Engine-driven heat pump provides cooling, heating, water heating, and electrical power.
Project Summary

**Timeline:**
Start date: 01-Oct-2010  
Planned end date: 30-Sept-2015

**Key Milestones:**
1. Complete lab tests of Beta version heat pump with power generation capability  
2. Complete development of low cost power generation module and improved control strategy  
3. Construct pre-commercial unit and initiate laboratory testing  

**Budget:**
Total DOE $ to date: $2,304k  
Total future DOE $: $500k

**Target Market/Audience:**
Target market is residential gas space heating and water heating; estimated at 4.2 Q in 2030

**Key Partners:**

**Project Goals:**
The outcome of this project will be the development of a 4 ton natural gas residential multifunction heat pump with the following design criteria:
1) 1.2 cooling COP
2) 1.5 heating COP
3) 80% primary energy savings for water heating
4) 1 to 2 kW electricity generation capability for ancillary loads
5) 5 year payback
6) Off-grid operation
Purpose & Objectives

Problem Statement:
Develop gas engine-driven heat pump that provides heating, cooling, water heating, and emergency electrical power
• reduces space heating costs by 35%
• reduces water heating costs by 80%

Target Market/Audience:
• 71 M homes w/gas heating
• 73 M homes w/gas water heating
• space heating (gas) – 2.7 Quads
• water heating (gas) – 1.5 Quads
• estimated savings in 2030 – 2.1 Quads

DOE/BTO goal is 50% reduction in building energy use by 2030
Purpose & Objectives

**Impact of Project:**

**Goals:**
- develop advanced residential gas heat pump/water heater with 50% overall energy savings vs. high efficiency gas furnaces and standard efficiency gas water heaters
- initial product announcement by early CY2016

**Impact pathway:**
- **Near-term**
  - publish results of laboratory and field testing in conference papers and technical journals
- **Intermediate term**
  - obtain funding for field tests in regions outside southwest region (DOE-RBI or other)
  - continue working with partner to deploy by 2016
- **Long-term**
  - utilize low cost controllers developed in this project for control of other building equipment projects
  - basis for future micro-CHP units
Approach

**Determine Project Goals**

Develop model to assess performance

- **Inputs**
  - engine and main system component characteristics (compressor, heat exchangers, fans, etc.)

- **Outputs**
  - heating and cooling capacity
  - efficiency
  - water heating capacity based on available waste heat from engine
  - power generation for emergency uses

Design for Southwest Gas utility market

- elevated temperatures
- larger cooling loads/sq.ft.

1.8 million customers
Approach

Assess Performance

Build prototypes and test in environmental chamber at AHRI rating conditions and high ambient conditions

- cooling capacity/COP
- heating capacity/COP
- water heating capacity and output temperature
- electrical generation output
- engine temperatures
- condenser pressure
- engine rpm
- auxiliary power requirements (fans, pumps, controls)
Approach

**Perform field test**

Construct 20 units based on alpha prototype design (space conditioning and water heating) and install in field (Southwest Gas area) to evaluate overall performance

- electric consumption
- gas consumption
- water heating capability
- reliability
- maintain comfort levels
- noise
- vibration
- installation issues
- maintenance issues
Approach

Reduce costs

Several design changes were evaluated to reduce costs from original prototype

- replace high cost modulating valve ($50 savings)
- replace PLC with low cost controller ($1500 savings)
- lower cost alternator ($5500 savings)
- direct coupling engine to compressor (no savings; field failures)
- future plans include evaluation of insulation, engine, compressor, recuperator, and cabinet for further cost savings
Approach

Key Issues

Following are key issues that are being addressed based on field and laboratory tests

- optimal control of space conditioning, water heating, and power generation
- reliability/noise/vibration

Distinctive Characteristics

Partnership with utility, national lab, and manufacturing partner

- 50% increase in overall efficiency
- natural gas space cooling
- waste heat from engine provides water heating and boosts space heating efficiency
- off-grid operation
- 1.5kw available for emergency power

Builds on previous successful development of GHP-RTU

- successful market introduction
- sales and service network
## Alpha RGHP Testing Results

<table>
<thead>
<tr>
<th>ORNL goals @ 95ºF</th>
<th>Test results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooling Cap. = 3 ½ - 5 tons</td>
<td>✓ 4.1 tons</td>
</tr>
<tr>
<td>Cooling COP = 1.3</td>
<td>✓ 1.28 COP</td>
</tr>
<tr>
<td>Heating Cap. = 50-70,000 btuh</td>
<td>✓ 72,000 btuh</td>
</tr>
<tr>
<td>Heating COP = 1.5</td>
<td>✓ 1.48 COP</td>
</tr>
<tr>
<td>Domestic H2O = 60 gal.</td>
<td>✓ 60+ gal.</td>
</tr>
<tr>
<td>Water temp. = 140º F</td>
<td>✓ ~ 140º F</td>
</tr>
<tr>
<td>Ancillary loads = 0.75 – 1.0 kW</td>
<td>✓ ~ 0.95 kW</td>
</tr>
</tbody>
</table>
**Alpha Unit Customer Survey Results**

**System/Unit operation is not intrusive**
- Strongly Agree: 25%
- Agree: 37%
- Neutral: 38%
- Disagree: 11%
- Strongly Disagree: 11%

**System/Unit operation meets your expectations**
- Strongly Agree: 50%
- Agree: 50%
- Neutral: 0%
- Disagree: 0%
- Strongly Disagree: 0%

**Comfort level provided is the same or better**
- Strongly Agree: 38%
- Agree: 62%

**Noticeable difference (improvement) in water heating**
- Strongly Agree: 14%
- Agree: 29%
- Neutral: 29%
- Disagree: 11%
- Strongly Disagree: 11%

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## Cost Targets for a Viable Product

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost for 1,000 units</th>
<th>Priority</th>
<th>Achieved</th>
</tr>
</thead>
<tbody>
<tr>
<td>Controls (Engine/System)</td>
<td>1,000</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Recuperator</td>
<td>600</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Compressor</td>
<td>500</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Insulation</td>
<td>200</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Radiator/fan</td>
<td>450</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Drive assembly</td>
<td>250</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Outdoor coil</td>
<td>800</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Cabinet</td>
<td>1,300</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Alternator</td>
<td>500</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Refrigerant assembly (w) parts</td>
<td>1,100</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Engine</td>
<td>2,300</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>9,000</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Simple Payback

<table>
<thead>
<tr>
<th>Years using 14 SEER</th>
<th>Years using 18 SEER</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.3</td>
<td>5.8</td>
<td>National Avg</td>
</tr>
<tr>
<td>3.9</td>
<td>3.7</td>
<td>Elko, NV</td>
</tr>
<tr>
<td>7.3</td>
<td>8.9</td>
<td>Las Vegas, NV</td>
</tr>
<tr>
<td>7.5</td>
<td>11.7</td>
<td>Phoenix, AZ</td>
</tr>
<tr>
<td>3.6</td>
<td>3.9</td>
<td>New York, NY</td>
</tr>
<tr>
<td>4.0</td>
<td>4.1</td>
<td>Chicago, IL</td>
</tr>
</tbody>
</table>

Based on $9,000 first cost
Lessons learned:
• Need to reduce noise/vibration (field test)
• Direct coupling engine to compressor resulted in short term failures in field and has been abandoned (field test)
• More work is needed to balance control of all the unit functions for optimal energy performance (lab tests)
• Full-time power generation is an ineffective strategy (lab tests)
• Further cost reductions are required to meet goal

Accomplishments:
• Alpha prototype design completed and tested; goals achieved
• Alpha prototype field test completed
• Reduced cost of Alpha prototype by $1,550
• Completed lab tests of Beta version gas heat pump with power generation capability (larger engine to accommodate power generation)
• Low cost power generation module resulted in $5,500 reduction


Awards and Recognition: None yet
Project Integration and Collaboration

**Project Integration**: The project is based on a collaborative R&D agreement (CRADA) with Southwest Gas and IntelliChoice Energy. Mestek is the manufacturing partner and brings their history of successful heat pump innovation along with market savvy and distribution/service infrastructure – keys to GHP market penetration. Past successes in similar CRADAs show that such close collaboration with manufacturers is best path to success – e.g. GeoSpring HPWH, Trilogy GS-IHP, NextAire GHP, Trane CDQ hybrid desiccant AC system

**Partners, Subcontractors, and Collaborators**: CRADA partner Southwest Gas/IntelliChoice Energy. Marathon Engine Systems has a subcontract with Southwest Gas to provide engines and construct prototypes. Mestek is the manufacturing partner.

**Communications**: Three papers summarizing the development to date have been presented at the ASHRAE and Purdue conferences; regular progress reports & reviews for DOE and Southwest Gas
Next Steps and Future Plans:

• Complete design of pre-commercial unit to incorporate low cost ($500 vs. $6,000) power generation module and improved controller; 30-Jun-2014

• Construct pre-commercial unit and initiate laboratory testing; 30-Sep-2014

• Complete evaluation of additional cost improvements and incorporate into final commercial unit; 31-Mar-2015

• Complete field test of final commercial unit; 30-Sep-2015
Project Budget: **DOE total $2,804k FY11-15**
Variances: None
Cost to Date: **$2,227k through February 2014**
Additional Funding: None expected

### Budget History

<table>
<thead>
<tr>
<th>FY2011 – FY2013 (past)</th>
<th>FY2014 (current)</th>
<th>FY2015 (planned)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOE</td>
<td>Cost-share</td>
<td>DOE</td>
</tr>
<tr>
<td>$1854k</td>
<td>*</td>
<td>$450k</td>
</tr>
</tbody>
</table>

* In-kind contribution from CRADA partner – exceeds DOE funding level; exact total is over 3 times DOE share
## Project Plan and Schedule

Original initiation date: 01-Oct-2010 -- Planned completion date: 30-Sept-2015 (no delays in prototype fabrication and testing schedules)
Complete design of pre-commercial unit to incorporate low cost power generation module and improved controller; 30-Jun-2014 (Go/No-Go)

<table>
<thead>
<tr>
<th>Past Work</th>
<th>FY2013</th>
<th>FY2014</th>
<th>FY2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complete proof of concept controller development</td>
<td>Q1 (Oct-Dec)</td>
<td>Q2 (Nov-Feb)</td>
<td>Q3 (Mar-Jun)</td>
</tr>
<tr>
<td>Complete Alpha unit lab testing</td>
<td>Q3 (Jul-Sep)</td>
<td>Q4 (Oct-Dec)</td>
<td></td>
</tr>
<tr>
<td>Complete Beta unit design with power generation module</td>
<td>Q1 (Oct-Dec)</td>
<td>Q2 (Nov-Feb)</td>
<td>Q3 (Mar-Jun)</td>
</tr>
<tr>
<td>Complete lab tests of Beta unit with power generation capability</td>
<td>Q2 (Jan-Mar)</td>
<td>Q3 (Apr-Jun)</td>
<td>Q4 (Jul-Sep)</td>
</tr>
<tr>
<td>Complete development of lower cost power generation module</td>
<td>Q1 (Oct-Dec)</td>
<td>Q2 (Nov-Feb)</td>
<td>Q3 (Mar-Jun)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Current/Future Work</th>
<th>FY2013</th>
<th>FY2014</th>
<th>FY2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complete pre-commercial design w/low cost PG module</td>
<td>Q1 (Oct-Dec)</td>
<td>Q2 (Nov-Feb)</td>
<td>Q3 (Mar-Jun)</td>
</tr>
<tr>
<td>Construct pre-commercial unit and initiate lab testing</td>
<td>Q2 (Jan-Mar)</td>
<td>Q3 (Apr-Jun)</td>
<td>Q4 (Jul-Sep)</td>
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