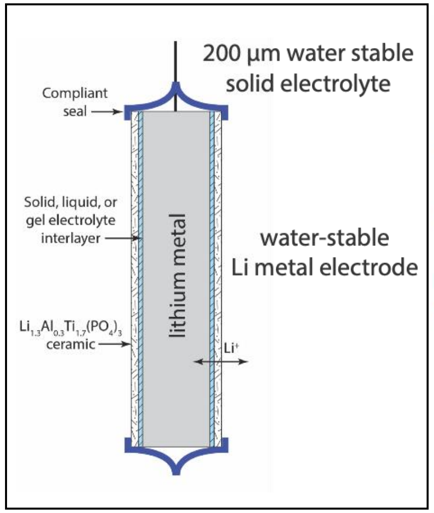
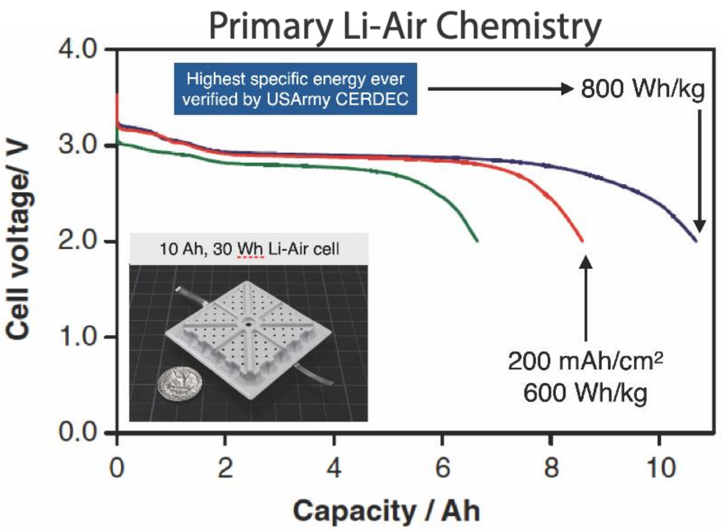
Technology Innovation Blast – Thursday AM

July 13, 2023

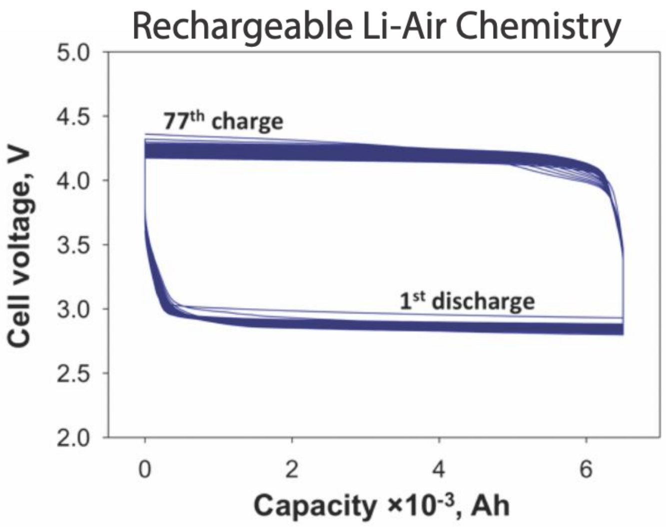
Lithium/Air batteries for Ultra High Specific Energy Applications



Primary Li-Air Chemistry



Rechargeable Li-Air Chemistry



Li/O_2 in aqueous electrolytes:

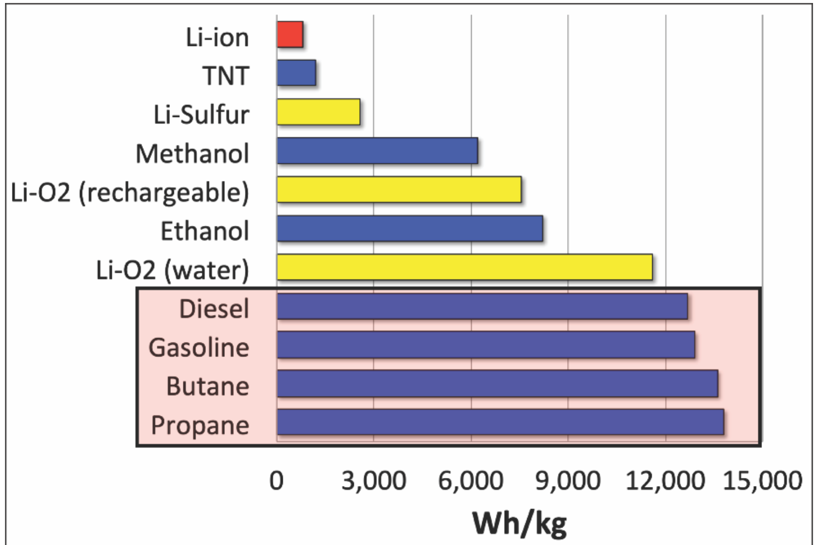
Basic electrolyte: $4Li + O_2 + 2H_2O = 4LiOH$ **E=3.45V**

Acidic electrolyte: $4Li + O_2 + 4H+ = 2H_2O + 4Li$ **E=4.27V**

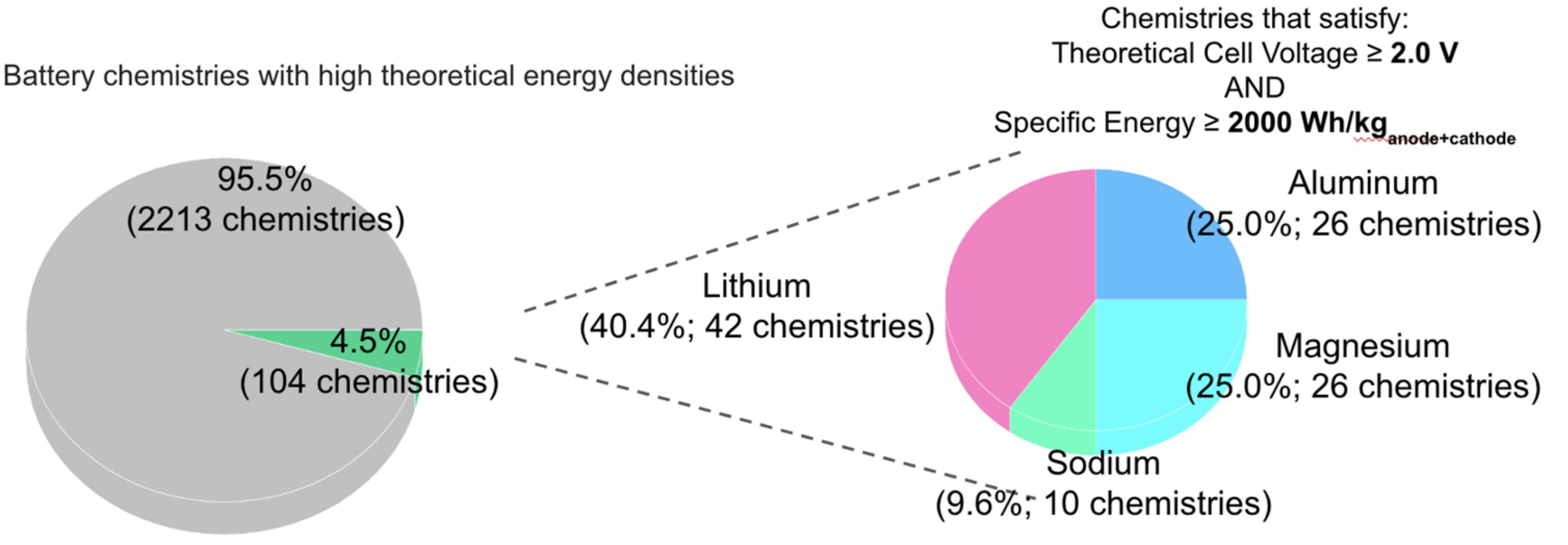
Li/O2 in non-aqueous electrolytes:

$Li + O_2 = Li_2O_2$ (peroxide) **E=2.96V**

- Primary Li-Air cells have active loading of approximately 250 mAh/cm²
- Protected lithium electrodes (PLEs) are water-stable with a self-discharge rate of zero
- Secondary Li-Air cells typically cycle O_2 capacity of 3 to 6 mAh/cm²
- Primary Li-Air cells have consistently achieved **800 Wh/kg** in government laboratories and over **1,000 Wh/kg** in testing at PolyPlus
- Polycrystalline ceramic LATP membranes are 20 to 200 µm in thickness depending on the needs of the specific application



Key parameter	As modeled	Experimentally demonstrated	Projected (commercialized)
Onboard gravimetric energy density (kWh/Kg)	Li/Water	1300 Wh/kg	≥ 2000 Wh/kg
	Li/Air	800 Wh/kg	≥ 1000 Wh/kg
Onboard volumetric energy density (kWh/L)	Li/Water	700 Wh/l	≥ 1900 Wh/l
	Li/Air	500 Wh/l	≥ 700 Wh/l
Refuel, recharge, reactivation time	Mechanical swap in minutes	600 mAh/cm² Li capacity in 150 hours	TBD
Power capability (kW/kg)	Li-Water	2000 Wh/kg at 28 W/kg today	TBD
Life expectation (years and cycles)	More than fifty 10 Ah PLEs have been stored for about 4 years with no loss in capacity. >10 years life is predicted. > 300 cycles expected		
Temperature operating range (°C)	Li-Water cells operate over the entire range of ocean temperatures (-2°C to 32°C). Li-Air cells operate in temperatures suited to aqueous electrolyte, typically 15°C to 30°C.		

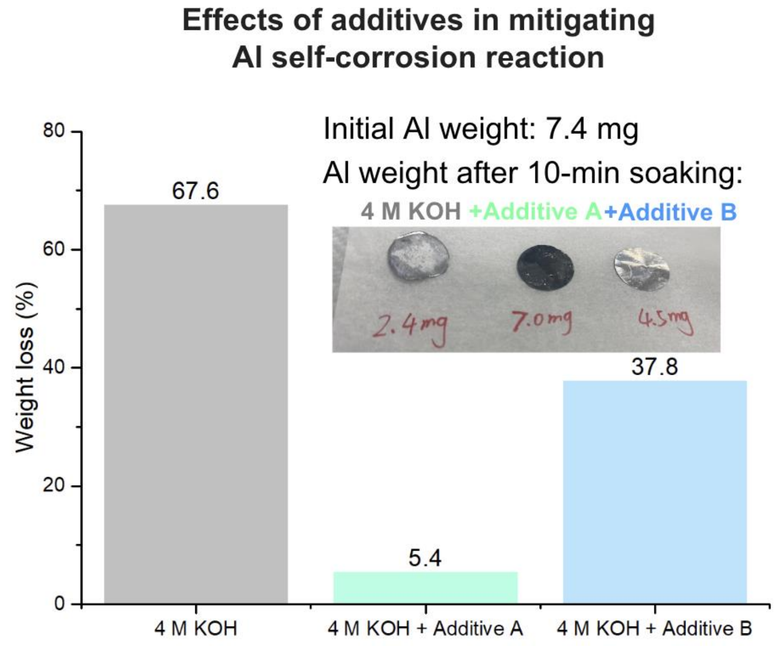


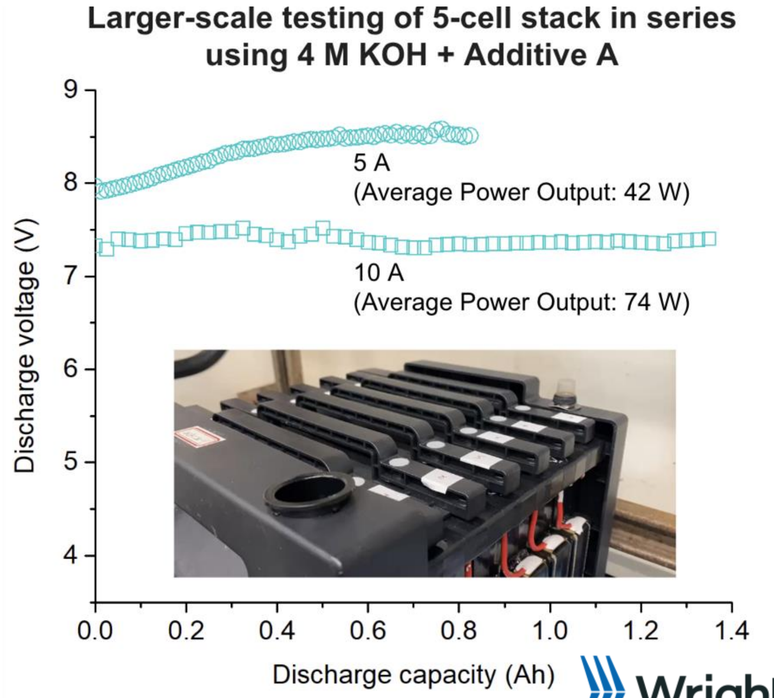
Total cell chemistries surveyed: **2317**

Li-based chemistries: 401
K-based chemistries: 384
Al-based chemistries: 379
Na-based chemistries: 393
Mg-based chemistries: 381
Zn-based chemistries: 379

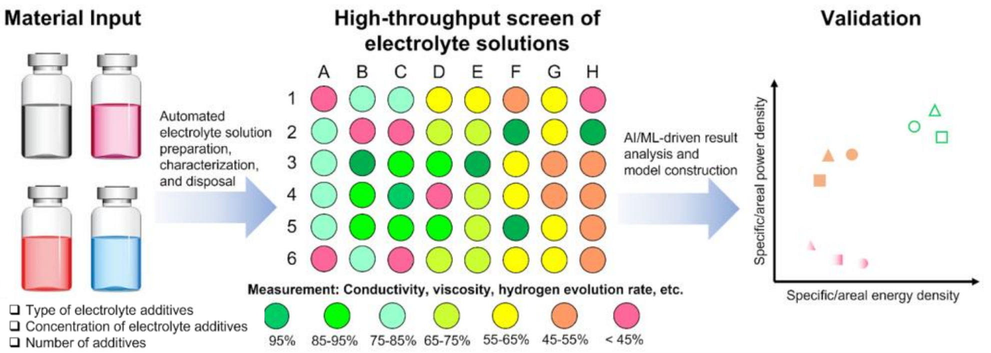
Aluminum and Magnesium account for 50% of potentially promising chemistries

Cao, Wenzhuo, Jienan Zhang, and Hong Li. "Batteries with high theoretical energy densities." *Energy Storage Materials* 26 (2020): 46-55.

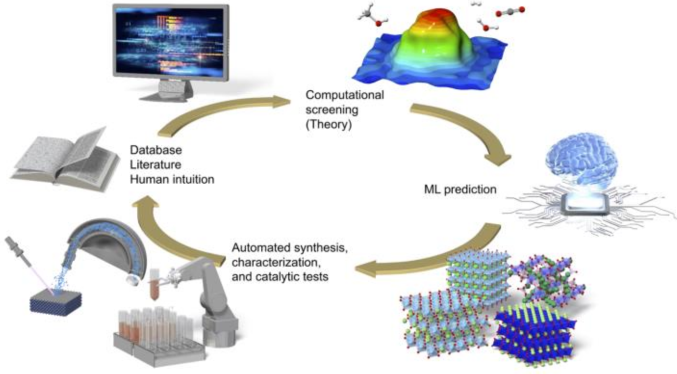




1. High-throughput screening of performant electrolyte additives

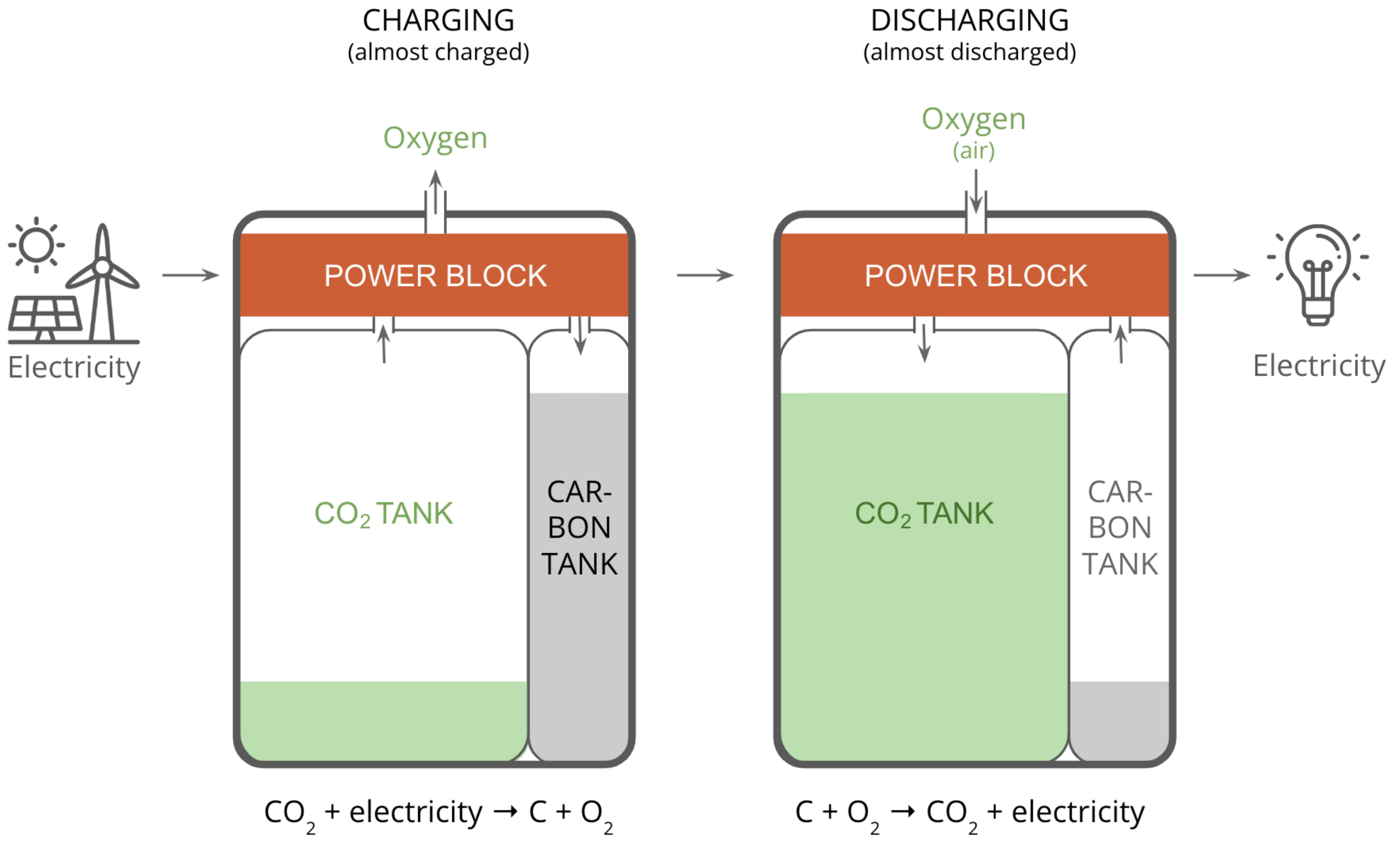


2. AI/ML-assisted discovery of next-generation ORR catalysts



Wright

Noon Energy's carbon-oxygen battery optimized for long-range electric transportation

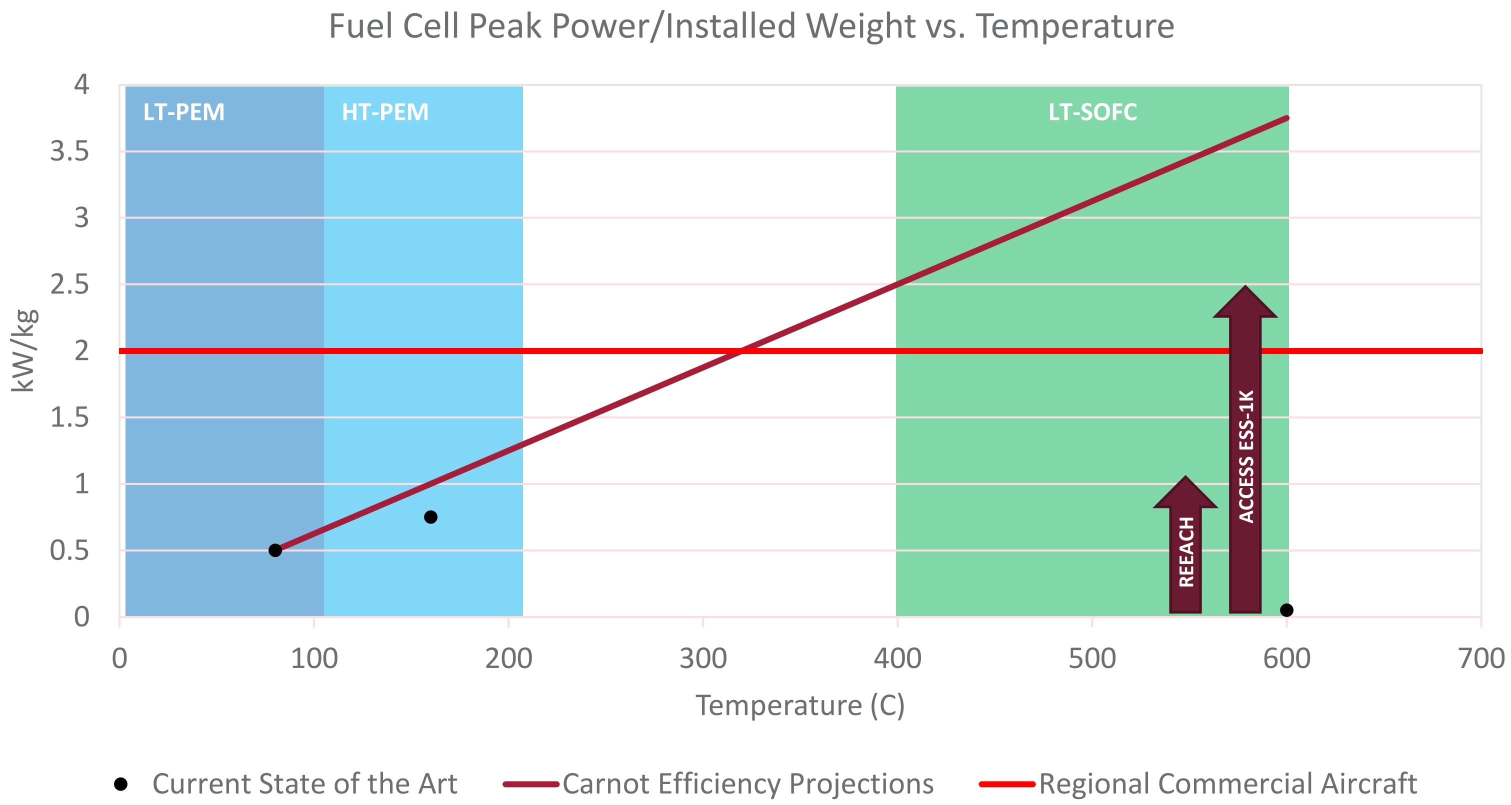


- Independent energy (kWh) and power (kW) capacity
- >1000 Wh/kg and Wh/L possible for full system for 100+ hr long-range applications*
- Good match for long-range marine shipping applications
- <$20/kWh capital cost for long-range
- "Fast-charging" possible by mechanical swapping charged and discharged chemicals (similar to refueling)

* The ceiling (storage media alone) is 2480 Wh/kg at 100% RTE.

ACCESS to the Future of Aviation

Aviation Capable Commercial Energy Storage Solution



magniX

Making Primary Rechargeable

$SE_{practical} = \alpha_{(t-p)} SE_{theoretical}$

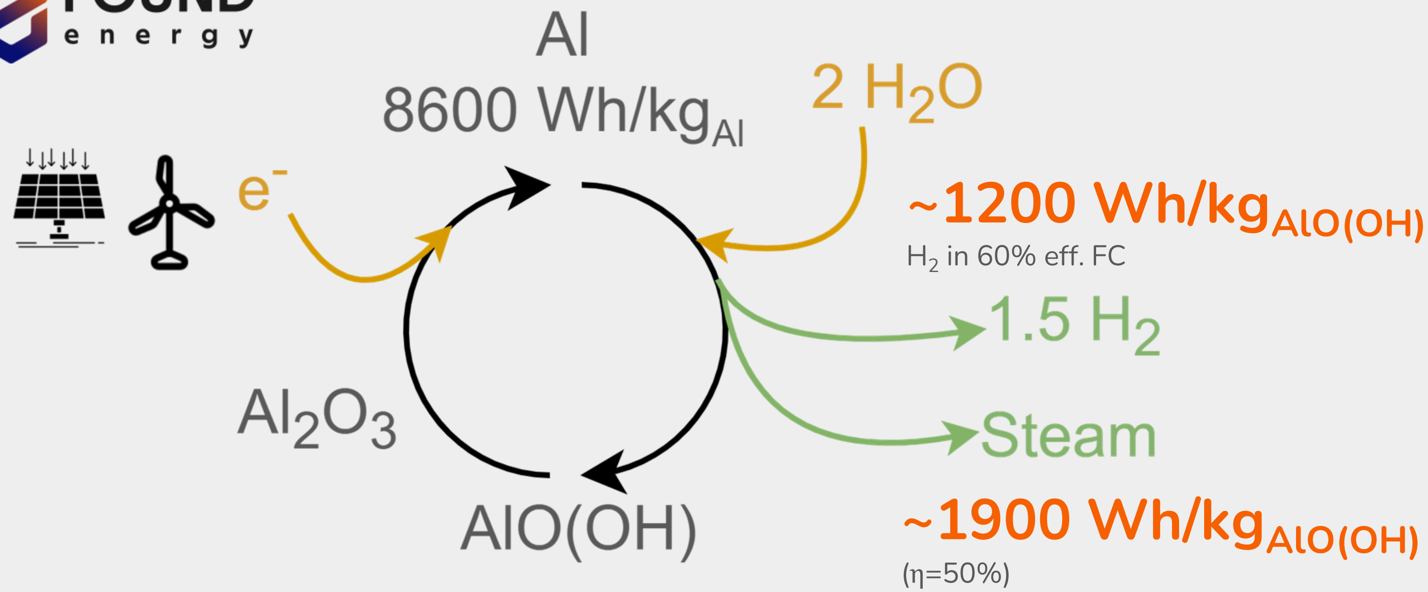
$\alpha_{(t-p)}$, of about 0.5–0.6

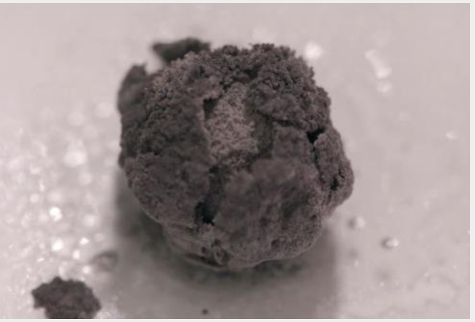
Chemistry	Voltage (V)	Electrons transferred	Theoretical capacity (mAh g^{-1})	Theoretical specific energy (Wh kg^{-1})
Li metal CFx	4	1	900	3600
SF_6	3.69	8	1063	3922
BF_3		3	1186	

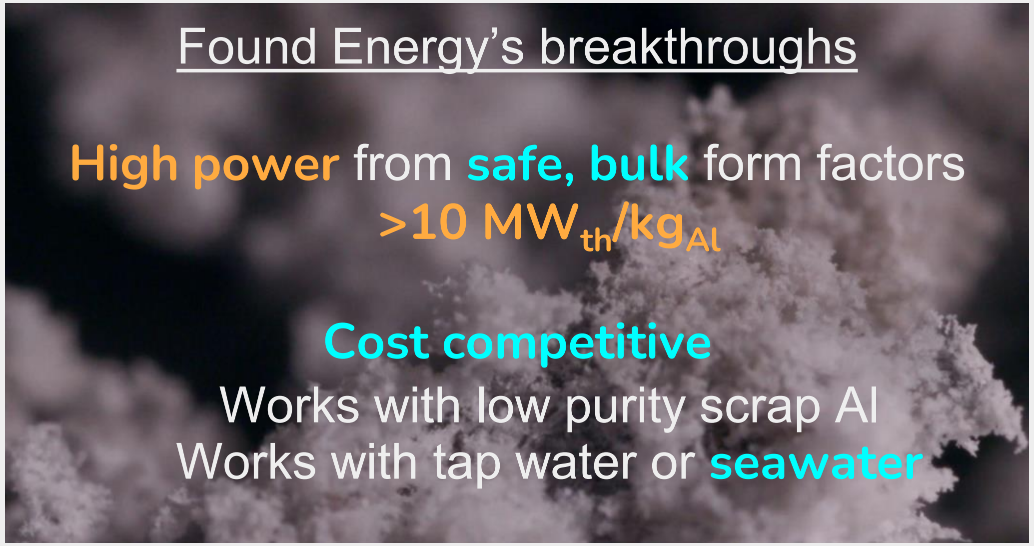
$Li + AF_x \rightleftharpoons LiAF_x \rightarrow LiF + A$

Carnegie Mellon University

V. Viswanathan, A. Epstein, Y.-M. Chiang, E. Takeuchi, M. Bradley, J. Langford, M. Winter, Nature (2022) 601, 519–525

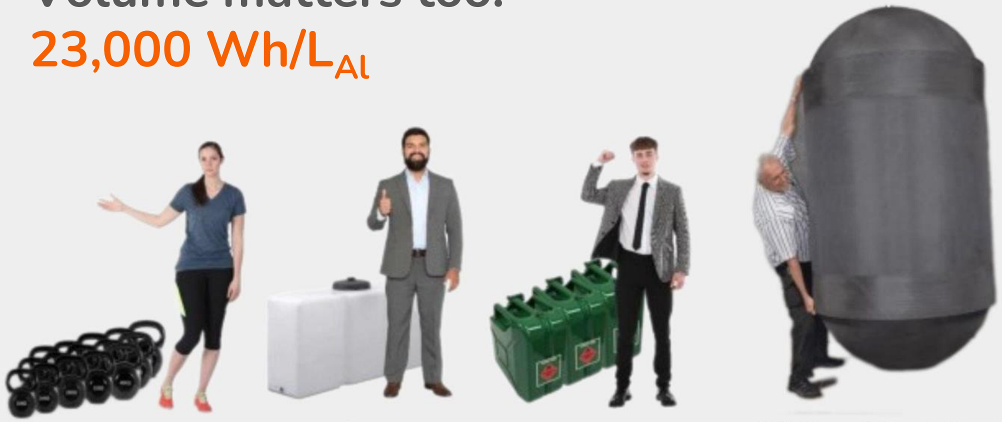






Volume matters too!

23,000 Wh/L$_{Al}$



150 kg of aluminum

150 kg of water

150 kg of diesel

150 kg of liquid hydrogen (excluding insulation and cryogenic cooling)

Source: Liebreich Associates

What's next?

Prototypes (50 kW) → Pilots (> 1 MW)

Improved catalyst economics

Steam utilization trials

Planes, Trains, & (especially) Ships

Washington University in St. Louis

Li-Air Flow Batteries

Dr. Xianglin Li, lxianglin@wustl.edu
Associate Professor, Washington University in St. Louis

arpa-e
EES-1K Workshop
May 10-11, 2023

Challenges of Li-Air Batteries

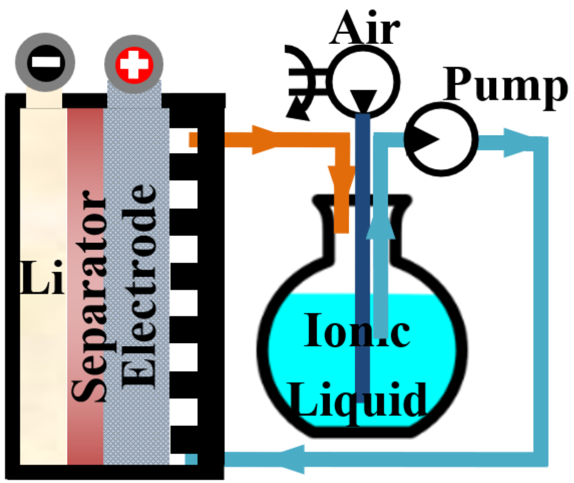
☹ **Low Current/Power Density**
- Li-Air : 0.1 mA/cm^2
- Fuel Cell: 1,000 mA/cm^2

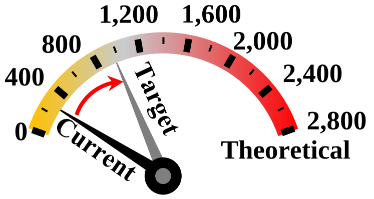
Low diffusivity of oxygen in liquid electrolyte
- 0.22×10^{-4} cm^2/s (O_2 in liquid electrolyte)
- 0.22 cm^2/s (O_2 in air)

☹ **Evaporation of Electrolyte (Open System)**

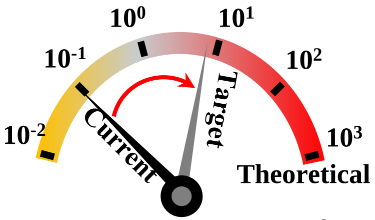
Theoretical Capacity of Li-Air Battery: **2,790 Wh/kg** (Li + separator + electrolyte + carbon electrode)

☺ **Li-Air Flow Battery Using Ionic Liquids (ILs)**

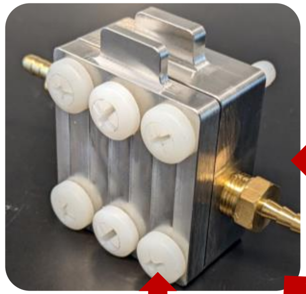




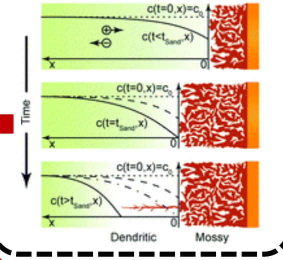
Specific Capacity (Wh/g)
Increase the Flight Range



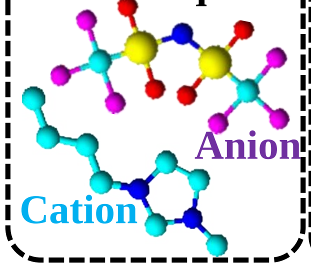
Current Density (mA/cm^2)
Improve the Acceleration



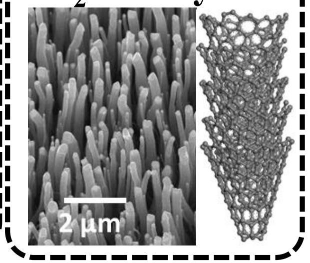
Li Protection



Ionic Liquid



O_2 Catalysts



Benefits of our design:

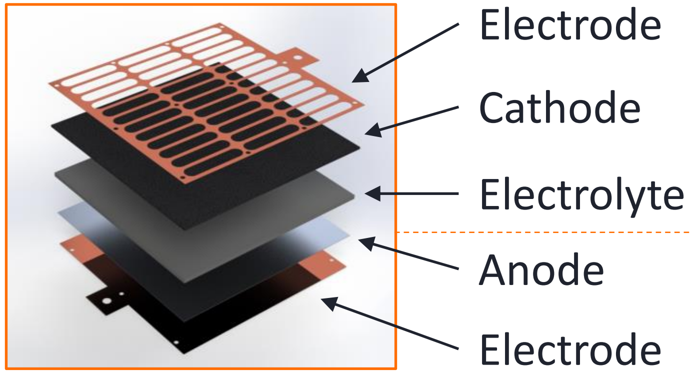
- Non-flammable and non-evaporating IL electrolytes.
- Electrode with high power and capacity.
- Active control of mass transfer and thermal management.
- The pumping power is <1% of the discharge power.

Washington University in St. Louis KU HYDROGRAPH

Achievable Capacity: >1,000 Wh/kg

Metal Light: Clean Electricity From Metal

Metal-Air Battery Architecture



- Metal-air system provides energy densities of **1200+ Wh/kg**
- Removable anode for instantaneous recharge and circular fuel
- Safe non-flammable battery chemistry

Containerized Metal-Air Generator

- Suitable for maritime shipping and freight rail
- Projected 800 kW and 30 MWh capabilities in 40-foot container
- Low capital cost and comparable operating costs to diesel

Contact Us For:

- Partnerships
- Specifications

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