Metal-Air Harvester

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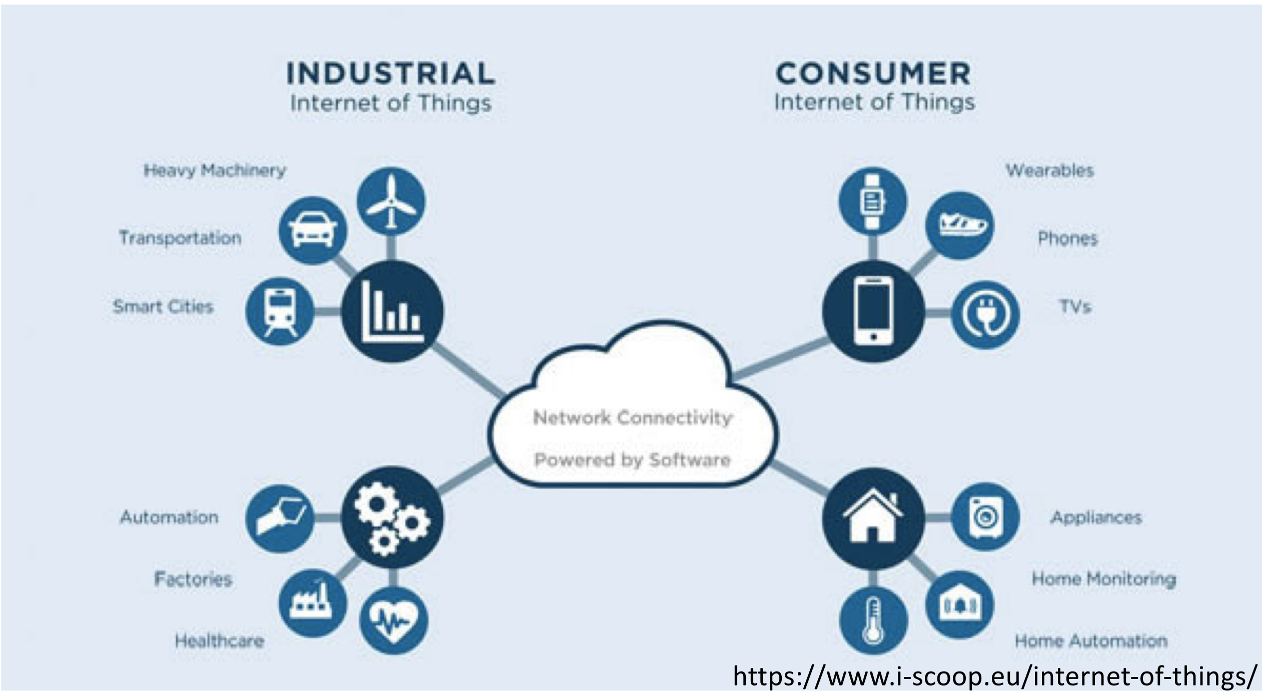
What needs energy?

Internet of Things (IOT)



IOT devices is projected to grow from 27 billion in 2017 to 125 billion by 2030.

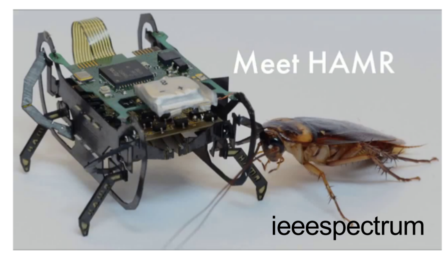
Robots

Spot

60 minute

Quadcopter

15 minute



HAMR Microrobot

1 min. as shown. 4.5 min. max

The endurance and performance of most robots are limited by their ability to store energy.

How do we provide energy?

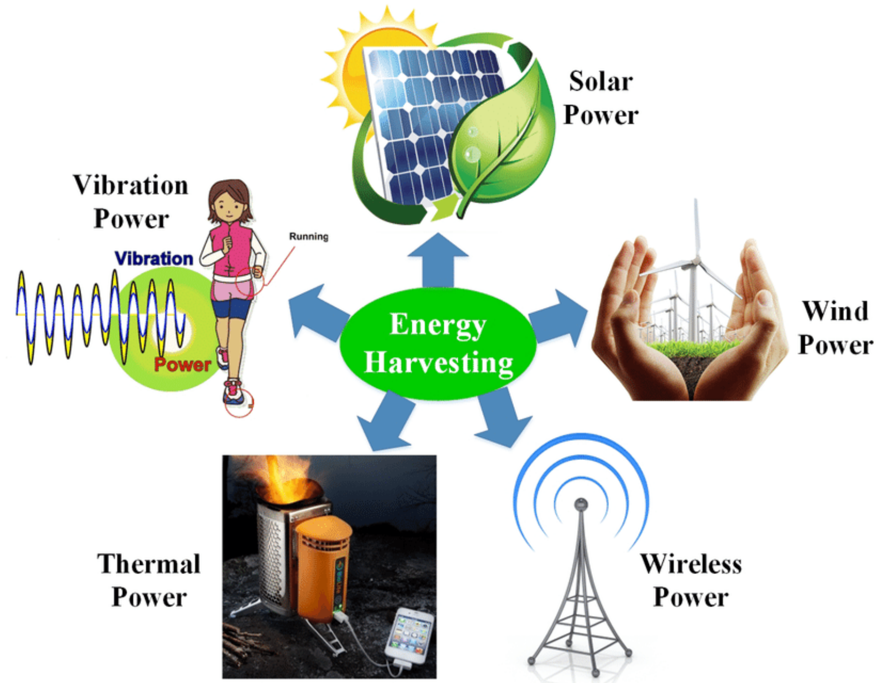
Energy stored in an on-board battery or fuel cell.

Toolstation.com

https://www.impactbattery.com/etx9.html

- 5 to 8% energy density growth per year
- In 9 – 15 years, our micro-robots will operate for 2 minutes and our drones will fly for 30 minutes

Harvesting energy from the local environment



Zhao et al., *IEEE Access*, vol. 5, 2017

- Low power
- Periodic delivery
- Require specific environments.

A new source of harvested energy: metal

Aluminum	**Iron**
38 kJ/g 84 MJ/L	5 kJ/g 40 MJ/L
Gasoline 34 MJ/L	**Lithium ion battery** ~2 MJ/L

M1A1 tank
3 x 10^{11} J of energy

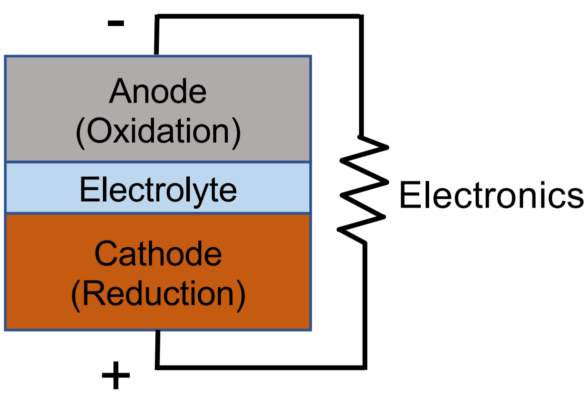
- Approximate food energy consumed by an average human in an 80-year lifetime.
- Energy used to power an average US household car for ~4 years.

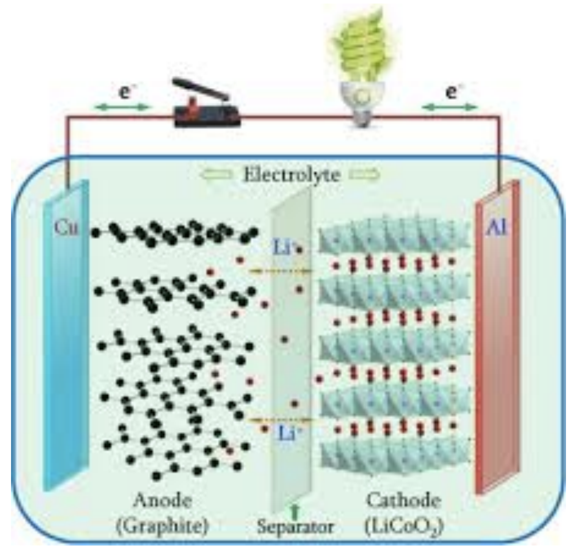
City Street

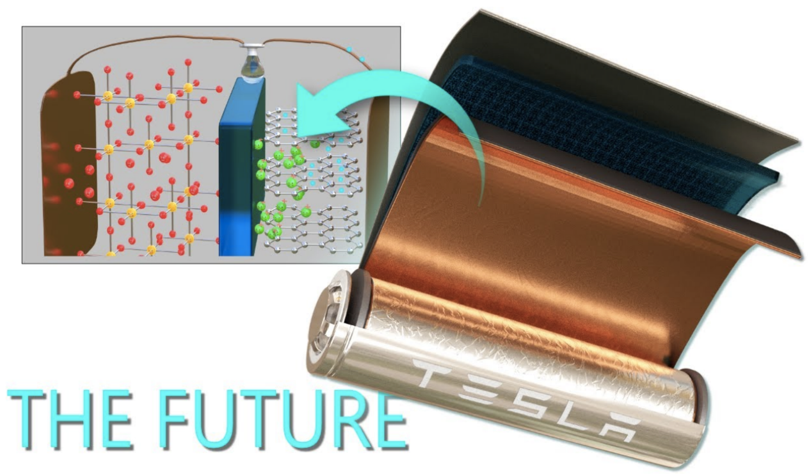
If this robot were to operate on a 30” aluminum stop sign, where the MAS can extract 316 mWh/cm^2, the total energy available would be 1,500 Wh, about 23X greater than a $37 laptop battery and enough to power a 1 mW sensor for 171 years. Corrodes about 300 μm of Al, or 15% of the stop sign.

The benefit of harvesting metal: Metal-Air Harvester

Typical battery design







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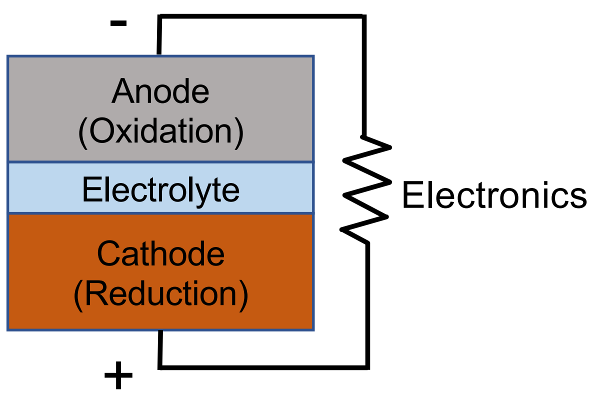
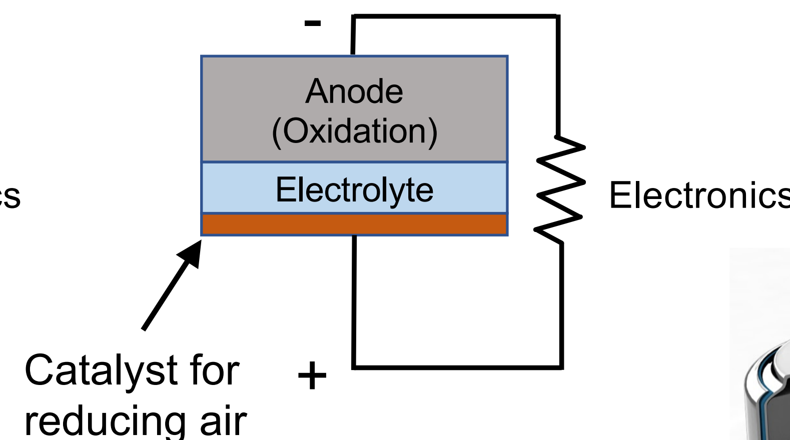
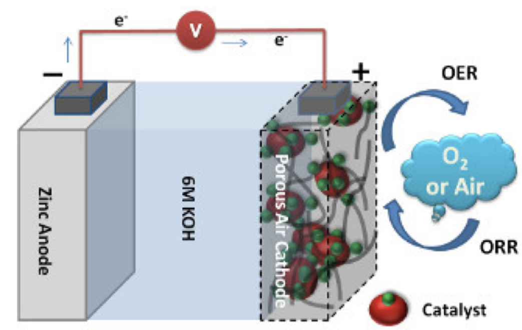


Air battery design

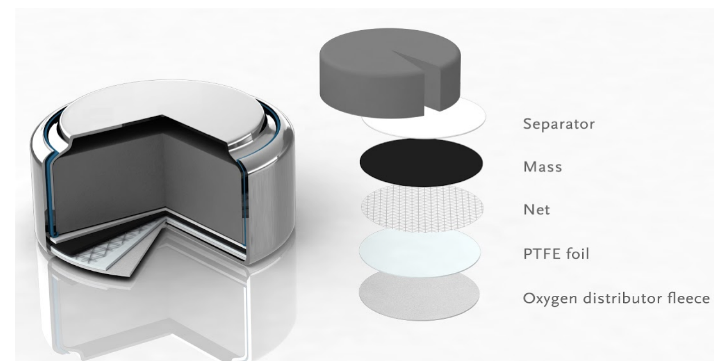
$Zn + 4OH^- \rightarrow Zn(OH)_4^{2-} + 2e^-$ (E_0 = −1.25 V)

$Zn(OH)_4^{2-} \rightarrow ZnO + H_2O + 2OH^-$





- Oxygen is the cathode
- Oxygen is free



$1/2\ O_2 + H_2O + 2e^- \rightarrow 2OH^-$ (E_0 = 0.34 V pH = 11)

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Typical battery design

Air battery design

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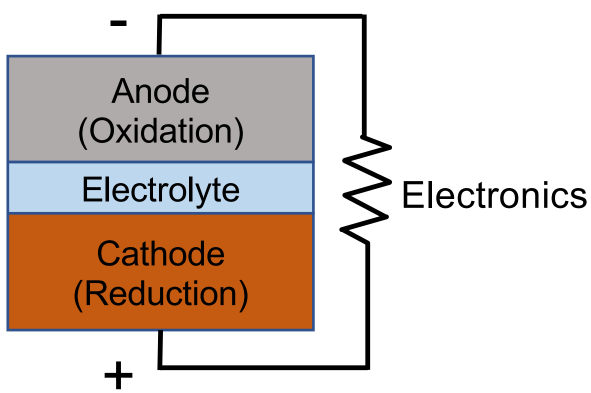
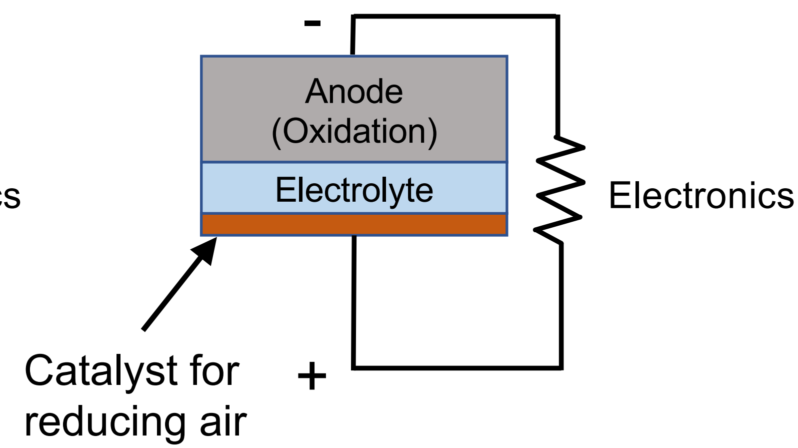
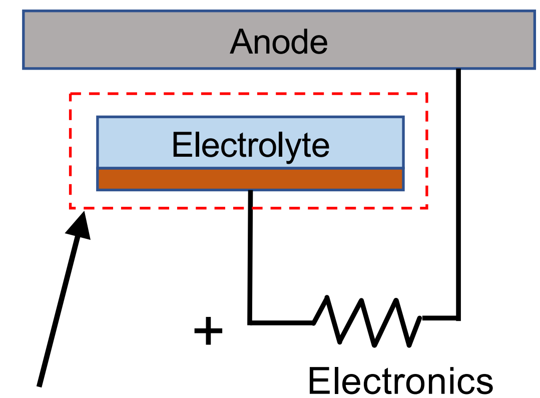






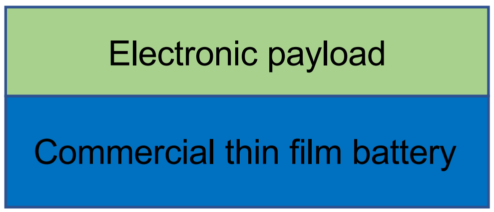
The device only carries the electrolyte and cathode current collector

- Oxygen is the cathode
- Oxygen is free

$$1/2\ O_2 + H_2O + 2e^- \rightarrow 2OH^- \ (E_0 = 0.34\ V\ pH = 11)$$

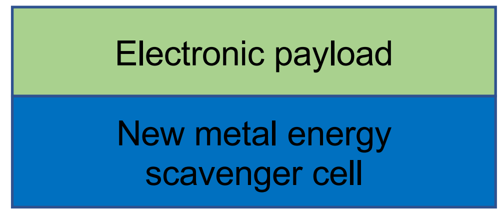
The benefit of harvesting metal: Metal-Air Harvester

Current technology



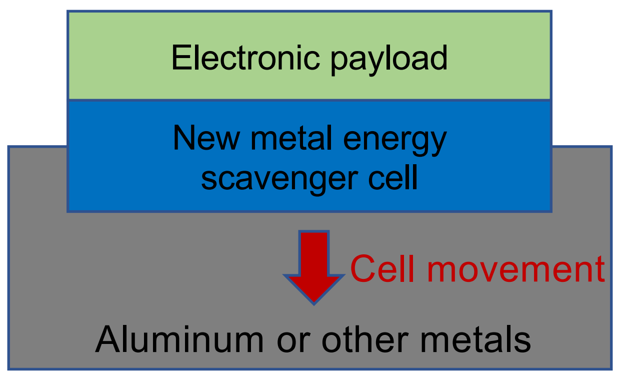
1 mWh/cm^2 energy density

Future metal energy scavenger



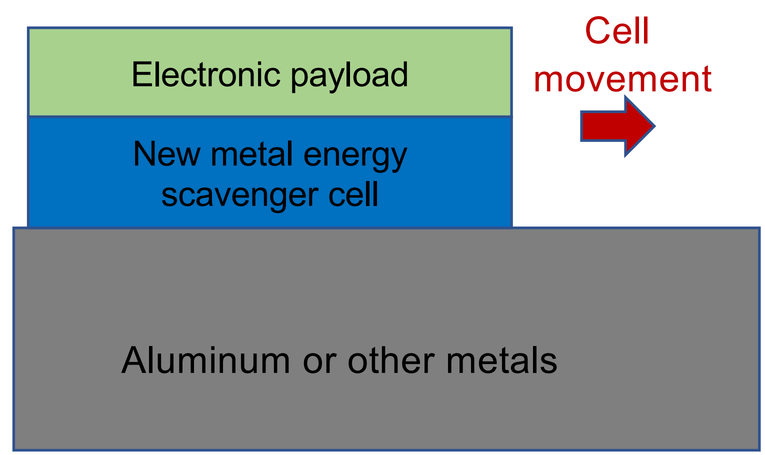
Two design paths

1. ”eat” through surface



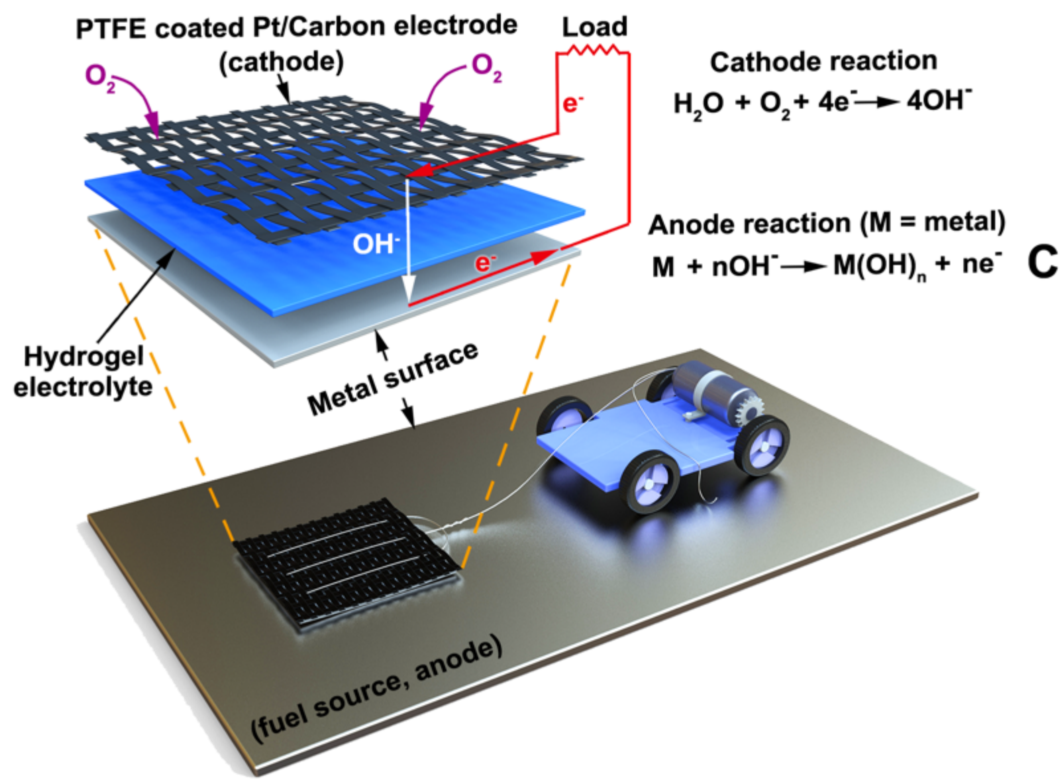
Up to 1,000 mWh/cm^2 energy density for a 1 mm thick aluminum plate

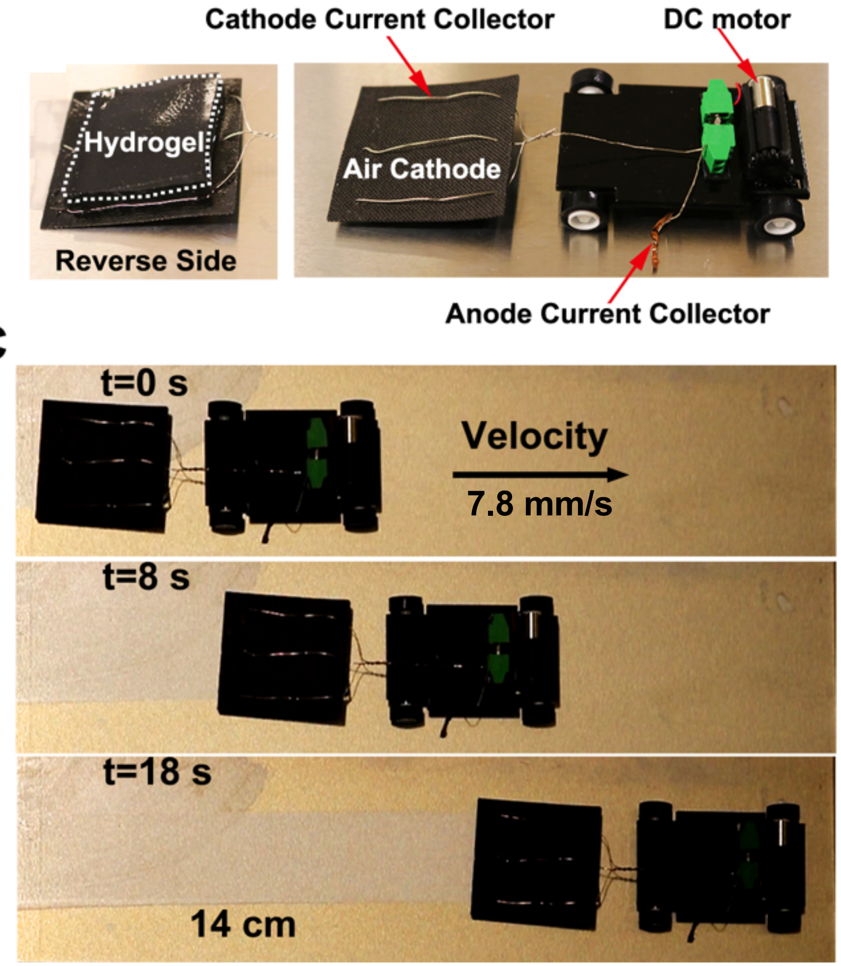
2. ”eat” across surface



~80-300 mWh/cm^2 * (area of plate) energy density for a 100 um thick discharge

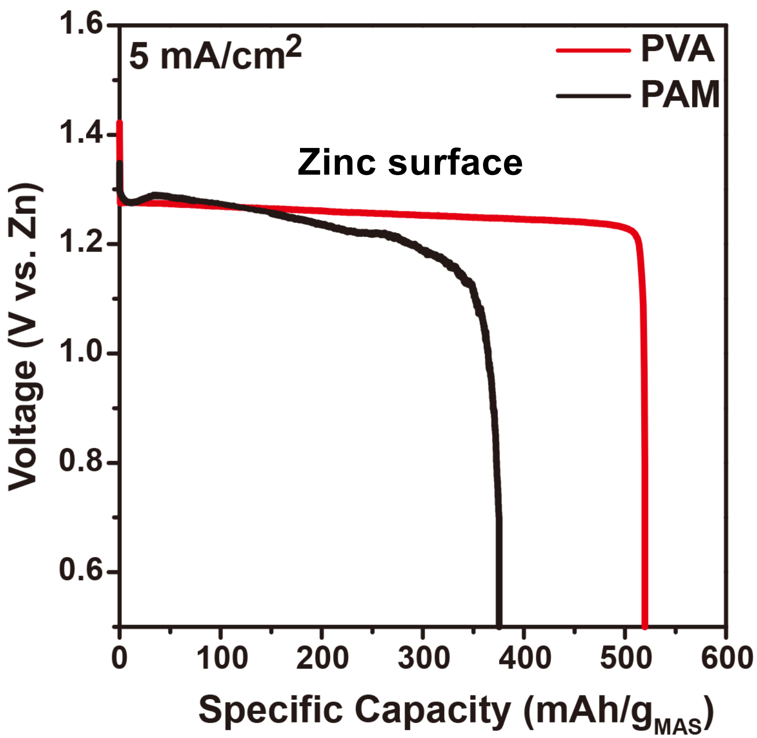
Metal-air harvester (MAH)

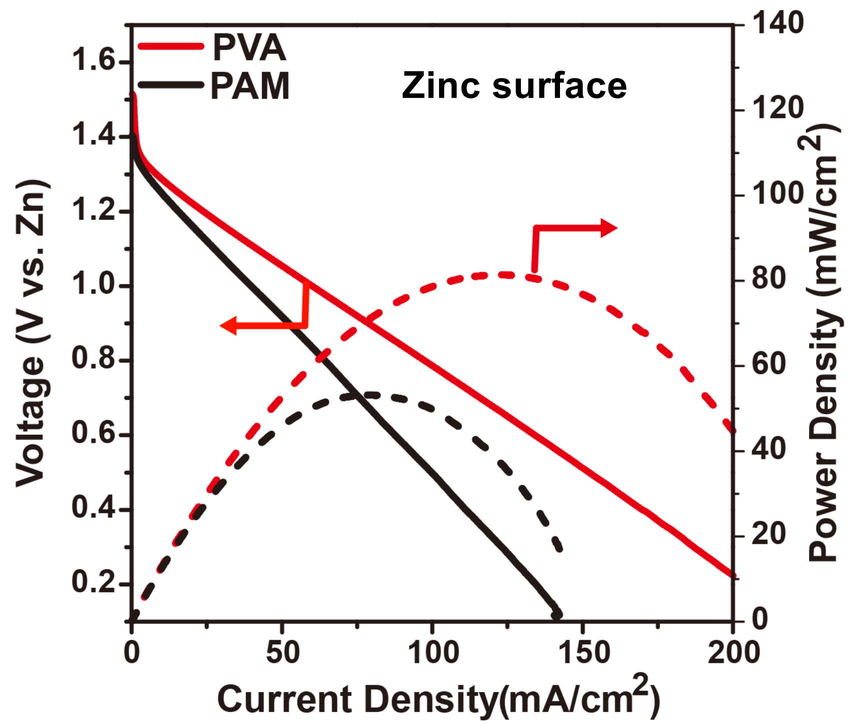




The MAH can power electronics by consuming metal from external surfaces and breathing oxygen from the air.

Performance

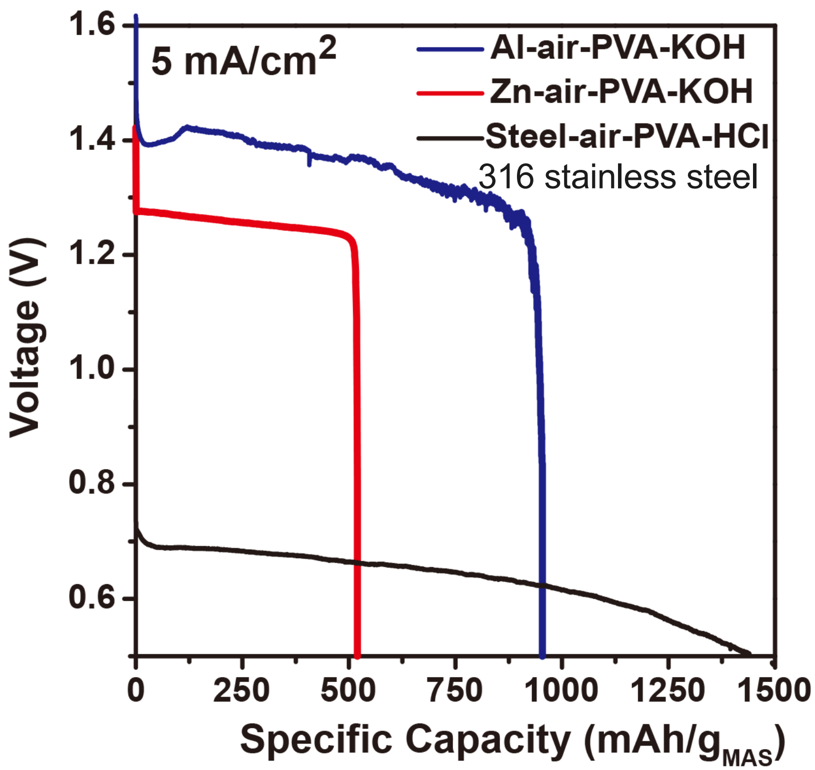


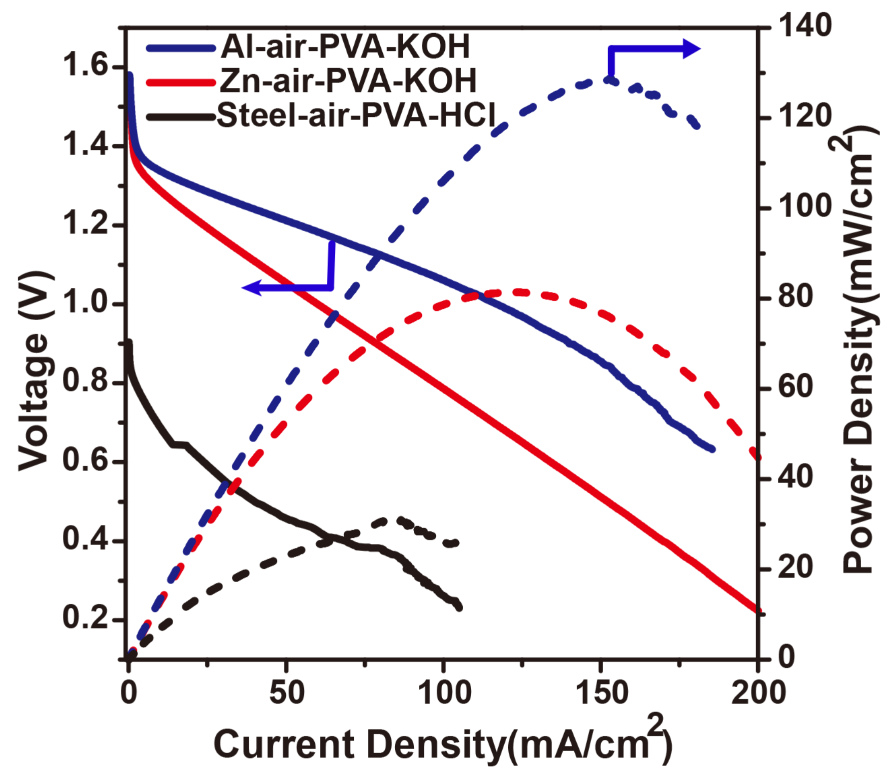


PVA = poly(vinyl alcohol)
PAM = polyacryalamide

- MAS penetrates ~110 μm into the surface
  - 83 mWh/cm^2

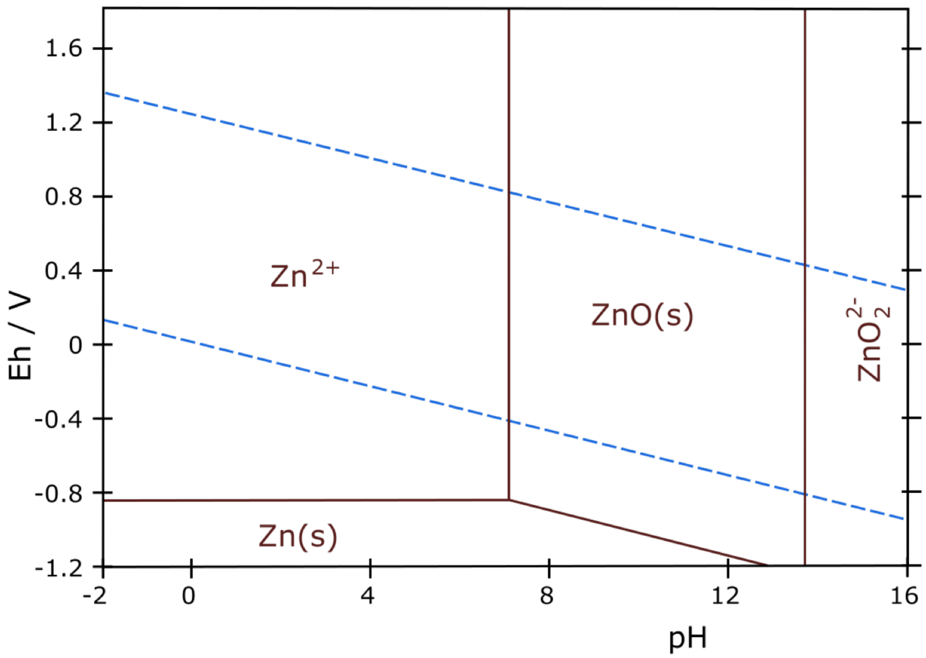
Performance

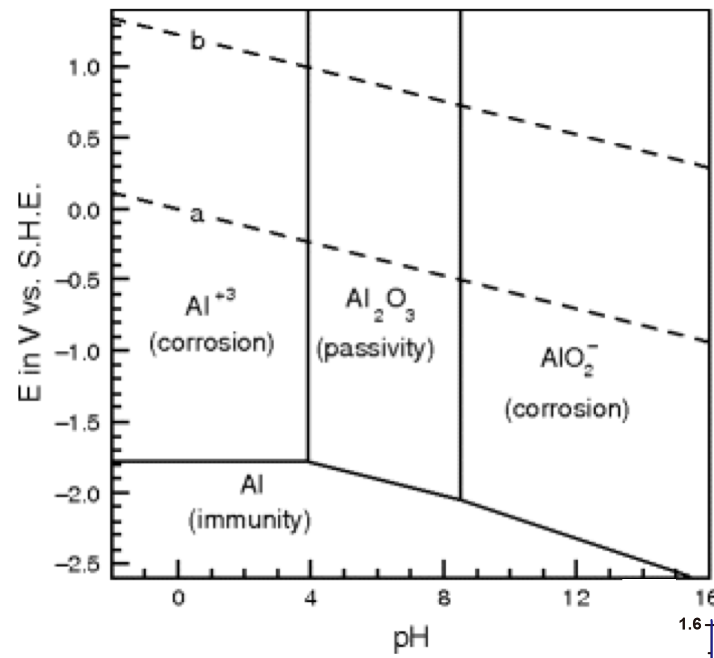


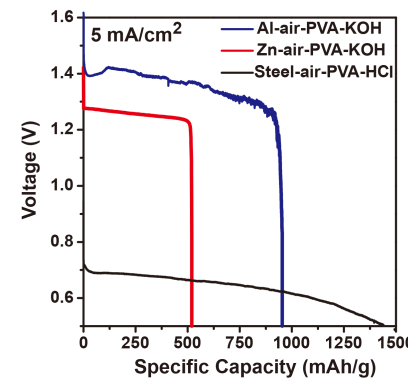


- MAS on Al penetrates ~285 μm into the surface
    - 316 mWh/cm^2

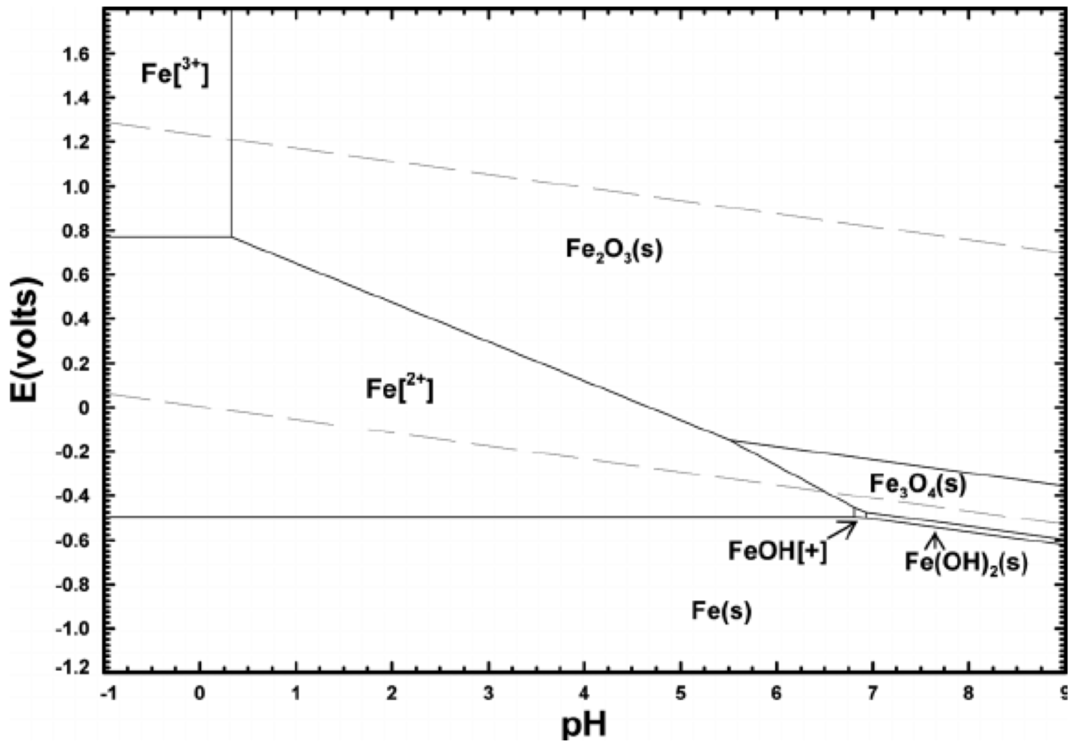
Pourbaix diagram

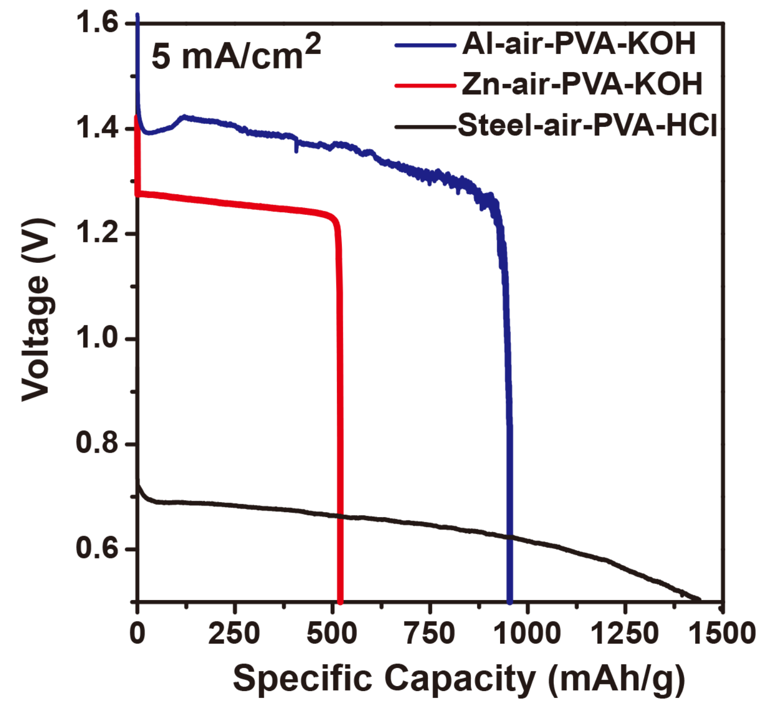




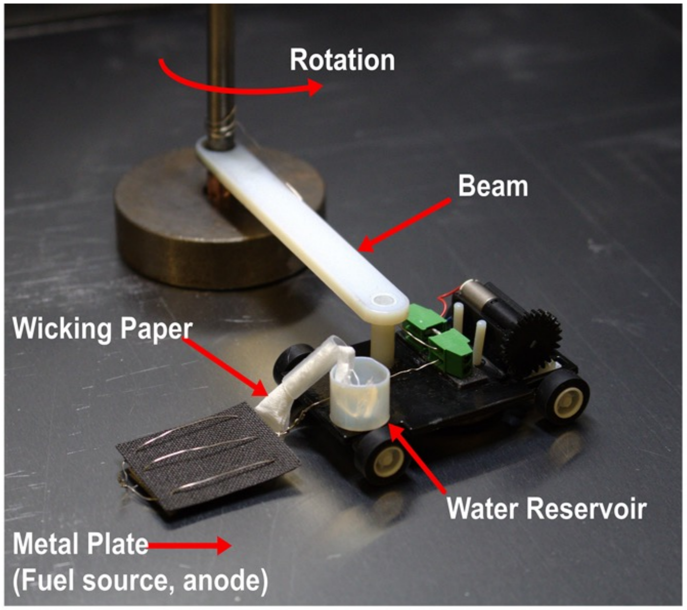


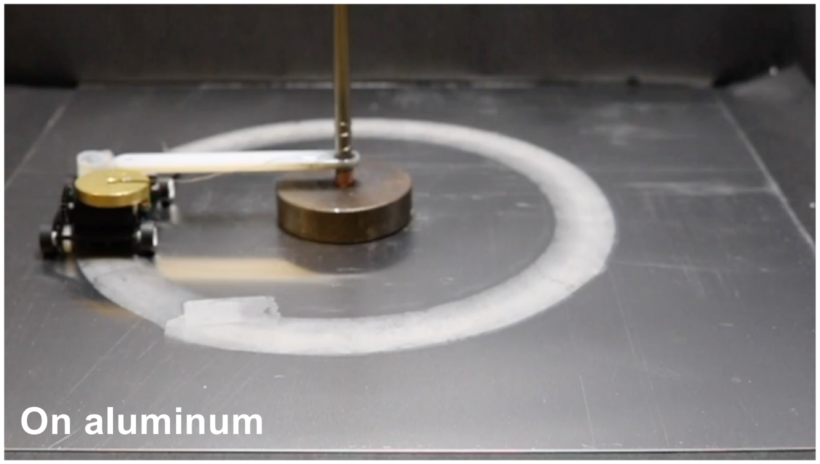
Pourbaix diagram

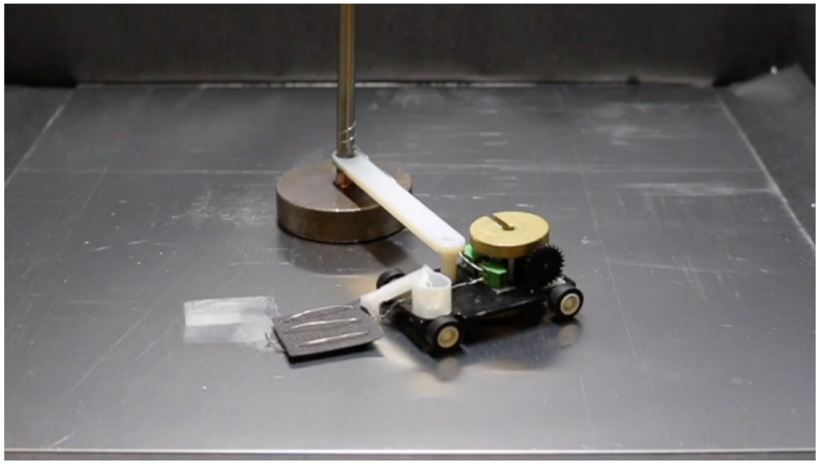




Demonstration



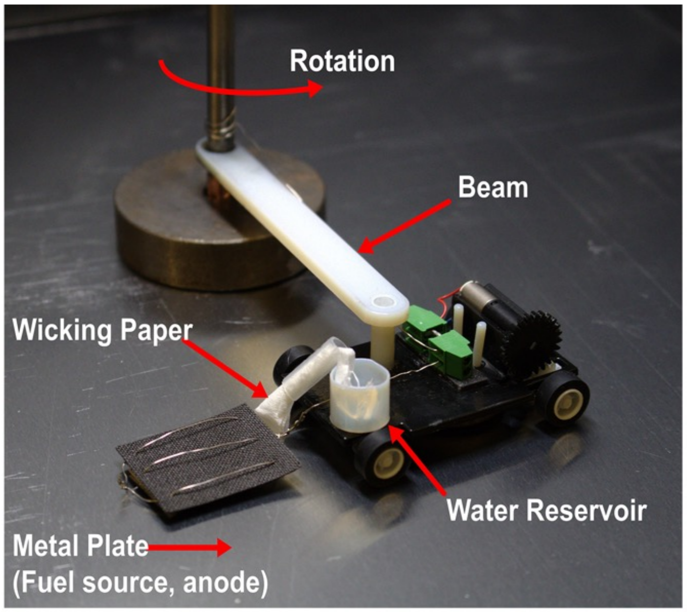


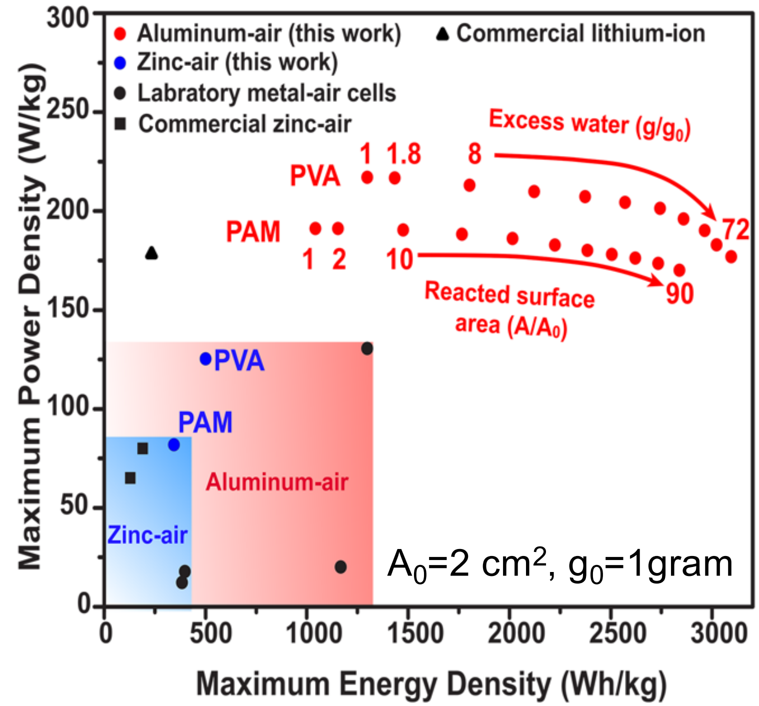


- MAS can power robots, vehicles, and electronics by traversing metal surfaces.

- Toy-vehicle driving in a circle on top of an aluminum sheet that is powering the vehicle.

Energy density





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The ability to move and extract energy from metals makes the effective energy density of our technology very high.

- Like you, the technology does need to drink water (at least 0.34 g/Ah on aluminum)