The Role of Energy Storage: What is Needed?

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The World Online

<table>
<thead>
<tr>
<th>Percentage of people online</th>
<th>Description</th>
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<tr>
<td>80–100%</td>
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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.
The Archipelago of Disconnection

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

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

This visualization uses 2013 data from the World Bank's Worldwide Development Indicators project and data from Natural Earth.
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
  - design holistically
inventing a colossal yet cheap battery

pose the right question

- 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

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

1886

Charles Martin Hall
Paul-Louis-Toussaint Héroult

liquid metal battery

- liquid magnesium
- molten salt electrolyte
- liquid antimony

refractory lining
Liquid Metal Battery Team at MIT (summer 2007)
home: coupled with solar
$4 million

community: mini-grid
$7 million
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 Wang¹, Kai Jiang², Brice Chung², Takanari Ouchi¹, Paul J. Burke¹, Dane A. Boysen¹, David J. Bradwell¹, Hojong Kim¹, Ulrich Muecke² & Donald R. Sadoway¹
๏ cell operated at accelerated rate (~300 mA/cm²) & 93% DOD

> 99% initial capacity after 10 years of daily cycling

> 80% initial capacity after 607 years of daily cycling
grid-level storage

- 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?

- temperature: low high
- scaling: many fewer
- human resources: experts novices
Culture eats strategy for breakfast.

“Never, ever, think outside the box.”
Prof. A. Volta