Kinetic Energy Storage and Power Generation

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- **The Need – Structural composites with revolutionary strength and modulus increases**
  - **Composite materials and relationship to inertial energy storage and power generators**
- **Overview of application areas**
- **Example**
  - **Large energy storage (GJ) for grid connection**
  - **Sizing using today's composites**
- **Structured nanocomposites – Path to the future?**

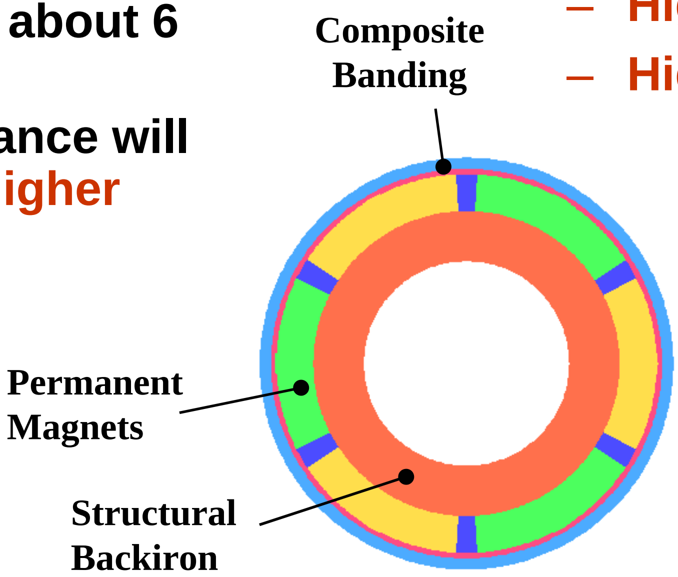
Composite Materials Relationship to Inertial Energy Storage and Power Generation

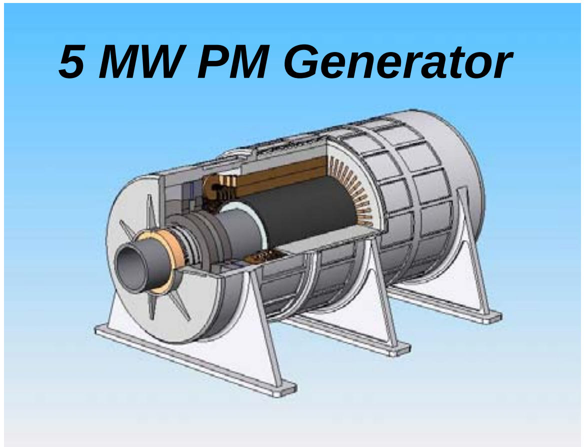
Kinetic energy storage

- **Stored energy ~ Jω^2**
- **Specific Energy (wh/kg)**
  - **Proportional to σ_t/ρ**
  - **Current composites offer a factor of about 6 over steel**
  - **Higher performance will be realized by higher strength, stiffer composites**

PM Generators

- **PM generator's power can be described by $P \sim D^2\omega$, where**
  - **D is mean air gap diameter**
  - **ω is shaft speed**
- **Higher performance machines require**
  - **Increased D and ω**
  - **Higher strength composites**
  - **Higher stiffness composites**





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Application Areas of Technology

Space

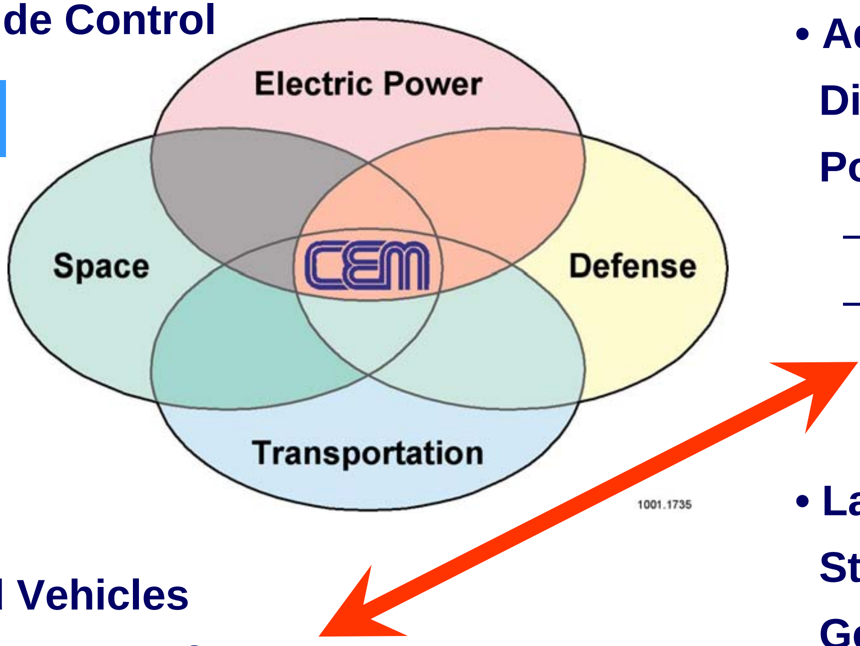
- Dual mode use
  - –Space Power
  - –Satellite Attitude Control

Transportation

- Advanced Hybrid Trains
- Hybrid Passenger Cars

Defense

- Advanced Hybrid Vehicles
- MW Class PM Generators for Directed Energy Systems

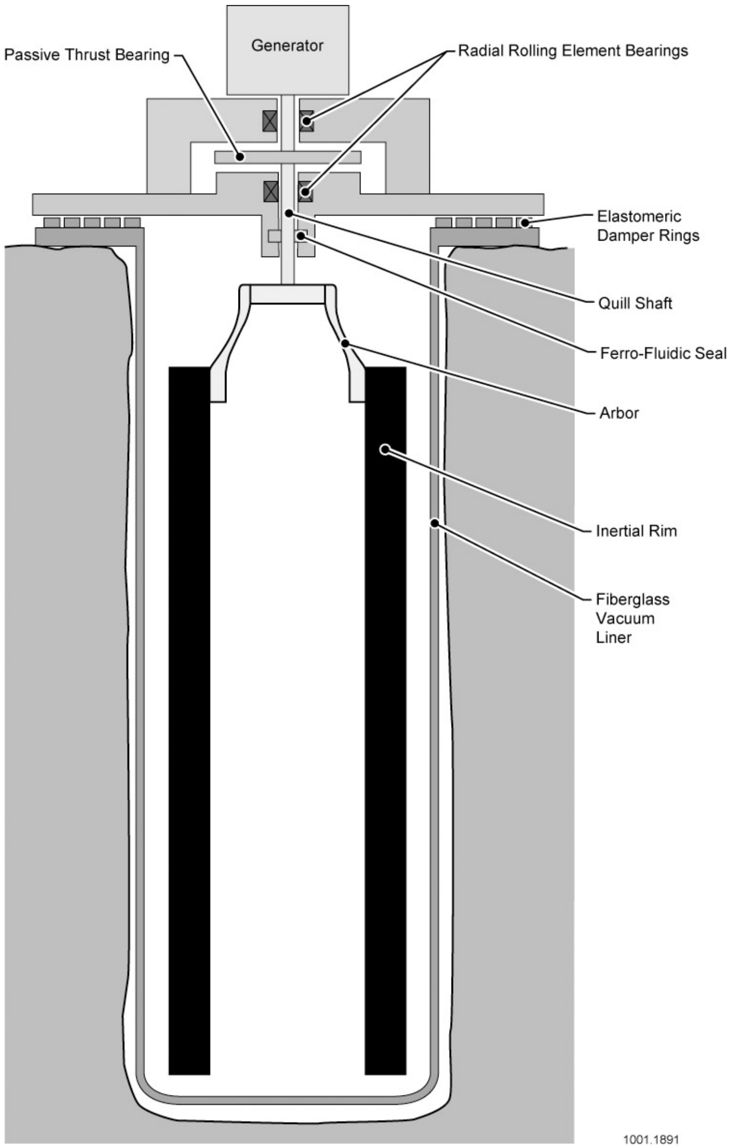


Electric Power

- Advanced Generators for Distributed and Remote Power
  - – MW class machines
  - – PM generators with composite overwrap
- Large Scale Energy Storage for Power Generation

Example: Energy Storage for Grid Connection

- 8 GJ, 2.2 MW-hours stored energy
- Composite energy storage rim
  - Using today's materials
  - Rim weight is 65,000 lbs
- System performance/cost driven by
  - Cost of materials
  - Amount of materials needed ($J\omega^2$)
    - Operating speed dependence upon materials strength and modulus
- Performance vs cost improvement directly related to
  - Price of materials
  - Enhanced material properties



An Approach to Structured Nanocomposites (Sponsored Activity)

- **Identify leading organizations developing**
  - **Fiber: Revolutionary property improvements**
  - **Matrix: Compatible with these new fibers**

- **Maturation Issues**

First set of milestones:

- **Demonstration of beneficial properties on R&D scale**
- **Independent verification of properties**

Second Milestone:

- **"Out of the Lab" Processing**
- **Material availability in a form useable for kinetic energy storage, power generators**

Summary of Initial Findings: Matrix (Literature Search)

- **Matrix (Resin) fillers**
  - **Most widely used is montmorillonite, MMT (nanoclay)**
  - **Enhances both structural and thermal properties in neat resin (polymers)**
    - **Increased strength, impact resistance**
    - **Additional resistance to microcracking and increased Tg**
  - **These resin enhancements translate into reinforced polymer composites, but on a reduced scale**

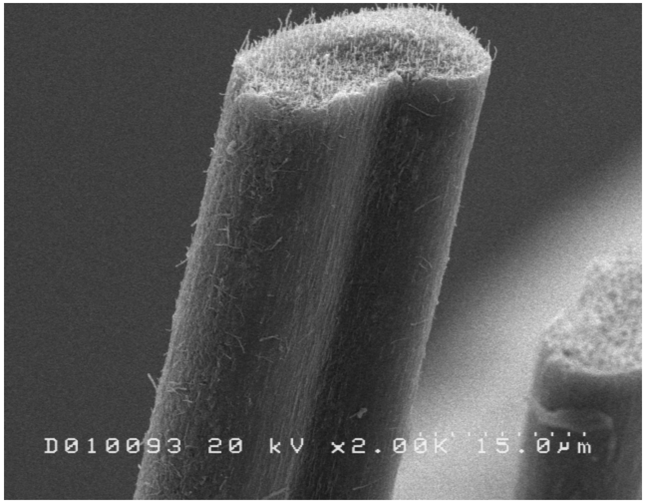
Summary of Initial Findings: Fiber (Literature Search)

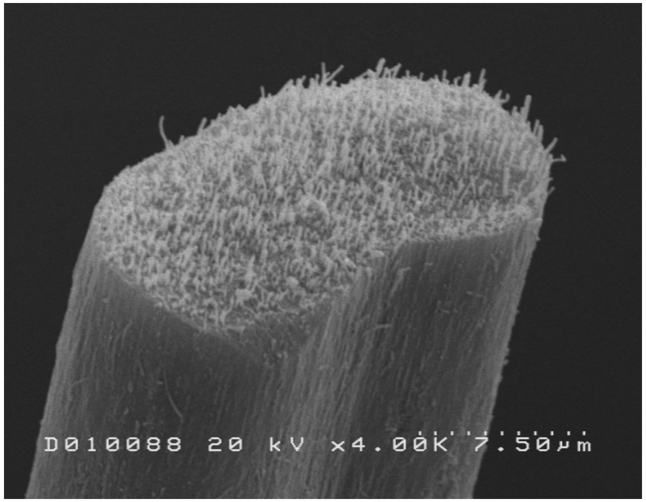
- Fiber
  - Magellan's M5 fiber (incremental improvement)
  - Carbon nanotubes (revolutionary improvement)
    - Embedded CNT in thermosets has had mixed results
      - Problems with alignment, NT/matrix adhesion
      - Both surface treatments and alignment techniques are improving
    - Emerging technologies
      - Polymer wrapping
      - In-situ polymerization, or co-polymerization

Fiber Technology: Carbon Nanotubes - In-situ polymerization

- NT embedded and aligned with PAN fiber precursor
  - Strong NT interfacial strength
- Two approaches are possible
  - Carbonize PAN precursor to produce PAN/NT fibril
    - Generate fibril roving
    - Impregnate with B-stage thermoset
    - Filament wind laminate structure
  - Carbonize PAN precursor to produce carbon/carbon NT structure
- In-situ polymerization: Encouraging results
  - Tensile strength doubled over PAN fiber
  - Modulus strength doubled over PAN fiber
  - Some development has begun
    - Army (AMCOM) is funding to develop light-weight, high-strength missile cases

20 wt% MWNT/Carbon Fiber





Path to the Future?

- What is the next enabling technology for structured composites?
  - Offers revolutionary improvements
  - Benefits kinetic devices and generators
- Need further understanding of technologies and maturation issues
- Begin direct communication with leading organizations