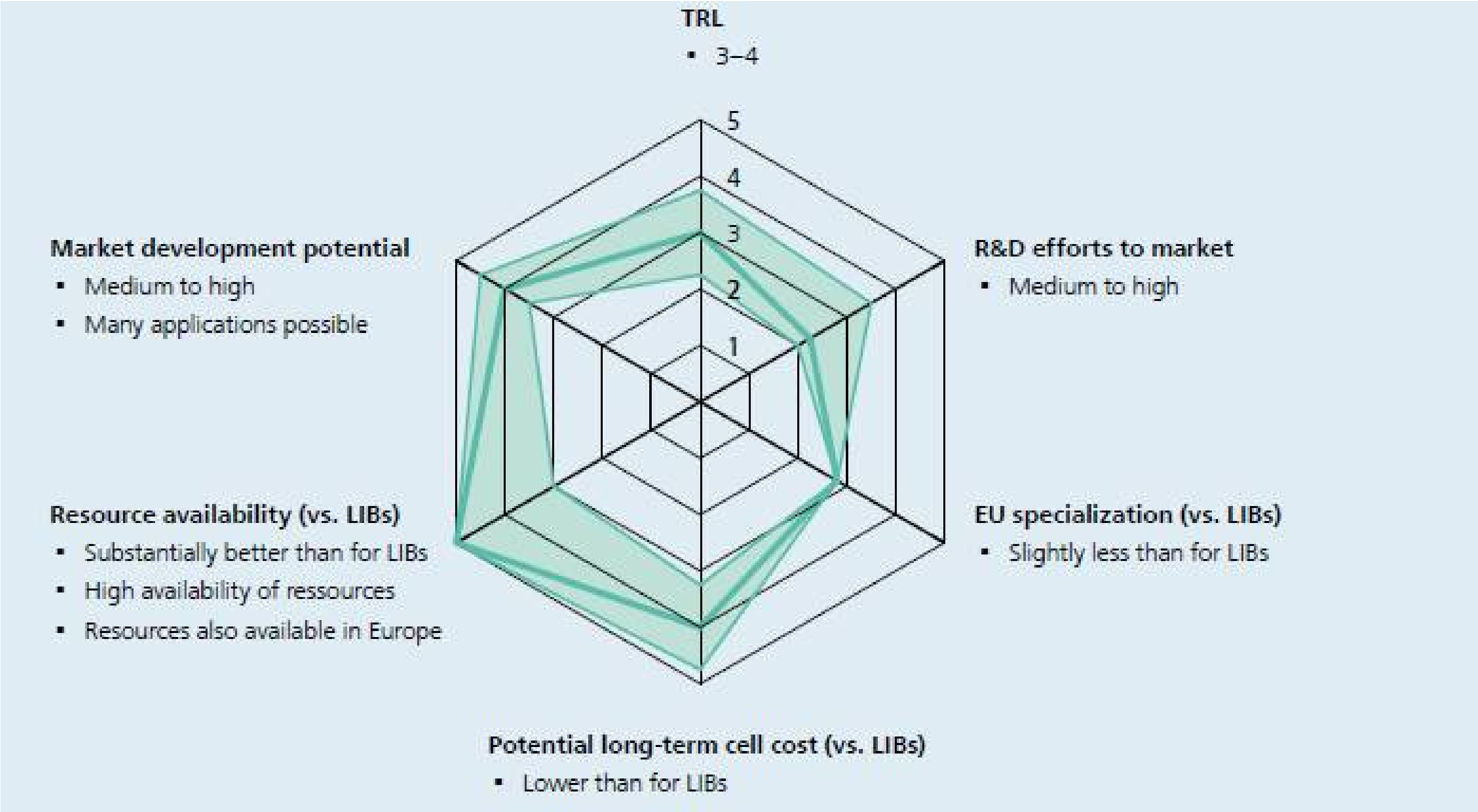




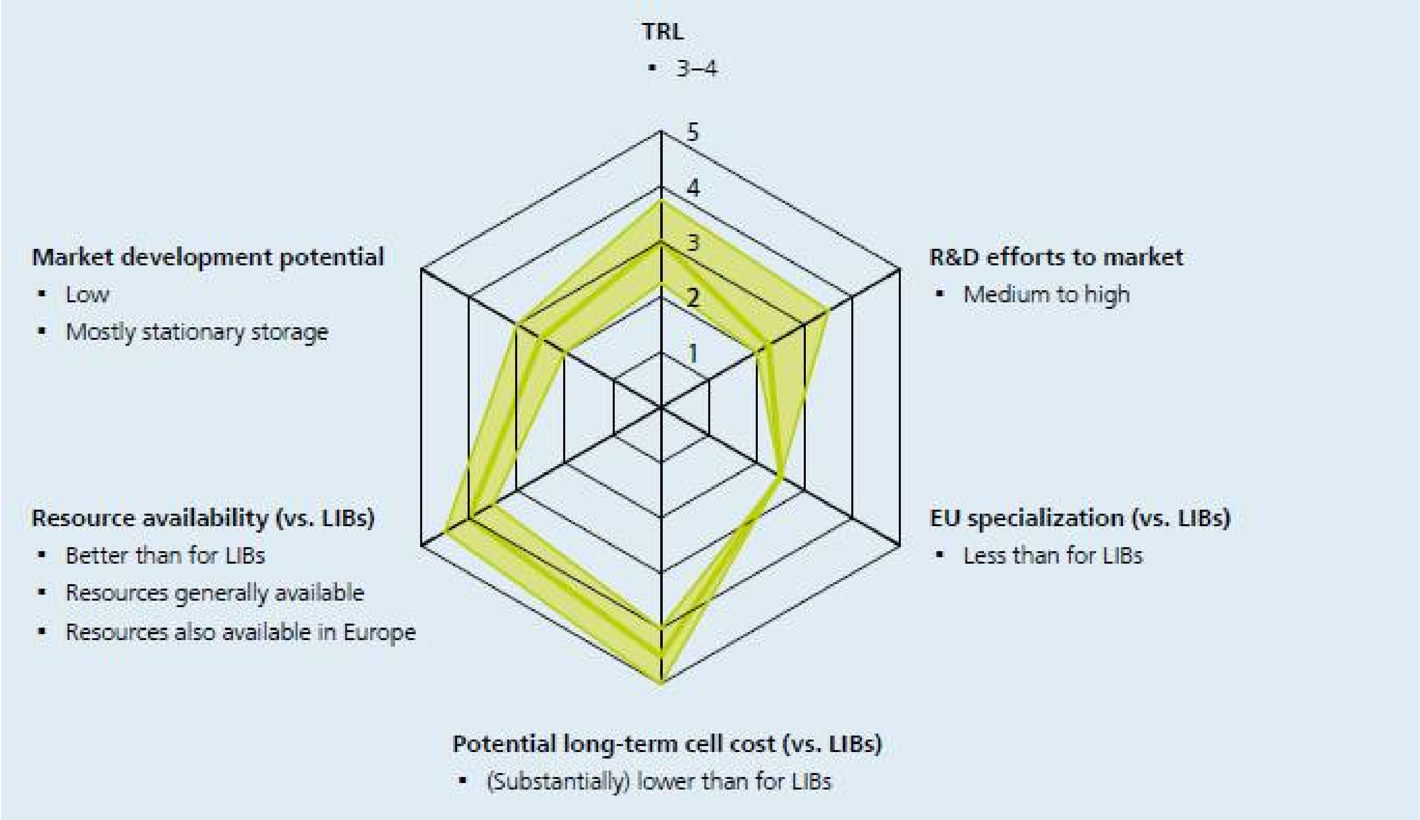
Source: https://www.isi.fraunhofer.de/content/dam/isi/dokumente/cct/2023/abt-roadmap.pdf

CHEAP ENERGY TYPE STORAGE TECH. VS. PHS

Magnesium-ion



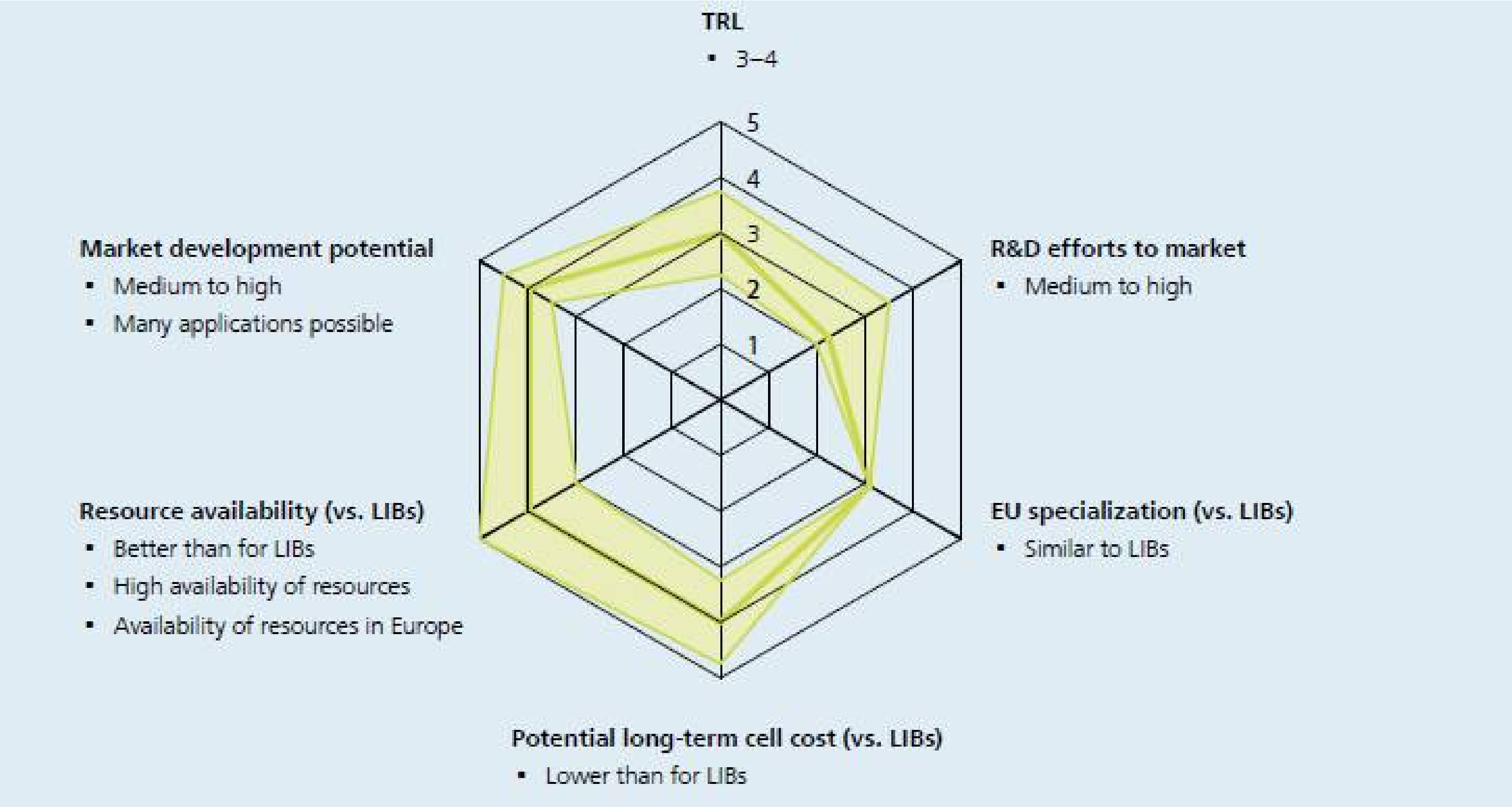
Zn-ion



Source: https://www.isi.fraunhofer.de/content/dam/isi/dokumente/cct/2023/abt-roadmap.pdf

CHEAP ENERGY TYPE STORAGE TECH. VS. PHS

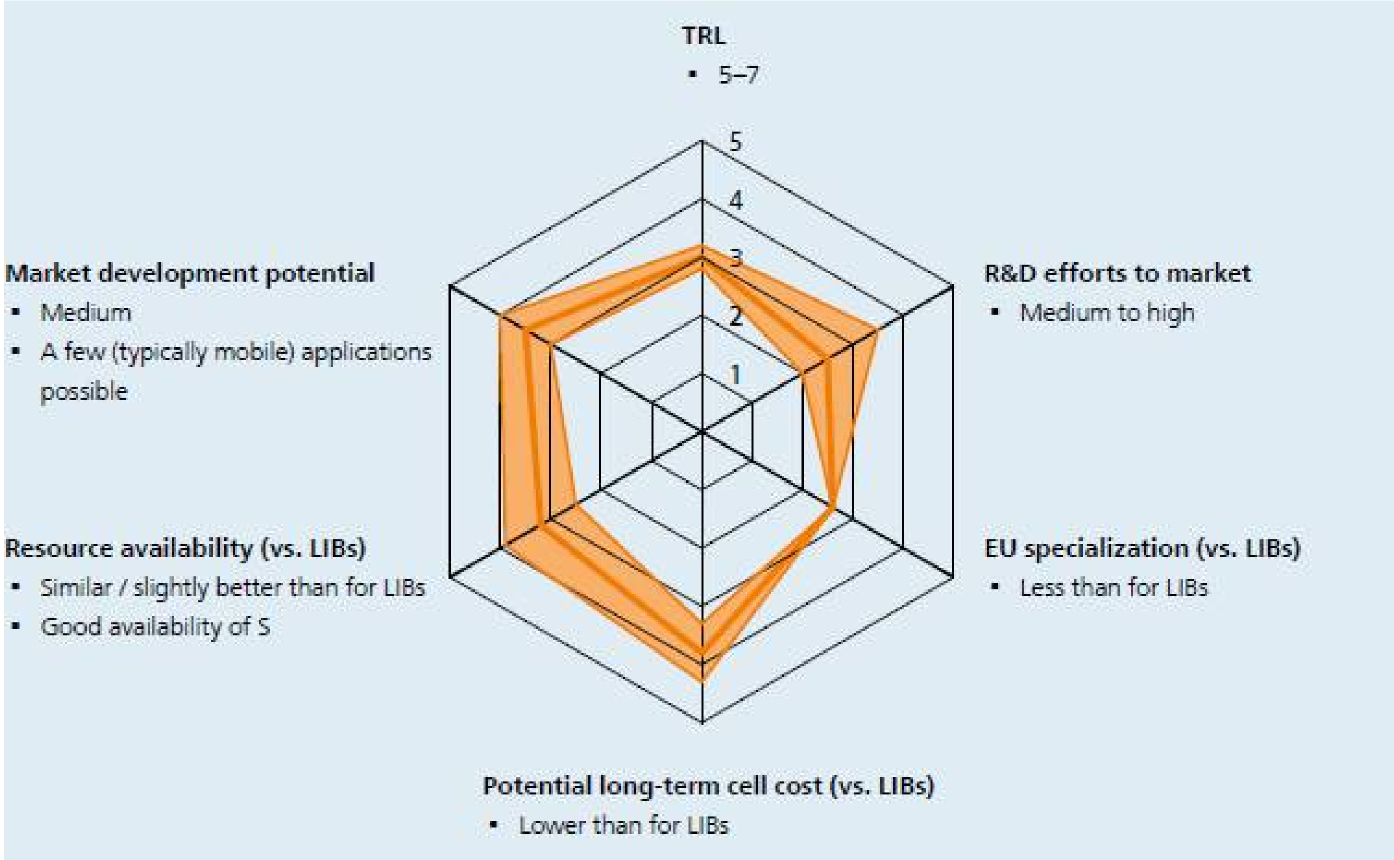
Aluminum-ion



Source: https://www.isi.fraunhofer.de/content/dam/isi/dokumente/cct/2023/abt-roadmap.pdf

CHEAP ENERGY TYPE STORAGE TECH. VS. PHS

Li-S



TRL
- 5–7

Market development potential
- Medium
- A few (typically mobile) applications possible

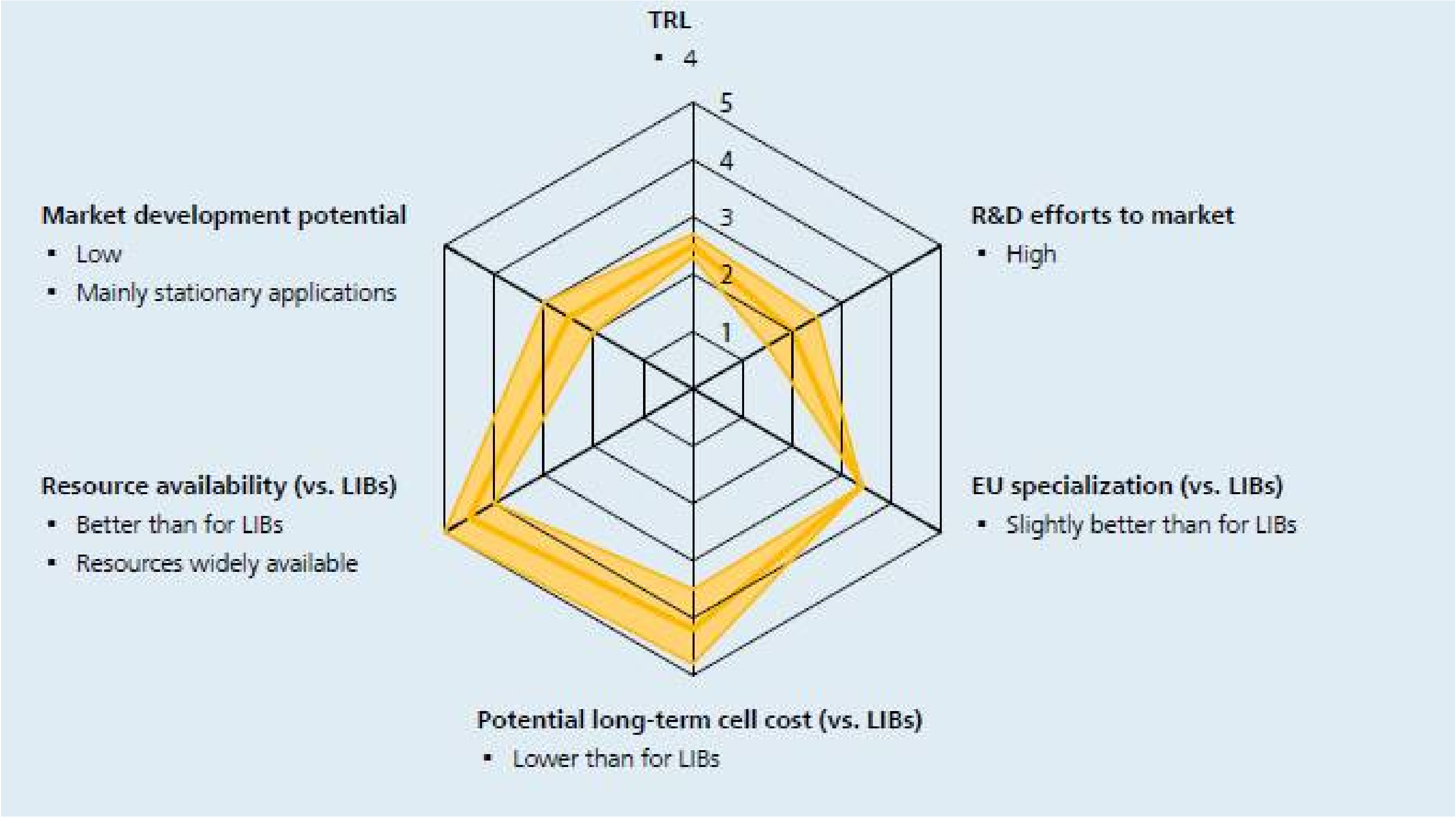
R&D efforts to market
- Medium to high

Resource availability (vs. LIBs)
- Similar / slightly better than for LIBs
- Good availability of S

EU specialization (vs. LIBs)
- Less than for LIBs

Potential long-term cell cost (vs. LIBs)
- Lower than for LIBs

Na-S



TRL
- 4

Market development potential
- Low
- Mainly stationary applications

R&D efforts to market
- High

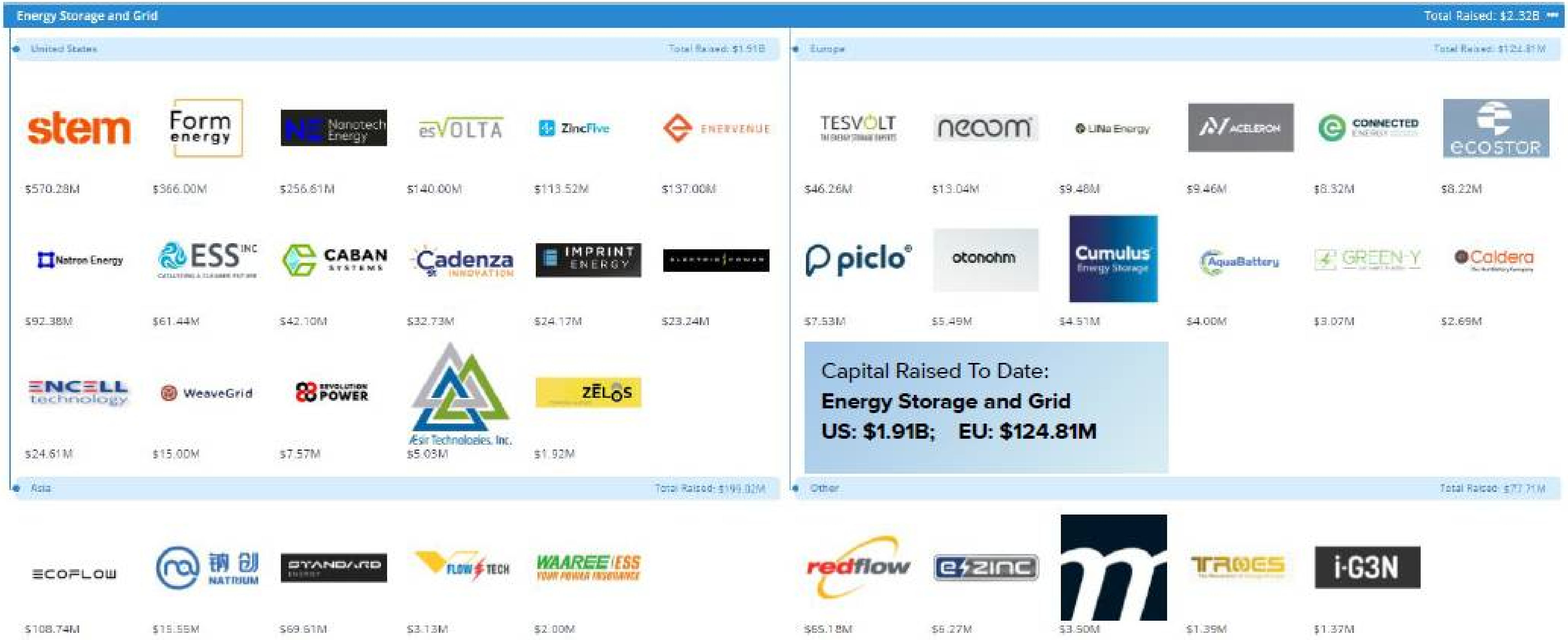
Resource availability (vs. LIBs)
- Better than for LIBs
- Resources widely available

EU specialization (vs. LIBs)
- Slightly better than for LIBs

Potential long-term cell cost (vs. LIBs)
- Lower than for LIBs

Source: https://www.isi.fraunhofer.de/content/dam/isi/dokumente/cct/2023/abt-roadmap.pdf

EMERGING TECHNOLOGIES



Energy Storage and Grid — Total Raised: $2.32B

United States — Total Raised: $1.91B

stem	$570.28M
Form energy	$366.00M
Nanotech Energy	$256.61M
esVOLTA	$140.00M
ZincFive	$113.52M
ENERVENUE	$137.00M
Natron Energy	$92.38M
ESS INC	$61.44M
CABAN SYSTEMS	$42.10M
Cadenza INNOVATION	$32.73M
IMPRINT ENERGY	$24.17M
	$23.24M
ENCELL technology	$24.61M
WeaveGrid	$15.00M
REVOLUTION POWER	$7.57M
Æsir Technologies, Inc.	$5.03M
ZELOS	$1.92M

Europe — Total Raised: $124.81M

TESVOLT	$46.26M
neoom	$13.04M
LiNa Energy	$9.48M
ACELERON	$9.46M
CONNECTED ENERGY	$8.32M
ecostor	$8.22M
piclo	$7.53M
otonohm	$5.49M
Cumulus Energy Storage	$4.51M
AquaBattery	$4.00M
GREEN-Y	$3.07M
Caldera	$2.69M

Capital Raised To Date:
Energy Storage and Grid
US: $1.91B; EU: $124.81M

Asia — Total Raised: $199.02M

ECOFLOW	$108.74M
钠创 NATRIUM	$15.55M
STANDARD ENERGY	$69.61M
FLOW TECH	$3.13M
WAAREE ESS	$2.00M

Other — Total Raised: $77.71M

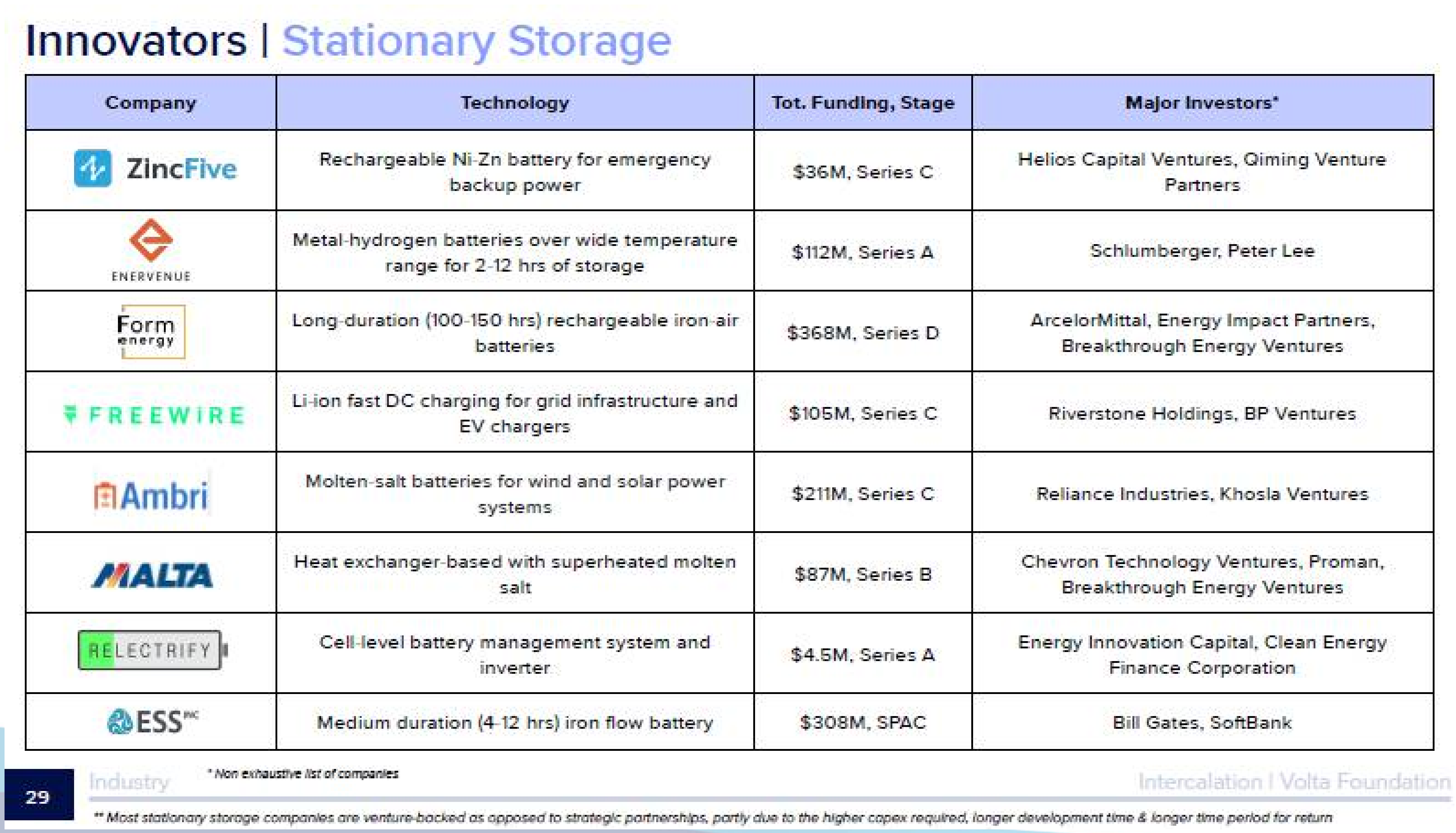
redflow	$65.18M
e-zinc	$6.27M
	$3.50M
TRAMES	$1.39M
i-G3N	$1.37M

Capital Raised To Date: **Energy Storage and Grid Asia: $199.02M**

Capital Raised To Date: **Energy Storage and Grid Other: $77.71M**

Source: The Battery Report 2021" Volta Foundation & Intercalation, 8 January 2022. Web [20 May, 2022]

EMERGING TECHNOLOGIES



Innovators | Stationary Storage

Company	Technology	Tot. Funding, Stage	Major Investors*
ZincFive	Rechargeable Ni-Zn battery for emergency backup power	$36M, Series C	Helios Capital Ventures, Qiming Venture Partners
ENERVENUE	Metal-hydrogen batteries over wide temperature range for 2-12 hrs of storage	$112M, Series A	Schlumberger, Peter Lee
Form energy	Long-duration (100-150 hrs) rechargeable iron-air batteries	$368M, Series D	ArcelorMittal, Energy Impact Partners, Breakthrough Energy Ventures
FREEWIRE	Li-ion fast DC charging for grid infrastructure and EV chargers	$105M, Series C	Riverstone Holdings, BP Ventures
Ambri	Molten-salt batteries for wind and solar power systems	$211M, Series C	Reliance Industries, Khosla Ventures
MALTA	Heat exchanger-based with superheated molten salt	$87M, Series B	Chevron Technology Ventures, Proman, Breakthrough Energy Ventures
RELECTRIFY	Cell-level battery management system and inverter	$4.5M, Series A	Energy Innovation Capital, Clean Energy Finance Corporation
ESS INC	Medium duration (4-12 hrs) iron flow battery	$308M, SPAC	Bill Gates, SoftBank

** Non exhaustive list of companies*

*** Most stationary storage companies are venture-backed as opposed to strategic partnerships, partly due to the higher capex required, longer development time & longer time period for return*

Source: The Battery Report 2021” Volta Foundation & Intercalation, 8 January 2022. Web [20 May, 2022]

EMERGING TECHNOLOGIES

EnerVenue secures 250 MWh order for nickel-hydrogen batteries

EnerVenue has agreed to supply batteries to Green Energy Renewable Solutions for use in customized building blocks for maritime applications, construction sites, and other heavy industry projects. The agreement marks EnerVenue's fourth major battery supply deal since it launched operations in 2020.

SEPTEMBER 23, 2022 **BEATRIZ SANTOS**

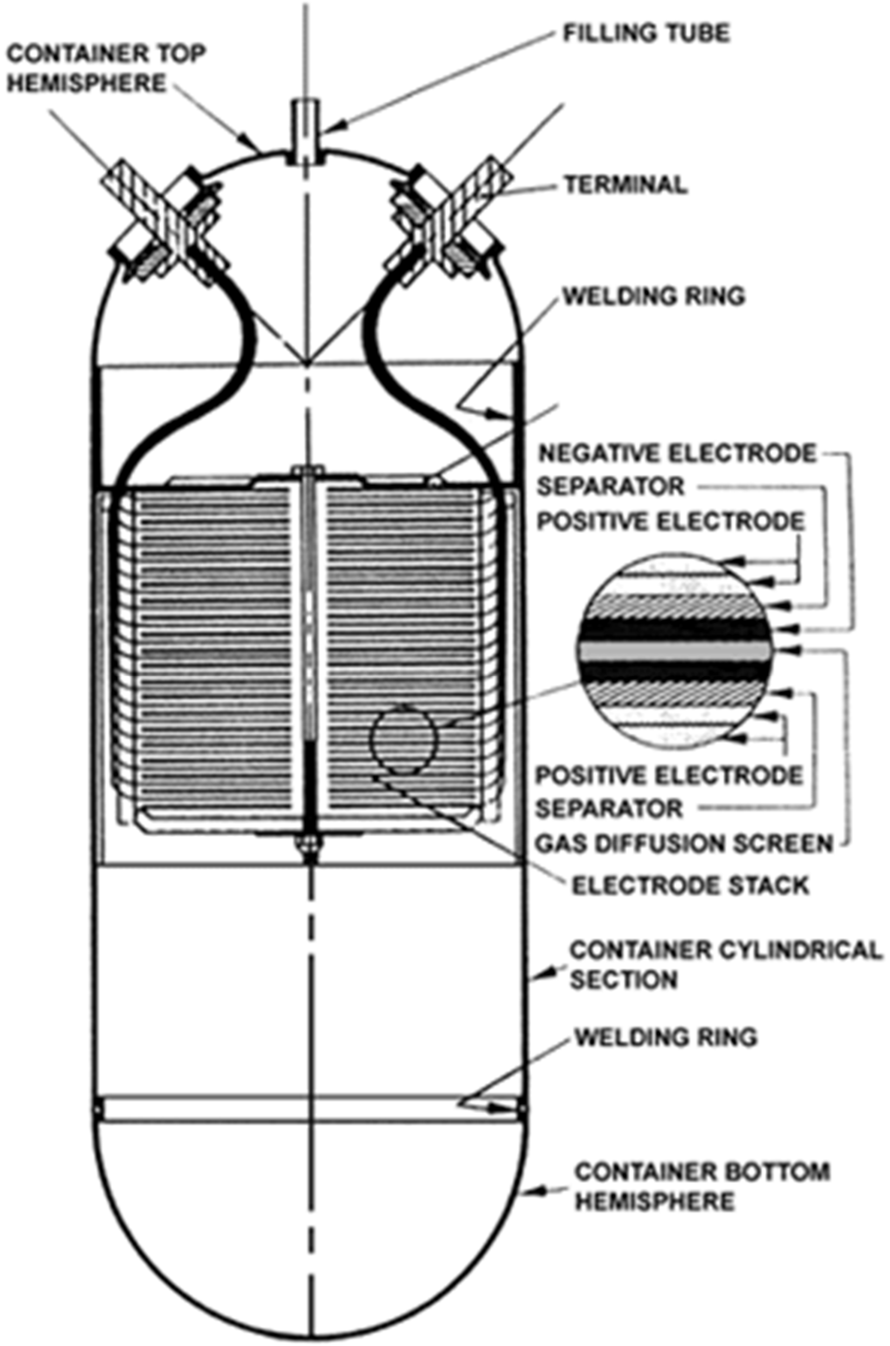
- Found in 2020 w/ $12M
- Series A $100M
- “Reinventing technology that's been used for space exploration for nearly 30 years.”
- Wide range of operating T
- Long life time >30,000 cycle
- $20,000/kWh → $100/kWh

Source: https://www.energy-storage.news/we-think-we-can-beat-lithium-ion-enervenue-bids-for-battery-storage-supremacy/

EMERGING TECHNOLOGIES

ENERVENUE

Ni-H2 BATTERY



Source: https://www.energy-storage.news/we-think-we-can-beat-lithium-ion-enervenue-bids-for-battery-storage-supremacy/

EMERGING TECHNOLOGIES

Eos Energy Storage

Zn-ion BATTERY

- Found in 2008
- NASDAQ 2020
- 3-12 duration for grid
- Current deal $325/kWh (@MWh scale) -> Targeted $95/kWh

Eos customer takes zinc battery storage master supply agreement to 1GWh

By Andy Colthorpe

July 6, 2022

Americas, US & Canada · Grid Scale · Business, Products, Technology

Source: https://www.energy-storage.news/we-think-we-can-beat-lithium-ion-enervenue-bids-for-battery-storage-supremacy/

EMERGING TECHNOLOGIES

Eos Energy Storage

Zn-ion BATTERY

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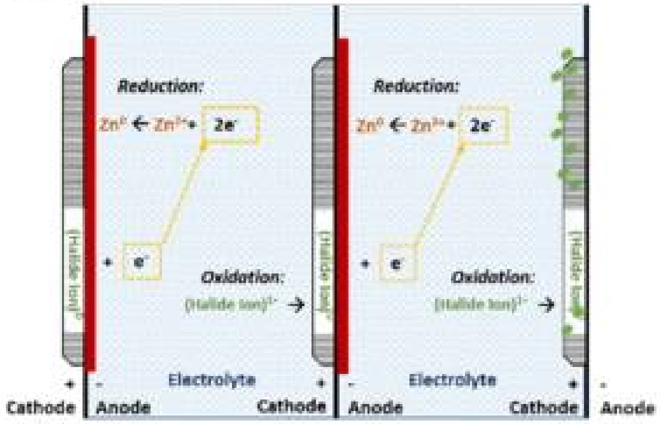
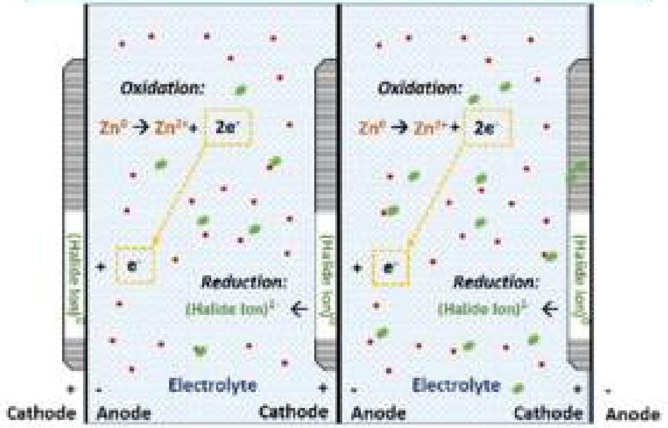
- 3-12 duration for grid
- Current ~ $325/kWh -> Targeted $95/kWh

Chemical Inspiration: Zinc Plating Baths

Top of Charge



End of Discharge and Rest



Source: https://eosenergystorage.com/

EMERGING TECHNOLOGIES

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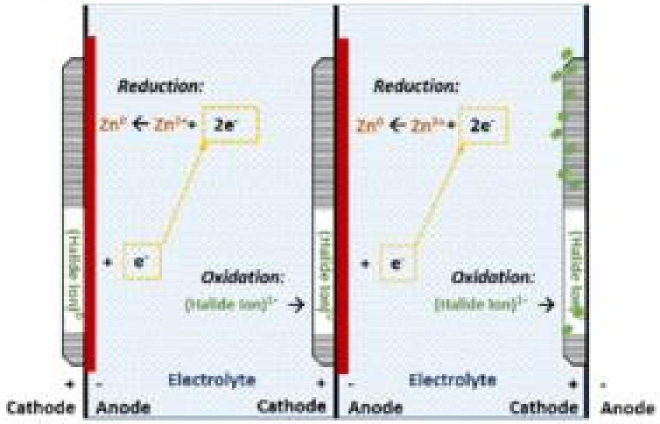
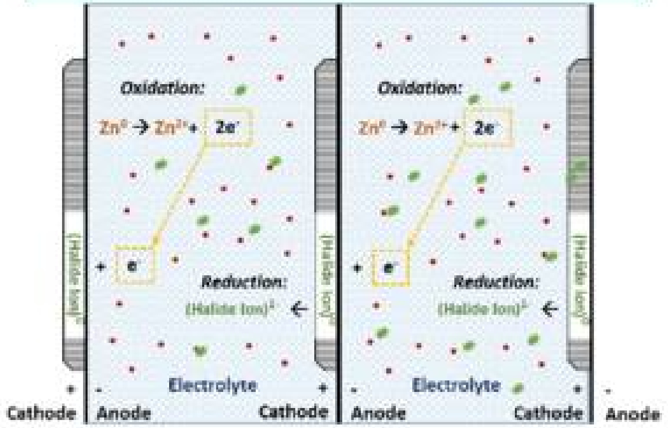


End of Discharge
and Rest



Source: https://eosenergystorage.com/

EMERGING TECHNOLOGIES

Ambri

Batteries for clean energy

Liquid Metal BATTERY

- Found in 2010
- Sb based battery
- Backed by Bill Gates
- 5 pilot projects planned in 2023
- 4-12 hr duration
- 20 years life

DIVE BRIEF

Liquid battery startup Ambri ready to embark on first utility demonstration project with Xcel Energy

Published Sept. 6, 2022

By Emma Penrod

Petmal via Getty Images

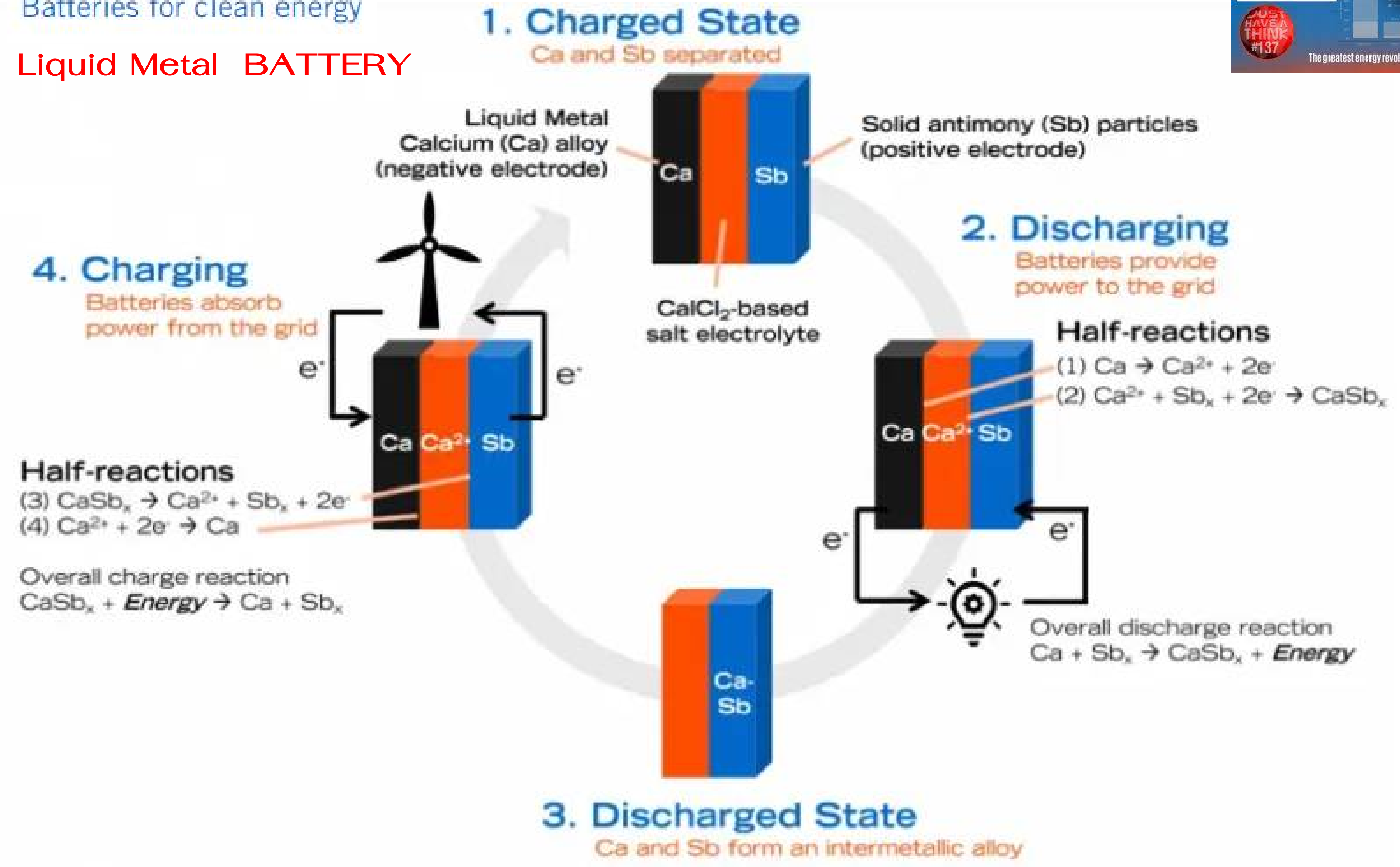
Source: https://www.utilitydive.com/news/ambri-xcel-battery-storage/631005/

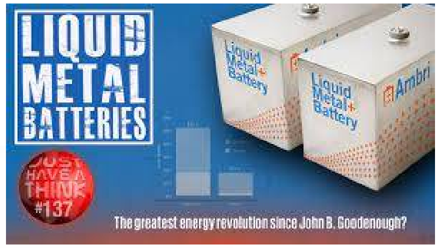
EMERGING TECHNOLOGIES

Ambri

Batteries for clean energy

Liquid Metal BATTERY





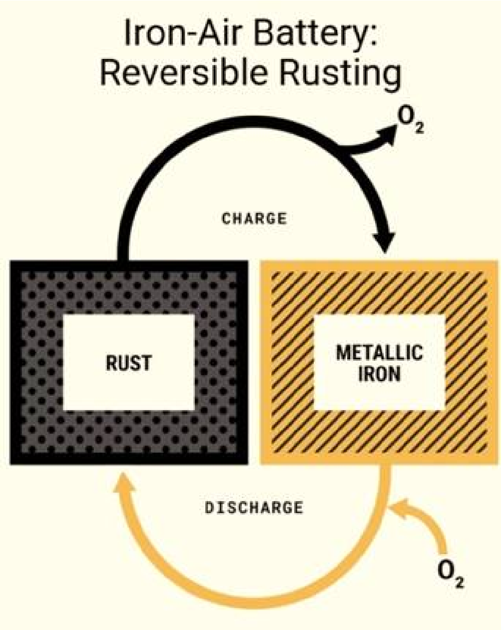
Source: https://www.utilitydive.com/news/ambri-xcel-battery-storage/631005/

EMERGING TECHNOLOGIES

Form energy

Fe-Air BATTERY

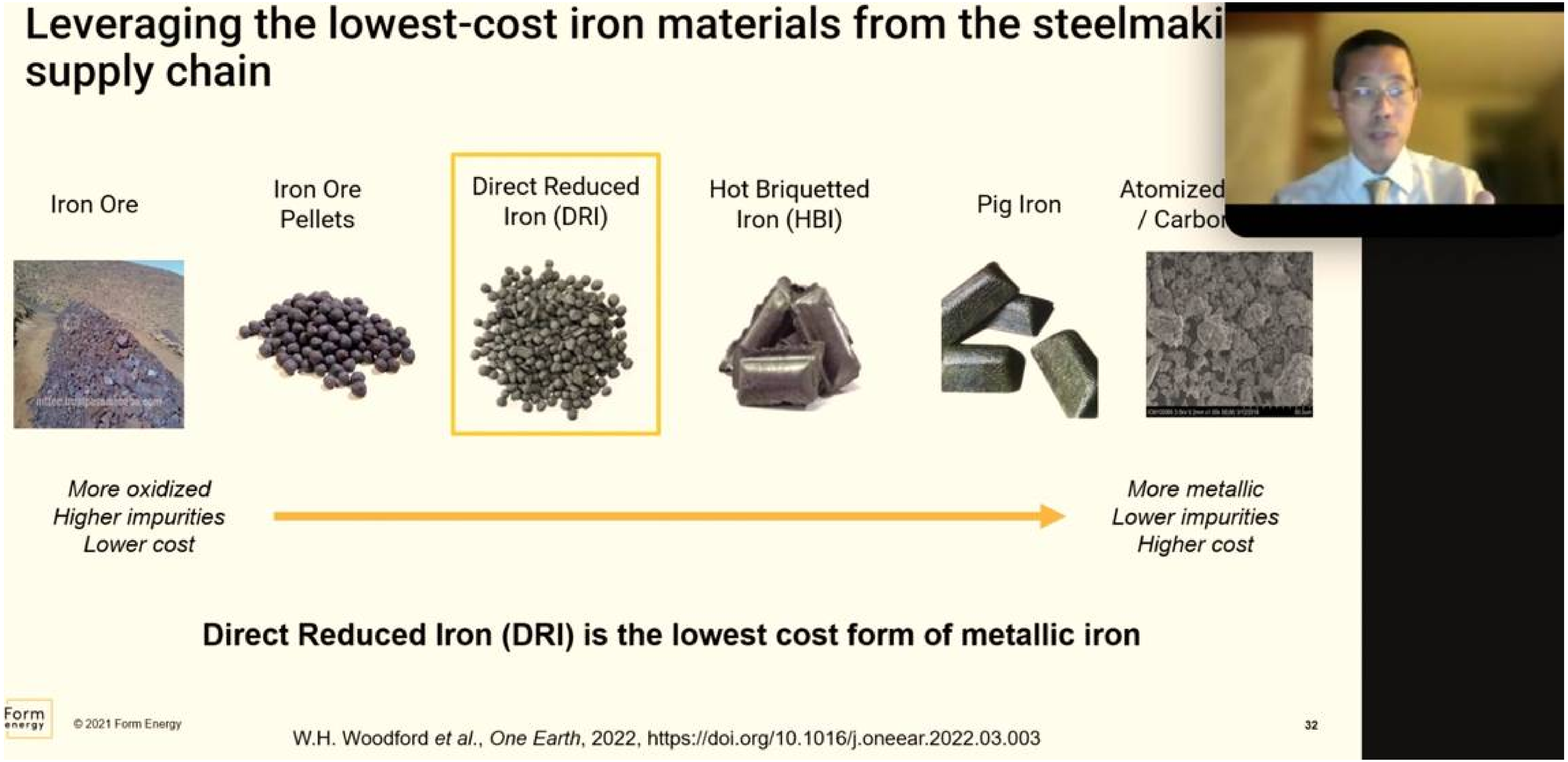
- Found in 2017
- Backed by Bill Gates and Jeff Bezos
- Cheap → $20/kWh
- Long duration – multidays
- Hundreds of cycles



Source: Y-M. Chiang, Presentation @ TESTA Symposium No. 2, September 16, 2022

EMERGING TECHNOLOGIES

Fe-Air BATTERY



Leveraging the lowest-cost iron materials from the steelmaki supply chain

Iron Ore

Iron Ore Pellets

Direct Reduced Iron (DRI)

Hot Briquetted Iron (HBI)

Pig Iron

Atomized / Carbo

More oxidized
Higher impurities
Lower cost

More metallic
Lower impurities
Higher cost

Direct Reduced Iron (DRI) is the lowest cost form of metallic iron

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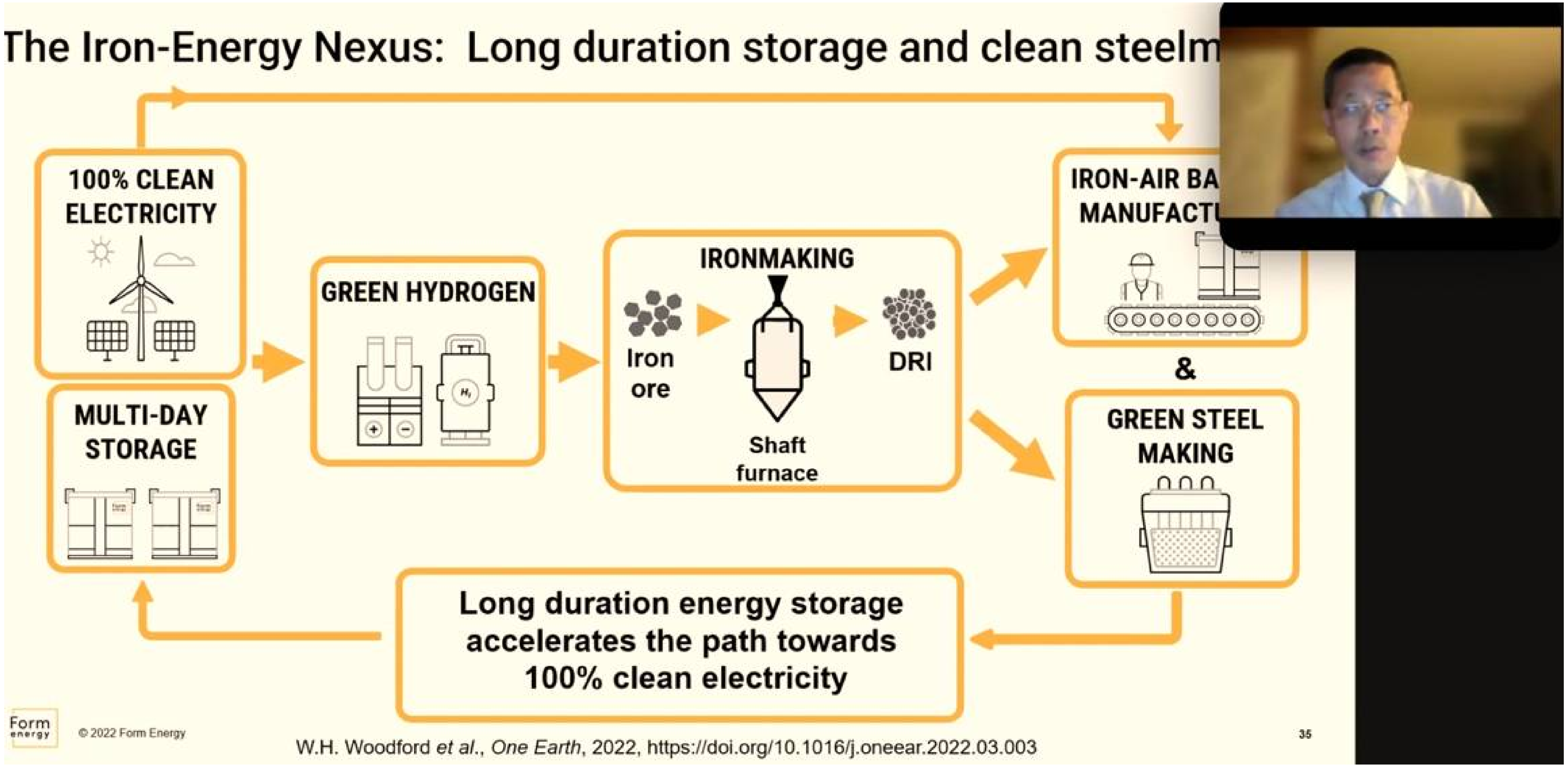
W.H. Woodford *et al.*, *One Earth*, 2022, https://doi.org/10.1016/j.oneear.2022.03.003

32

Source: Y-M. Chiang, Presentation @ TESTA Symposium No. 2, September 16, 2022

EMERGING TECHNOLOGIES

Fe-Air BATTERY



The Iron-Energy Nexus: Long duration storage and clean steelm

Long duration energy storage accelerates the path towards 100% clean electricity

© 2022 Form Energy

W.H. Woodford *et al.*, *One Earth*, 2022, https://doi.org/10.1016/j.oneear.2022.03.003

Source: Y-M. Chiang, Presentation @ TESTA Symposium No. 2, September 16, 2022

EMERGING TECHNOLOGIES

FLYWHEEL

- Found in 2014 (France)
- 10kWh – 1 MWh
- > 1M cycles
- Used pre-stressed concrete

French flywheel storage system specialist secures €10 million investment

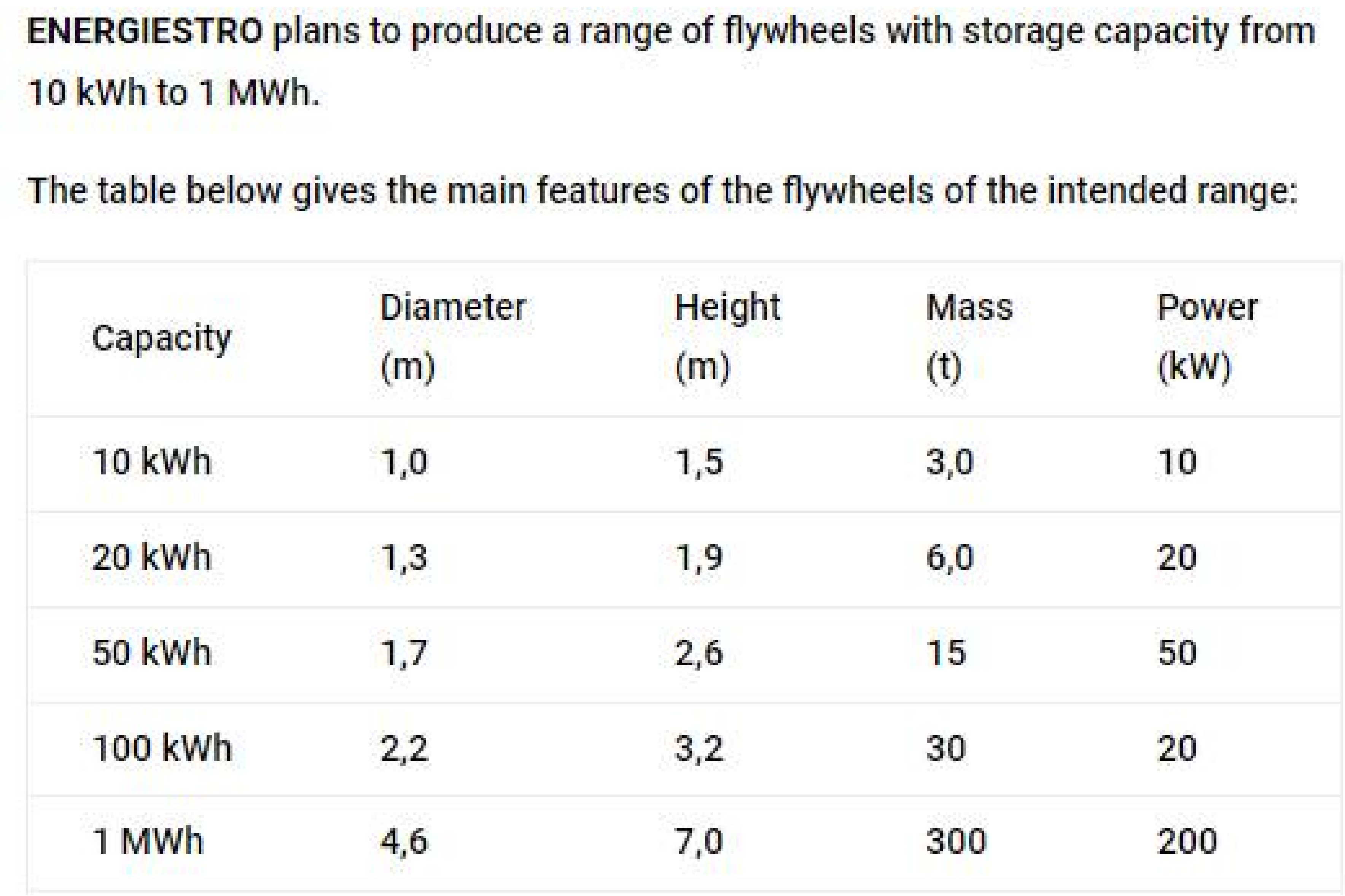
Madagascar-based Filatex has invested €10 million in French flywheel storage system manufacturer Energiestro. The two companies are planning to deploy Energiestro's flywheel storage solutions across Madagascar and Mauritius

FEBRUARY 24, 2022 GWÉNAËLLE DEBOUTTE

Source: : https://energiestro.net/

EMERGING TECHNOLOGIES

FLYWHEEL



ENERGIESTRO plans to produce a range of flywheels with storage capacity from 10 kWh to 1 MWh.

The table below gives the main features of the flywheels of the intended range:

Capacity	Diameter (m)	Height (m)	Mass (t)	Power (kW)
10 kWh	1,0	1,5	3,0	10
20 kWh	1,3	1,9	6,0	20
50 kWh	1,7	2,6	15	50
100 kWh	2,2	3,2	30	20
1 MWh	4,6	7,0	300	200

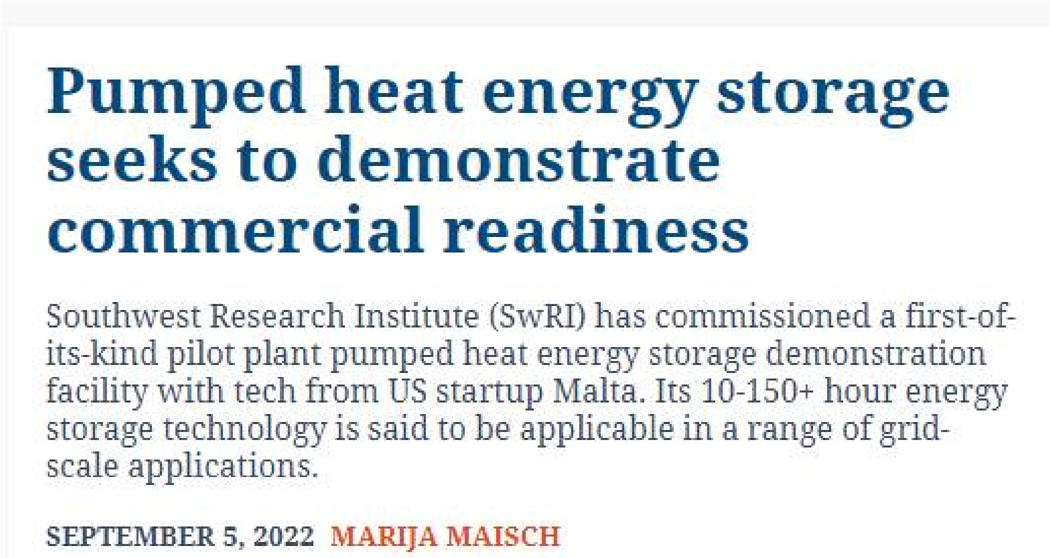
Source: : https://energiestro.net/

EMERGING TECHNOLOGIES

MALTA

THERMAL STORAGE

MOLTEN SALT



Pumped heat energy storage seeks to demonstrate commercial readiness

Southwest Research Institute (SwRI) has commissioned a first-of-its-kind pilot plant pumped heat energy storage demonstration facility with tech from US startup Malta. Its 10-150+ hour energy storage technology is said to be applicable in a range of grid-scale applications.

SEPTEMBER 5, 2022 MARIJA MAISCH

- 10-150 hr storage
- < $100/kWh
- 100MW/ 1000+ MWh
- Life 30 years

8 HR – 8 DAYS 1000MWH SYSTEM SIZE

Source: : https://www.maltainc.com/

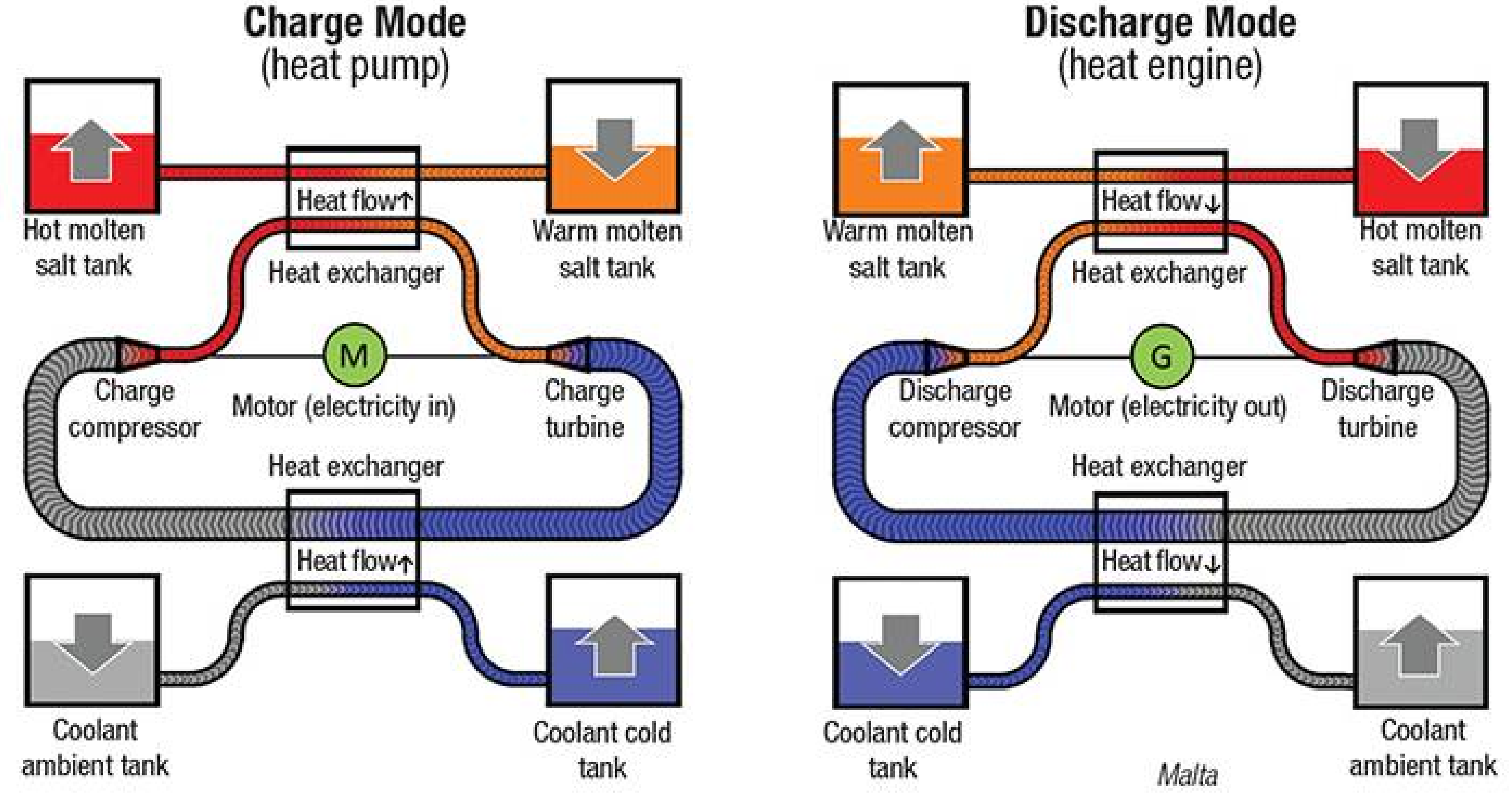
EMERGING TECHNOLOGIES

MALTA

THERMAL STORAGE

MOLTEN SALT

8 HR – 8 DAYS 1000MWH SYSTEM SIZE



Source: : https://www.maltainc.com/

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NEWS

Energy Vault gets 2GWh mandate for gravity energy storage solution at industrial parks in China

By Cameron Murray

September 20, 2022

Asia & Oceania, Central & East Asia | Grid Scale | Business

- Found in 2017 (Switzerland)
- Backed by Bill Gates
- Long duration (4-8 hr)
- Demonstration 150 m tower @ 7-8 MUSD
- Eff ~ 80% cost ~ $875/kW

Source: : https://www.pv-magazine.com/2022/04/29/energy-vault-ntpc-sign-deal-for-gravity-based-energy-storage/

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The left-most image shows the system in its fully charged state; the images to the right show various stages of discharge. (Source: Energy Vault)

Source: MIT "The Future of Energy Storage Report" 2022

SUMMARY

- Pump Hydro storage is still the cheapest and will totally get explored extenstively first
- Underground CAES will be next
- Li-ion will still dominate in this coming 1-5 years.
- Other technologies development are still needed to get there.

Established September 2020

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Thank you ☺