

**ESLI**

Energy Science Laboratories, Inc.  
Thermal Composites Division

# **Phase-Change Composite TES for Nickel-Hydrogen Batteries<sup>†</sup>**

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## CONTENTS

- Ni-H2 Thermal Control Problems**
- Passive Thermal Control with TES**
- Phase-Change Composites (PCC)**
- Candidate Materials**
- Design Options**
- Fabrication & Freeze-Melt Cycling**
- Thermal Modeling**
- System Benefits**
- Applications**

## **Ni-H2 THERMAL CONTROL PROBLEMS**

### **Ni-H2 thermal characteristics:**

- cycle life sensitive to temperature control
- need lower temperatures ( $\approx 0^{\circ}\text{C}$ ) than NiCads ( $\approx 21^{\circ}\text{C}$ )
- high T transients at end of charge and during discharge
- T gradients in cell & across battery are detrimental

### **Cold-bias design is typical for aerospace battery thermal control**

- radiators sized for larger than average heat dissipation
- high T transients remain
- heaters needed to prevent excessive low T
- option = VCHP, louvers also used to reduce heating

### **Passive high-heat-capacity option:**

- thermal inertial reduces high and low T variations
- the heating needs are reduced
- the radiator may be sized for average load with low heating

## **PASSIVE THERMAL CONTROL WITH TES**

**Add thermal energy storage (TES) to the battery**

- **reduce temperature variations, both hot and cold**
- **time-average the heat delivered to the radiator**

**A phase-change material (PCM) makes TES light weight**

- **PCMs have 20x-40x higher specific heat than batteries**

**Phase-change composite (PCC) = PCM matrix + conductive fins**

- **high heat conductance and high heat capacity**
- **capillary gaps control position of fluid and voids**

**Potential benefits of PCC-TES are**

- **improved battery temp control, efficiency, cycle life**
- **reduced battery heater power**
- **reduced radiator area and system weight**

## PHASE-CHANGE COMPOSITES (PCC)

Composite a high conductivity (k) material with a high heat capacity (c) material for high speed TES = thermal capacitor.  
Figure of Merit for a TES material is the kc-product.

Thermal time constant  $\tau = RC = (C/A)^2 / kc$

Thermal flux  $F \propto 1/\tau \propto kc$

Flux / Weight  $F/W \propto kc^2 / \rho$

where  $R = L/kA$ ,  $C = cLA$ ,  $c = \rho C_p$ ,  $\rho =$  density,  $L =$  TES thickness,  $A =$  heat transfer area

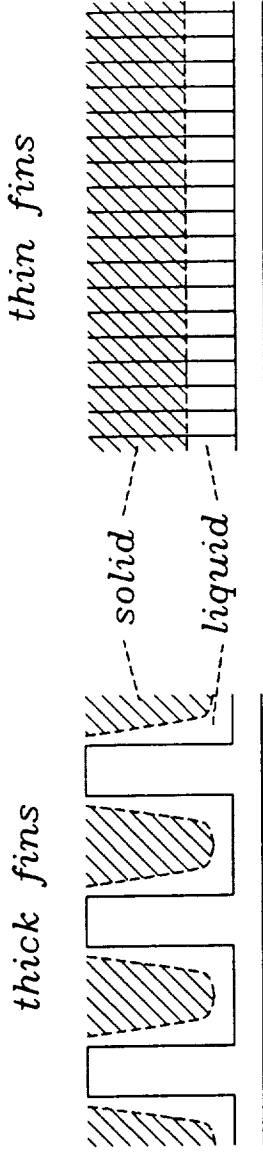
TABLE: Combine high-k and high-c materials (illustrative values)

MATERIAL	k	c	F $\propto kc$	$\rho$	F/W
high-k (metal, carbon)	100	1	100	3	33
high-c (PCM)	1	100*	100	1	10,000
50-50 composite (PCC)	50	50*	2,500	2	62,500
25-75 composite (PCC)	25	75*	1,875	1.5	93,750

\* effective over a limited temperature range around the phase-change temperature

## PCC STRUCTURE

Performance is best when homogeneous, with planar isotherms



Requires fins so thin that the thermal resistance across the PCM layer is less than the thermal resistance along the fin.

Fin widths required: < 10 microns, for 5 mm TES thickness.

PCC thermal properties obey simple rule of fractions

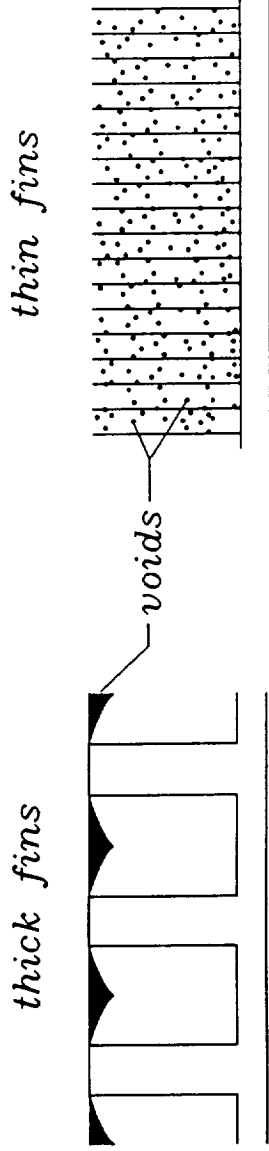
$$\begin{aligned}
 K_{PCC} &= K_F X + K_{PCM} (1 - X) && \text{(parallel)} && F = \text{fin} \\
 C_{PCC} &= C_F X + C_{PCM} (1 - X) && && x = \text{fin volume fraction} \\
 \rho_{PCC} &= \rho_F X + \rho_{PCM} (1 - X) && && \rho = \text{density} \\
 H_{PCC} &= H (1 - X) && && H = \text{latent heat}
 \end{aligned}$$

## SHRINKAGE VOIDS, STRESS RELIEF

High capacity PCMs generally have large volume changes ~10% during solid-liquid phase change causing expansion stress.

Fine capillary structure in PCC prevents expansion stress

- capillary forces > gravity forces for small gaps
- shrinkage voids are finely distributed
- expansion into distributed voids avoids stress
- light weight encapsulation is adequate



## CANDIDATE MATERIALS

Many PCMs are available between -20°C and 10°C  
Encyclopedia of Organic Chemistry cites 975  
Aldrich Chemical Company offers ~440

Two candidates currently under study are:

- **WATER (H<sub>2</sub>O, D<sub>2</sub>O)**  
high latent heat, but high stress potential  
MP = 0 - 3.8°C (range); BP = 100-101°C;  
H = 334 J/g; c = 4.19 J/g-K; ρ = 0.92 g/cm<sup>3</sup>, ice @ 0°C
- **n-TETRADECANE (C<sub>14</sub>H<sub>30</sub>)**  
a benign paraffin that wets carbon fiber  
MP = 5.6°C; BP = 254°C; FP = 99°C; MW = 198.4  
H = 227 J/g; c = 2.21 J/g-K; ρ = 0.763 g/cm<sup>3</sup> @ 20°C



## **PCC DESIGN OPTIONS**

### **PCC-TES LOCATION OPTIONS**

<b>cell sleeve</b>	<b>good thermal control; simple retrofit</b>
<b>cell interior</b>	<b>recommended for Common Pressure Vessels</b>
<b>pockets</b>	<b>use open space between cells</b>
<b>baseplate</b>	<b>interferes with wiring, heat pipes, fasteners</b>

### **SLEEVE LINER OPTIONS**

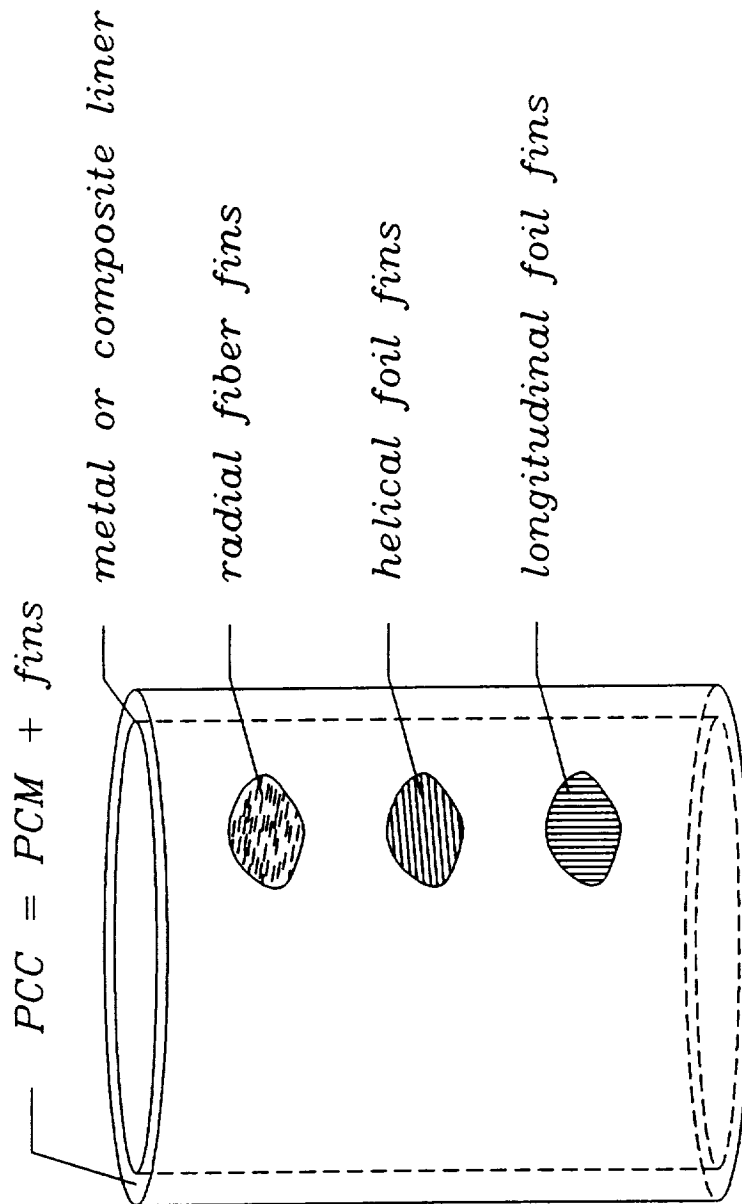
<b>thin metal</b>	<b>good heat transfer; corrosion?</b>
<b>fiber composite</b>	<b>light weight; reliable encapsulation?</b>

### **FIN STRUCTURE OPTIONS**

<b>radial fibers</b>	<b>good heat transfer, void control; low cost</b>
<b>axial fins</b>	<b>too conductive, higher cost metal fabrication</b>
<b>helical fins</b>	<b>good heat transfer; adequate stress control?</b>
<b>helical tubing</b>	<b>poor heat transfer; low stress in poly tubing</b>

## PCC SLEEVE FOR IPV

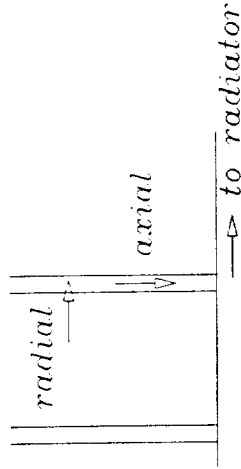
**Retrofit PCC-TES sleeves on IPVs. Increase volume 10%.  
Sleeve conductivity design options:**



## SLEEVE THERMAL RESISTANCE

Conventional aluminum sleeve needs thick walls for heat conductance, and is 11% of battery weight

PCC-TES sleeve stores heat, then releases it at  $\approx$  constant temp  
 PCC-TES does NOT need thick conductive walls



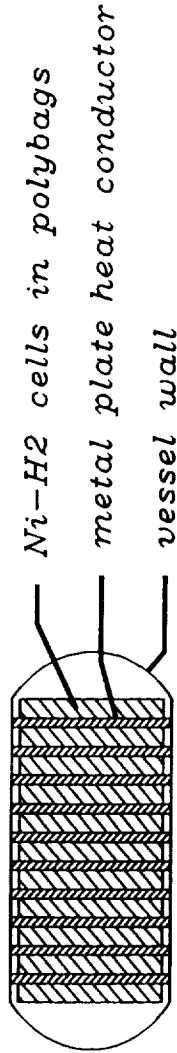
**TABLE: Axial and radial sleeve thermal resistances.**

	Axial	Radial
conventional 1-mm aluminum sleeve =	6.15	0.00010
3-mm water =	675.74	0.10365
2.75-mm PCC (361% of cell heat cap.) =	442.9	0.00207
PCC-TES: 0.25-mm Al + 2.75 mm PCC =	23.40	0.00178

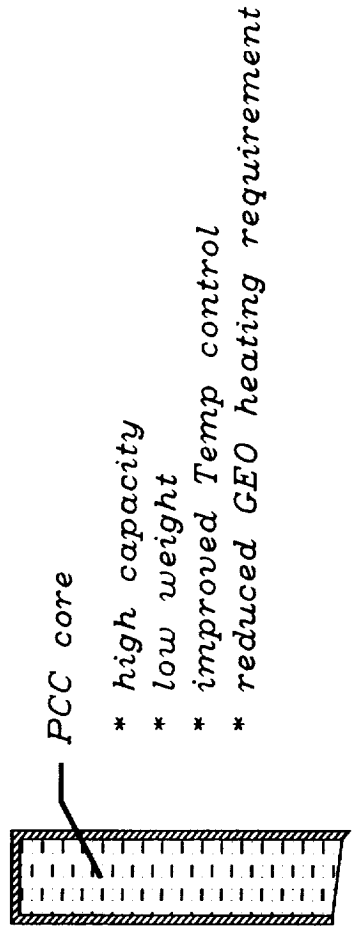
## PCC PLATE FOR MULTICELL CPV

CPV has same heat generation in more compact geometry.  
Interior PCC-*TES* plates reduce transients, average heat release.

COMMON PRESSURE VESSEL (eg 22 cells)



OPTION: PCC-*TES* Plates



## FABRICATION & TESTING

**Phase 1 progress: fabrication of subscale sleeves and demonstration of freeze-melt survival for limited cycling**

- sleeve size = 10 cm long, 2.3 cm ID, 3.9 cm OD.
- aluminum liner, polymer encapsulation.
- PCMs = tetradecane, water
- fin material = high-k carbon fiber felt

**Without fins, expansion stress causes fracture and leak during first freeze/melt cycle.**

**Fin structures have been developed for which no fracture or leak has occurred in all 16 cycles run.**

**PCMs encapsulated in polyethylene also can survive freeze/melt cycling, but the heat conductance is too low.**

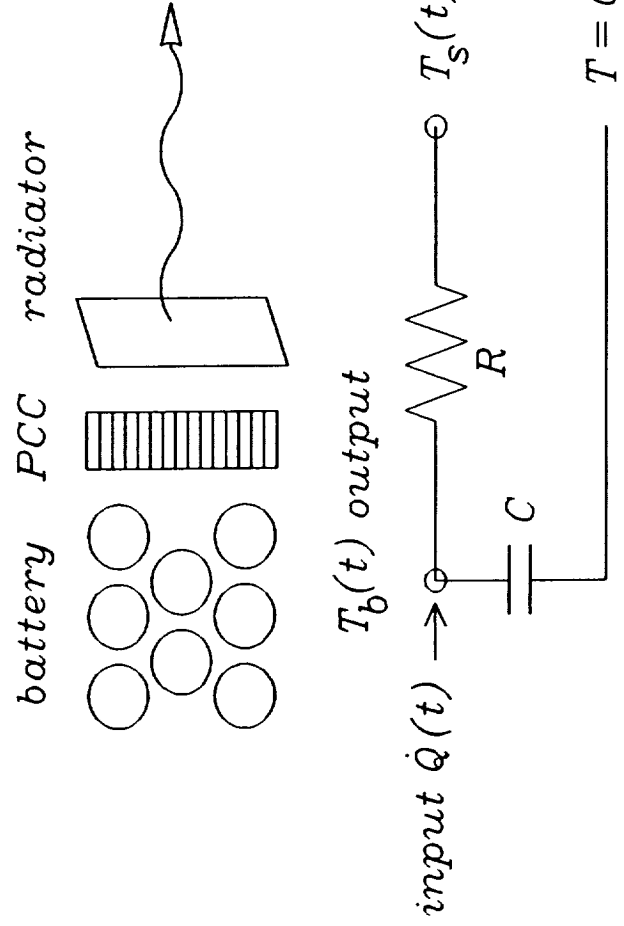
**Phase 2 objectives**

- PCC-TES prototype development
- reliability testing

## THERMAL MODELING

For qualitative system study use two-node RC model

- lump battery and TES capacity into single node
- couple node to space node via radiator resistance
- input cell heat record and space temperatures
- predict battery transient temperatures

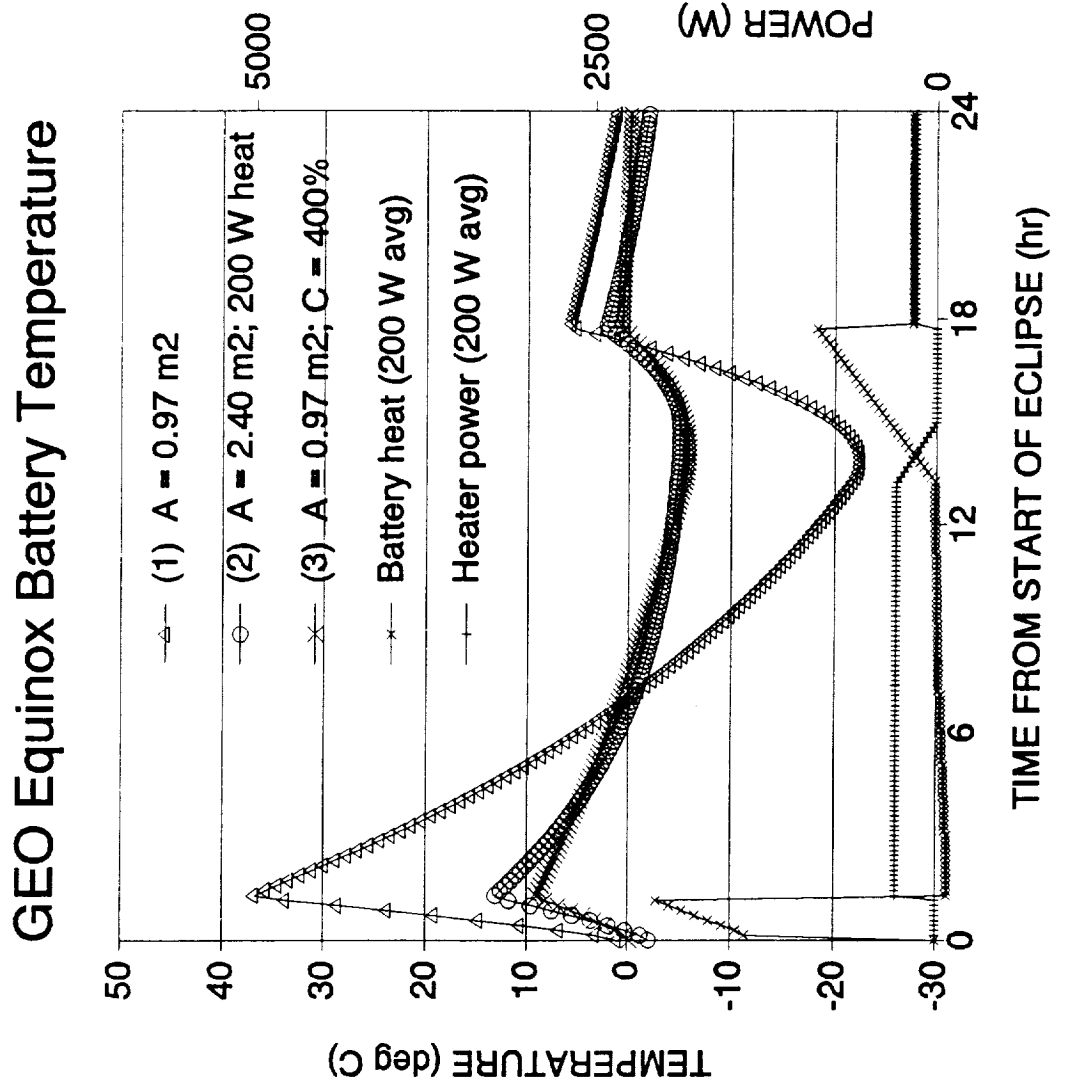


## GEO NI-H2 BATTERY TEMPERATURES

Calculate temperature response of battery using 2-node model for different heater, radiator and TES configurations.

	COMPONENT WEIGHT (lbs)					Battery + TCS
	Battery	Thermal Control System (TCS)			Total TCS	
		Radiator + heat pipes	Heater subsystem	PCC-TES subsystem		
Case 1	450	26	0	0	26	476
Case 2	450	65	66	0	131	581
Case 3	450	26	0	43	69	519

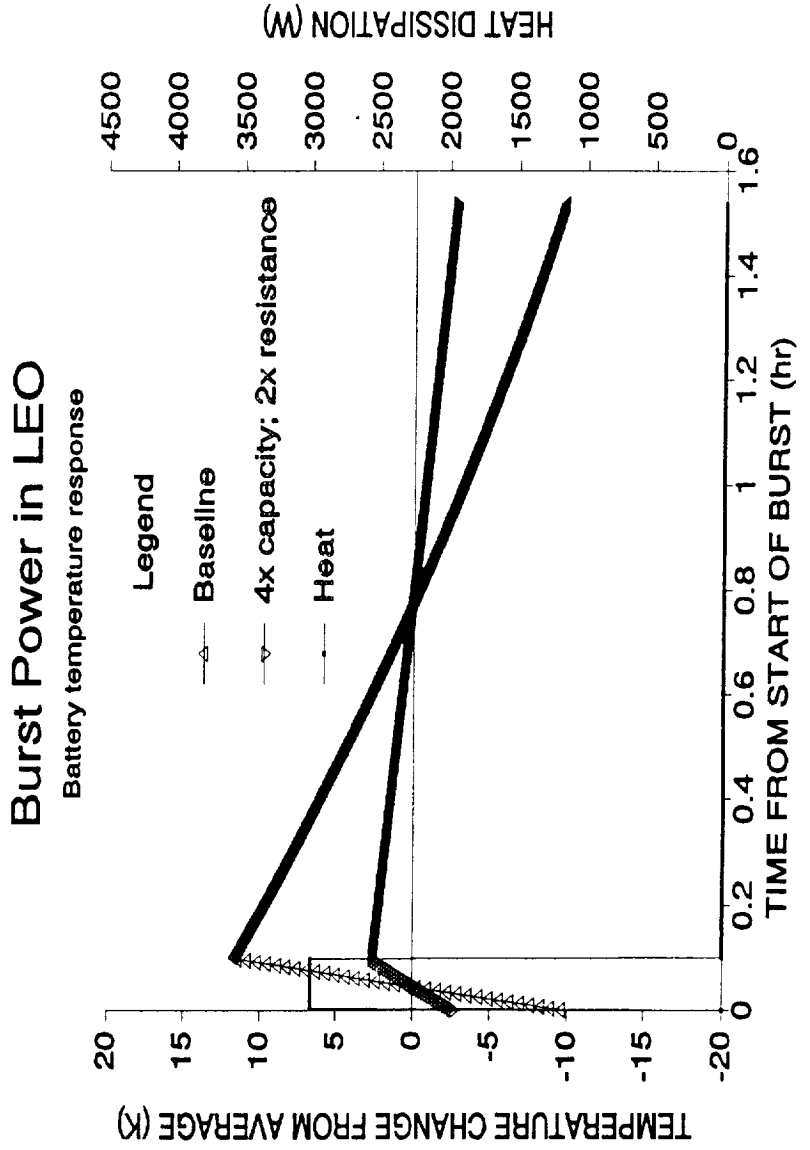
**PCC-TES option (case 3) offers improved temperature control and 62 lb weight saving = 47% weight reduction of the TCS**





# LEO NI-H2 SURGE POWER BATTERY TEMPERATURES

Calculated temperature response of battery with 1 m2 radiator, compared with temperature response for 400% capacity.



## SYSTEM BENEFITS SUMMARY

### Potential system benefits:

- Improved cell temp control during high rate discharge
- Improved temperature uniformity across the battery
- Smaller, lighter radiator sized for average load
- Less heater power required
- Less reliance on active louvers, VCHPs
- More options for high rate, deep discharge use
- Less satellite repositioning for thermal control
- Fewer active control functions
- More satellite resources available for primary function

**HIGH-C thermal control (PCC-TES) is best for short transients.**

**LOW-R thermal control (heat pipe radiators) is best for steady state.**

**Ni-H2 batteries do benefit from HIGH-C option, but PCC-TES components are not space qualified.**

## POTENTIAL APPLICATIONS

### Retrofitting Ni-H2 for Ni-Cd batteries

- TES lowers peak load to radiator and may allow existing NiCad radiator area to be used for Ni-H2

### GEO communications and data relay satellite

- TES may reduce battery temperature transients, reduce heater requirement, and reduce radiator size.

### Multicell CPV batteries

- TES inside the vessel may reduce temperature gradients and reduce heat flux through vessel wall

### LEO satellite surge battery power

- TES may lower peak battery temperatures in mobile telephone satellites over high traffic centers
- TES may lower peak battery temperatures in Space Based Radar

### Other battery applications

- Na-S, Ni-MH2

