Project Summary

Timeline:
Start date: Oct 1, 2009
Planned end date: Sep 30, 2015

Key Milestones
1. Optimize wrap-around coil; Dec 2013
2. Achieve EF>2.0; March 2014

Budget:
Total DOE $ to date: $2,147k
Total future DOE $: $200k

Key Partners:

| GE Appliances | CRADA partner |

Project Goal:
Develop CO\textsubscript{2} heat pump water heater that meets Energy Star standards for HPWHs at an installed cost that will enable widespread adoption in US residential market.

Target Market/Audience:
Residential electric water heating
Purpose and Objectives

Problem Statement:
- Heat pump water heaters can save significant energy, however they currently use refrigerants with high GWP.
- Low-GWP heat pump water heaters based on CO₂ exist, but first cost of existing products is too high to enable widespread adoption in the US residential market.

Target Market and Audience:
Electric water heaters currently use 1.4 Quads/yr.

Impact of Project:
- CO₂ heat pump water heater at price point viable for the US residential market
- Technical potential of increasing EF from 0.92 to 2.0 is savings of 0.8 Quads/yr
- Using CO₂ as a refrigerant, this can be done with near-zero GWP and zero ODP
Approach

**Approach**: Utilize low cost components; maintain Energy Star performance
- Single-speed compressor, single expansion device
- Optimized *wrap-around* gas cooler instead of double-wall *external* gas cooler

**Key Issues**: Cost of CO$_2$ components, thermodynamic characteristics of CO$_2$, need for careful gas cooler wrap-around coil design

**Distinctive Characteristics**: Heat pump water heater with natural refrigerant (inexpensive with GWP=1)
Approach

Context:
- EcoCute CO₂ water heaters (a few million units in Japan, Europe and Australia)
  - First cost: ~6,000 $US, plus installation (4-5 kW heat pump heating capacity)
  - Variable speed compressor
  - External heat exchanger and circulation pump; stratified tank
  - Electronically controlled expansion valves and sophisticated controls
- HFC-based HPWHs
  - Available in US from various manufacturers, ~$1,000 (2-3 kW heat pump heating capacity)
  - Wrap-around condenser coil; non-stratified tank
  - Max water temperature limited
Approach

This project:

EcoCute:

Additional elements:
- Split system (high installation cost)
- Inverter-driven compressor
- Electronic expansion valves
- Variable speed pump
- External gas cooler
Progress and Accomplishments

**Accomplishments**: Constructed coupled tank-heat pump design tool in ANSYS to evaluate wrap-around coil designs.
Progress and Accomplishments

Accomplishments: Validation of design tool

- Boundary conditions:
  - Initial temperatures
  - Geometry; material properties

- Empirical values

- Heat pump performance
- CO₂ pressure
- CO₂ pressure drop

- Experimental validation data
- Simulation validation data

Validation: compare at end of test:
- Tank average temp
- Tank probe temps
- WAGC CO₂ outlet T

Calibrate paste conductivity
Progress and Accomplishments

Accomplishments: Validation of design tool

- Thermal conductivity of CFD mesh’s thermal paste treated as free variable (representing contact resistance)
- Experimental data from second WAGC (improved construction)
- Good agreement found at 0.4 W/m-K
Progress and Accomplishments

Accomplishments: Evaluation of designs with CFD
Progress and Accomplishments

Accomplishments: Progressive improvements in wrap-around gas cooler (WAGC)

Temperature approach at the pinch: \( \sim 10 \text{ K} \)

**Improved coil construction with insights from CFD**

Temperature approach at the pinch: \( \sim 5 \text{ K} \)

**CFD-aided design**

Temperature approach at the pinch: \( \sim 2.5 \text{ K} \)
Progress and Accomplishments

Lessons Learned:

- CFD validation is not a straightforward problem; especially with a dynamic system coupled with nonlinear boundary condition
- CO₂ system components are not readily available, e.g. low cost compressors at desired capacity

Accomplishments:

- Development of validated CFD model
- Fabrication and validation of optimized wrap-around gas cooler design
- Achieving EF of 2.1 with prototype CO₂ HPWH based on low cost components (single speed compressor, single XV, wrap-around gas cooler)

Market Impact:

- We have demonstrated a more affordable path to ENERGY STAR rated CO₂ HPWH (low GWP – no direct environmental impact)
- Sentech/SRA market assessment showed an estimated 37,000 – 112,000 total unit shipments one year following commercial viability, and 72,000 – 180,000 total unit shipments five years following commercial viability to account for 0.037 Quads in annual national primary energy savings

Awards/Recognition:

- None yet
Project Integration and Collaboration

Project Integration:
- Participate in “2013 ACEEE Hot Water Forum”
- Discuss with industry partners
- Participate in different venues and activities like the DOE water heating roadmap workshop

Partners, Subcontractors, and Collaborators:
- General Electric Appliances
  - Natarajan Venkatakrishnan, Director Advanced Technologies
  - Craig Tsai, PI

Communications: Publication in progress for wrap-around coil CFD design tool
Next Steps and Future Plans:
- Evaluate cold climate performance
- Evaluate performance at different air temperatures without high side pressure management
- Develop next generation prototype
- Optimize design for fixed charge
REFERENCE SLIDES
Project Budget

**Project Budget**: DOE total $2,347k FY2010 - FY2015

**Variances**: None

**Cost to Date**: $2,010k through Feb 2014

**Additional Funding**: None expected

### Budget History

<table>
<thead>
<tr>
<th>FY2010 – FY2013 (past)</th>
<th>FY2014 (current)</th>
<th>FY2015 (planned)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOE $1,797k</td>
<td>Cost-share *</td>
<td>DOE $350k</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cost-share *</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DOE $200k</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cost-share *</td>
</tr>
</tbody>
</table>

* In-kind contribution from CRADA partner – exact total is confidential information
Project Plan and Schedule

- Delays in FY2013 under transition of ORNL PI and CFD validation issues
- Go/no-go decision point met with EF>2.0