The University of Texas at Austin
Center for Electromechanics

2016 ADVISORY PANEL
ENERGY STORAGE

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Energy Storage: Importance

Energy security and reliability-

- As the legacy grid continues to show its age, ES plays a key role in meeting ever-increasing dependence and demand for power.
- Vulnerability needs to be addressed before it is exploited.

Affordable Clean Energy-

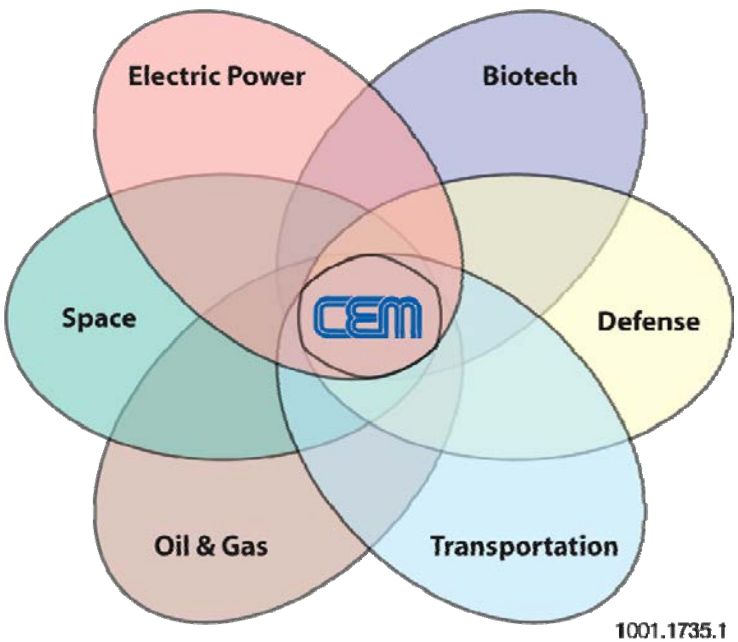
- Enables use of low-cost and low-carbon energy sources.

Developing Countries / Remote Areas-

- There is an established link between access to energy and health (lighting, refrigeration, sanitation).
- ES enables use of distributed energy resources and renewable energy where infrastructure does not exist.

Energy Storage: Aspects and Applications

Energy storage is critical to solving many of today's technical challenges...



	Reliability	Stability	Peak Power	Load Leveling	Power Density
Electric Power: for Microgrids, Remote bases, Legacy Grid	☐	✓	✓	✓	✓
Space & Aerospace: ISS, Satellites, Aircraft	✓	☐	☐	✓	✓
Defense: Navy Ships, Advanced weapons and sensors	✓	✓	✓	✓	✓
Transportation: Alternative Vehicles	✓	☐	✓	✓	✓

… and plays a role in virtually all of CEM's core competencies.

Energy Storage: Approach

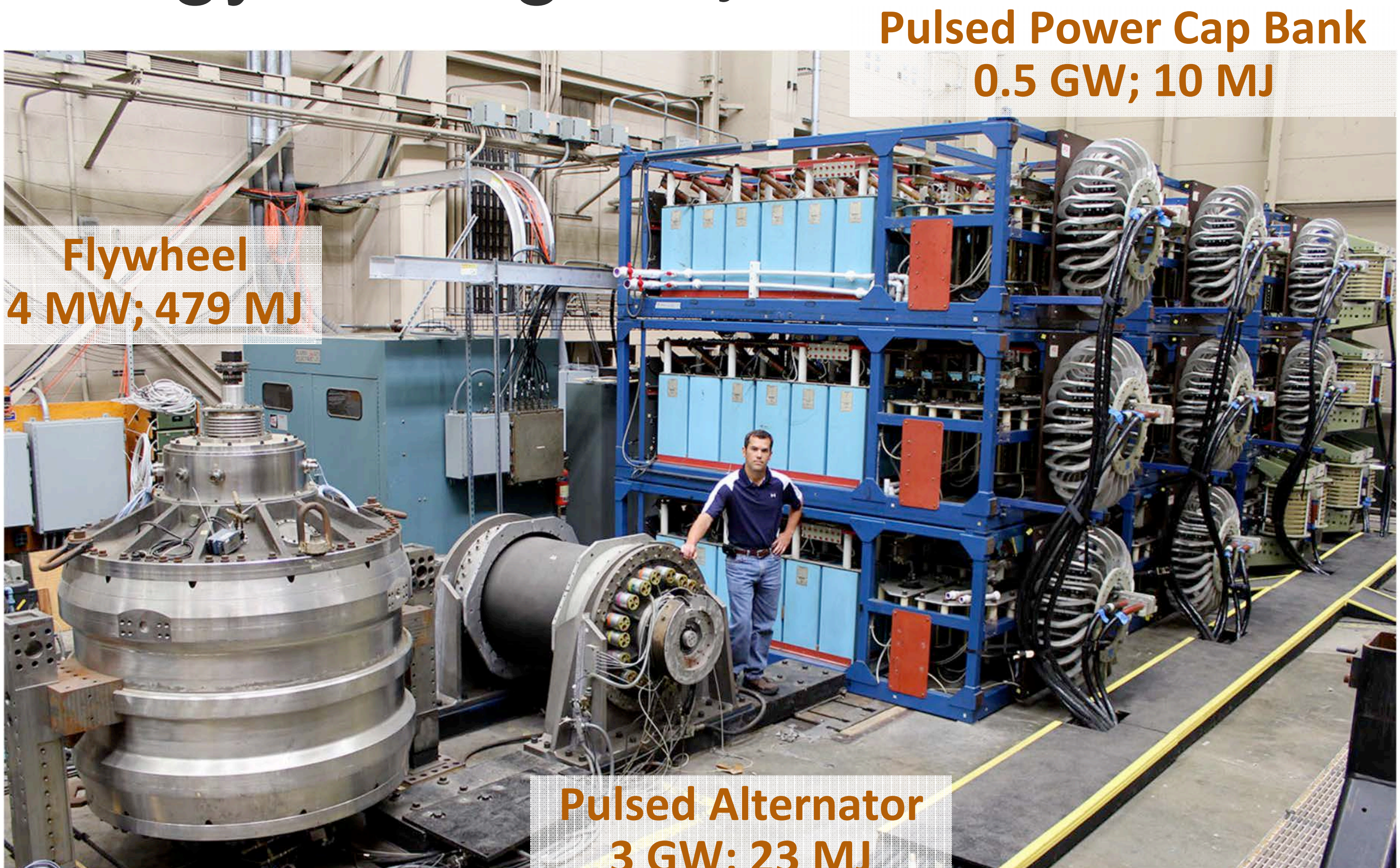
- ***Vision***: Develop the most efficient and effective ES technologies over relevant range of power, energy, and time scales.

- ***Foundation***: Decades of experience in the design, analysis, fabrication, and testing of ES solutions including: rotating, capacitive, inductive, and battery storage systems. World class composite design, analysis, fabrication, and test experience.

- ***Recent Activities***: PM machine energy storage and retention bandings. Advanced composite materials, processes, and geometries to enhance performance and lower cost. Impact of ES in naval power systems.

- ***Future***: Analyzing the role of ES in the integration of renewables in legacy grids and microgrids; Unmanned Underwater Vehicles

Energy Storage: Systems

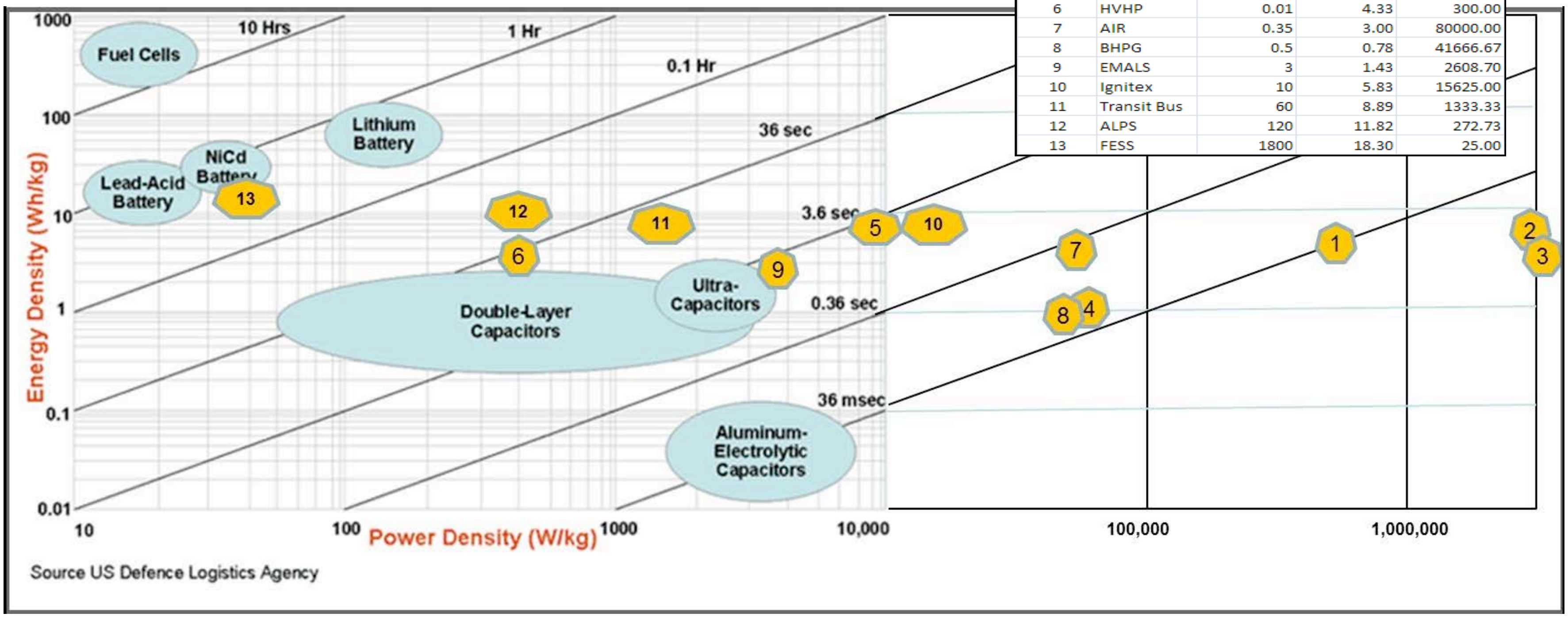


Note: Power numbers are nominal – Energy numbers are stored

Energy Storage: Solutions

Ragone Plot

#	Machine	pulse width (s)	Energy Density (Whr/kg)	Power Density (W/kg)
1	Small Cal	0.01	2.89	768518.52
2	Cannon Cal	0.01	5.50	1200000.00
3	Sub Scale	0.01	2.67	1250000.00
4	Iron Core	0.01	1.05	80000.00
5	CHPS	0.01	7.00	10000.00
6	HVHP	0.01	4.33	300.00
7	AIR	0.35	3.00	80000.00
8	BHPG	0.5	0.78	41666.67
9	EMALS	3	1.43	2608.70
10	Ignitex	10	5.83	15625.00
11	Transit Bus	60	8.89	1333.33
12	ALPS	120	11.82	272.73
13	FESS	1800	18.30	25.00



The Ragone plot compares the performance of a range of electrochemical and electromechanical devices.

Energy Storage: Batteries





	Lead-Acid		Nickel Metal Hydride		Lithium Ion and Variants				Ultracap
Battery	Trojan T145	Deka 8G31	SAFT NHE 5-200 NiMH	COBASYS Series 1000 NiMH	Valence U24-12XP LiFeMgPO4	PHET DOSBAS C-LiFePO4	Valence U1-12XP LiFeMgPO4	Altairnano Lithium Titanate	Maxwell BMOD0165
Application	Stock Electric & Plug-In Fuel Cell	Stock Electric	Plug-In Fuel Cell	Fuel Cell dominant hybrid	Plug-In Fuel Cell	Fuel Cell dominant hybrid	Fuel Cell dominant hybrid	State of the art electric	Fuel Cell dominant hybrid
Specific Energy Storage	39 Wh/kg	36 Wh/kg	64 Wh/kg	45 Wh/kg	90 Wh/kg	63 Wh/kg	79 Wh/kg	71 Wh/kg	2 Wh/kg
Volumetric Energy Storage	91 Wh/L	88 Wh/L	132 Wh/L	86 Wh/L	141 Wh/L	77 Wh/L	110 Wh/L	134 Wh/L	3 Wh/L
Specific Power	75 W/kg	100 W/kg	150 W/kg	1000 W/kg (10 s pulse)	350 W/kg	830 W/kg	310W/kg	1250 W/kg (10 s pulse)	7900 W/kg

Battery systems offer advantages where high energy density is the primary concern.
Ultracapacitors (supercapacitors) can deliver very high power but the storage capacity is very limited.

Battery Applications

<u>Electric Transit Bus</u>

- Opportunity to collect data/knowledge on advanced batteries
- Battery life prediction and feasibility of on-route fast charging vs on-board slow charging

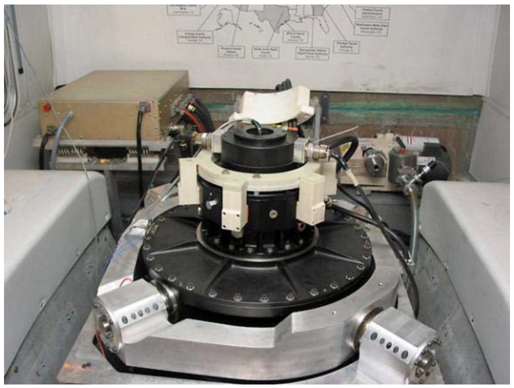
<u>Extended Range Hydrogen Utility Vehicle</u>

- Goal: Significantly increase range without reducing performance.
- Hydrogen fuel cell retrofit of existing battery powered vehicle.
- Completed successful 12 month demonstration.

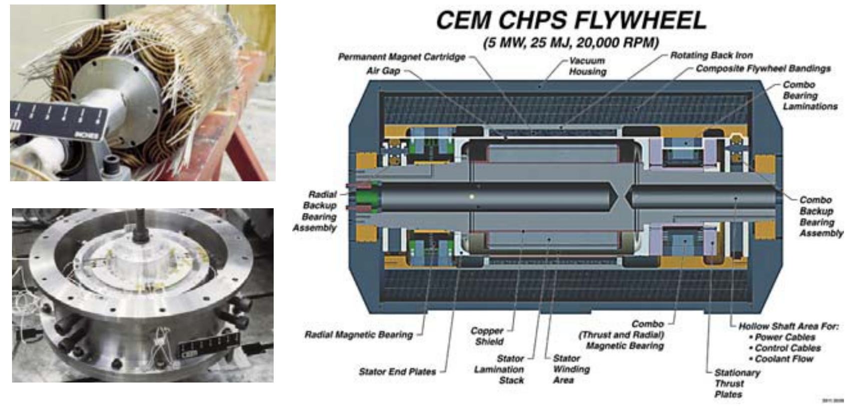
Advanced batteries can more than double the range of stock electric vehicle with lead-acid energy storage

Fuel cell dominant hybrids increase range ~25% over fuel cells alone.

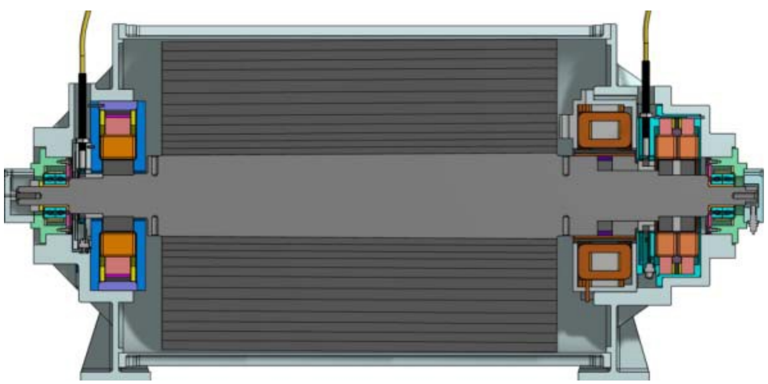
Energy Storage: Flywheels



Transit Bus Flywheel
150-250 kW (peak), 100 kW (cont.), 2 kW-h



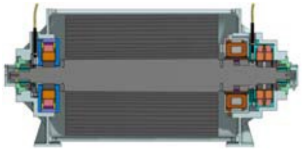
Combat Hybrid Power Systems (CHPS) Flywheel
5-10 MW (peak), 350 kW (cont.), 7 kW-h

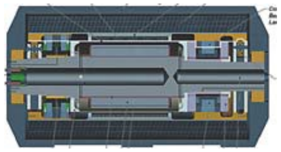


Space Station Flywheel (FESS)
~5.0 kW (peak), 3.66 kW (cont.), 3.66 kW-h

Advanced Locomotive Propulsion System Flywheel
3 MW (peak), 2 MW (cont.), 130 kW-h

Energy Storage: Flywheels





Parameter	NASA FESS	ALPS System	Bus System	CHPS System
Function	Energy Storage	Load Leveling	Load Leveling	Leveling/Pulsed
Energy Stored (kWhr)	3.6	133	2	7
Peak Power (kW)	5	2,000	150	5,000
Typical Discharge Time	30 minutes	~ 3 minutes	30 seconds	3 seconds
Rotational Speed (RPM)	53,000	15,000	40,000	20,000
Machine Weight (lbs)	250	19,000	450	1,100
Motor/Generator	Permanent Magnet	Induction	Permanent Magnet	Permanent Magnet
Topology	Partially Integrated	Non-Integrated	Partially Integrated	Fully Integrated
Cooling	Cold Plate	Air/Oil and Water	Oil and Water	Oil
Bearings	Homopolar Magnetic	Hompolar Magnetic	Homopolar Magnetic	Homopolar Magnetic
Backup Bearing Duty	Limited	Limited	Significant	Significant
Gimbal	NA (Torque Balanced)	Required	Required	Required
Flywheel Design	CEM Cylindrical	CEM Cylindrical	CEM Cylindrical	CEM Mass Loaded
Rotor Tip Speed (m/s)	920	1,015	935	600
Safety	RSL&NDE	RSL & Containment	RSL&Containment	RSL

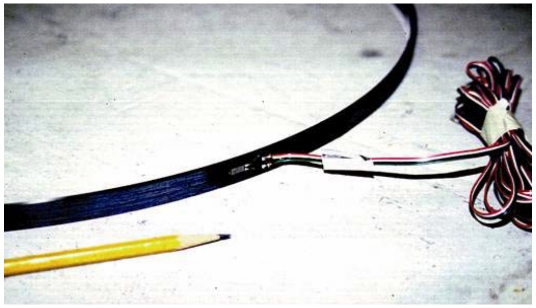
Flywheels and other rotating machines can operate over a wider range of power densities where shorter discharge times and very high cycle life are important.

Advanced Composites for Flywheels

- ***Advanced materials and processing***: Investigating use of nanoparticles in composite resin matrix to enhance strength and resist cracks. Investigating out-of-autoclave curing to reduce manufacturing cost.

- ***Composite flywheel containment***: CEM developed a lightweight composite, rotatable structure to contain burst energy and dissipate rotational energy over extended time.

- ***Design, analysis, and test:*** CEM has leveraged world class design and analytical tools, manufacturing processes, and expertise to develop and demonstrate advanced composite structures.



Composite Design & Analysis

1. Define candidate design (using CEMWIND)

- Mandrel shape, wind angles, layer thicknesses
- CEMWIND performs fabrication checks (friction, bridging)
- Finite element model input file created

2. Finite Element analysis (ABAQUS)

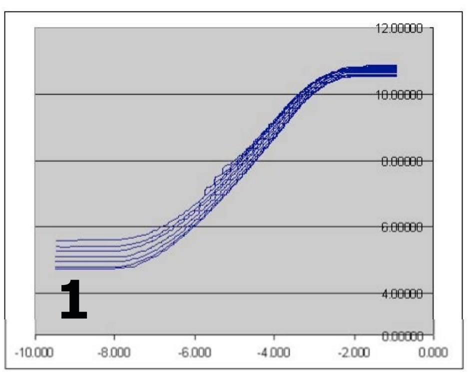
- Radial growth, stresses at rest and design speed
- Stiffness calculated for rotordynamics model

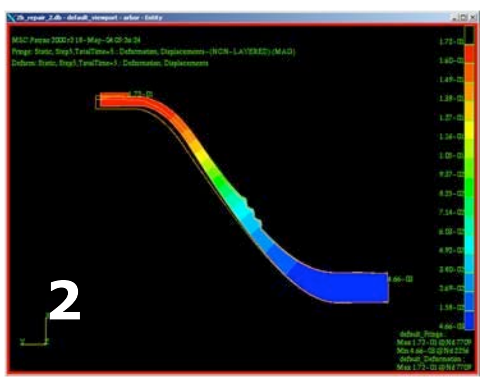
3. Post-processing of finite element results (CEMWIND)

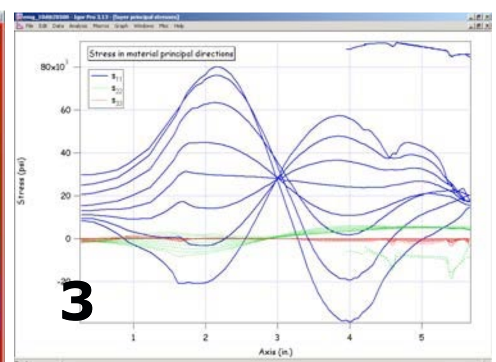
- Strain and stress translated to fiber principal directions

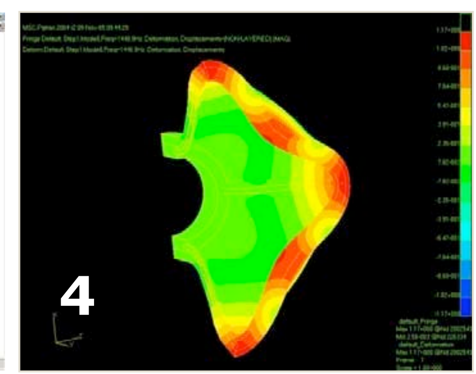
4. Rotordynamic analysis (TXROTOR)

- Stiffness values used to determine critical speeds

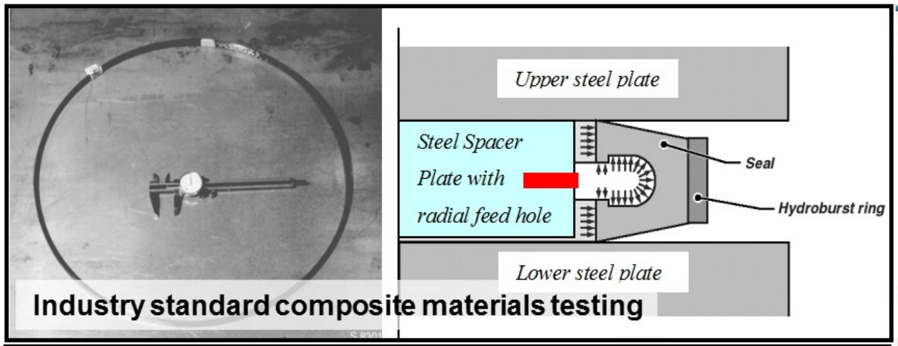




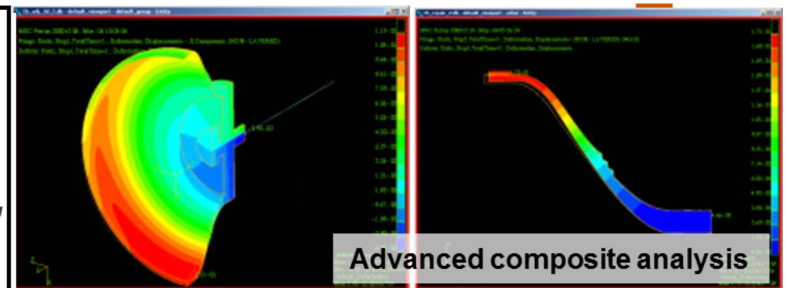




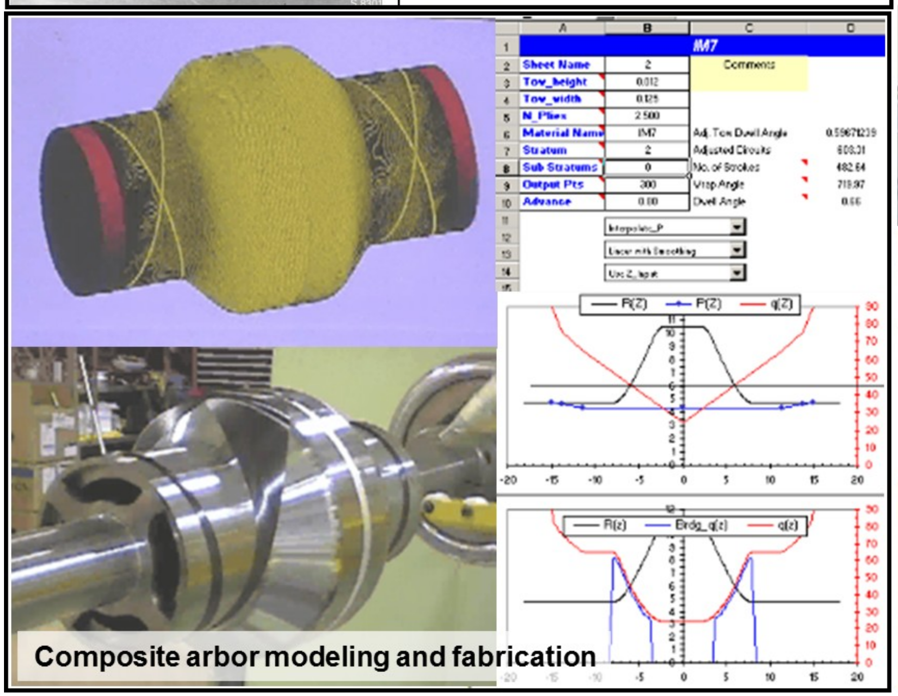
Composite Manufacture & Test



Industry standard composite materials testing


Advanced composite analysis


Test article spin test validation


Composite arbor modeling and fabrication


Large-scale composite manufacture & assembly

Energy Storage: Areas of Interest

- ***High Speed Machines*:** Advanced composite structures for PM and other machines operating at 10-100 of krpm.

- ***Energy Storage Hardware*:** Analysis and demonstration testing of ES and associated technologies using established MW scale distributed test bed.

- ***Naval Power Systems*:** Continued study of energy storage solutions for Navy including the technology, size, and spatial distribution of ES.

- ***Unmanned Underwater Vehicles*:** Improve efficiency to extend range of UUVs. Harness energy in ocean currents.

- **Renewables:** Analysis and validation testing of increasing penetration of renewables on legacy power grid.

Summary

CEM has both the experience and capabilities to make a difference by developing ES solutions for a variety of customers and applications.

- ES is vital for integrating distributed energy resources and renewables to strengthen new and existing power grids.
- Advanced rotating machines and flywheels appear to be gaining interest once again as battery development (and growing pains) continues.
- Advanced materials and processing will enable further growth.