Home Battery System

National Renewable Energy Laboratory
Dane Christensen, Senior Engineer
dane.christensen@nrel.gov
303-384-7437
Project Summary

Timeline
Start date: May, 2016
Planned end date: Sept, 2018

Key Milestones
1. Demonstrated automated, self-learned control of simulated loads. **9/20/2016**
2. Demonstrated improved efficiency, resource predictions, and laboratory readiness for scenario experiments. **7/20/2017**
3. Document laboratory findings. Release open source software modules to enable industry adoption. **9/30/2018**

Budget
Total project, to date: $2.64M
- DOE: $684k
- Cost Share: $1.96M ($1.20M BPA, $760k Bosch)

Total project: $2.83M
- DOE: $750k
- Cost Share: $2.08M ($1.25M BPA, $830k Bosch)

Key Partners:

Project Outcomes
Foundational automation strategies enable future product solutions to deliver win-win grid-interactive efficiency for homeowners, utilities, and energy service aggregators.

Increase residential sector energy efficiency (goal: 5% savings per home, or ~1 Quad potential) and demand response participation (goal: >2 kW firm resource per home), by easing consumer adoption of integrated solutions, towards enabling >10% active devices to provide flexibility by 2035.
Challenge

- Residential electricity consumption is larger than any other sector, and dominates utility peak load
- But...
  - Residential buildings are 96% of utility customers
  - There is high occupant and building diversity
  - Decisions are less financially-motivated
  - Awareness of grid issues is lacking
  - *Internet of Things* creates dozens of new cybersecurity risks per home
  - *Rapid growth in rooftop PV* challenges existing grid control and business models

How can we leverage connected residential products to generate more EE and DR, while avoiding occupant intervention & discomfort? Are there Win-Win solutions?

ERCOT Peak Loads

- **Wednesday August 3, 2011 5:00 PM**
  - Peak ERCOT Load: 68,416 MW
  - Temp in Dallas: 109°F

- **Wednesday March 9, 2011 5:15 PM**
  - Peak ERCOT Load: 31,262 MW
  - Temp in Dallas: 64°F
The Home Battery System project expects to achieve the following **technical objectives**:

1. Guaranteed comfort and improved energy savings for homeowners
2. Optimal operation of home based on user preferences and grid signals
3. Cybersecure demand response (DR) compliant with critical infrastructure protection (CIP)
4. Delivery of highly-available (more than 90%) DR capacity, >2 kW/home, from individual homes
5. Reliable DR capacity prediction from individual homes across multiple look-ahead time frames
Approach

1. Interface for homeowner engagement, preferences
2. Multi-criterion decision making control algorithms
3. Cybersecurity layer for privacy, grid security
4. Develop & install hardware
5. Validate under realistic lab use cases

Year 1
- Develop fundamental methods and architecture

Year 2
- Integrate software to improve control and reduce uncertainty.
- Prepare laboratory

Year 3
- Conduct laboratory experiments to study dynamic operation and validate outcomes from simulation.
Impact

• Demonstrates feasibility of fundamental methods and algorithms for a residential automation serving homeowners, utilities, and energy service aggregators.

• Demonstrates 5% annual energy savings and >2 kW firm resource per home from demand response participation without sacrificing occupant comfort or requiring user intervention.

• Laboratory experiment results will establish technical feasibility, leading to:
  – Market-driven solutions contributing to >10% of active devices providing grid flexibility by 2035, and
  – Informed field experiments in the future.
Progress: User Preference Elicitation

- Three methods evaluated; 1,000 respondents each
- Follow-up survey, 250 each, to assess predictiveness

<table>
<thead>
<tr>
<th>Method</th>
<th>Correct Predictions</th>
</tr>
</thead>
<tbody>
<tr>
<td>AHP</td>
<td>49.0%</td>
</tr>
<tr>
<td>DCM</td>
<td>68.0%</td>
</tr>
<tr>
<td>SMARTER</td>
<td>72.2%</td>
</tr>
</tbody>
</table>

SMARTER selected as the initialization method for foresee

\[ U_i = \beta_{i,m} M + \beta_{i,c} C + \beta_{i,d} D + \beta_{i,l} L + \beta_{i,s} S + \beta_{i,t} A^2 + \beta_{i,tn} I_{A<0} A^2 + \epsilon_i \]

Money  Dishes  Shower length  Asym. term

Source energy  Laundry  Air temperature  Error
Progress: Control Architecture

**Human control drivers**

- **User Preferences**
  - weights

- **Statistical Learning**
  - data

**Utility or Aggregator**

- grid signals
- load forecast

**Optimized Multi-Criterion Decision Making**

- ctrl

**Environmental control drivers**

- **Weather Service**
  - weather data & forecasts

- **System Identification**
  - predictive models

**Utility**

- **Battery Storage**
  - ctrl
- **PV Inverter**
  - ctrl
- **HVAC**
  - ctrl
- **Water Heater**
  - ctrl
- **Dish Washer**
  - ctrl
- **Refrigerator**
  - ctrl
- **Laundry**
  - ctrl
- **Unctrl Loads & Sensors**
  - ctrl
Progress: ESIF Experimental Testbed
Progress: Demand Response Use Case

Comparison of whole home power consumption

- DR Time Period
- Demand Response Mode
- Baseline Mode
- Energy Mode
- Energy Efficiency Mode

**Comparison Highlights:**

- **Incoming DR event notified at 12:30**
- **Load shed DR event from 14:30 to 16:30**
- **Occasional loads for maintaining thermal comfort in DR mode**
- **Recovery from the DR event**
- **Foresee reduced building loads during the DR event**
- **Foresee minimized power backfeeding in EE mode**
- **Foresee shifted loads (charged the battery, pre-cooled the home, and pre-heated the water heater) in DR mode**
**Daily Energy Savings Breakdown**

- Daily energy savings in EE mode, vs RBSA
- Daily energy savings in DR mode, vs RBSA
- Energy takeback/cost when DR is called

<table>
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<tr>
<th>Location</th>
<th>Heating Energy (kWh)</th>
<th>Cooling Energy (kWh)</th>
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<tr>
<td>Tenino</td>
<td>3.58</td>
<td>1.70</td>
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<tr>
<td>Eugene</td>
<td>5.79</td>
<td>1.11</td>
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<tr>
<td>Seattle</td>
<td>6.37</td>
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<tr>
<td>Emmett</td>
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<tr>
<td>Tacoma</td>
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<tr>
<td>Tenino (cooling)</td>
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<tr>
<td>Eugene (cooling)</td>
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</table>

(4-hour load-shed event)
Progress: DR Demand Reduction Breakdown

(4-hour load-shed event)
Progress: Solar Firming Use Case
Progress: Cybersecurity Layer

- Documented rigorous risk assessment
- Created an implementation plan to address risks in software, hardware
- Developed the cybersecurity layer based on the implementation plan
- Developed a security test plan and CIP compliance document
- Assessed platform hardening and documented best practices
- Penetration testing underway
Stakeholder Engagement: **Advisory & Outreach**

- Industry advisory board on sizing batteries for a smart home, using multi-criterion model predictive control
- Laboratory demonstrations for eight major utilities and industry stakeholders.
- Active industry discussions to resolve real-world issues via field experiments/pilots.

2 Journal papers, 3 in development
5 Conference papers, 5 in dev.
9 Conference presentations, to date
2 Published presentations/webinars
1 Copyrighted open-source software
Remaining Project Work

1. Perform laboratory experiments to evaluate Technical Objectives per approved Scenario Test Plan
   - Automated satisfaction of three different archetype homeowners’ preferences
   - “Business as usual” baseline in three climates
   - EE operation under TOU rates in three climates
   - Locationally-relevant DR in three climates
   - 24 physical performance scenarios
   - 11 different cybersecurity scenarios

2. Perform simulations to evaluate aggregated impacts

3. Document and close out project – end of FY 2018

4. Complete in-process publications, including:
   - Application of NERC CIP Standard requirements to aggregated end-use loads & building energy management systems
   - Preference elicitation methodology comparison for multi-criterion control of residential equipment
Thank You!

The Home Battery System Team
National Renewable Energy Laboratory
Dane Christensen, Senior Engineer
dane.christensen@nrel.gov
303-384-7437
REFERENCE SLIDES
Stakeholder Engagement: Publications


- Webinar on Battery Sizing for the Smart Home, driven by foresee, was delivered. (paper in development) Slides: https://www.nrel.gov/docs/fy18osti/70684.pdf & recording: https://attendee.gotowebinar.com/register/7159243851961563905

Most Impactful Publications:


## Project Budget

### Project Budget:

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<th>Bosch</th>
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<td>500</td>
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<td>2,830</td>
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### Variances:
No significant variances. Bosch delivered all expected effort at slightly lower accrued cost share than initially expected.

### Cost to date:
$2,640k

### Additional funding:
non-BTO DOE Extension to enhance project impact, $250k

## Budget History

<table>
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<th>FY 2016 – FY 2017 (past)</th>
<th>FY 2018 (current)</th>
<th>FY 2019 Project Concluded</th>
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<td>$ 500k</td>
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U.S. DEPARTMENT OF ENERGY  OFFICE OF ENERGY EFFICIENCY & RENEWABLE ENERGY
# Project Plan and Schedule

**Planned start date:** 10/1/2015  
**Actual start date:** 5/1/2016  
- Delayed start due to contracting  
- Increased effort/spending & met Year 1 Go/No Go Milestone on time  
- Met Year 2 Go/No Go Milestone on time  
**Project end date:** 9/31/2018

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<th>FY17</th>
<th>FY18</th>
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**Current work**
- Laboratory scenario experiments underway  
- Cyber penetration testing is underway

**Next major milestone:** Project completion