Sustainable Energy Generation, Distribution, and Security

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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
> 1 GWh / year production capacity line

Global production (kg/yr)

Atomic number, Z
a modern aluminum smelter

1886
Charles Martin Hall, USA
Paul L.T. Héroult, France

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

liquid metal battery
on discharge

\[ \text{Mg}_{\text{liquid}} \rightarrow \text{Mg}^{2+} + 2 \text{e}^- \]

\[ \text{Mg}^{2+} + 2 \text{e}^- \rightarrow \text{Mg}_{\text{liquid alloy}} \]
on charge: electrorefine Mg out of Sb
attributes of LMB

- composed of earth-abundant elements
- self-assembling ✅ easy to manufacture
- round-trip efficiency ≈ 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

BANCA D'ITALIA

Prof. A. Volta
MIT Energy Initiative

Total

home:
coupled with solar
$4 million

community:
mini-grid
$7 million

arpae
Liquid Metal Battery Team at MIT (summer 2010)

20 × 3  ⇒  3 × 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
Lithium–antimony–lead liquid metal battery for grid-level energy storage
Kangli Wang, Kai Jiang, Brice Chung, Takanari Ouchi, Paul J. Burke, Dane A. Boysen, David J. Bradwell, Hojong Kim, Ulrich Muecke & Donald R. Sadoway
liquid metal battery status report

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- 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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Free lecture notes, exams, and videos from MIT.
No registration required.

» Learn more
from cells to batteries: all new manufacturing facility
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 (~300 mA/cm²) & 93% DOD
- fade rate is ~0.00009%/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)

- Discharge Capacity (Ah)
- Coulombic Efficiency
- Cycle Count

- tot_discharge_capacity
- cyc_q_Eff
grid-level storage: 1 MWh on a 50 m\(^2\) 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

\[ \text{Mg}^{(\text{liquid alloy})} + 2 \text{e}^- \rightarrow \text{Mg}^{2+} \]

\[ \text{Mg}^{2+} + 2 \text{e}^- \rightarrow \text{Mg}^{(\text{liquid})} \]
on further charging

\[ \text{Mg}^{2+} + 2 \text{e}^- \rightarrow \text{Mg}^{\text{liquid}} \]

\[ \text{Sb} + 3 \text{e}^- \rightarrow \text{Sb}^{3+} \]
ZEBRA unchained
10 cm × 10 cm with 240 Ah
20 cm × 20 cm with 1,140 Ah
and near-zero capacity fade
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