Project Summary

Timeline:
Start date: November 2010
Planned end date: October 2015

Key Milestones:
1. TO2 Detailed Test & Work Plan, Phase 1: Planning; May 2011
2. TO2 Technical Report, Phase 2: Prelim Design–Development; Feb 2012
4. TO4 Technical Report, Phase 3: Prototyping; Mar 2014

Budget:
Total DOE $ to date: $810,426
Total future DOE $: $1,090,113 proposed

Key Partners:
Accuvent       AFM
Bayer Material Science  BASF
Certainteed     Dow
Factory Home Builders  Hunter Panels
Johns Manville  Louisiana Pacific
Mitsubishi      MHI
Owens Corning   SBRA
Senco          Tjernlund

Target Market/Audience:
Manufactured housing industry

Project Goal:
Provide factory homebuilders with high performance, cost effective alternative envelope designs as a comprehensive solution for reaching net zero energy use
**Relevance to BTO Needs and Objectives**

**BTO Objective**: Develop and deploy technologies and systems that reduce building energy consumption by 50%

<table>
<thead>
<tr>
<th>BTO’ Strategies</th>
<th>How this Project Fulfills BTO’s Needs and Objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Research and develop advanced technologies</td>
<td>Develop and test technologies to reduce new MH energy use by half</td>
</tr>
<tr>
<td>Stimulate the market for innovations</td>
<td>Partner with those responsible for 80%+ of all new MH through a process referred to as “Collective Impact”</td>
</tr>
<tr>
<td>Develop and implement codes and standards</td>
<td>Participate in the ongoing MH standards development process – informed by the R&amp;D work</td>
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</tbody>
</table>
Purpose and Objectives: Problem Statement

How to move a highly price-sensitive industry to exemplary levels of energy efficiency.

**Barriers**
- 1st cost is king
- Communicating energy benefits faces major hurdles

**Challenges**
- Technologies must be production friendly
- New building methods must be HUD approved
- Sold by dealers like autos

**Knowledge Gaps**
- Industry mindset focused on 1st cost; must shift to total ownership costs
- Few examples of high performance homes
- HUD energy standards last updated in 1994, many iterations behind the IECC
Manufactured Homes (MH) are built in plants across the nation and shipped to sites nearly ~95% complete.

~70% of unsubsidized affordable housing nationally (Congressional study)

Preemption of HUD standards enables home standardization, key to achieving efficient production

10-12% of all new homes on average

Financial crisis hurt affordable housing hardest and earliest. MH is likely to bounce back fast due to pent up demand and attractive pricing.
Purpose and Objectives: Target Market and Audience

75% of MH are owner-occupied (Foremost)

Nearly 7 million MH use 0.47 quad Btu/yr (site) (RECS)

Homeowners quality of life greatly impacted by efficiency. Energy costs can be as high as home payments.
Purpose and Objectives: Impact

**Project Output**
- Demonstrated solutions for building affordable, high performance MH; clear guidelines for plants and installers.

**Measuring Achievement**
- Interim—testing and prototype evaluation.
- Ultimate—number of homes built using high performance measures.

**Impact Path**
- Working with manufacturers to develop and demonstrate solutions
- Mfgs will drive the adoption: “affecting the operation of a few companies will change the industry.”
- If successful, can be wildly successful
- Industry needs cost-effective strategies for complying with the new energy code

**Goals**
- Near-term (through 2016): Pilot projects; limited adoption by progressive plants.
- Long-term (2020+): Reach critical mass; adoption starts in north then spreads south. SBRA helps facilitate adoption.
Approach: Collective Impact

Collective Impact is the commitment of a group of actors from different sectors to a common agenda for solving a specific problem, using a structured form of collaboration.

The Five Conditions of Collective Impact

- Common agenda
- Shared measurement
- Mutually reinforcing activities
- Continuous communication
- Backbone support

The concept of collective impact is clearly articulated in the 2011 Social Innovation Review article Collective Impact, by John Kania and Mark Kramer.
Approach: Partners

**DOE/NREL Oversight**

**Builder Partners**
- Project Advisory Committee:
  - Robert Garcia — Fleetwood Homes
  - Manuel Santana — Cavco Industries
  - Mark Ezzo — Clayton Homes
  - Michael Wade — Cavalier Homes
  - Bert Kessler — Palm Harbor
  - Jeff Legault — Skyline Homes
  - Jess Maxcy — CMHI
- Plants:
  - Southern Homes, Russellville, AL
  - Karsten Homes, Sacramento, CA
  - Golden West Homes, Perris, CA
  - Skyline Homes, Woodland, CA
  - Fleetwood Homes, Riverside, CA
  - Hallmark-Southwest, Loma Linda, CA
  - Champion Homes, Corona, CA

**ARIES**
- Team Lead:
  - Emanuel Levy (PM) — The Levy Partnership, Inc.
  - Jordan Dentz — The Levy Partnership, Inc.

**Allied Partners**
- Industry Allies:
  - Systems Building Research Alliance (SBRA)
  - California Manufactured Housing Institute (CMHI)
- Suppliers:
  - AFM Corporation
  - BASF Corporation
  - DOW Chemical Company
  - Johns Manville
  - Owens Corning
  - Senco Brands
  - Mitsubishi Electric Corp.
  - Tjernlund Fans

**Subcontractors**
- Dr. Michael Mullens, PE
- Mike Zieman — RADCO
- Jay Mishra — RADCO
Approach: Key Issues

For a defined market segment, a holistic solution, including:

- **Thermal envelope:** wall, roof, airtightness, windows
- **Space conditioning and ventilation**
- **Integrating into the building process** (production environment requires speed)
- **Cost and installation:** quality key considerations

**Ultimate goal is market transformation**
Approach: Planning

TO1
Planning
Screen design options
Select three options to move forward

TO2
Design Development
Code compliance
Thermal performance
Moisture analysis

TO3
Advanced Design Development
Detailing
Wall component prototyping and testing

TO4
Component Prototyping
Constructability assessment
Transportation test
Cost-benefit analysis

TO5
Whole House Prototyping
Monitoring of moisture and thermal performance
### Approach: Heat Maps

Process for structuring committee input and focusing down on those solutions most likely to succeed in the long run

<table>
<thead>
<tr>
<th>Option</th>
<th>DK</th>
<th>ME</th>
<th>BK</th>
<th>MW</th>
<th>BS</th>
<th>MS</th>
<th>KF</th>
<th>LS</th>
<th>Man.</th>
<th>Code</th>
<th>Thermal</th>
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<tr>
<td>1. Structural insulated panels or SIPS for ceilings</td>
<td>33 (7)</td>
<td>26 (3)</td>
<td>31 (5)</td>
<td>24 (4)</td>
<td>(6)</td>
<td>23 (5)</td>
<td>(4)</td>
<td>32 (6)</td>
<td>5</td>
<td>5</td>
<td>5</td>
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<tr>
<td>2. Structural insulated panels or SIPS for walls</td>
<td>23 (2)</td>
<td>25 (2)</td>
<td>34 (6)</td>
<td>20 (1)</td>
<td>(5)</td>
<td>23 (5)</td>
<td>(3)</td>
<td>23 (4)</td>
<td>2</td>
<td>4</td>
<td>4</td>
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<tr>
<td>3. Stud wall with insulating sheathing board</td>
<td>23 (2)</td>
<td>24 (1)</td>
<td>20 (1)</td>
<td>20 (1)</td>
<td>(2)</td>
<td>10 (1)</td>
<td>(2)</td>
<td>17 (1)</td>
<td>1</td>
<td>2</td>
<td>1</td>
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<tr>
<td>4. Un-vented attic with insulating sheathing board</td>
<td>24 (4)</td>
<td>31 (7)</td>
<td>26 (4)</td>
<td>25 (5)</td>
<td>(3)</td>
<td>11 (2)</td>
<td>27 (5)</td>
<td>2</td>
<td>6</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>5. Flash and batt wall construction</td>
<td>11 (1)</td>
<td>29 (5)</td>
<td>25 (3)</td>
<td>23 (3)</td>
<td>(1)</td>
<td>20 (4)</td>
<td>(1)</td>
<td>20 (3)</td>
<td>1</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>6. Poured closed cell foam</td>
<td>25 (5)</td>
<td>29 (5)</td>
<td>22 (2)</td>
<td>27 (6)</td>
<td>(4)</td>
<td>19 (3)</td>
<td>19 (2)</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td></td>
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<tr>
<td>7. Innovative new floor</td>
<td>28 (6)</td>
<td>28 (4)</td>
<td>31 (5)</td>
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<td>---</td>
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</table>

Scores indicate the simple sum of the qualitative ratings. Figure in parenthesis is the rank for that rater.

Key: red box = top pick; yellow box = second pick; green box = third pick.
Approach: Distinctive Characteristics

Collective Impact

Heat Maps

Three lab homes side by side – located at the production facility

Dovetail with code update process – hand in glove
Progress and Accomplishments
Progress and Accomplishments: TOs1-2

Developed advanced wall design that improves the thermal performance of the envelope and reduces annual energy use.

**Analysis of proprietary products**

<table>
<thead>
<tr>
<th>Supplier</th>
<th>Product</th>
<th>Structural sheathing</th>
<th>WRB/Sealant</th>
<th>VR</th>
<th>Fastener</th>
<th>FG Batt</th>
<th>Freight factor</th>
<th>TOTAL</th>
<th>$/home</th>
<th>$/sq. ft.</th>
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</thead>
<tbody>
<tr>
<td>AFM</td>
<td>Nailbrace</td>
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<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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<td></td>
<td>6,151</td>
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<tr>
<td>DOW</td>
<td>Styrofoam</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>2,860</td>
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<tr>
<td>Johns Manville</td>
<td>ValuTherm</td>
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<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
<td>1,415</td>
<td>0.49</td>
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<td>Johns Manville</td>
<td>AP Foil</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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<td></td>
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<tr>
<td>Johns Manville</td>
<td>Structural Insul. Sheathing</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
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<tr>
<td>Owens Corning</td>
<td>Foamular</td>
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<td>✓</td>
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<td>✓</td>
<td>✓</td>
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<td>Neopor UnFaced</td>
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<td>BASF</td>
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<td></td>
<td>3,667</td>
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</table>

TO2 – Design development and material selection
Progress and Accomplishments: TOs 3-4

Tested, prototyped and perfected the advanced wall design over five prototype builds at different manufacturing plants.

TO3 – Component prototyping and testing

TO4 – Whole-house prototyping and constructability assessment
Developed advanced roof design that reduces heat loss at the eaves – traditionally a weak link in the thermal performance of attics.
Progress and Accomplishments: TO5

Full-scale wall and roof prototyping; instrumentation and testing of advanced roofs, monitoring of moisture and thermal performance.

- Constructed and instrumented three side-by-side lab homes
- Monitored for one year (on going)

<table>
<thead>
<tr>
<th>Traditional MH Home</th>
<th>Advanced (ZERH) MH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard fiberglass batt in wall cavities</td>
<td>Reduced thermal bridging with exterior rigid insulation</td>
</tr>
<tr>
<td>Cooling equipment site installed</td>
<td>High efficiency equipment plant-installed, commissioned</td>
</tr>
<tr>
<td>Ducts under floor and in crawl</td>
<td>No ducts</td>
</tr>
<tr>
<td>Code minimum 13 SEER / 8 HSPF or electric resistance</td>
<td>22 SEER / 12 HSPF</td>
</tr>
<tr>
<td>Envelope $U_o = 0.116$</td>
<td>Envelope $U_o = 0.063$</td>
</tr>
</tbody>
</table>
Progress and Accomplishments: TO5

Better understanding of the interplay between heat pump, fan locations and home configuration
Progress and Accomplishments: Advanced Wall Construction
Progress and Accomplishments: Advanced Roof Construction

- Baffles and insulation dams
- Dense-pack insulation
Progress and Accomplishments: Ductless Mini-split Heat Pump
Progress and Accomplishments: Transfer Fan Distribution
Progress and Accomplishments: Lab Home Results

Code and ES used similar cooling energy because less cool-off for ES home in evening.

ES and ZERH used similar heating energy because the mini-split heat pump unexpectedly operated at about the same COP as a traditional, split system heat pump.

Other Results:

- Site-installed equipment problems – how typical is this?
- Transfer fan configuration in heating.
- Effective ventilation rates with traditional POS systems.
Progress and Accomplishments: Awards/Recognition

Building America Top Innovation Award 2014

ZERO Housing Innovation Award 2014
Progress and Accomplishments: Summary

Lessons Learned
In-situ performance of mini-split heat pump in heating unexpected (further analysis needed)

Accomplishments
Developed, tested advanced wall and roof designs that improve envelope thermal performance, reduce energy use, cut CO₂ emissions, reduce equipment size, improve comfort and durability

Market Impact
Impacted ASRAC process – new standard based on IECC 2015. Engaged many factories in demonstrating new building methods

Awards/Recognition
BA Top Innovation Award 2014 and ZERH Housing Innovation Award 2014
Project Integration

- Stakeholders participate and guide the research
- Bi-monthly stakeholder conference calls
- All major decisions owned by steering committee
- Participation of many companies, not just those involved in the prototyping
- More than 70% of industry
- In-kind contributions $274k
- Demos/prototyping/testing at industry facilities

Left to Right: Emanuel Levy, TLP; Brian Lieburn, DOW; Kevin Clayton, Clayton Homes; Bryan Mallon, DOW; Jim Morey, DOW; Sam Rashkin, DOE; David Brewer, Southern Homes
Project Collaboration

- **Funding Partners:** DOE, TVA, CEC
- **Research Collaboration:** NREL on lab home instrumentation, experiments and analysis
- **Industry Partners:**

![Logos of industry partners]
## Project Integration and Collaboration: Roles

<table>
<thead>
<tr>
<th>Industry Partner</th>
<th>Role</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clayton Homes</td>
<td>Engineering, plant selection and logistics</td>
</tr>
<tr>
<td>Southern Homes</td>
<td>Manufacturer of lab homes</td>
</tr>
<tr>
<td>Mitsubishi</td>
<td>Provider of space conditioning equipment and technical support</td>
</tr>
<tr>
<td>DOW</td>
<td>Provider of wall insulation, flashing system and technical support</td>
</tr>
<tr>
<td>Johns Manville</td>
<td>Provider of roof insulation and technical support</td>
</tr>
<tr>
<td>Accuvent</td>
<td>Provider of roof ventilation system and technical support</td>
</tr>
<tr>
<td>Tjernlund</td>
<td>Provider of transfer fans and technical support</td>
</tr>
<tr>
<td>Senco</td>
<td>Provider of fasteners, fastening tools and technical support</td>
</tr>
</tbody>
</table>

Collaboration on Lab Home Construction
Project Integration and Collaboration: Communications

- MHI Meetings
- MH Congress & Expo
- MH NewsWire
- The Journal
- BA Reports
- CFED and others
Next Steps and Future Plans: Ongoing CEC Work

Roof test structure: Five roof configurations being tested in Jamestown, CA

2015 Plans:
- Radiant barrier/cool roof testing
- Full scale production testing
- Multiple full-scale homes at multiple plants
- Multiple occupied homes monitoring
Next Steps and Future Plans: Integrated Solution

Ongoing experiments will answer important outstanding questions pertinent to high performance MH and site built homes, including:

- In-situ performance of mini-split heat pumps
- Performance of transfer fan distribution strategy (heating & cooling)
- Impact of open doorways on airflow and comfort

Future Work – Important for commercialization

- Understand airflow dynamics via calibrated CONTAM/TRNSYS model
- Level of envelope efficiency by climate necessary for success of point-source space conditioning strategy
- Interaction of real life homeowners with advanced home
REFERENCE SLIDES
Project Budget

**Total Project Budget:** $1,084,364 ($810,425 DOE; $273,939 cost-share)

**Variances:** $95,000 increase in TO5 for additional tasks/modified scope of work

**Cost to Date:** 81% of project budget expended to date (FY2011-FY2015 to date)

**Additional Funding:** California Energy Commission, Tennessee Valley Authority, Industry partners

### Budget History

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<tr>
<td>DOE</td>
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<td>$229,855</td>
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<td>Cost-share</td>
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<td>$353,500</td>
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# Project Plan and Schedule

## Project Schedule

<table>
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<tbody>
<tr>
<td><strong>Past Work</strong></td>
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<td></td>
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<tr>
<td>TO1: 1.2 Draft Project Plan</td>
<td>Q4 Nov-Dec</td>
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<td>TO1: 1.3 Final Project Plan</td>
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<td>Q1 Jan-Mar</td>
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<td>TO2: 2.1 Detailed Test and Work Plan</td>
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<td>Q1 Jan-Mar</td>
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<td>TO2: 2.2.1 Draft Technical Report</td>
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<td>Q2 Apr-Jun</td>
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<td>Q3 Jul-Sep</td>
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<td>Q4 Oct-Dec</td>
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<td>TO3: 2.1.2 Draft Technical Report</td>
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<td>Q1 Jan-Mar</td>
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<td>TO3: 2.1.3 Final Technical Report</td>
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<td>Q2 Apr-Jun</td>
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<td>TO4: 2.1.1 Draft Technical Report</td>
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<td>Q3 Jul-Sep</td>
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<td>TO4: 2.1.2 Final Technical Report</td>
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<td>Q4 Oct-Dec</td>
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<td>TO5: 3.1.1 Test Plan</td>
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<td>Q1 Jan-Mar</td>
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- **Completed Work**: Milestone/Deliverable (Originally Planned)
- **Active Task (in progress work)**: Milestone/Deliverable (Actual)