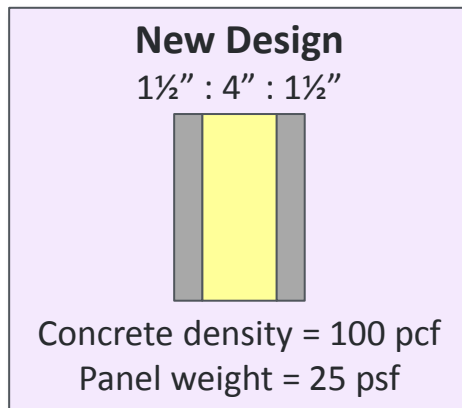
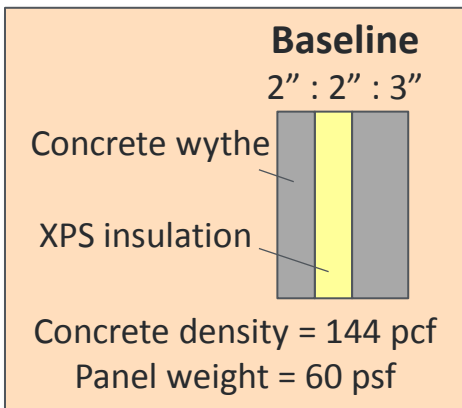




# Passive Envelope Advancement

2017 Building Technologies Office Peer Review

U.S.-China Clean Energy Research Center  
Building Energy Efficiency (CERC-BEE)



## Next Generation of Architectural Precast Concrete Wall Panels for New Construction

- 50% lighter
- 50% higher thermal performance
- Cost neutral design

## Assessment of Techniques to Retrofit Commercial Building Envelopes

Before Retrofit



Rendering of Retrofitted Building



U.S. DEPARTMENT OF  
**ENERGY**

Energy Efficiency &  
Renewable Energy

Diana Hun, [hunde@ornl.gov](mailto:hunde@ornl.gov)  
Oak Ridge National Laboratory

Uday Vaidya, Catherine Mattus, Alex Rollins

# Project Summary

## Timeline

Start date: 4/1/16

Planned end date: 3/30/21

## Key Milestones

1. 3/31/17: Designed and manufactured 1 - 2 prototypes of composite accessories
2. 3/31/17: Designed 5 - 6 concrete formulations that could achieve  $\geq 600$  psi flexural strength at 12 hours and 100 pcf density

## Budget

### Total Project to Date

- DOE: \$545K
- Cost Share: \$983K

### Total Project

- DOE: \$2.7M
- Cost Share: \$4.3M

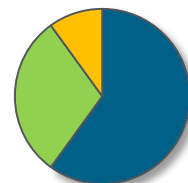
## Key Partners



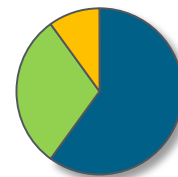
CHINA STATE CONSTRUCTION ENGINEERING CORPORATION

## Project Outcomes

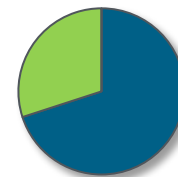
- Next-gen architectural precast insulated walls
- Cost-effectiveness evaluation of commercial building envelope retrofits
- New air sealing technologies



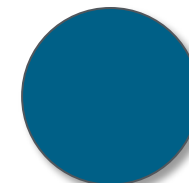
Year 1  
4/16 - 3/17



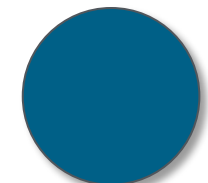
Year 2  
4/17 - 3/18



Year 2  
4/18 - 3/19



Year 4  
4/19 - 3/20



Year 5  
4/20 - 3/21

# Purpose

## Problem Statement

### 1. New commercial buildings:

Envelope energy saving technologies typically take longer and cost more to install properly in onsite than offsite construction

### 2. Existing commercial buildings:

~50% of buildings lack or have minimal insulation and lack an air barrier system because built before energy codes

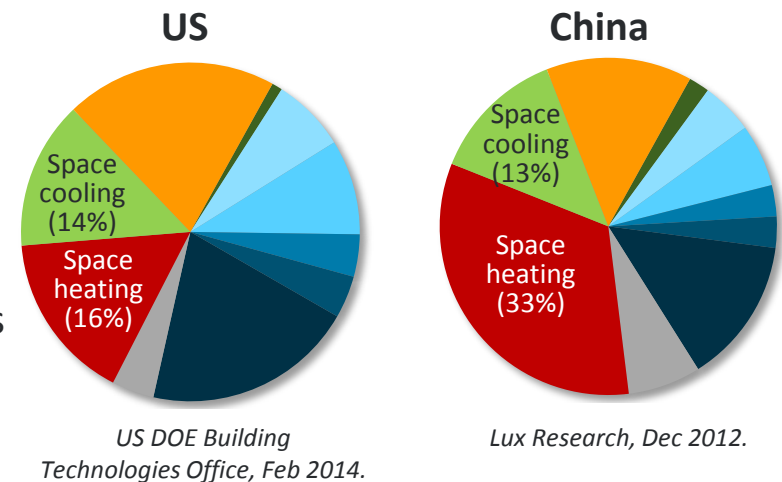
### 3. Air sealing technologies:

Easy-to-install air barrier technologies needed to increase airtightness in new and existing buildings

## Target Market and Audience

- Market: new and existing commercial buildings in the US and China
- Audience: architects, designers, general contractors
- 2030 total energy market for commercial buildings
  - Precast insulated walls for new construction
  - Retrofit of existing envelopes
  - Air sealing technologies

Envelopes contribute  
>50% of space heating and cooling loads



US = 35 TBtu

China = 320 TBtu

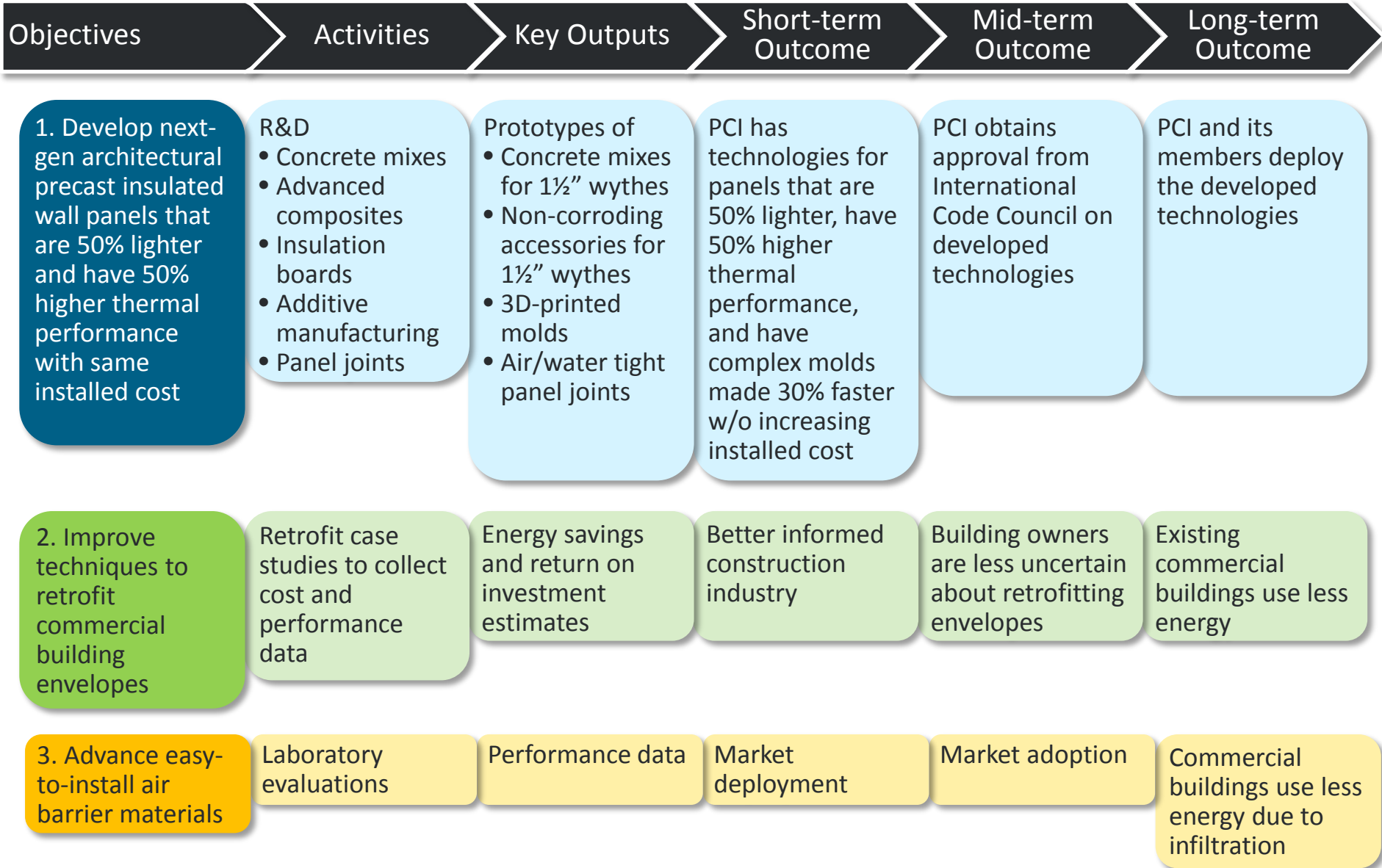
US = 120 TBtu

China = 140 TBtu

US = 43TBtu

China = 49 TBtu

# Logic Model of Project's Objectives



# Approach: Precast Walls

## Tasks to develop new system

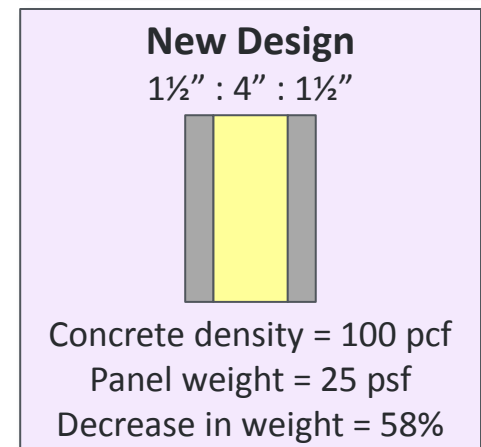
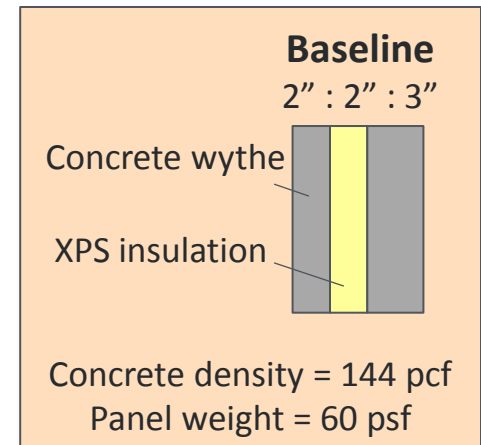
1. Reduce weight by  $\geq 50\%$  to decrease transportation and installation cost  $\rightarrow$  1½"-thick concrete wythes
  - a. High performance concrete mix: 600 psi flexural strength at 12 hours
  - b. Lower concrete density: 100 pcf
  - c. Non-corroding accessories made of composites:  
lifting inserts, panel-to-building connectors, reinforcement
2. Double thermal performance
  - a. Non-corroding accessories with low thermal conductivity
  - b. Airtight panel joints
  - c. No increase in panel thickness
3. 3D print molds for concrete
  - a. ~30% faster manufacture of complex molds
4. Improve air/water tightness of panels joints
  - a. New joint designs or sealants

## Key Issues

Success of new system depends on success of new components

## Distinctive Characteristics

- Multi-disciplinary team designing new precast system
- Design developed with guidance from precasters



# Approach: Envelope Retrofit & Air Sealing Technologies

## Tasks to generate retrofit case studies

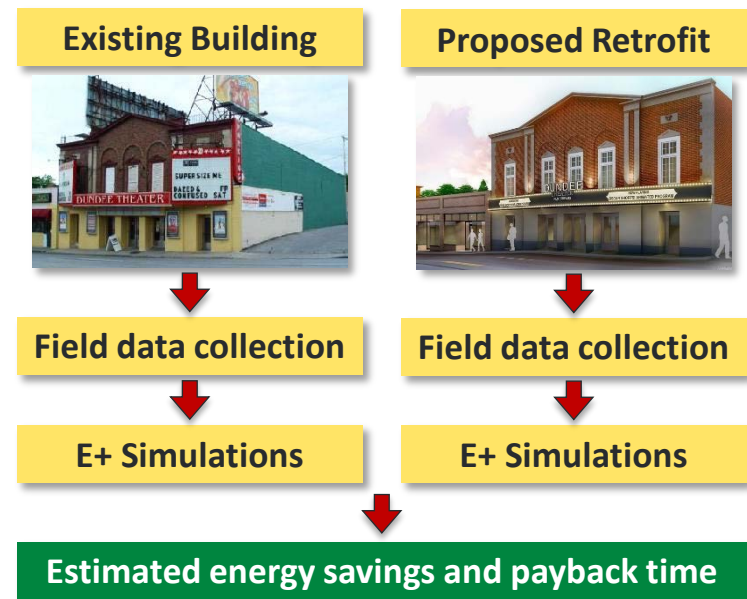
1. Gather before and after retrofit data:  
blower door tests, thermal insulation, energy bills
2. Estimate energy savings thru simulations
3. Estimate return on investment

## Key Issues

Slowly increasing network of potential sources

## Distinctive Characteristics

Using actual data to estimate energy savings and ROI



## Tasks to develop new air sealing technologies

1. Dow and 3M designing new formulations
2. ORNL evaluates performance per manufacturer's/market needs

## Distinctive Characteristics

Dow and 3M focusing on developing easier-to-install technologies

# Progress: Precast Walls – High Performance Concrete

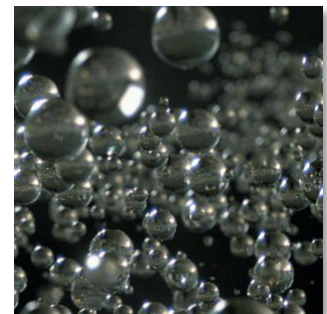
- Requirements for 1½”-thick wythes
  - $\geq 600$  psi flexural strength at 12 hours
    - Low-cost chopped and recycled carbon fibers
    - Polypropylene and polyvinyl alcohol (PVA) fibers
    - Basalt mini bars
  - 100 pcf density
    - Lightweight aggregate
    - Hollow microspheres
- Selected results from  $\geq 8$  non-optimized mix designs
  - Mix A: 610 psi and 99 pcf
  - Mix B: 720 psi and 99 pcf
  - Mix C: 750 psi and 103 pcf
  - Mix D: 720 psi and 102 pcf



**Chopped Carbon Fibers**



**Basalt Mini Bars**



**Glass Beads**

# Progress: Precast Walls – Non-Corroding Accessories

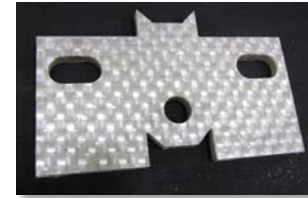
## Accessories for 1½”-thick wythes

- Erection lifting insert (16,000 lbs)
- Stripping lifting insert (10,000 lbs)
- Tieback connection (10,000 lbs)
- Bearing connection (10,000 lbs)

### Erection Lifting Insert Prototypes



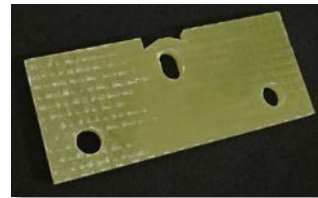
Installed carbon lifter at Gate precast



Continuous glass fibers/PET



Long discontinuous glass fibers/PPS



Continuous glass fibers/vinyl resin

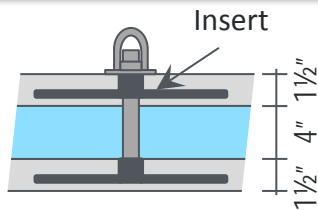


Long discontinuous carbon fibers/PA6

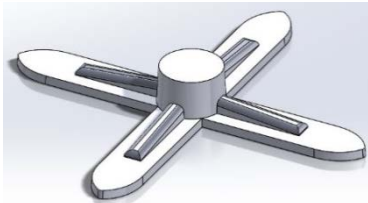


Long discontinuous carbon fibers/TPU

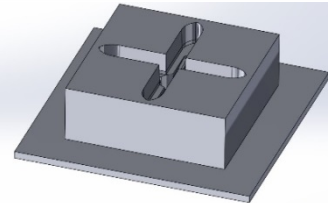
### Mold Design for Lifting Stripping Insert Prototype



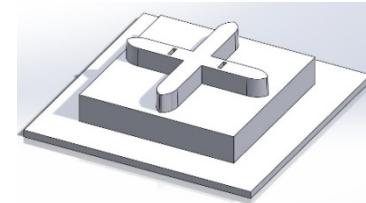
Assembly



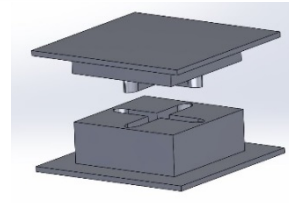
Prototype



Female Mold



Male Mold



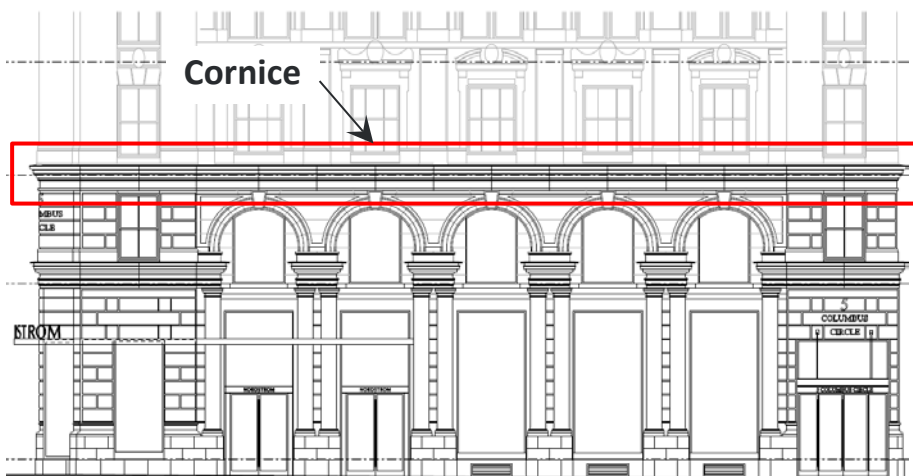
Mold Assembly



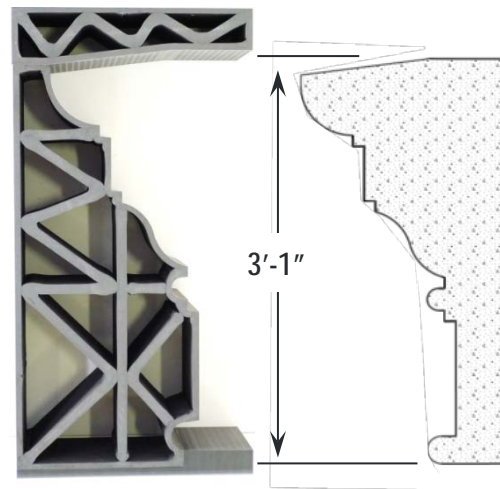
# Progress: 3D Printed Molds

- Complex molds take 1 to 2 weeks to assemble by hand
- Advanced manufacturing could decrease assembly time by ~30%

## Building Elevation



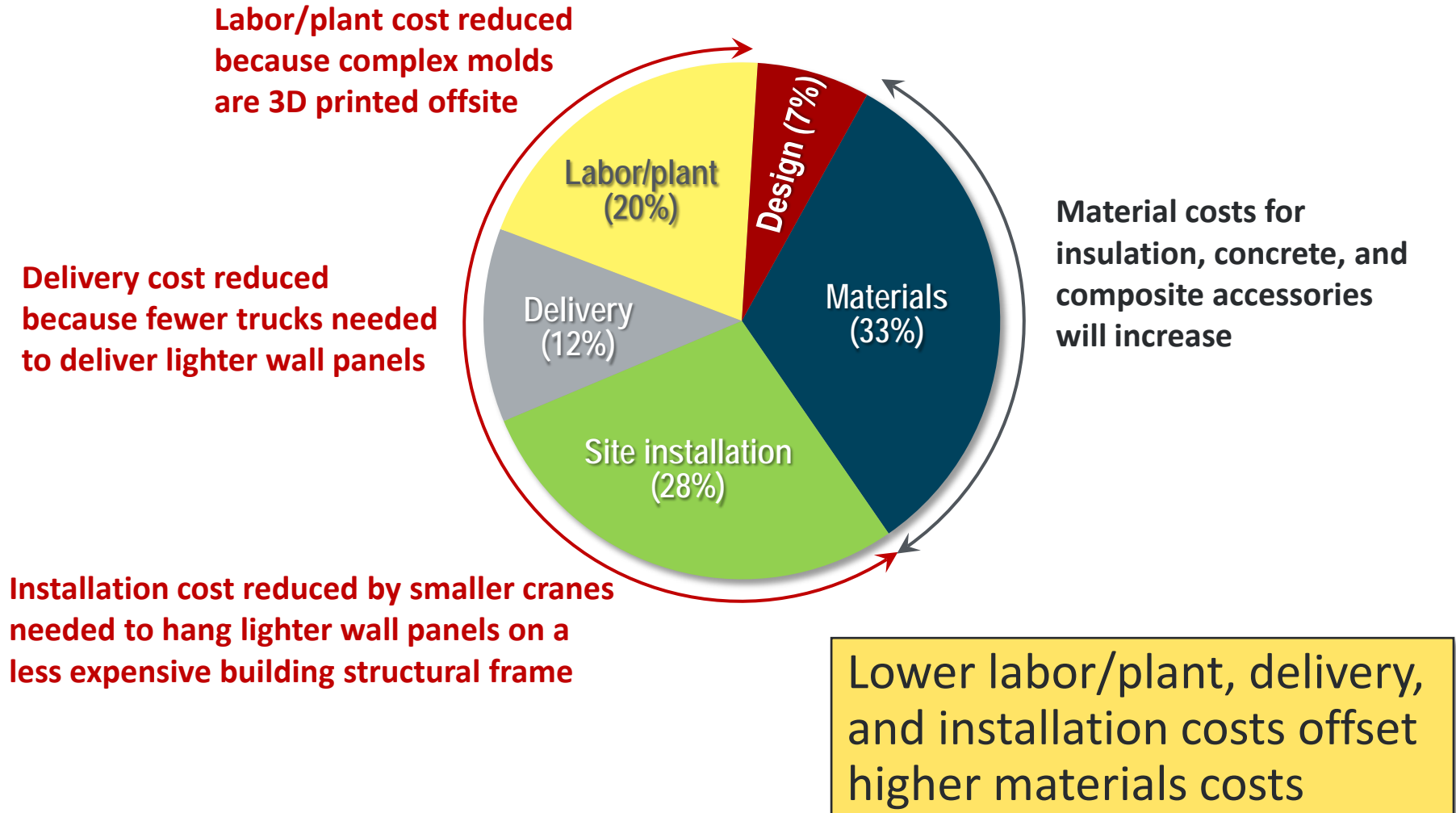
## 1 Foot Long Cornice Mold Prototype



3D-printed and CNC-finished prototype mold (L) with cornice cross section (R)

Casted concrete

# Progress: Cost-Neutral Installed Precast Walls



# Progress: Retrofit of Dundee Theater

- Omaha, NE
- Circa 1925
- ~4,000 ft<sup>2</sup>
- Uninsulated exterior masonry walls
- No air barrier system
- Retrofit schedule: February to October 2017
- Proposed envelope retrofit
  - Spray closed-cell foam on interior of masonry
  - Increases number of freeze/thaw cycles
  - WJE
    - Evaluation of existing masonry
    - Recommendations to lower freeze/thaw risk
- Before retrofit blower door test in March

Before Retrofit



Rendering of Retrofitted Building



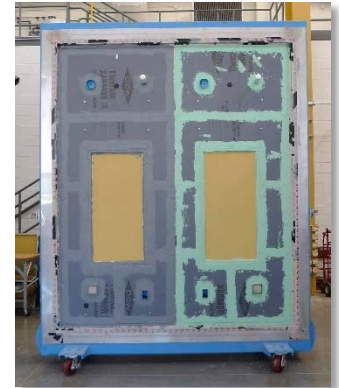
# Progress: Air Sealing Technologies

- Dow's LIQUIDARMOR™ LT
  - Silicone-based liquid flashing that can be applied as low as -20°F
  - Lab tests: performance after 20°F installation
  - Launched in October 2016
- Dow's LIQUIDARMOR™ QS
  - Spray-applied liquid flashing 3-4× faster install than tape
  - ~4 times faster drying time than LIQUIDARMOR™ CM
  - Lab tests: performance on different substrates
  - To be launched in ~Spring 2017
- 3M's 3015VP
  - Primer-less self-adhered membrane
  - Up to 50% faster installation than membranes that require priming
  - High vapor permeance
  - Lab tests: performance after exposure to 20-115°F and 20-80% RH cycles
- Lab tests
  - ASTM E381, E2357, E1424, E331, E2268

Dow  
LIQUIDARMOR™ QS



Dow  
LIQUIDARMOR™ LT



3M 3015VP



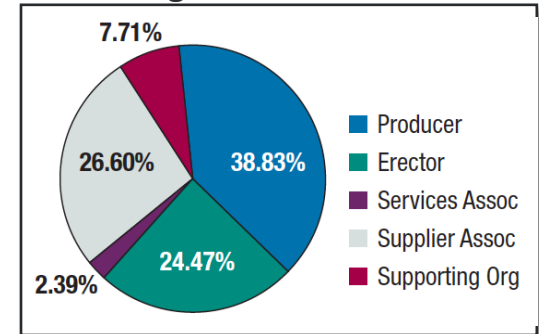
# Integration and Collaboration within US Team

- Precast walls

- ORNL/PCI finalizing Collaborative R&D Agreement (CRADA)
- PCI
  - Coordinate pilot project
  - Deploy technologies



Precast/Prestressed Concrete Institute  
2016 Organizational Members



- Envelope retrofit



- Air sealing



- Publications

- *The case for retrofitting building envelopes, D+D In Depth*
- *Building Envelope Advancement under the US-China Clean Energy Research Center for Building Energy Efficiency, Interface*

# Integration and Collaboration with Chinese Team

- China State Construction Engineering Corp (CSCEC)
- Largest construction company in the world
  - Excellent mechanism to deploy new technologies
- Performs construction and R&D
  - Precast construction
  - 3D printing
  - Retrofit
  - Air sealing
- CSCEC recently submitted its research proposal
- ORNL and CSCEC to define collaboration



CCTV Headquarters  
Beijing, China



Novena Hotel  
Singapore



Malabo International Conference Center  
Equatorial Guinea



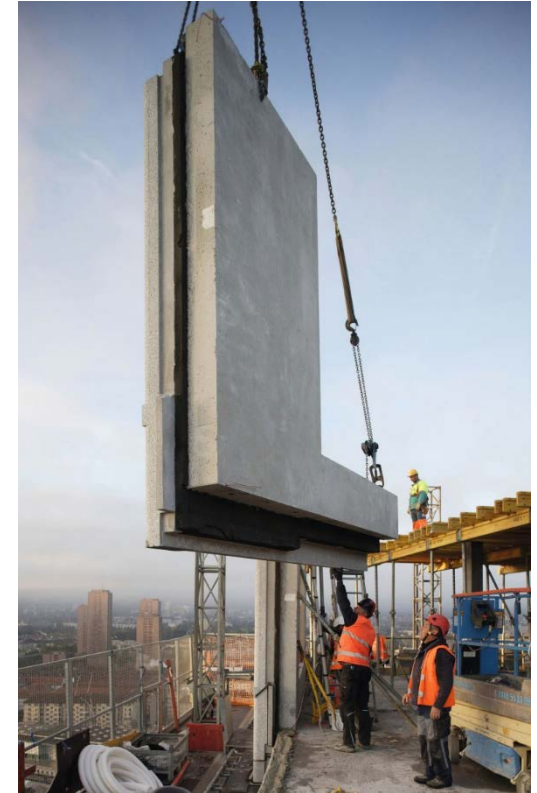
Darla Moore School of Business  
University of South Carolina



Al Hekma Tower  
Dubai, United Arab Emirates

# Global Benefits

- Worldwide forecast
  - Precast construction market worth \$177B by 2021  
*(Markets and Markets, 2017)*
    - Asia-Pacific region will be the largest market
    - $\geq 30\%$  of new buildings in Beijing will be prefabricated by 2020
    - $\sim 8,000$  production plants in Europe
  - Global revenue for energy efficiency commercial building retrofits expected to grow from \$71.4 in 2016 to  $> \$100B$  in 2025  
*(Navigant Research, 2016)*
- US advances in passive envelope will have international outcomes
- Partnership with CSCEC should promote deployment of new technologies worldwide



# Next Steps: Precast Walls

- High performance concrete mix
  - Optimize mix based on mechanical properties and cost
  - Replace max amount of Portland cement without compromising mechanical properties and cost
  - Scale up mix at precast plant and further optimize
- Non-corroding composite accessories
  - Produce prototypes, evaluate performance, and optimize designs
- 3D printed molds
  - Print prototypes from actual projects and perform cost analysis
- Panel joints
  - Develop/test new sealants/details at panel joints
- Insulation boards
  - Dow to continue efforts using low-GWP blowing agents
- ORNL/PCI complete CRADA
- Finalize collaboration plan with CSCEC

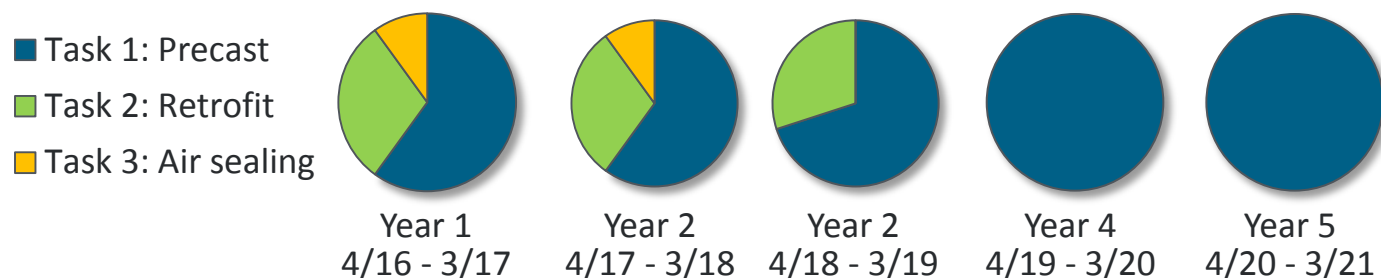
**Perot Museum of  
Nature and Science**





# Next Steps: Envelope Retrofit & Air Sealing Technologies

- Envelope retrofit
  - Expand network of potential sources for case studies
  - Target consultants that specialize in renovations
  - Continue data collection
- Air sealing technologies
  - Continue evaluations of LIQUIDARMOR™ to launch as an air barrier system
- Finalize collaboration plan with CSCEC



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# REFERENCE SLIDES

# Project Budget

**Variations:** Will have 1 demonstration retrofit project instead of 2 because masonry retrofit requires more in-depth evaluations

**Cost to Date:** ~80%

**Additional Funding:** none

## Budget History

04/16 – 03/17 (current)		04/17 – 03/18 (current)		04/18 – 03/21 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
\$545K	\$938K	\$545K	\$703K	\$1,635K	\$2,539K

# Project Plan and Schedule

- Start date: 4/1/16
  - Slipped milestones because funds arrived 1.5 months late or slow identification of demos
- Planned end date: 3/31/21

Deliverables/Milestones	BTO FY16		BTO FY17				BTO FY18	
	Year 1 CERC BEE		Year 2 CERC BEE					
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
<b>Task 1: Architectural Precast Insulated Concrete</b>								
D1.1.1 – Revised Tasks 1.3, 1.4 and 1.5 of this Gantt chart if needed.	■	◆						
D1.2 – Completed modification of ORNL's facilities.		■	◆					
D1.3.1.1.1 – Held at least 3 meetings between ORNL and PCI.	■	◆						
D1.3.1.1.2 – Selected 3 to 5 potential composite materials for inserts and connectors.		■	◆					
M1.3.1.1.4 – Developed 1 to 2 prototypes and gathered feedback from PCI.			■	◆	◆			
D1.3.2.1 – Summarized requirements and standard tests to be followed in the design of high performance concrete.	■	◆						
M.1.3.2.4.1 – Selected a component for each of those listed under Subtask 1.3.2.2 for concrete testing.			■	◆				
D.1.3.2.4.2 – Designed 5 or 6 concrete formulations that meet or exceed properties using regular quantities of cement.			◆	■	◆			
M.1.3.2.5.1 – Selected a component for each of those listed under Subtask 1.3.2.3 for concrete testing.			■	◆				
D1.4.1 – Produced CAD models of 3D printed mold.		■	◆					
M1.4.2 – Produced two 3D molds and four concrete precast samples.			◆	■	◆			
M1.3.1.1.6 – Manufactured ≥50 samples of 2-ton erection lifting inserts w/ near net shape aluminum mold.							◆	
M1.3.1.1.8 – Manufactured ≥50 samples of 10,000 lbs. stripping lifting inserts w/ near net shape aluminum mold.								◆
M1.3.2.6.2 – Designed the most economical concrete mix for the outer wythe that reaches the required mechanical properties.							◆	
D1.3.2.7.2 – Measured baseline length change of mortars for the outer wythe and confirmed acceptability with PCI advisory board.								◆
<b>Task 2: Retrofits</b>								
D2.1 – Methodology to gather data from retrofitted buildings.	■	◆						
D2.2 – Selected two demonstration buildings.			◆	■	◆			
M2.3.1 – Estimated energy savings due to building envelope retrofits from 1 <sup>st</sup> demo.					◆			
M2.4.2 – Measured the air leakage rate of two building envelopes before they are retrofitted.							◆	
D2.4.4 – Estimated energy savings from the retrofit of two building envelopes.								◆
<b>Task 3: Air Sealing</b>								
M3.1 – Dow to determine if readily available LIQUIDARMOR formulation can be utilized in below freezing temperatures.			■	◆				
M3.2 – 3M to determine if readily available 3015VP membrane can be utilized in below freezing temperatures.				■	◆			
D3.5.2.1 – Issued interim report on 1 <sup>st</sup> wall evaluation.							◆	
M3.5.3 – Issued suggestions to Dow on how to improve the LIQUIDARMOR™ air barrier system.								◆

20 ■ Completed ■ Active ◆ Originally planned milestone/deliverable ◆ Actual completion of milestone/deliverable

Not all milestone/deliverable are shown due to lack of space