



Research & Technology

Boeing Flywheel Energy Storage Technology

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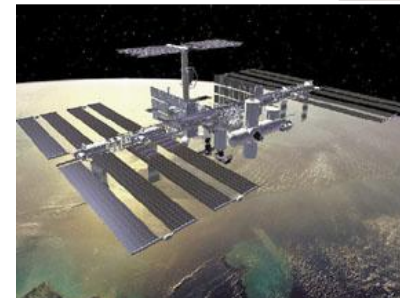
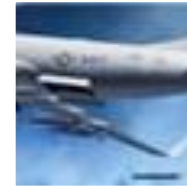
Discussion Topics

- **Organizational context**
- **Flywheel technology background**
- **Synopsis of Boeing's ARPA-E Grid-Scale Rampable Intermittent Dispatchable Storage (GRIDS) Tasking**

Boeing Aerospace Products

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Systems & Electronics Technology

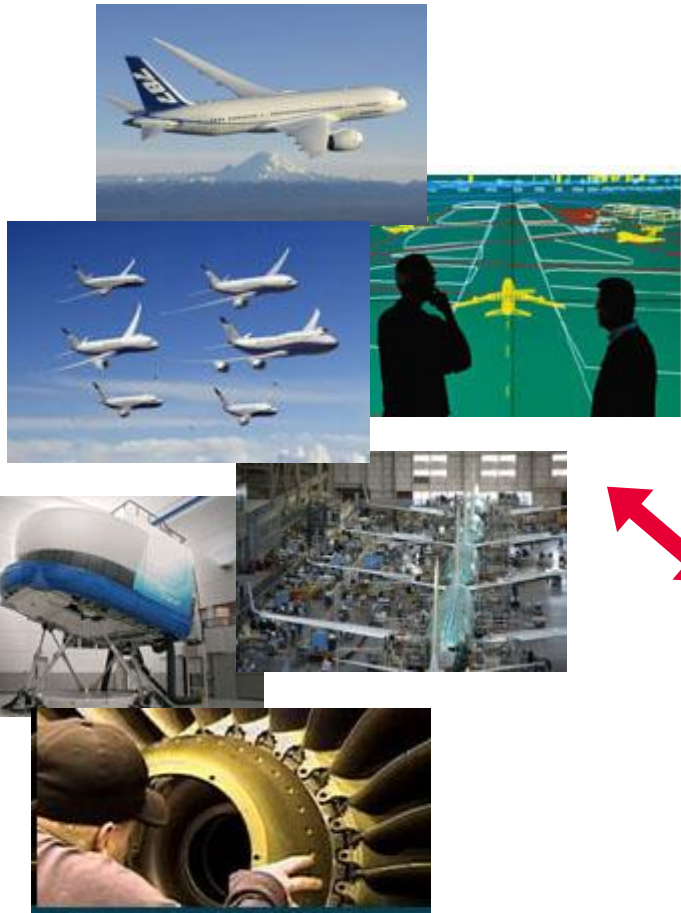


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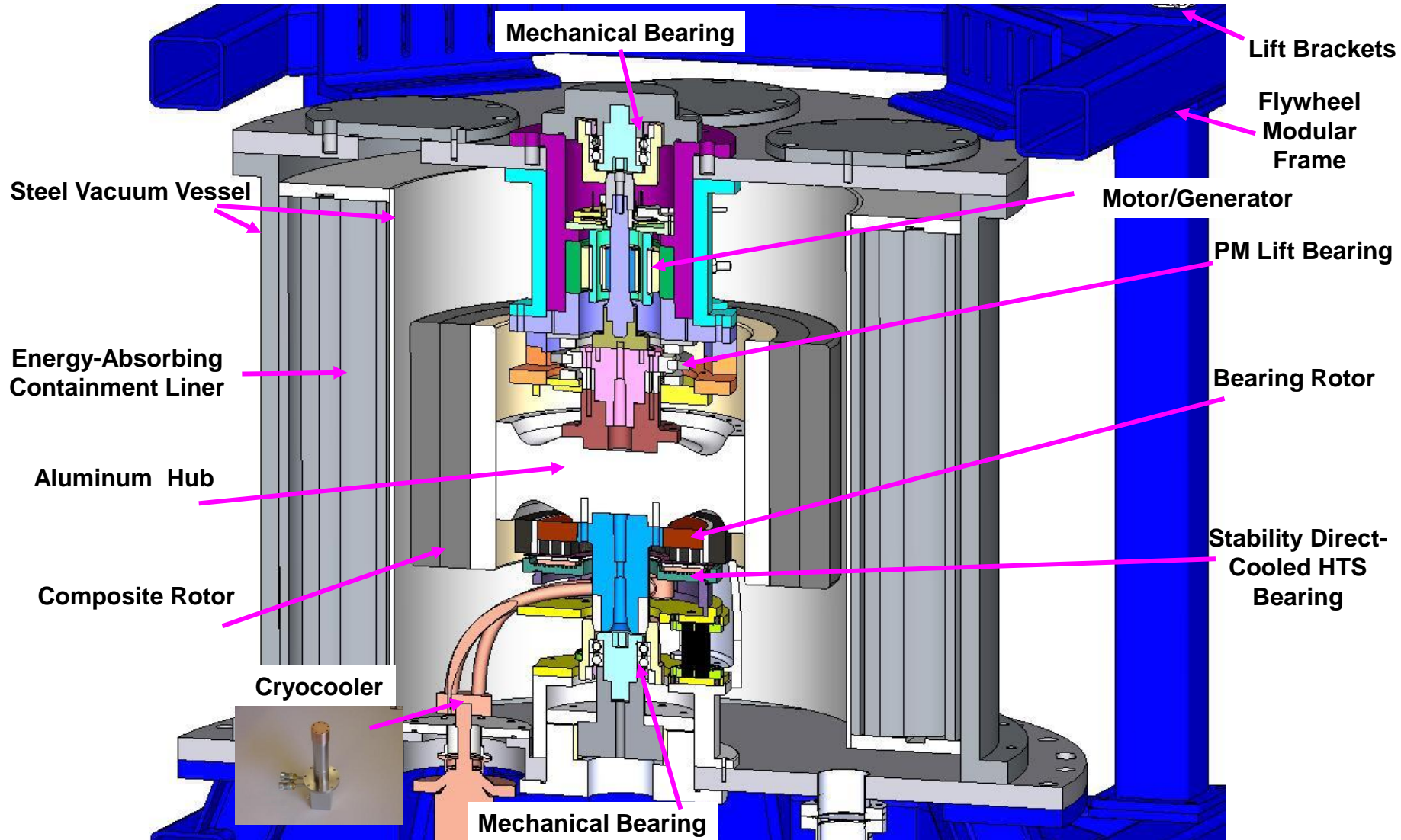
Boeing Commercial Airplanes



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Boeing Modular Flywheel Design



Boeing Flywheel Basics

Flywheel Energy Storage

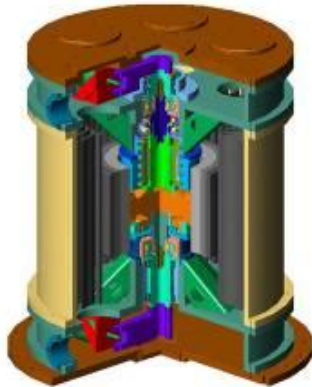
- Stores Kinetic Energy in Rotating Mass (Thick wall cylinder)

$$E_k = \frac{1}{2} \cdot I \cdot \omega^2$$

$$I = \frac{1}{2} m(r_1^2 + r_2^2)$$

ω is the angular velocity, I is the moment of inertia, m is the mass, r is the radius

Best designs spin as fast as possible to take advantage of ω^2



Premier Boeing Technology is HTS Bearing

- Keeps kinetic energy in reserve by utilizing the Boeing patented low-loss high-temperature superconducting (HTS) magnetic non-contact bearing system
- The rotational kinetic energy of the flywheel can be converted into electrical power as needed by the load

The flywheel systems are similar to batteries **except:**

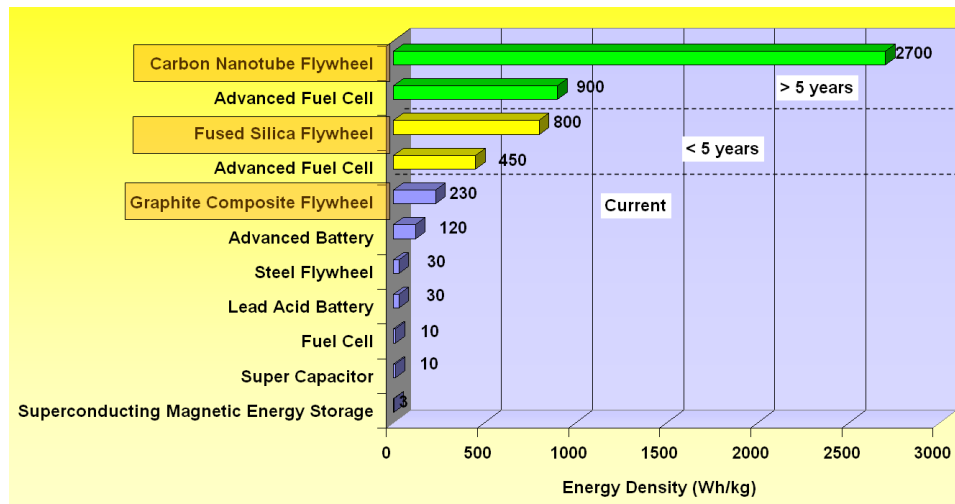
- Environmentally clean (green)
- No hazardous materials
- Long life expectancy (>20 yrs)
- Ideally suited to multiple power applications
- Can handle rapid discharge rates without degradation

Present day Boeing FW tip speed is 800 m/sec. World record on small test rotor is about 1,405 m/sec. FW tip speed is limited by material properties. Our plan is to develop new materials that would allow us to reach 3,000 m/sec.

Flywheels with Superconducting Bearings

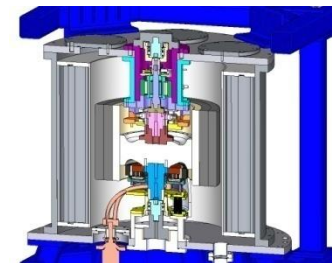
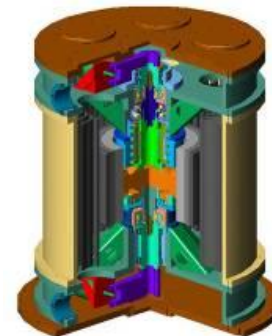
Flywheel Energy Storage

- Non-toxic and low maintenance
- Potential for high power density (W/ kg) and high energy density (W-Hr/ kg)
- Fast charge / discharge times possible
- Cycle life times of >25 years
- Broad operating temperature range



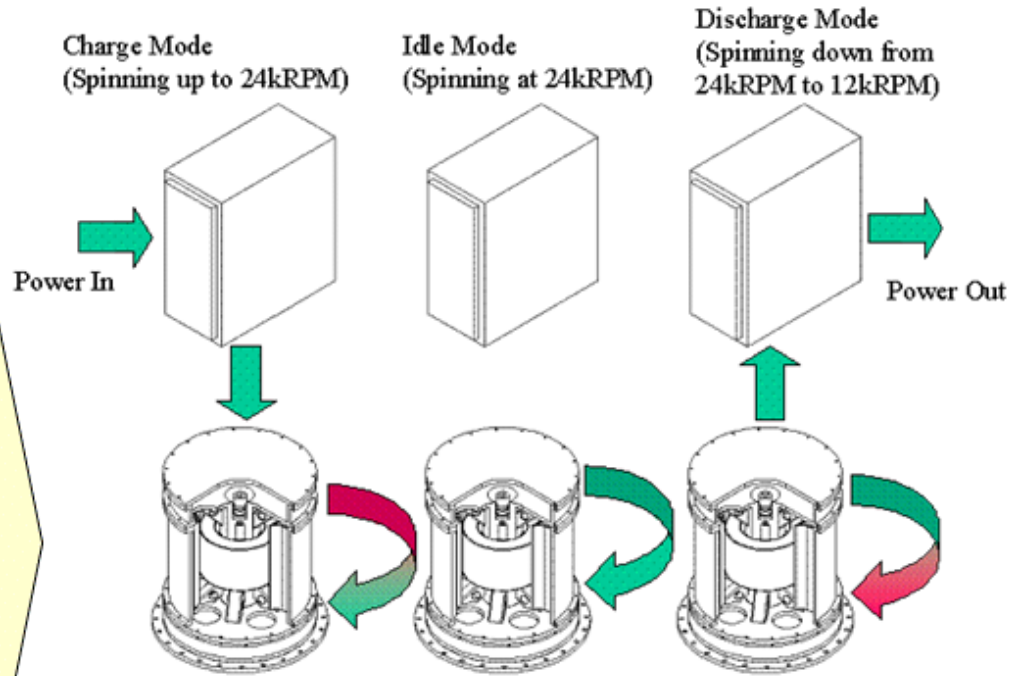
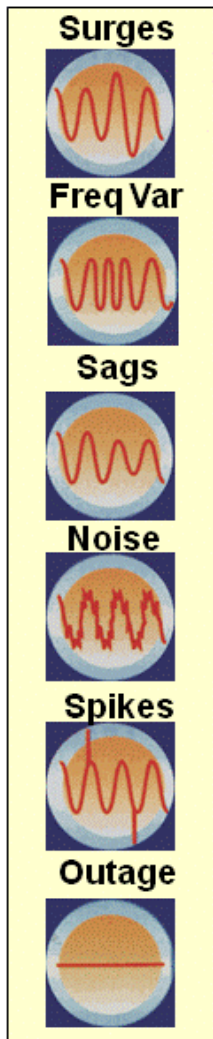
HTS bearings

- Simple passive system
- Very low frictional loss
- Very long lifetime
- Low cost and maintenance
- Lower tolerance for balancing of dynamic structures
- High speed capability (> 500,000 RPM)
- Adjustable stiffness and damping



Superconducting Bearings Offer Many Design & Operational Benefits Over Conventional Bearing Systems

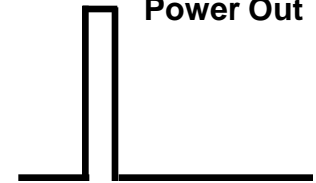
Flywheel Electricity Systems



Uninterrupted Regulated (Load Leveled) Power Out

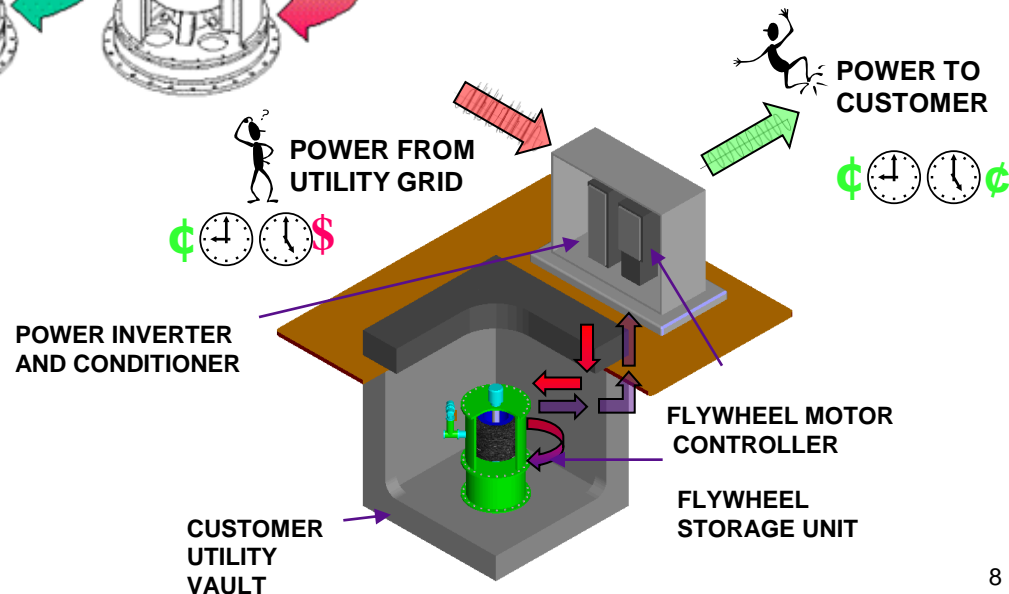


High Pulsed Power Out



Flywheel Functions

- Standby Power Source
- Power Quality
- Load Leveling
- Peak Shaving
- Reactive Power Support
- Voltage Support



Boeing ARPA-E Flywheel Project Overview

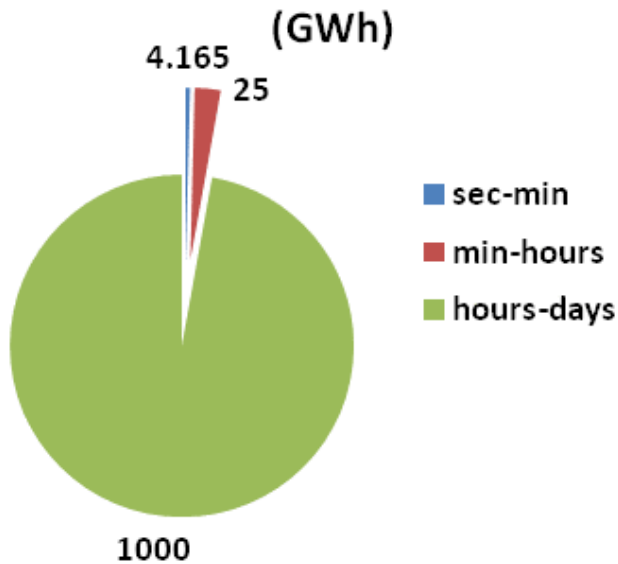
“Low-Cost, High-Energy Density Flywheel Storage Grid Demonstration”

Project Objective

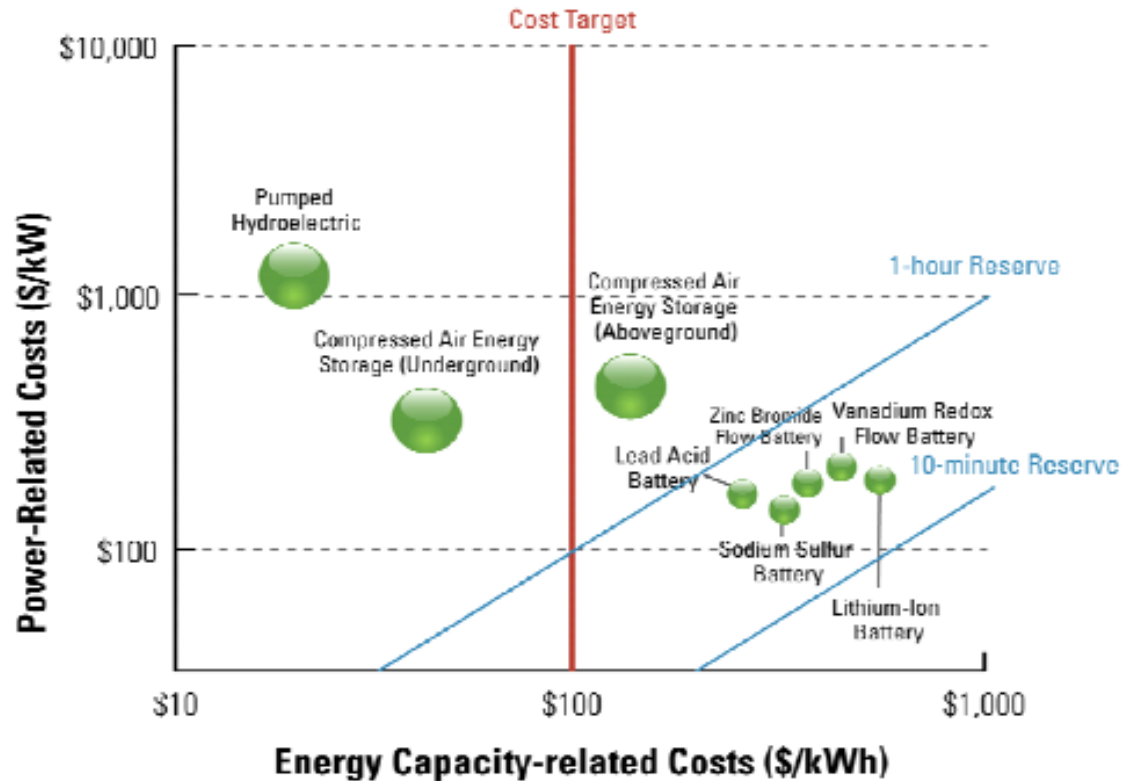
- A combination of **advanced fiber technology** and **superconducting bearings** enables the development of a **low-cost**, extremely high energy-density, **high-efficiency** flywheel energy-storage system. The superconducting bearings enable high efficiency and high spin rates. The new proprietary fiber enables high rotor tip speeds resulting in high energy density, with a projected cost of \$100/kWh for the flywheel system at utility scale and large-rate factory production
- The project will produce test quantities of the new fiber and provide proof-of-concept performance data of the fiber properties. The prototype flywheel will be small enough (7 kWh/5kW) to facilitate rapid development with a design that is easily scalable to a utility-size unit (~100 kWh) and amenable to factory production to achieve low cost
- The vision for commercial production is that individual 100-kWh flywheels will be arrayed in a transportable container with a total storage of 2 MWh for utility applications

Energy Storage Technologies

US Storage Market for Renewables (GWh)



Capital Costs of Energy Storage Technologies

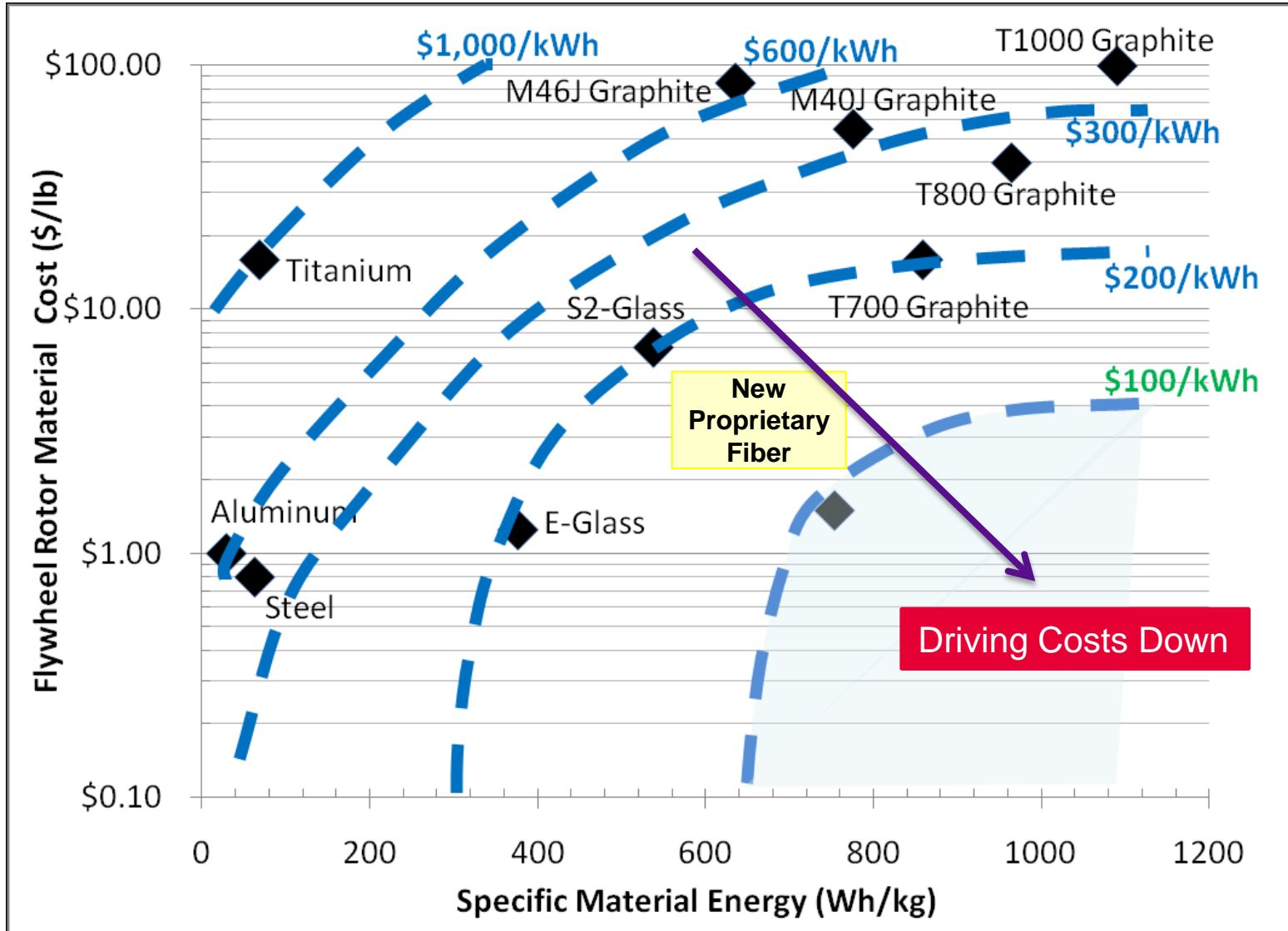


Reference
 U. S. Department of Energy - Headquarters
 Advanced Research Projects Agency – Energy (ARPA-E)
 Grid-Scale Rampable Intermittent Dispatchable Storage (GRIDS)
 Funding Opportunity Number: DE-FOA-0000290
 CFDA Number: 81.135
 Issue Date: 3/2/2010

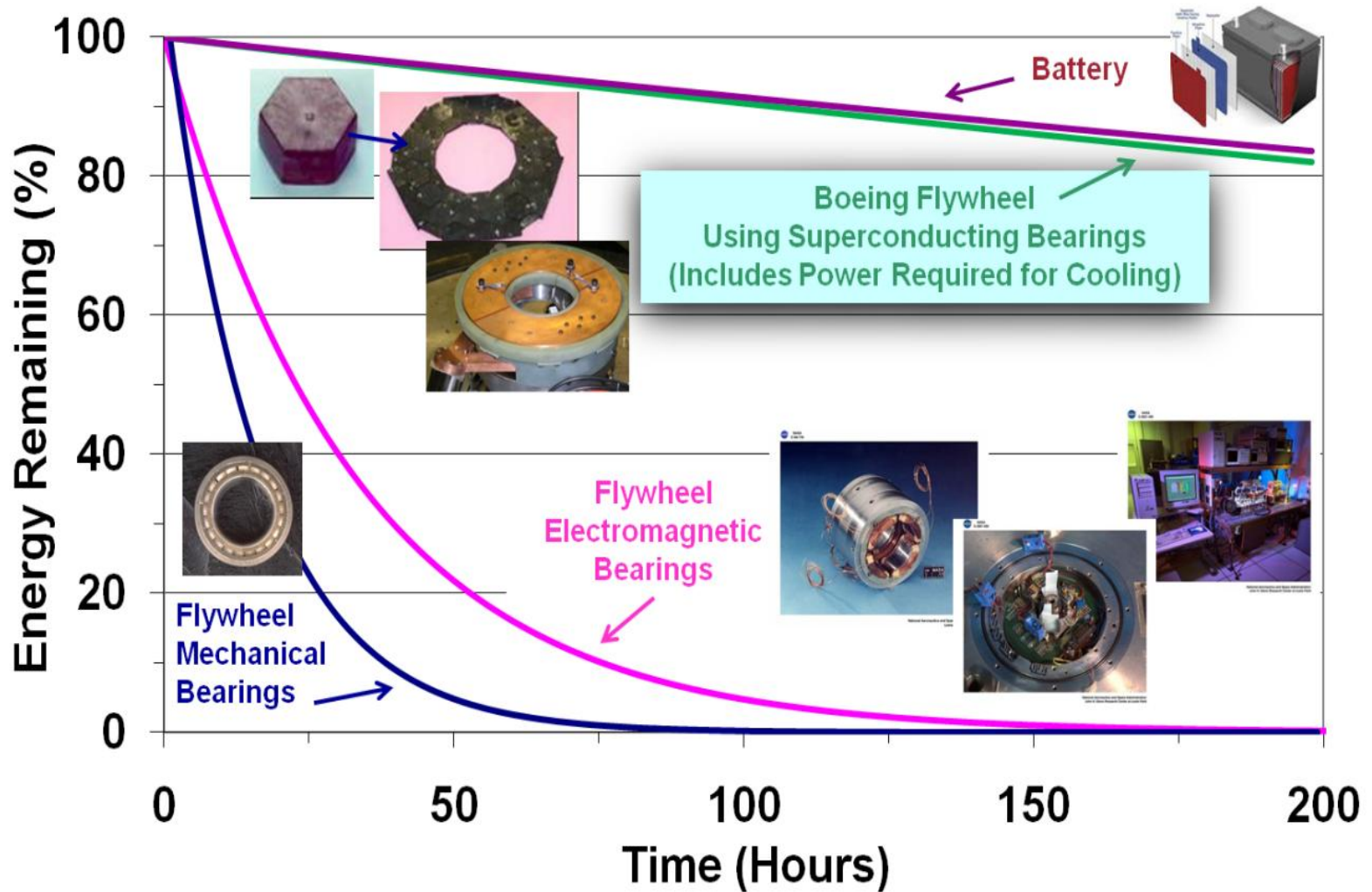
Link to ARPA-E GRIDS website: <http://arpa-e.energy.gov/ProgramsProjects/GRIDS.aspx>



New Fiber Will Reduce Flywheel Cost

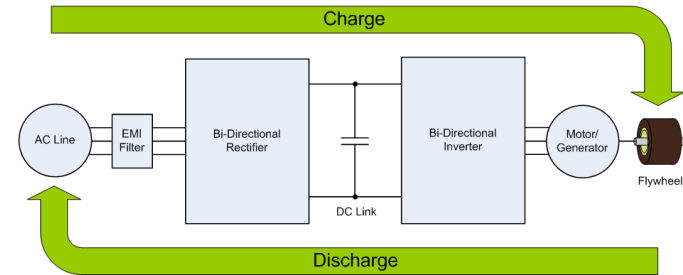


Superconducting Bearings - Low Energy Loss



Design for Lower Cost & Higher Efficiency

- New composite material
- Automated rotor production
- Improved touchdown bearing
- Lower parasitic losses for vacuum system
- Optimized direct-cooled HTS bearing design – no LN2
- Higher efficiency, lower cost AC to AC power electronics (GaN)
- Baseline: 480VAC 3Ø 60 Hz to 480VAC 3Ø 0-750 Hz
- Bi-Directional Power Flow



Standard Si Solutions	Round Trip	Generating	Motoring
Diode Rectifier/Inverter	83.6%	91.4%	91.4%
MOSFET Rectifier/Inverter	82.3%	90.7%	90.7%
Active Rectifier/Inverter	73.4%	85.7%	85.7%
Boeing GaN Solution	94.9%	97.4%	97.4%

Key Accomplishments

- **100's of meters of new fiber produced**
- **All flywheel design completed**
- **All flywheel hardware analysis completed**
- **Most flywheel hardware ordered and some already received**
- **Composite rotor winding under way**
- **Higher efficiency, lower cost AC to AC power electronics (GaN) design in-work**
- **New more efficient motor/generator (patent pending) for wider operating speeds fabricated and in test**
- **Controller & power electronics designed and in fabrication**

Questions?



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