



U.S. Army Research, Development & Engineering Command

Power Considerations for Micro-Autonomous Systems



TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

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- Army Needs & Niche
- Energy & Power Requirements
- Power Source Options
 - Bring energy with you
 - Get more on site
- Suggestions

- It is burdensome to **carry & sustain** everything
- Soldiers need to be more **survivable**
- There is never enough **power**
- We must operate in **extreme environments**
- **24/7 situational awareness** of actions & intent is key to success





Micro-Autonomous Systems & Technology (MAST) CTA

To enhance tactical situational awareness in urban and complex terrain by enabling the autonomous operation of a collaborative ensemble of multifunctional, mobile microsystems

Lead & Platform Integration

BAE Systems

Processing for Autonomous Operation

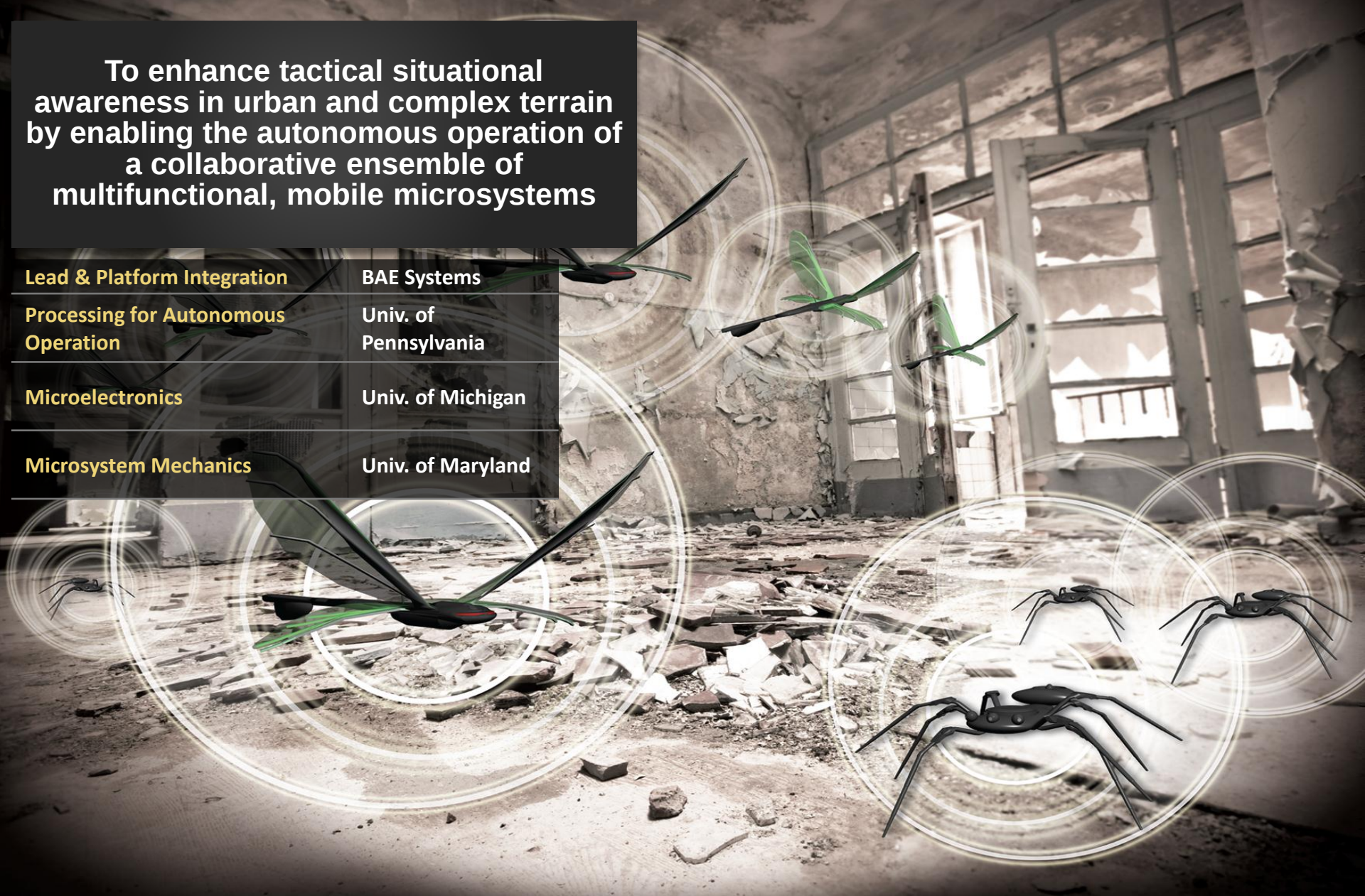
Univ. of Pennsylvania

Microelectronics

Univ. of Michigan

Microsystem Mechanics

Univ. of Maryland





Autonomy

MAST
Goal

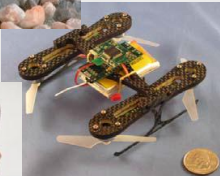
Biology

1g

1kg

1000kg

Size / Maturity

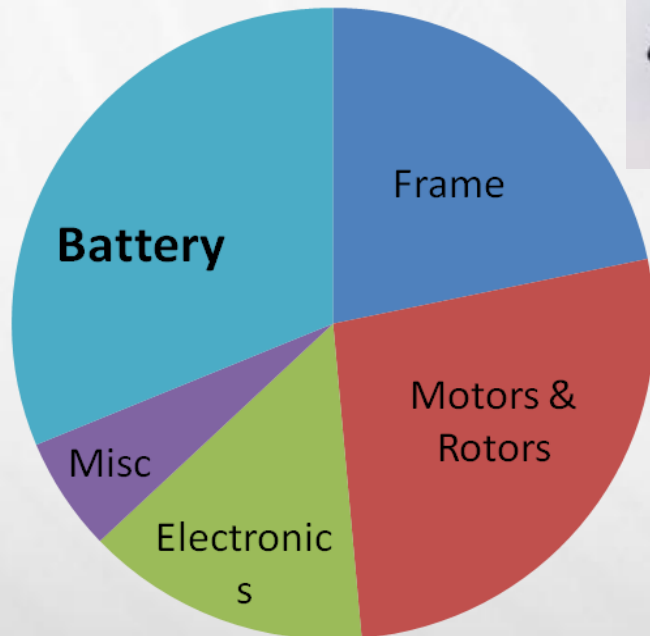




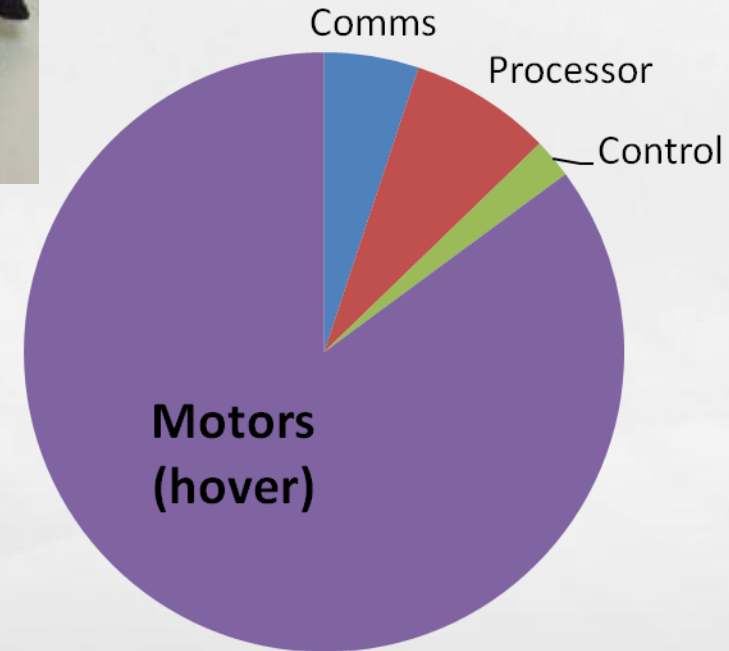
Energy & Power Needs

Representative Platform: DFS/UMD MicroQuad

Weight Breakdown
(Total = 77.4g)



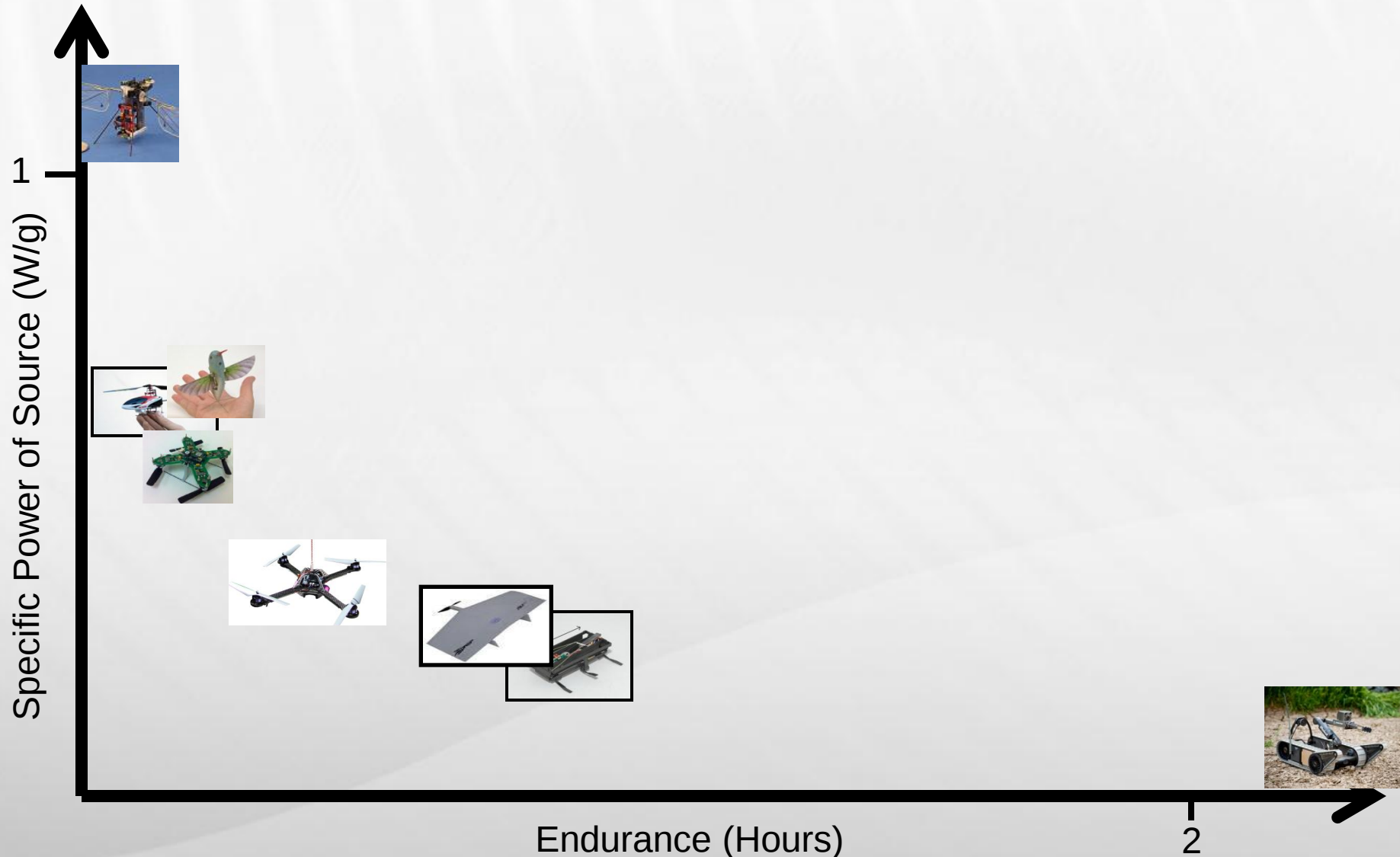
Power Breakdown
(Total = ~12W)



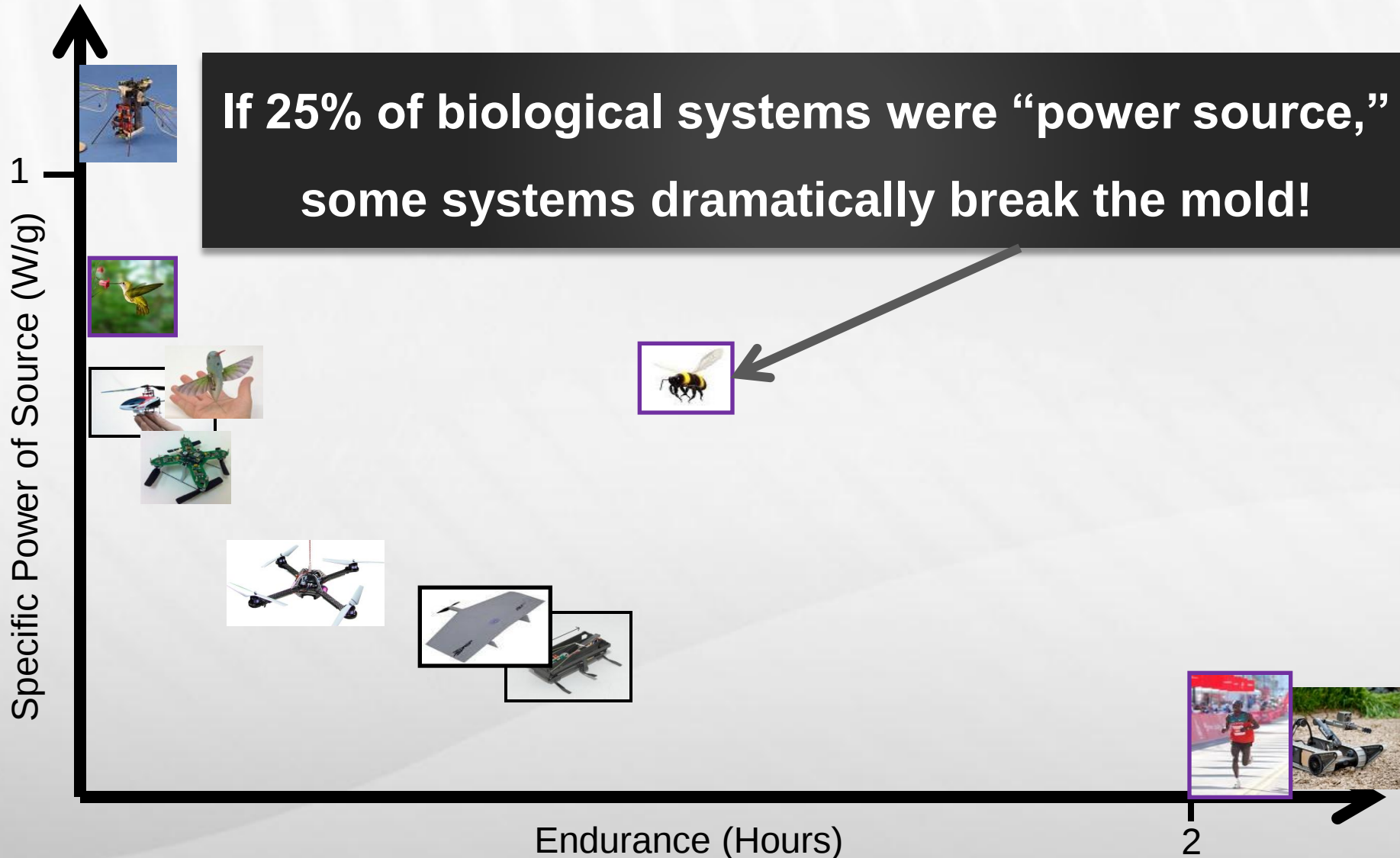
*Numbers courtesy of Dr. Joe Conroy, ARL/UMD

**Power for mobility dominates over sensors & Comms;
especially for aerial platforms (~10:1)**

Non-Ragone Plot



Non-Ragone Plot



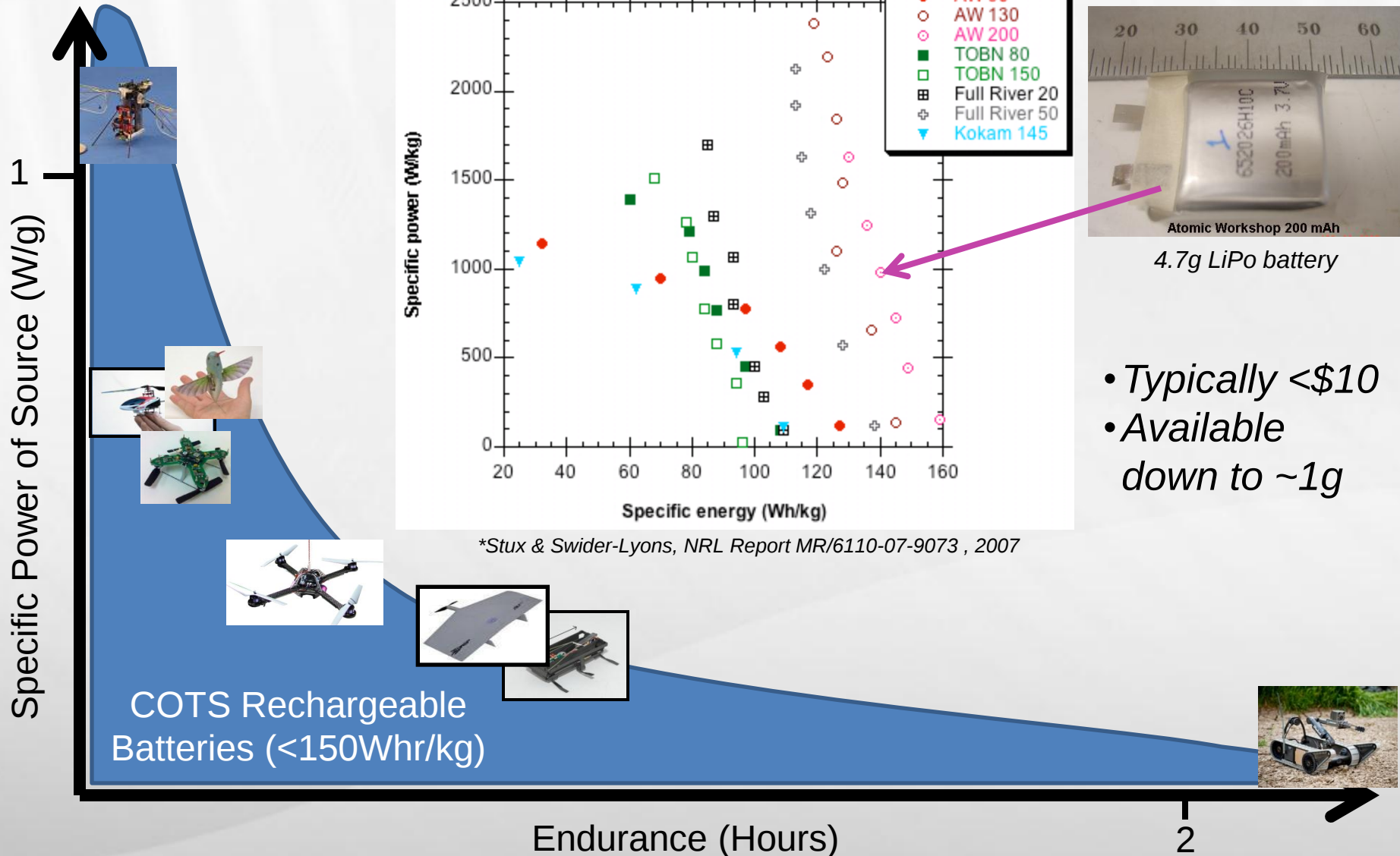
NOTE: When necessary, power source estimated as 25% of body weight



Option 1:

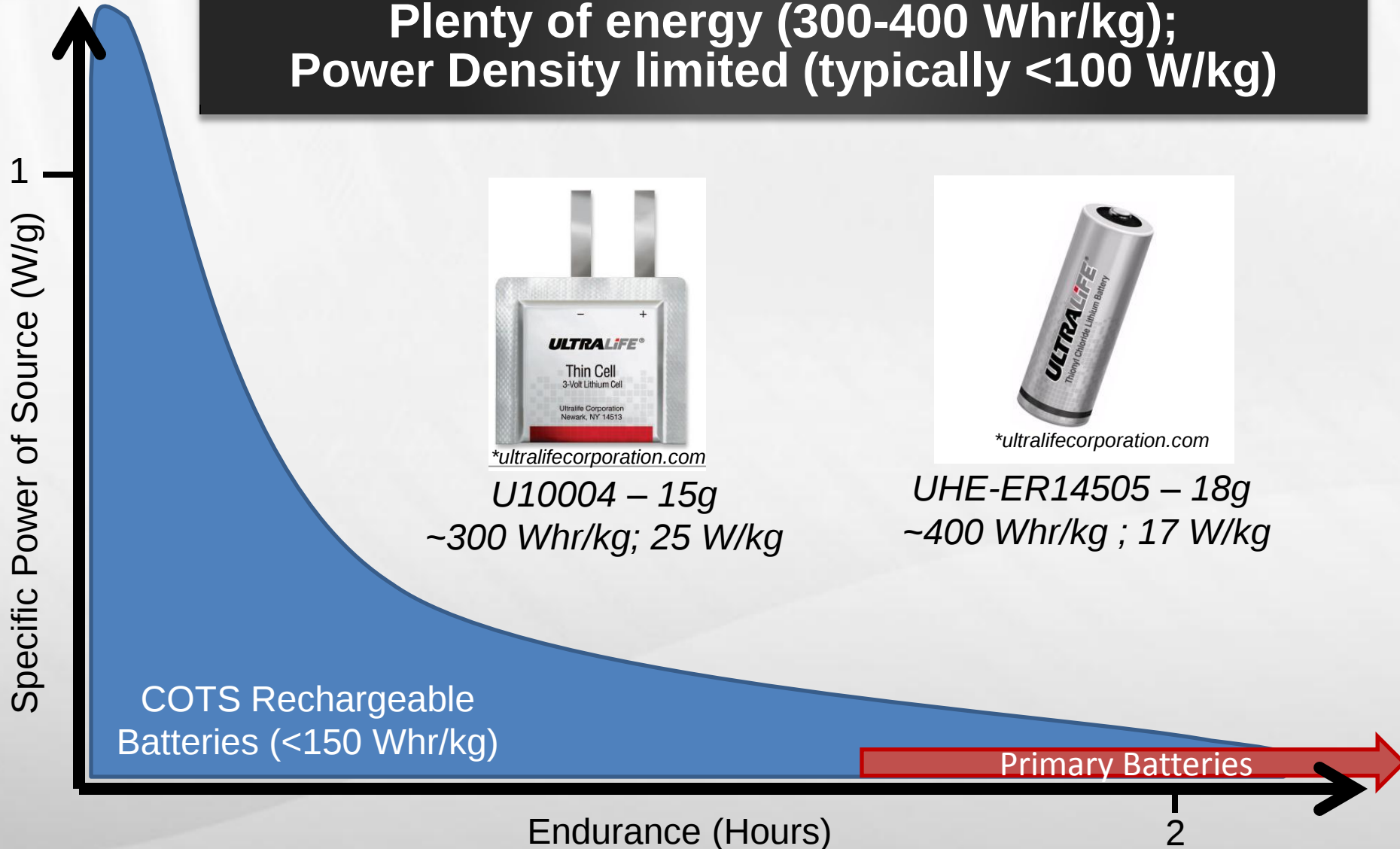
Bring what you need

COTS Rechargeables



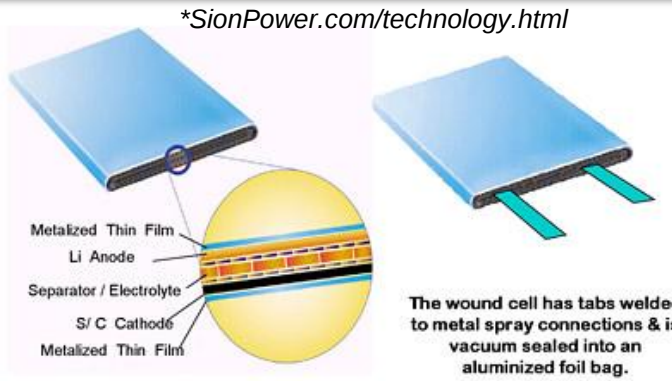
COTS Primary Batteries

**Plenty of energy (300-400 Whr/kg);
Power Density limited (typically <100 W/kg)**



Emerging Batteries: Secondary used as a Primary

Typical Li-S problem: performance degrades with cycling
→ Commercial electronics care; MAST does not!



16g, 2V battery

- *Lithium-Sulfur: promising rechargeable technology*
 - Up to 350 Wh/kg at 60 W/kg
 - Project >200 Wh/kg @ 800 W/kg

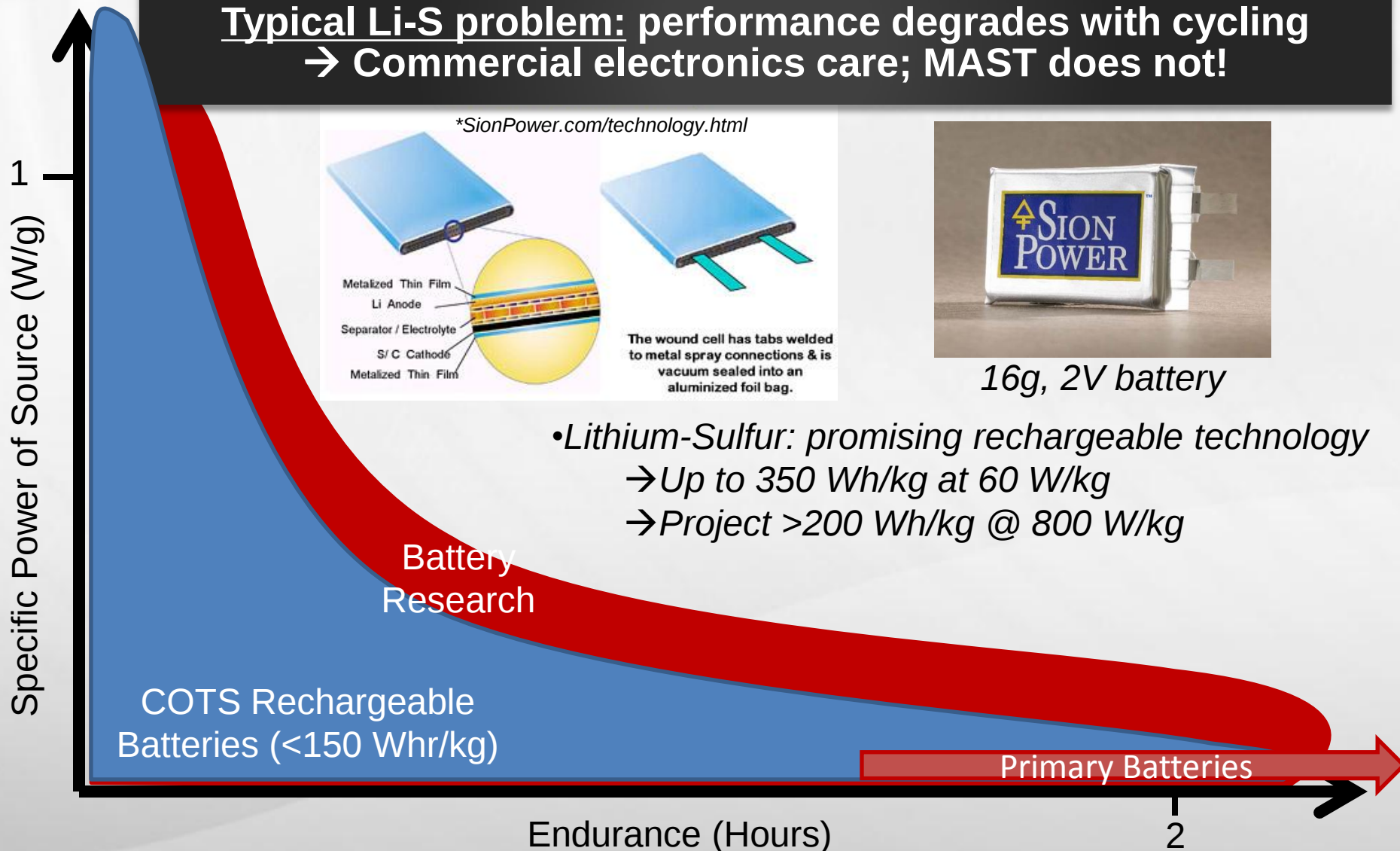
Battery
Research

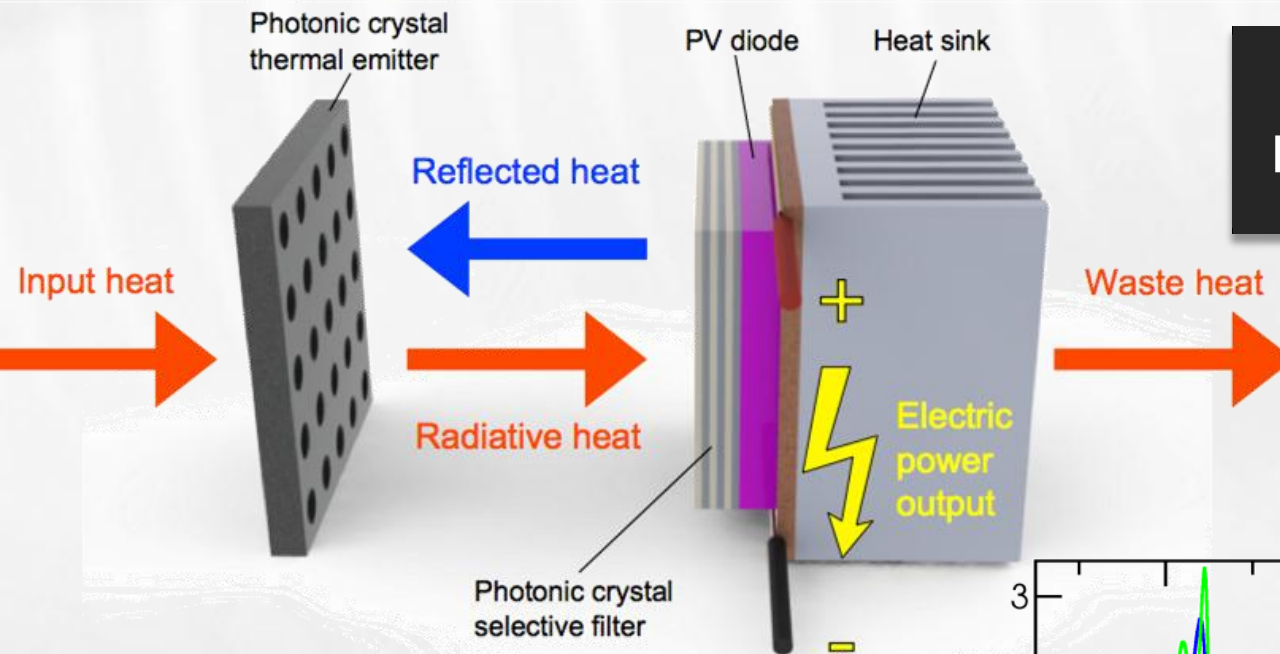
COTS Rechargeable
Batteries (<150 Whr/kg)

Primary Batteries

Endurance (Hours)

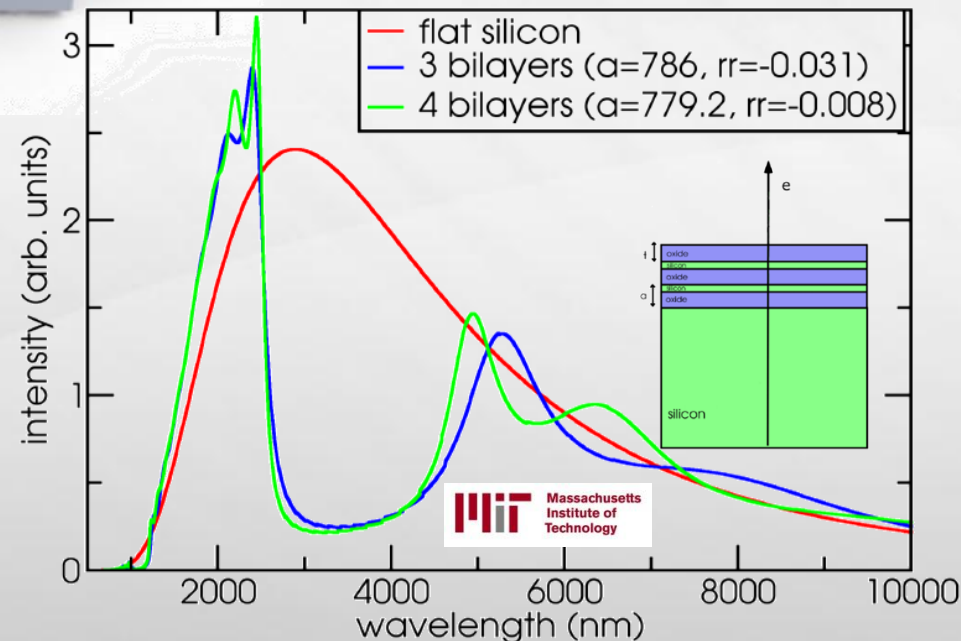
2





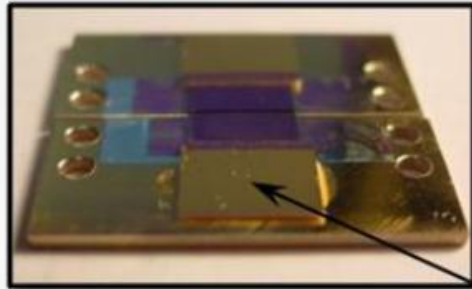
Thermal Radiation to Electricity via a PV cell

Photonic Crystals Predicted to Double System Efficiency

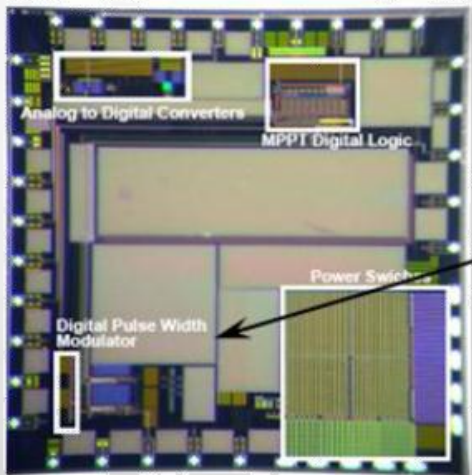




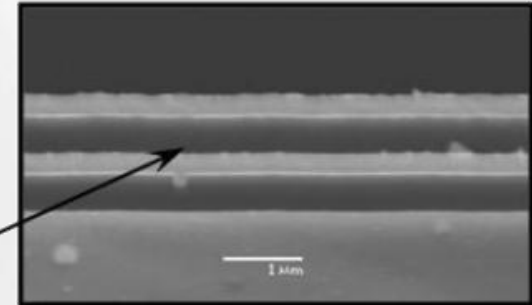
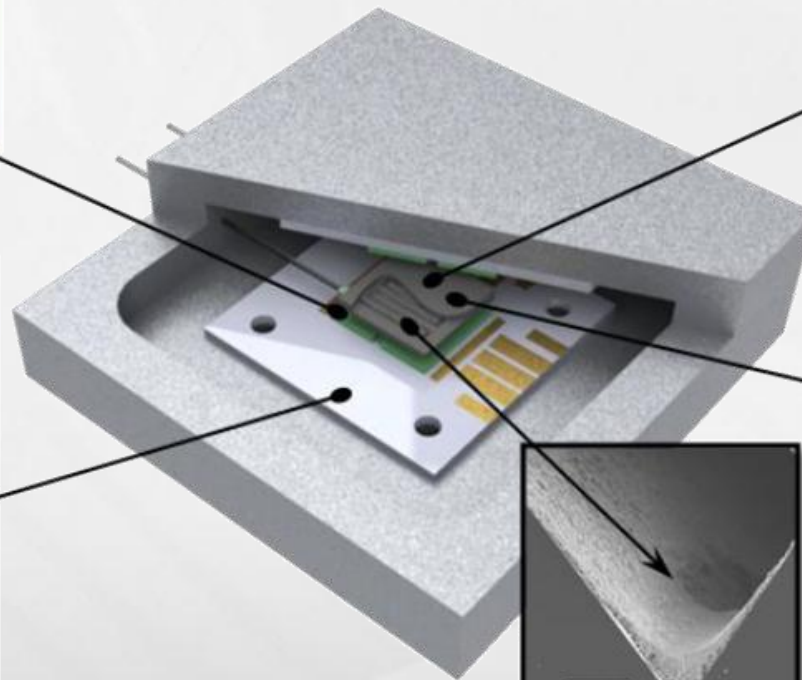
Micro-Thermo-Photovoltaics



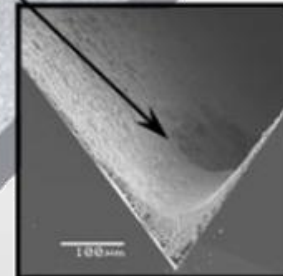
GaInAsSb PV diodes



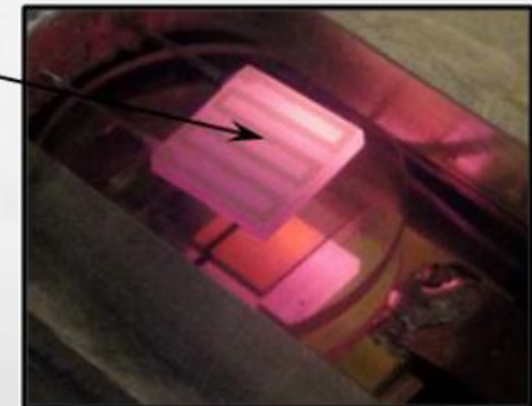
low-power MPPT



1D PhC emitter



micro channel

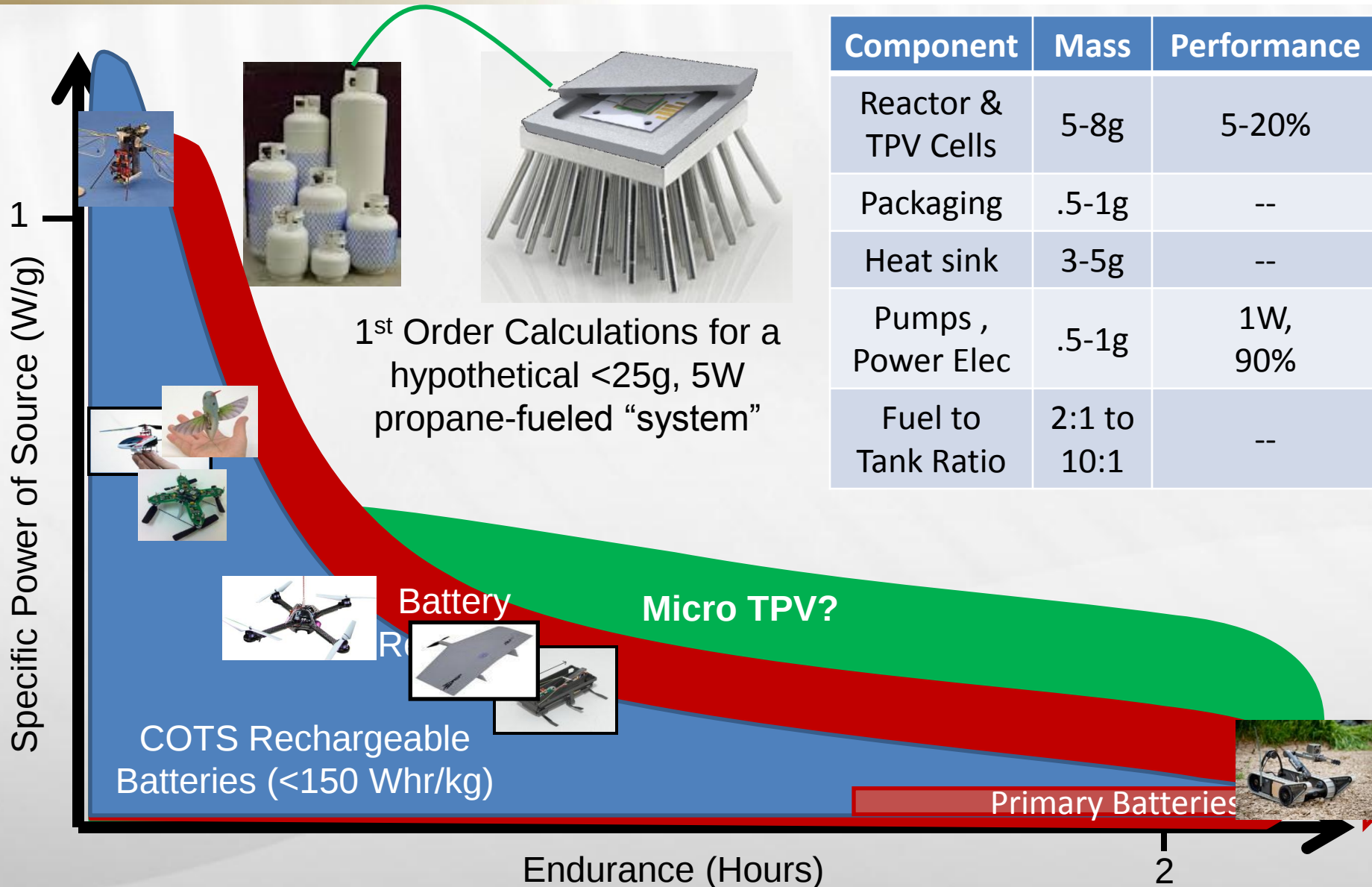


Silicon MEMS reactor

POC: Ivan Celanovic



Micro-Thermo-Photovoltaics



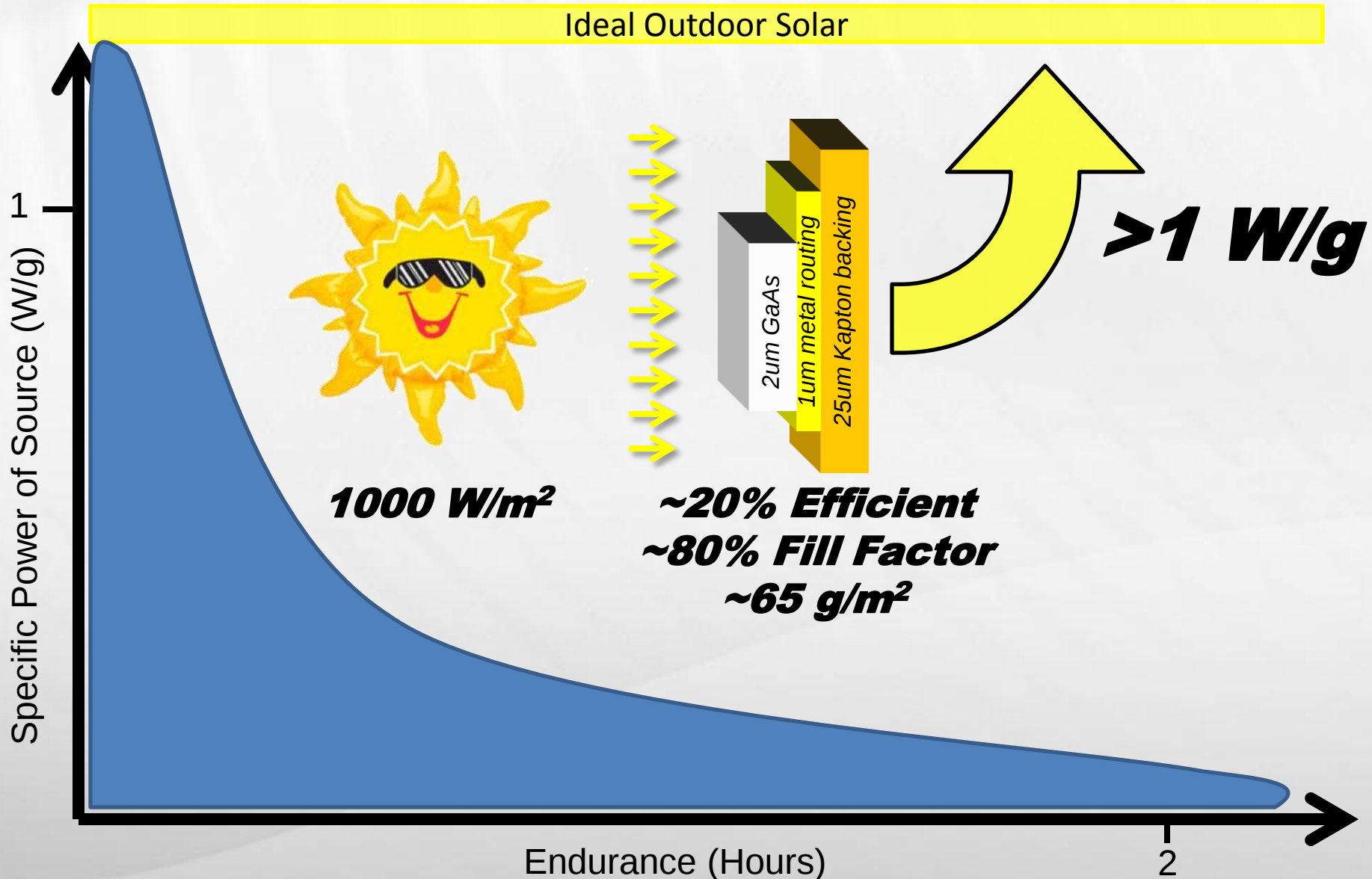


Option 2:

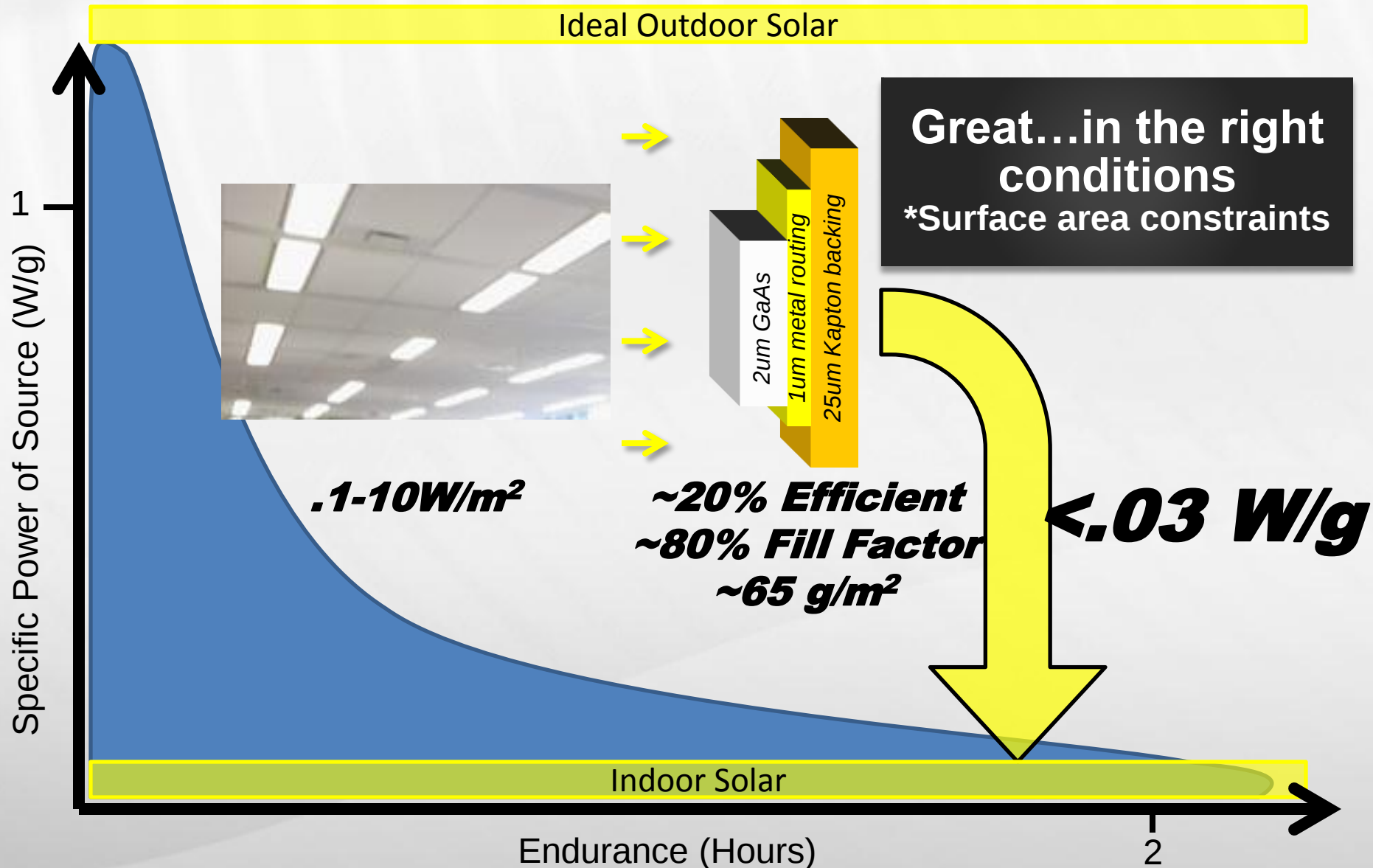
**Get more energy
on site**



Solar Photovoltaics

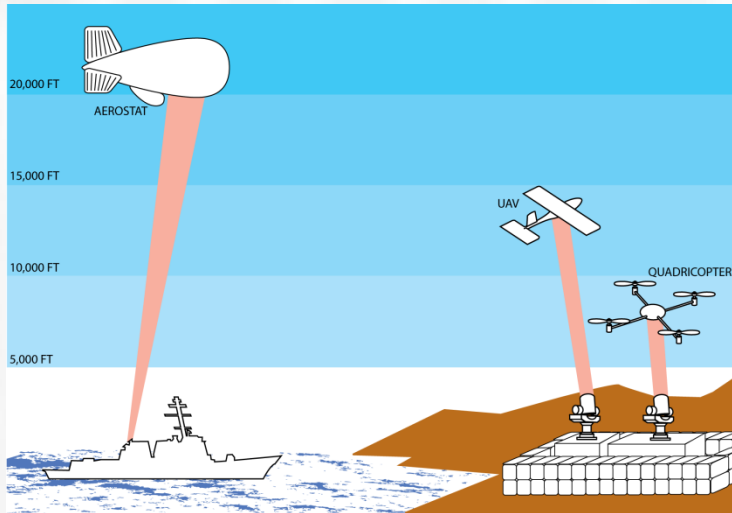


Solar Photovoltaics





Power Beaming



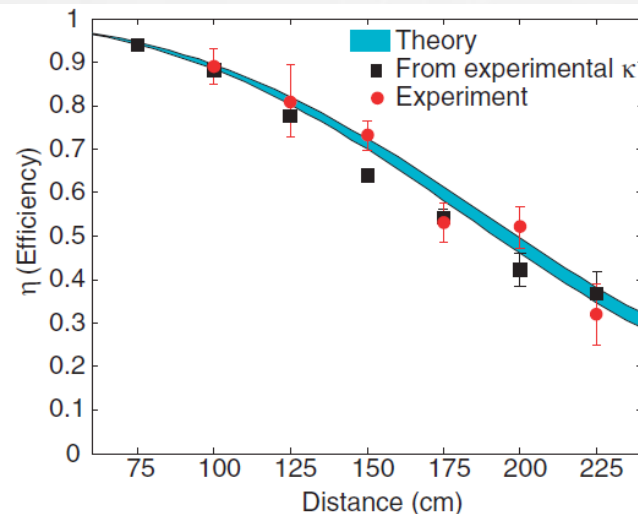
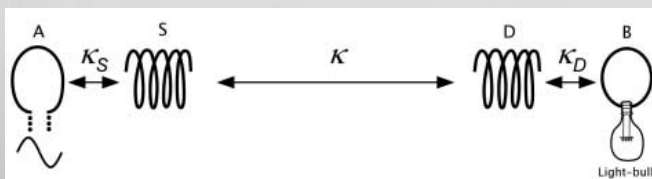
Pro's:*
 >20% Net Efficiency
 Scalable to kW & km
 800 W/kg (receivers)

*Nugent & Kare, SPIE DSS, 2011

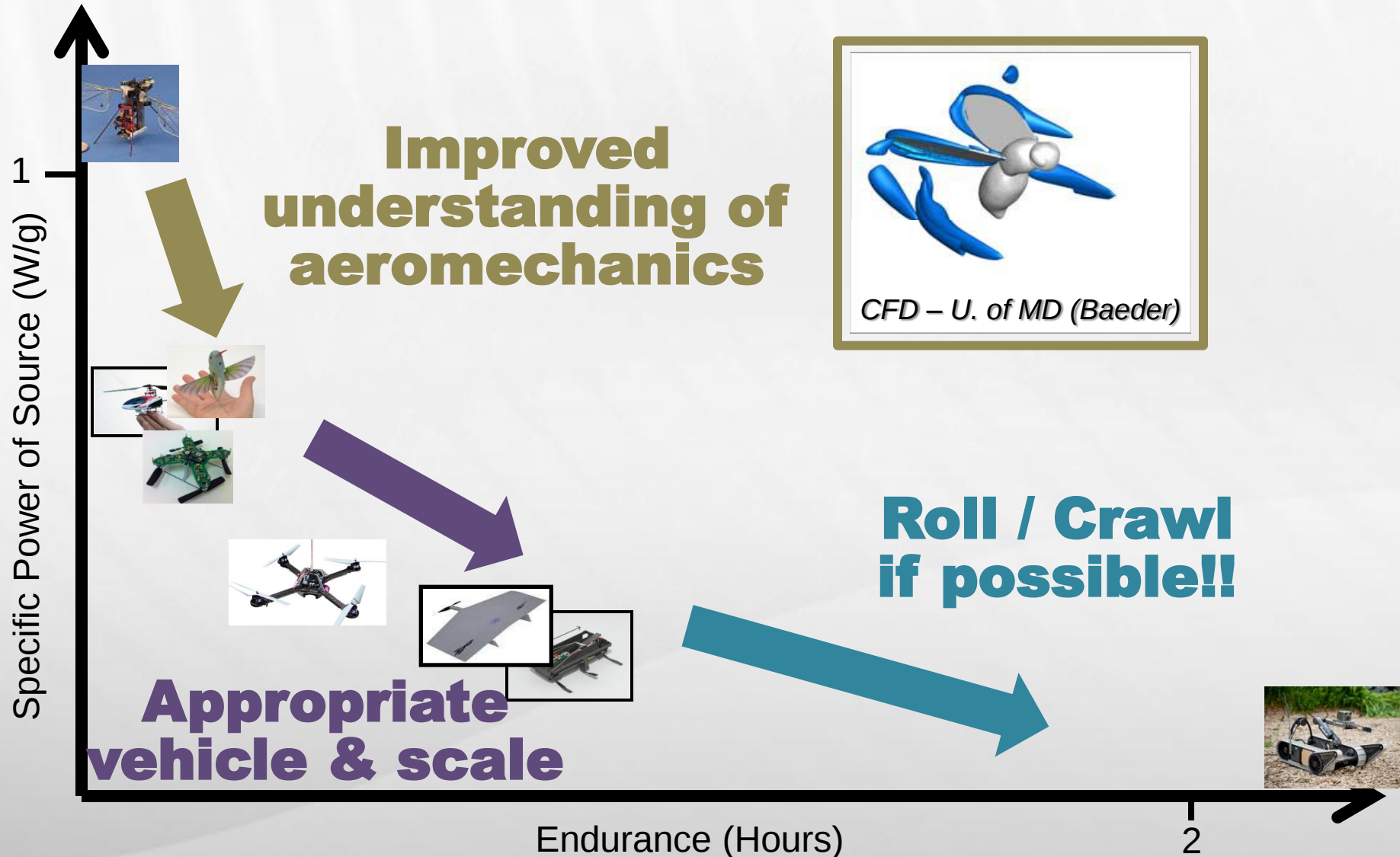


Con's:
 Line of sight
 Safety & reflections

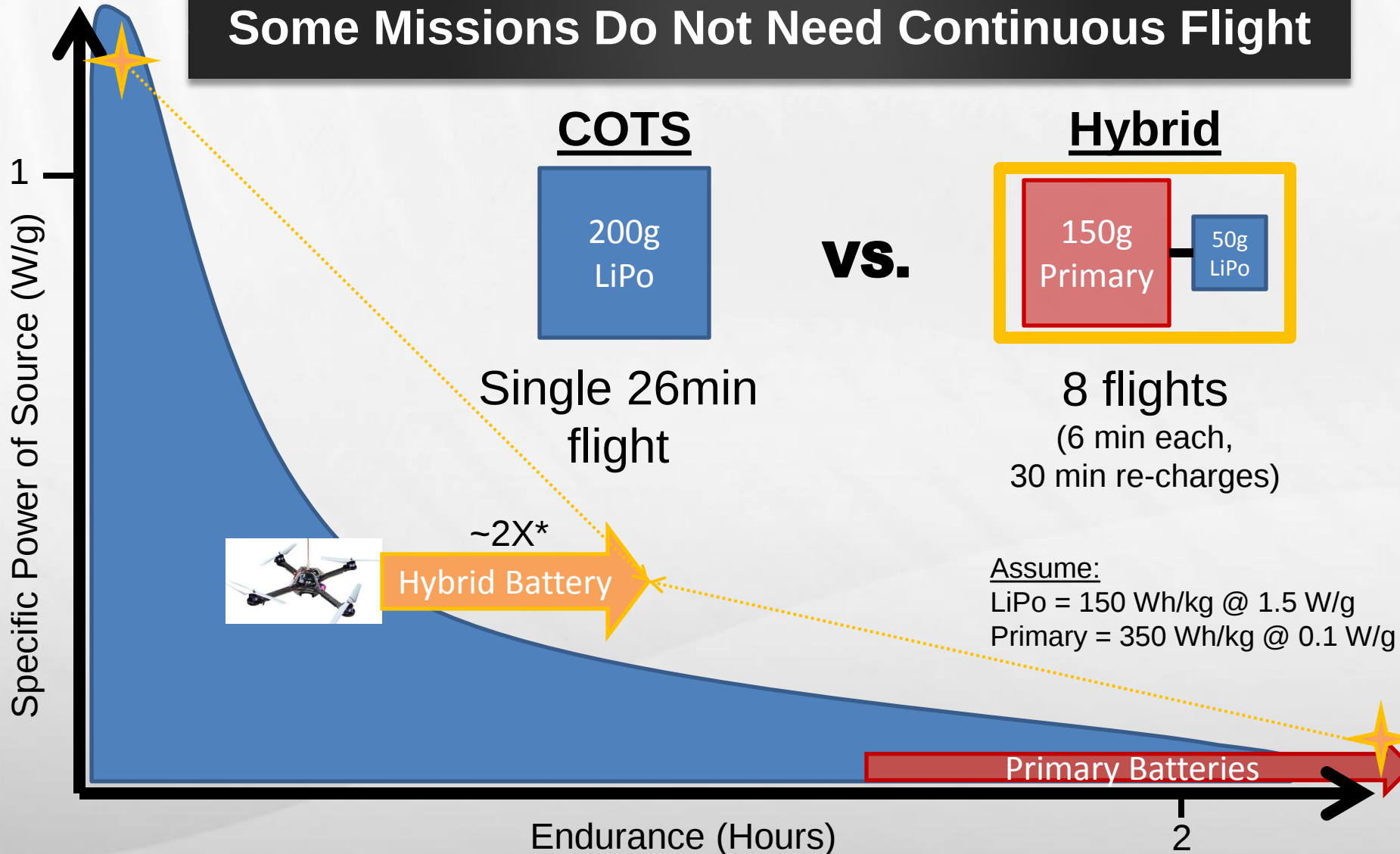
Demonstrated 60W over 2m at 40-50% efficiency (~60cm coils)



Suggestions

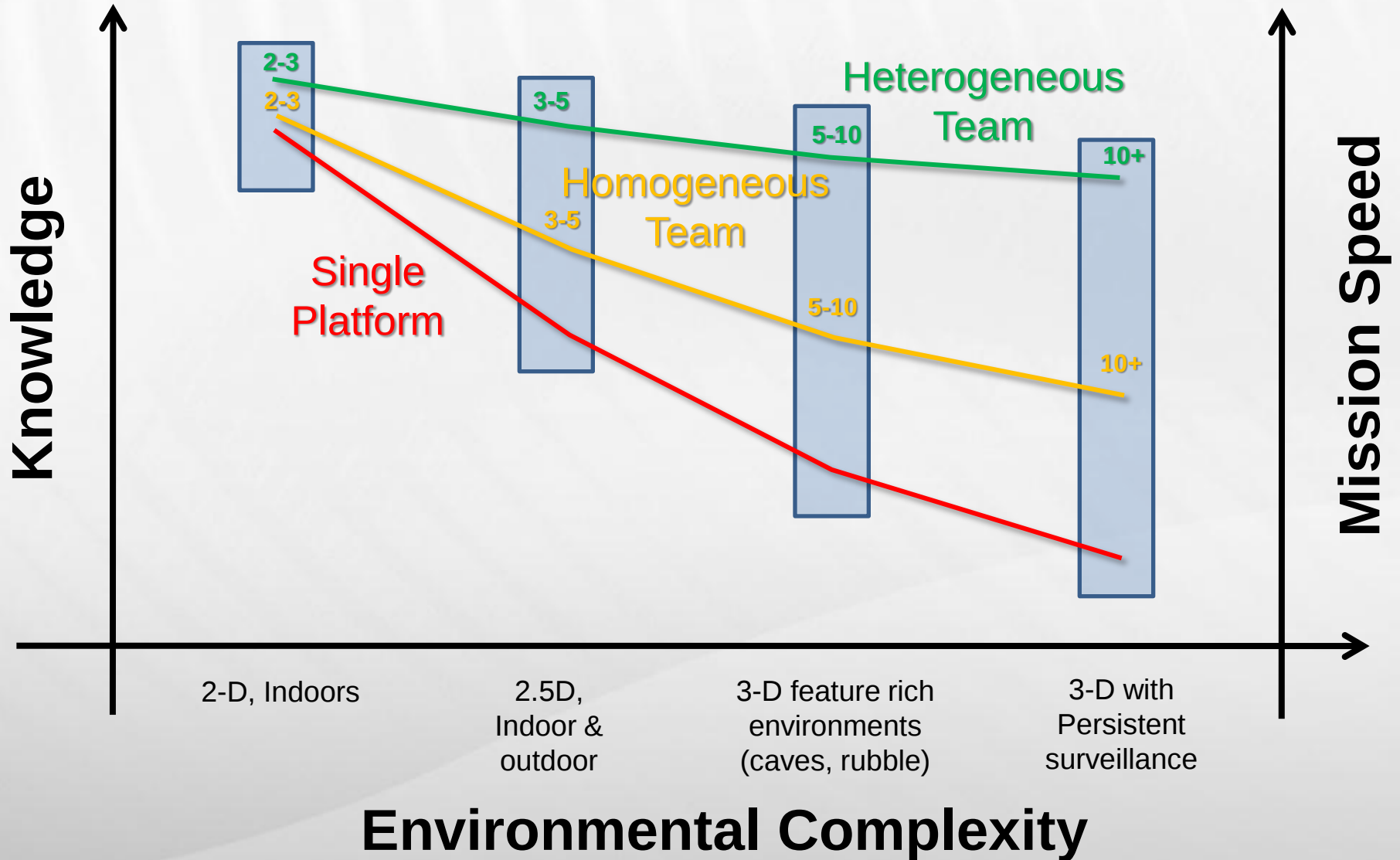


Some Missions Do Not Need Continuous Flight

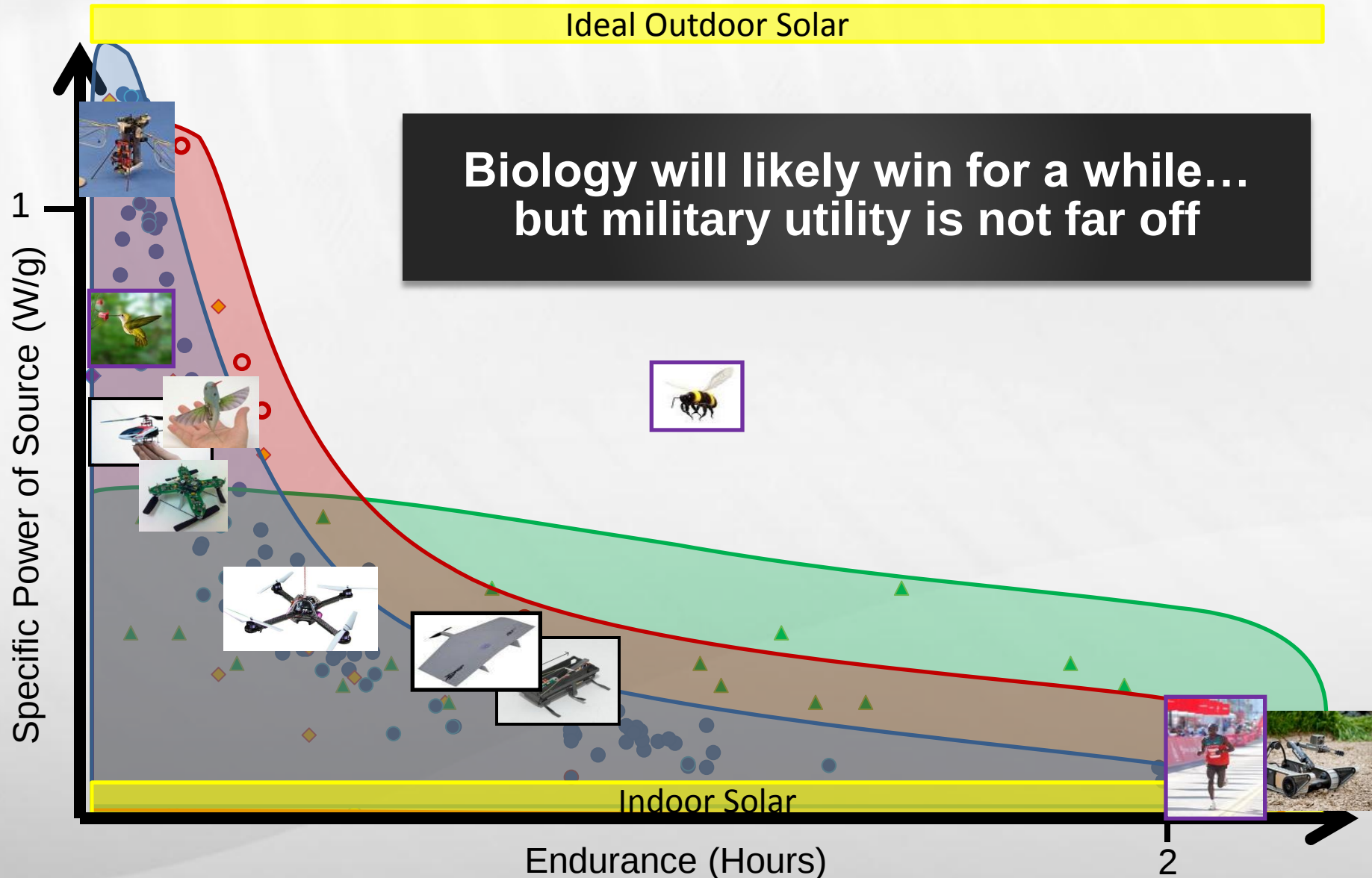




Embrace Cooperation

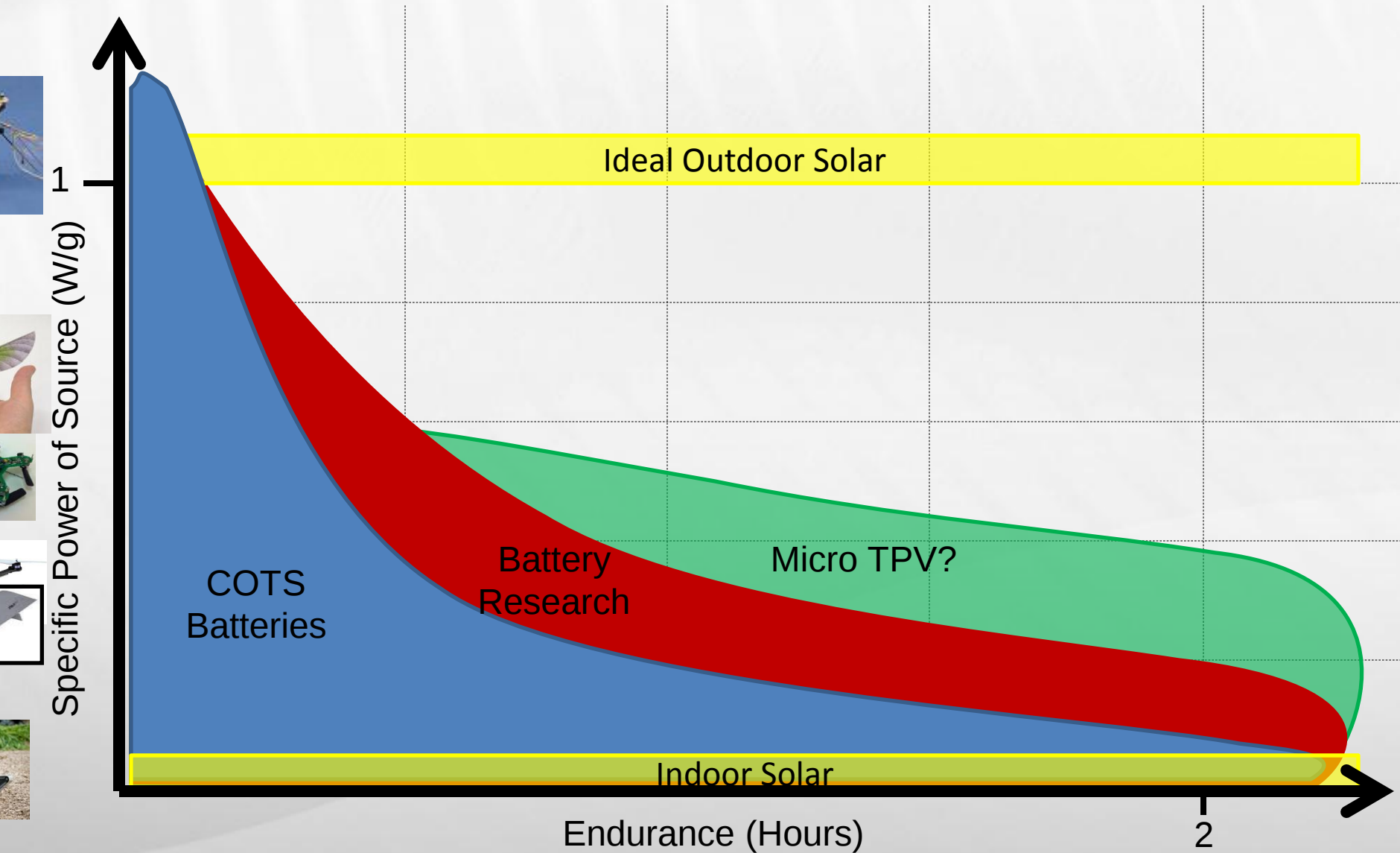


Final Non-Ragone Plot

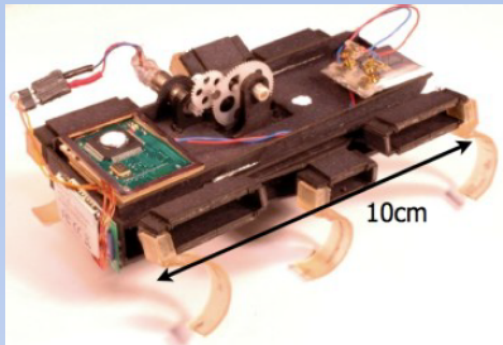


END

Non-Ragone Plot



Representative Platforms: DynaRoACH from UC Berkeley



Current dynaRoach 1.0 (24 grams)

- measured COT at cruise: $5 \text{ J/kg-m} = 120 \text{ mW}$
- cruise speed: 1 m/sec (flat ground)
- total power for cruise: 600 mW
- range: 1.8 km
- max power density 10 W/kg (900 mW, 1000 sec)
(Hoover et al BioRob 2010)v

motor 3 grams 0.24/0.6 W	LiPo 2.5 grams 1100 J	Structure 17 grams	CPU 1.5 grams 0.3 W
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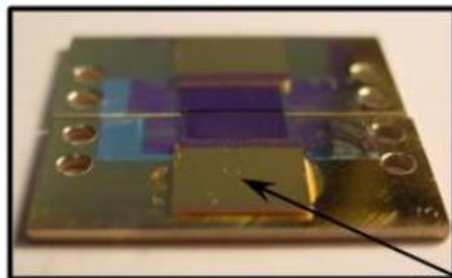
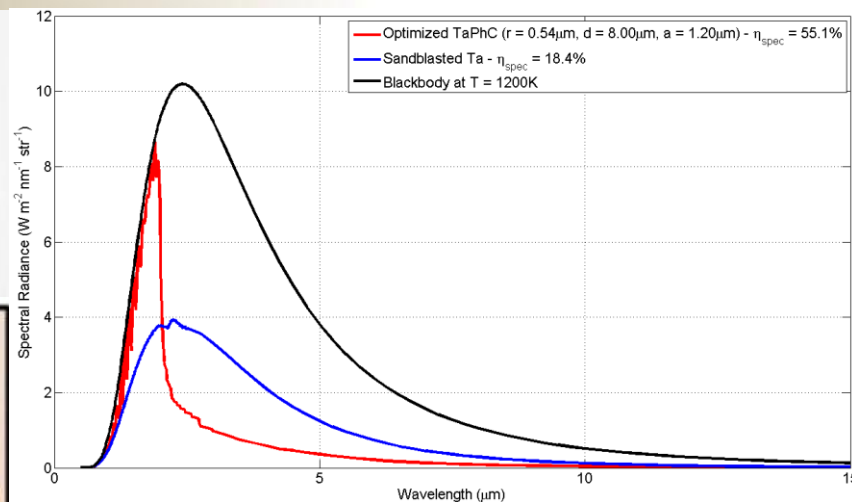
motor 1.7 grams 0.6/1.5 watts	LiPo Battery 3.2 grams 1600 J	proposed structure Goal: 3.6 grams	CPU 1.5 grams 50 mW
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Hypothetical dynaRoach 2.0 (10 grams)

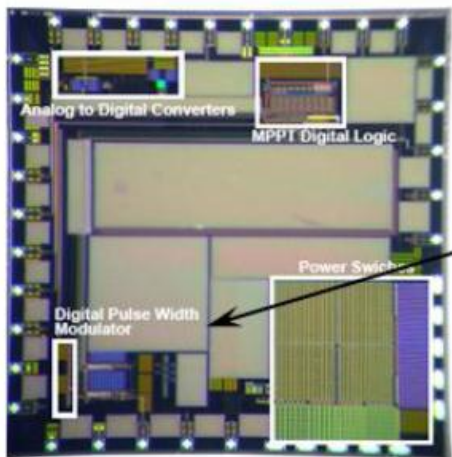
- COT at cruise: $2 \text{ J/kg-m} = 40 \text{ mW}$
- cruise speed: 2 m/sec (flat ground)
- total power for cruise: 130 mW
- range: 25 km
- max power density 150 W/kg (3000 mW, 500 sec)



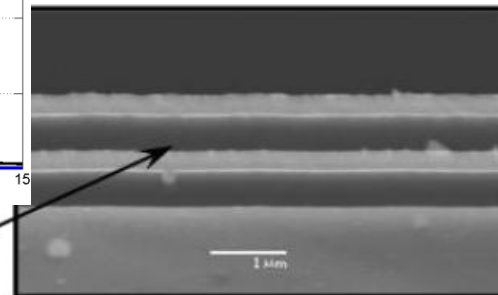
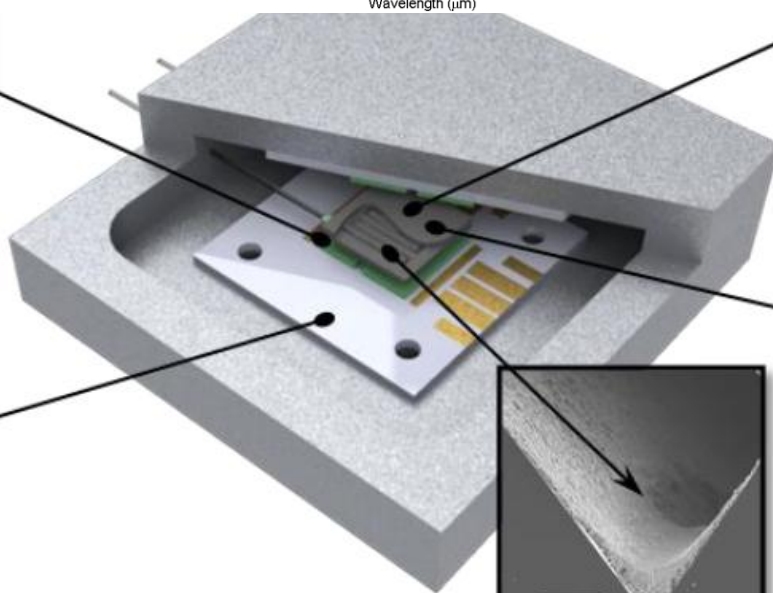
Micro-Thermo-Photovoltaics



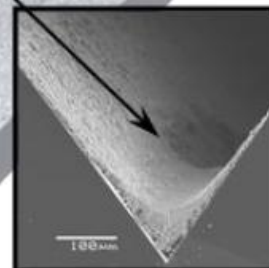
GaInAsSb PV diodes



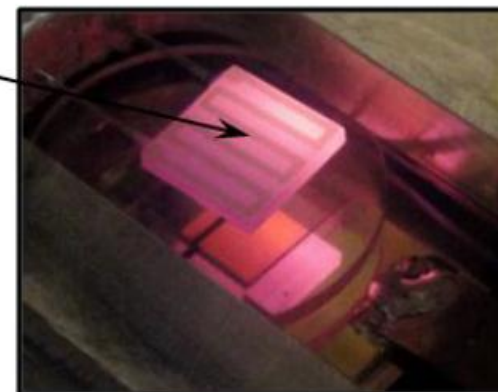
low-power MPPT



1D PhC emitter



micro channel



Silicon MEMs reactor

Representative Platforms: DynaRoACH from UC Berkeley

