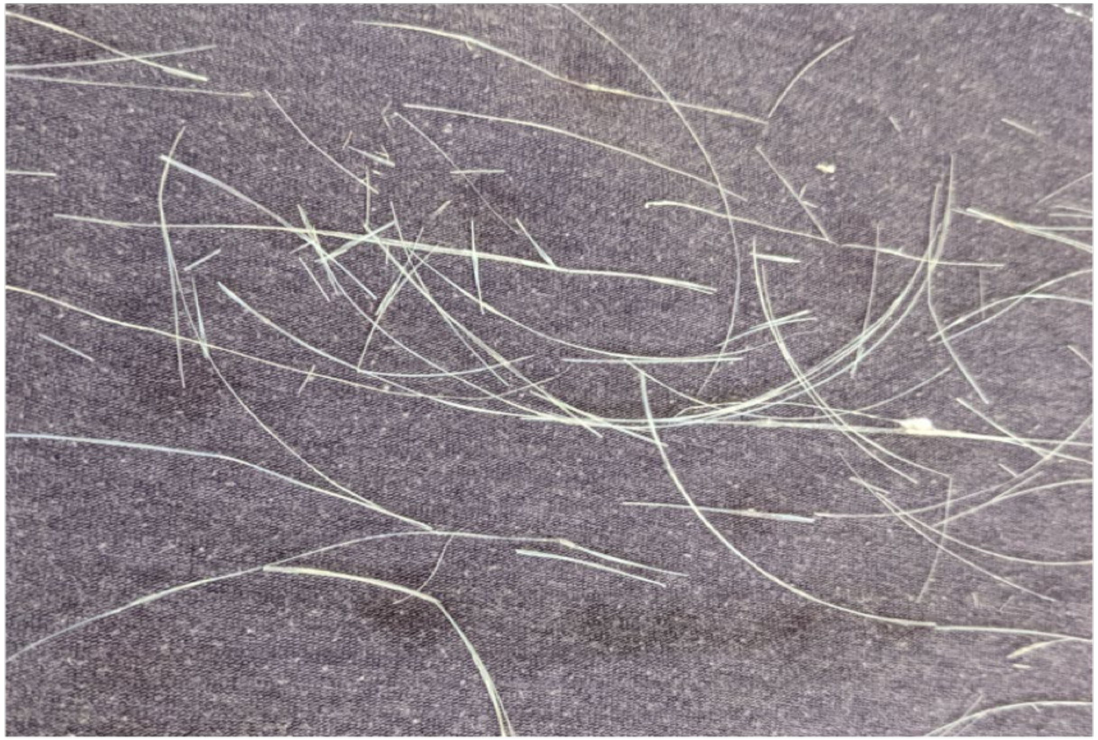
A new approach to encapsulate salt hydrate PCM



Oak Ridge National Lab (ORNL) and Phase Change Energy Solutions (PCES)
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Project Summary

Timeline:
Start date: 10/01/2020
Planned end date: 09/30/2023

Key Milestones
1. Encapsulation of salt hydrate PCM (09/30/2021)
2. Encapsulated salt hydrate has volumetric and gravimetric energy density >70% that of the pure salt hydrate without coating (9/30/2022)

Budget:

Total Project $ to Date:
- DOE: $300,000
- Cost Share: $70,000

Total Project $:
- DOE: $1,200,000
- Cost Share: $300,000

Key Partners:

PHASECHANGE energy solutions

Project Outcome:

The overarching project goal is to reduce the amount of energy lost through building envelopes and thus minimize the utility bills of occupants, which will indirectly reduce the greenhouse gas emissions to the the atmosphere and thus help in lowering the global warming.

The project outcome will address the long-standing problem of encapsulation of salt hydrate phase change materials (PCMs), which will enable the widespread use of thermal energy storage materials (e.g., PCMs) in the building envelope.

Team

ORNL

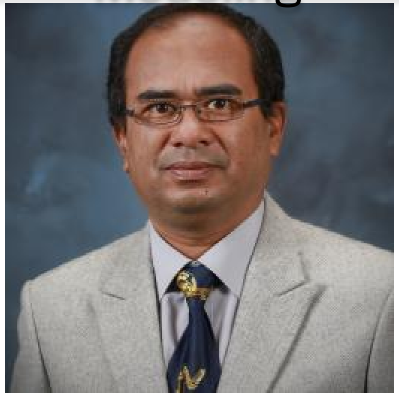
Synthesis | Polymer coatings | Characterization | Characterization | Modeling

Jaswinder Sharma, Ph.D.

Georgios Polyzos, Ph.D.

Diana Hun, Ph.D.

André Desjarlais, Ph.D.



Som Shrestha, Ph.D.

PCES

Testing & product development

Reyad Sawafta, Ph.D.

Anne McClean, Ph.D.

Team expertise

- Phase change materials
- Building envelope
- Fiber synthesis
- Materials chemistry
- Polymer chemistry
- Cost analysis
- Modeling and theoretical calculations

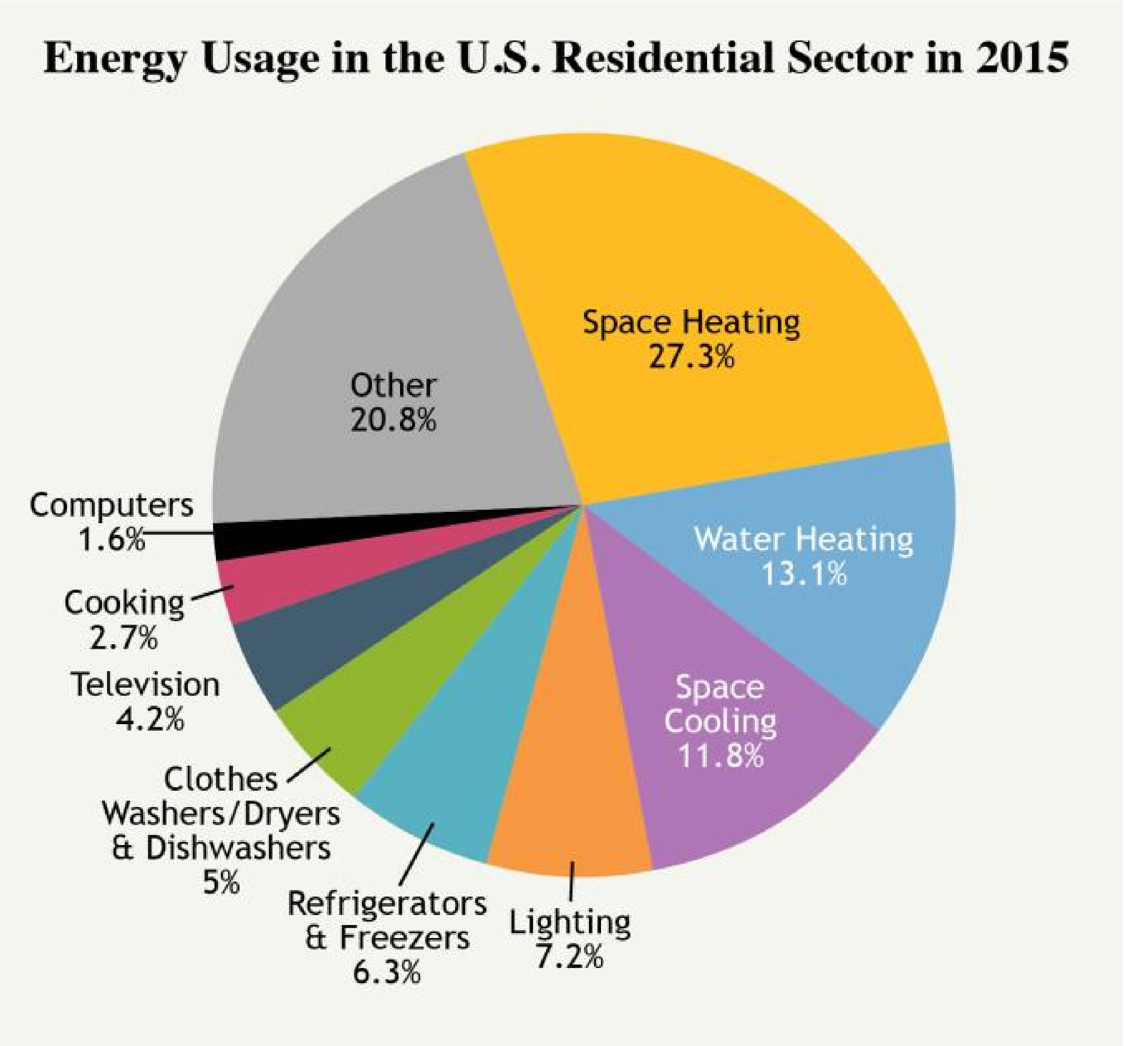
Challenge

- Approximately, 50% of building energy consumption can be attributed to thermal loads—a main contributor to the the utility bills of common households

- 45 million (14.5% of population) US households make less than $23,500 per year, and lowering their utility bill will be a big help

- Utility bills can be reduced by upgrading appliances, better thermal insulation, or thermal energy storage (e.g., by using phase change materials; PCMs)

- The use of PCMs is hindered by several issues: leakage, high cost, and several other technical challenges



Challenge

❑ Organic PCMs

Advantages: Easy to encapsulate

Disadvantages: High cost

- Low energy storage density (average 50 kWh/m^3)
- Leakage
- Low thermal conductivity (average 0.2 W/m.K)

❑ Inorganic PCMs (e.g., salt hydrates)

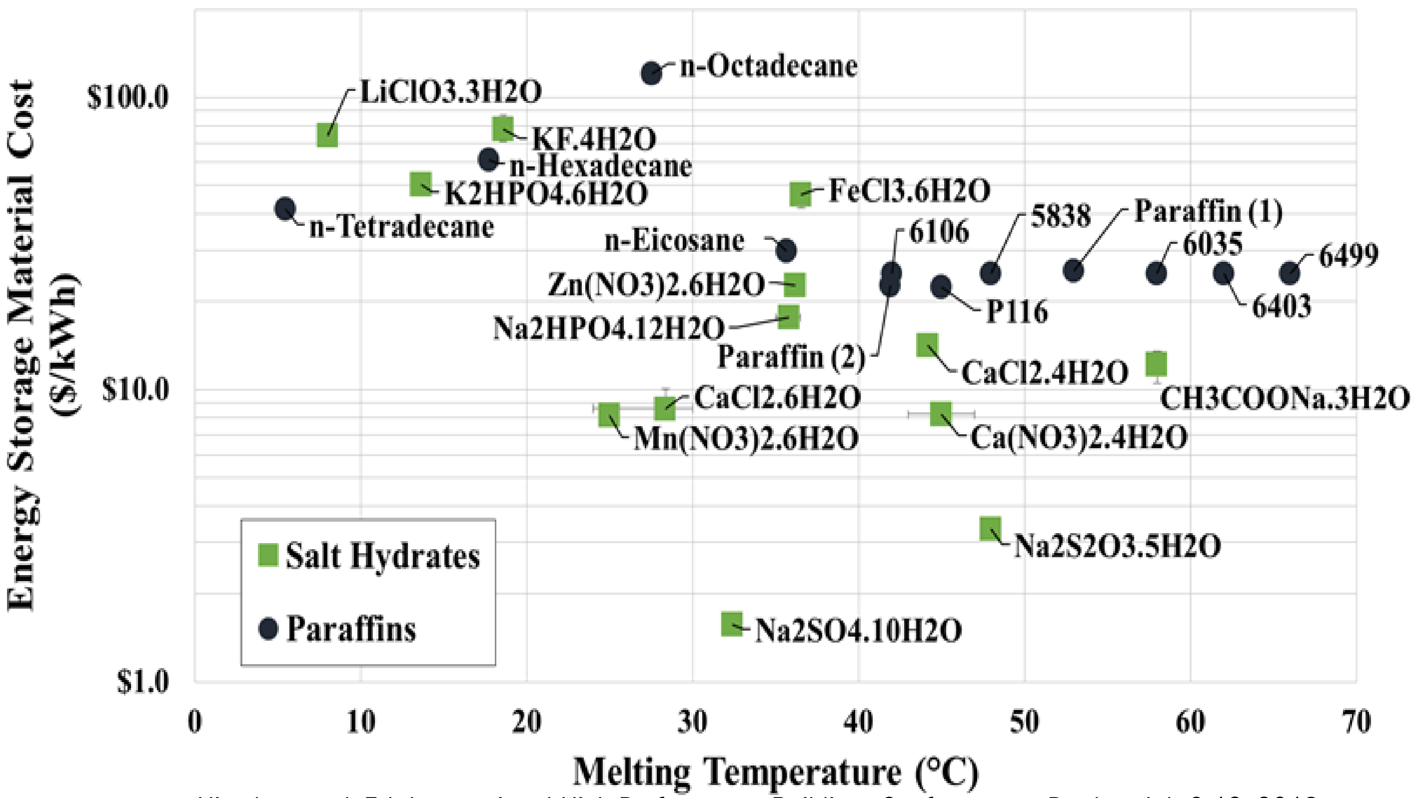
Advantages

- Low cost
- High energy density (average 90 kWh/m^3)

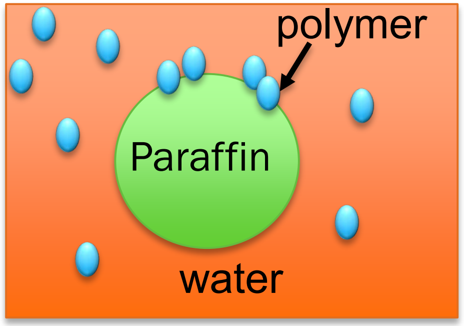
Disadvantages

- Leakage
- Supercooling
- Phase segregation
- Low thermal conductivity (0.5 W/m.K)

❑ No reliable encapsulation strategy for salt hydrates



Hirschey et al, 5th International High Performance Buildings Conference at Purdue, July 9-12, 2018



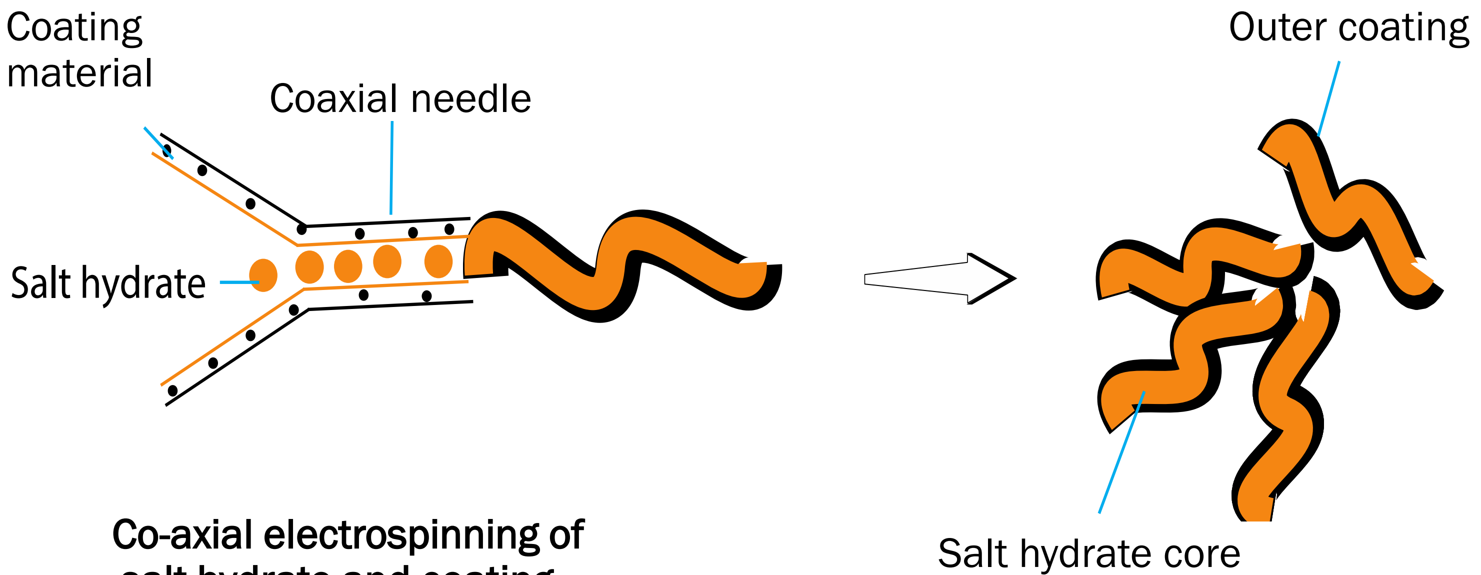
Conventional encapsulation approach (emulsification)

Approach

Our approach: Co-axial electrospinning

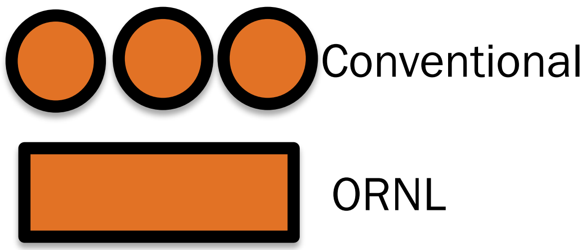
Benefits

- ❑ Better control of coating composition
- ❑ Better thermal conductivity
- ❑ Better energy density
- ❑ Scalable
- ❑ Reproducible/quality control



Co-axial electrospinning of salt hydrate and coating material

Encapsulated salt hydrate fibers



Approach

Achieving project targets

1. Cost

- ➢ Minimize use of electricity
- ➢ Use of inexpensive materials

2. Thermal conductivity

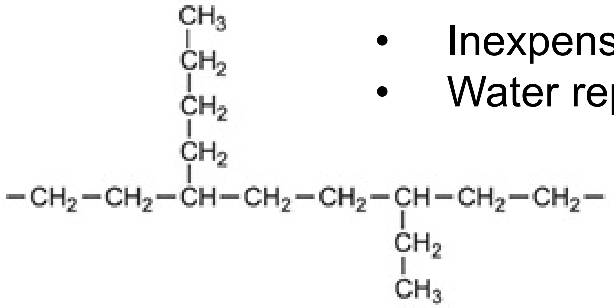
- ➢ Add high thermal conductivity additives

3. Supercooling

- ➢ Add nucleation agents

4. Energy density

- ➢ Increase the salt hydrate core/polymer shell ratio

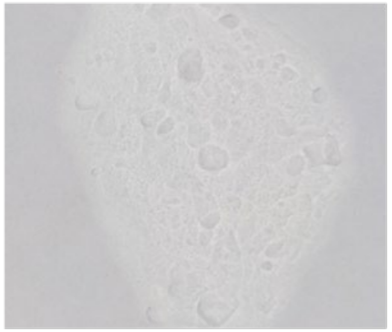


- Inexpensive
- Water repelling

Low/high-density polyethylene

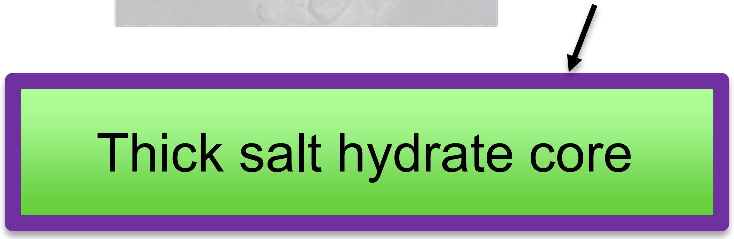
https://jrproductsinc.com/product/graphite-powder/

Graphite powder



Nucleating agent ($SrCl_2$)

Thin coating



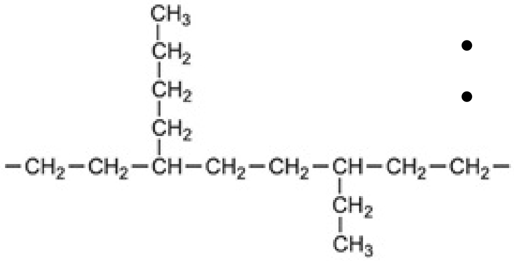
Approach

Key risks and mitigation

Risk 1. Leakage
- ➢ Use of water insoluble coatings
- ➢ Optimization of coating composition

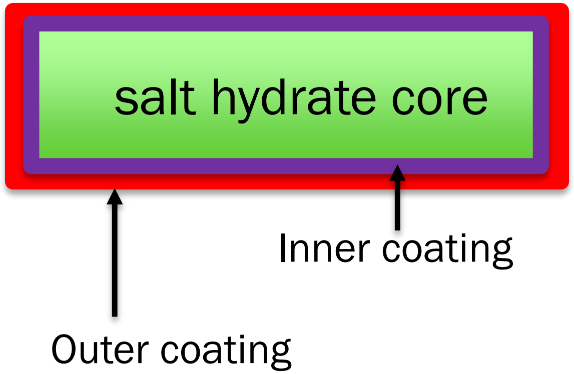
Risk 1. Water vapor escape
- ➢ Use of water insoluble coatings
- ➢ Coating thickness optimization
- ➢ Gradient coatings

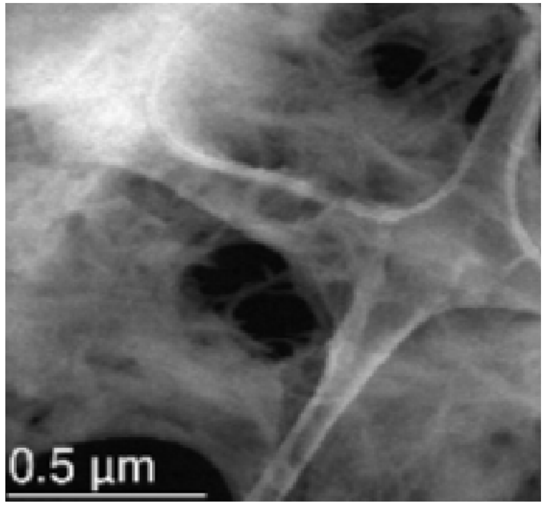
Risk 3. Phase segregation
- ➢ Thickening agents
- o cellulose
- o expanded graphite



Low/high-density polyethylene

- Inexpensive
- Water repelling





cellulose

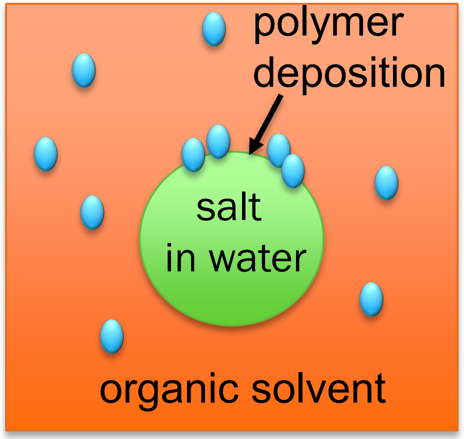
Approach

Other competing approaches

- Encapsulation approaches
  - Emulsification
  - In-situ polymerization
  - Electroplating

Challenges

- Scalability
- Reproducibility

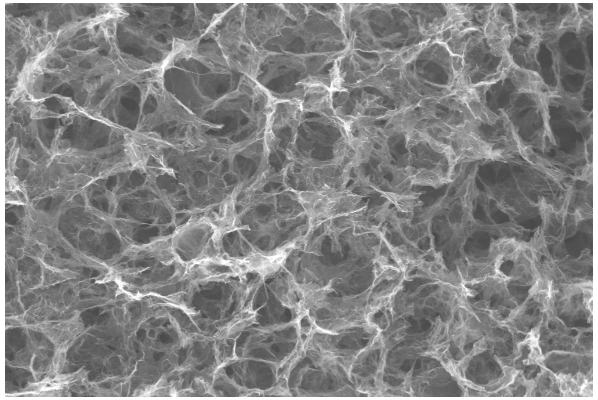


Emulsification

- Form stable approaches
  - Composites with conductive porous materials

Challenges

- Not suitable for envelope applications
- Low volumetric energy density



Graphene flake porous network

Impact

The project aligns excellently with BTO's Windows and Building Envelope Sub-program which focuses on developing and accelerating next-generation technologies & tools that reduce the amount of energy lost through building enclosures, contribute to improved occupant comfort, and have low product and installation cost.

- The project outcome will address the longstanding challenge of salt hydrate encapsulation, which will allow the widespread use of salt hydrate PCMs in the building envelope
- Will provide better volumetric energy density for the occupied space compared to conventional approaches
- Will lower the electricity consumption, and thus lower the CO_2 emissions to the atmosphere
- The project's market impact will be estimated by calculating the possible energy savings that can be achieved by incorporating these encapsulated salt hydrate (PCM) fibers in the building envelope

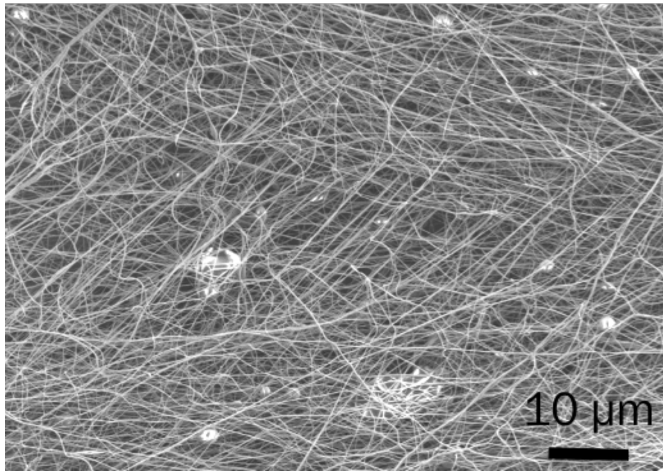
Progress

Selected salt hydrate candidates

Salt Hydrate and Salt Hydrate Eutectic PCM	Chemical Name	Melting Temp (°C)	Cost $/kWh	Volumetric Storage Capacity (kWh/m^3)	Thermal Conductivity (W/m-K)	Nucleator	Super-cooling
Calcium Chloride Hexahydrate	$CaCl_2.6H_2O$	28	6.0	81-87	K_{solid} = 0.85 K_{liquid} = 0.45	Stronium Chloride	< 3°C
Sodium Sulfate Decahydrate	$NaSO_4.10H_2O$	32	1.0	96	K_{solid} = 0.54 K_{liquid} = 0.38	Borax	< 2.5
40% Sodium carbonate decahydrate 60% Disodium phosoahe dodecahydrate	40% $Na_2CO_3 \bullet 10H_2O$ + 60% $Na_2HPO_4 \bullet 12H_2O$	28	5.0	≈100	unknown	unknown	<3.6

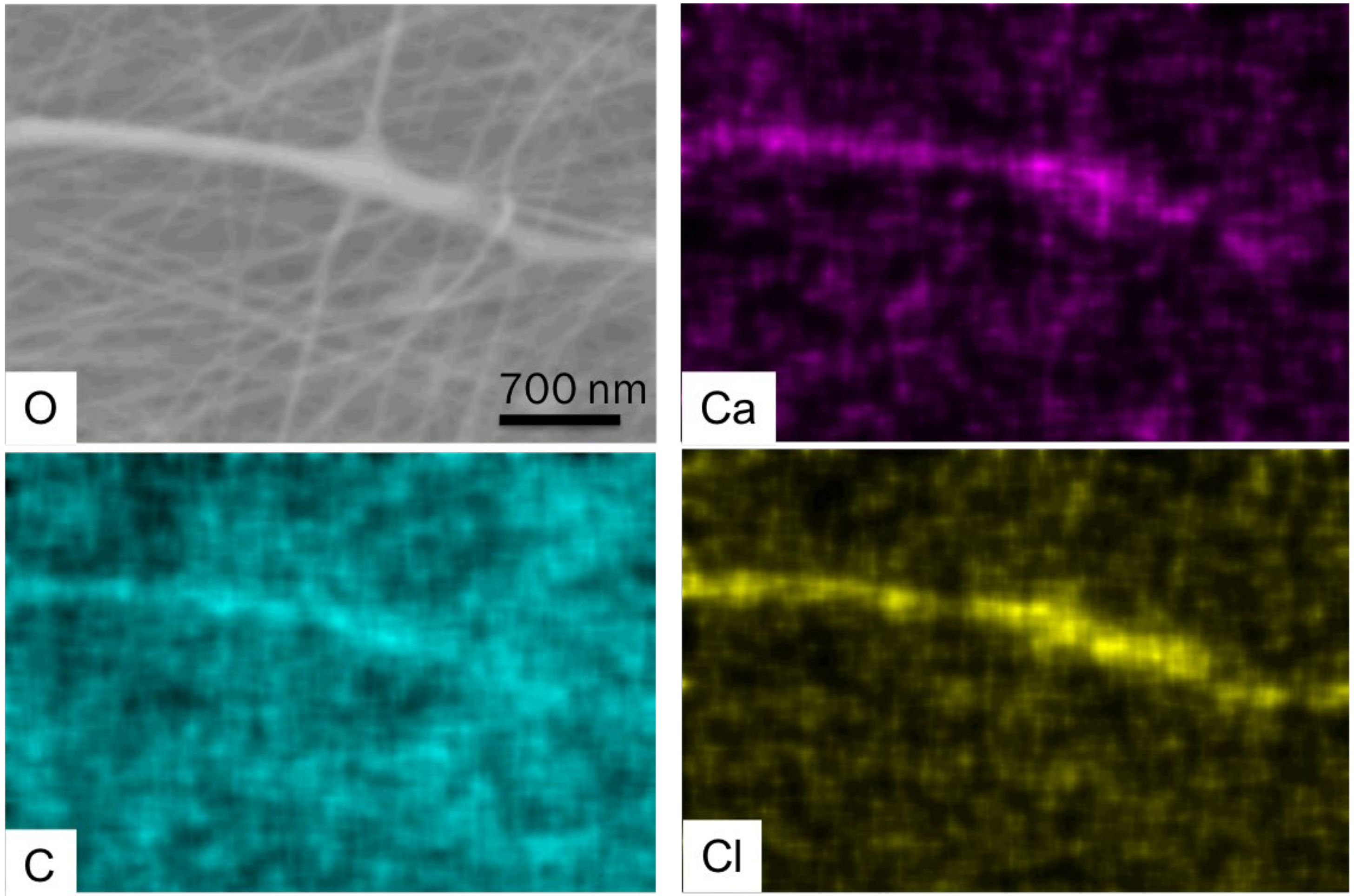
Progress

Energy dispersive X-ray (EDX) confirmed the core-shell nature of fibers



SEM image of encapsulated fibers

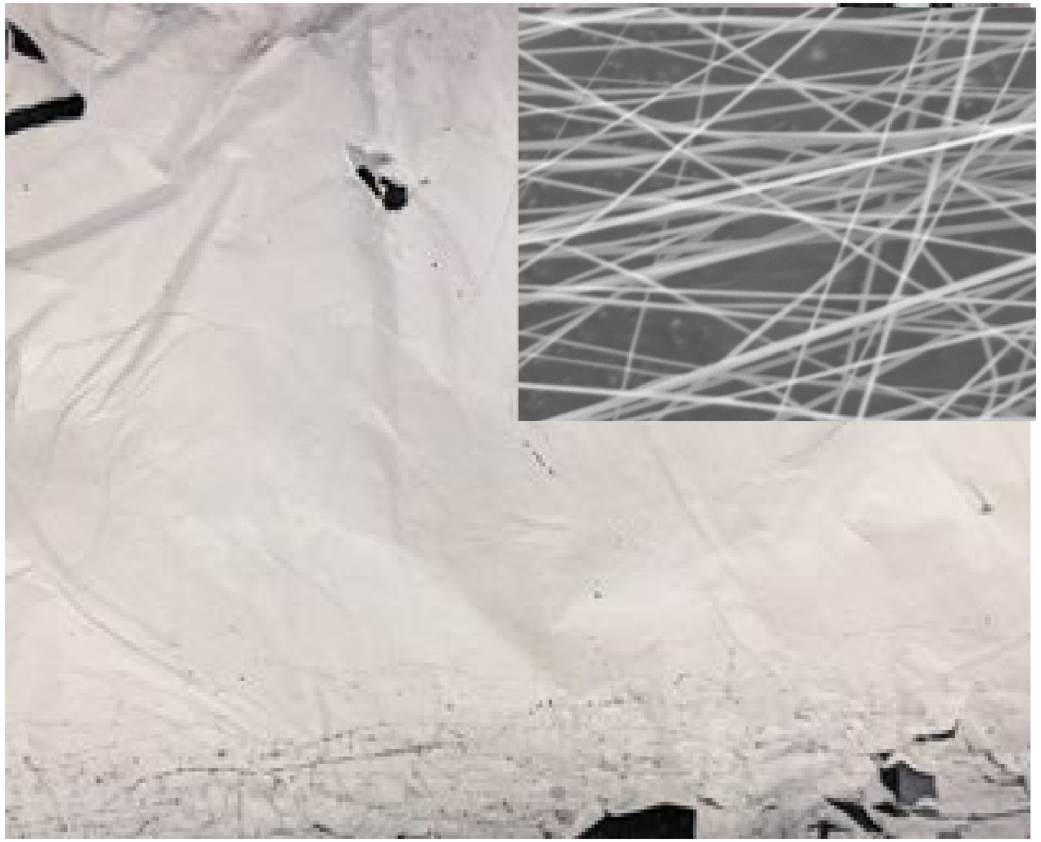
Other techniques
(X-ray photoelectron spectroscopy; XPS)
also confirmed the core-shell nature of fibers



EDX element maps

Progress

Water-soluble polymer coatings are not suitable



An encapsulated salt hydrate fiber mat with water-soluble polymer coating

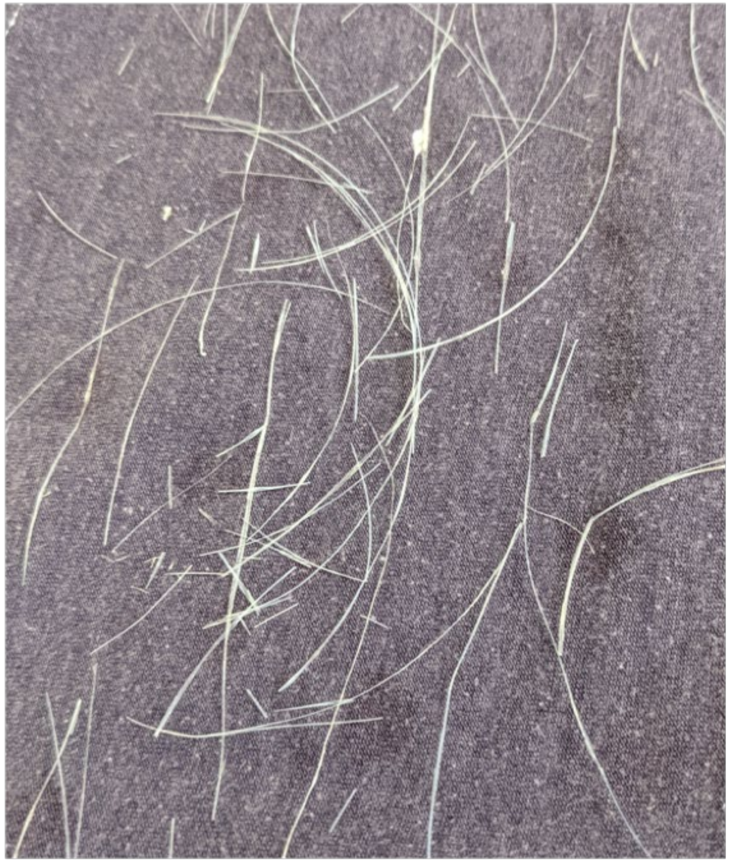
After

2 months

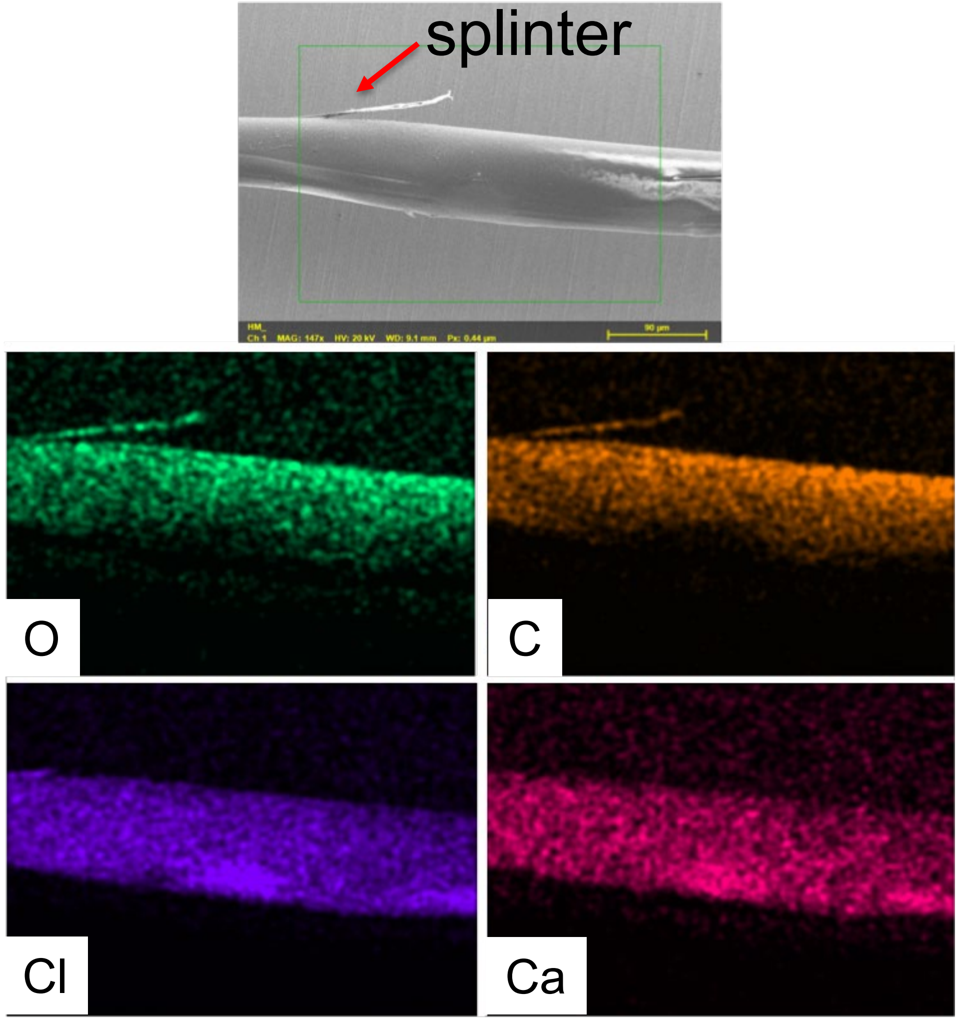
Dissolved fibers

Progress

Current status: encapsulation has been achieved



Digital photograph of core-shell fibers



SEM and EDX images of fibers

Stakeholder Engagement

- Phase Change Energy Solutions (PCES) is already partnering on the project

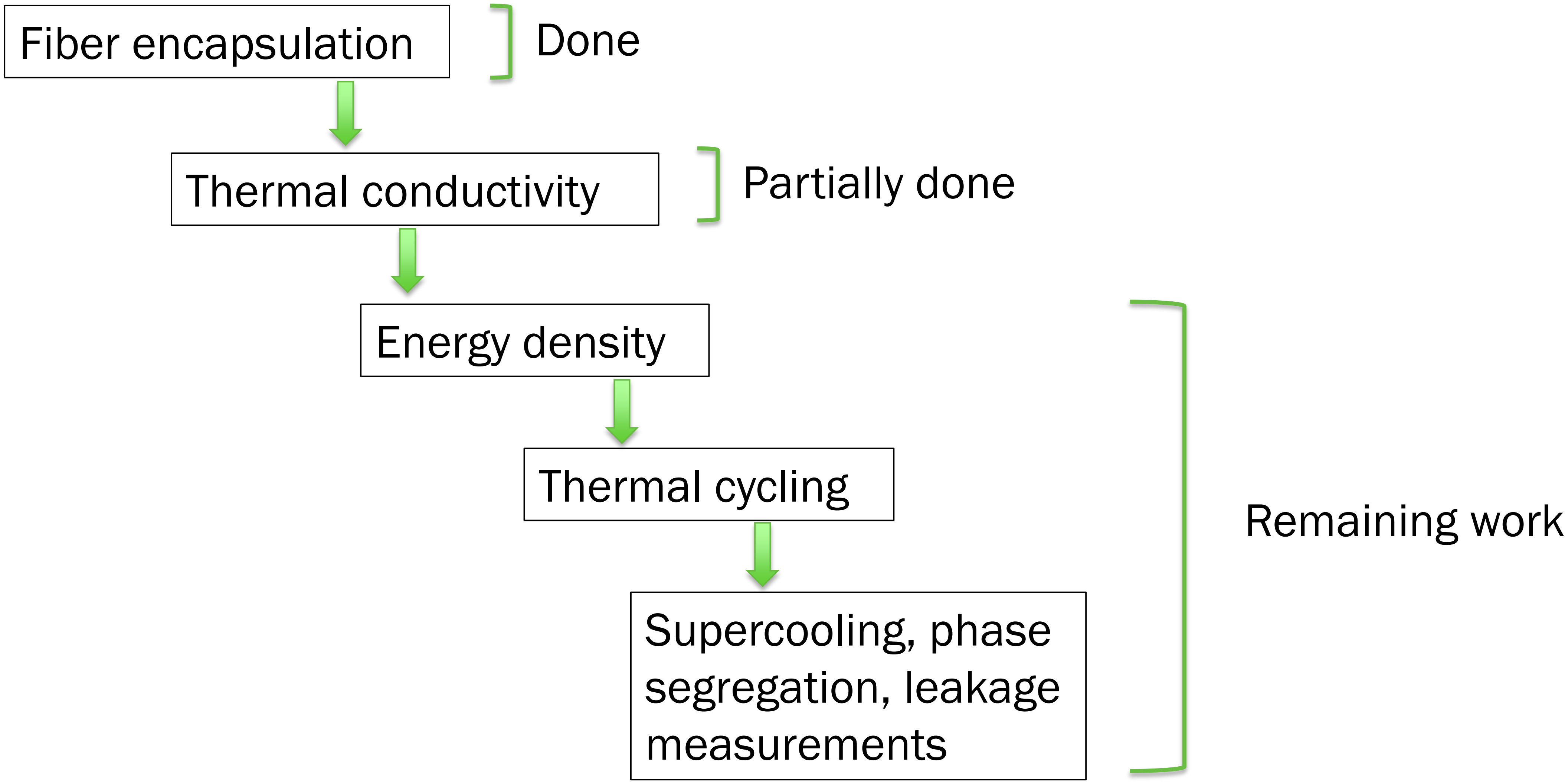
- PCES has performed initial cost analysis and plans to incorporate the project outcome into its own products

- Project is in early stage, and thus we are in the initial steps to engage more stakeholders

- Team has involved ORNL technology to market manager for presenting the work at various platforms, e.g., TechConnect Conference

- Contact with experts from other National Labs/Universities/industries for further guidance for final product development

Remaining Project Work



Thank you

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ORNL's Building Technologies Research and Integration Center (BTRIC) has supported DOE BTO since 1993. BTRIC is comprised of 50,000+ ft^2 of lab facilities conducting RD&D to support the DOE mission to equitably transition America to a carbon pollution-free electricity sector by 2035 and carbon free economy by 2050.

Scientific and Economic Results
238 publications in FY20
125 industry partners
27 university partners
10 R&D 100 awards
42 active CRADAs

BTRIC is a DOE-Designated National User Facility

REFERENCE SLIDES

Project Budget

Project Budget: Total budget: $1,500,000, Spent to date: $370,000
Variances: No
Cost to Date: $370,000
Additional Funding: No

Budget History					
Oct 01, 2020– FY 2021		FY 2022 (planned)		FY 2023 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
400,000	100,000	400,000	100,000	400,000	100,000

Project Plan and Schedule

Project Schedule												
Project Start: 10/01/2020	Completed Work											
Projected End: 09/30/2023	Active Task (in progress work)											
	◆ Milestone/Deliverable (Originally Planned) use for											
	◆ Milestone/Deliverable (Actual) use when met on time											
	FY2021				FY2022				FY2023			
Task	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Past Work												
Q1 Milestone: Selected salt hydrate candidates	◆											
Q2 Milestone: Performed initial encapsulation trials, documented the challenges faced, and proposed a path forward		◆										
Q2 Milestone: Built an effective medium approximation (EMA) model to calculate the thermal conductivity of the coating component in the encapsulated systems		◆										
Q2 Milestone: Present preliminary cost analysis of the manufacturing process to BTO		◆										
Q3 Milestone: Electron microscopy results clearly demonstrate encapsulated salt hydrates			◆									
Q3 Milestone: Presented data to BTO based on modelling results and initial experiments, and estimated the (1) diameter of fibers, (2) thickness of salt hydrate core, (3) thickness of coating			◆									
Current/Future Work												
Q4 Milestone: Perform detailed cost analysis of encapsulation process				◆								
Q4 Milestone: Achieved the yield of encapsulation process >50%				◆								
Q4 Milestone: Demonstrated that the proposed encapsulation procedure is scalable by producing at least 1.0 g of the salt hydrate fibers				◆								
Q4 Milestone: Demonstration of encapsulated salt hydrates with atleast 50% loading density of salt hydrate				◆								
Q1 Milestone: Less than 30% water vapor leakage after 10 thermal cycles					◆							
Q2 Milestone: Fiber surface salt content ≤20% of the core material after 100 phase change cycles while retaining 75% of original energy density (energy density at '0' cycles)						◆						
Q2 Milestone: Present detailed cost analysis of the manufacturing process and path forward to address the key cost drivers						◆						
Q2 Milestone: Encapsulated salt hydrates have a 'k' > 0.75 W/m•K and a volumetric and gravimetric energy density >50% than that of the pure salt hydrate without coating						◆						
Q2 Milestone: Set up an advisory board of experts to seek advice regarding critical aspects of the project						◆						
Q2 Milestone: Achieved supercooling ≤ 15 ºC						◆						
Q2 Milestone: Less than 30% water vapor leakage after 100 thermal cycles						◆						
Q3 Milestone: Encapsulated salt hydrates have a 'k' ≥ 1.0 W/m•K and a volumetric and gravimetric energy density >70% that of the pure salt hydrate without coating							◆					
Q3 Milestone: Less than 20% water vapor leakage after 100 thermal cycles							◆					
Q3 Milestone: Fiber surface salt content ≤20% of the core material after 1000 phase change cycles while retaining 75% of original energy density (energy density at '0' cycles)							◆					
Q4 Milestone: Present detailed cost analysis of the manufacturing process after addressing the key cost drivers identified in milestone								◆				
Q4 Milestone: Encapsulated salt hydrates have a 'k' > 1.5 W/m•K at volumetric and gravimetric energy density >70% that of the pure salt hydrate without coating								◆				
Q4 Milestone: Achieved supercooling 10 ºC								◆				
Q4 Milestone: Less than 20% water vapor leakage after 1000 thermal cycles and reported its effect on energy density								◆				
Q4 Milestone: Fiber surface salt content ≤10% of the core material after 1000 phase change cycles while retaining 75% of original energy density (energy density at '0' cycles)								◆				
Q1 Milestone: Encapsulated salt hydrates have a 'k' ≥1.5 W/m•K at volumetric and gravimetric energy density >90% that of the pure salt hydrate without coating									◆			
Q2 Milestone: Achieved supercooling < 5 ºC										◆		
Q2 Milestone: Presented detailed lab to market analysis and efforts on starting a follow on CRADA project either with current industry partner or finding potential CRADA partners										◆		
Q2 Milestone: Less than 20% water vapor leakage after 3000 thermal cycles while retaining 80% original energy density										◆		
Q3 Milestone: Achieved supercooling < 2 ºC											◆	
Q4 Milestone: Less than 20% water vapor leakage after 5000 thermal cycles while retaining 90% original energy density												◆
Q4 Milestone: Reported any incongruent melting if found to BTO												◆
Q4 Milestone: The encapsulated salt hydrate prototype has a k ≥1.5, supercooling ≤ 2 ºC, volumetric and gravimetric energy density ≥90% that of the pure salt hydrate without coating, and a cost ≤ $10/kWh												◆