Next Generation Energy Storage Technologies

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APPLIED MATERIALS

Overview

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OUR VISION

Our innovations **make possible** the technology shaping the future

OUR MISSION

To lead the world with **materials engineering** solutions that enable customers to transform possibilities into reality

FOR THE PAST DECADE,

~$1Billion invested annually in RD&E

Our Story

50 years of materials innovation

FOUNDED in 1967

Applied Materials began in a small industrial unit in Mountain View, California

World's #1

semiconductor and display equipment company

$17.3 billion
revenue

$2.0 billion
R&D spending

>12,500
patents

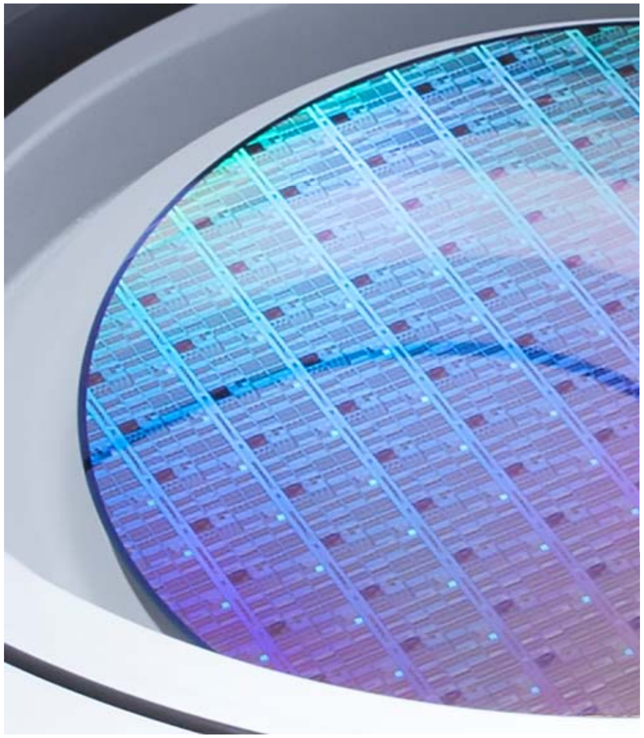
AMAT stock
listing on
NASDAQ

Headquartered
in California's
Silicon Valley

~21,000 employees
93 locations
In **17** countries

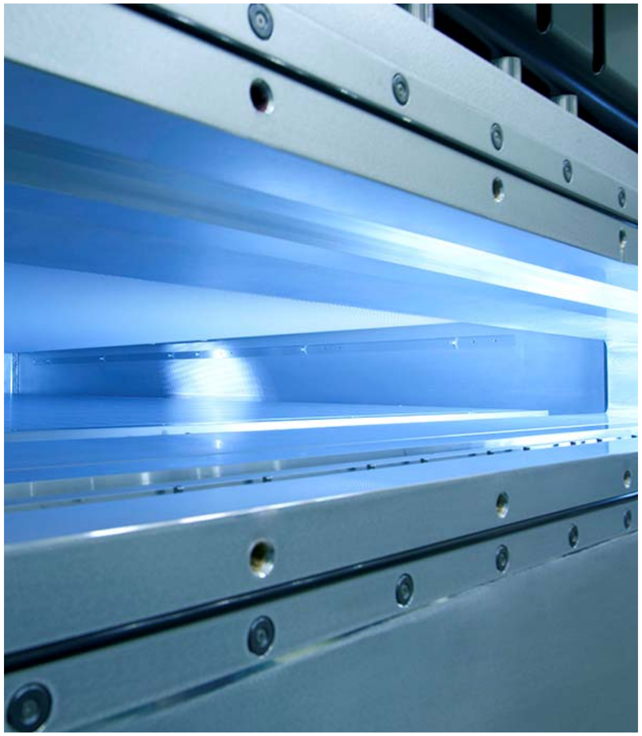
Data as of fiscal year end, October 28, 2018

Businesses



Semiconductor Systems

Applied Global Services



Display and Adjacent Markets

APPLIED MATERIALS®

Accelerating Innovation


Deposition


Thermal

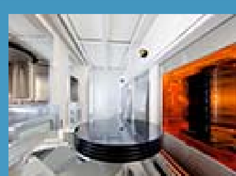

Metals


Planarization


Inspection


Etch


Plating


Implant

Collaborate earlier and deeper
with customers on inflections

Extend the technology roadmap
with fast cadence in product innovation

Drive materials-enabled scaling to improve PPAC*
with new materials, new structures, new devices

Solve customers' complex technical challenges
with Integrated Materials Solutions (IMS)

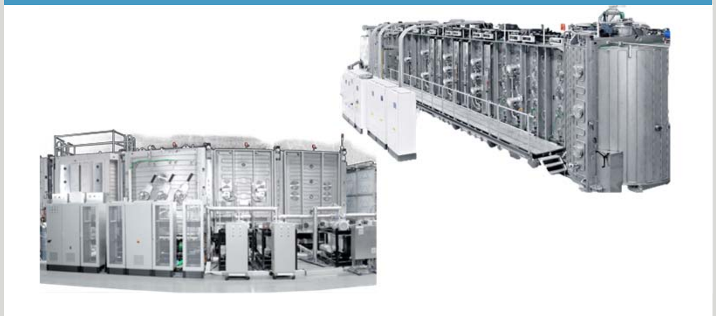
Enable faster learning and breakthrough technologies
through the Maydan Technology and META Centers

* PPAC = Power Performance Area Cost

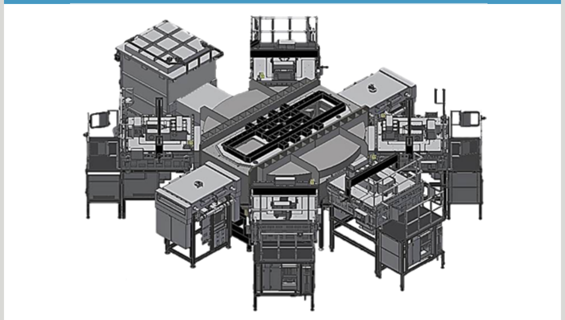
Applied's Display and Flexible Technology Products

CVD

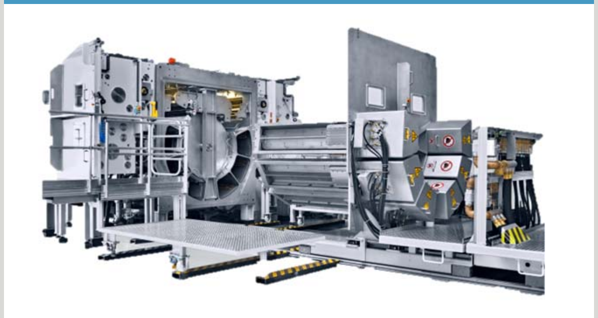
PVD



Thin Film Encapsulation



Roll-to-Roll
E-Beam Evaporation PVD CVD



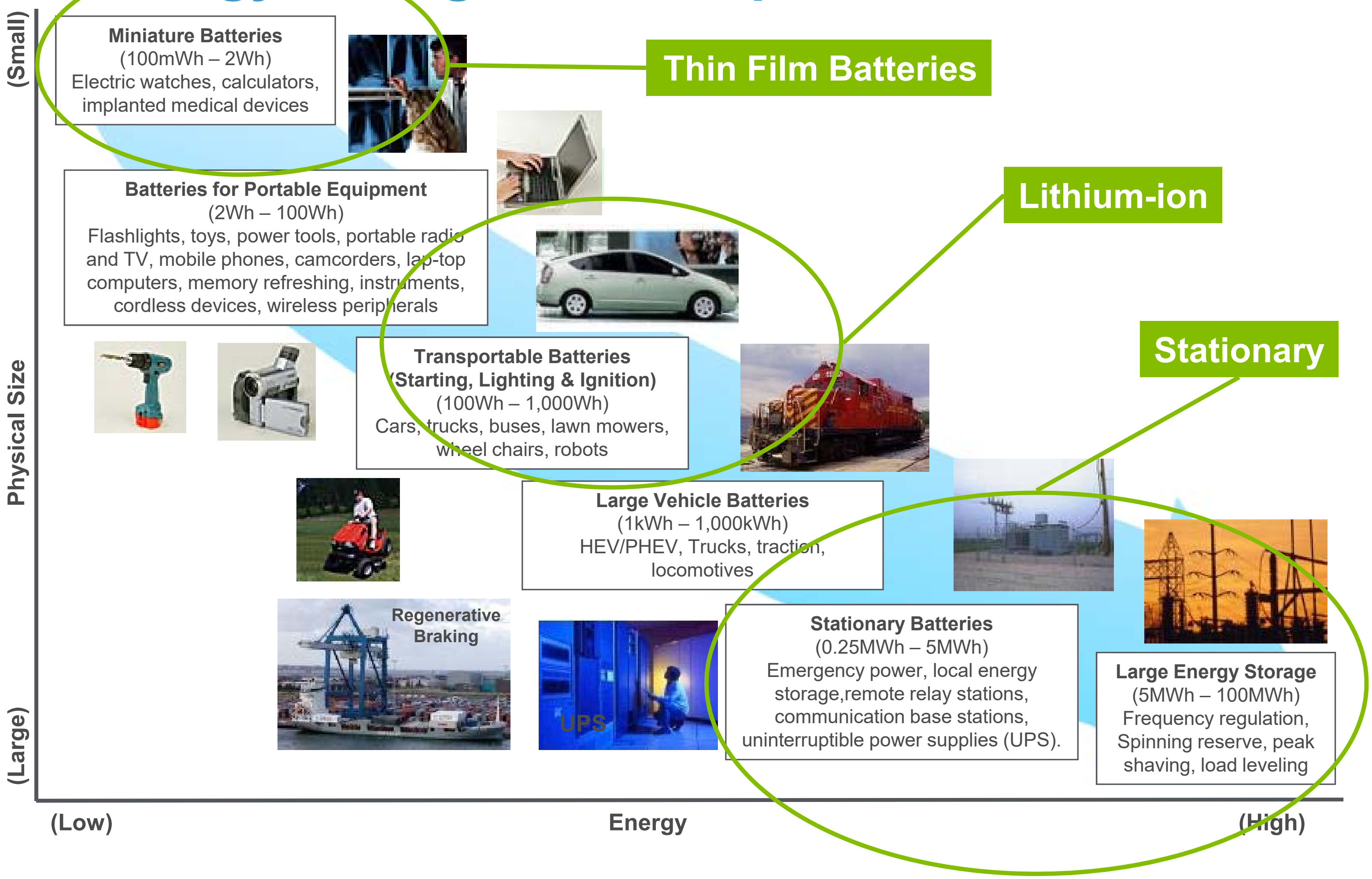
E-Beam Tester

In-Line SEM Review

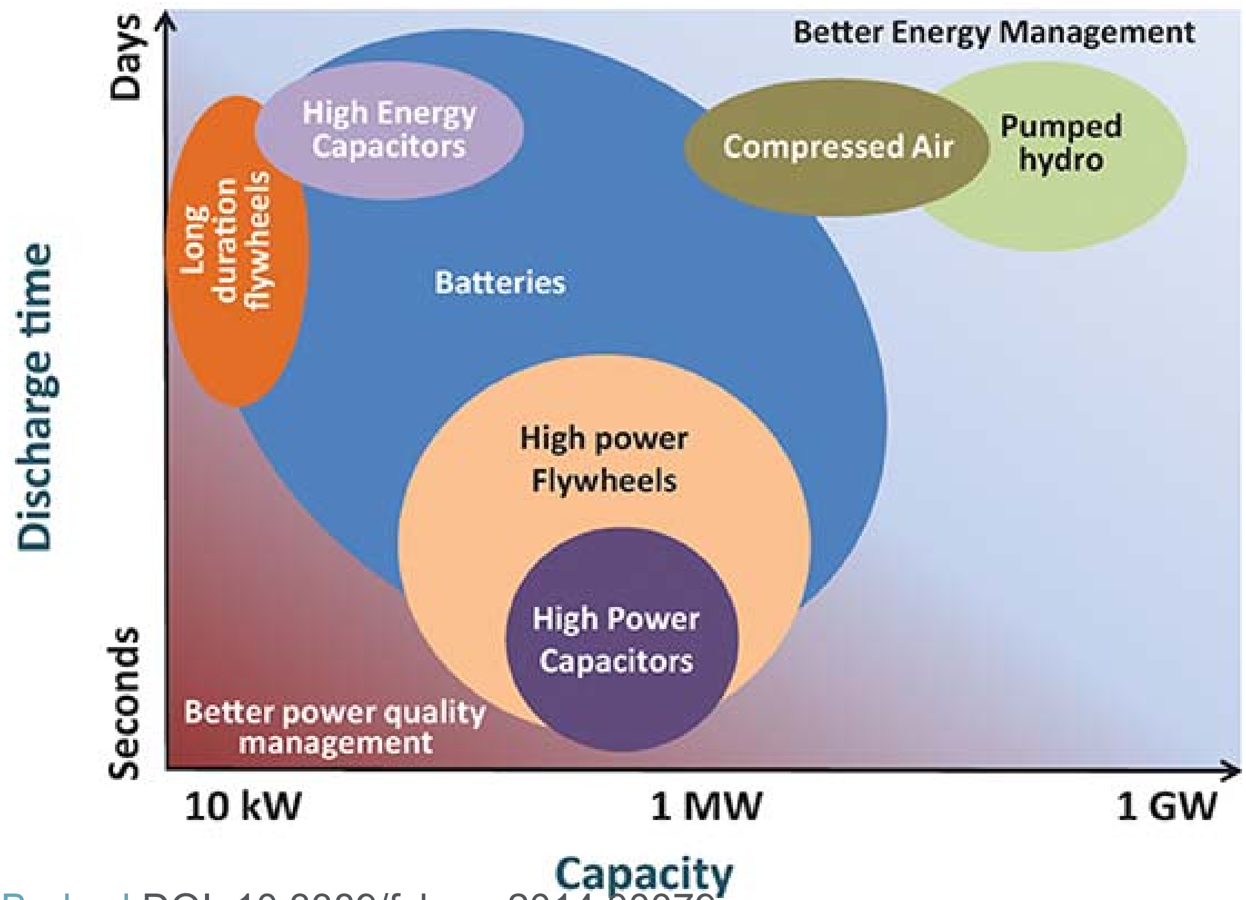
More Products in the Pipeline that will Triple our Footprint in Display

Energy Storage Technologies

Energy Storage Landscape

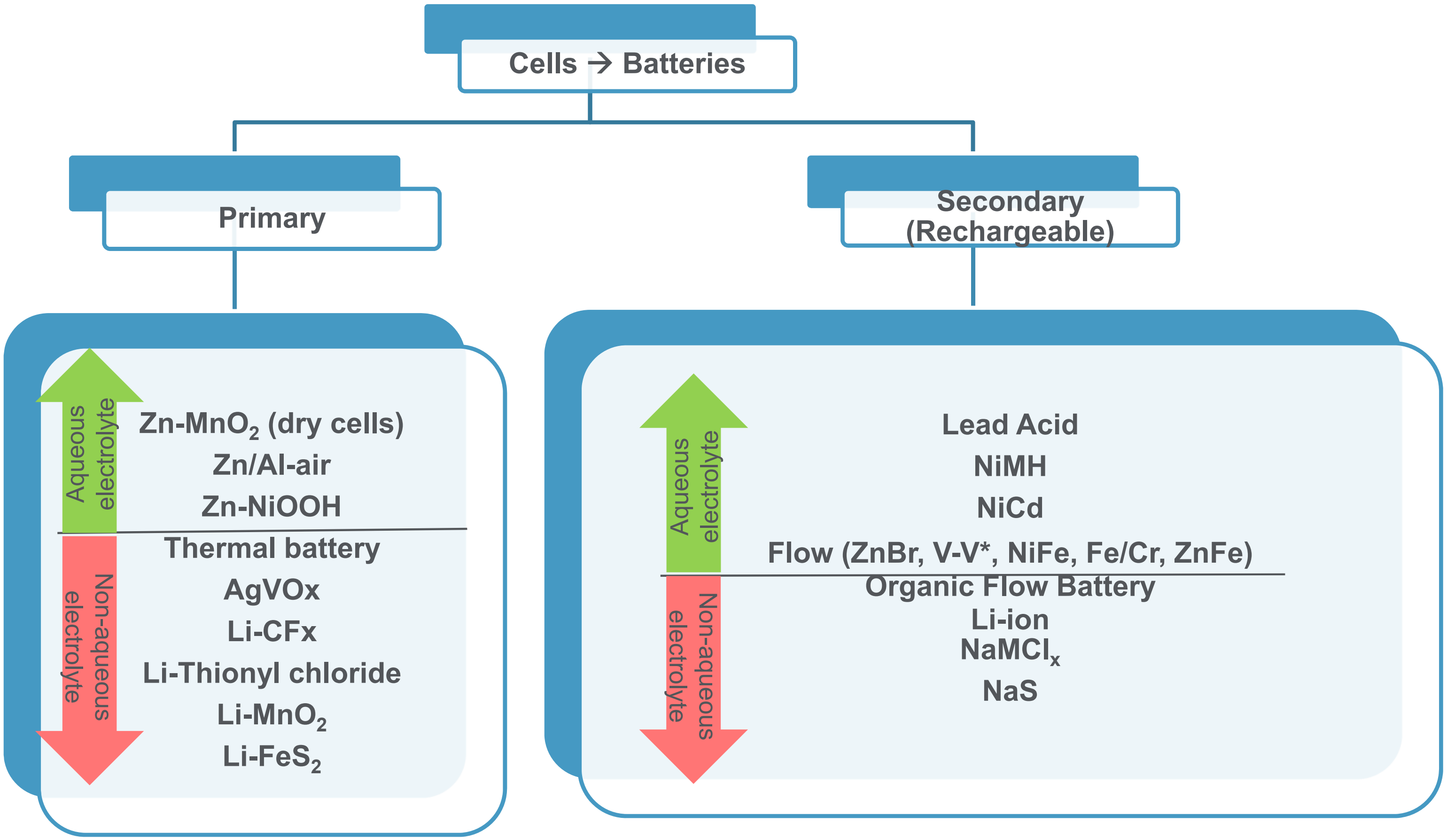


Energy Storage Technologies

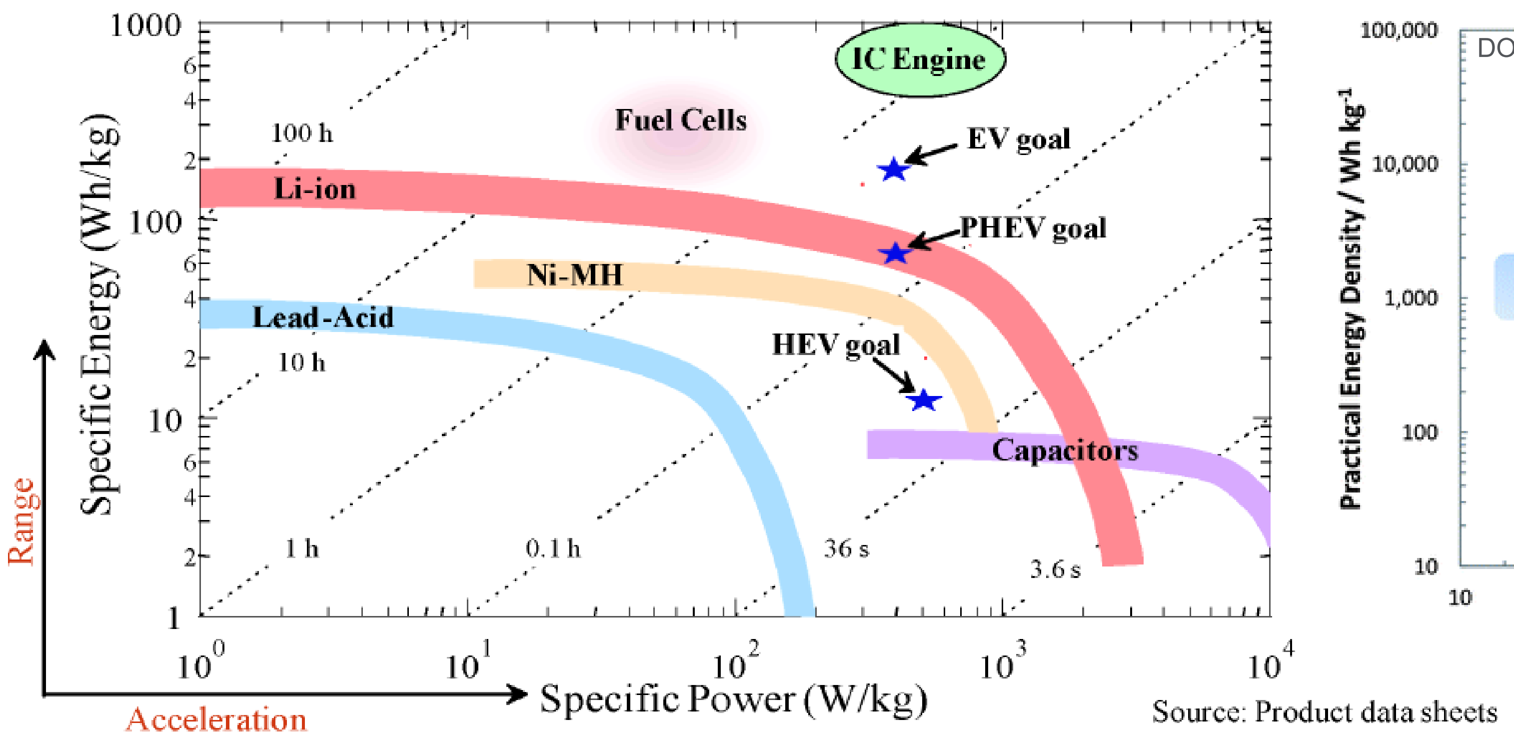


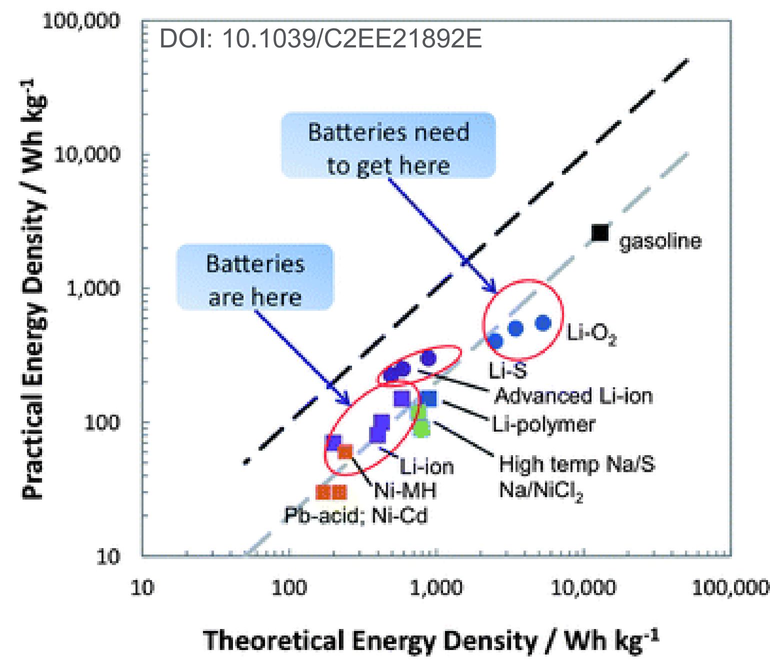
Sukhvinder Badwal DOI: 10.3389/fchem.2014.00079

Commercially Available Battery Technologies



Battery Energy Density and Ragone Plot

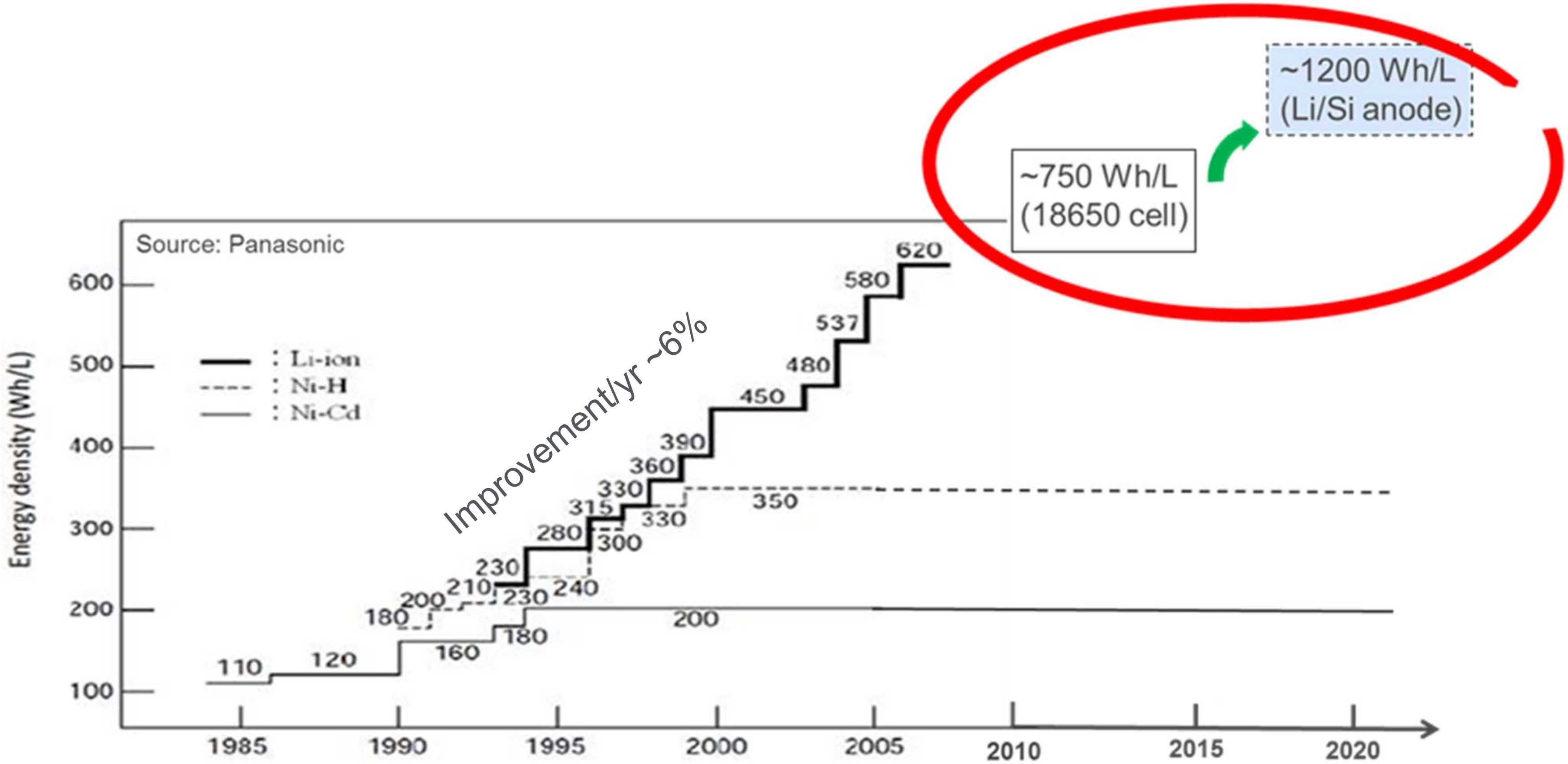




Source: Product data sheets

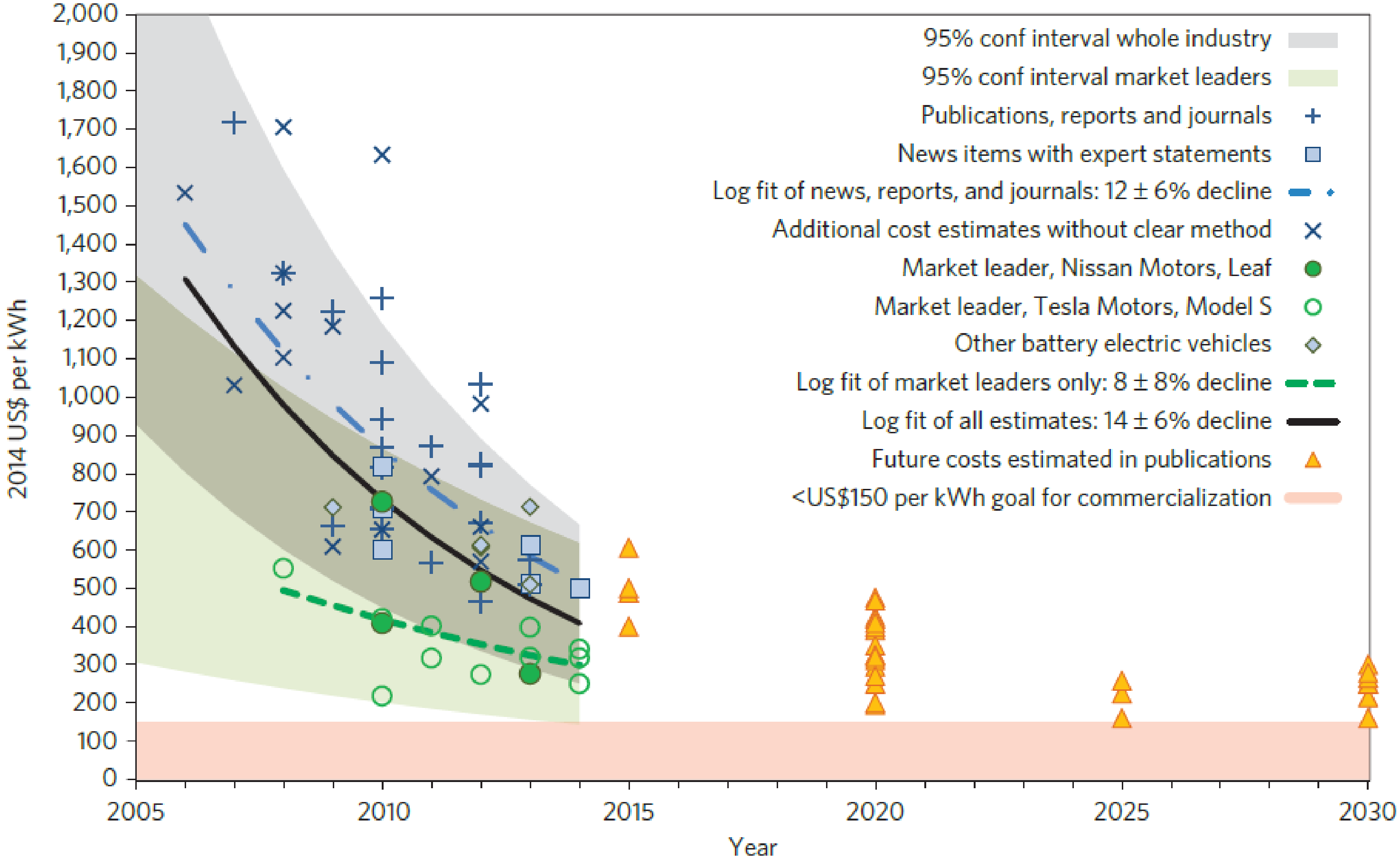
- Cell chemistry and cell design determines Ragone chart
- New cell chemistries needed to increase practical energy density of cells

Performance Limits of Battery Chemistries



Si/Li metal anode will enable > 1000 Wh/L battery

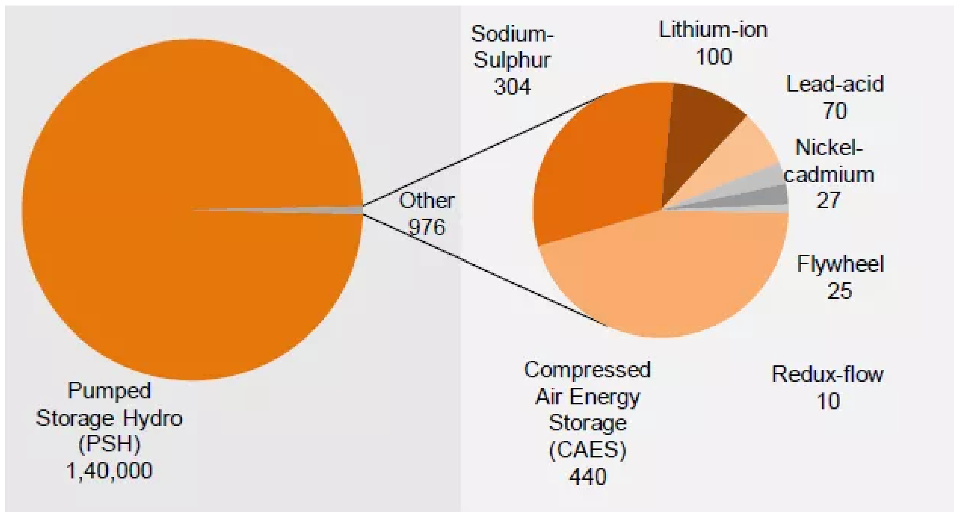
Rapidly Falling Costs of xEV Battery Packs



http://www.nature.com/doifinder/10.1038/nclimate2564

Electricity Storage: Mobility, Transportation and Grid Storage

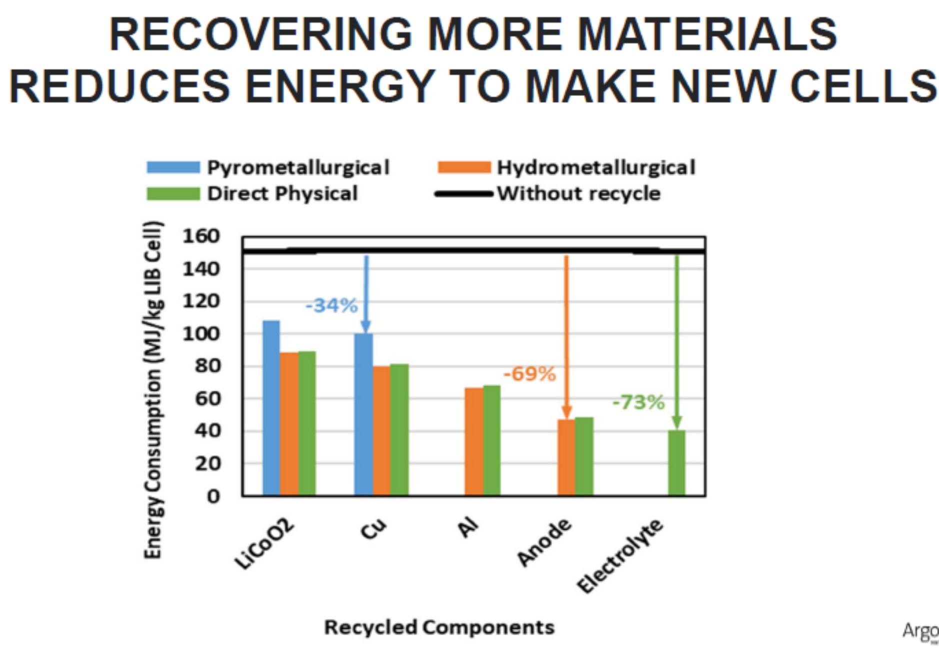
Global installed grid-connected electricity storage capacity (MW)

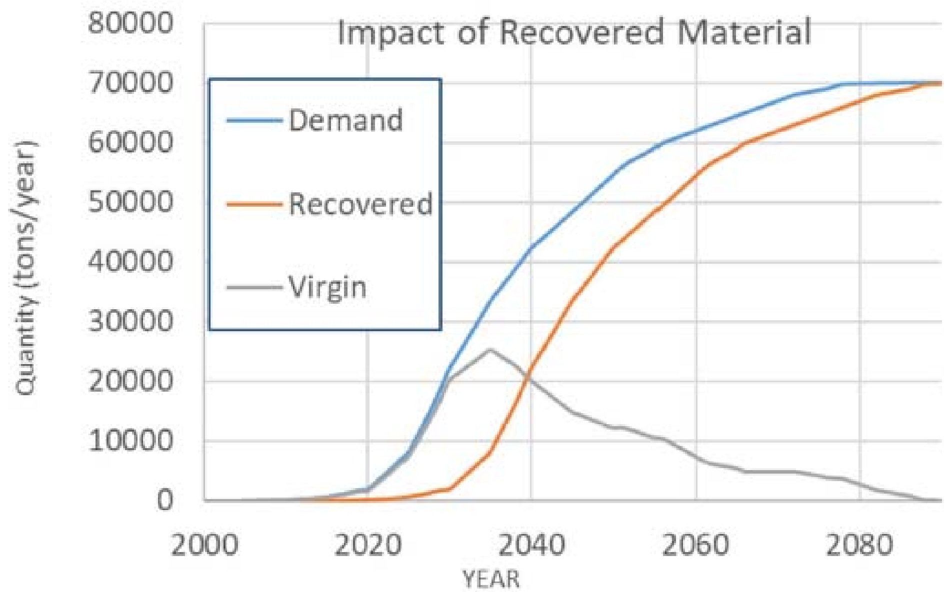


Source: IEA, Technology Roadmap 2014

Grid: Next big opportunity; cost sensitive & regulated market

Li-ion Recycling Could Supply Most of Needed Material …Eventually





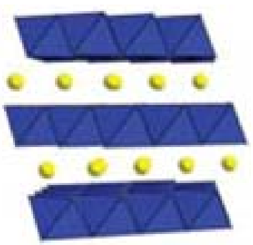
Argonne

Ref: Linda Gains, ARNL, International Battery Seminar and Exhibit 2018

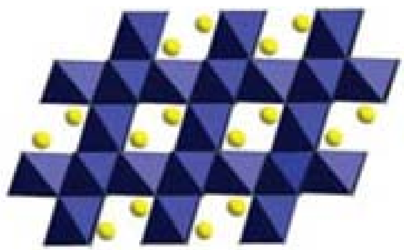
Low cost recycling technology is essential for sustainability

Active Materials

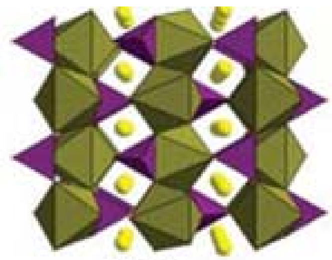
Factors Affecting Battery Design (Li-ion)



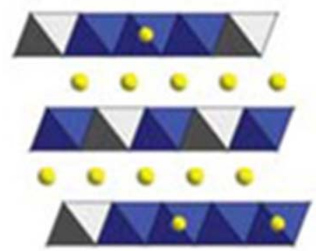
Layered $LiMO_2$ (M=Co, Ni, Mn)



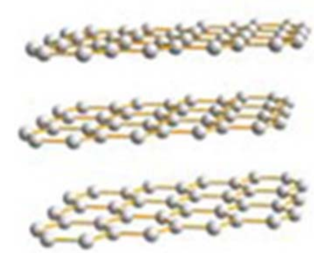
Spinels $LiMn_2O_4$, $Li_4Ti_5O_{12}$



$LiFePO_4$



Layered-layered Composite

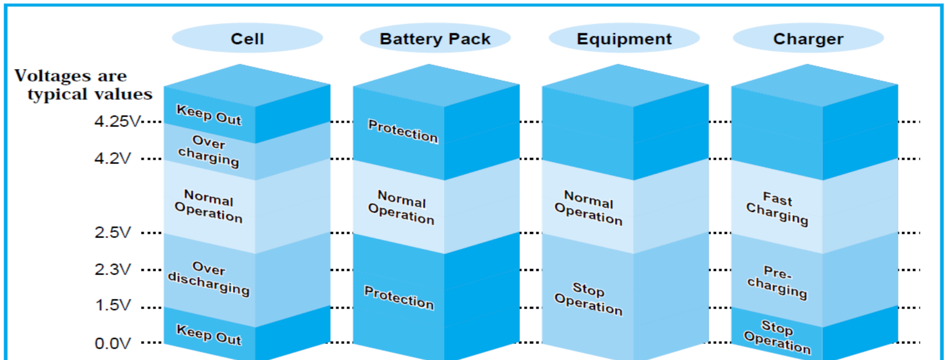


Graphite

Tradeoffs

- Energy
- Power
- Safety
- Gas
- Cost
- Life

Graphite/$LiCoO_2$ cell : Typical usage guidelines



Source: Sony

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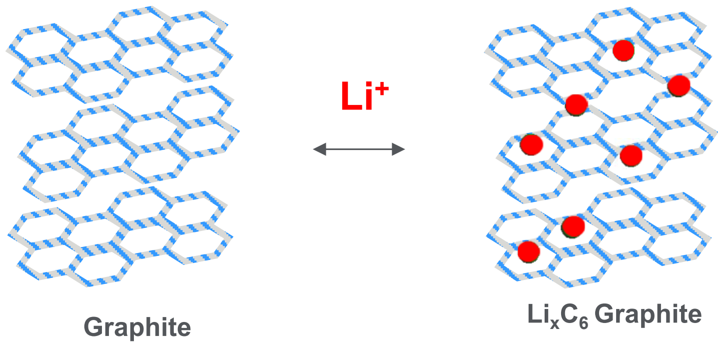
Comparison of Anodes

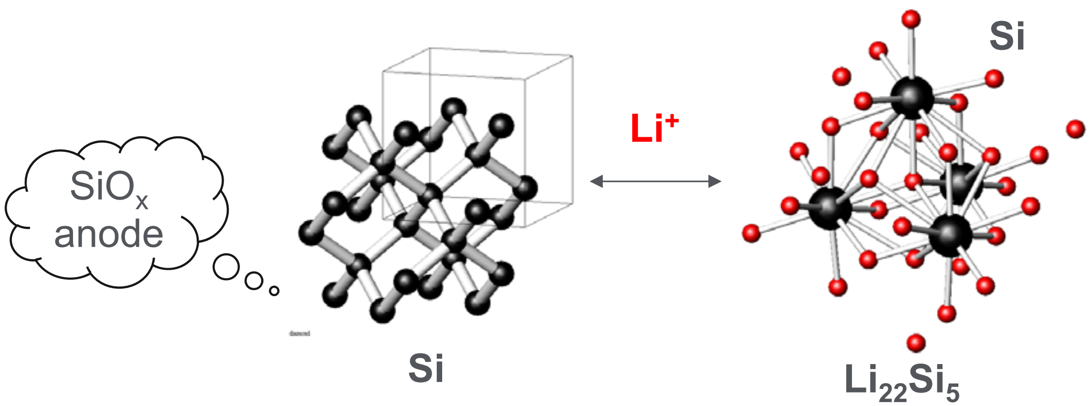


Lithium intercalation, Limited capacity

No C-C bond breaking

Limited volume expansion ~12%

~10% 1st cycle irreversible Li loss

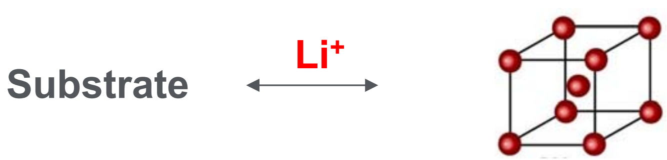


All Si-Si bonds are broken, high capacity

Many Li-Si bonds formed

Large 3D volume expansion (> 300 %)

~30% 1st cycle irreversible Li loss

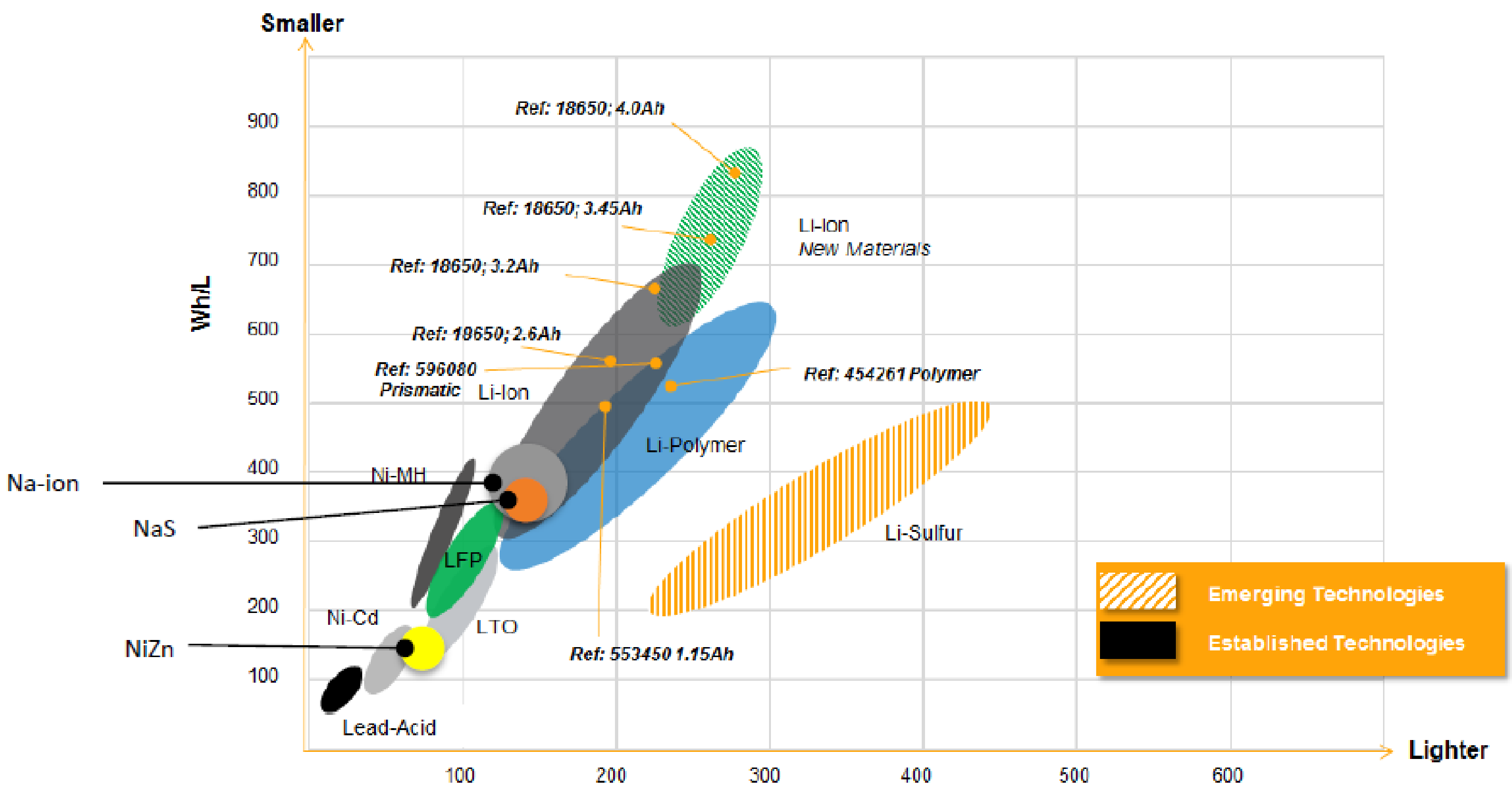


Metallic Li-Li bond, highest capacity

Large 2D volume expansion

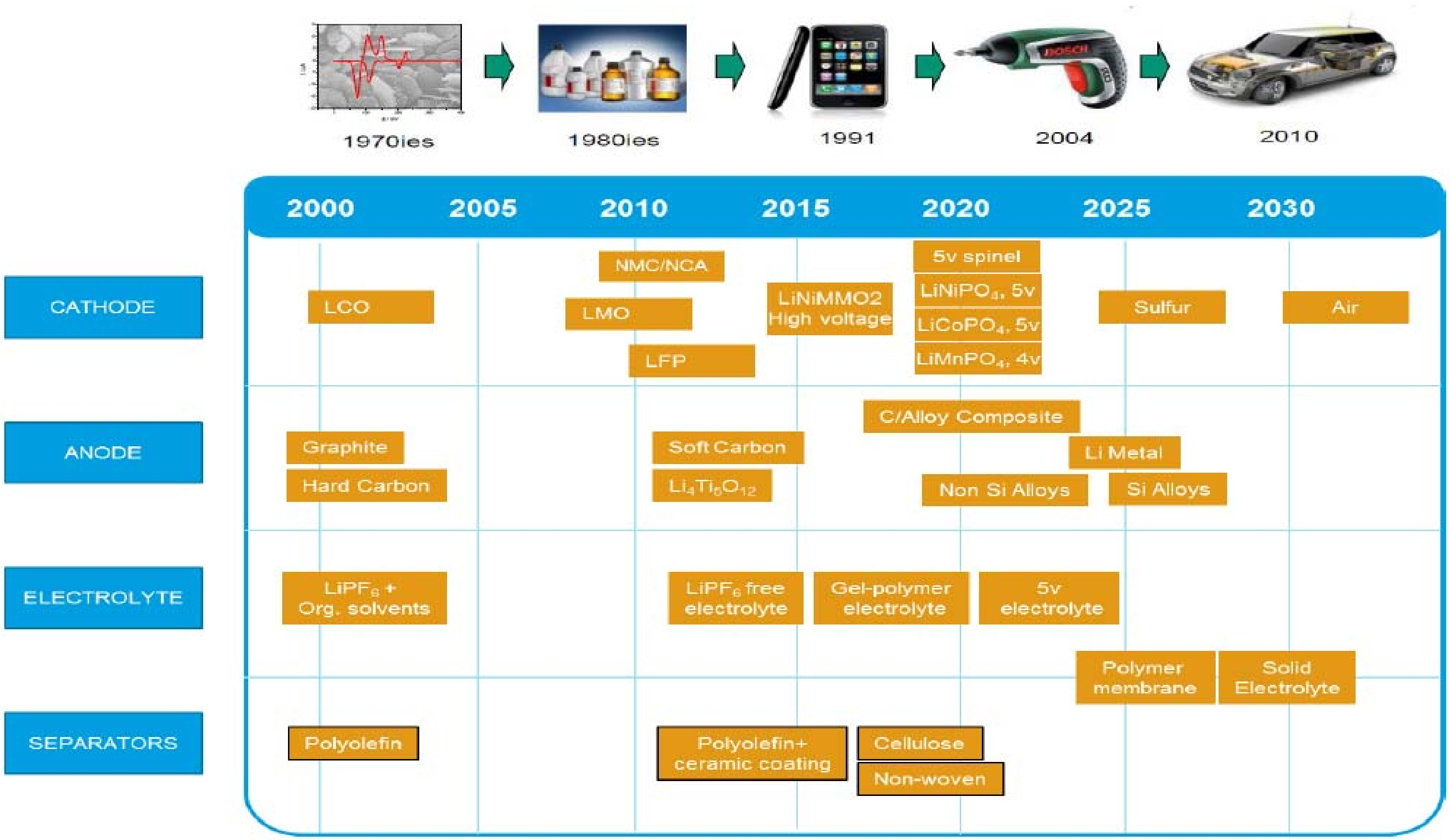
Next Gen Storage Technologies

2017-2025 Available Battery Technologies



Source: AVICENNE Analysis 2018, Inventus Power

Time to Market for New LiB Materials



Source: AVICENNE ENERGY 2016 68

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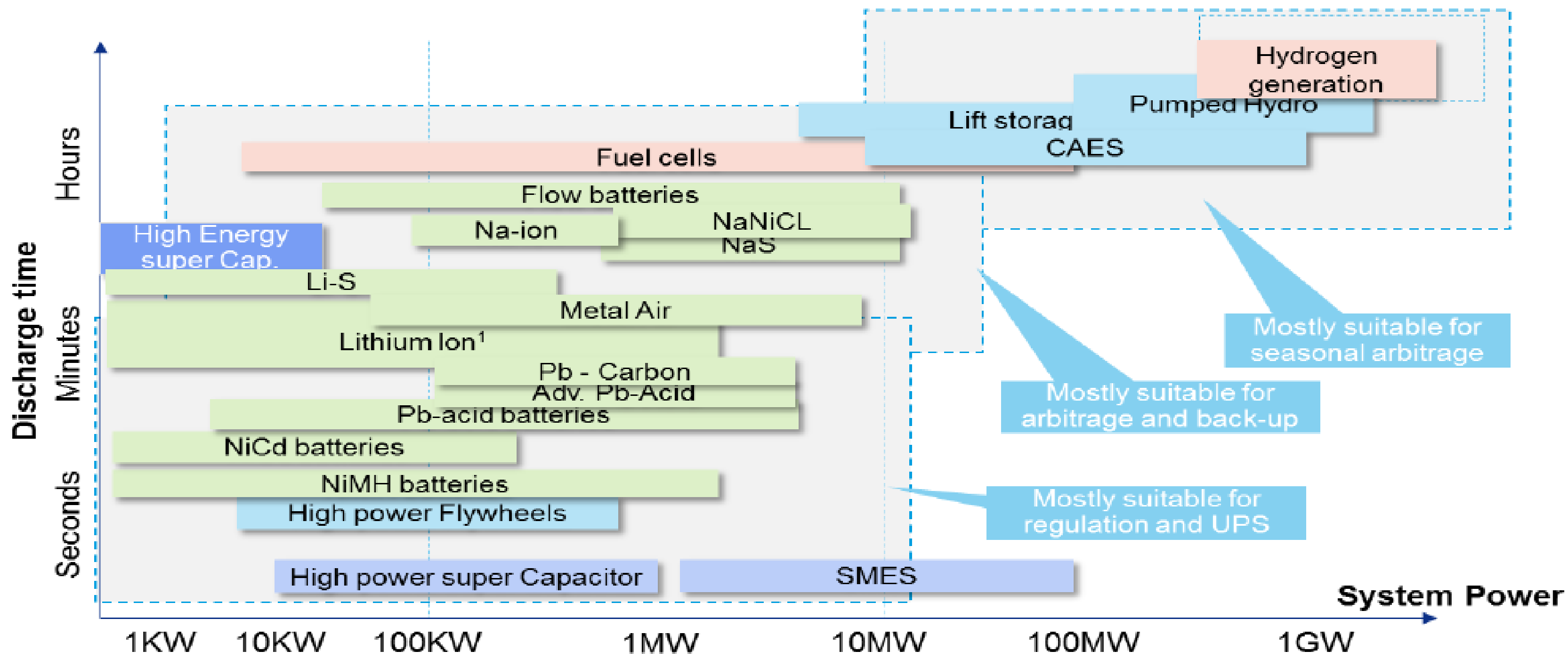
Energy Storage Solutions

System power and discharge time of energy storage technologies



Source: AVICENNE Energy, 2016

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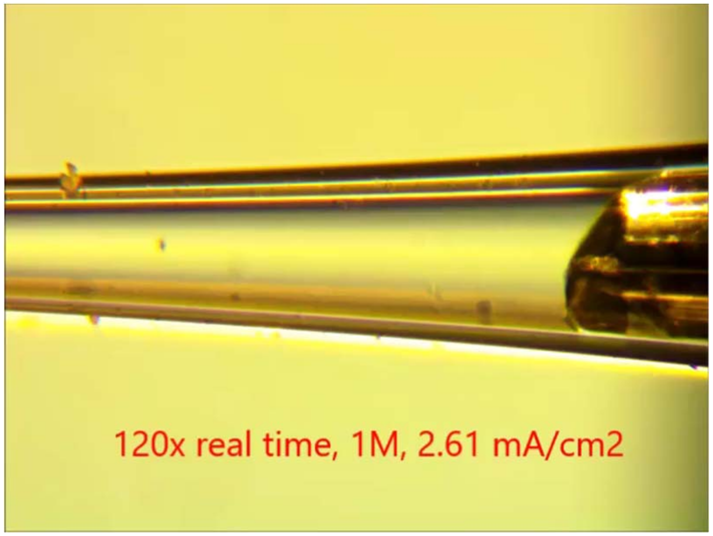
Technical Challenges

Li Dendrite

Ref: Prof. Wittingham, 1980



Ref: Prof. Bazant, 2016

Summary

1. Battery Manufacturing Capacity is Growing Fast

   >$ 90 Bn investment announcements by automakers till 2030 for EV

   Global capacity for energy storage is expected to reach 8.6 GW/ 21.6 GWh by 2022, enough to power to electrify roughly 6 million homes

2. Lithium-ion is Becoming the Technology of Choice for Solar-based ESS

   The prices for Lithium-based batteries are steadily declining by 8% on an annual basis (the average price of batteries has dropped 80% since 2010), making solar + storage projects more investment-friendly.

3. Asia is On Track to Become the World Leader in ESS

   Alternate energy storage technologies available including fuel cell technologies

4. Utilities are Primed to Partner With / Acquire ESS Companies

   There were four Energy Storage M&A transactions in Q2 2018.

5. Government Incentives for Energy Storage are Driving Growth

   At the federal level, the 30% Investment Tax Credit remains available for energy storage, provided it is coupled with renewable generation

6. Energy Storage-as-a-Service (ESaaS) is Becoming a Key Service Model

7. Residential ESS Growth is Outstripping Utility-scale

   Residential installations of battery storage beat commercial installations in Q1 of 2018, 15.9 MW to 11.7 MW (almost beat utility-scale installations at 16 MW)

8. Levelized Cost of Storage (LCOS) is Emerging as a Popular Revenue Metric

   Cost of storing electricity in ESS and divides by the retail price of electricity stored. LCOS has only been in existence for the last 3 years, and this new metric will continue to evolve and provide a standard metric of providing better insights to the financiers

9. Ethical Sourcing is Increasingly Critical for Battery Materials

10. Recycling of battery and materials is critical for sustainability

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make possible