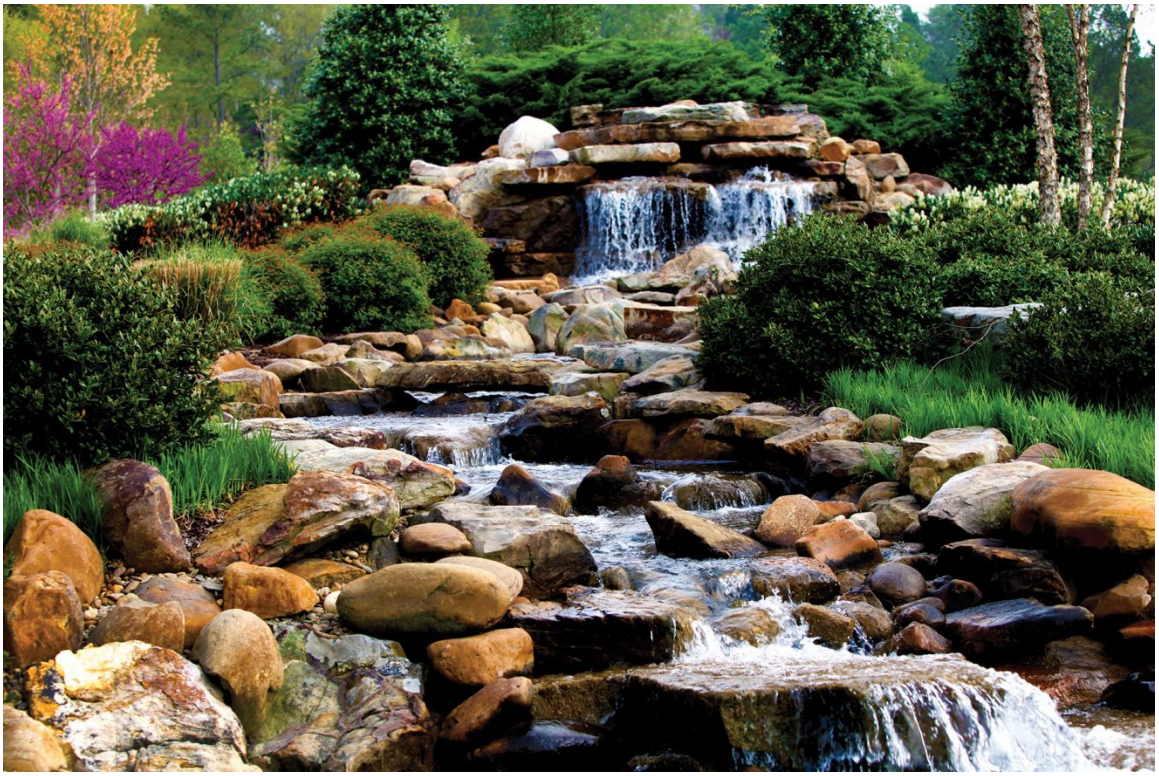
ORNL/SPR-2022/2572

Smart, Connected Manufactured Housing Solutions through High-Performance Design



Michael Lubliner
William Eckman
Joe Hagerman

September 2022

Final CRADA Report
NFE-21-08568

OAK RIDGE National Laboratory

ORNL IS MANAGED BY UT-BATTELLE LLC FOR THE US DEPARTMENT OF ENERGY

DOCUMENT AVAILABILITY

Reports produced after January 1, 1996, are generally available free via OSTI.GOV.

Website www.osti.gov

Reports produced before January 1, 1996, may be purchased by members of the public from the following source:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone 703-605-6000 (1-800-553-6847)
TDD 703-487-4639
Fax 703-605-6900
E-mail info@ntis.gov
Website http://classic.ntis.gov/

Reports are available to US Department of Energy (DOE) employees, DOE contractors, Energy Technology Data Exchange representatives, and International Nuclear Information System representatives from the following source:

Office of Scientific and Technical Information
PO Box 62
Oak Ridge, TN 37831
Telephone 865-576-8401
Fax 865-576-5728
E-mail reports@osti.gov
Website https://www.osti.gov/

ORNL/SPR-2022/2572

Buildings and Transportation Science Division

SMART, CONNECTED MANUFACTURED HOUSING SOLUTIONS THROUGH HIGH-PERFORMANCE DESIGN

Michael Lubliner
William Eckman - Principal Investigator
Joe Hagerman

September 2022

Prepared by
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, TN 37831
managed by
UT-BATTELLE LLC
for the
US DEPARTMENT OF ENERGY
under contract DE-AC05-00OR22725

CONTENTS

ABSTRACT 1
1. BENEFITS TO FUNDING DOE OFFICE'S MISSION 1
    1.1 OPPORTUNITIES IN MANUFACTURED HOUSING 1
        1.1.1 Plans for Future Collaborations 2
        1.1.2 Commercialization Possibility: Focusing on Affordability 4
        1.1.3 Commercialization Possibility: Focusing on Sustainability 4
2. STATEMENT OF TASKS AND OBJECTIVES 5
3. TECHNIAL DISCUSSION OF WORK PERFORMED/CONTINUED BY ALL PARTIES 6
4. SUBJECT INVENTIONS 10
5. CONCLUSIONS 10
APPENDIX A. POWERPOINT SLIDES FOR ORNL/CMH PHASE I STAKEHOLDERS A-1

ABSTRACT

This report focuses on HVAC, domestic hot water, and miscellaneous electric loads via voluntary opportunities that may arise from partnerships with utilities, as well as future US Environmental Protection Agency ENERGY STAR and DOE Zero Energy Ready Manufactured Home programs.

Phase I of this project has begun the technical dialogue toward developing an implementation plan among DOE's Oak Ridge National Laboratory, Clayton Manufactured Homes, and US Department of Housing and Urban Development Code manufactured housing stakeholders. These activities have focused on delivering high-performance design through integration of technology. Project tasks include the following:

- Identifying baseline energy analysis resources opportunities from a variety of DOE and utility stakeholders
- Developing a smart home and business solution by leveraging existing utility programs working with Smart Homes Partners resources such as ACE IoT Solutions, Google Nest, and Ecobee
- Developing improved smarter ventilation systems with industry ventilation partners such as the Madison Group
- Developing improved building science QA/QC testing equipment with manufacturers such as The Energy Conservatory, and supporting other feasible concepts vetted under DOE's Advanced Buildings Collaborative with Slipstream, reinventing HVAC in manufactured housing
- Developing smart home short- and long-term viable technical solutions in coordination with Clayton Manufactured Homes in new and/or revitalized community scales for future Phase II prototype demonstrations, which may include design (and perhaps construction) of single-section homes targeting rental property developers and multi-section homes targeting low- to middle-income affordable housing community developers

Given the ongoing US Department of Energy (DOE) rulemaking activities, baseline energy analysis assessments of envelope prescriptive and Uo (i.e., the overall thermal energy efficiency of the home in British thermal units per square foot of exterior heat loss/gain surfaces) measures were removed from the scope of Phase I of this project.

1. BENEFITS TO FUNDING DOE OFFICE'S MISSION

1.1 OPPORTUNITIES IN MANUFACTURED HOUSING

To concurrently balance utility and consumer needs, the building industry is facing many unique challenges, including the persistence of inefficient building methods, high costs, limited availability of capital to manufacturers, and the inability for consumers to find financing. Therefore, many consumers, developers, and public/private groups are seeking new options to realize energy-efficient, cost-effective, and highly durable buildings while minimizing the delivered costs through reduced construction time frames, innovative delivery, new installation/setup, and new construction types. In particular, smart homes are homes that are healthy, comfortable, affordable, energy-efficient, durable, and environmentally responsible. Smart homes often exceed code minimums in terms of their energy usage (e.g., achieving or exceeding ENERGY STAR targets), as well as improving structural integrity, accessibility, security, life cycle costs, and purchasing affordability.

Tasks 1.1–1.3 will occur in Phase II after the US Department of Energy's (DOE's) Energy Conservation Standards for Manufactured Housing Rulemaking are promulgated, finalized, and incorporated into US Department of Housing and Urban Development (HUD) Manufactured Home Construction and Safety

Standards (MHCSS). Shifting these tasks into Phase II will result in a more appropriate and accurate energy savings technical analysis that reflects the new thermal efficiency changes made to the baseline manufactured homes.

Technical analysis of HVAC energy savings and consumer economic analysis is proposed to continue in Phase II. The effort will involve ongoing support from DOE's Oak Ridge National Laboratory (ORNL) and Clayton Manufactured Homes (CMH) related to the DOE-funded Advanced Buildings Collaborative (ABC) effort by contractor Slipstream. This effort, Reimagining HVAC in MH,[1,2] focuses on the preliminary energy analysis and consumer economic evaluation of HVAC equipment and thermal distribution system energy-saving options in single- and multi-section prototypes for a variety of climate zones.

1.1.1 Plans for Future Collaborations

CMH is a key market leader well positioned to help address future societal and environmental challenges to design, produce, market, and finance more energy-efficient, durable, healthy, and ruggedized HUD Code manufactured housing (MH). Affordable MH can provide low- to middle-income home buyers with an appropriate balance in choosing what is affordable to purchase (e.g., to finance) and affordable to operate (e.g., to pay utility bills). At the April 2022 Manufactured Housing Institute National Congress and Expo in Orlando, in a panel of industry leaders, Kevin Clayton reaffirmed CMH's commitment to the Biden administration's effort to connect future manufactured home customers to the Internet of things (IoT) while targeting the goal of DOE's Zero Energy Ready Manufactured Home program.[3] Current and new potential, utility demand-side management (DSM), distributed energy resource (DER) programs, and HUD/government-sponsored enterprise (GSE) lending initiatives may facilitate incentives to CMH and others, such as $5,000 manufacture incentives for each home built to comply with Zero Energy Ready MH requirements. Furthermore, US Environmental Protection Agency (EPA) ENERGY STAR and IRS 45L corporate energy efficiency $1,000–$2,000 tax credits, if continued, are likely to achieve high efficiency metrics, which may include more efficient envelopes, HVAC systems, appliances, and DERs using the IoT to help the electric grid. CMH leadership working with MH communities. ORNL represents an opportunity for DER "batteries" that can provide DSM and DER benefits to the occupants, MH communities, the utility transmission smart grid, and society.

A commitment toward connected communities by CMH must also consider the appropriate transformation of the status quo toward the long-term development of new factories focused on smart home integration to take advantage of CMH procurement economies of scale through bulk procurement opportunities with industry partners. In addition, CMH must minimize disruption to existing factory production backlogs and consider current material and labor supply chain challenges.

Smart home integration in MH represents the next frontier in grid management opportunities for CMH, electric utilities, IoT industry leaders (e.g., Google), and new MH buyers. These opportunities for CMH to work with key industry leaders may help the nation meet the significant challenges to decarbonize the energy grid in the buildings sector. Furthermore, IoT will help meet the challenges posed by greater saturation of grid-connected electric vehicles that can be charged at home and provide reliability to the grid during power outages.

---

[1] "Reimagining HVAC in New Manufactured Housing." Slipstream. https://slipstreaminc.org/sites/default/files/documents/research/reimagining-hvac-new-manufactured-housing.pdf.
[2] S. Pigg, D. Chasar, L. Gu, and R. Vieira. "Energy Modeling and Cost Effectiveness Report." Slipstream, 2021. https://slipstreaminc.org/sites/default/files/2022-05/reimagining-hvac-new-manufactured-housing_0.pdf.
[3] "Zero Energy Ready Homes." Office of Energy Efficiency & Renewable Energy. US Department of Energy. https://www.energy.gov/eere/buildings/zero-energy-ready-homes.

Public and private utilities (e.g., TVA, BPA) may have interests in supporting CMH. For example, for more than 25 years, the Pacific Northwest (PNW) utilities, MH factories, retailers, and state associations have demonstrated voluntary partnerships between MH new home utilities and the MH industry, which have improved capital cost and life cycle cost savings for MH buyers. These partnerships have resulted in incentives to assist CMH and others to find the appropriate affordability balance in the PNW MH market. To date, PNW utilities and BPA have provided more than $100,000,000 in utility incentives to 10–20 HUD Code factories and hundreds of retailers. These MH industry partnerships continue to provide cost-effective savings to ratepayers and new MH buyers while providing a low-cost alternative to the construction of new power plants in providing base and peak load demand to the BPA-managed power grid.[4] More than 150,000 energy-efficient manufactured homes have been built to equivalent energy efficiency thermal requirements (windows/doors) to site-built energy codes in the PNW because of the PNW Manufactured Home Acquisition Program (MAP). Contracts between PNW MH factories and BPA required the factories to build all their homes according to MAP (e.g., the Super Good Cents program) specifications.[5] MAP standardization for energy efficiency features in the areas of envelope insulation, fenestration, mechanical, plumbing, electrical, and appliance helped avoid more expensive and disruptive special orders for engineering, QA costs, and workforce skillset training. MAP also helped factories leverage bulk procurement buying power, which in some cases extended to the national corporate level.

PNW MH industry/utility partnerships are based on the Northwest Energy Efficient Manufactured Home (NEEM) program.[5] The NEEM program's 10 factories (2 of which are owned by CMH) produce more than 60% of their homes to NEEM 1.0, which qualifies for EPA ENERGY STAR Manufactured 45L IRS incentives. In addition, some local utilities continue to provide incentives to local retailers and/or consumers. The NEEM 2.0 specifications have been evaluated in research, design, and development (RD&D) efforts. ORNL/CMH CRADA efforts represents a great smart home opportunity for utility and other industry stakeholders in the PNW, as well as national partners. These smart homes will provide new or additional values and benefits to MH.

To deliver higher-quality products at a lower cost and greater efficiency, the MH industry must leverage new technologies. A solution must be offered so that home buyers can lessen their environmental impact and protect their health within their financial means.

Significant opportunities exist to improve thermal comfort and the indoor environment via the use of simple low-cost smart whole-house ventilation controls (SVC) and the "build tight, ventilate right" building science philosophy. SVC can help educate occupants in the O&M of their HVAC systems, reduce occupant exposure to indoor air pollutants of concern, and improve moisture control and durability. Employing build tight, ventilate right building science principles will reduce moisture- and mold-related issues that can result in customer dissatisfaction and CMH liability. DOE Environmental Impact Statements associated with 2023 rulemaking and efforts by the HUD Manufactured Housing Consensus Committee to improve ventilation and adopt requirements for window and door flashing and water-resistive barriers are examples of a systems approach toward the build tight, ventilate right philosophy.[6]

Occupant health can be improved by empowering occupants to better understand how to control their MH indoor environment by employing climate-specific SVC system approaches. Improved indoor air quality may result in reduced childhood asthma and other health care expenditures, increase disposable income to

[4] Pacific Northwest Power Plan. https://www.nwcouncil.org/media/filer_public/4b/68/4b681860-f663-4728-987e-7f02cd09ef9c/2021powerplan_2022-3.pdf
[5] "Program Information." NEEM. ENERGY STAR. https://www.neemhomes.com/program-info
[6] "Appliance and Equipment Standards Rulemakings and Notices." Building Technologies Office. US Department of Energy. https://www1.eere.energy.gov/buildings/appliance_standards/standards.aspx?productid=64

the MH occupant, and provide societal benefits to the US health care system.[7] Building product innovations in indoor air quality source control innovations and the use of SVC with embedded indoor air quality sensors that measure carbon dioxide, volatile organic compounds, and particulate matter 2.5 particles are emerging in the residential home automation marketplace. SVC can also help to improve HVAC filtration and further optimize HVAC operation and energy efficiency. Embedded HVAC fault detection diagnostics connected to the IoT can further improve the indoor environment by providing more responsive maintenance, operation, and service technician guidance to reduce ramifications of deferred maintenance.

1.1.2 Commercialization Possibility: Focusing on Affordability

Affordability is a core value of MH. Better products with lowered operating costs are in high demand. The efforts in Phase I and the future implementation of the Phase II ORNL/CMH CRADA will result in affordably priced homes made available to a large community-scale market.

As noted in DOE 2014 and 2022 MH energy standards, Appliance Standards and Rulemaking Federal Advisory Committee meetings, and Manufactured Housing Consensus Committee meetings, the phrase *affordable housing* has different meanings to different stakeholders.[6] CMH recognizes the affordability needs of low- to middle-income new home buyers and is working to find the appropriate balance between being affordable to purchase and affordable to operate. Leveraging federal government and utility incentives for building greater energy and sustainability features in new CMH dwelling units, single-home sites, and MH communities represents an opportunity to broaden the definition of *affordability*. Furthermore, new innovative industry-supported, HUD/GSE financing initiatives in the areas of real and personal property will increase the number of new CMH home buyers that can afford to purchase and qualify for a home loan. For example, recent DOE rulemaking price elasticity research suggests that the original proposed energy standards could price 30,000 new home buyers out of the MH market by the 2050s.[6] As a result of proposed rulemaking, a focus on both single-section homes in rental communities and multi-section homes in planned communities with community housing developer partners will provide more specific targeted design opportunities for a wide variety of MH homeowners tenants, utilities, and other affordable housing stakeholders.

1.1.3 Commercialization Possibility: Focusing on Sustainability

Sustainability is another core value of MH. Integrated design of new technologies into the MH supply and delivery chain can optimize the efficiency of a home to use energy efficiently while adding strength, value, and durability. Integrated design is one of the least expensive ways to capitalize on savings and efficiency.

CMH is a key socially conscious market leader well positioned to help address future societal and environmental challenges to design more energy-efficient, durable, healthy, and ruggedized HUD Code MH from cradle to grave. Affordable housing can provide low- to middle-income home buyers with an appropriate balance for what is affordable to purchase and operate, and it also provides a product to high-income buyers in the off-site, factory-built, and modular housing market sectors looking for inexpensive and energy-efficient options from CMH. After MAP, the MH market in the PNW expanded significantly in this new market area.[8] This may have resulted in improved valuations on Wall Street and expanded the

[7] "Healthy Homes and Asthma: A healthy housing blueprint to improving asthma outcomes." Green & Healthy Homes Initiative, 2017. https://www.greenandhealthyhomes.org/wp-content/uploads/GHHI-Healthy-Homes-Asthma_final-002.pdf

[8] T. Eckman. "How A Midlife Fling with "Trailer Trash" Changed the Market Transformation Strategy for Manufactured Housing in the Northwest." *Residential Buildings: Program Design, Implementation, and Evaluation* 2.65–2.78, 2000.

market to more financially solvent buyers who purchase more profitable, energy-efficient HVAC systems and other options in multi-section homes (e.g., triple-section).

A growing number of MH buyers are IoT-aware, representing a great opportunity for CMH to invest in IoT integration in housing. The multi-section MH sector is likely to include the IoT in its homes. Furthermore, the single-section MH sector also represents great opportunities for cost-effective IoT-related energy savings that balance being affordable to purchase and operate while providing social equity leadership from CMH, as well as significant societal and utility benefits for low- to medium-income MH home buyers and renters in communities and/or single-site properties.

2. STATEMENT OF TASKS AND OBJECTIVES

Tasks 1.1–1.3 will occur in Phase II after DOE's Energy Conservation Standards for Manufactured Housing Rulemaking are promulgated, finalized, and incorporated into HUD MHCSS.

Task 1.1: Derive baseline energy analysis resources from DOE Technical Support Documents (TSDs)

In this task, ORNL and CMH will continue discussions regarding the use of mass simulations to improve system controls planning in various "baseline and beyond" building typologies and HVAC systems. This effort seeks to build on DOE's mass simulation work. This task will occur in Phase II after DOE's Energy Conservation Standards for Manufactured Housing Rulemaking are promulgated, finalized, and incorporated into HUD MHCSS. In this task, dialogue will continue between ORNL and CMH to demonstrate the potential of using mass simulations to improve the energy efficiency of model MH. Furthermore, prescriptive options will be developed for MH built to MHCSS, ENERGY STAR, and Zero Energy Ready standards.

ORNL and CMH will continue discussions to take the following actions:

- Use existing TSD data and estimate the amount of energy waste in a home through HVAC equipment packages: The findings will build on and support efforts by Reimagining HVAC in MH[1,2] and other DOE HUD Code MH efforts with CMH and the Manufactured Housing Systems Building Research Alliance.[9]
- Engage in discussions to take the TSD data and dissect home energy usage versus the equipment/design packages to estimate the building's annual consumption and Energy Reference Index/Home Energy Rating System scores in three HUD MHCSS climate regions focused on single- and multi-section CMH prototypes
- Engage in discussions to take the TSD data and model/analyze the issues regarding climate adaptation versus the climate zones to explain how the building's conditions will change in 5, 10, and 15 years so that designers can evaluate solutions on longer-term time horizons

Task 1.2: Develop a smart home business solution by leveraging existing utility programs and resources

ORNL and CMH will continue to engage ORNL's Building Technology Research and Integration Center (BTRIC) to bring distinct industry partners together, including building component manufacturers, utilities, and technology integrators. These distinct constituents have interests in the ORNL/CMH CRADA activities and potential opportunities. For example, a utility's DSM program incentives can lower initial costs in enabling responsive loads, smart neighborhoods, and smart homes. This model is not revolutionary in utilities that offer DSM options to their customers since they historically have either

[9] "About SBRA." Systems Building Research Alliance. https://www.research-alliance.org/pages/about.htm.

incentivized purchases or directly served customers advanced DSM control options. Leveraging this approach, ORNL and CMH will work with interested utilities and utility stakeholders to adapt DSM/DER offerings into connected, smart home enablement and test solutions at ORNL's BTRIC.

Task 1.3: Develop a smart home technical solution comprising a single part (e.g., the development of a minimum viable products)

ORNL and CMH will continue to develop a smart home enablement from the prior tasks with a minimal viable product for CMH's inventory. This will be accomplished with a focus on the following:

- HVAC systems that can respond to conditions such as MH indoor air quality and mechanical ventilation operations based on research by Lawrence Berkeley National Laboratory and working with HVAC MH leaders such as the Madison IAQ and Google Nest: The use of simple, smart ventilation controls will continue to be evaluated for HVAC systems in MH.[10,11,12]
- The use of improved lower-cost building science QA/QC HVAC and envelope screening tests and tools developed with The Energy Conservatory (TEC) and Slipstream's ABC research: TEC currently uses its own QA/QC tools and has expressed interest in this new QA/QC tool kit currently under development.[13,14]
- The use of EPA-approved connected thermostats and IoT platforms (e.g., Google Nest, Google Home): CMH is working with ORNL to identify options to enhance DSM/DER options and enhance the indoor environment in future connected CMH homes and communities using EPA-approved smart thermostats such as Google Nest and Ecobee.

3. TECHNIAL DISCUSSION OF WORK PERFORMED/CONTINUED BY ALL PARTIES

The proposed CRADA Phase II will continue to support Phase I–III tasks.

Task 2.1 seeks to expand ORNL's relationship with CMH to use EPA-approved connected thermostats such as Google Nest and IoT platforms such as Google Home and Matter. Benefits in multi- and single-section MH for Google Nest–connected thermostats are based on significant site-built research under the leadership of Google Nest senior researcher Michael Blasnik. This research will use demonstration prototypes and community-measured HVAC runtime, utility energy and per-load demand, and weather data to perform the following:

- Reduce space heating and cooling conditioning energy use by 5%–15% by optimizing HVAC operation to occupancy patterns
- Improve the control of the electric resistance heater "strip" of furnaces with heat pumps that maximize energy savings to the occupant and the utility grid
- Improve HVAC systems to provide greater energy savings and occupant comfort via optimized thermostat settings when shifting between seasonal operations

[10] "Energy Conservation Standards for Manufactured Housing." Office of Energy Efficiency and Renewable Energy. US Department of Energy, 2022. https://ecs-mh.evs.anl.gov/.
[11] Madison IAQ. https://www.madisoniaq.com/.
[12] "HVAC monitoring from Google Nest." Google. https://support.google.com/googlenest/answer/9984225?hl=en.
[13] The Energy Conservatory. https://energyconservatory.com/.
[14] S. Stendel, S. Pigg, D. Chasar, J. McIlvaine, B. Peeks, and M. Lubliner. "Feasibility Assessment Report." Slipstream, 2021. https://slipstreaminc.org/sites/default/files/2022-05/reimagining-hvac-new-manufactured-housing_1.pdf.

- Use connected thermostats to allow MH homeowners, park managers, utilities, and/or HVAC service technicians to provide a demonstrated platform to identify O&M issues before more expensive serving is required

ORNL proposes to work with CMH, Google, and others on a path of RD&D and market transformation, starting with a small demonstration of Google Nest technologies in test homes in a community setting. Google will work with ORNL and CMH to measure HVAC runtime and energy use and savings. The long-term goal of this partnership is to incorporate the IoT in every appropriate CMH development, using Google Nest as a potential platform. The Phase II CRADA may consider the following actions:

- Develop a cutting-edge roadmap for future RD&D and potential market transformation working with utility stakeholders and clients of BPA and TVA, starting with cost-effective, market-ready measures and evaluating NEEM 2.0 technologies in the PNW
- Research justifying energy credits for MHCSS thermal standards, ENERGY STAR, the Zero Energy Ready Manufactured Home program, the Energy Reference Index, and the Home Energy Rating System
- Provide support and feedback to Reimagining HVAC in MH, focused on improving the distribution system by evaluating cost benefits and market factors of the following:
    - Test/measure envelope, duct leakage, and ventilation system airflow; use the TEC MH QA screening tool kit and pro tool kit that measures duct leakage, envelope leakage, and ventilation flow all in one screening test; and use the TEC MH pro tool kit to document QA to incorporate QA cloud-based testing results to document for CMH engineering and production divisions in CMH factories and retailers throughout the United States[13]
    - Move ducts from a vented attic to buffered belly semi-conditioned space, which costs less than locating them in the attic and saves energy (DSM) and peak load (DERs)
    - Cross over to thru-rim joists: Once duct designs locating ducts in the belly are redesigned to the thru-rim system, no R8 flex crossover is needed in the vented crawlspace. The thru-rim system also has a negative capital cost when compared with crossovers in a vented crawlspace, and it saves energy and helps reduce utility costs. Damaged crawlspace crossover ducts are a typical reason for high-bill complaints from occupants living in MH, so this crossover would help prevent that issue.[15]
    - Use super-insulated crossover ducts: When thru-rim design is not feasible because of airflow conditions or large A/C loads, a super-insulated, durable R16 crossover duct will be employed for multi-section homes.
- Provide support and feedback to Reimagining HVAC in MH by using higher-efficiency partially or totally factory-installed air source heat pumps, focusing on the following:
    - Lower SEER/HSPF single-speed credit for air source heat pump variable refrigerant flow, perhaps for climate zones 2 and 3
    - Downsize defrost/emergency/backup strip box from 15 to 5 kW and have thermostat lockout below the balance point of the heat pump using proper HVAC sizing tools
    - For single-speed air source heat pump with auxiliary electric resistance heat or gas furnace backup, specify EPA-approved connected smart thermostats with strip lockout at 35°F or a learning algorithm to determine the balance point of the heat pump
    - Leave electric furnace in the MH as is and downsize to an auxiliary strip heat from 15 to 5 kW to assist in conditioning the bedroom zones; then, install a ductless heat pump (DHP) in the main living zone as the primary heating and cooling system. Phase II concepts to explore include the following:

[15] P. Keegan. "Five ways to winterize your manufactured home." Alabama Living, 2020. https://alabamaliving.coop/articles/five-ways-to-winterize-your-manufactured-home/.

  - Optimize central furnace controls to have DHP distributed heat and cooling to the entire home and offer ultrahigh-efficiency room A/C and central or room dehumidifiers, if needed, as options in hot humid climates
  - Employ an adequately sized DHP to provide the primary space conditioning to the entire manufactured home: The added cost of a newly emerging market of centrally ducted variable refrigerant flow HVAC systems may increase the cost of the HVAC system. As compared with the potentially lower cost single-head DHPs located in the main living area of the MH, this approach may be an appropriate bridge toward an affordable HVAC strategy.
  - Reduce cooling load via building envelope measures, as well as site and home awning shading and window treatment shading
- Improve domestic hot water system efficiency:
  - Use a heat pump water heater with grid controls[16]
  - Consider heat pump water heater impacts to cooling and dehumidification design and seasonal loads
  - Employ energy- and water-saving plumbing designs that use small-diameter pipe for "branch and trig"[17] hot water piping to individual fixtures
- Improve indoor air quality via improved ventilation:
  - Consider RD&D on smart ventilation controls as part of the heat pump water heater or independent from it
  - Employ SVC that connect the supply Ventilaire to the ENERGY STAR bath/kitchen exhaust fans
  - Optimize SVC to use exhaust when runtime of furnace supply system is not sufficient
  - Examine heat/energy recovery ventilation equipment with MERV 13 filtration
  - Optimize the ventilation system to run when outside air is not too humid and runtime of the A/C is low (e.g., a humid spring or fall)
- Consider 100% LED lighting, 100% ENERGY STAR or better appliances, and condensing dryers for small homes controlled by ACE IoT Solutions, Google Home, or more generic Matter platforms
- Lower watt builder-installed electric 24/7 miscellaneous loads for GFI, doorbells, and other builder-installed electronic devices[18,19]
- Consider RD&D with solar photovoltaic awnings that can be storm shutters, and prewire to main load center and use microinverters: ORNL, CMH, HUD, and DOE are in communication with Dennis Knickerson (small business with federal funding) regarding RD&D of solar-powered awnings.
- Create an occupant education/marketing video to advertise the described features based on consumer benefits, climate, health, and safety; ensure that this educational and marketing web-based video tool empowers home buyers to understand energy efficiency DSM/DER options when they purchase or rent a new manufactured home; and empower homeowners to operate and maintain their CMH dwelling as intended to maximize energy efficiency, durability, and the indoor environment in the next generation of ruggedized HUD Code MH stock
- Develop a progress summary for Smart, Connected Manufactured Housing Solutions: High Performance Design Through the Integration of Technology. The Phase I CRADA with Clayton covered two items; as noted in this report, these items have been delayed until DOE rulemaking is

[16] "Residential Unitary Heat Pump Water Heater Qualified Products List." NEEA, 2022. https://neea.org/resources/residential-unitary-hpwh-qualified-products-list.
[17] Gary Klein and Associates. https://www.garykleinassociates.com/.
[18] M. Sofos. "Miscellaneous Electric Loads: What Are They and Why Should You Care?" Office of Energy Efficiency & Renewable Energy. US Department of Energy, 2016. https://www.energy.gov/eere/buildings/articles/miscellaneous-electric-loads-what-are-they-and-why-should-you-care#:~:text=Miscellaneous%20electric%20loads%20(MELs)%2C,%2C%20lighting%2C%20water%20heating%2C%20and.
[19] J. Butzbaugh, R. Hosbach, and A. Meier. "Miscellaneous electric loads: Characterization and energy savings potential." *Energy and Buildings* 241, 110892, 2021. https://doi.org/10.1016/j.enbuild.2021.110892.

completed and adopted by HUD in MHCSS. Delaying this effort will facilitate the use of the new Thermal Requirements (Uo baseline) required for an accurate analysis. These items—mining the DOE regulatory TSD and applying smart MH to an ORNL connected community for the MH sector—are proposed to be completed in Phase II, with ongoing support from CMH and other potential partners, as listed in Table 1.

Table 1. Communications with stakeholders involved in CRADA Phase I discussions with Joe Hagerman (JH) and/or Michael Lubliner (ML)

Count	Organization	Contact	Support focus	ORNL staff communication	RD&D partners
1	CMH	Weldy, J.	Engineering	JH and ML	Yes
2	CMH	Made, G.	Engineering	JH and ML	Yes
3	CMH	Carnathan, D.	Community	JH and ML	Yes
4	CMH	Brooks, D.	Community	JH	Yes
5	CMH	Janey, P.	New plants	JH	Yes
6	CMH	Jenkins, W.	New plants	JH	Yes
7	TVA	Latta, B.	Utility	JH	Yes
8	Redding	PV/DSM program representative	Utility	JH	No
9	KCHA PHA	Auer, D.	Community	ML	Yes
10	NEXT Step	Epperson, S.	Community	ML	Yes
11	VIEC	Schneider, P.	Community	ML	Yes
12	WA LNI	F AS	IPIA	ML	Yes
13	NEEM	Peeks, B.	DOE/ABC	ML	Yes
14	Parks Air (MHCC)	Parks, B.	DOE/ABC	ML	Yes
15	Slipstream	Stendel, S.	DOE/ABC	ML	Yes
16	FSEC	Viera, R.	DOE/ABC	ML	Yes
17	TEC	Olsen, C.	Testing/QA	ML	Yes
18	Madison IAQ	Treleven, D.	HVAC indoor air quality	ML	Yes
19	Google Nest	Blasnik, M.	Smart thermostats	ML	Yes
20	HUD	Blanford, M.	Technical	ML	Yes
21	HUD	Grey, R.	Policy	ML	Yes
22	HUD	McJury, J.	Technical	ML	Yes
23	NTA	Tempos, D.	Technical	ML	Yes
24	LBNL	Walker, I.	Indoor air quality	ML	Yes
25	PNNL	Metzner, C.	Test home	ML	Yes
26	EPA	Hurst, N.	Indoor Air+	ML	TBD
27	DOE	Werling, E.	ZER	ML	TBD
28	DOE	Glickman, J.	BTO	ML	TBD
29	NIST	Healy, W.	Technical	ML	TBD
30	Klein Assoc.	Klein, G.	DHW	ML	Yes
31	Solar Awning	Nickerson, D.	Photovoltaic awnings	ML	Yes
32	Newport	Nebbia, J.	DOE mtgs	ML	TBD
33	ORNL	Fricke, B	HVAC	ML	TBD
34	ORNL	Hun, D.	RD&D for CMH	ML	Yes
35	ORNL	Desjarlais, A.	Envelope	ML	TBD
36	ORNL	New, J.	Connected community	ML	TBD

4. SUBJECT INVENTIONS

No inventions were contemplated by the Phase I CRADA.

5. CONCLUSIONS

This final report closes the Phase I activities contemplated by the CRADA and provides direction for future discussion and development of specific emerging and current energy-saving technologies and building systems, with a significant focus on HVAC systems. The Phase I activities completed by ORNL and CMH created a foundation for investigation, specification, and commercialization of existing technologies into next-generation MH.

Future collaboration through an ORNL/CMH CRADA Phase II will provide opportunities to evaluate, demonstrate, analyze, and refine test prototypes, and on a community scale, the next generation of HUD Code manufactured homes. CMH has the opportunity as an MH corporation to provide leadership to the entire industry toward the implementation of more affordable and sustainable HUD Code off-site built housing for a broader group of low-, moderate-, and high-income customers. Designs that focus on single-section homes may provide significant benefits for low-income home buyers and renters, which provides additional benefits to utilities, society, and the environment. This research supports innovations that will assist in greater social justice and contribute to resolving the challenges of climate change. With the proper governmental and utility program leadership related to future affordable housing opportunities, CMH can provide viable solutions to building Zero Energy Ready manufactured homes.[3]

APPENDIX A. POWERPOINT SLIDES FOR ORNL/CMH PHASE I STAKEHOLDERS

APPENDIX A. POWERPOINT SLIDES FOR ORNL/CMH PHASE I STAKEHOLDERS

The following PowerPoint slides have been used to share with ORNL/CMH Phase I Stakeholders.

Smart, Connected & Affordable Manufactured Housing Community

Technology Summary

Clayton Homes proposes an affordable, connected community of manufactured housing in communities throughout the USA where the buildings & community improve their energy utilization, neighborhood value, & the operational performance of the serving utility

Technology Impact

Multi-section Home Focus: Business case development such that connected communities are a good business case for a MH developer of a neighborhood while understanding the needs of the utility and moderate-income customers as resources for demand response.

Single-section Home Focus: Business case development such that connected communities are a good business case for a MH park/developer of a rental neighborhood while understanding the needs of the utility and affordable housing customers as a resources for demand response. and provide "low-income" utility benefits such as less high bill complaints. Landlord benefits from occupant reduction of HVAC operation that helps improve comfort, humidity control and lower maintenance/repair expenses.

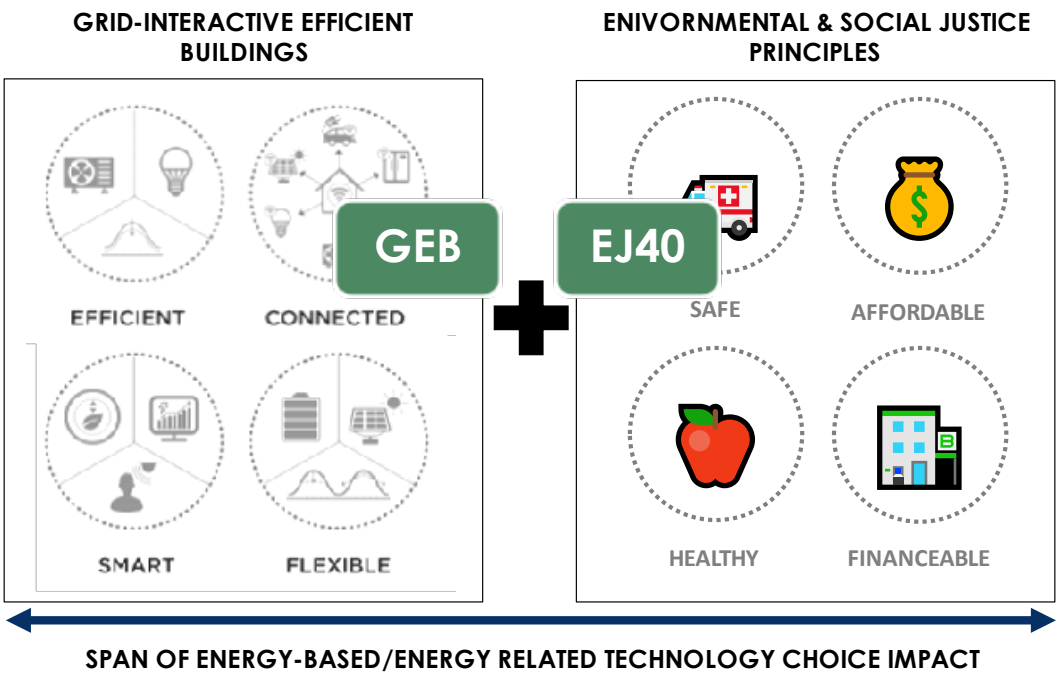
What advantage does utility owned DER at the meter provide the consumer and the utility when there is secured connectivity?

2 OAK RIDGE National Laboratory | BUILDING TECHNOLOGIES RESEARCH AND INTEGRATION CENTER

Why this ORNL/CMH CRADA is important?

- Corrects Longstanding Energy Justice Issue
  - Energy cost for low to moderate income
  - **Energy Access for All**
- Corrects Longstanding Social Justice Issue
  - Stigmatization of affordable housing
  - **Technology Access for All**
- Corrects Longstanding Manufactured Housing Issues
  - Stigmatization of MH
  - **Options for New Technologies**
- Serve as Model Community
  - MH Community with new features
  - **Place-based Community**
- Serve to Test Business Model
  - Smart MH Community
  - **Scalable Business Model**
- Serve to Demonstrate Technology Integration
  - Coordination w/o human intervention
  - **Pursues ORNL Science**
- Serve to Aggressive EE
  - Different use cases with clear economic payback
  - **GEB**
- Integrate into Community
  - Can serve different utility case studies

1 OAK RIDGE National Laboratory | BUILDING TECHNOLOGIES RESEARCH AND INTEGRATION CENTER



Components of a Smart MH Community

- ✓ New MH model
  - ✓ climate specific and deep EE

Science (use case) | **Technology** (business case) | **Policy** (to scale with value)

- Integrated technologies
  - improve quality of life, IAQ, home experience
- Coordination to provide services
  - to the customer, to the neighborhood, and to the community

GEB

pull

- Quick to deploy, quick to scale, quick to deliver housing
- Addresses Issues Facing MH Communities:
  - Negative Public Perception
  - Affordability
  - Place-based

EJ40

4

OAK RIDGE National Laboratory | BUILDING TECHNOLOGIES RESEARCH AND INTEGRATION CENTER