The Future of (Electrochemical) Energy Storage

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1. There is still a need for a better battery
2. Batteries evolve slowly… at 6% increase in energy density a year
3. We need to discover new materials and manufacturing them at scale
4. Need to connect research and manufacturing to accelerate innovation

Quick introduction

Batteries Materials Research (BMR) Program

Next-generation materials for batteries

Joint Center for Energy Storage Research (JCESR) (Battery "Hub")

Revolutionary new storage concepts

CalCharge

Public-private partnership focussed on storage

The history of battery research and manufacturing

★ Battery Research ★ Battery Manufacturing

But times are changing

Disruption has already occurred in the consumer electronics industry

Its happening in electric cars

Instead of this…

We have…

And it will happen on the grid

ENERGY 11/05/2014 @ 4:56PM | 1,996 views

Storage Industry Celebrates Big Win In California

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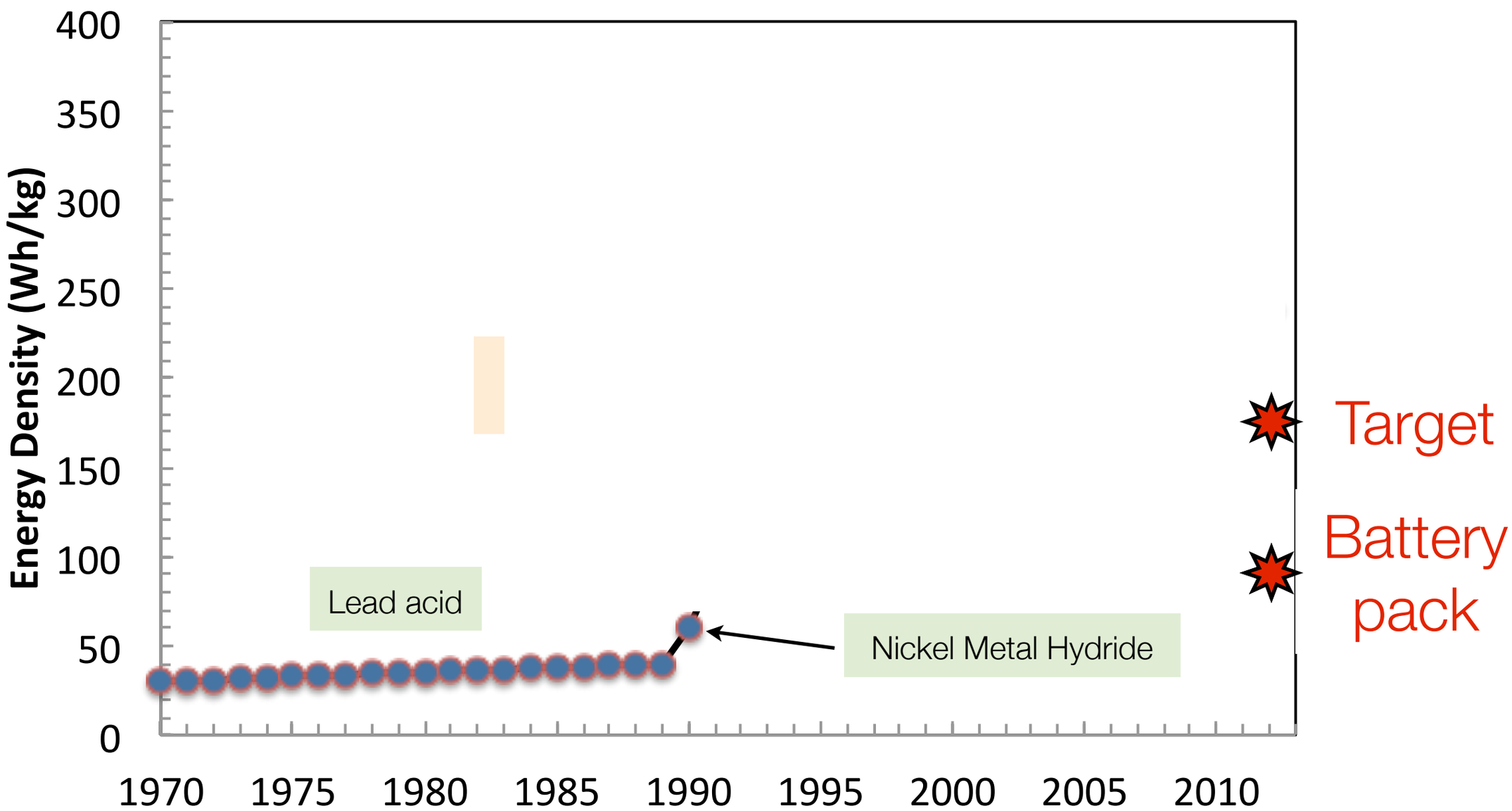
Something rather significant just happened in the energy storage industry: Southern California Edison (SCE) just announced the largest grid-connected storage purchase in the history of the United States. This commitment to purchase 261 MW of storage capability is five times greater than what the utility was required to do under the California Public Utilities mandate.

The companies chosen to provide storage are as follows:

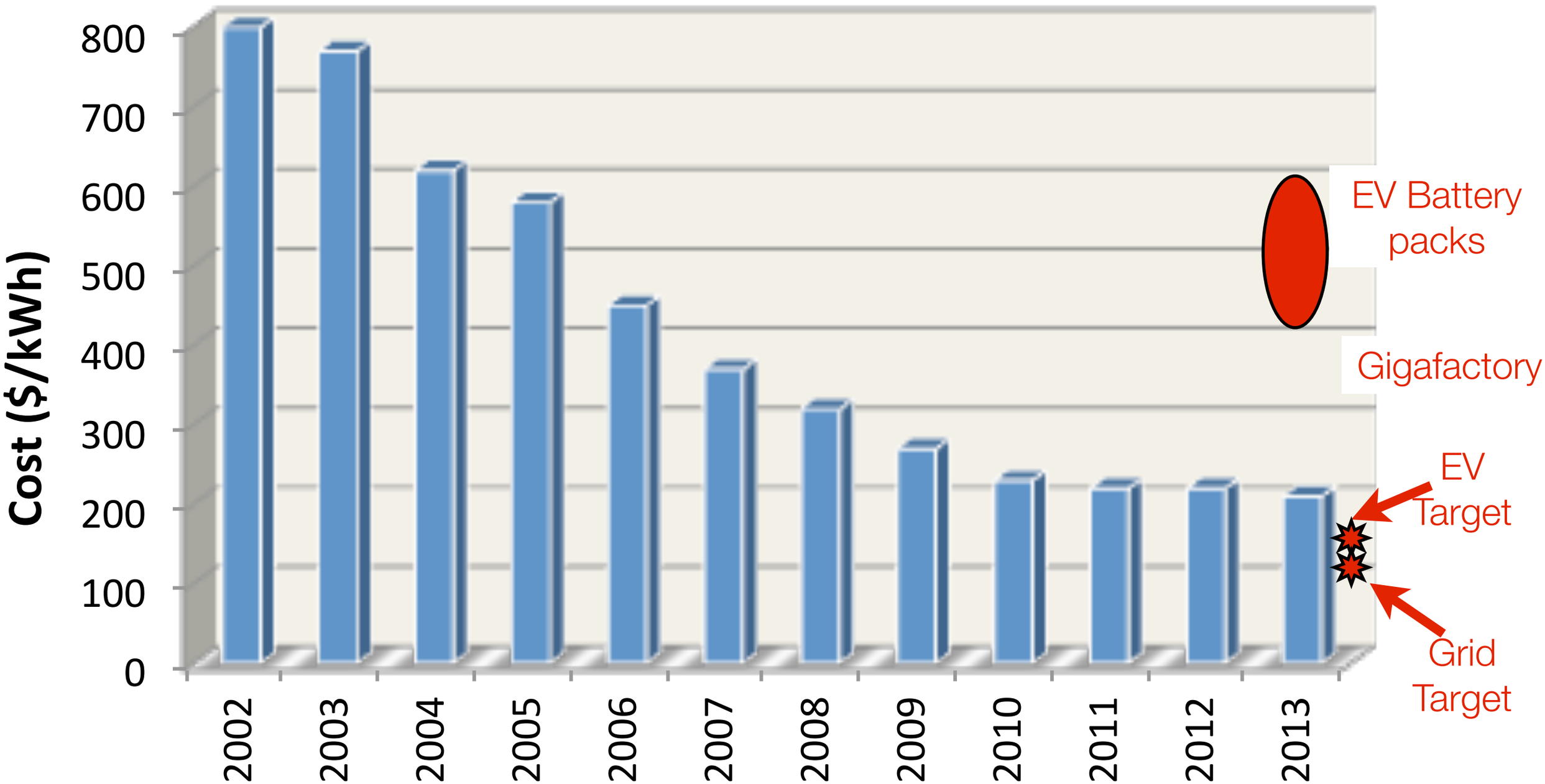
- NRG Energy NRG -0.03% 0.5 MW
- Ice Energy Holdings, Inc. 25.6 MW
- Advanced Microgrid Solutions 50.0 MW
- Stem 85.0 MW
- AES Energy Storage 100.0 MW

Moore's law for batteries



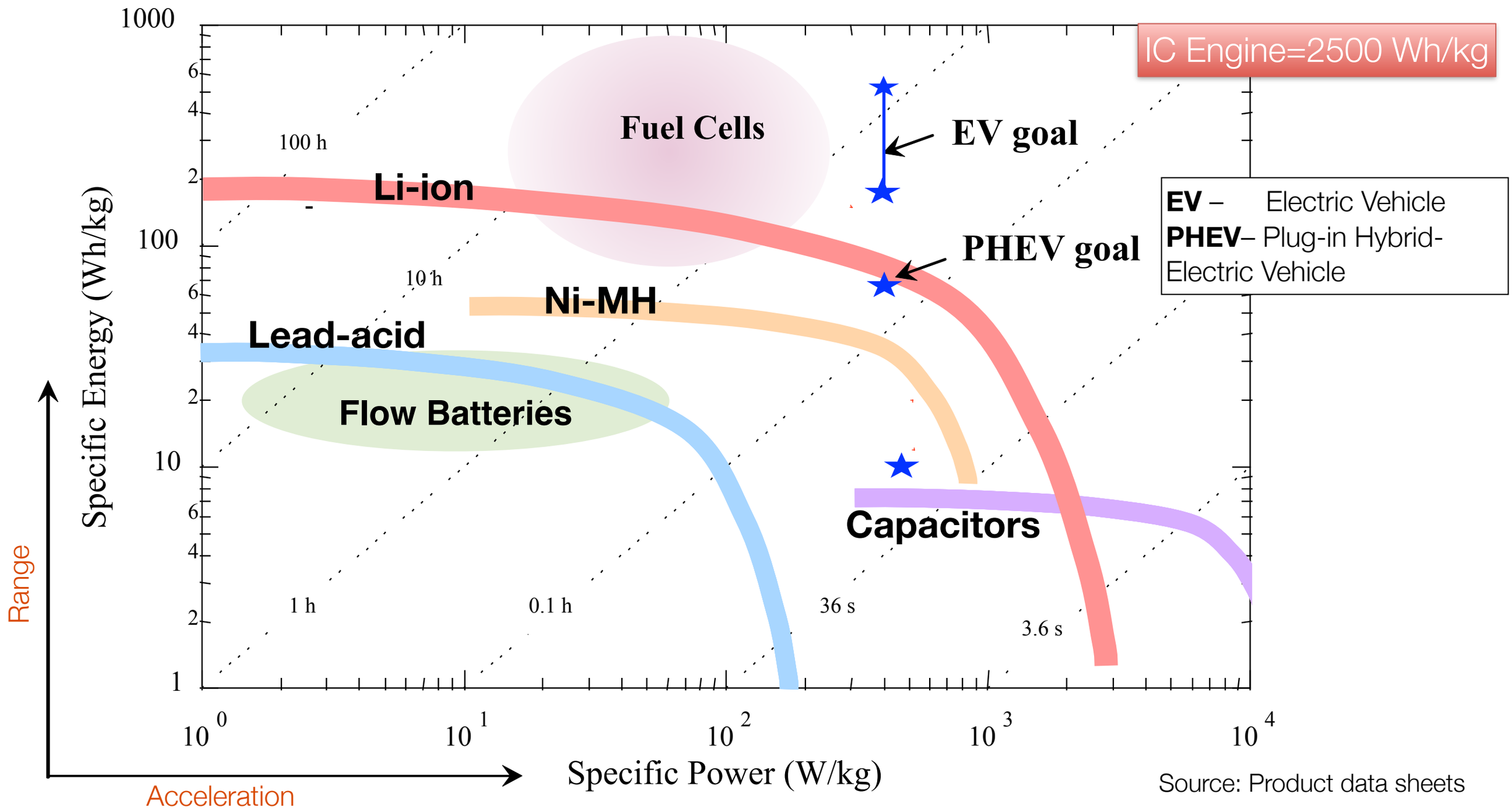
2-5x improvement in energy density needed to achieve <u>range parity</u> with gasoline cars

...and cost remains very high



Batteries at $100-$125/kWh will be the tipping point.

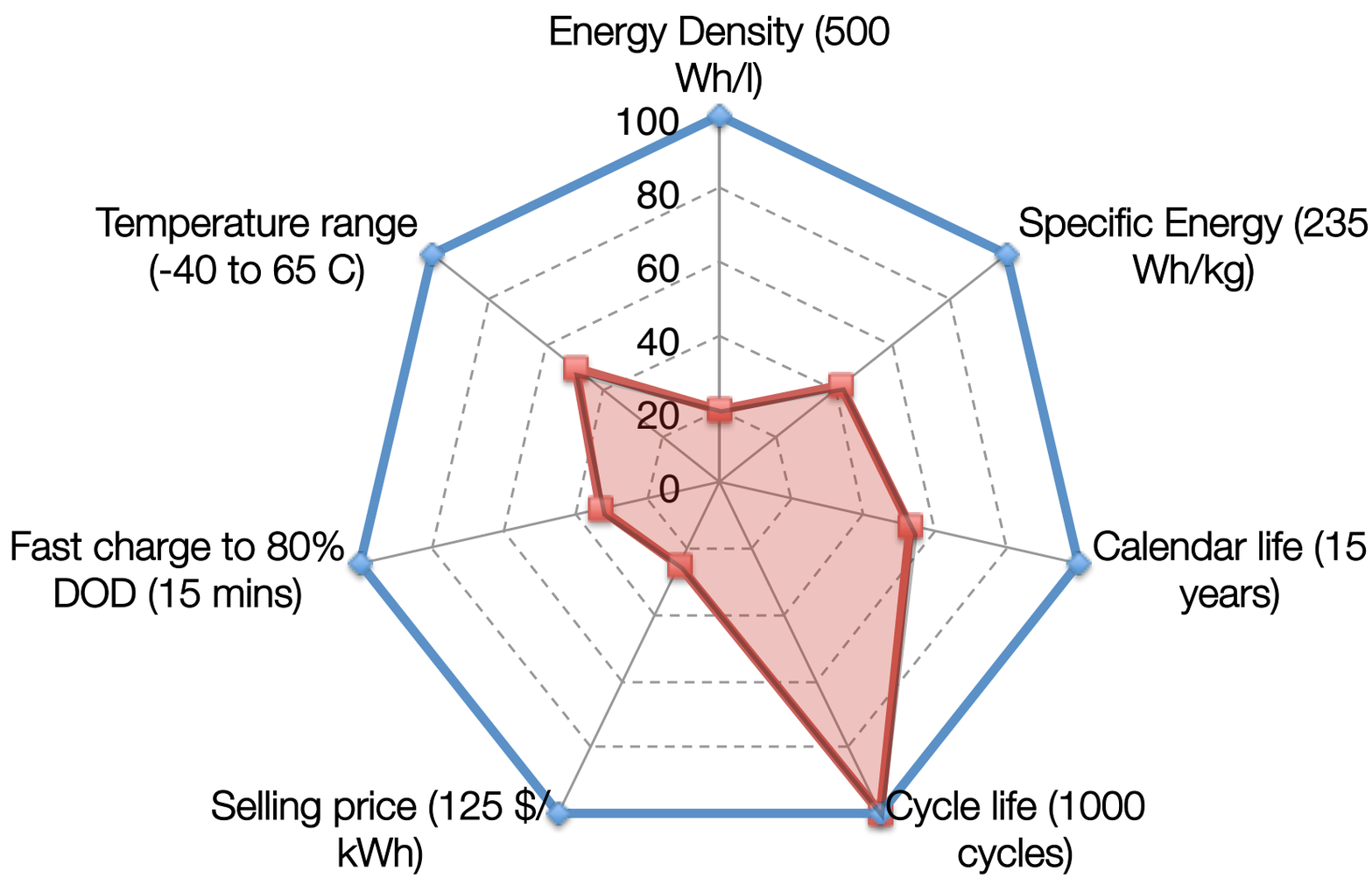
Status of batteries for vehicle applications



Source: Product data sheets

But its not just about energy and power density

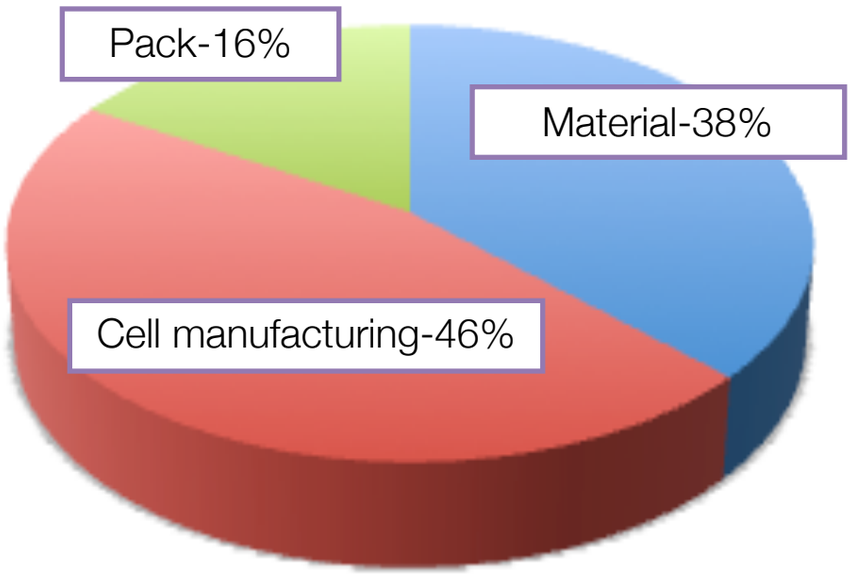
But its more than just energy and cost

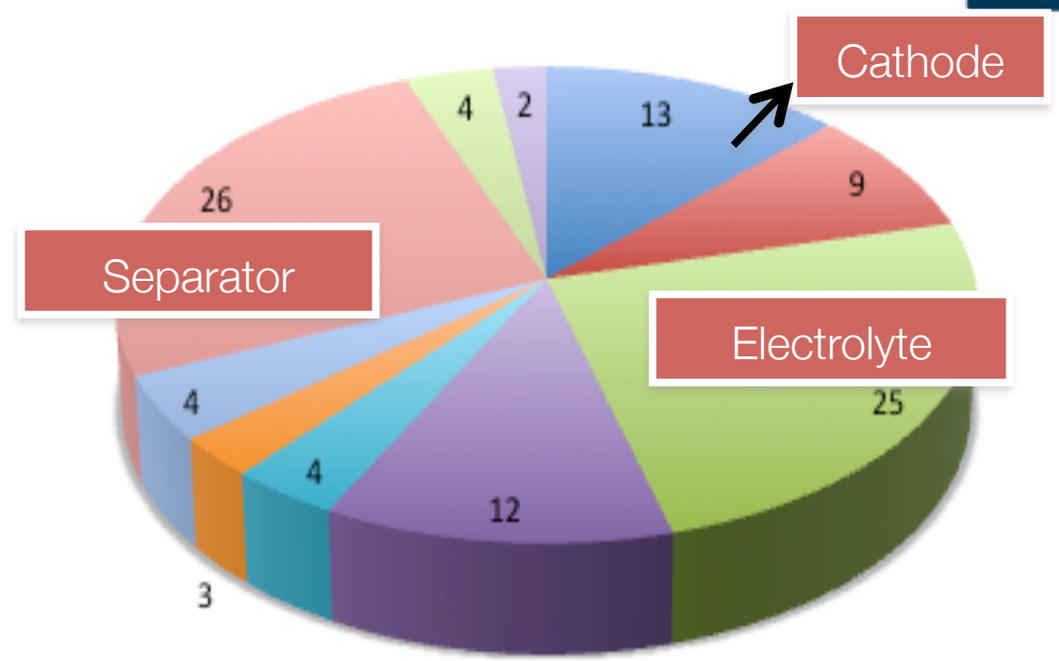


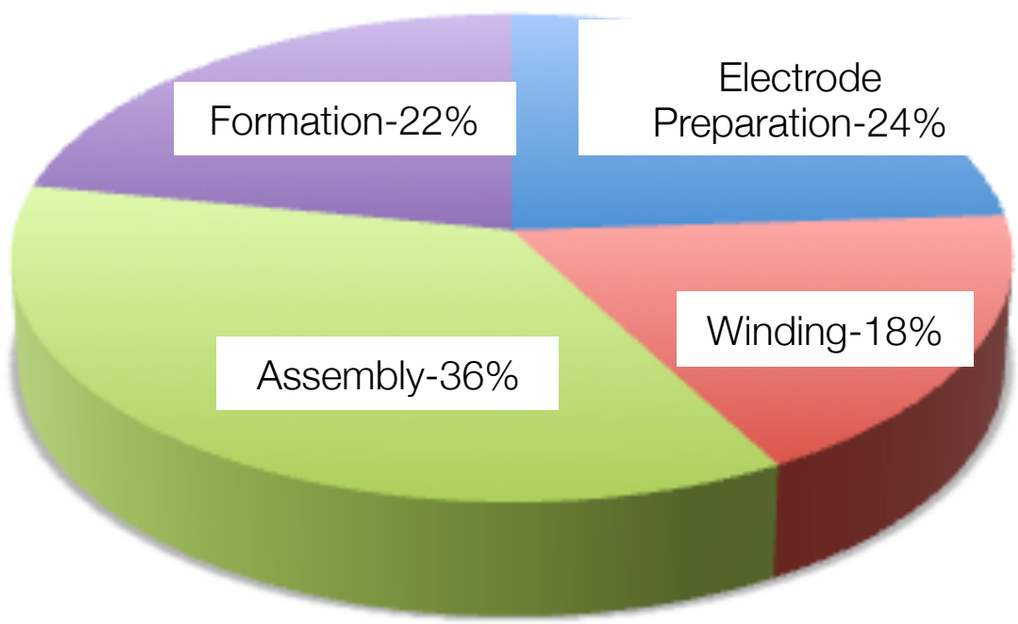
Li-ion in electric vehicles

Batteries are a compromise between these various requirements

Where is the cost in a Li-ion battery?

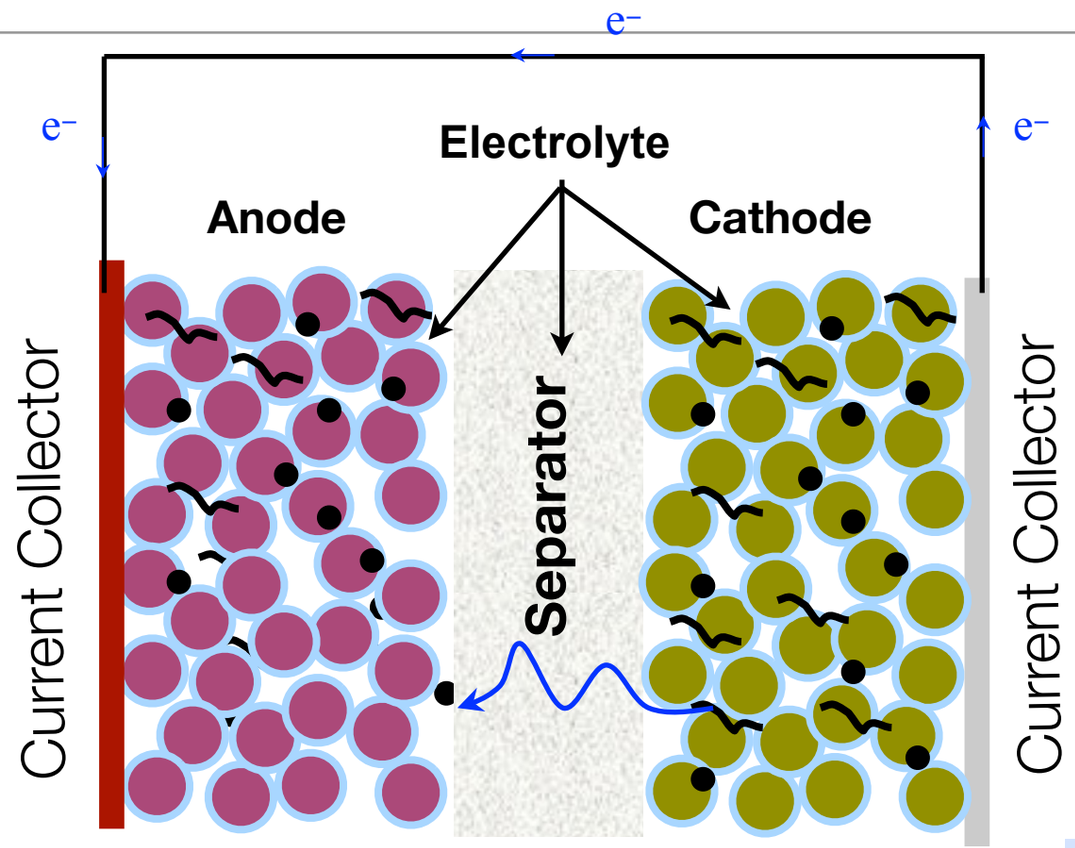






Need to focus on materials and on manufacturing

Battery 101- How do we make a better battery?



Anode:
- Lead sulfate
- Cadmium
- Metal Hydride

Electrolyte:
- Sulfuric acid
- Potassium hydroxide
- Potassium hydroxide

Cathode:
- Lead oxide
- Nickel Hydroxide
- Nickel Hydroxide

Anode:
- Carbon-based
- Alloys and intermetallics
- Oxides

Electrolyte:
- Liquid organic solvents
- Polymers
- Gels

Cathode:
- Layered oxides
- Spinel-based compositions
- Olivine-based compositions

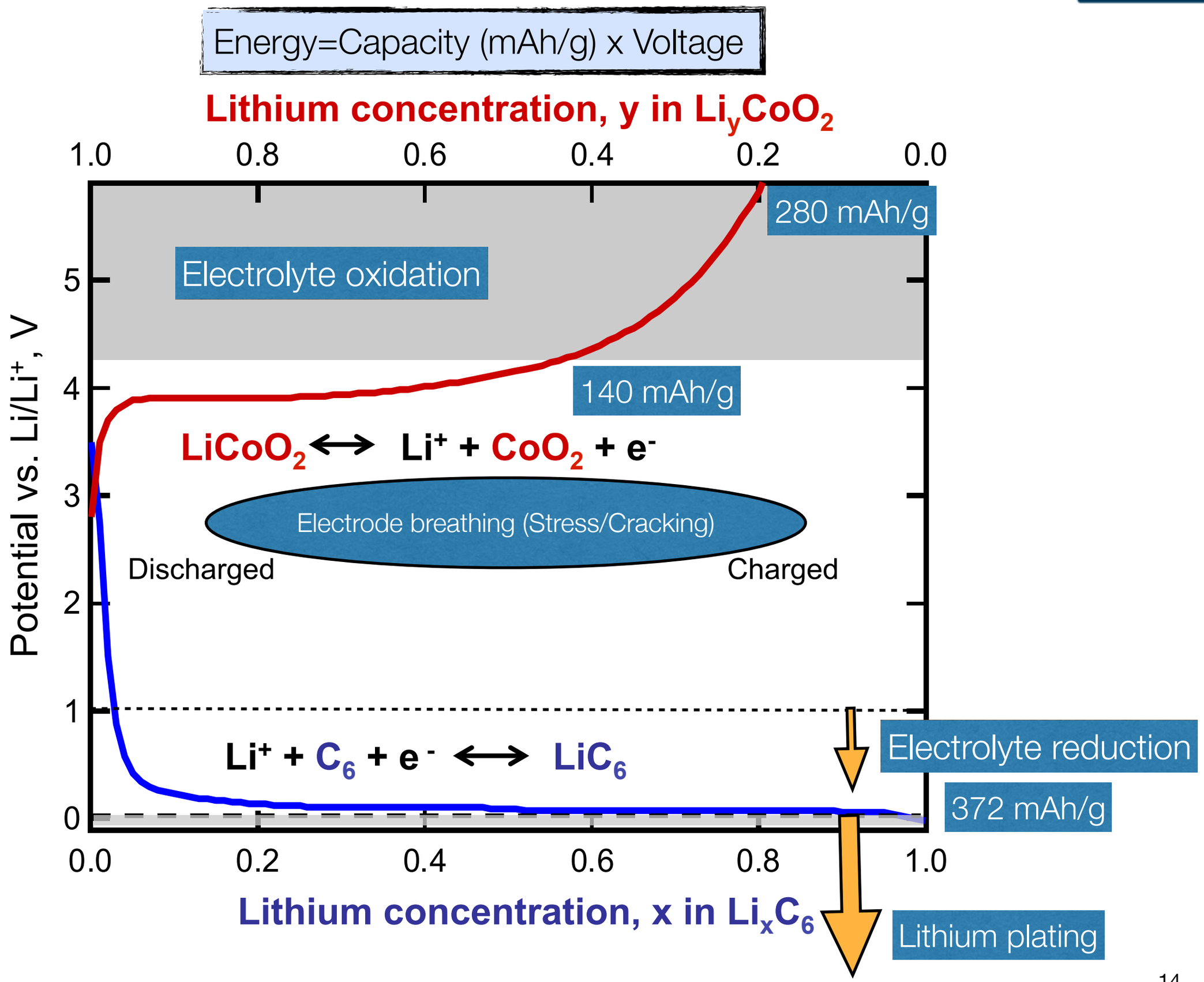
Cost can be lowered by: lower cost materials, higher energy materials/cells (lower $/kWh), and/or cheaper manufacturing

Summary

- Li-ion batteries will get cheaper as the Gigafactory ramps up.
- But, to reach a tipping point, a further 2-3x reduction in cost is needed.
- Complicated due to the many different metrics over which batteries have to be optimized.

We need innovations to ensure we hit the tipping point.
Some of these innovations will be in materials.
But we also need innovations in manufacturing.

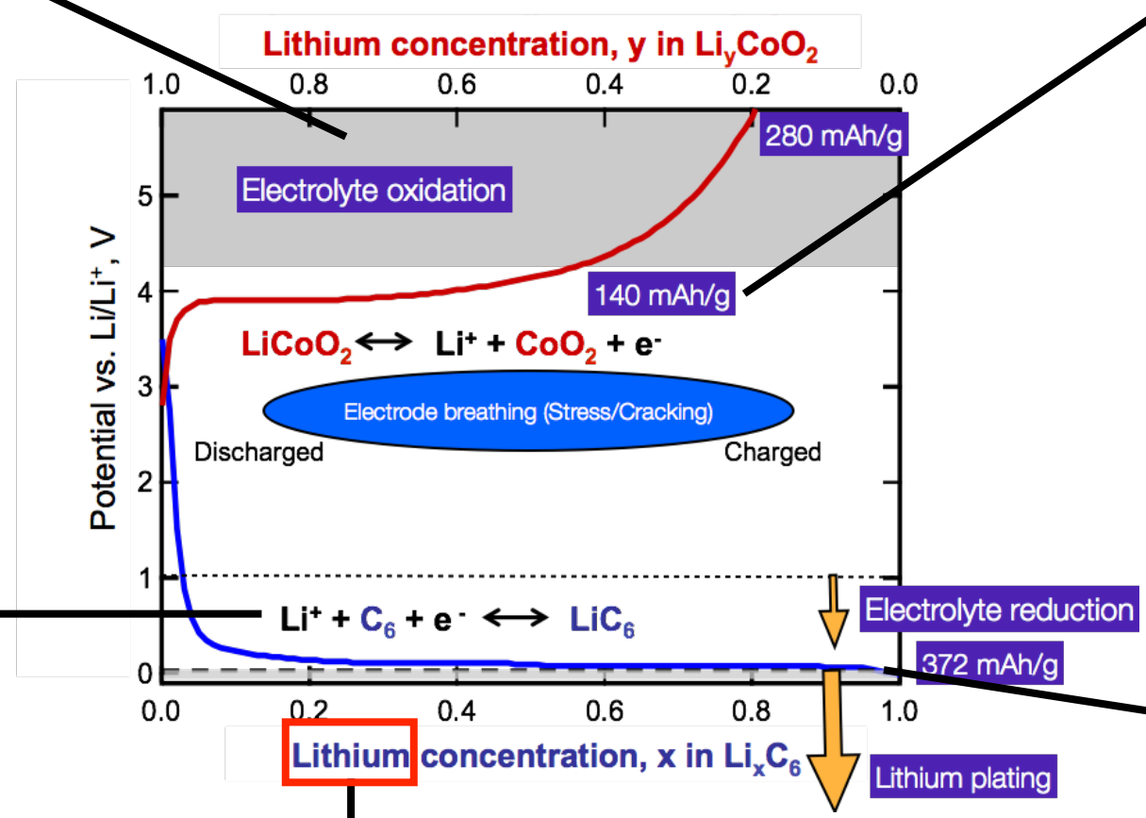
Finding new materials: The principle



Finding new materials: Focus areas

Enable high voltage cathodes (>4.3 V)

Sulfur cathodes: 1675 mAh/g vs. 140-180 mAh/g



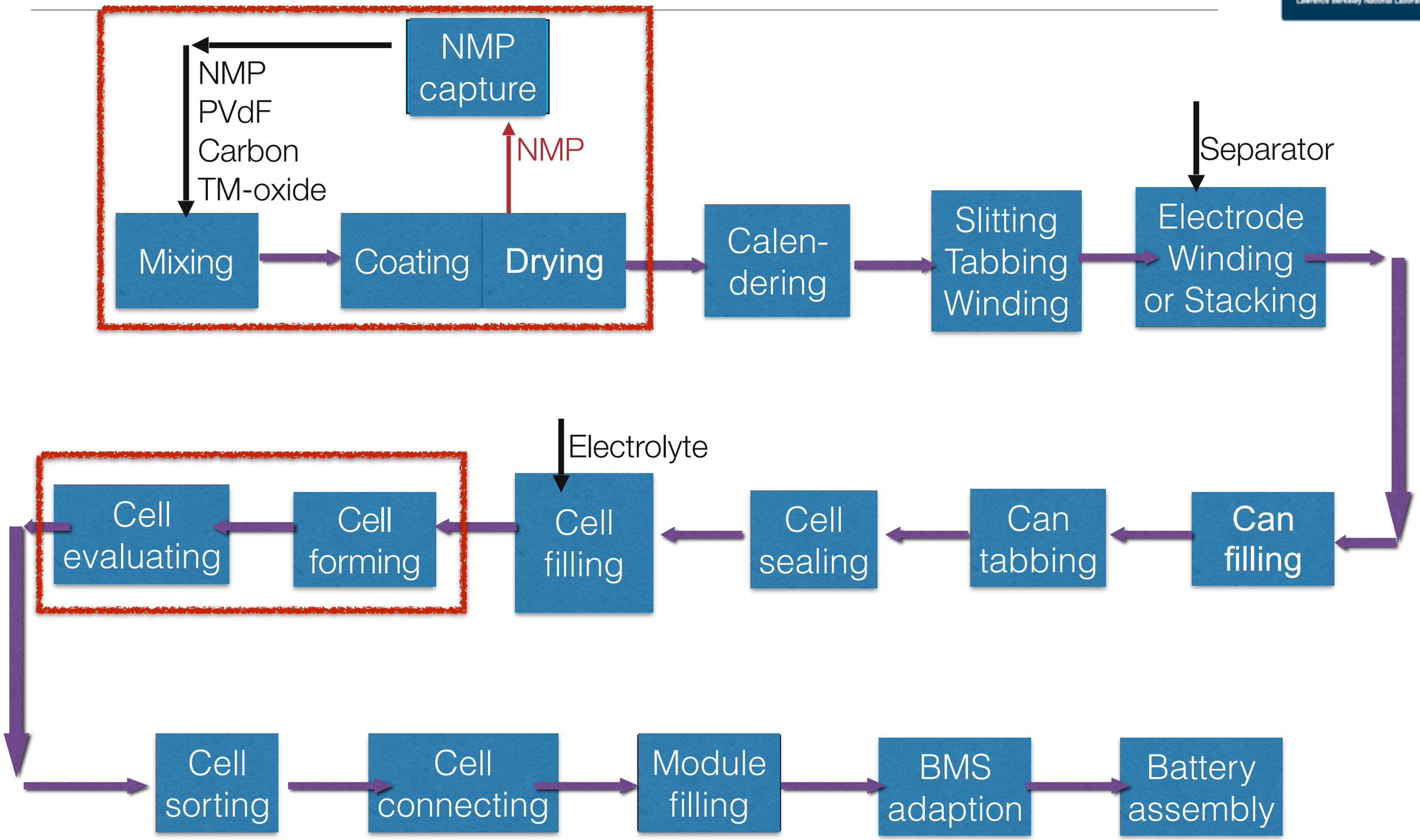
Silicon and tin anodes: 3-10x capacity vs. graphite

Lithium metal anode: 10x capacity vs. graphite at lower potential

Magnesium/Calcium-ion batteries: 2-3x capacity of lithium

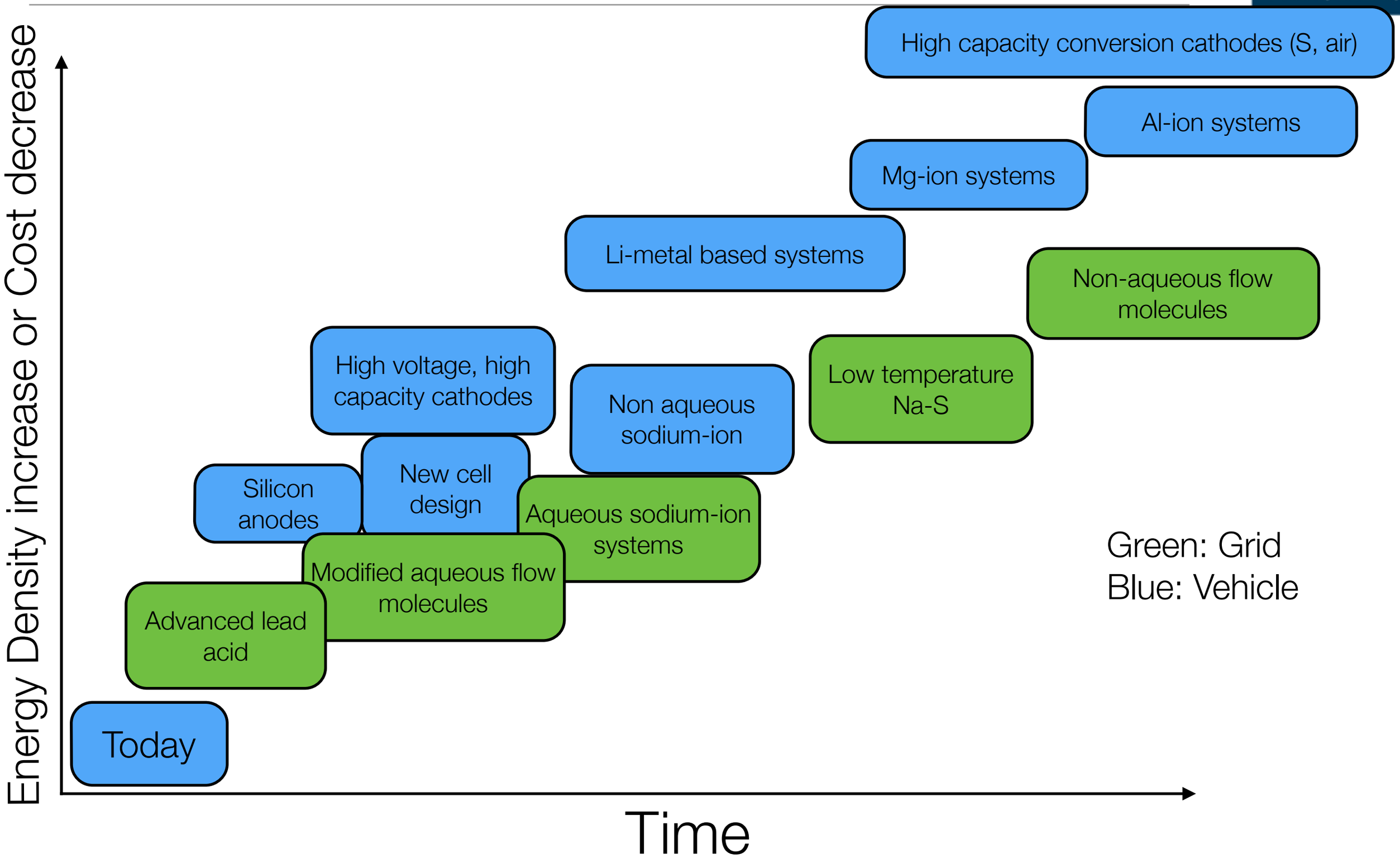
Each approach promises to increase energy/decrease cost

From materials to a battery



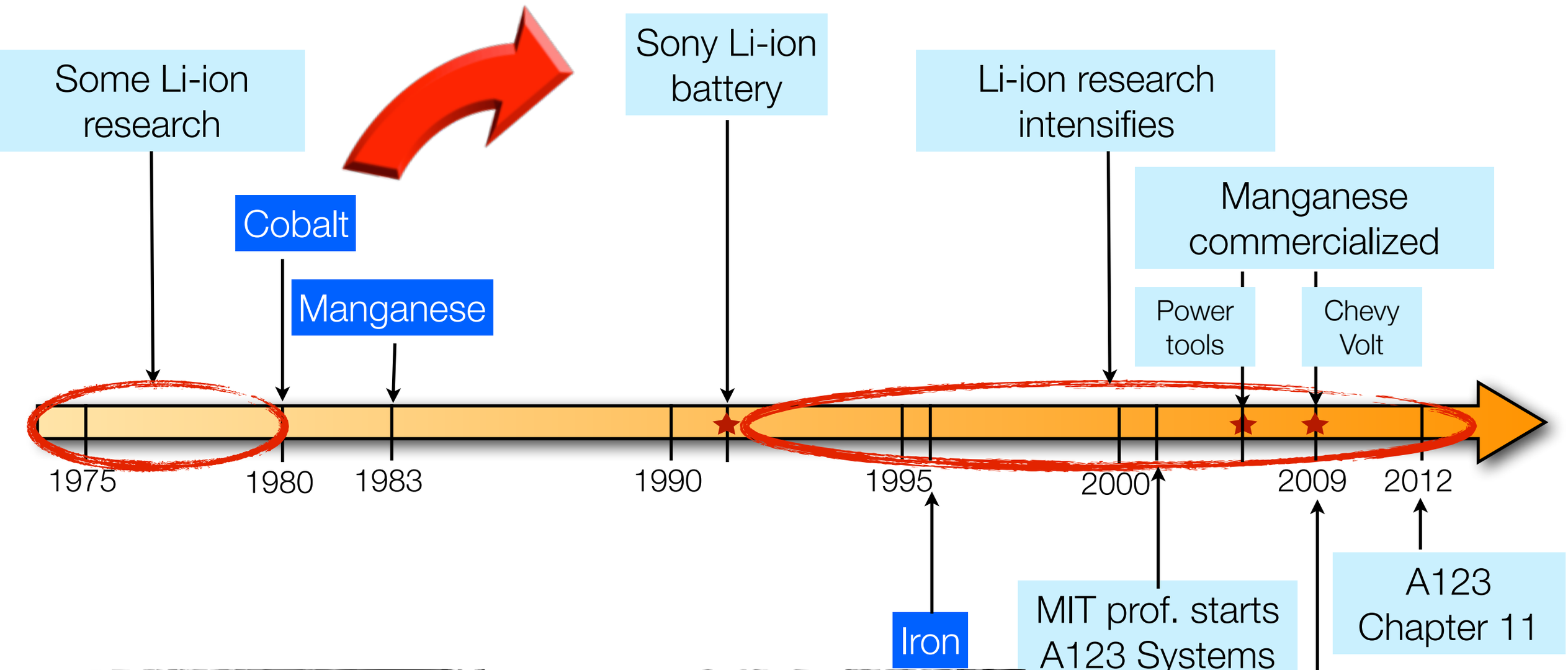
Eliminating process steps and new processing methods can lead to lower cost batteries

There are now numerous attempts to innovate in the lab



But when will these reach the market?

The Challenge of Translation from Lab to Market



1. Lab-to-market is slow!
2. Scale up and manufacturing is a challenge
3. Need close connection between R&D and manufacturing to accelerate innovation
4. Need to consider market demand

The history of battery research and manufacturing

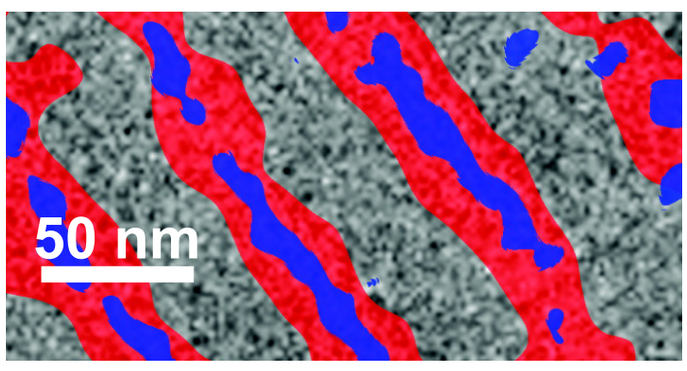
★ Battery Research ★ Battery Manufacturing

When R&D and manufacturing are disconnected, innovation is slow

Collaboration as an accelerator

Secret history of Silicon Valley, Steve Blank

The battery equivalent



Revolutionary new materials and storage concepts

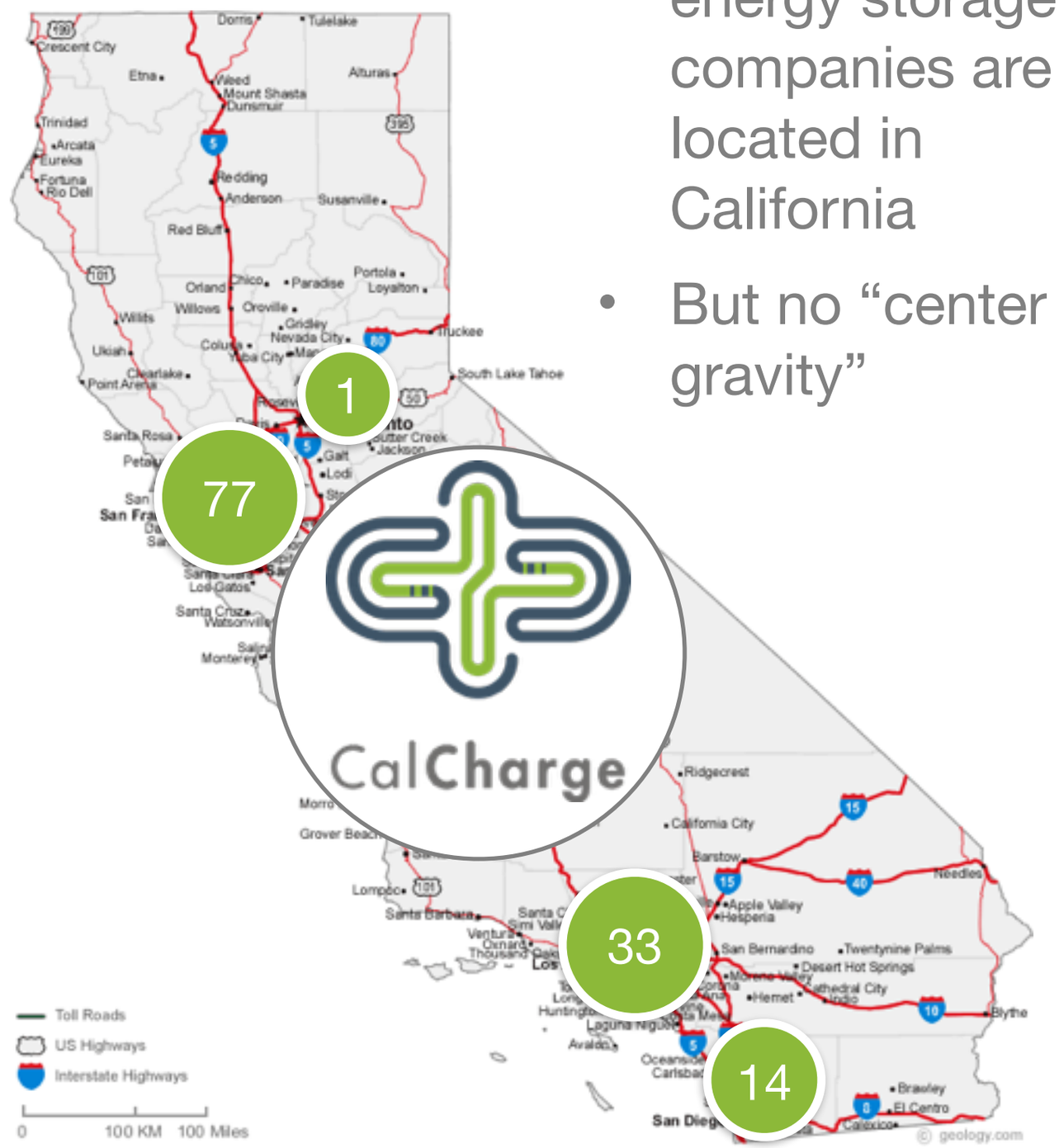
Process and manufacturing R&D

Markets for batteries (Vehicles, grid, vehicle-to-grid, second life)

Innovation will occur by co-locating R&D, manufacturing, and markets

Critical Mass and Global Impact

- California has one the largest and most dynamic concentrations of the energy storage sector in the world
- With an outsized impact on industry and market development globally



- More than 120 energy storage companies are located in California
- But no “center of gravity”

Program Areas

Accelerating from innovation to installation

Technology Acceleration

- Companies conduct propriety research inside Berkeley Lab

Pre-Commercialization Support

- Advanced Manufacturing Roadmap

Professional Development

- First MSE in Batteries with SJSU

Ecosystem Facilitation

- IBEW-NECA Energy Storage Standard and Certification Development

The history of battery research and manufacturing

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When R&D and manufacturing are disconnected, innovation is slow

The problem: A lesson from the PV industry

- Building the same technology that is already in Asia not compelling

ANALYSIS

View Article Online
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Assessing the drivers of regional trends in solar photovoltaic manufacturing†

Cite this: DOI: 10.1039/c3ee40701b

Alan C. Goodrich,*[a] Douglas M. Powell,*[b] Ted L. James,[a] Michael Woodhouse[a] and Tonio Buonassisi*[b]

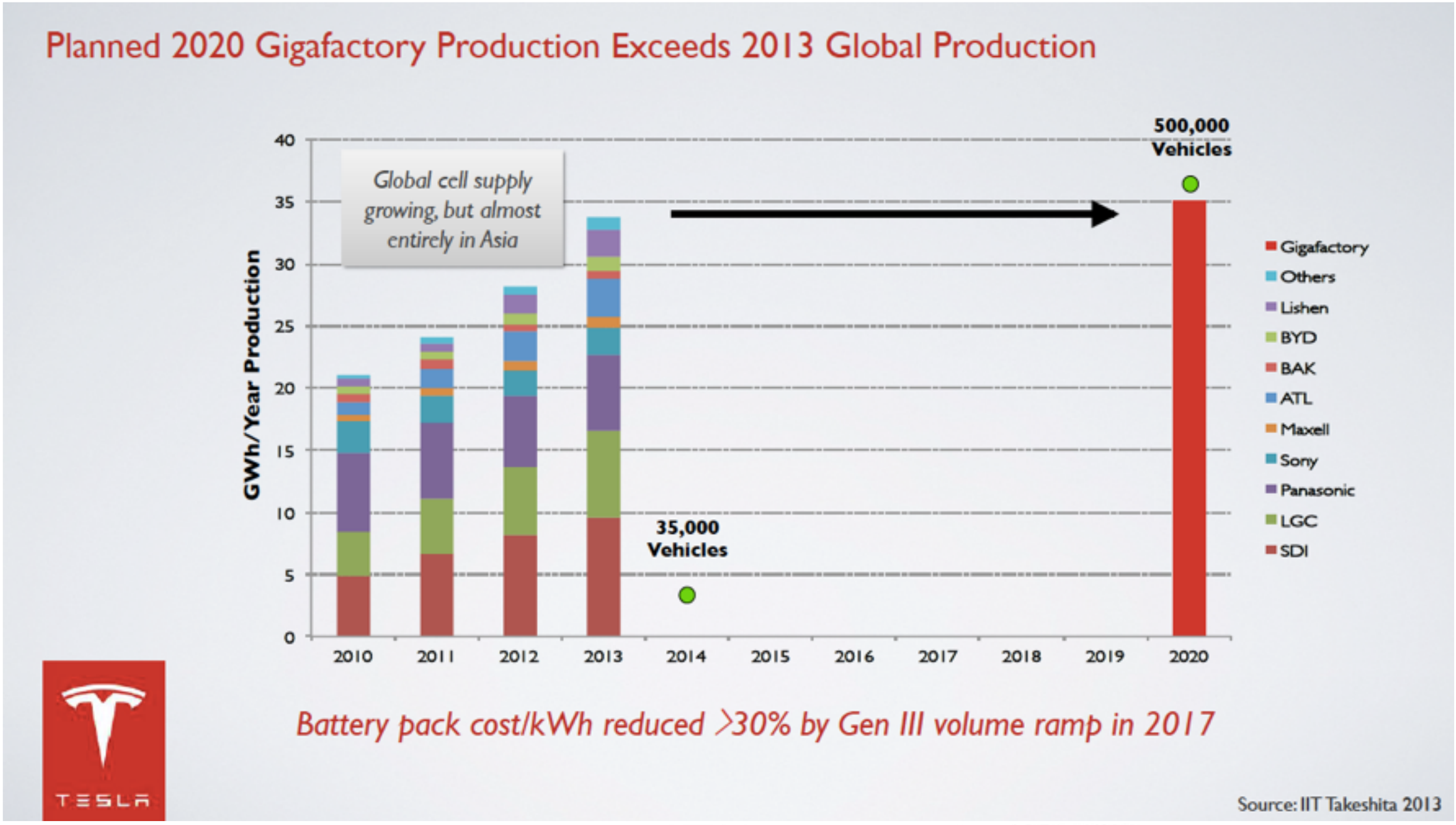
The photovoltaic (PV) industry has grown rapidly as a source of energy and economic activity. Since 2008, the average manufacturer-sale price of PV modules has declined by over a factor of two, coinciding with a significant increase in the scale of manufacturing in China. Using a bottom-up model for wafer-based silicon PV, we examine both historical and future factory-location decisions from the perspective of a

the role of innovative technology in altering regional competitive advantage. We find that the historical price advantage of a China-based factory relative to a U.S.-based factory is not driven by country-specific advantages, but instead by scale and supply-chain development. Looking forward, we calculate that

price advantage of a China-based factory relative to a U.S.-based factory is not driven by country-specific advantages, but instead by scale and supply-chain development. Looking forward, we calculate that technology innovations may result in effectively equivalent minimum sustainable manufacturing prices

How do we solve this challenge?

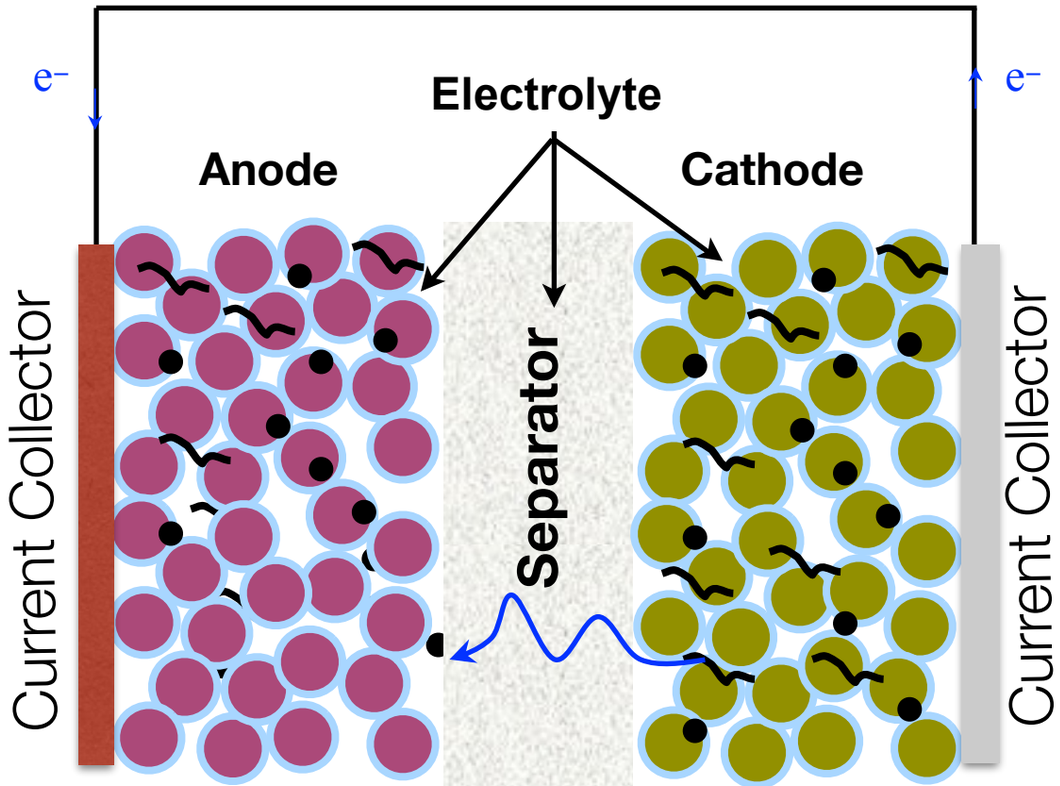
One approach- Rebuilt the supply chain and the scale

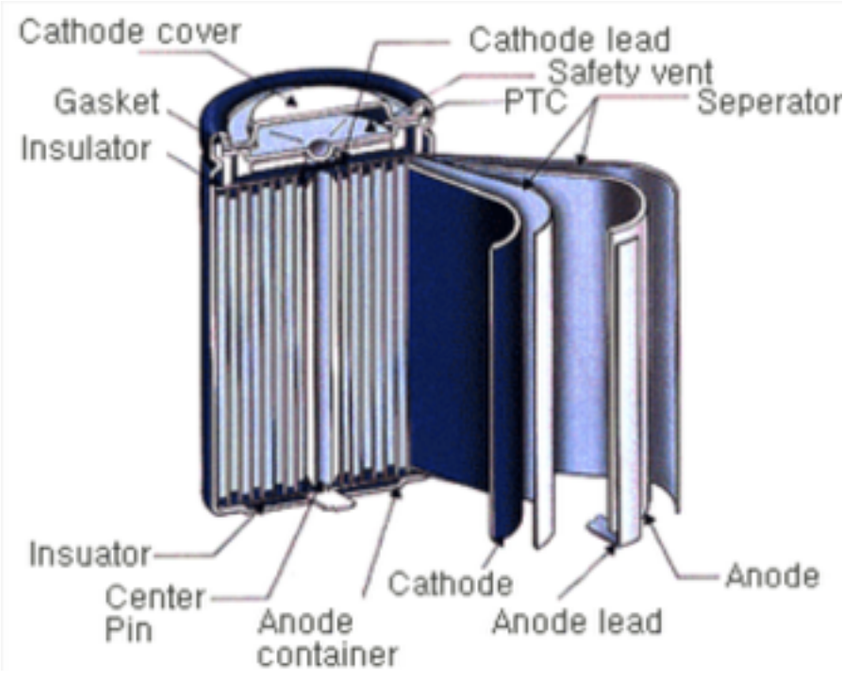


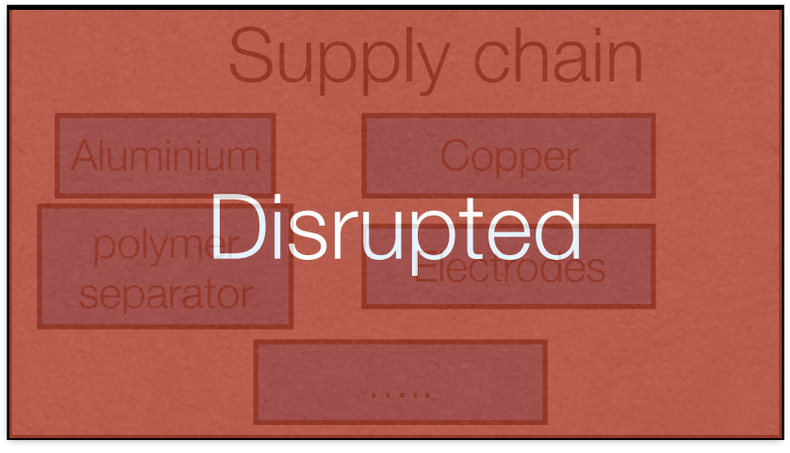
Cost of the factory: $4-5B

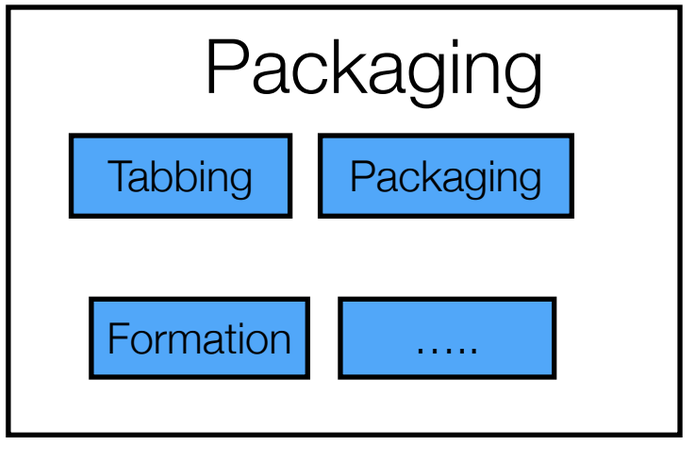
But is this the only way?

An alternate approach



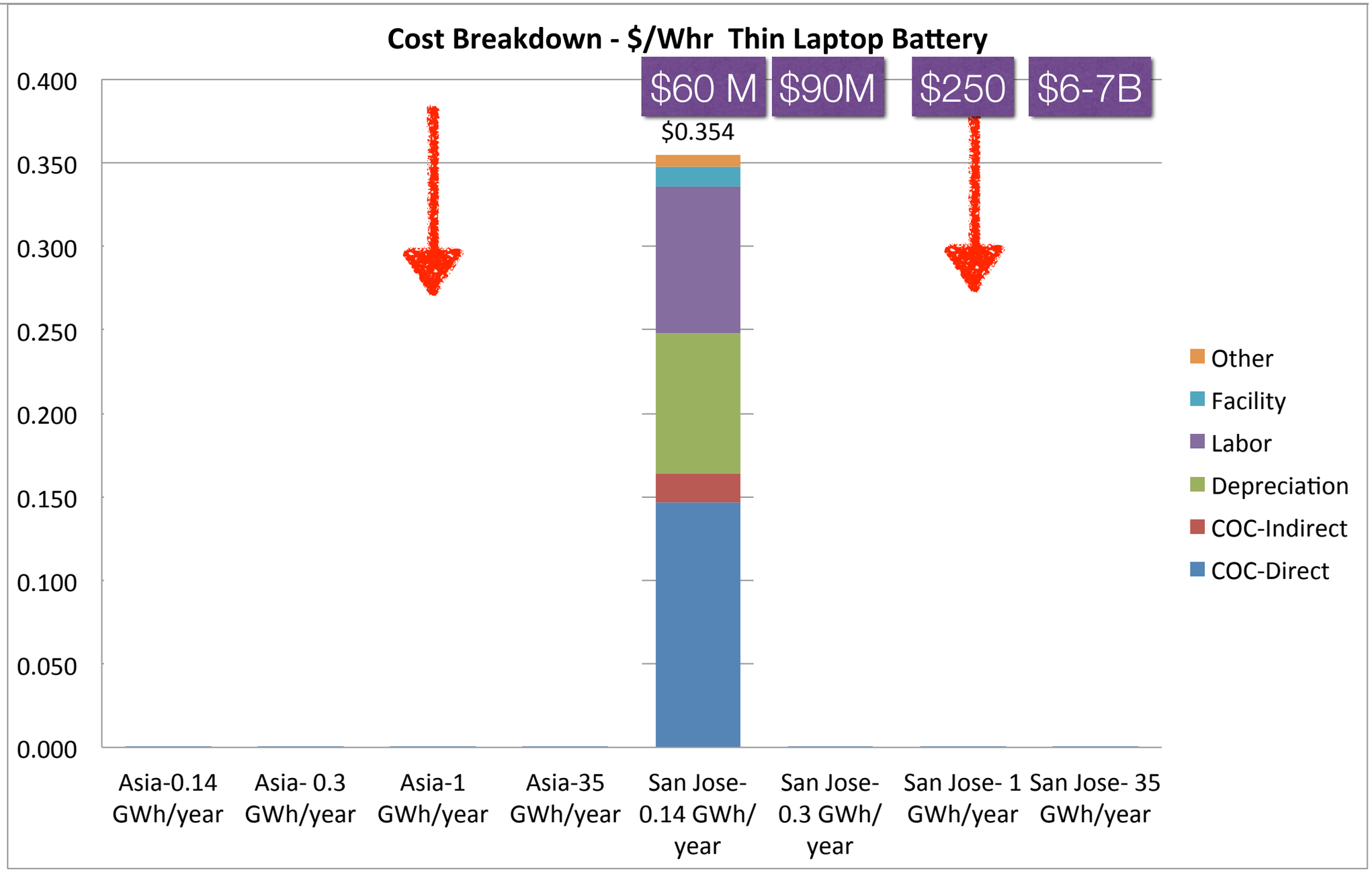






Would this “advanced” battery be amenable to manufacturing in the US?

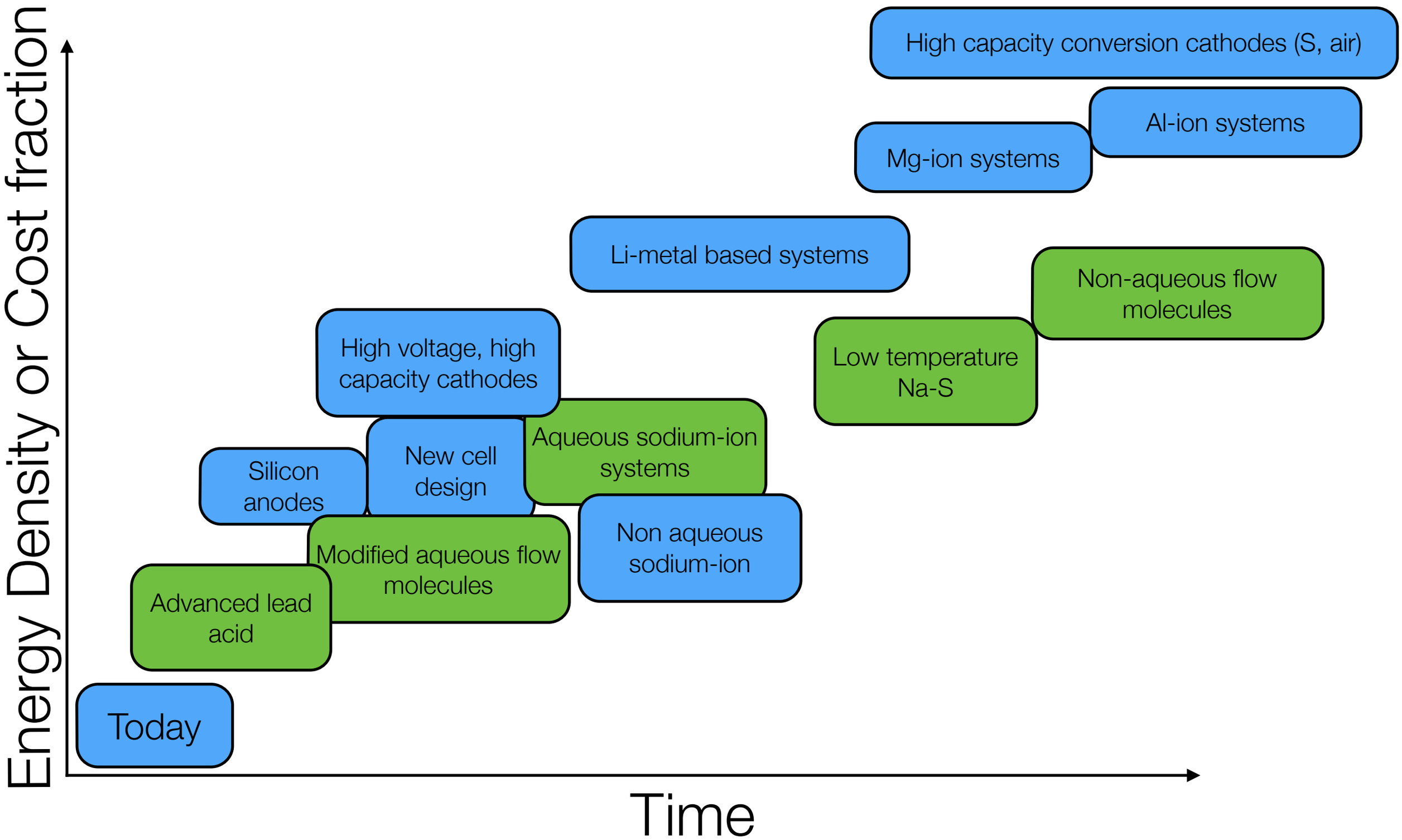
High volume automated manufacturing case



- Cost in CA is 4.7% higher than Asia (1.8% for Gigafactory case)
- The advantage of colocation, ease of continued innovation, IP protection, economic and political climate, and the enhanced performance of the device, would offset the higher cost

Key: Innovation not imitation

Manufacturing competitiveness map



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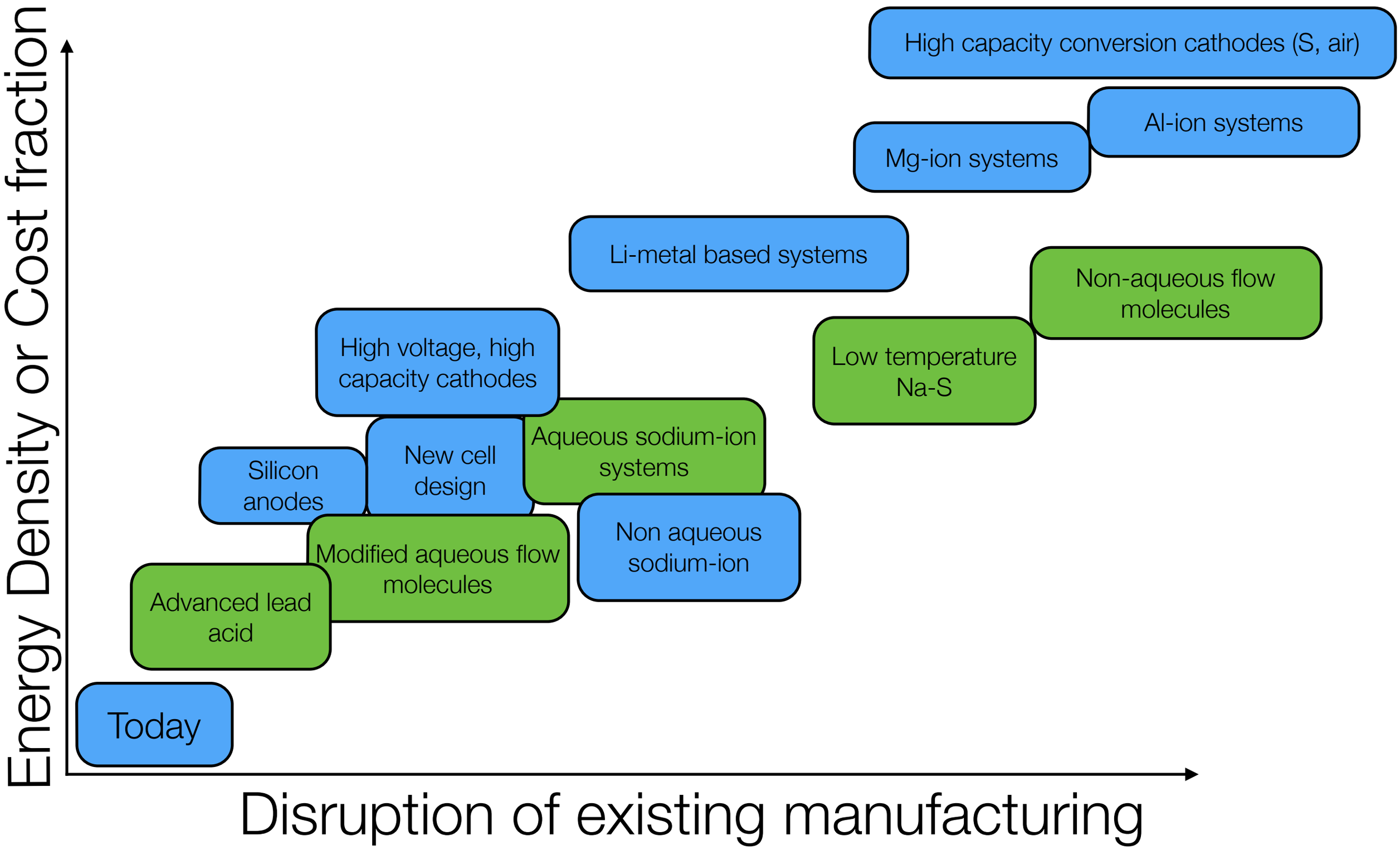

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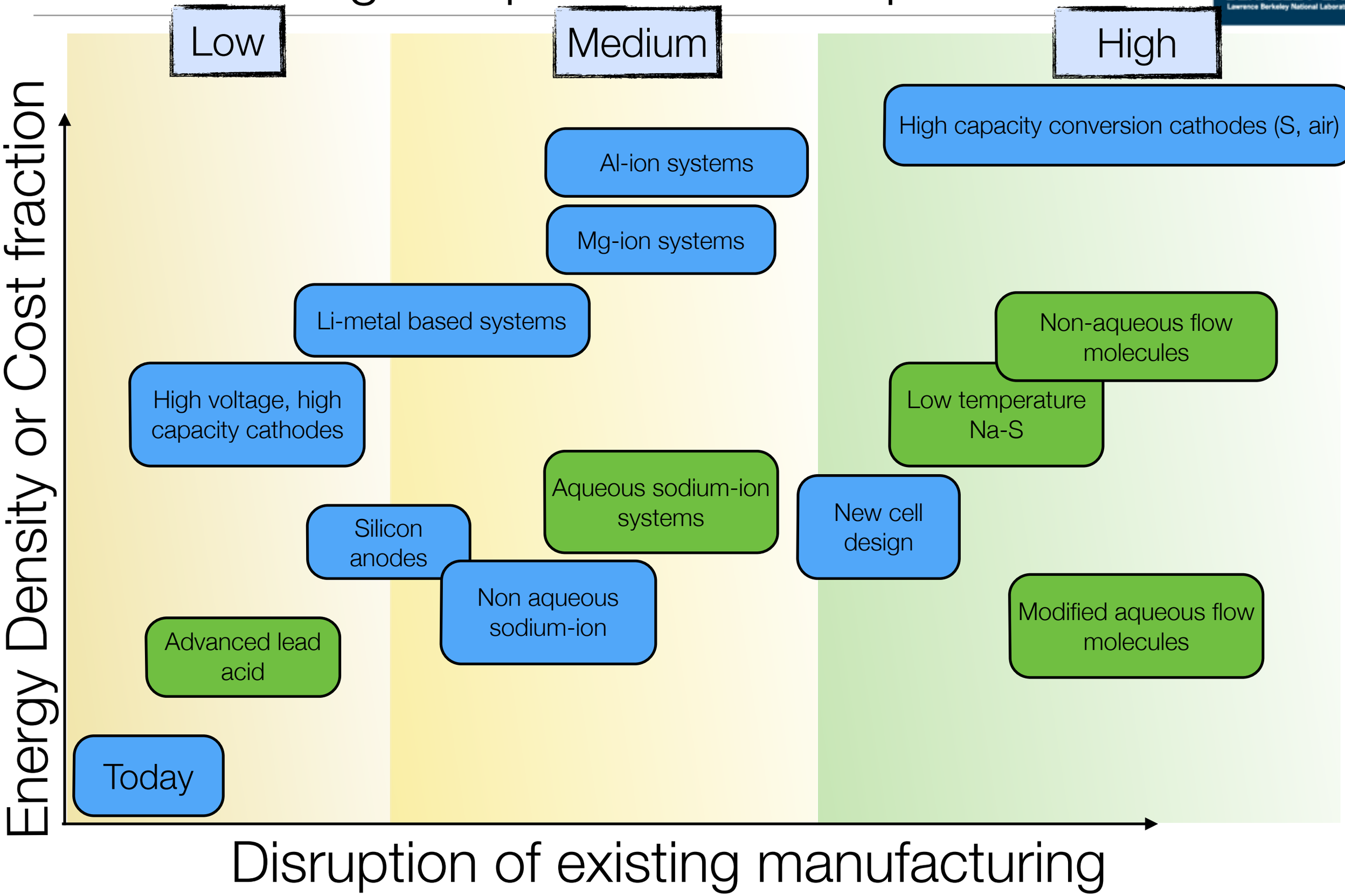

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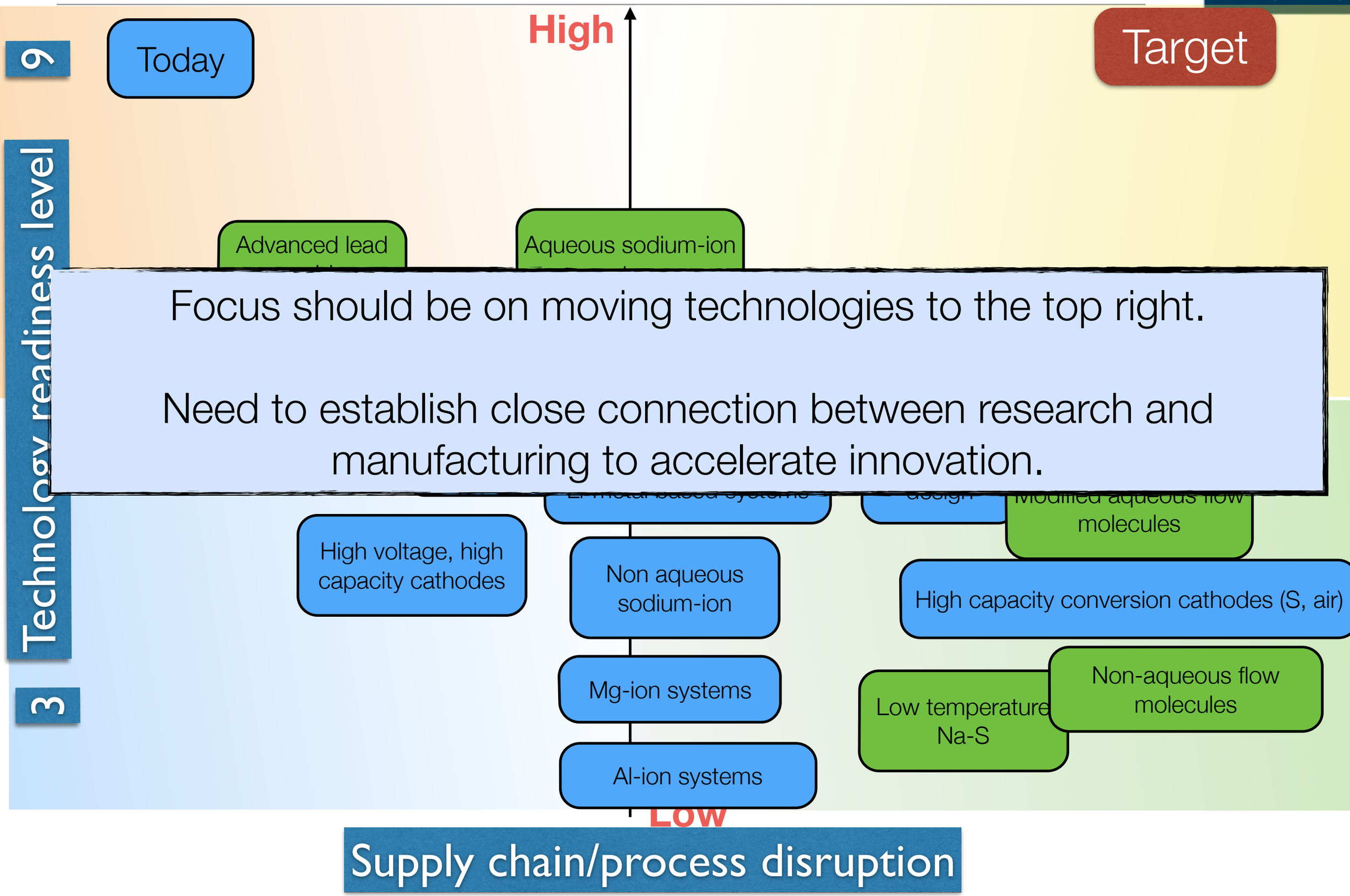

Focus should be on moving technologies to the top right.

Need to establish close connection between research and manufacturing to accelerate innovation.

Can we create the *Sematech* for batteries?

BERKELEY LAB
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Goal: How do we move to the top right?

Cut down process steps

1. Move away from slot die casting
2. "Fix" formation and use energy lost
3. Need to decrease process steps
4. Need reliable dry process

Modernize battery manufacturing

1. Bring "lean manufacturing" and six sigma principles to bear
2. Need modular manufacturing method
3. Use space 3D, rather than 2D

Develop new designs

1. Need sensing inside battery, go beyond voltage
2. Need high power cells that also achieve high energy and high safety
3. Need to develop designs that reduce losses at pack scale

Develop process metrology

1. Improve yield by ensuring adequate feedback loops
2. Need inline diagnostics
3. Ensure control over every process step

Need access to a pilot line

1. Access to analytical and testing equipment
2. Need standardization of materials and processes

Develop process models

1. Need accurate process flow models and cost estimates
2. Need believable accelerated tests
3. Need battery designs on a computer

More meetings are planned with companies across the supply chain (from materials to modules)

Summary

- Markets for storage are opening up and will grow
- Batteries will get cheaper (thanks to Tesla)
- But to reach mass market, we will need further innovations
- These innovations will involve new materials and new manufacturing processes.
- There are many attempts to achieve these innovations; but translation from lab to market takes a decade

We need to focus on scaling and manufacturing to accelerate innovation