Innovation in Energy Storage

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outline of this afternoon's talk

- energy storage landscape
- innovation in energy storage
  - electrometallurgical approach

for stationary storage applications

misconceptions about batteries

- not much has changed: not true!

electrochemistry and energy storage: noble origins

electrical energy storage

	(Wh/kg)	(MJ/kg)
lead acid	35	0.13
NiCd	45	0.16
NaS	80	0.28
NiMH	90	0.32
Li ion	150	0.54

misconceptions about batteries

- not much has changed: not true!
- no Moore's Law
  (transistor count doubles every 2 years)
- all microelectronics are silicon-based
- all new batteries are based on
  entirely new chemistries
  - ☞ radical innovation

different approaches for different applications

- don’t pay for attributes you don’t need
- cell phone needs to be idiot-proof
- car needs to be crashworthy
- how about service temperature?
  - ☞ human contact?
- stationary batteries: more freedom in choice of chemistry but very low price point

market price points

APPLICATION	PRICE POINT
laptop computer	$2,000 - $3,000 / kWh
communications	$1,000 / kWh
automobile traction	$250 / kWh
stationary storage	$100 / kWh

severity of service conditions

price

storage is the key enabler

- for deployment of renewables:
  intermittency obstructs contribution to baseload
- for load leveling, load following, frequency regulation,
  off-peak capture: colossal battery
- for grid-level storage, battery vs combustion
  - ☞ need to think differently
- today's Li-ion batteries fail badly
  - ☞ the whole is less than the sum of its parts:
    - ☞ ***plinergy***
- confine chemistry to earth-abundant elements
  - ☞ to make it dirt-cheap, make it out of dirt

accelerating the rate of discovery

- there is plenty of room at the top
- the field is woefully underfunded:
  energy research in total by government
  $1.4B (2006) < ⅙ 1979 figure
  - c.f. medical research rose by 4× to $29B
- private sector research spending? worse!
  US energy industry < 0.25% revenues
  - c.f. pharmaceuticals 18%
    - semiconductors 16%
    - automotive 3%

accelerating the rate of discovery

- more money ☞ more people
  ☞ sustained effort ☞ the brightest minds

- new approaches:
  computational materials science
  ☞ Volta meets Schrödinger

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for stationary storage applications

how to think about inventing a colossal yet cheap battery

- look at the economy of scale of modern electrometallurgy:
  - ☞ aluminium smelter
    - ✏ bauxite, carbon, 14 kWh electricity, $5000/tonne capital cost
    - ☞ metal cost < 50¢/lb

how to think about inventing a colossal yet cheap battery: pose the right question

☞ start with a giant current sink

convert this…

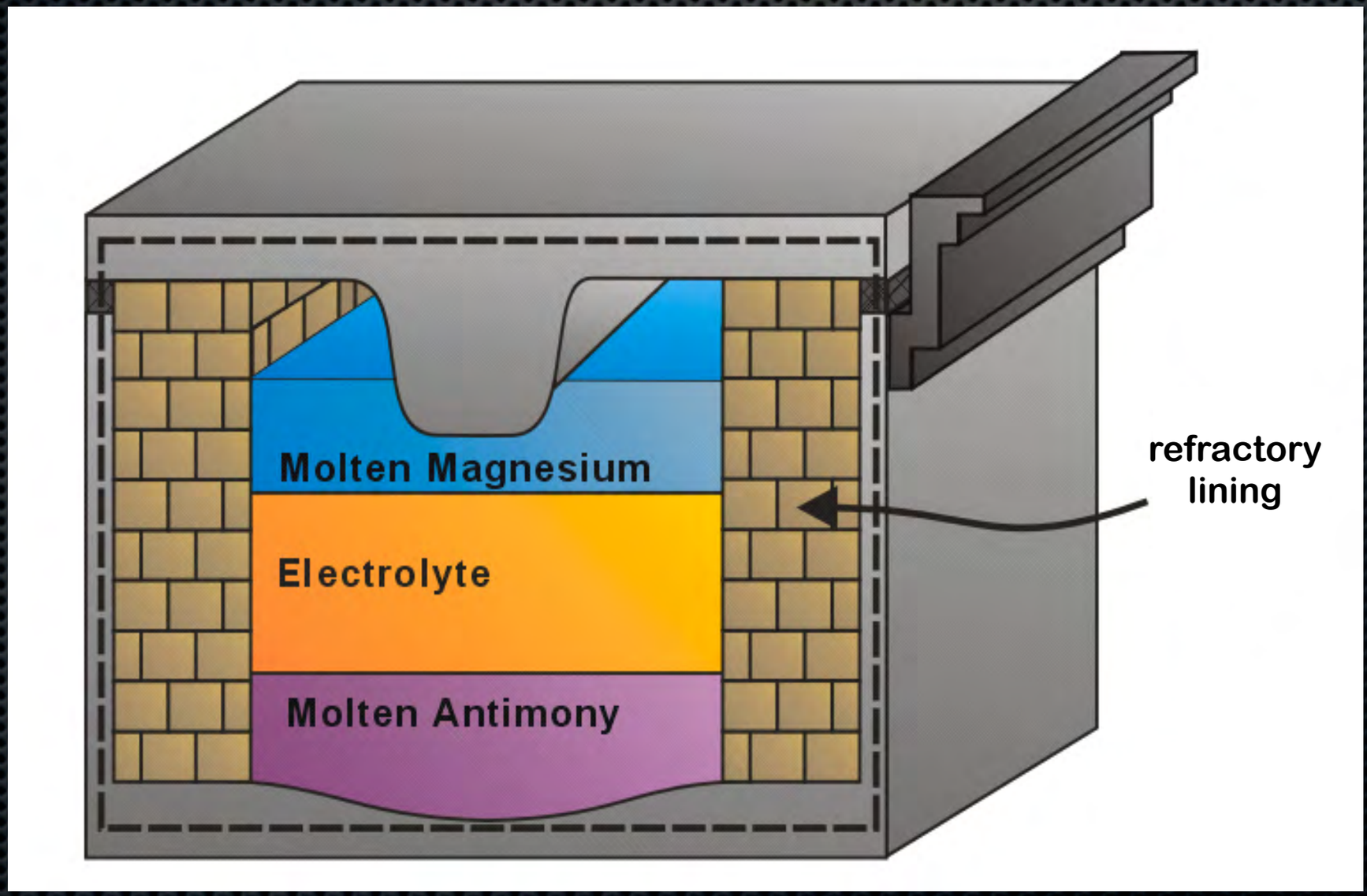
aluminium potline

350,000 A, 4 V

…into this

work started 6 years ago with internal funding from the Deshpande Center and the Chesonis Family Foundation

liquid metal battery

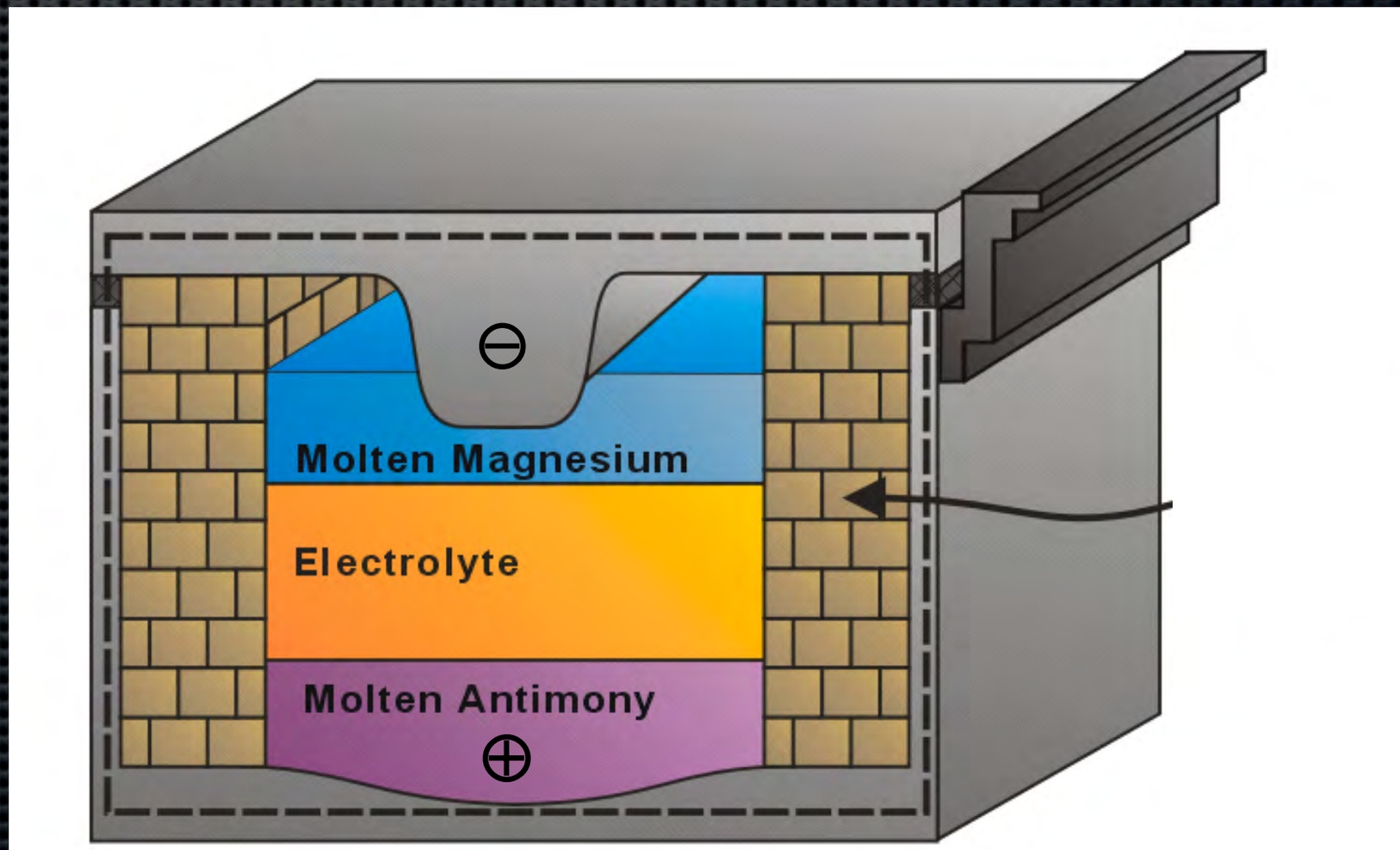


on discharge

$$Mg_{(liquid)} \Rightarrow Mg^{2+} + 2\,e^-$$

$$Mg^{2+} + 2\,e^- \Rightarrow Mg_{(liquid\ alloy)}$$

liquid metal battery



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DARPA

DESHPANDE CENTER FOR TECHNOLOGICAL INNOVATION

LIGHTSPEED VENTURE PARTNERS

CHESONIS FAMILY FOUNDATION

TOTAL

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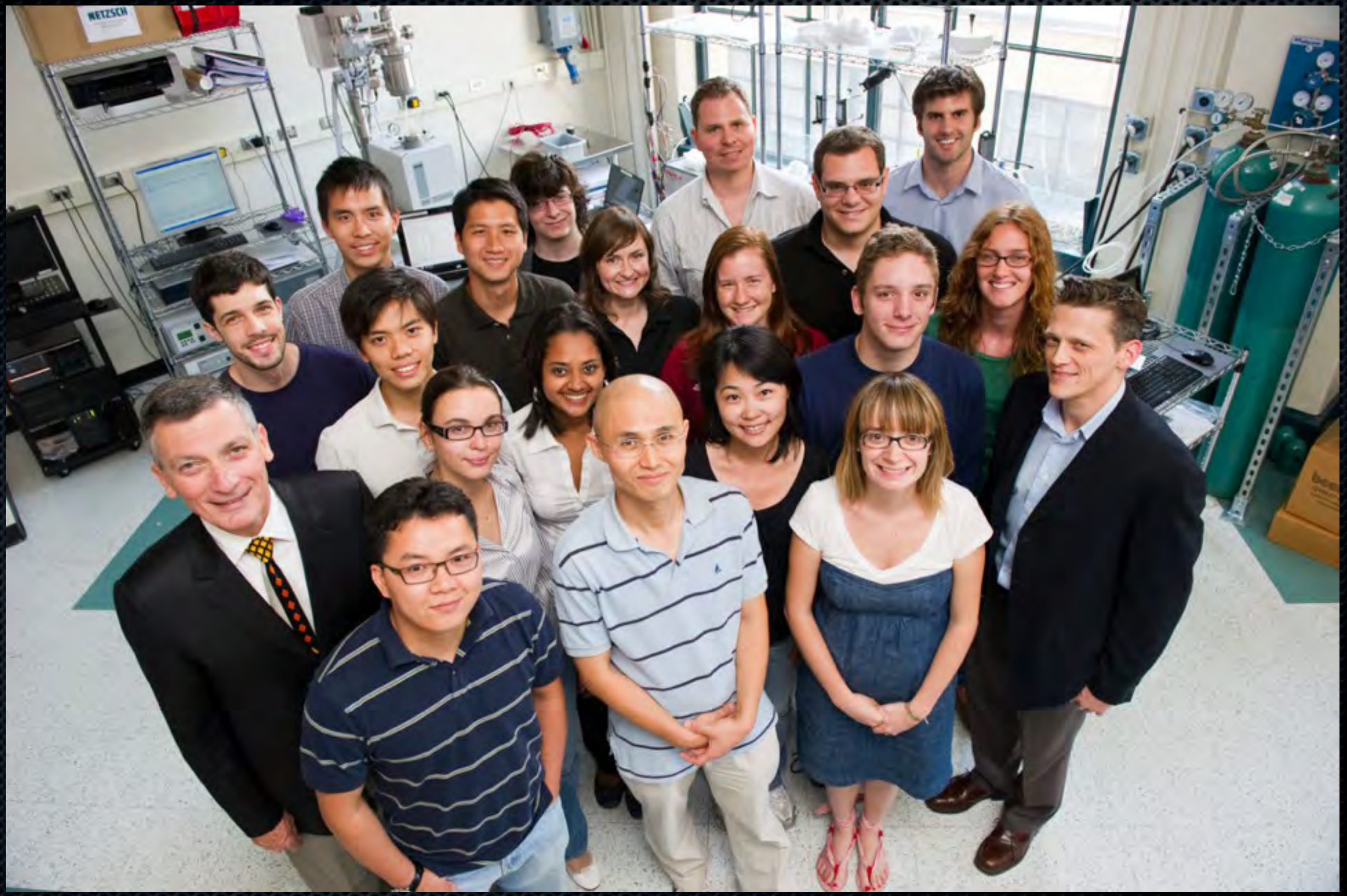
home:
coupled
with solar
$4 million

community:
mini-grid
$9 million

Liquid Metal Battery Team



opportunities for basic science

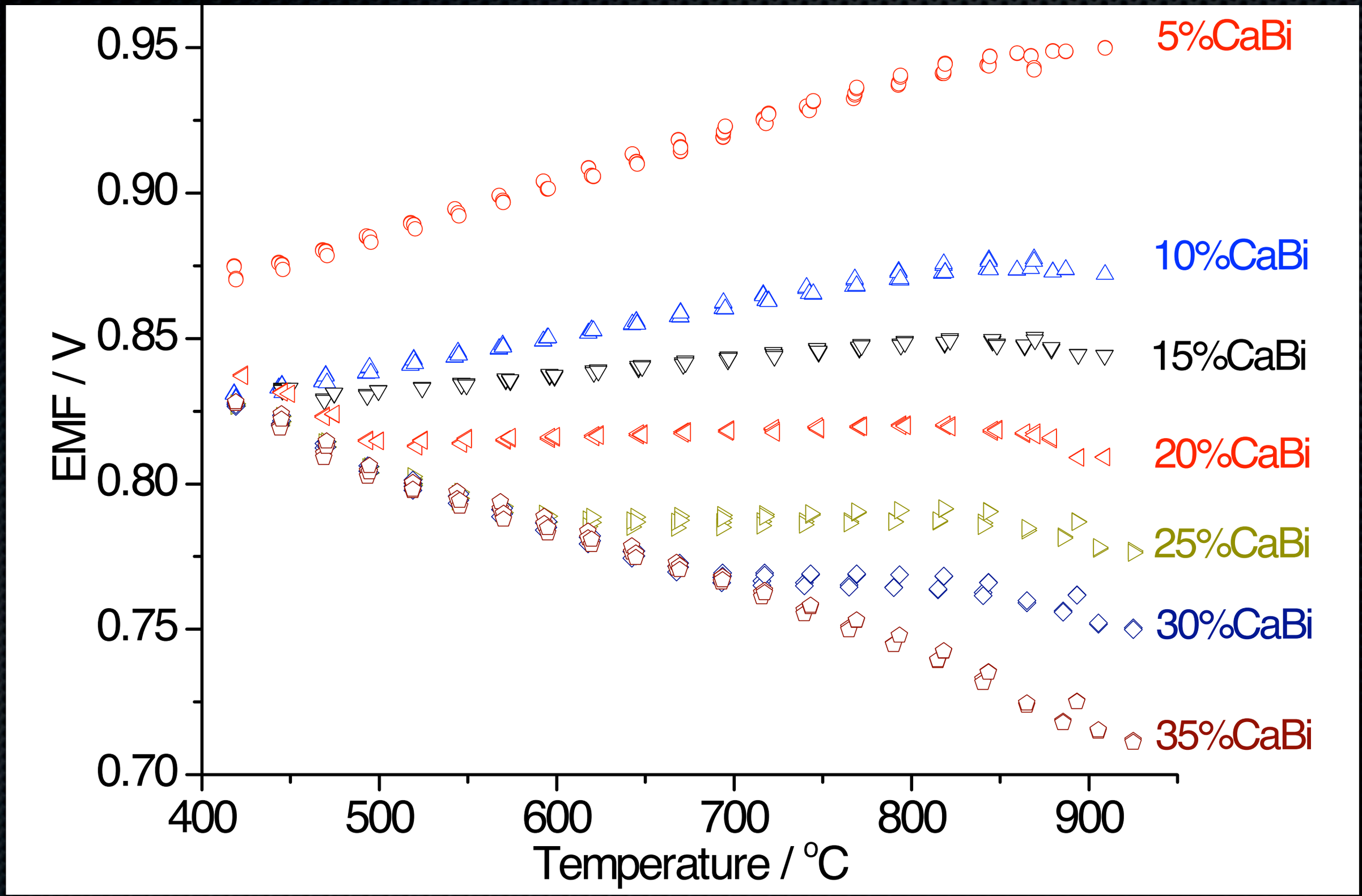
- database is spotty: alloys lacking widespread commercial use

- theory not ready to predict properties of liquid metals and alloys
  - properties must be measured

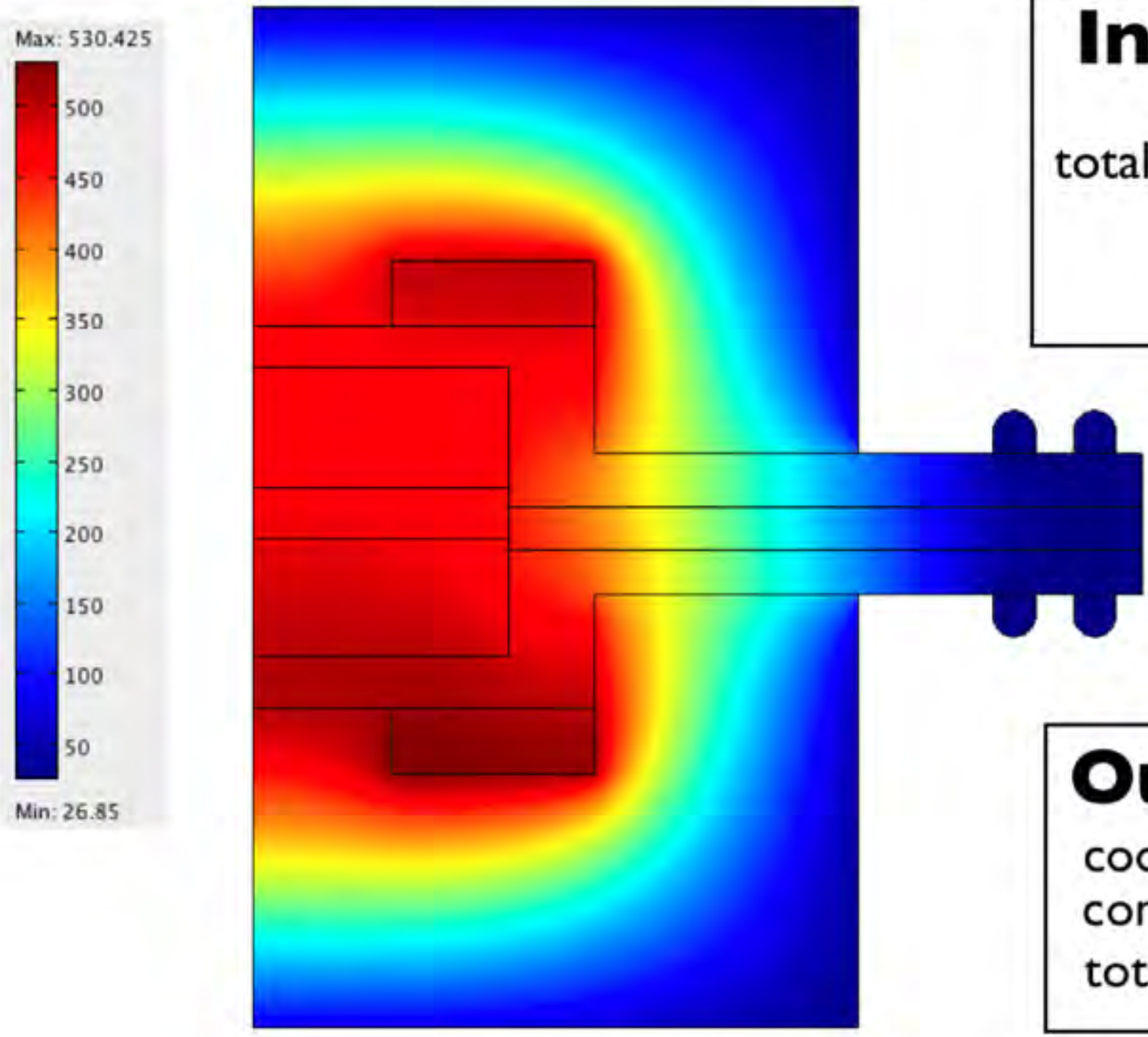
- emf data in molten salts require verification with candidate metal couples
  - "*доверяй, но проверяй*"
    ...*trust, but verify*...

activity measurements of Ca - Bi alloys

activity measurements of Ca - Bi alloys



Results: Addition of insulation



Input

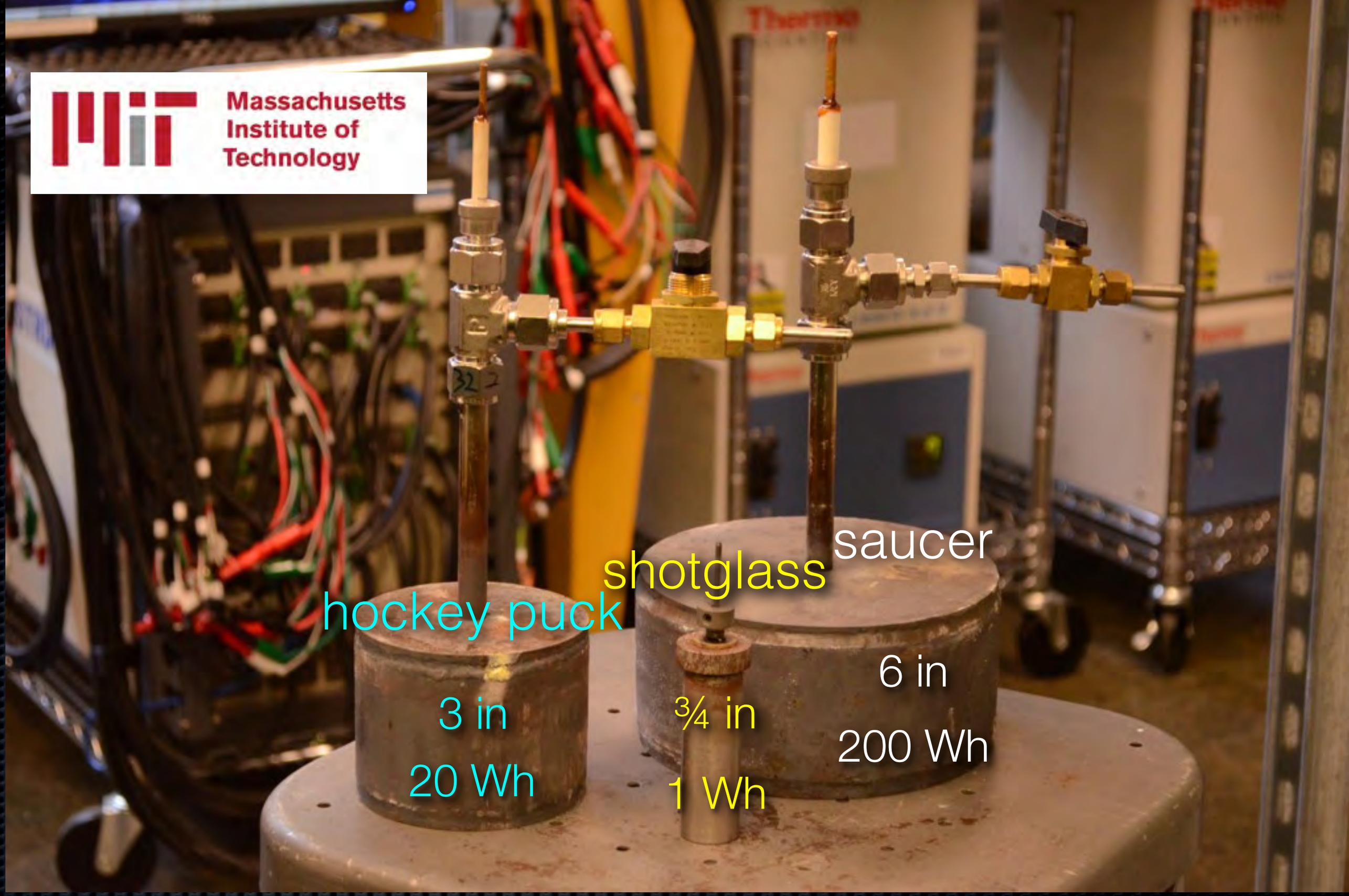
total = 934.6 W

Output

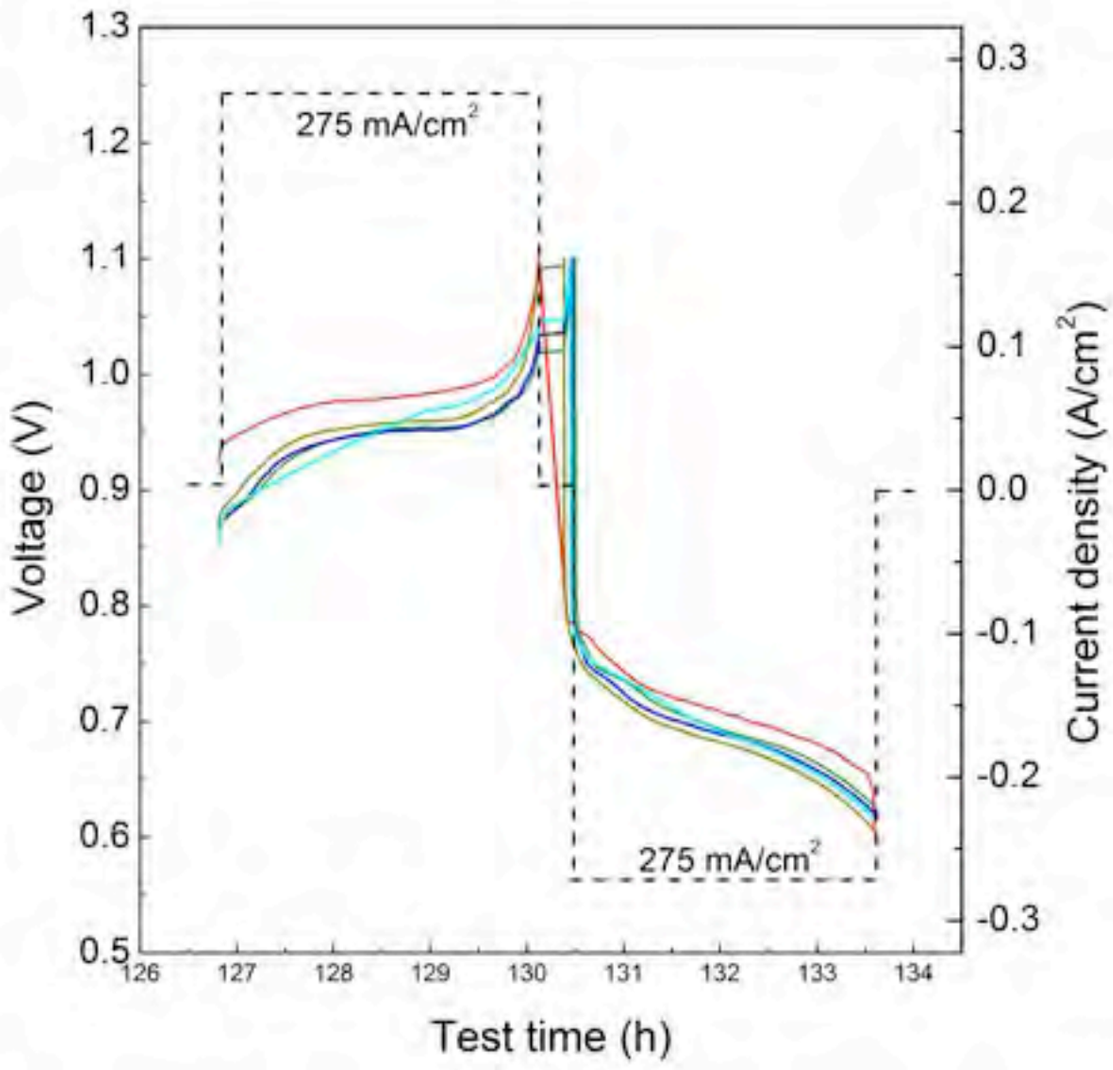
cooling lines = 719 W
convective = 146.5 W
total = 865.5 W

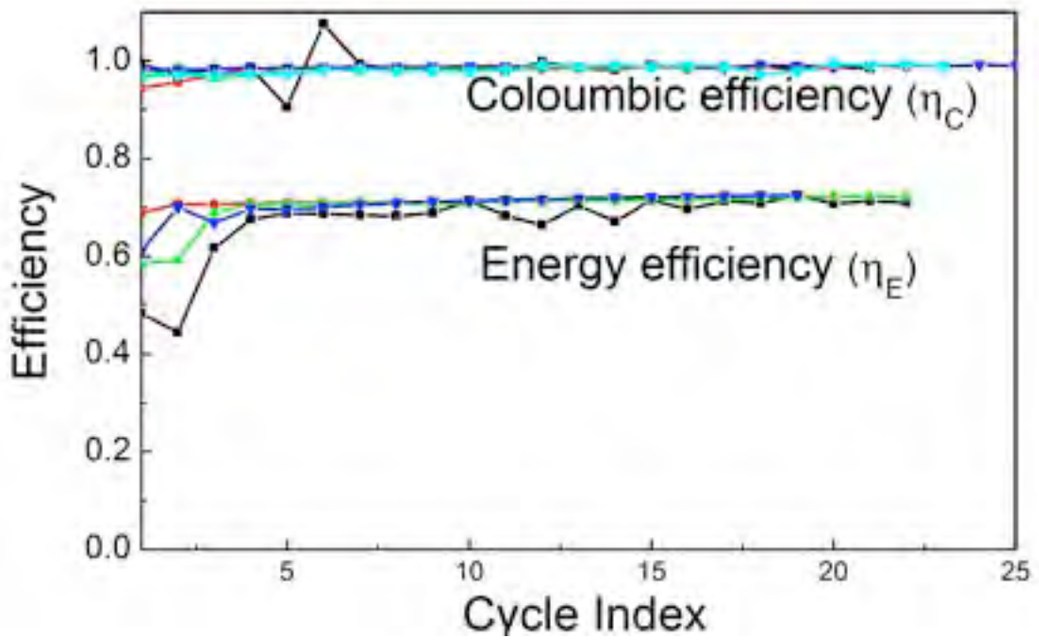
$$Q_{source} = 7.2 \left[\mathrm{W/cm^3} \right]$$

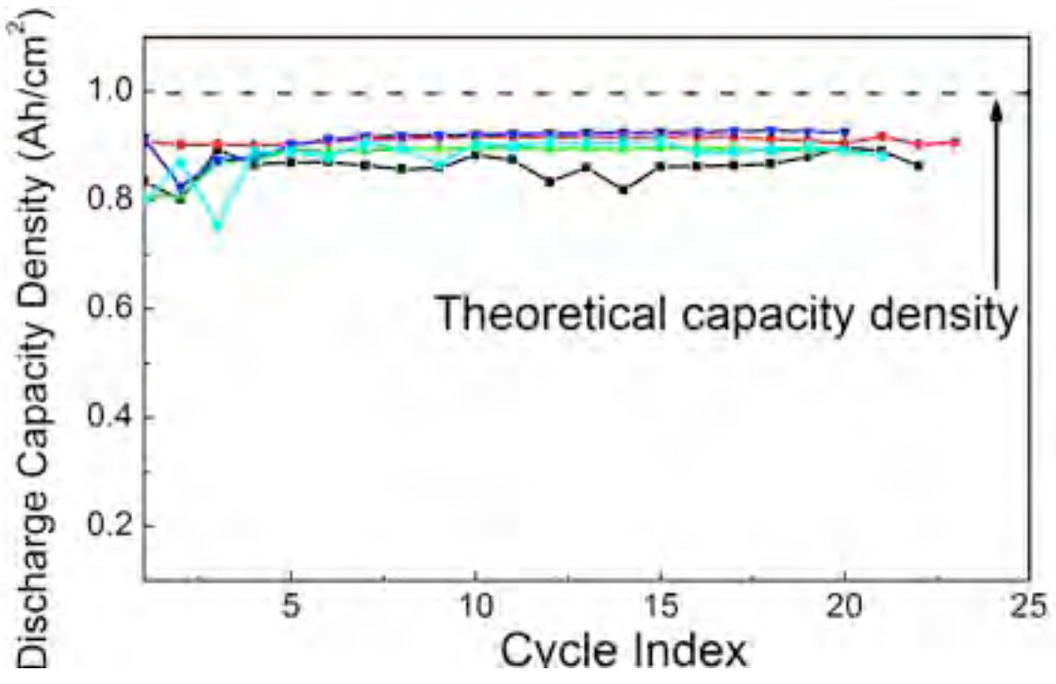
Massachusetts Institute of Technology

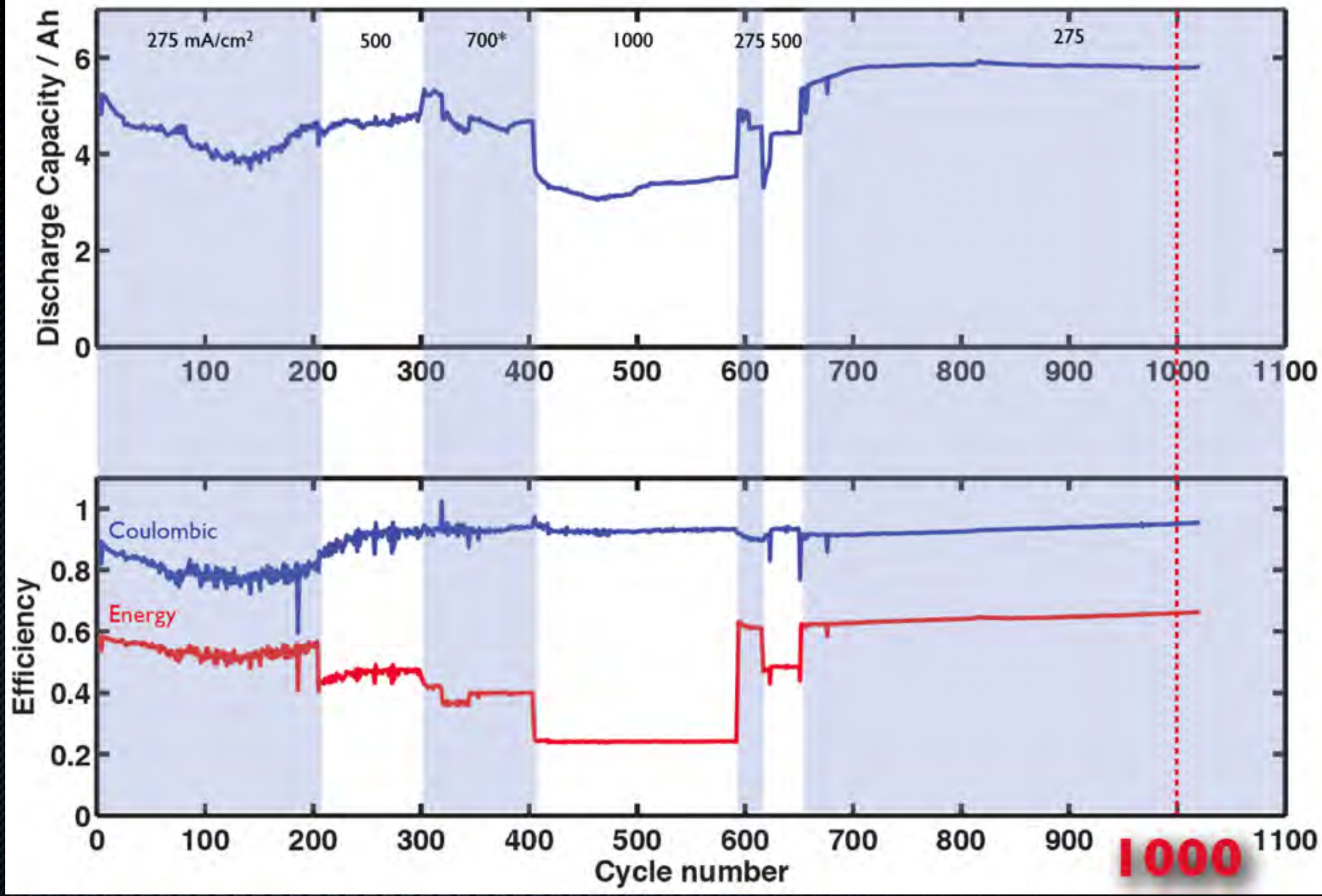


Performance Data from 20 Ah cells “hockey puck”








275 mA/cm²
500
700*
1000
275 500
275
Discharge Capacity / Ah
0
2
4
6
100
200
300
400
500
600
700
800
900
1000
1100
Coulombic
Energy
Efficiency
0
0.2
0.4
0.6
0.8
1
Cycle number
1000

liquid metal battery status report

- liquid metal battery works:
  - over 700 cells tested
  - many chemistries: alloys & salts
  - $100/kWh for electrodes + electrolyte

- capacity fade < 0.005% / cycle
  > 70% retention after 15 y of daily cycling

- accelerating scale-up to self-heating cell
  - startup company:
    Liquid Metal Battery Corporation

LIQUID METAL BATTERY CORPORATION
LMBC

Liquid Metal Battery Corporation

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

TOTAL

Liquid Metal Battery Corporation

- established in 2010 to bring liquid metal battery to market
- series B funding
  $15 million from

khosla ventures
venture assistance, strategic advice, venture capital

TOTAL

- 20 people at 700 m^2 facility in Cambridge

The LMBC Laboratory

Main laboratory:

Other major equipment :

- 500A & 100 A battery testers
- Test stands for medium and large cells

New equipment :

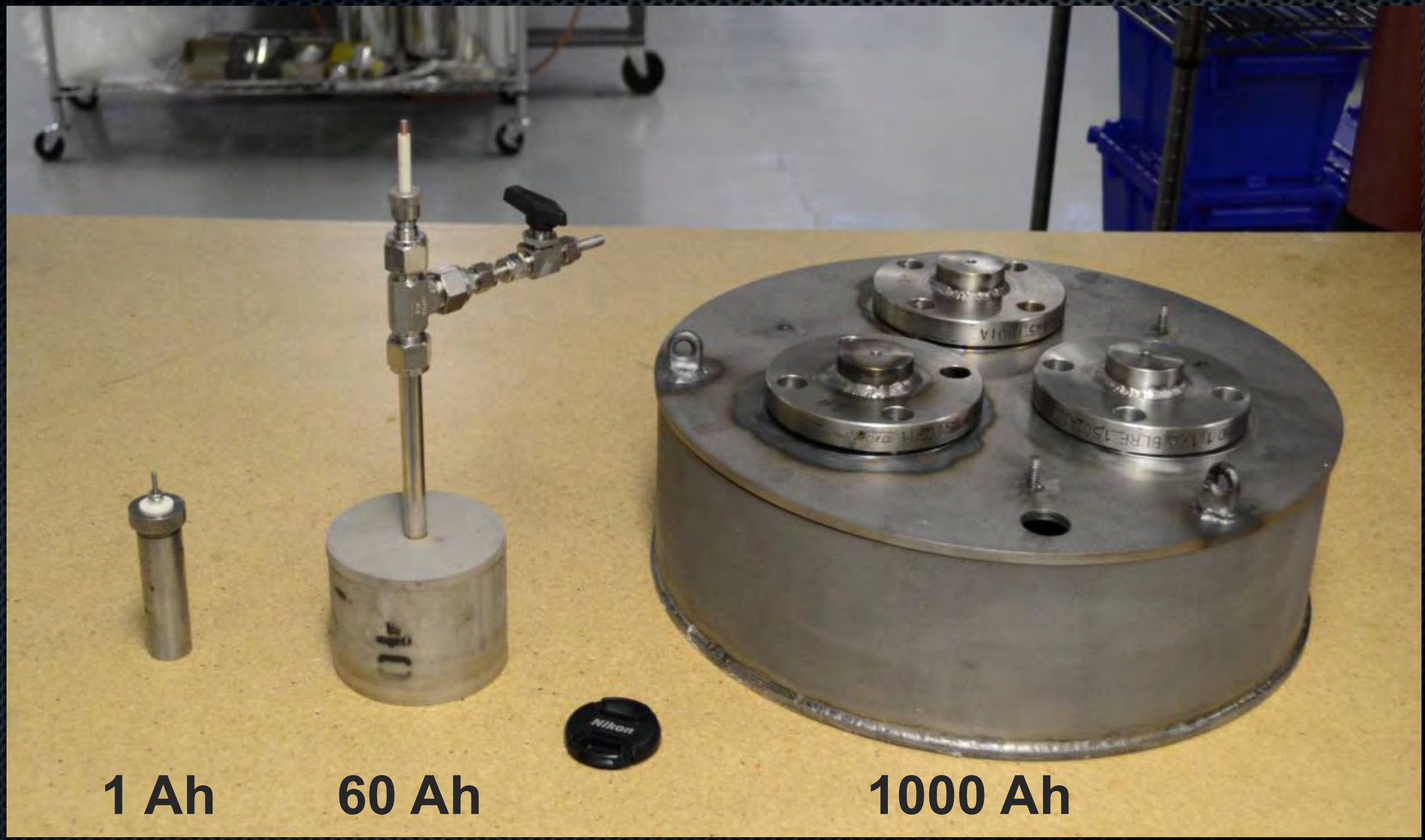
Band saw

Salt drying infrastructure

TIG welder

Sand blaster

Cell scale-up: shotglass ⇨ pizza



Cell

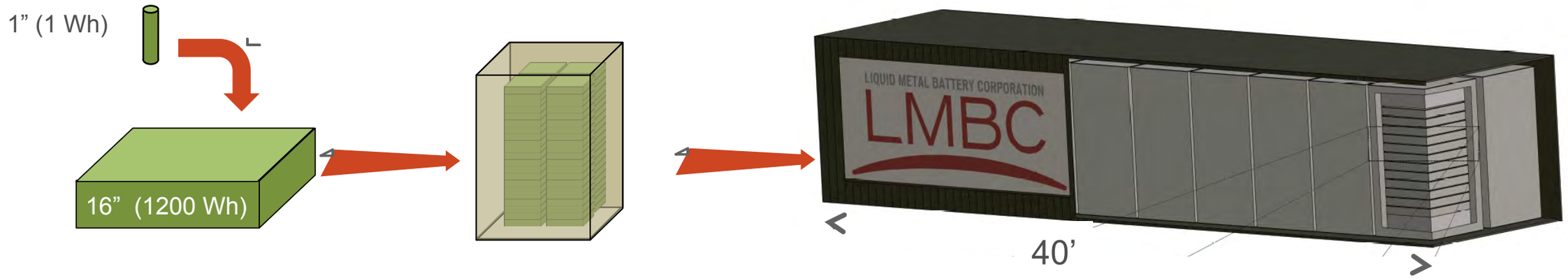
Scale 1 Wh to > 1200 Wh

Module

25 kW (100 kWh)

System

0.5 MW (2 MWh)



grid-level storage

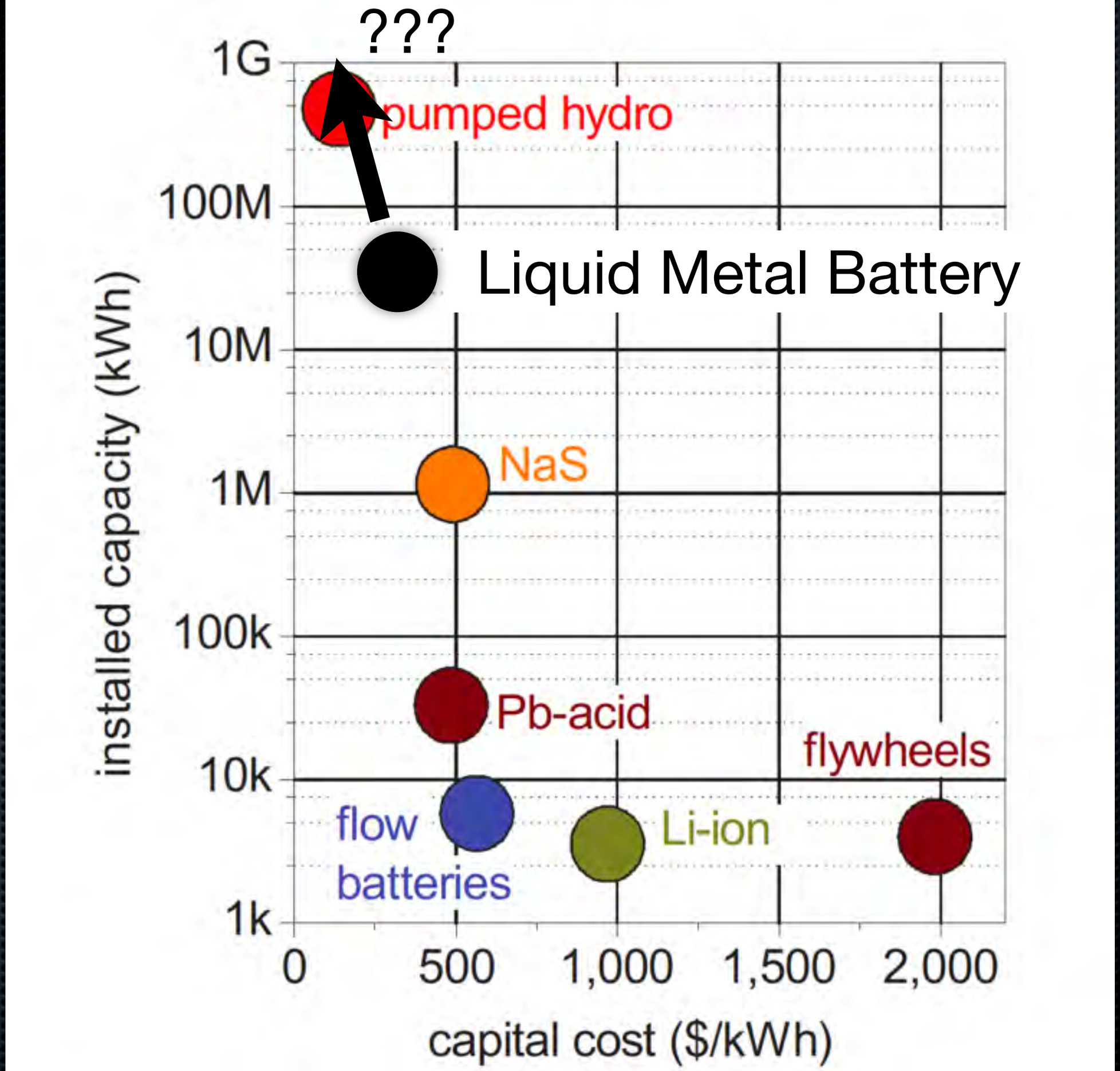
- silent
- emissions-free

- no moving parts
- remotely controlled
- designed to the market price point

- without subsidy!!!

advantages over competitors

- no siting limitations
- mechanically simple (fault tolerant)
  - pumps?
  - O-rings?
  - separators?
- high-capacity cell
  - 100× fewer connections
- simple electrochemistry
  - single phase: no TPJs, no intercalation


???
1G
100M
10M
1M
100k
10k
1k
installed capacity (kWh)
pumped hydro
Liquid Metal Battery
NaS
Pb-acid
flywheels
flow
batteries
Li-ion
0
500
1,000
1,500
2,000
capital cost ($/kWh)

… next steps

- ✏ continue basic research at MIT:
  - ☞ 20 Ah cell and 200 Ah cell
  - ☞ new chemistries: alloys & salts

- ✏ accelerating scale-up to self-heating cell at Liquid Metal Battery Corporation
  - ☞ establish relationships with strategic partners to define business opportunities

LIQUID METAL BATTERY CORPORATION
LMBC

electrochemistry and energy storage: noble origins bright future

The End

related viewing and contact information

http://www.ted.com/talks/donald_sadoway_the_missing_link_to_renewable_energy.html

http://www.youtube.com/watch?v=vDHET3aCI2U&feature=youtube_gdata_player

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