

PCMS FOR SOLAR THERMAL ENERGY STORAGE (TES)

Enhanced Energy Storage and Increasing Market Potential

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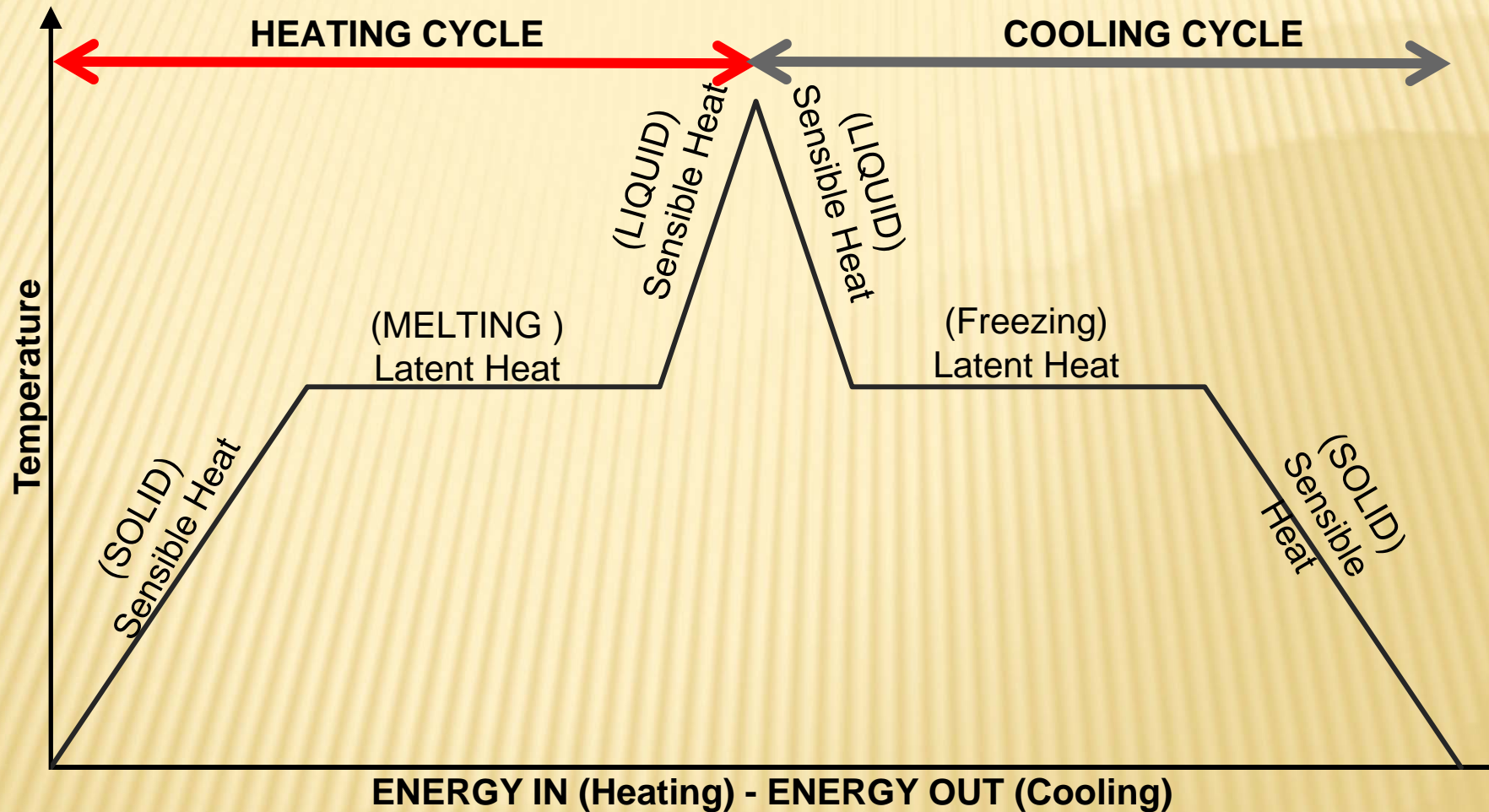
ENTROPY SOLUTIONS INC.

- Privately held thermal technology development company - Minneapolis
- R&D in technology related to new uses for agricultural products with an emphasis in passive thermal energy storage
- Industry Focus - Building & Construction, Refrigeration, Energy Storage, Food & Beverage, Cold Chain Shipping, Electronics, Medical Devices/Equipment
- Award Recognition
 - DuPont's Innovation Award
 - USDA Bio-preferred Program
 - Presidential Green Chemistry Award
 - Innovator of the Year
 - Top Technology of the Year

WHAT ARE PCM'S?

- Phase change materials are compounds which melt and solidify at certain temperatures and in doing so are capable of storing or releasing large amounts of energy. They take advantage of latent heat.
 - Water / Ice
 - Thermal energy storage
- Characteristics of a good PCM
 - Freeze and melt at a desired temperature
 - Freeze and melt in a narrow temperature range
 - Similar melting and freezing points
 - High latent heats
- Types of PCM's
 - Paraffin / Waxes
 - Salts/ Salt Hydrates
 - Fats and Oils

THEORETICAL LATENT HEAT CURVE FOR SOLID/LIQUID PHASE TRANSITION



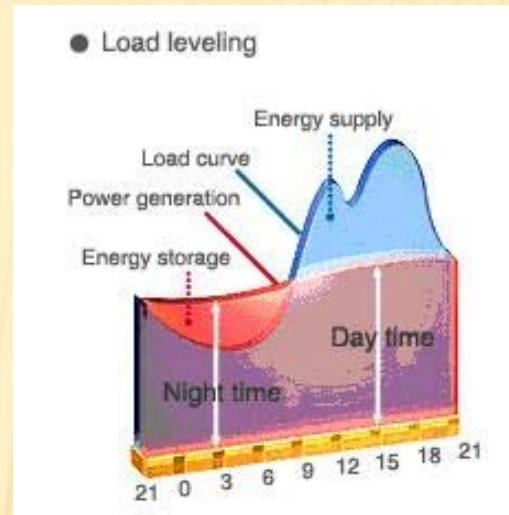
PCM TYPES

	PureTemp	Paraffin
SOURCE	VEGETABLE	PETROLEUM
AVERAGE LATENT HEAT	170 - 270 J/g	130 - 240 J/g
TEMP OPTIONS	MORE THAN 200	LIMITED
TEMP RANGE	-40°C TO 180°C	-8°C TO 160°C
TOXICITY	NON-TOXIC	MID
ENCAPSULATION	YES	YES
FLAMMABILITY	LOW	HIGH
STABILITY	UNLIMITED	UNLIMITED
RENEWABLE	YES	NO
BIODEGRADABLE	6 MONTHS	100+ YEARS

Key differences in yellow

THERMAL ENERGY STORAGE

- ✘ Electrical peak load shifting
- ✘ Solar energy storage
- ✘ Free cooling



FACT

- Specific Heat of Water is 4.2 J/g/C, (Latent Heat of Water/Ice is 334 J/g)

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- Water is very inexpensive
- PCMs can range from \$0.25 per kg to \$5.00 per kg (commercial volumes)

BARRIERS/DISADVANTAGES TO OVERCOME

- ✘ Thermal conductivity (about 0.2 W/mC)
- ✘ Supercooling (need for a nucleating agent)
- ✘ Coefficient of Expansion (about 8% upon melting)
- ✘ Price

BETTER SOLAR TES IN PCMS USING LOW FLOW RATE

Solar thermal energy availability and storage with varying flowrates of water (the transfer medium)

HTF Flow rate	Heat available (MJ)	Heat stored (MJ)	Percentage (%)
High (10 L/min)	98.4	14.9	15
Medium (5 L/min)	76	14.2	19
Low (3 L/min)	48.6	24.2	50

Average daily thermal energy stored by season of the year

Season	Thermal Energy Stored Daily (MJ)
Summer	19.57
Fall	14.13
Winter	2.44
Spring	14.49

Experimental Study on the Performance of a PCM-Based Solar Energy Storage System, Southern Illinois University, 2013

FROZEN PCM, WITHOUT THERMAL CONDUCTIVITY ADDITIVE

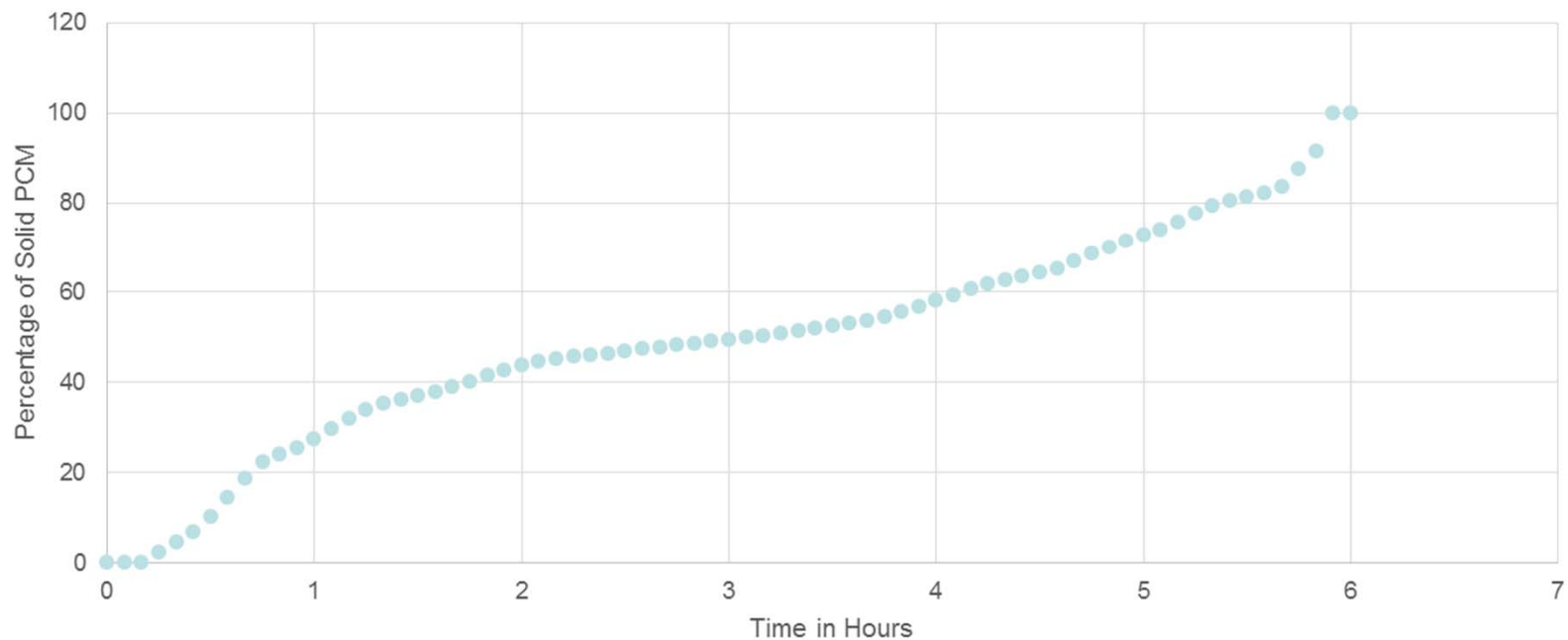


FROZEN PCM, WITH THERMAL CONDUCTIVITY ADDITIVE



PCM PLATES/PANELS IN TES CHILL SYSTEMS

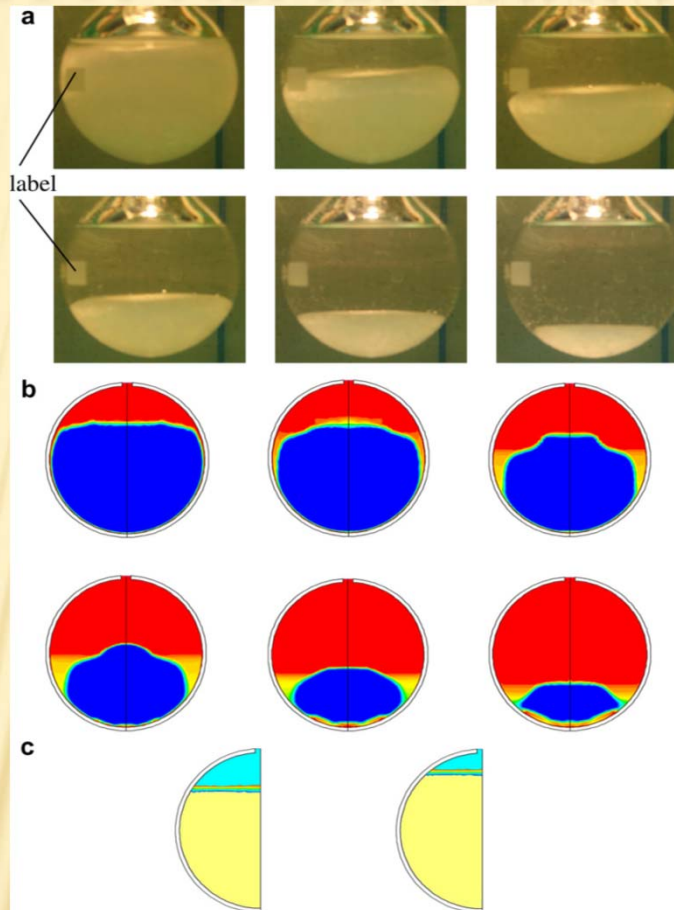
38F Charge 42F Transition Temperature 10x10x1 Inch Panel Simulation



PURETEMP SPHERES FROM 10mm TO 100mm



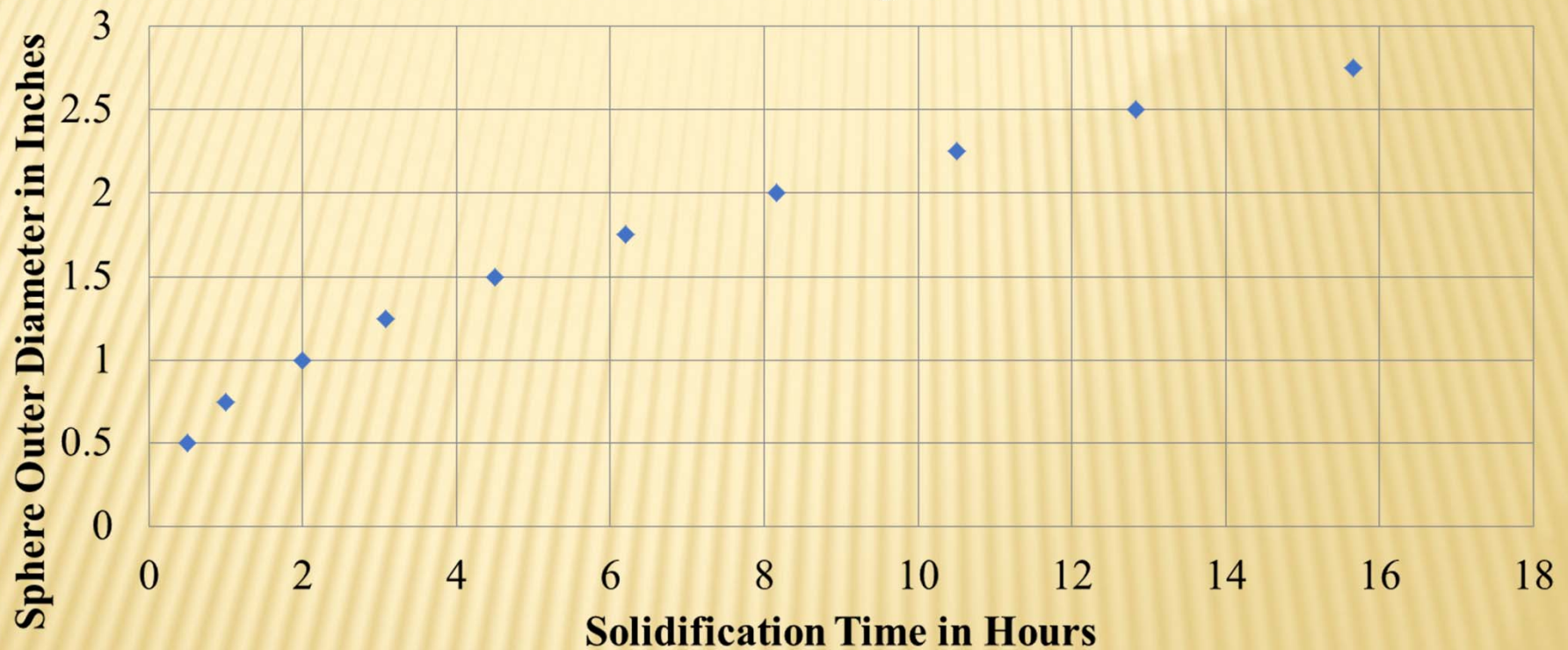
PCM MELT PATTERN IN SPHERES



Numerical and experimental study of melting in a spherical shell
E. Assis, L. Katsman, G. Ziskind *, R. Letan, January 2006

PURETEMP SPHERES IN TES CHILL SYSTEMS

Solidification Time vs. Sphere Diameter



Time for PureTemp 5.5 spheres to freeze in 3.3 degrees C water
Note: the smaller the sphere, the faster the freeze!

TES CAPACITY INCREASE PER AMOUNT OF WATER DISPLACED BY PURETEMP PCM

PureTemp Capacity Improvement				
% PCM	12F Delta	14F Delta	16F Delta	
10%	1.5X	1.4X	1.4X	
20	2.0X	1.8X	1.7X	
30	2.5X	2.2X	2.1X	
40	3.0X	2.7X	2.4X	
50	3.5X	3.1X	2.8X	
60	4.0X	3.5X	3.1X	
70	4.5X	3.9X	3.5X	
80	4.9X	4.3X	3.8X	
90	5.4X	4.7X	4.2X	
% of PCM Volume Displacing Stratified Water Volume				
feasible replacement in blue and red				

RETURN ON INVESTMENT FOR TES IN CHILL TANK APPLICATIONS

Delta \$/kWh (peak - off peak)	Years to payback*
0.32	2.3
0.2	3.7
0.15	4.9
0.1	7.4
0.06	12.32
0.02	36.98

* - not including any regional demand savings, using 3.2 kWh/ton chiller efficiency

GOOD NEWS FOR PCMS IN SOLAR TES SYSTEMS

- ✘ Organic PCMs typically melt faster than they crystallize (Stefans effect)
- ✘ Solar thermal collectors typically less expensive than chillers and less than/similar to utility driven heating systems
- ✘ PCMs are more T specific than water
- ✘ PCM TES systems make economical sense when the space available for TES is limited
- ✘ More to come as we scale up our testing in all TES type systems with various turn-key solutions!!

MANY THANKS!

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PCMS IN SOLAR TES APPLICATIONS

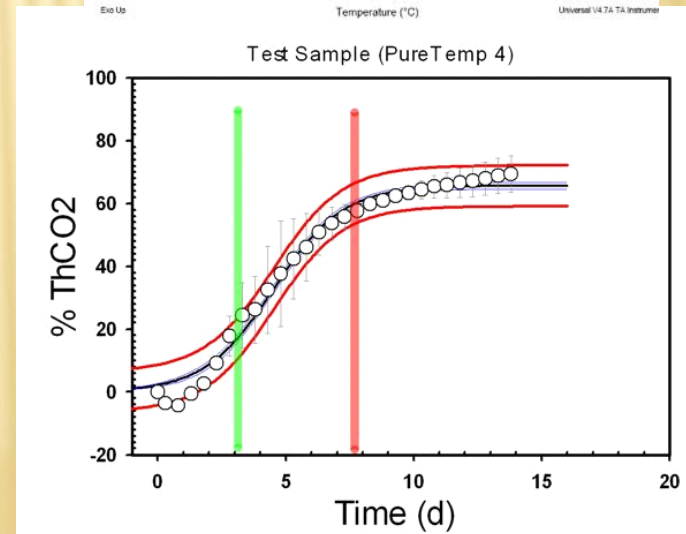
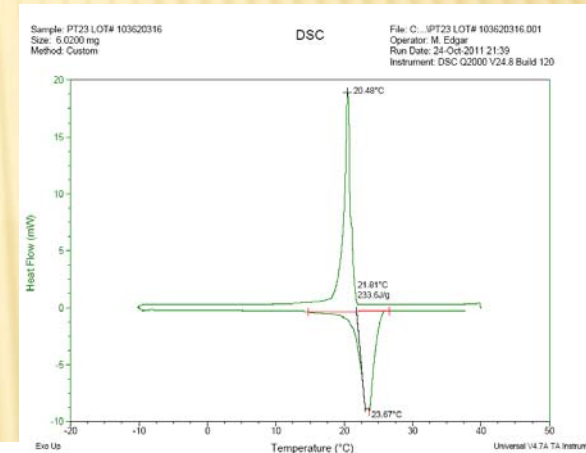
- ✘ Passive solar floor heating (20 °C - 25 °C)
- ✘ Exterior glass blocks (20 °C - 25 °C)

- ✘ PCM tanks, with thermal exchanger network (0 °C - 100 °C)
- ✘ PCM spheres (or tubes, etc) in tanks with water exchanger system (0 °C - 100 °C)

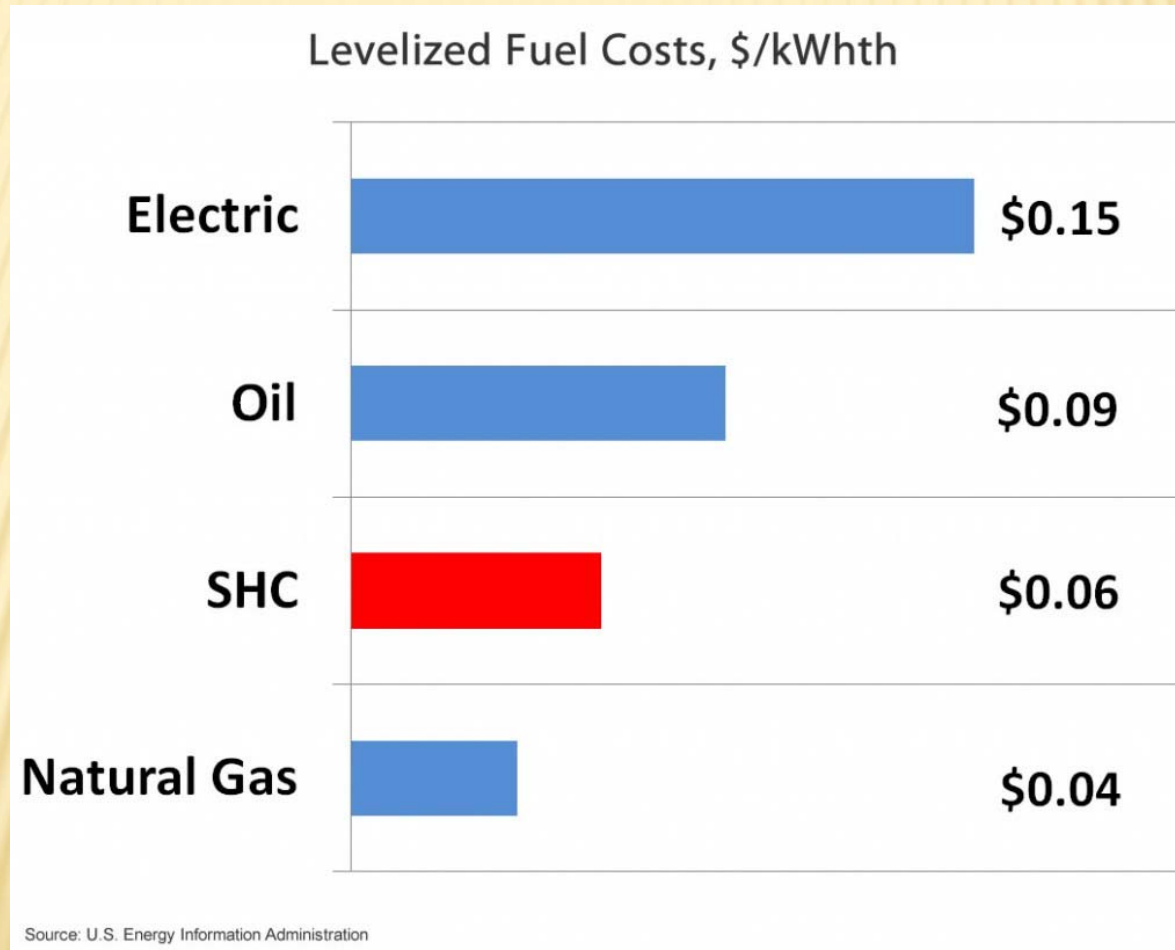


Renewable Phase Change Technology

- Current temperature options -40C to 180C
- Derived from agricultural feedstocks
- Latent heats average ~200 j/g
- Tight transition ranges - utilization
- Consistent repeatable performance
 - 65,000 thermal cycle tests
- Fire suppressant characteristics
- Listed on USDA Bio-Preferred Program
 - 6 month bio-degradable
- Non-corrosive
- Flexible containment options

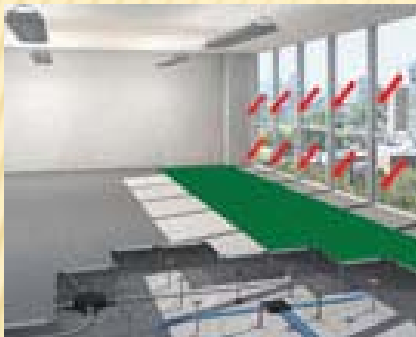


COMPARATIVE COSTS TO HEAT WATER



PCM FLOORING SYSTEMS

Absorb



Store

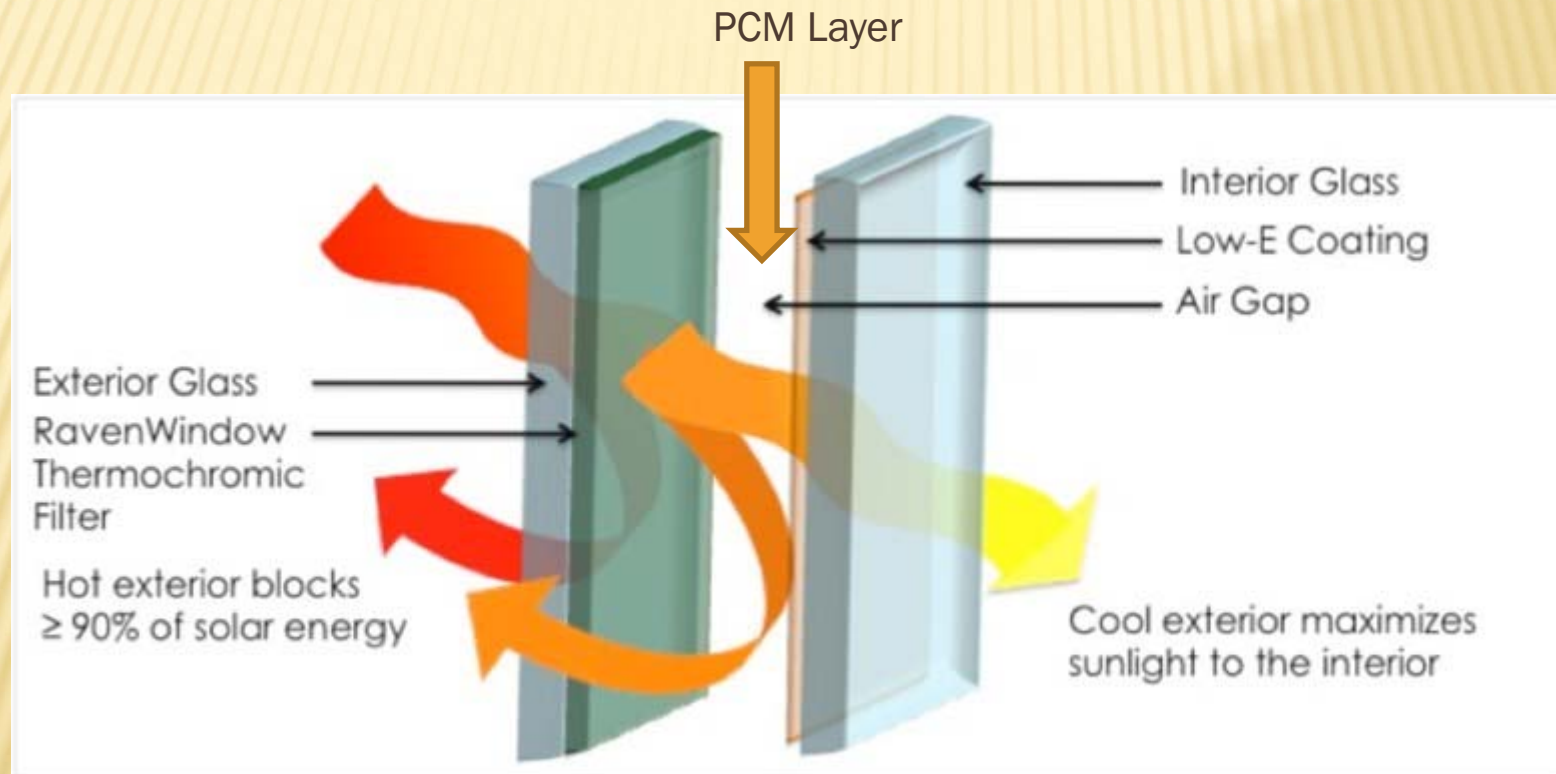


Release



Courtesy: Tate, Inc.

PCM WINDOWS AND GLASS BLOCKS



Courtesy: Ravenbrick