Low-mass, Efficient Power Systems for Lunar and Planetary Surface Packages

Dr. Elijah Jensen
BlackBox Energy Systems

The Problem — Reliable Power

BlackBox Energy Systems

Uninterrupted power is a necessity for any mission. Power systems need clean output power, and long cycle life for the batteries.

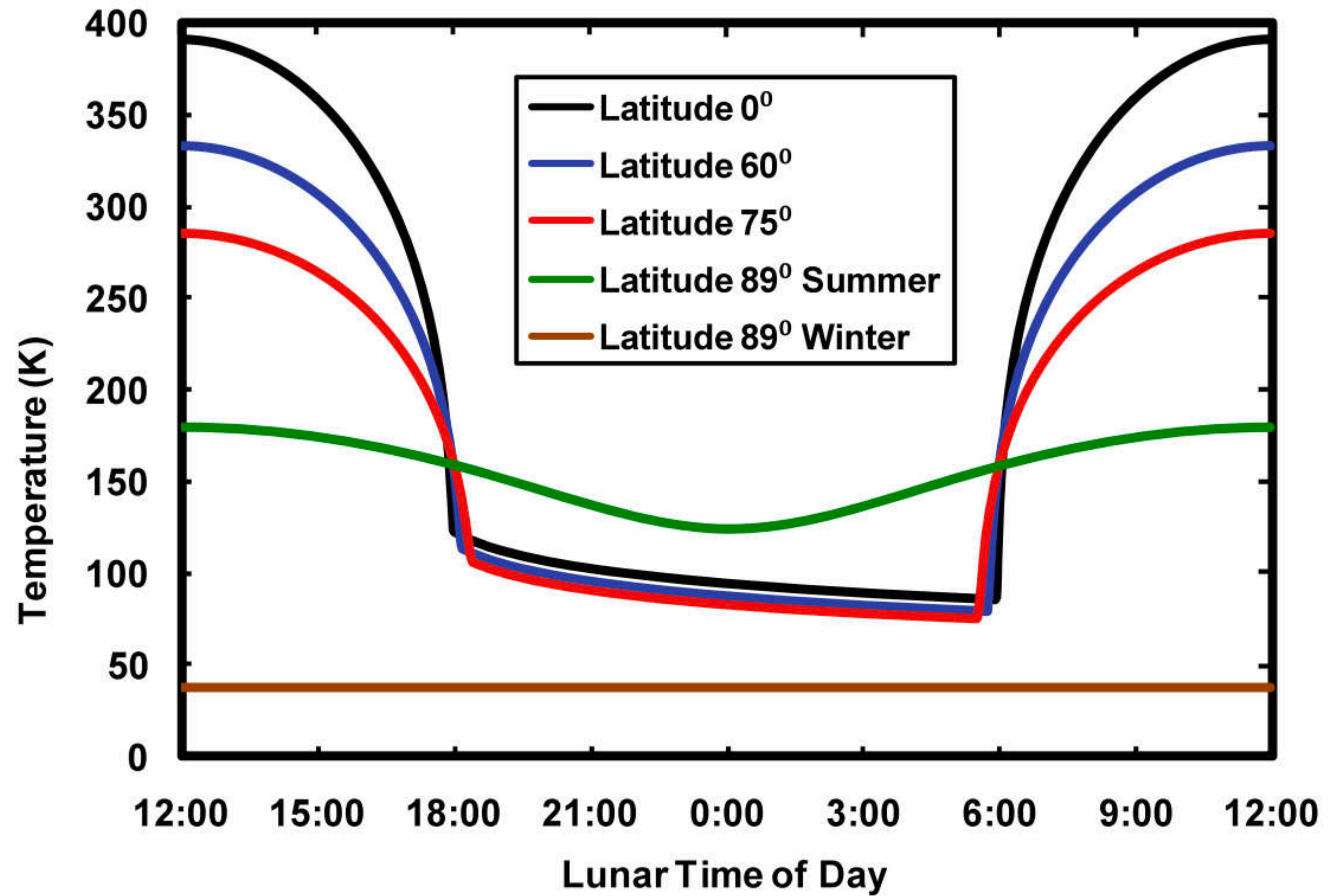
Current systems are difficult to manage thermally, and degrade with each cycle especially in harsh environments

The Problem — Harsh Environment

BlackBox Energy Systems

Space Environments are Harsh

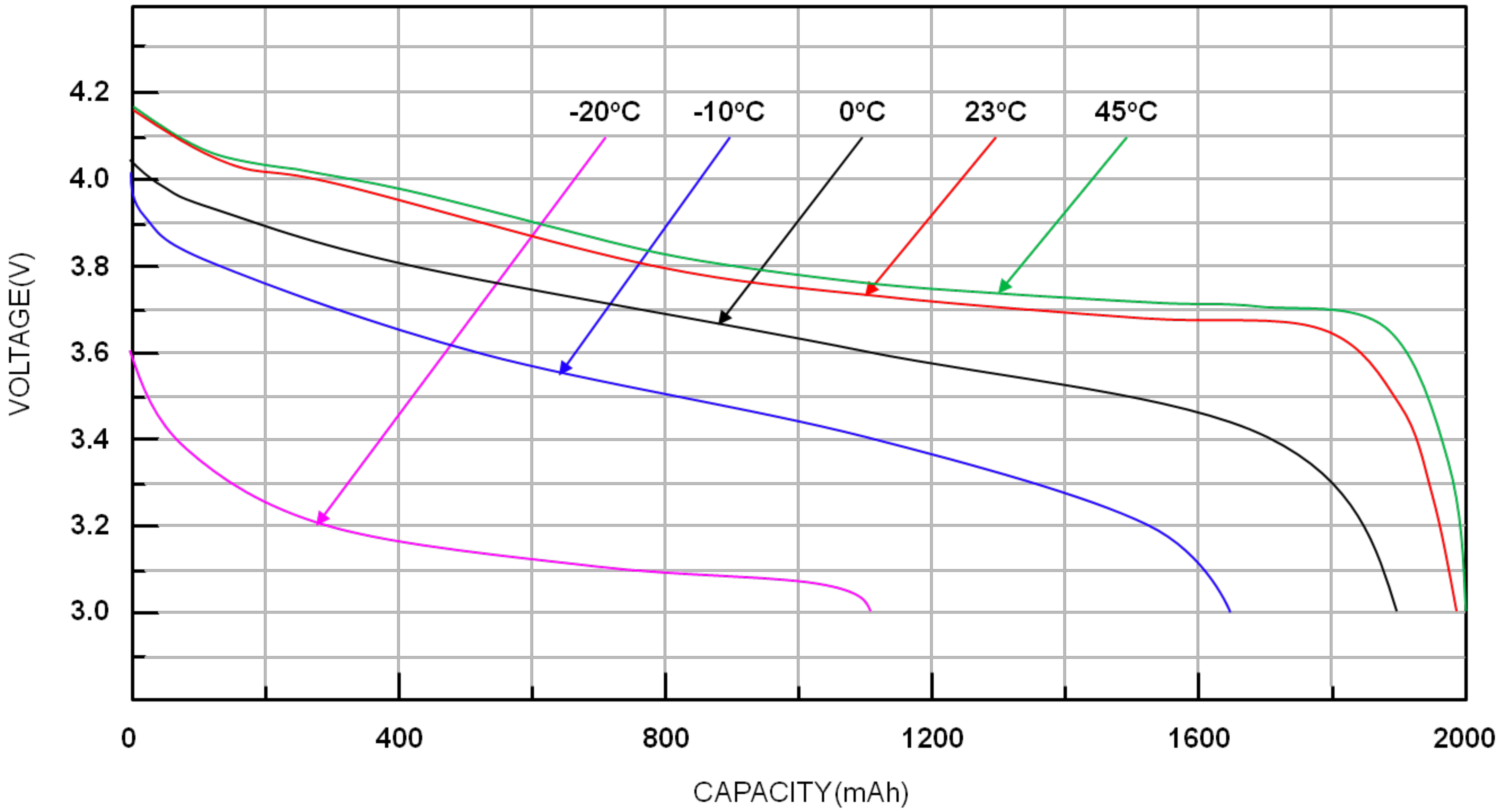
- High temperature Swings
- Low minimum temperature
- Radiation



The Problem — Batteries

BlackBox Energy Systems

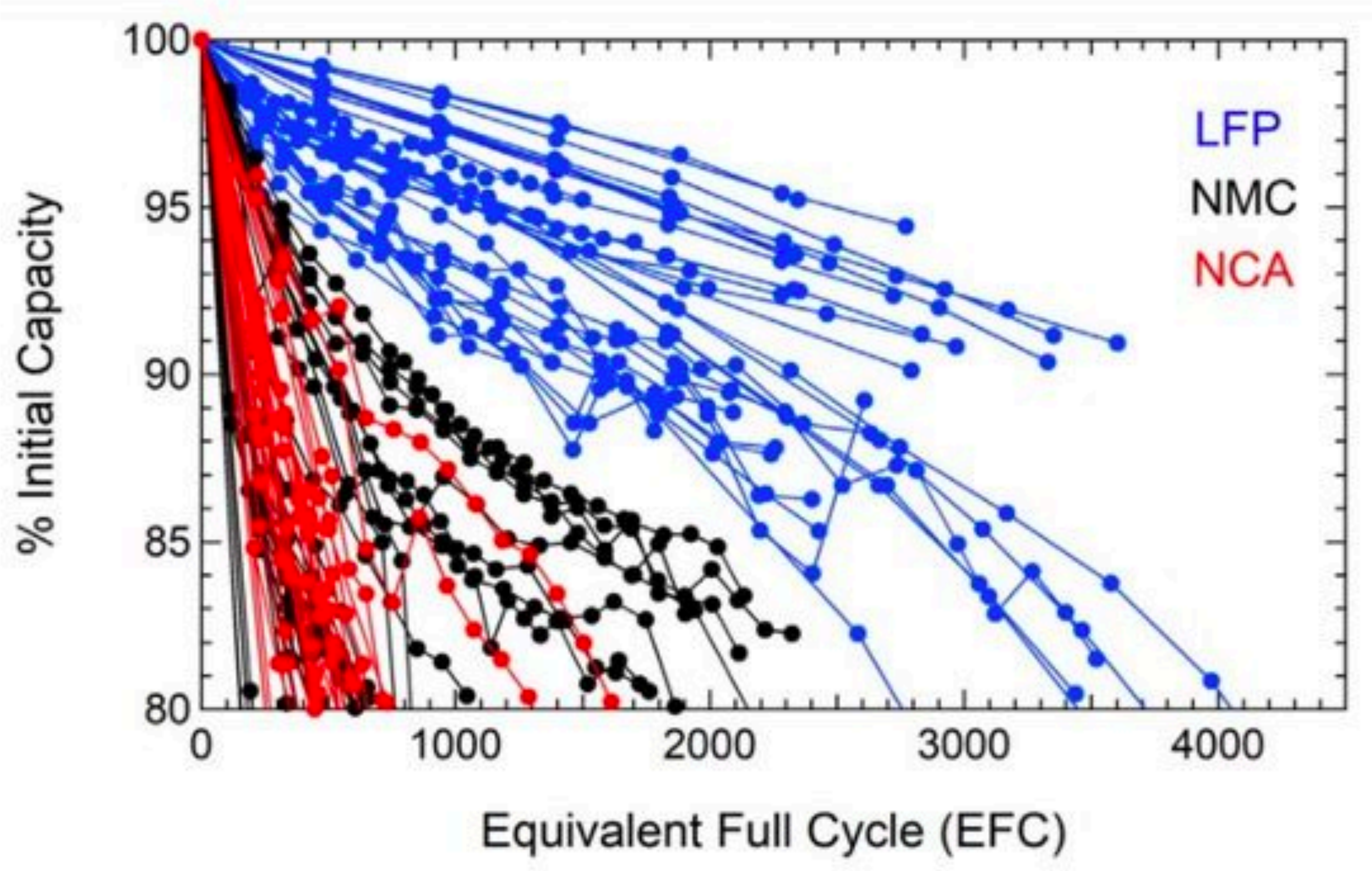
Chemical Based Batteries need higher temperatures to function properly



The Problem — Batteries

BlackBox Energy Systems

Chemical Based Batteries cycle life is low



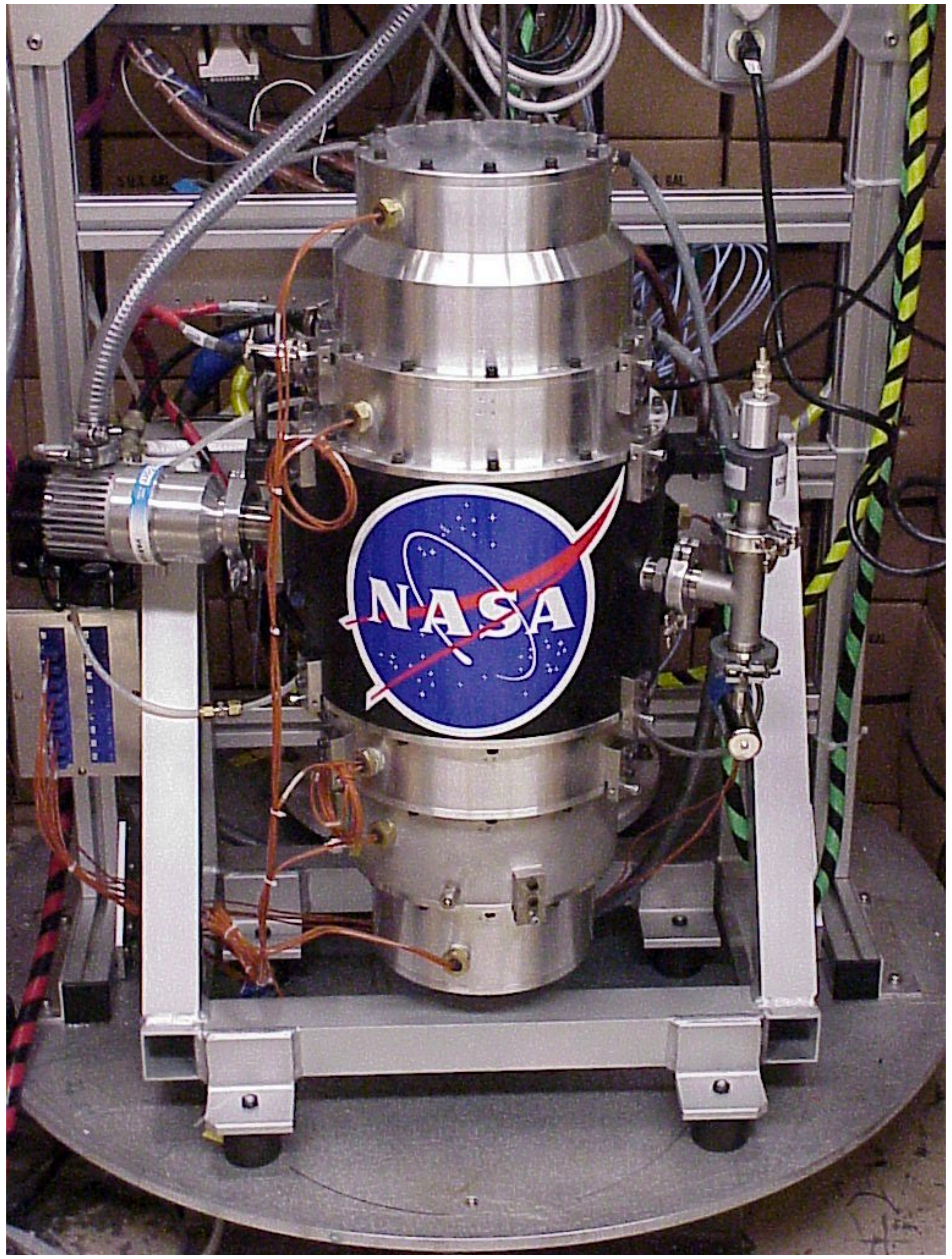
LiFePO4

LiNiMnCoO2

LiCoO2

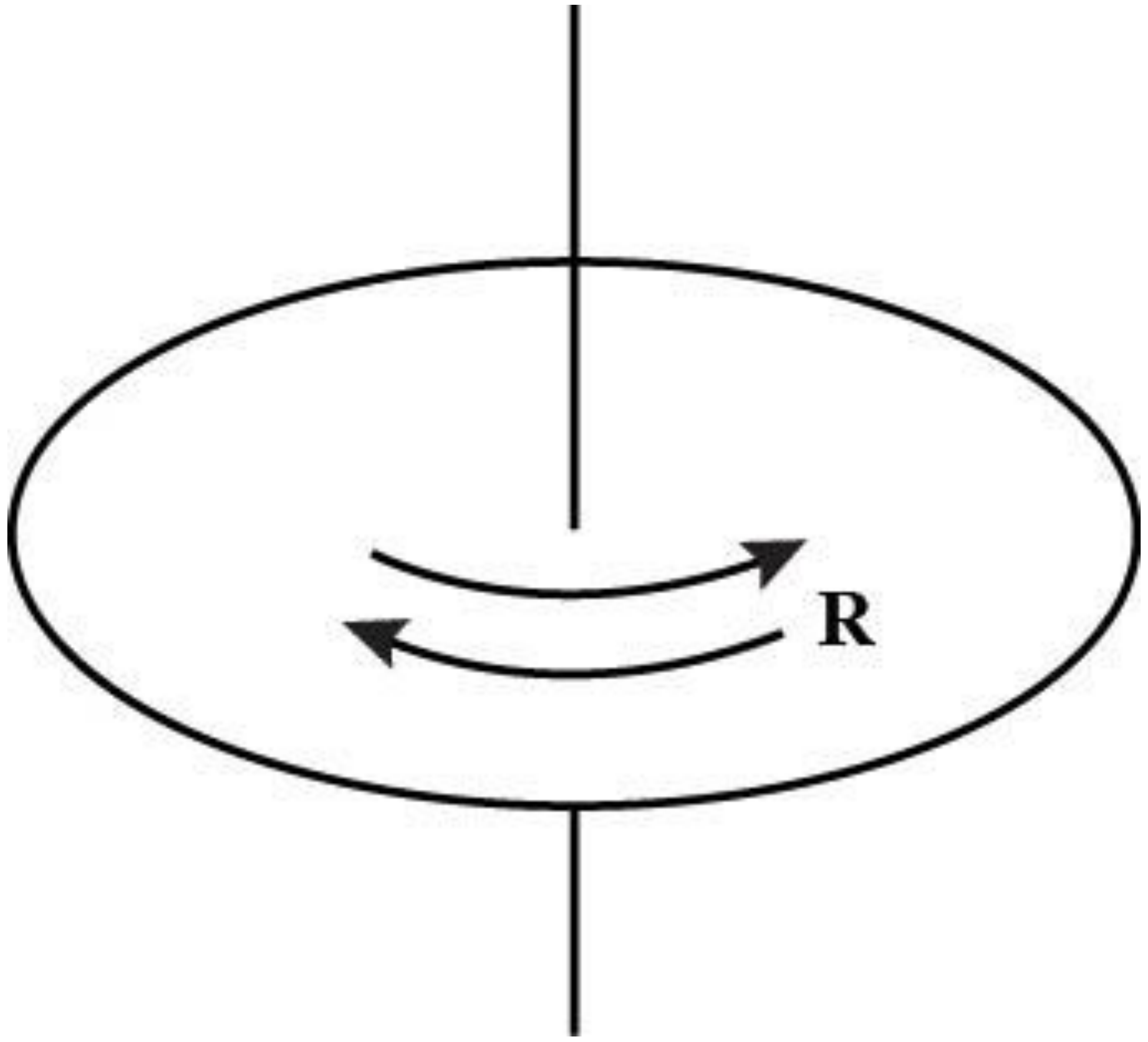
Solution: Flywheel storage

BlackBox Energy Systems

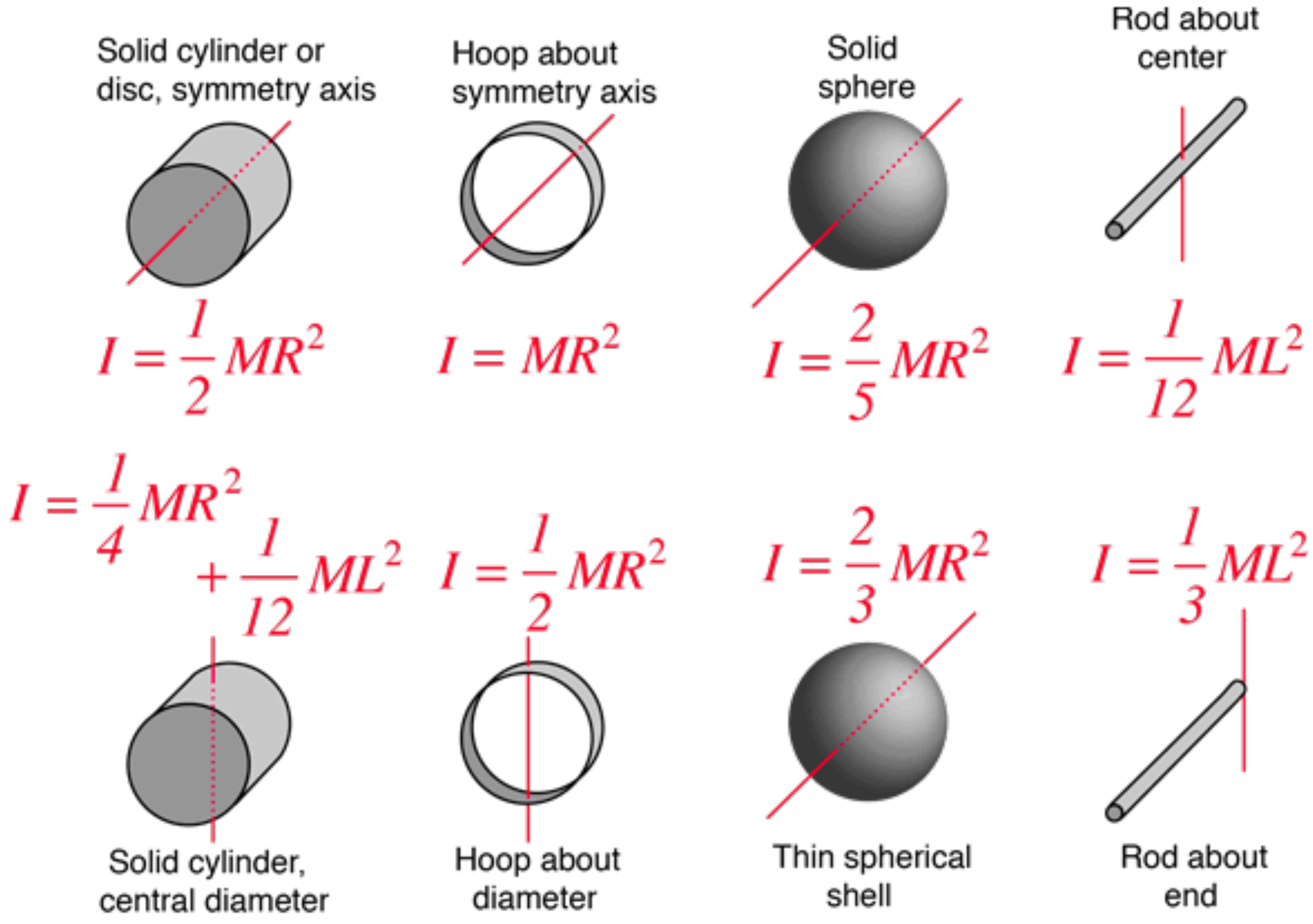


Flywheel Energy

BlackBox Energy Systems



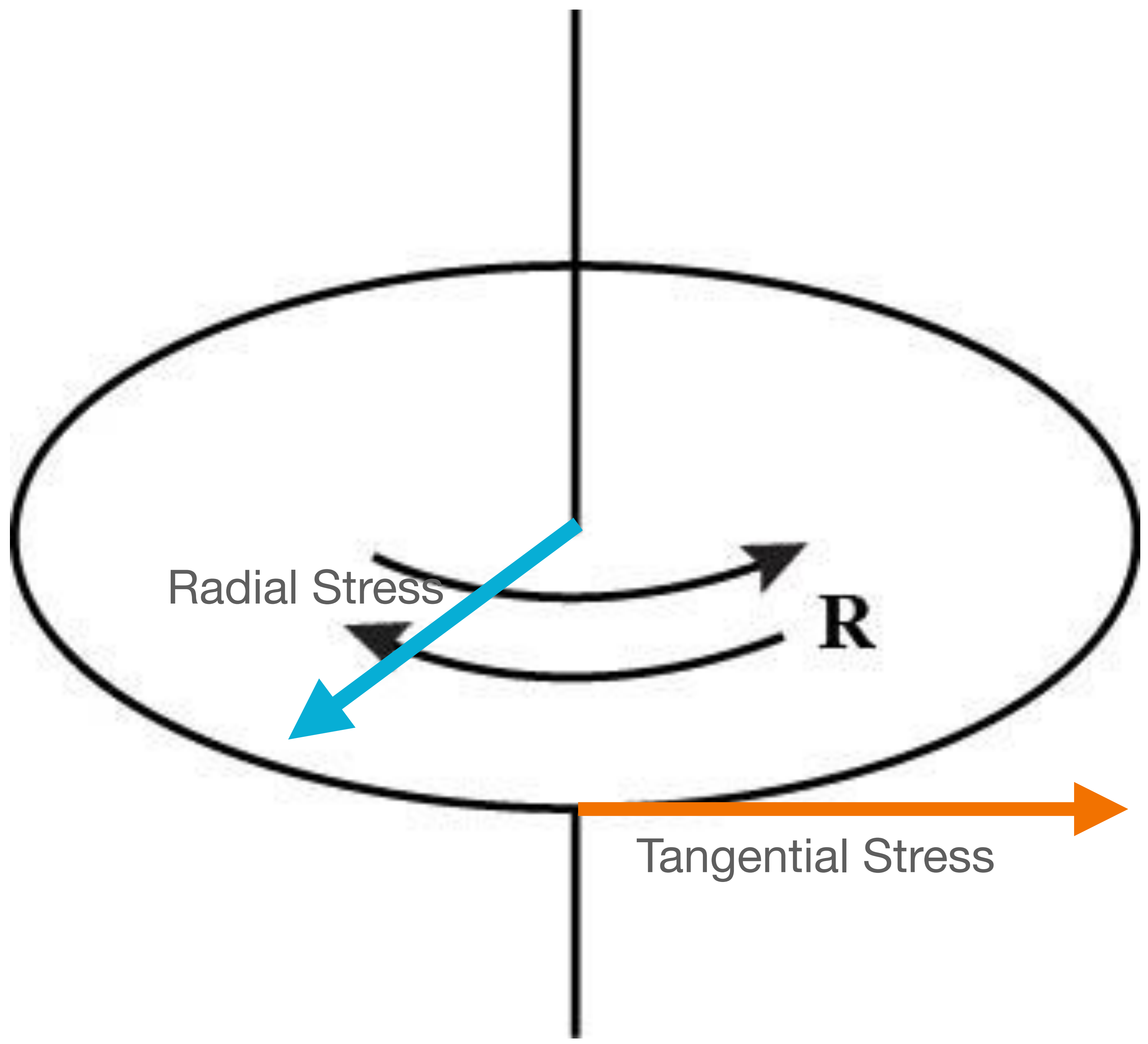
$$E = I\omega^2$$



$$E = \frac{1}{2}MR^2\omega^2$$

Disk Stress

BlackBox Energy Systems



$$\sigma_r = \frac{3 + v\delta\omega^2}{8g}(R^2 + R_0^2 + \frac{R^2 R_0^2}{r^2} - r^2)$$

$$\sigma_t = \frac{\delta\omega^2}{8g}[(3 + v)(R^2 + R_0^2 + \frac{R^2 R_0^2}{r^2} - r^2) - (1 + 3v)r^2)]$$

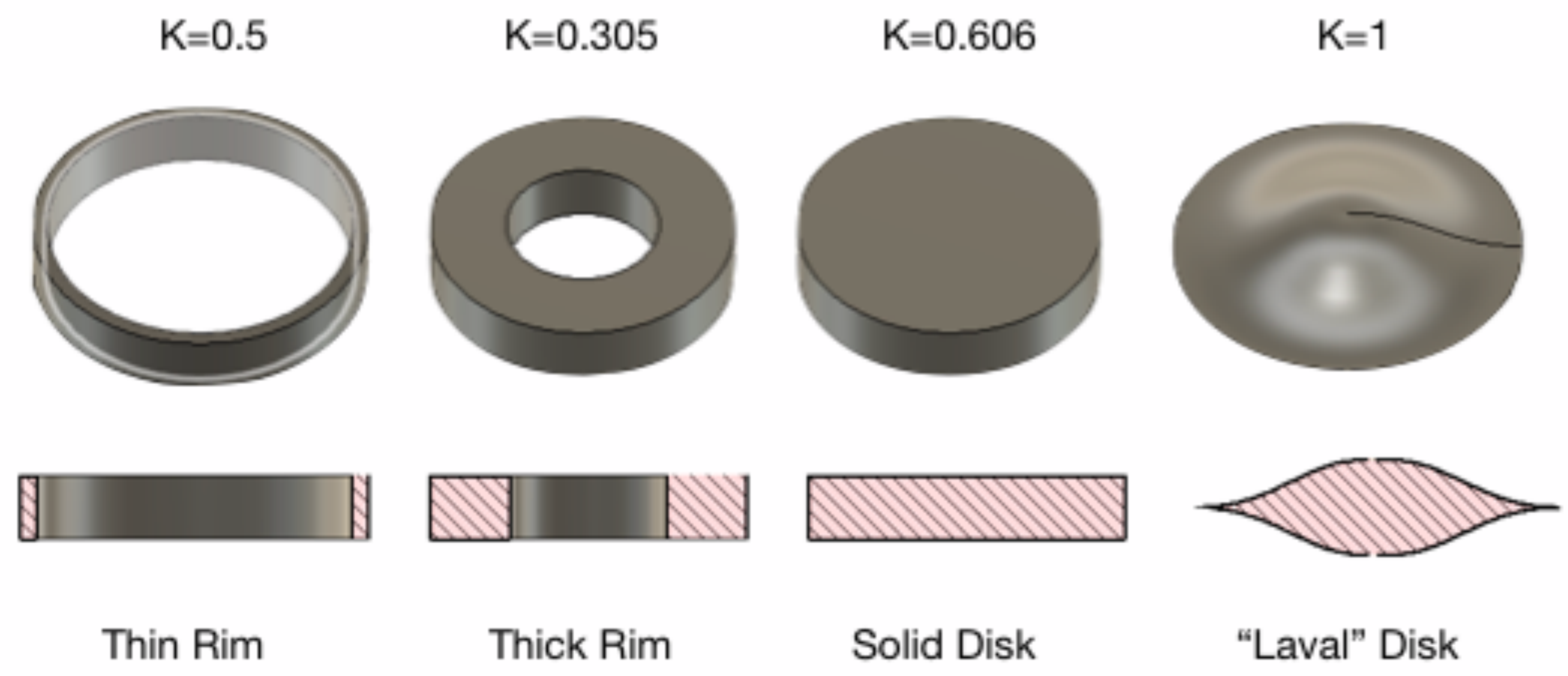
$\delta = density$

$v = poissionratio$

Total Stored Energy

BlackBox Energy Systems

$$E_m = k_f \frac{\sigma}{\rho}$$



We can see that energy stored depends on only 3 factors. Shape, Stress, and Density.

Total Stored Energy vs Material

BlackBox Energy Systems

$$E_m = k_f \frac{\sigma}{\rho}$$

Material	Yield Strength MPa	Density g/cm^3	Total Energy Factor Wh/Kg
Steel	250	7.85	8.84
Titanium	1260	4.5	77.76
Carbon Fiber Composite	3500	1.25	777.56
Glass Composite	2500	2.44	284.53

We can see that energy stored depends on only 3 factors. Shape, Stress, and Density.

Total Stored Energy vs Material

BlackBox Energy Systems

Applying a 4X safety factor on yield strength:

Material	Yield Strength MPa	Density g/cm^3	Total Energy Factor Wh/Kg
Steel	250/4	7.85	2.21
Titanium	1260/4	4.5	19.44
Carbon Fiber Composite	3500/4	1.25	194.39
Glass Composite	2500/4	2.44	71.13

CarbonFiber Flywheels yield higher energy density than LiFePO4 around 120Wh/Kg

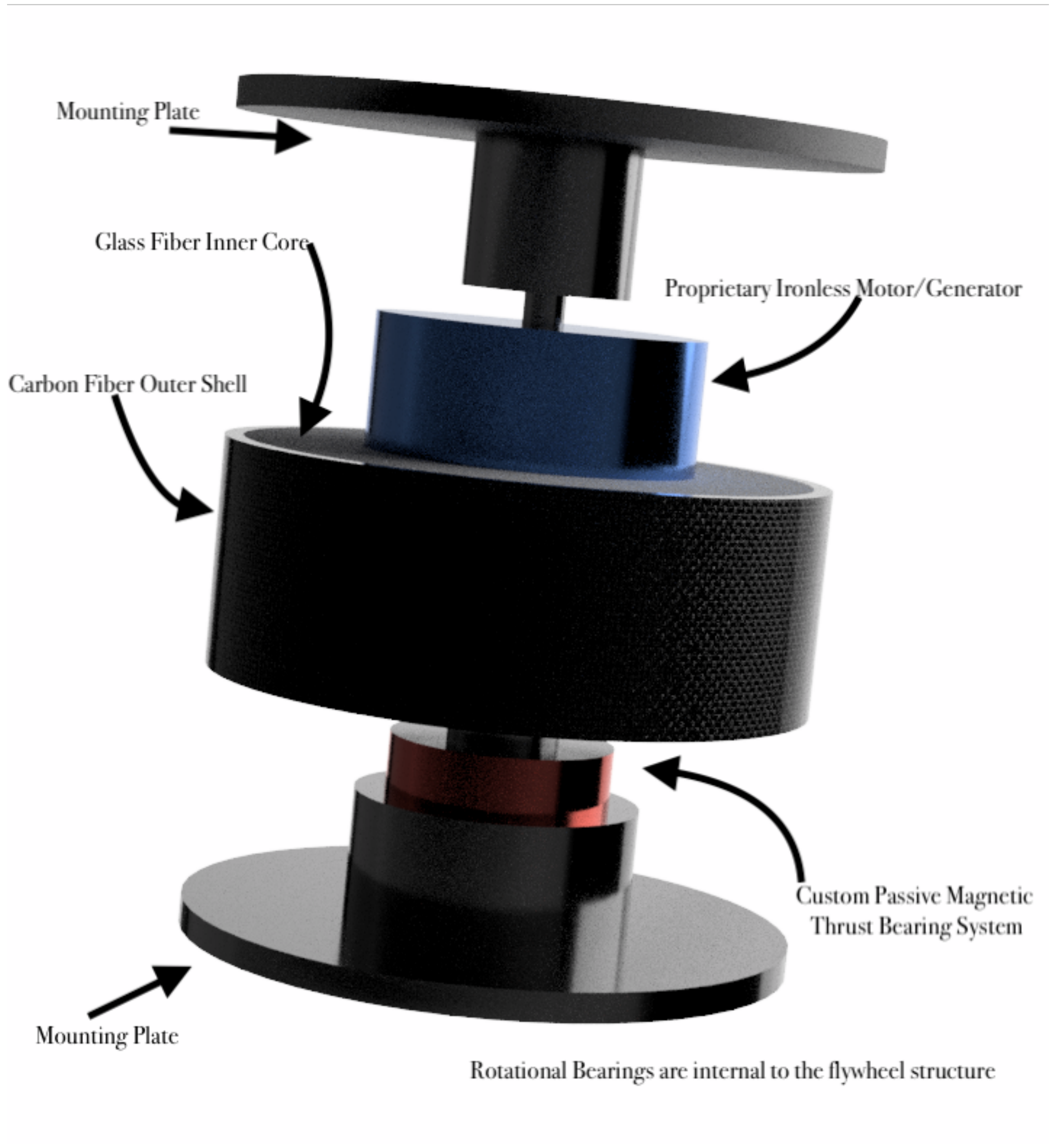
Design

BlackBox Energy Systems

- Carbon Fiber Composite Increases Strength in Cold temperatures!
- Range from -150C to 100C without damage.
- Package Solutions hope to achieve 120Wh/Kg with supporting structure.
- High Speed Magnetic Bearings reduce loss
- High speed ironless generator reduces cost/weight and complexity.

Design

BlackBox Energy Systems



Design Speed: 60kRPM

Energy Stored: 260wh

Weight: 1kg spinning mass: 1.5kg supporting mass

Total Weight 3kg

System Energy Density: 104wh/kg

Passive Magnetic Bearing (radial)

Passive Magnetic Thrust Bearings

Ironless motor/generator with zero hysteresis loss and extremely low static copper loss.

Progress/Future Work

BlackBox Energy Systems

- We have a prototype of our generator motor and electronics complete.
- We are currently working on integrating our flywheel with these components
- We have applied for an SBIR to experiment with novel flywheel shapes to increase the K factor.

Conclusions

BlackBox Energy Systems

- Mechanical batteries can help create robust energy storage devices for harsh environments both space-based and terrestrial.

- New technology combined with known principles can help make Flywheel Storage a solution in the next decade.

BlackBox Energy Systems

Powering our World

em-Powering People

THANK YOU!