

# The Role of Energy Storage: What is Needed?



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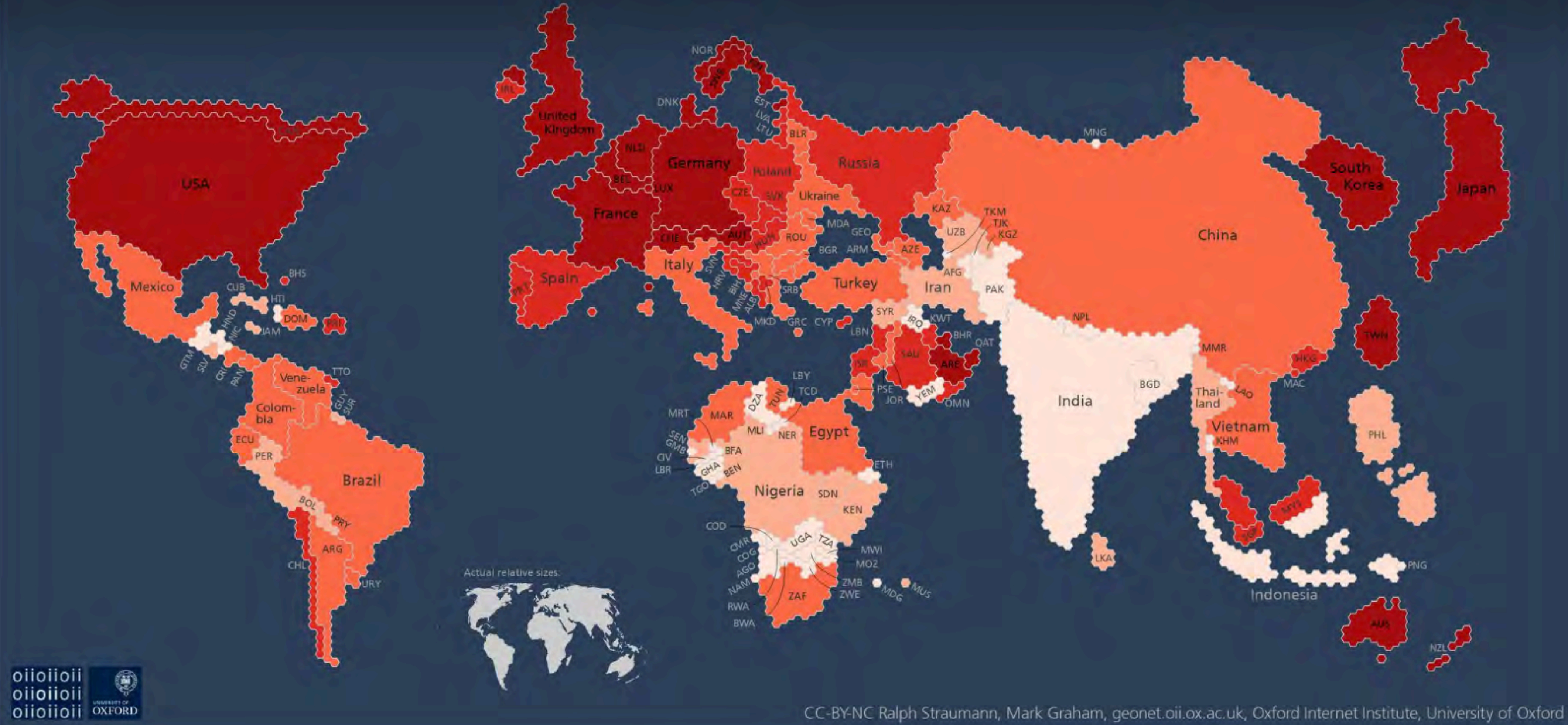
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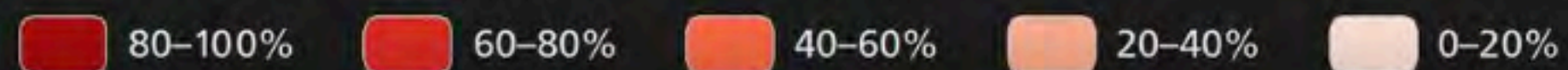
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# The World Online

## Percentage of people online



The countries are scaled proportionally to the number of Internet users in that country. Countries with fewer than 470,000 people online have been removed from the map. The shading indicates the percentage of the population that is online.



CC-BY-NC Ralph Straumann, Mark Graham, geonet.oii.ox.ac.uk, Oxford Internet Institute, University of Oxford

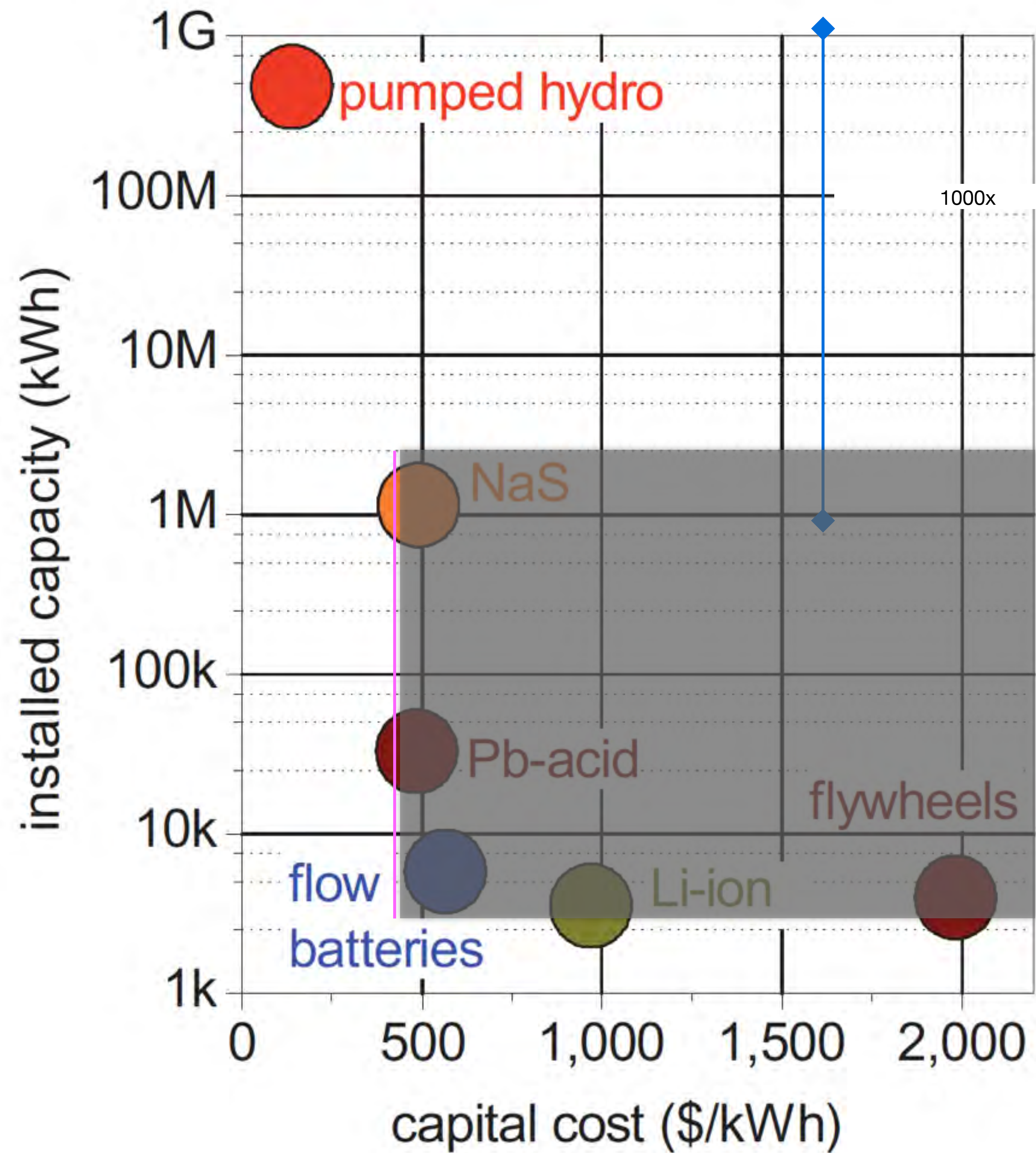
# The Archipelago of Disconnection

- Territories with Internet penetration below 10%
- Territories for which no data exists

grouped together with bigger entities (e.g., the United States Minor Outlying Islands with the United States), no data have been collected or inferred, or the territories lack widespread recognised statehood




For territories coloured orange no individual data exists from the World Bank. Potential reasons are for example: some of these territories are statistically

This visualization uses 2013 data from the World Bank's Worldwide Development Indicators project and data from Natural Earth.



# the path forward for storage

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- 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  
 design holistically



# inventing a colossal yet cheap battery

👉 pose the right question

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● look at the economy of scale of modern electrometallurgy:

👉 aluminium smelter

➡ bauxite, carbon, 13 kWh electricity / kg metal product,  
\$5000 / tonne capital cost

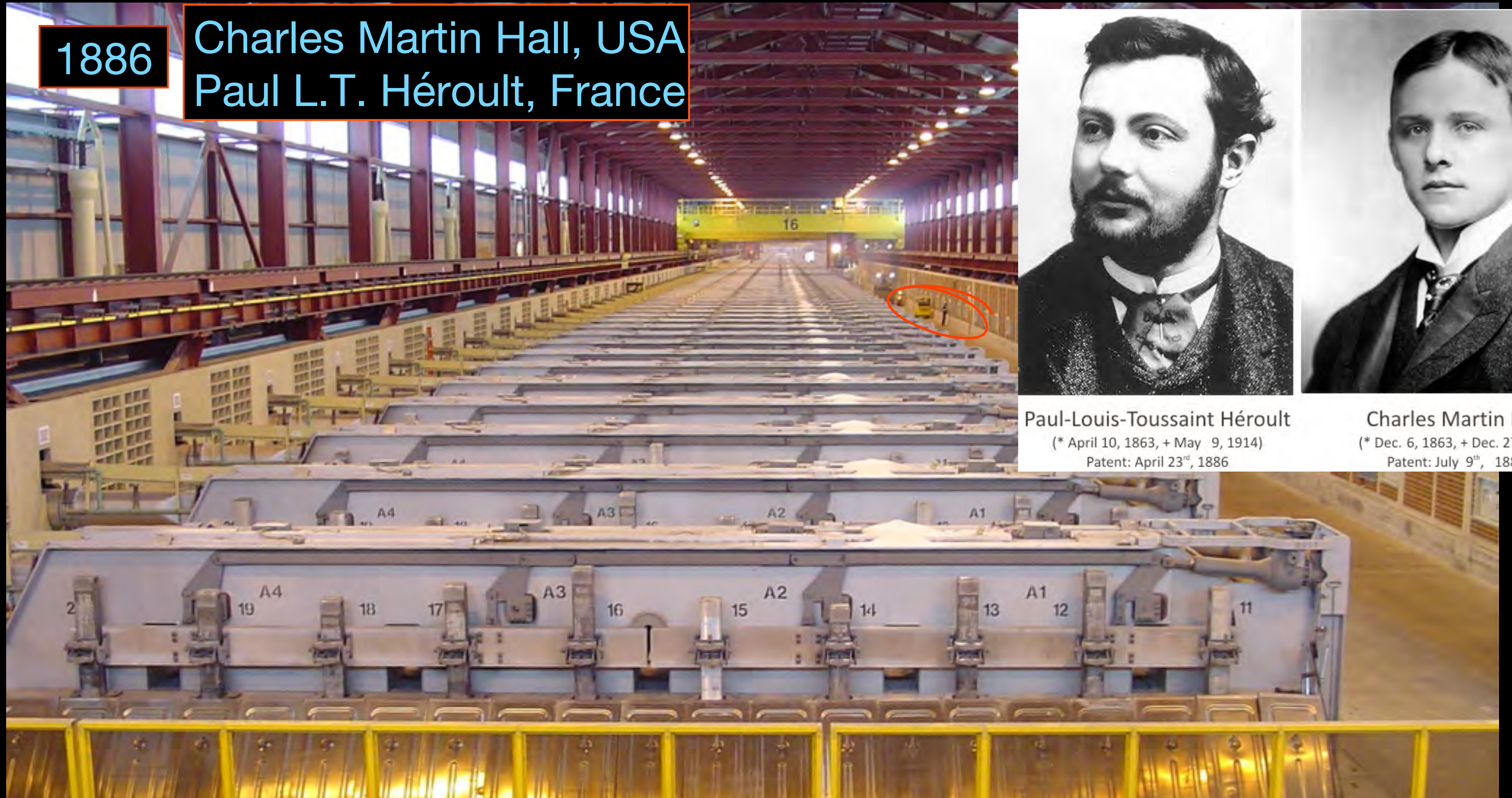
👉 dirt to metal < \$1.00 / kg



# a modern aluminium smelter

1886

Charles Martin Hall, USA  
Paul L.T. Héroult, France

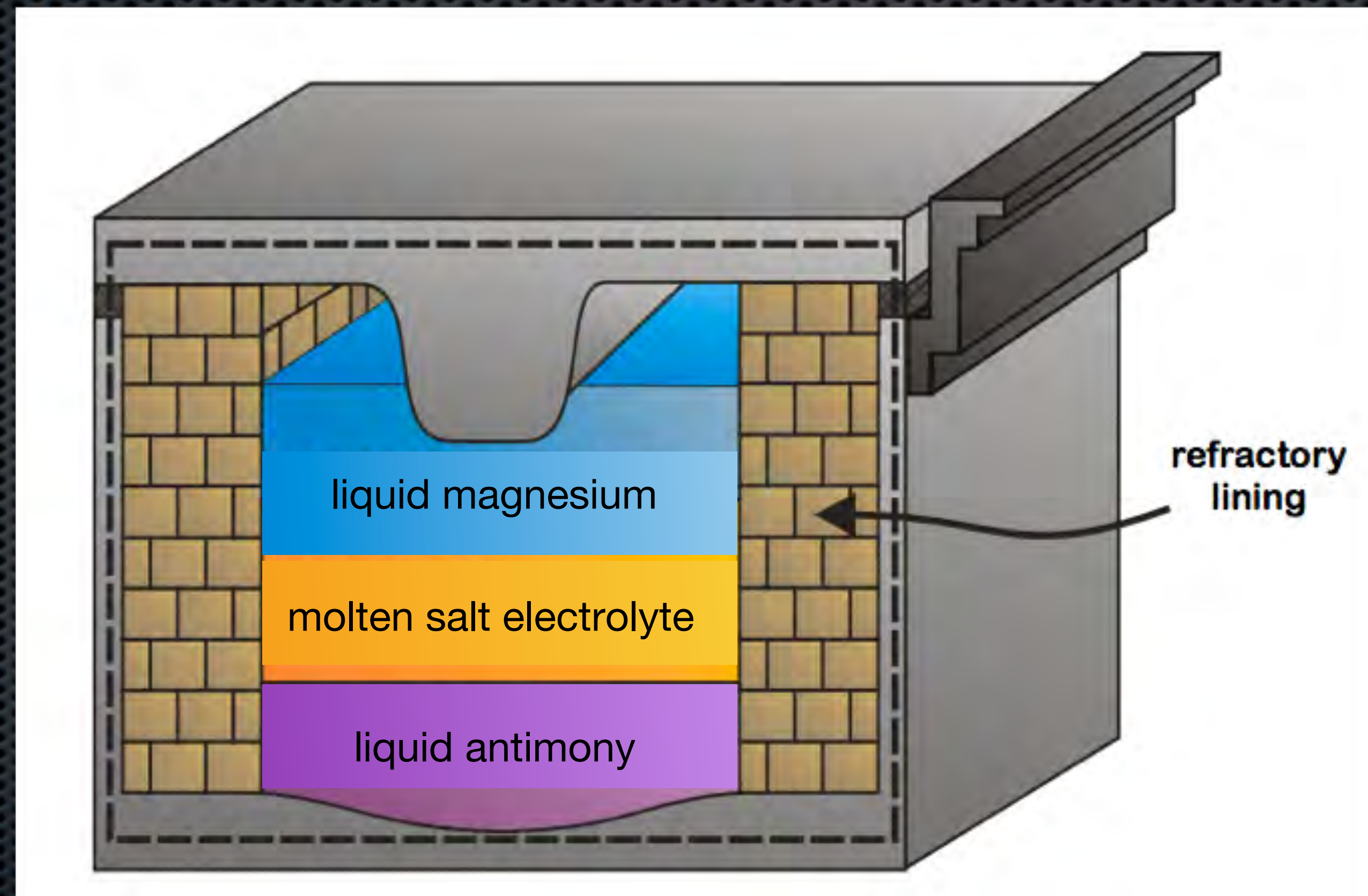


Paul-Louis-Toussaint Héroult  
(\* April 10, 1863, + May 9, 1914)  
Patent: April 23<sup>rd</sup>, 1886



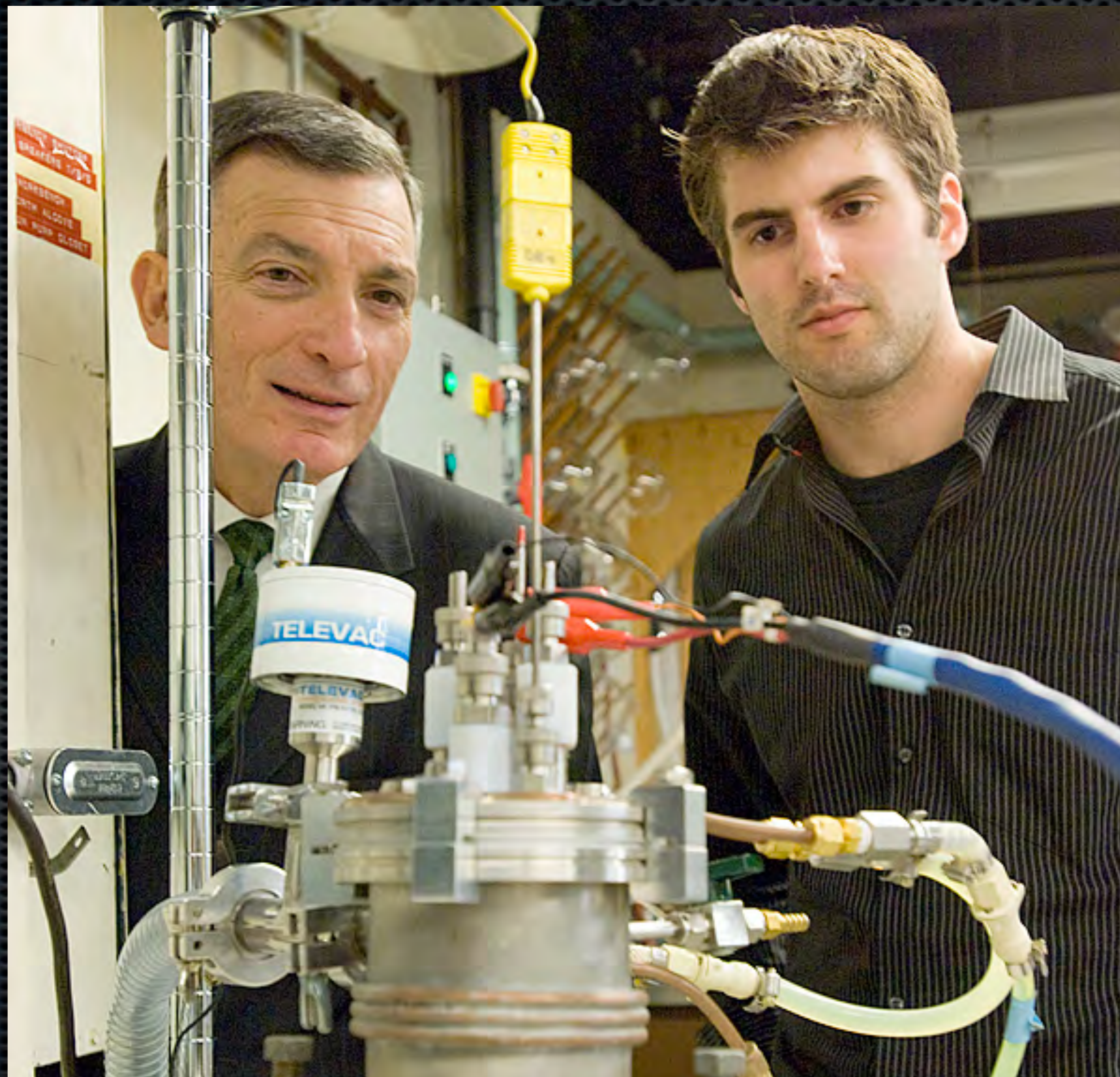
Charles Martin Hall  
(\* Dec. 6, 1863, + Dec. 27, 1914)  
Patent: July 9<sup>th</sup>, 1886

# liquid metal battery



# Liquid Metal Battery Team at MIT (summer 2007)

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home:

coupled with  
solar

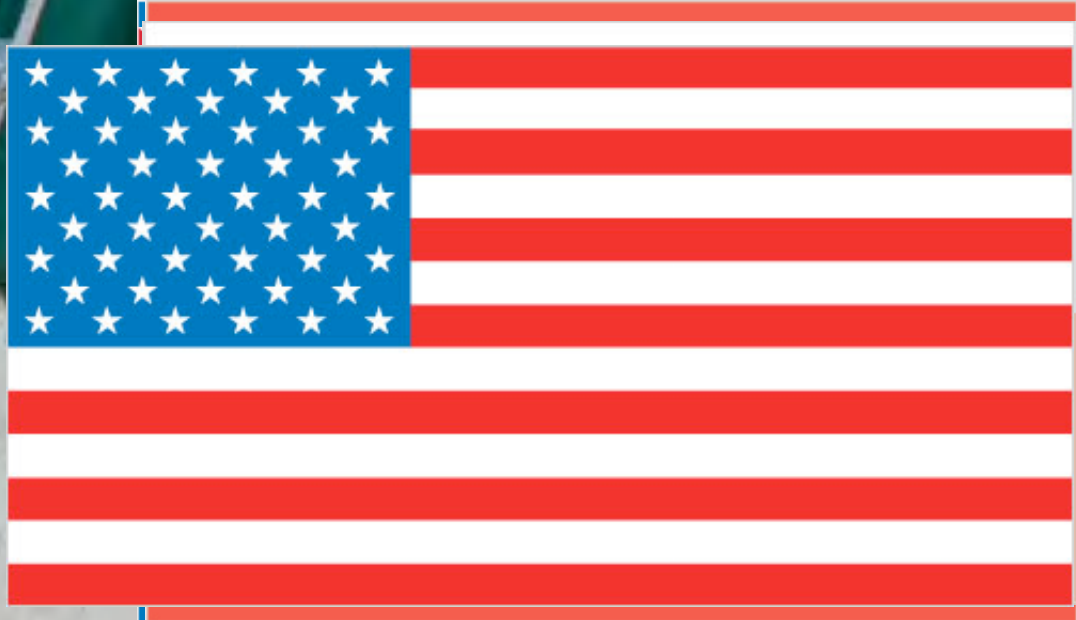
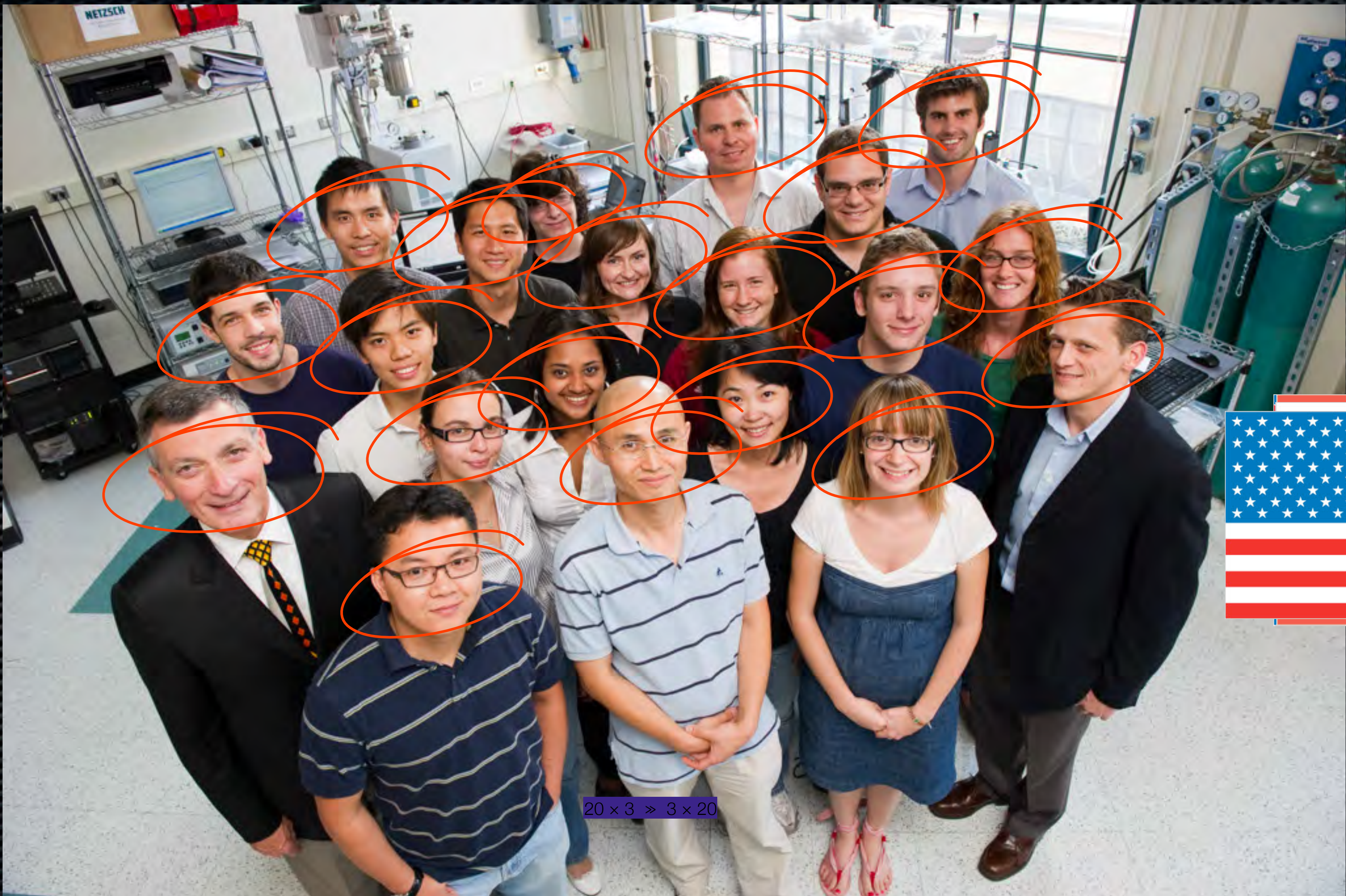
\$4 million

community:

mini-grid

\$7 million

# Advanced Metal Battery Team at MIT (summer 2010)

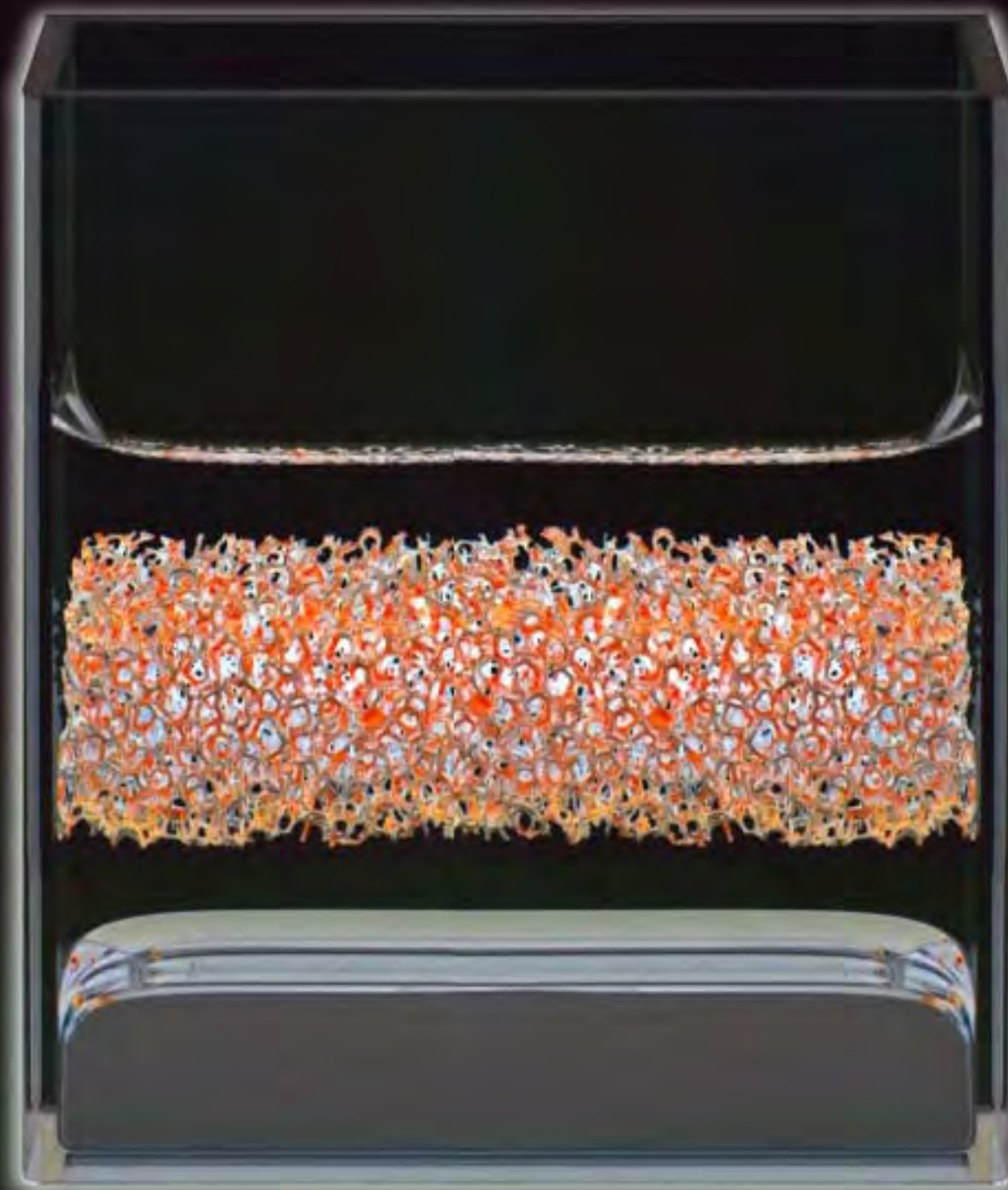


# liquid metal battery status report



liquid metal battery works:

- 👉 over 1000 cells tested
- 👉 many chemistries: alloys & salts
- 👉 <math>< \\$100/\text{kWh}</math> 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

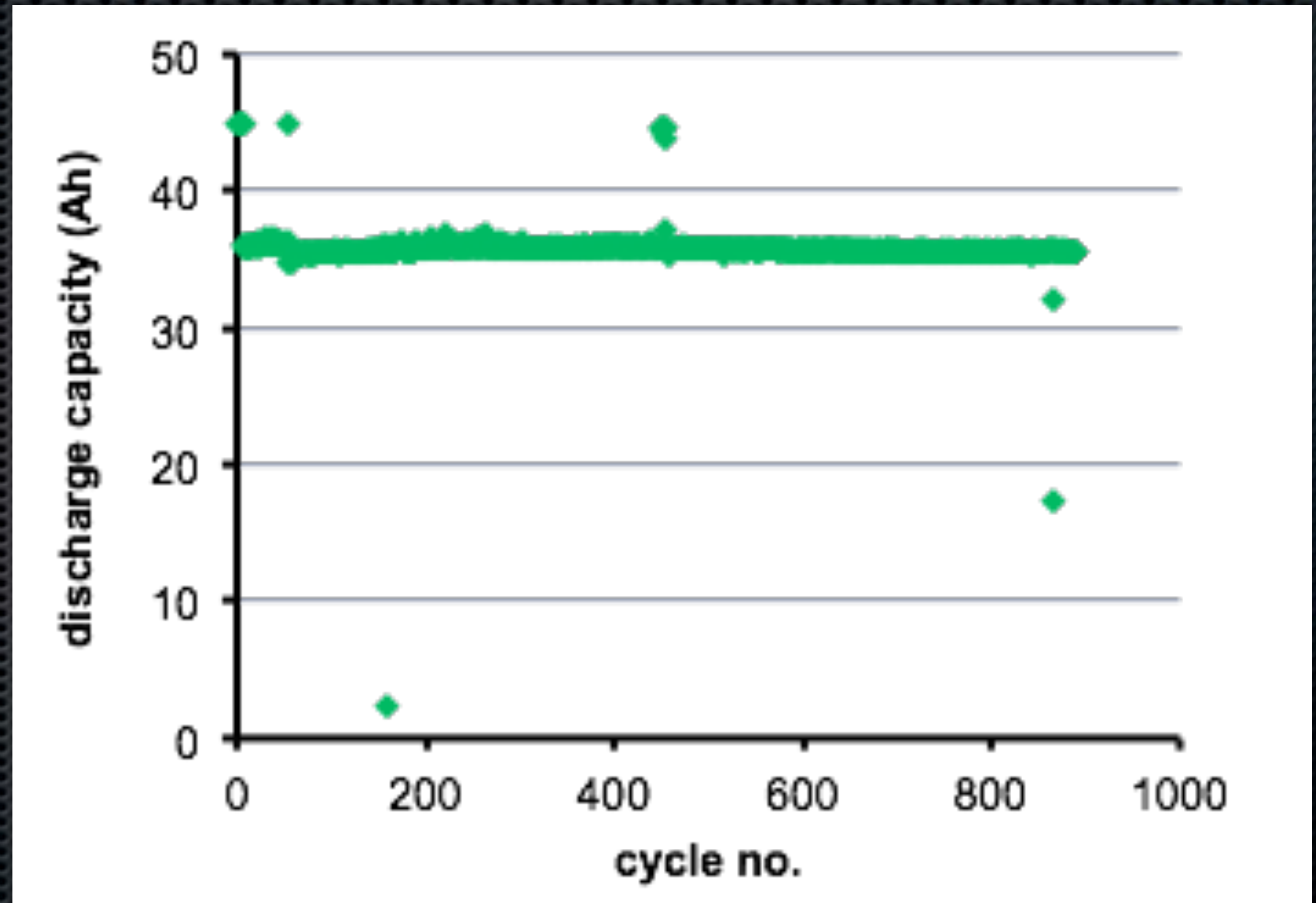
Kangli Wang<sup>1</sup>, Kai Jiang<sup>1</sup>, Brice Chung<sup>1</sup>, Takanari Ouchi<sup>1</sup>, Paul J. Burke<sup>1</sup>, Dane A. Boysen<sup>1</sup>, David J. Bradwell<sup>1</sup>, Hojong Kim<sup>1</sup>, Ulrich Muecke<sup>1</sup> & Donald R. Sadoway<sup>1</sup>

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

fade rate is  $\sim 0.0009\%/cycle$

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

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



# grid level storage

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- silent

- emissions-free

- no moving parts

- remotely controlled

- designed to the price point of today's electricity market





what have we learned?

what are the heterodoxies?

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● temperature: ~~low~~ high

● scaling: ~~many~~ fewer

● human resources: ~~experts~~ novices

Culture e



breakfast.

*“Never, ever, think outside the box.”*

10000 LIRE DIECIMILA

PAGABILI A VISTA AL PORTATORE

IL GOVERNATORE

*Antonio Fazio*

IL CASSIERE

*Alvina*

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