

Sustainable Energy Generation, Distribution, and Security




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Liquid Metal Battery: Cost-based Discovery




Donald R. Sadoway

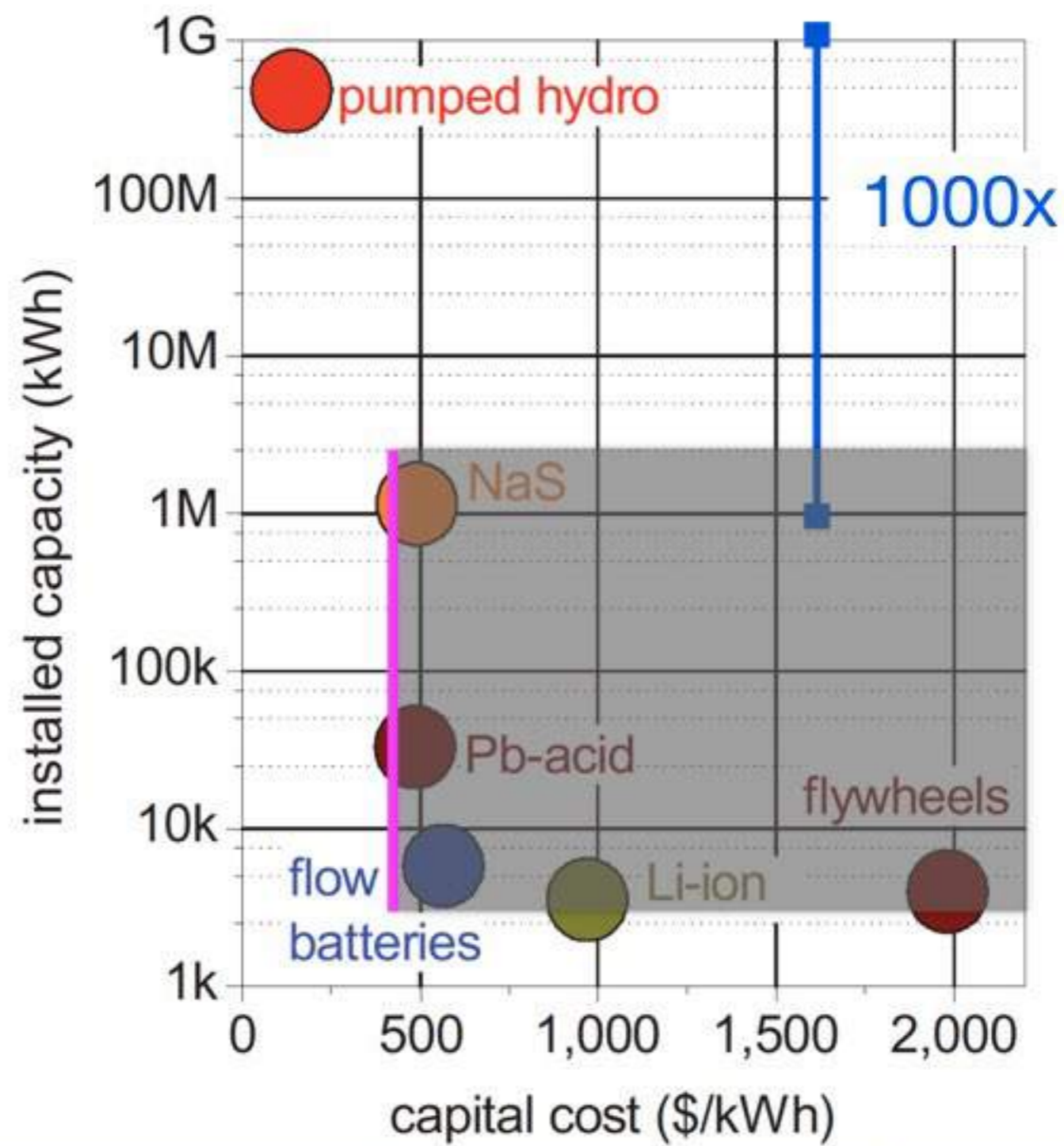
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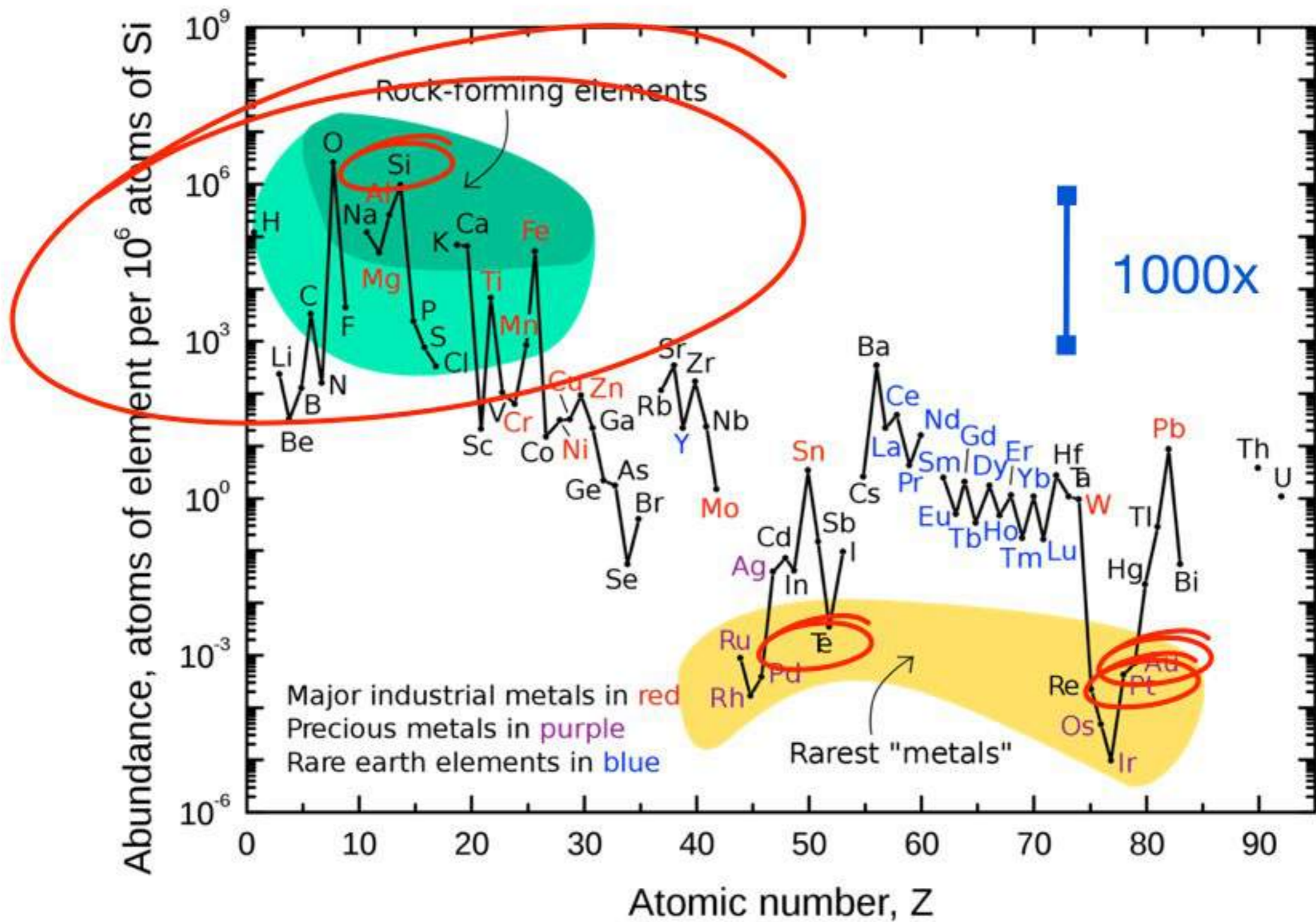
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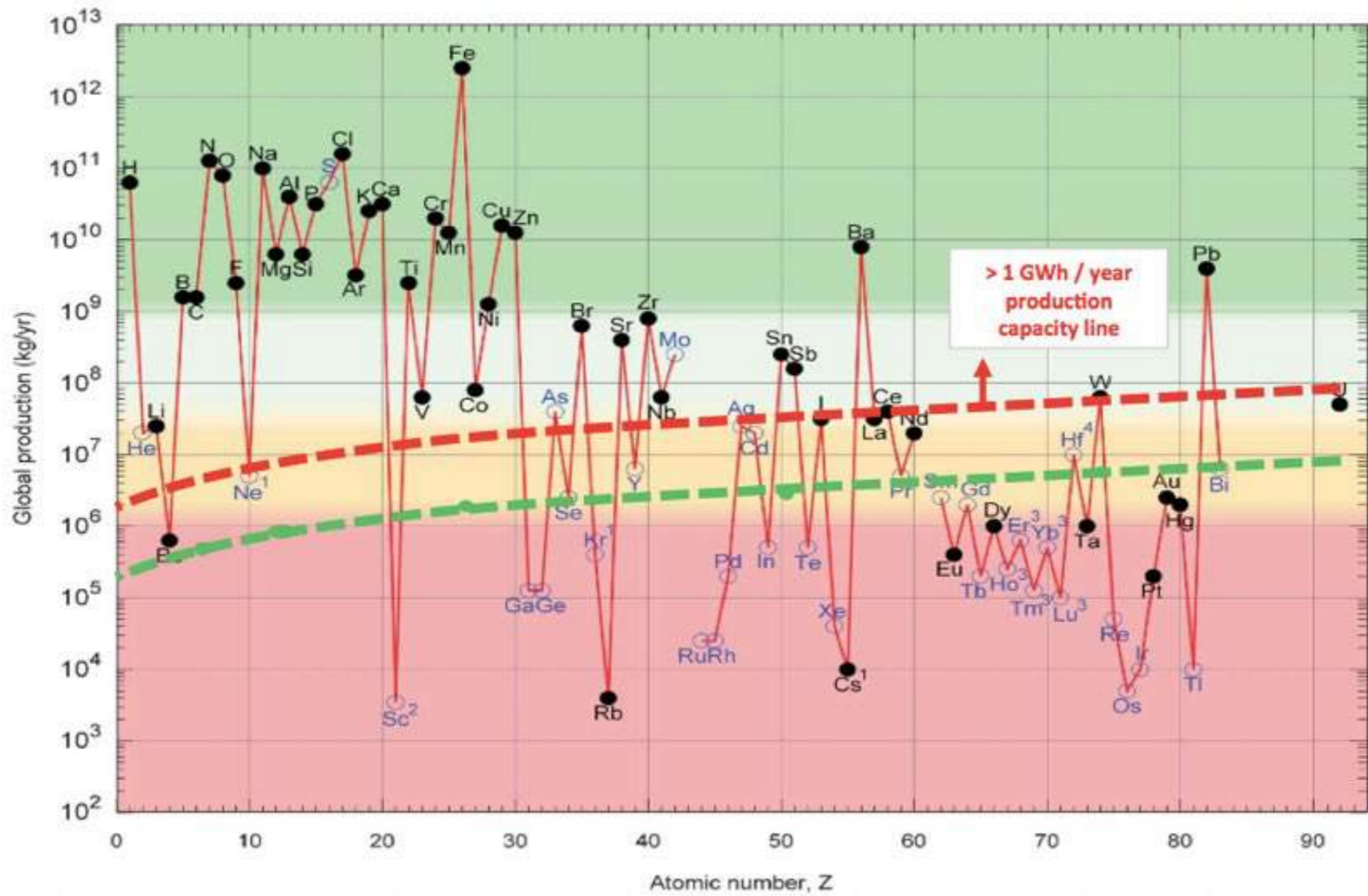




the path forward for storage

- for grid-level storage, battery vs combustion
(diesel & natural gas) → need to think differently
- today's Li-ion batteries fail on cost and lifetime
- confine chemistry to earth-abundant elements
→ to make it dirt cheap, make it out of dirt!
preferably local dirt
- and make it easy to manufacture





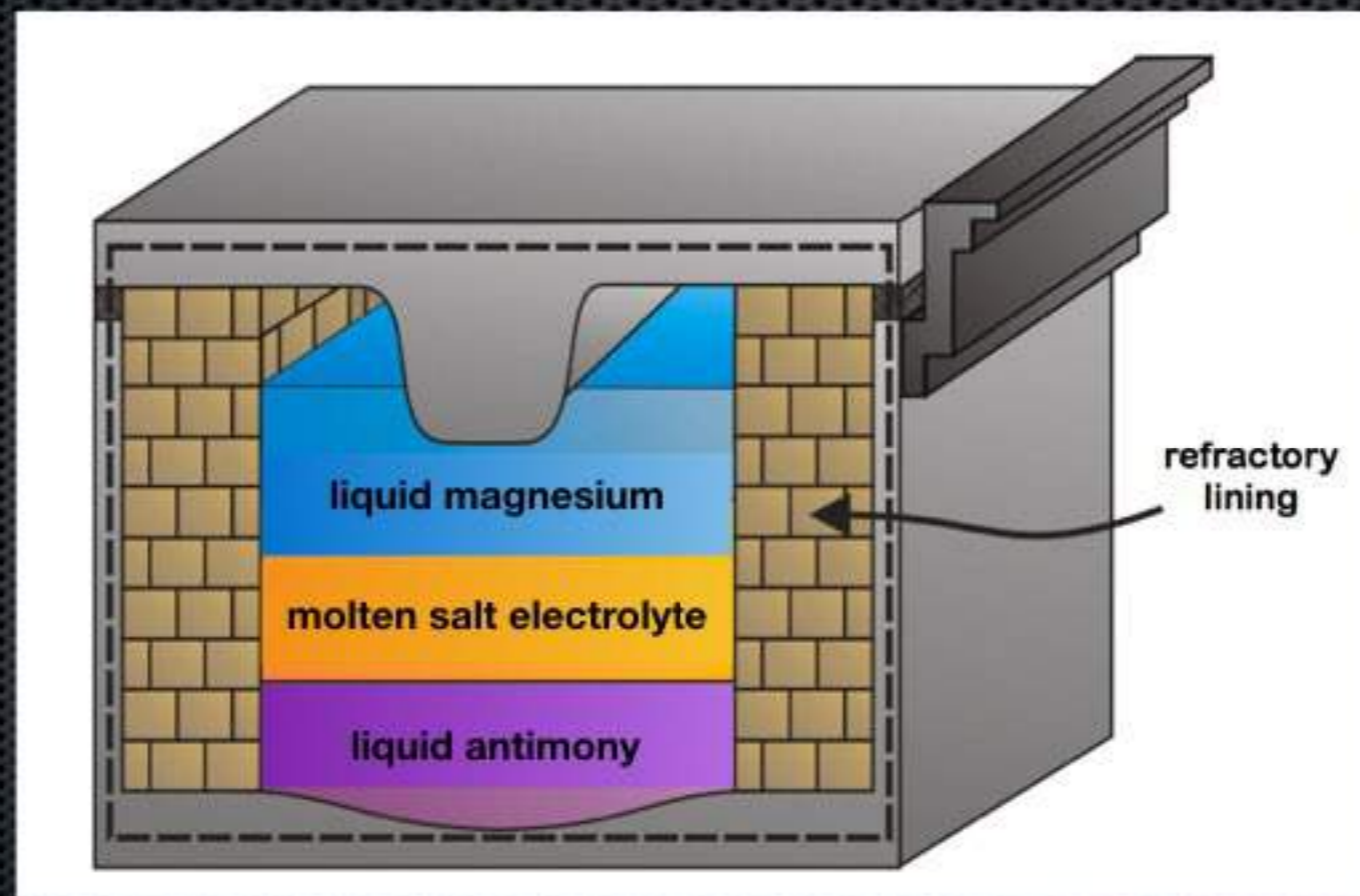
a modern aluminum smelter



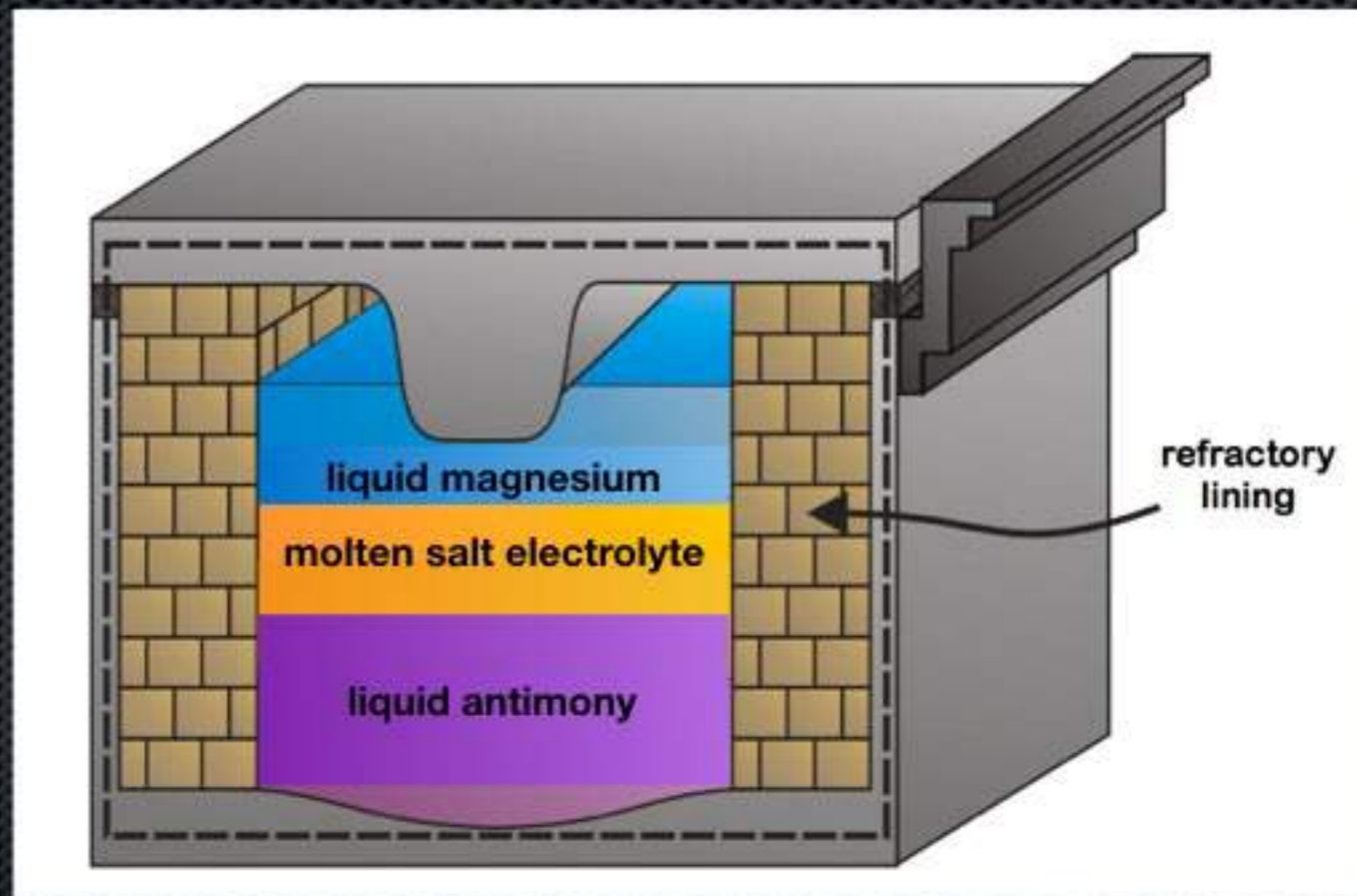
photo credit: "Phase II Makes Alouette the Largest Primary Aluminum Producer in the Americas," *Light Metal Age*, February 2006.

work started 10 years ago with **internal** funding from the **Deshpande Center** and the **Chesonis Family Foundation**

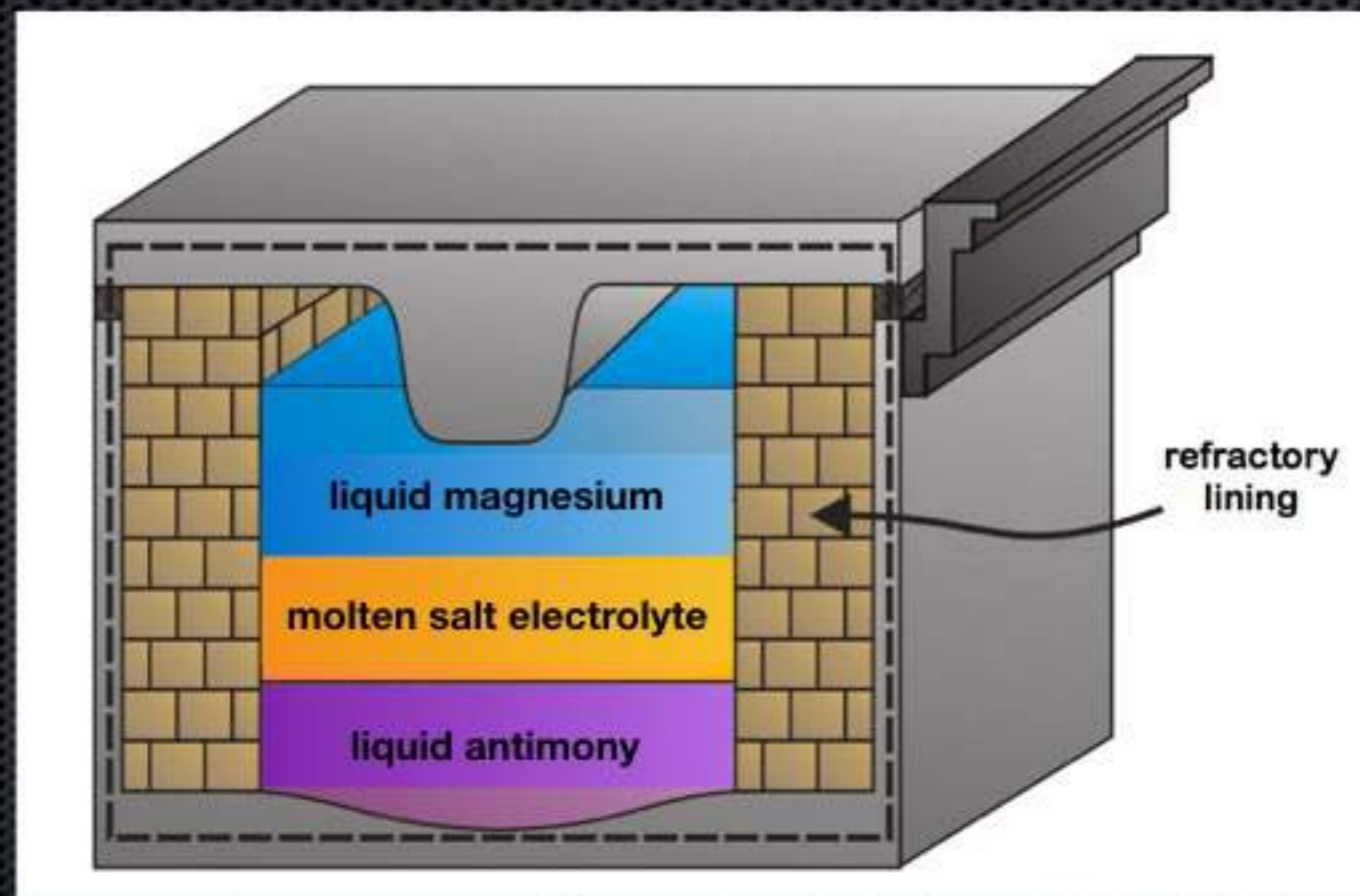
liquid metal battery



on discharge



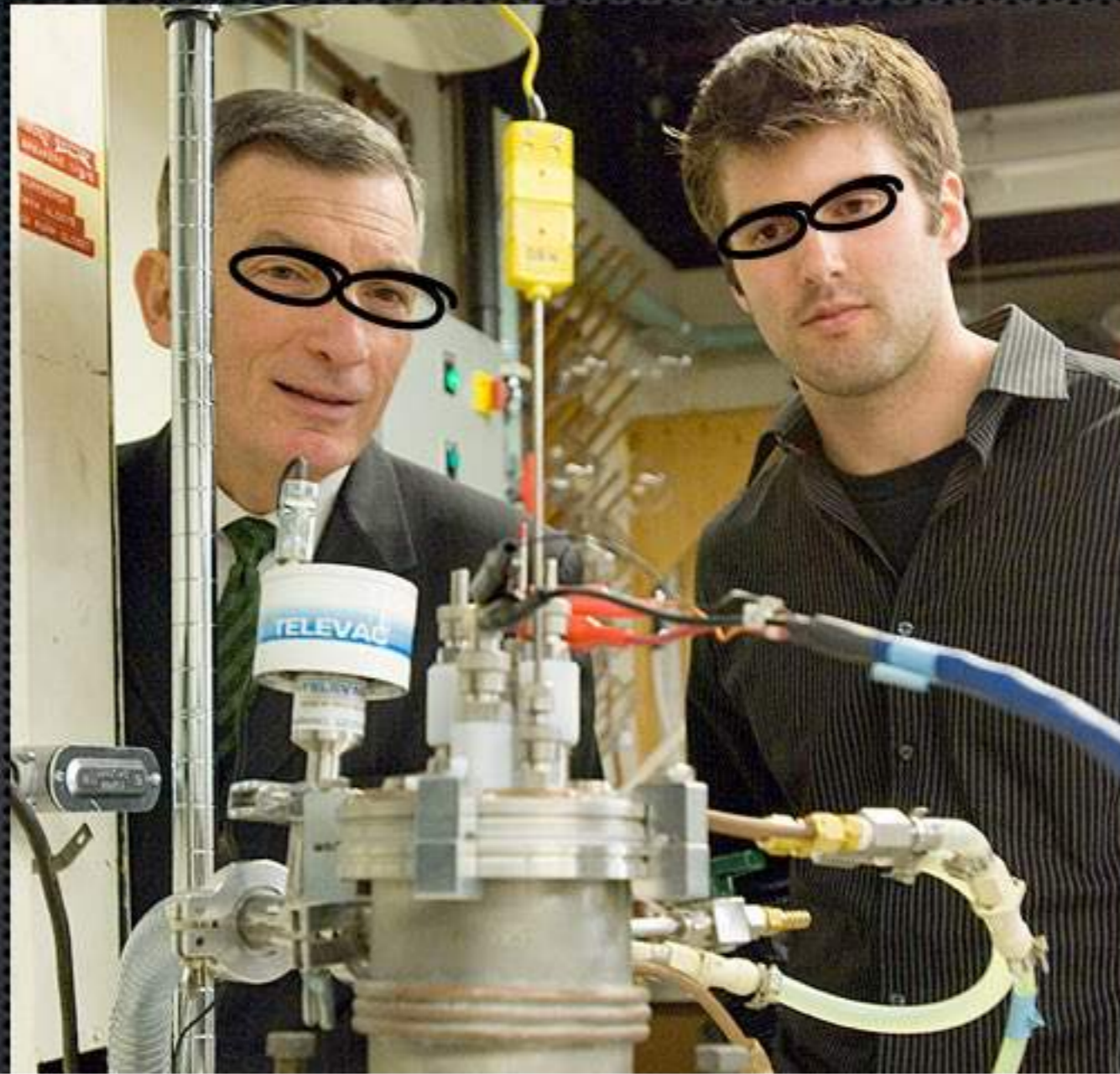
on charge: electrorefine **Mg** out of **Sb**



attributes of LMB

- composed of earth-abundant elements
- self-assembling → easy to manufacture
- round-trip efficiency $\approx 75\%$ > pumped hydro
- self-heating at commercial scale
- immune to thermal runaway
- safe to ship, even by air
- cost competitive in the electricity market?

Liquid Metal Battery Team at MIT (summer 2007)



10000 LIRE DIECIMILA

PAGABILI A VISTA AL PORTATORE

IL GOVERNATORE

Antonio Fazio

IL CASSIERE

Volta

OFFICINA DELLA BANCA D'ITALIA



BANCA D'ITALIA

A VOLTA

MH 195201 V

Prof. A. Volta



home:

coupled with
solar

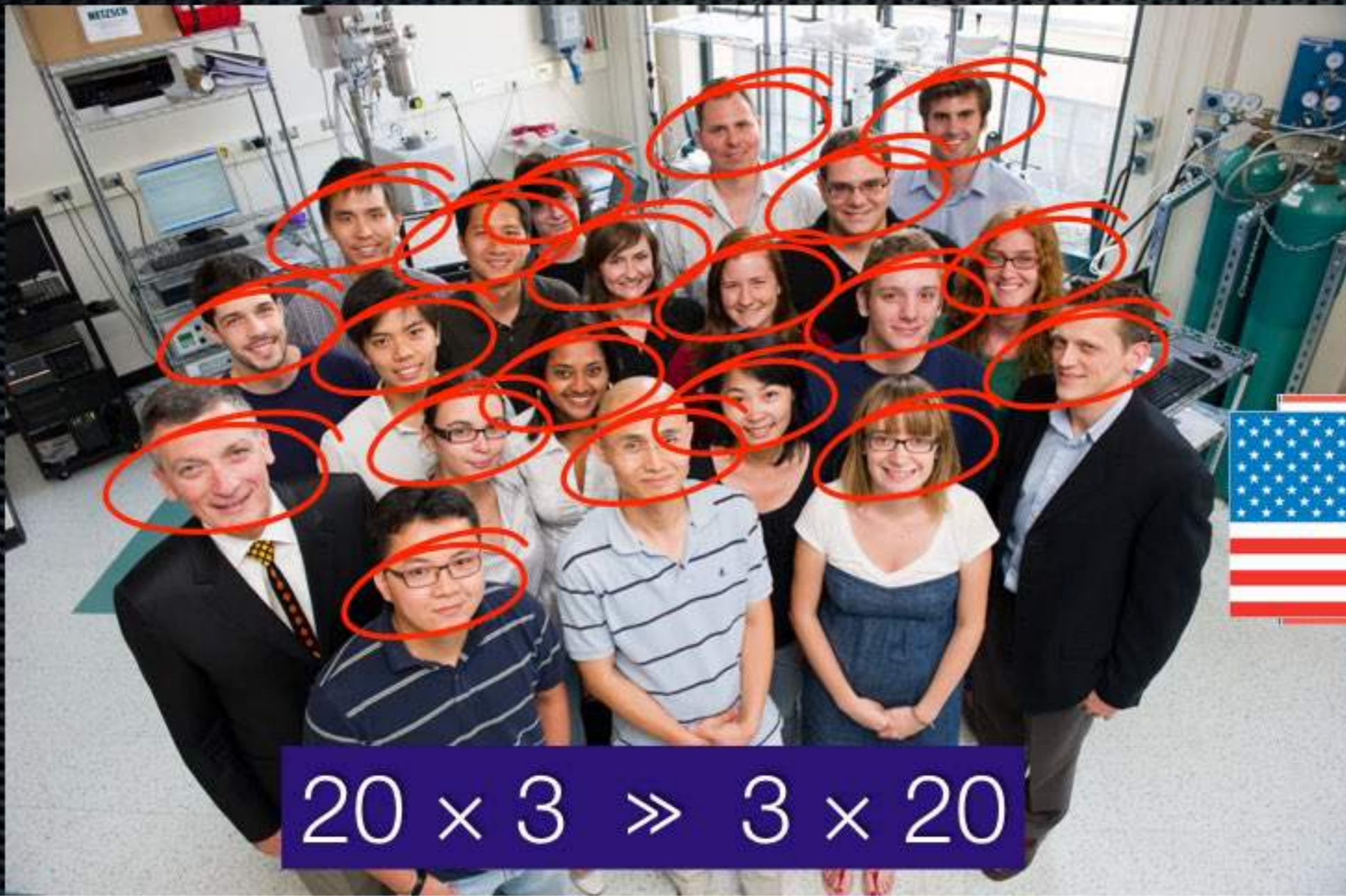
\$4 million

community:

mini-grid

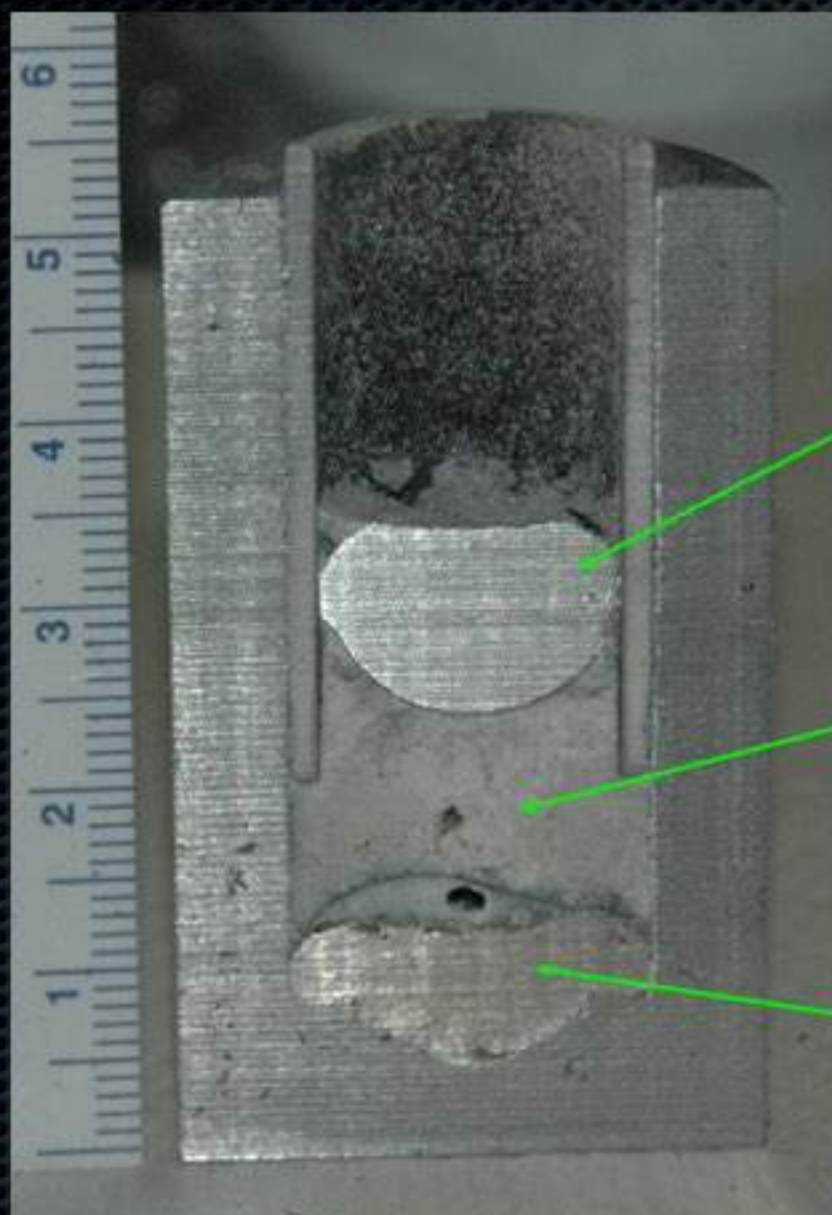
\$7 million

Liquid Metal Battery Team at MIT (summer 2010)



$20 \times 3 \gg 3 \times 20$

cell section after cycling 48 h at 700°C



magnesium
(-) anode

molten salt
electrolyte

antimony
(+) cathode



liquid metal battery status report

- ⇒ liquid metal battery works:
 - ☞ over 1000 cells tested
 - ☞ many chemistries: alloys & salts
 - ☞ <\$100/kWh for electrodes + electrolyte



LETTER

nature International weekly journal of science

doi:10.1038/nature13700

Lithium–antimony–lead liquid metal battery for grid-level energy storage

Kangli Wang¹, Kai Jiang¹, Brice Chung¹, Takanari Ouchi¹, Paul J. Burke¹, Dane A. Boysen¹, David J. Bradwell¹, Hojong Kim¹, Ulrich Muecke¹ & Donald R. Sadoway¹

liquid metal battery status report

- ⇒ liquid metal battery works:
 - ☞ over 1000 cells tested
 - ☞ many chemistries: alloys & salts
 - ☞ <\$100/kWh for electrodes + electrolyte
- ⇒ accelerating scale-up to commercial-scale device
 - ☞ startup company:
Liquid Metal Battery Corporation



new name: CAmbridge

CAmbridge

AMBRI

- ⇒ established in 2010 to bring liquid metal battery to market
- ⇒ series A funding from



Bill Gates



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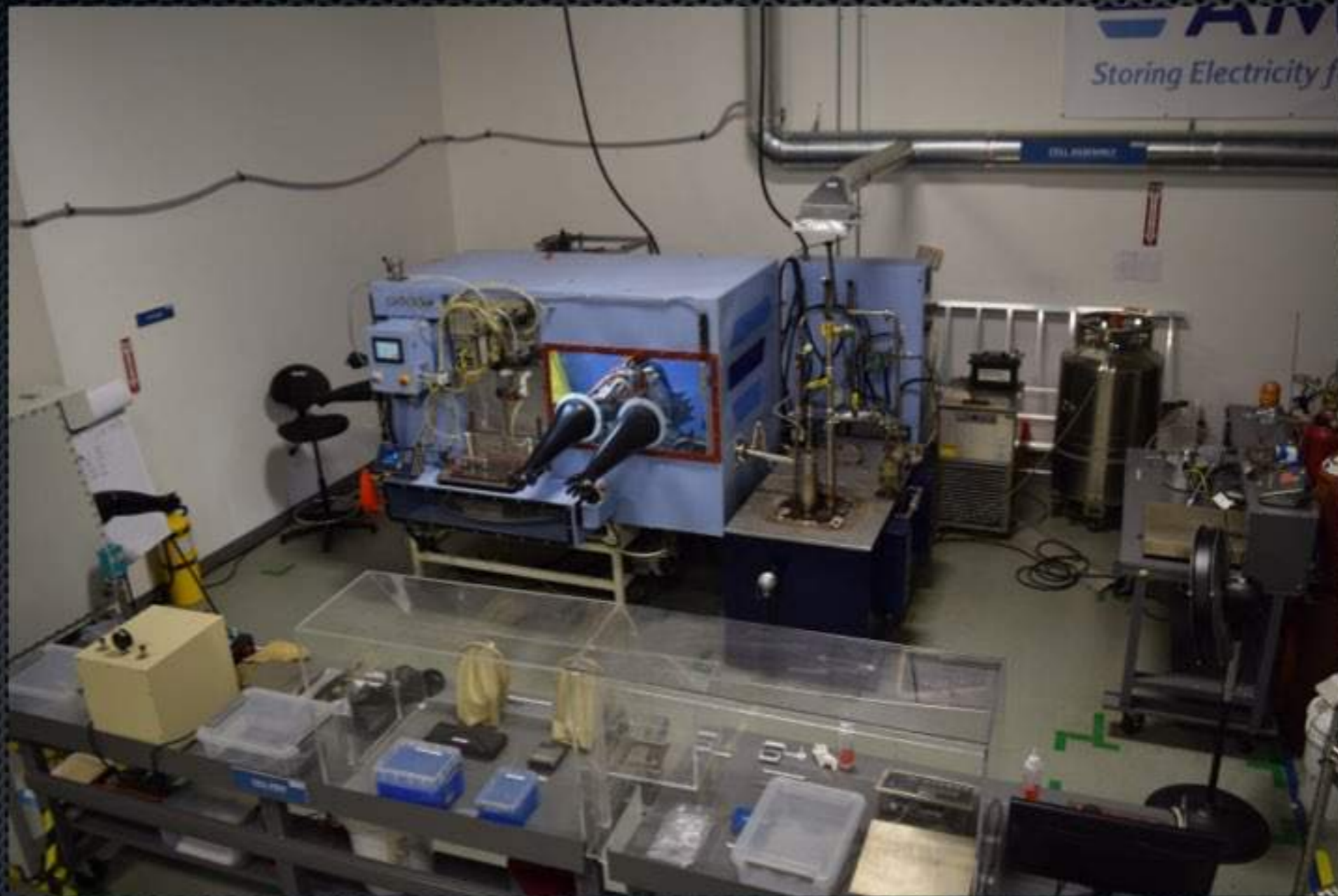
1

2

from cells to batteries: Marlborough, MA, November 7, 2013



from cells to batteries: all new manufacturing facility



AMBRI
Storing Electricity for Our Future



10 cm × 10 cm with 80 Ah
20 cm × 20 cm with 380 Ah



3 Ah for Li-ion 18650 cell

grid-level storage: 1 MWh on a 50 m² footprint



● in Li-ion = 93,000 cells (18650)

● in LMB = 2,600 cells (20 cm × 20 cm)

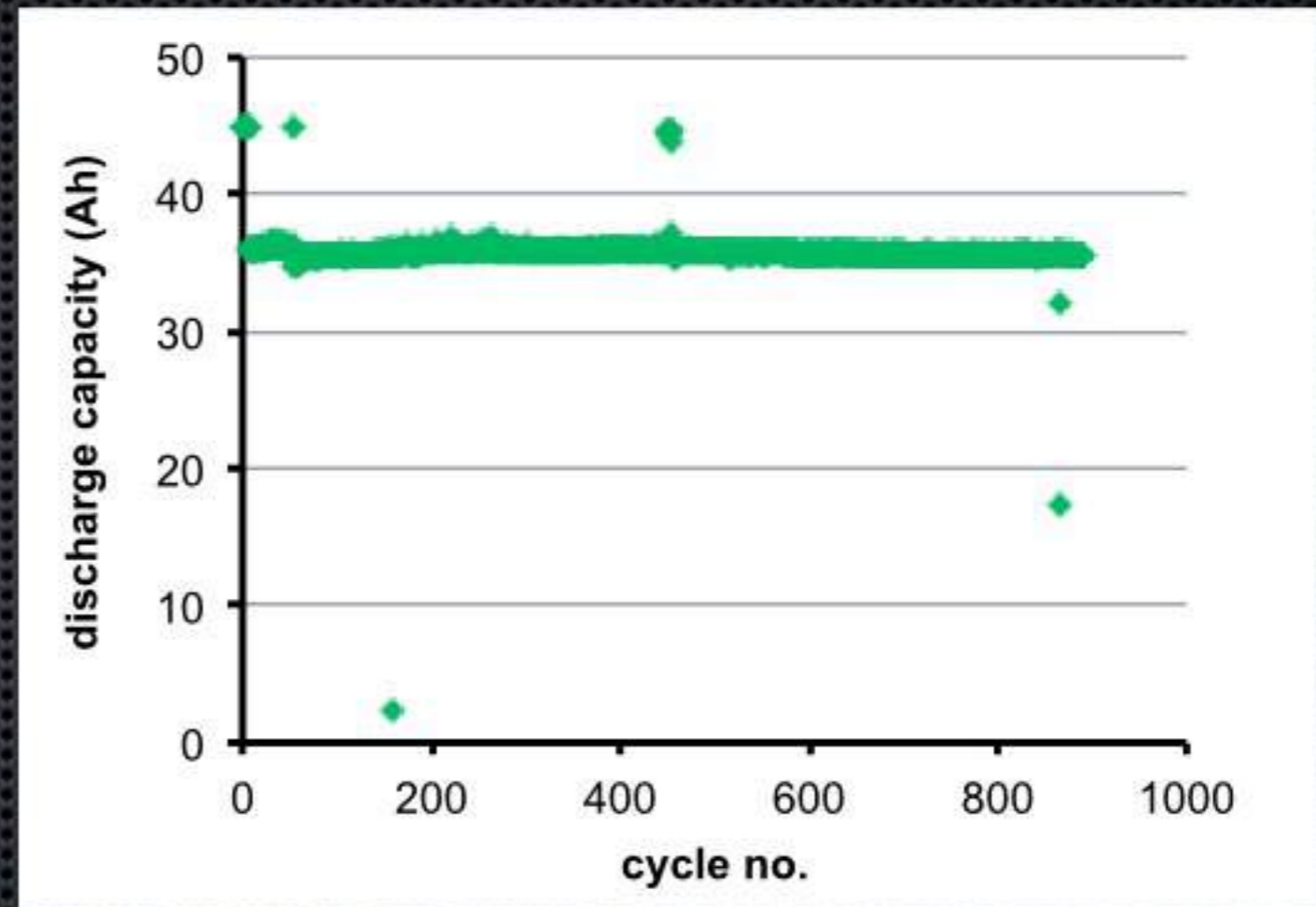
unparalleled service lifetime

● cell operated at accelerated rate ($\sim 300 \text{ mA/cm}^2$) & 93% DOD

● fade rate is $\sim 0.00009\%/ \text{cycle}$

> **99%** initial capacity
after 10 years of
daily cycling

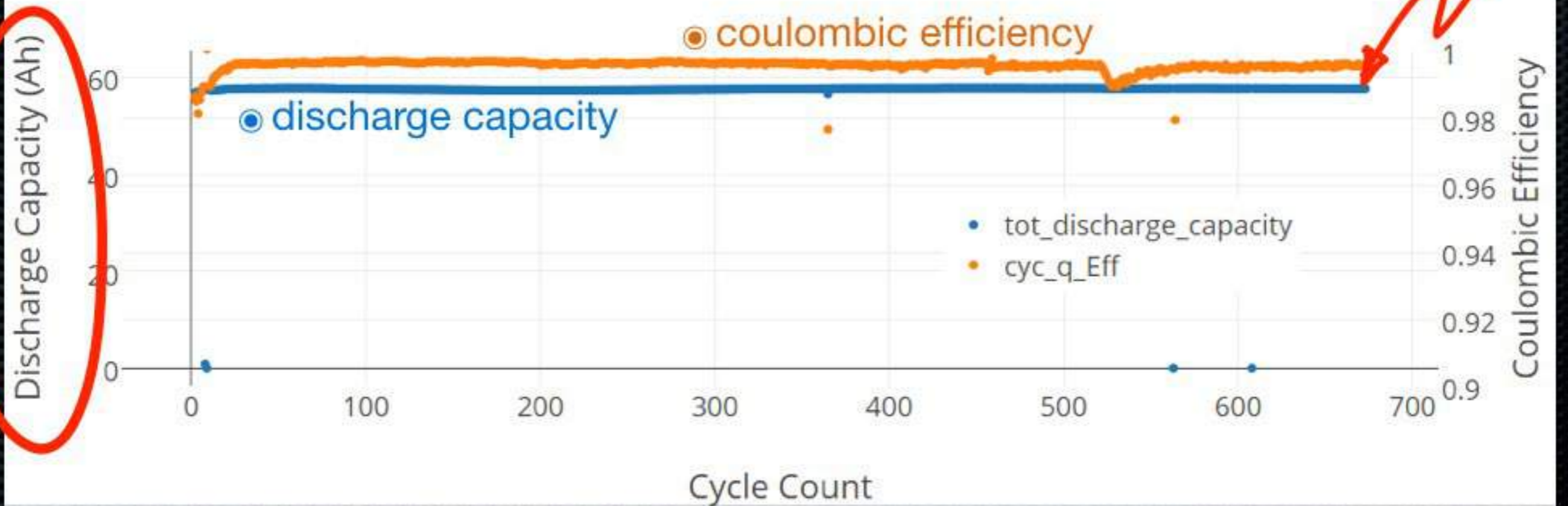
> **80%** initial capacity
after **607 years** of
daily cycling



this just in (October 23, 2015)

- cell operated for 1 year (706 cycles)
- fade rate is below threshold of detection

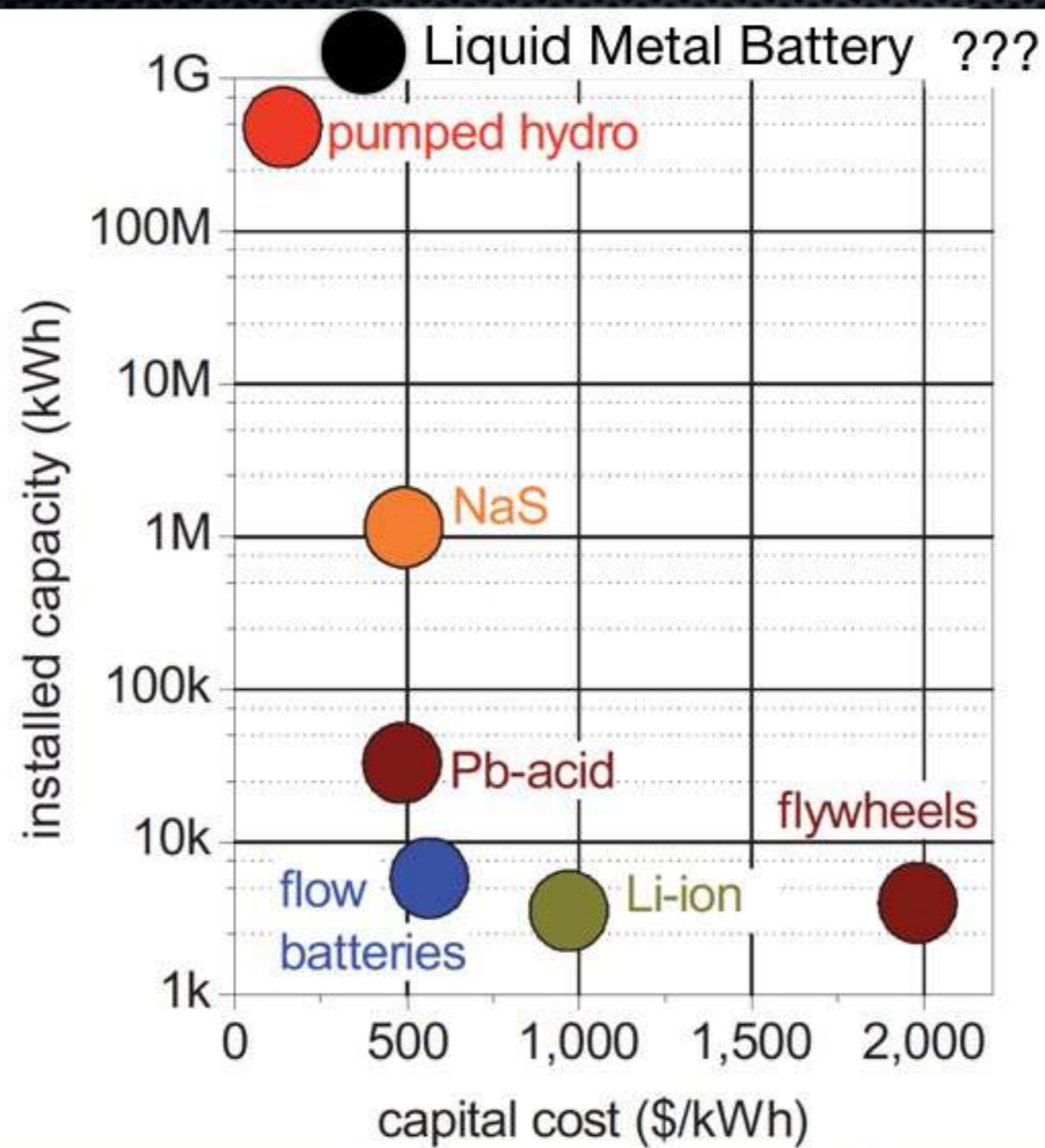
A year in the life of an Ambri Cell (a4-1505)



grid-level storage: 1 MWh on a 50 m² footprint

- silent
- emissions-free
- no moving parts
- remotely controlled
- designed to the price point of today's electricity market





... next steps

⇒ at MIT continue basic research:

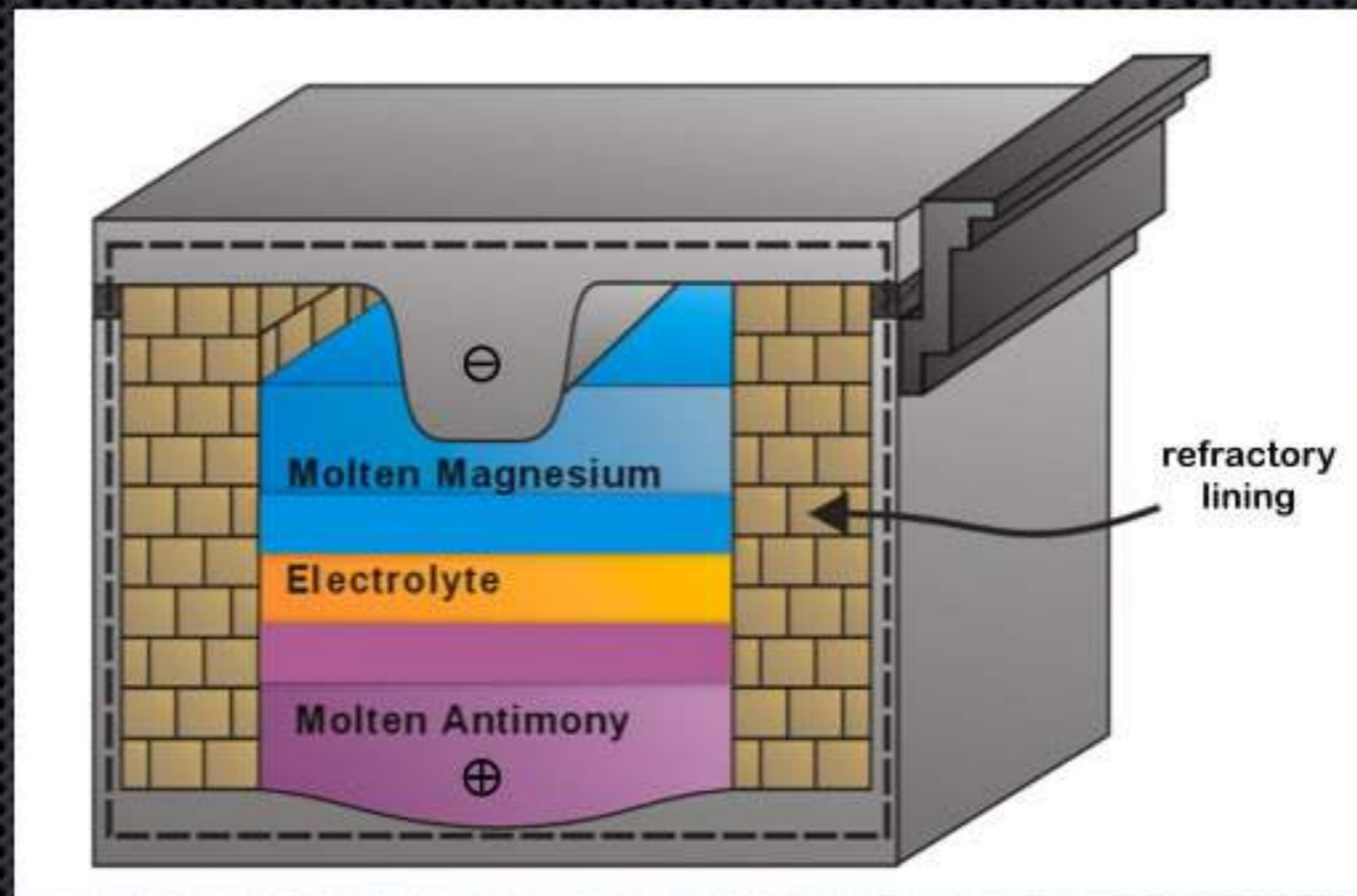
☞ new chemistries: alloys & salts

☞ ARPA-E research complete

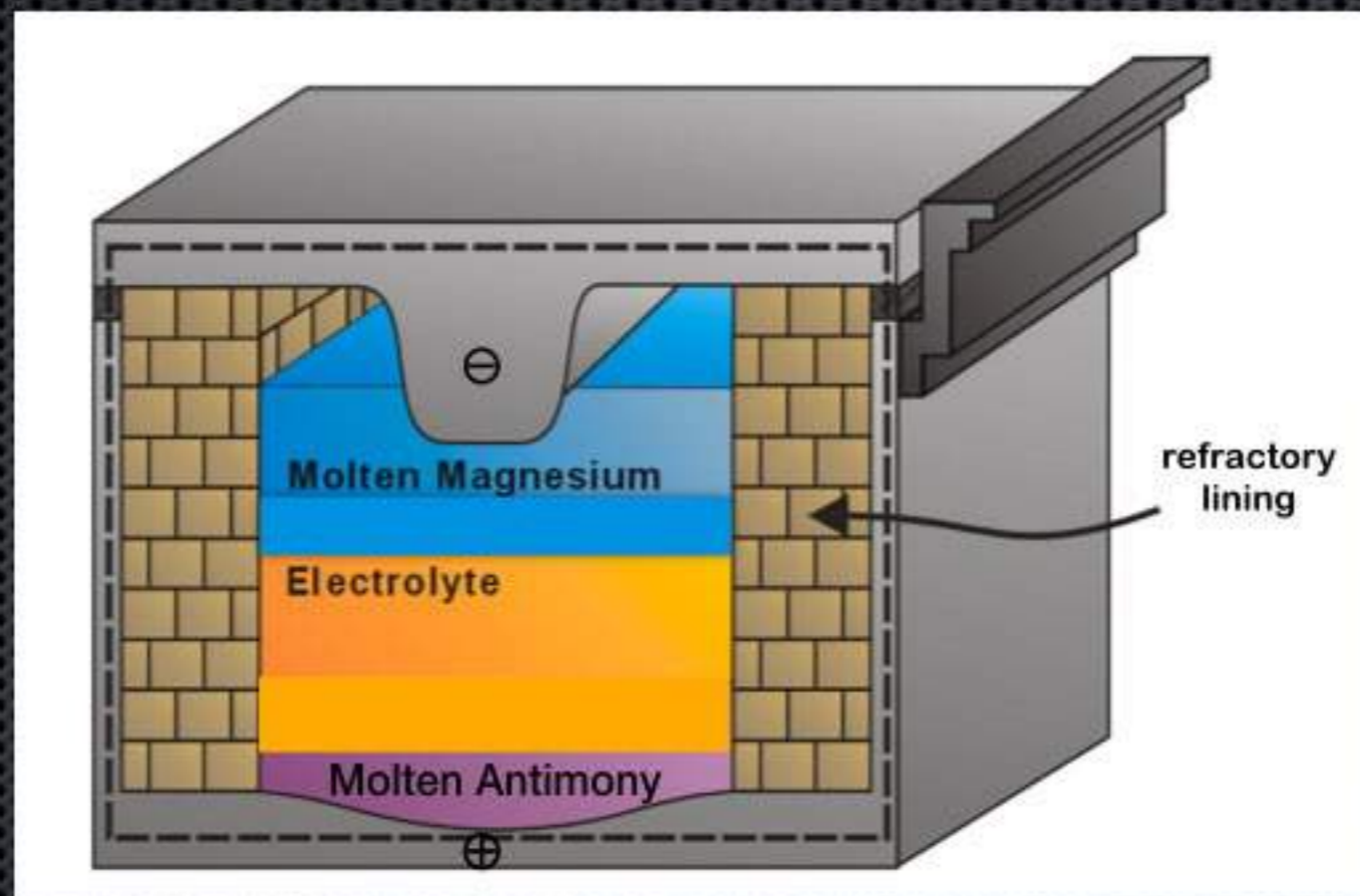
☞ seeking funding to invent new chemistries: *know any sponsors?*



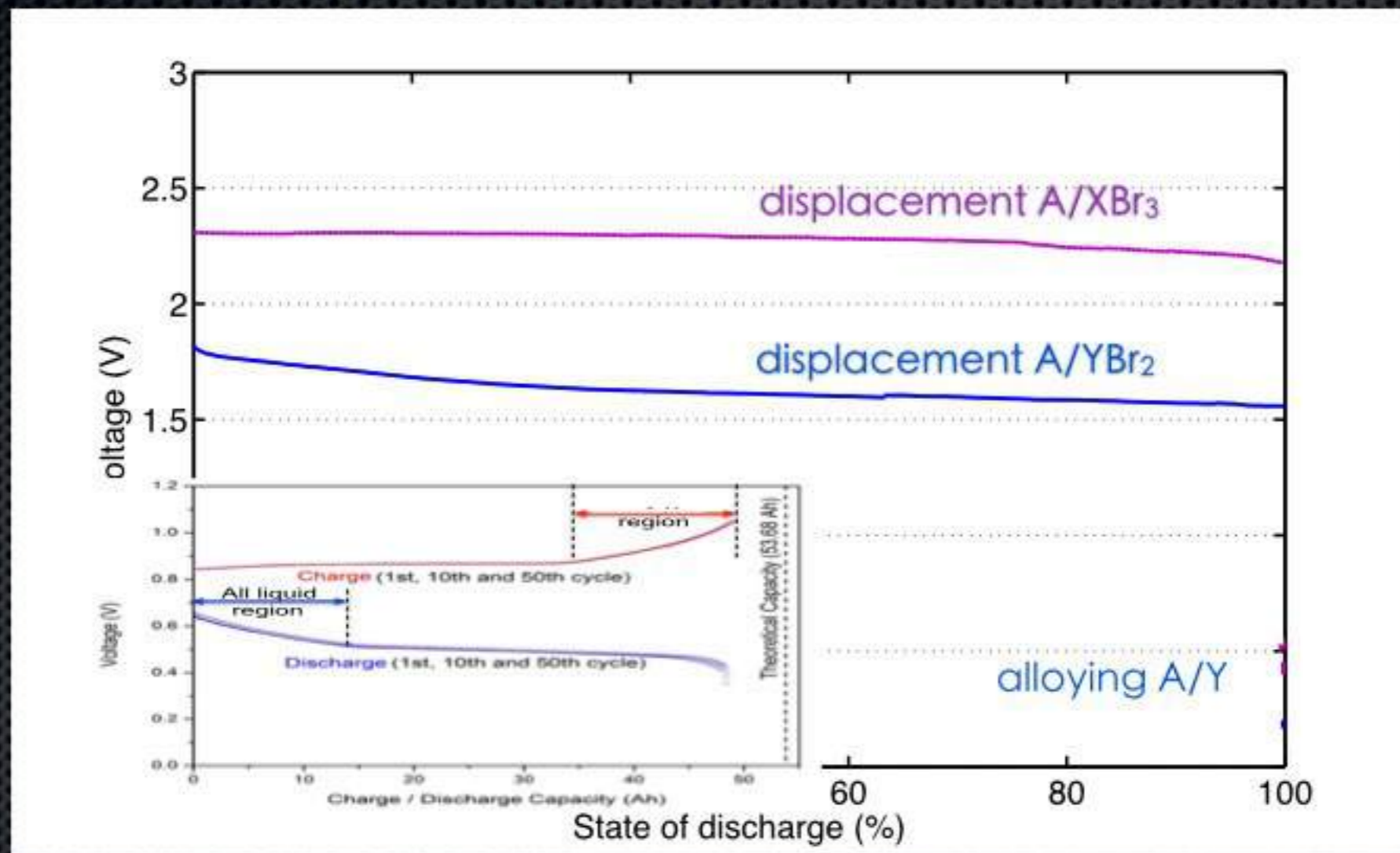
on charge



on further charging



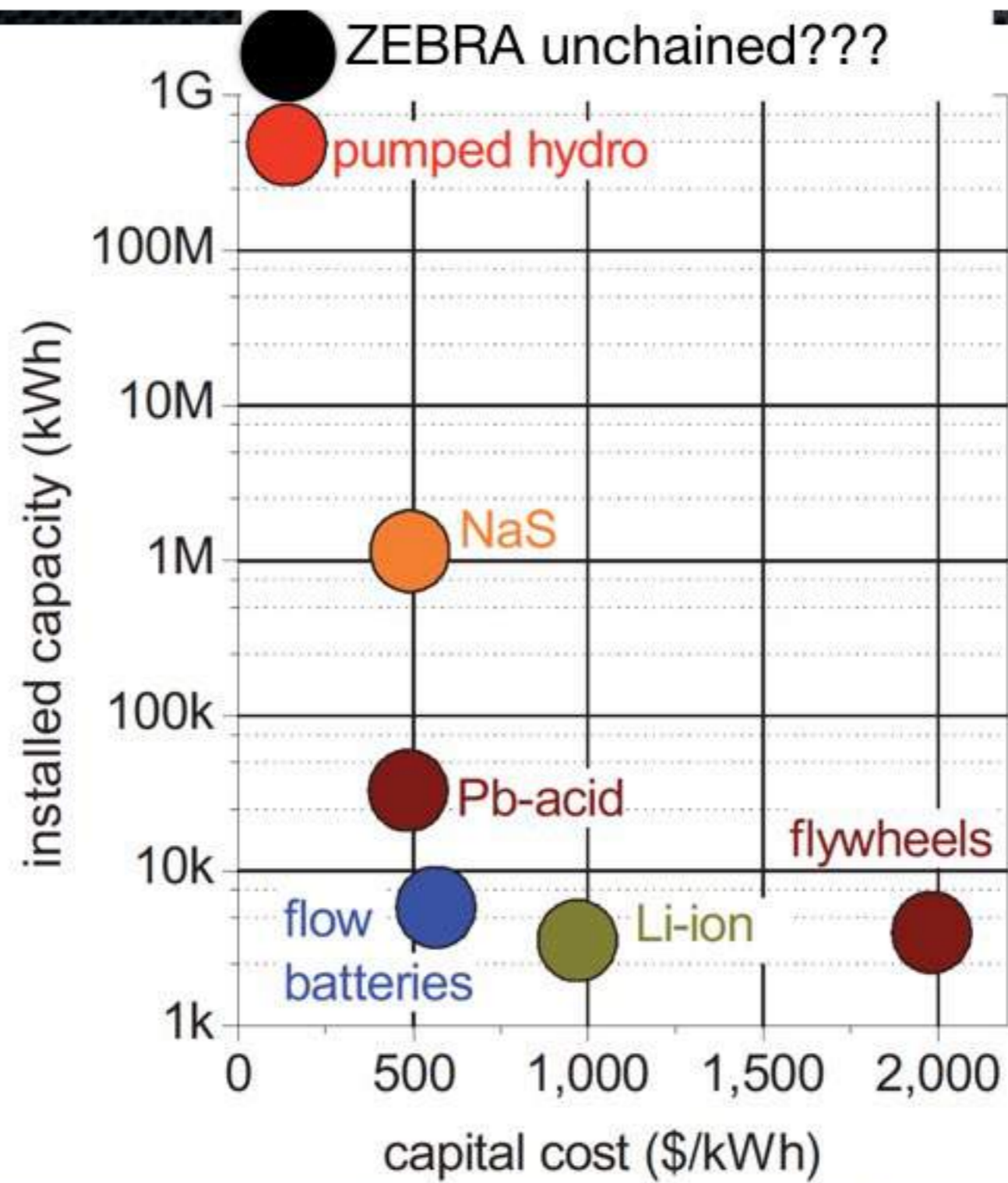
ZEBRA unchained



10 cm x 10 cm with 240 Ah
20 cm x 20 cm with 1,140 Ah
and near-zero capacity fade

ZEBRA unchained





what have we learned?

what are the heterodoxies?

- temperature: ~~low~~ high
- scaling: ~~many~~ fewer
- human resources: ~~experts~~ novices
- global dissemination: ~~centralized~~ localized



Soyez réalistes.

Demandez l'impossible!

- Paris, 1968

