Multi-function fuel-fired heat pump CRADA

2014 Building Technologies Office Peer Review

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

CRADA PARTNERS

SOUTHWEST GAS

INTELLICHOICE ENERGY

NEXTAIRE PACKAGED GAS HEAT PUMP

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Ed Vineyard, vineyardea@ornl.gov
Oak Ridge National Laboratory

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:

SOUTHWEST GAS

INTELLICHOICE ENERGY

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:

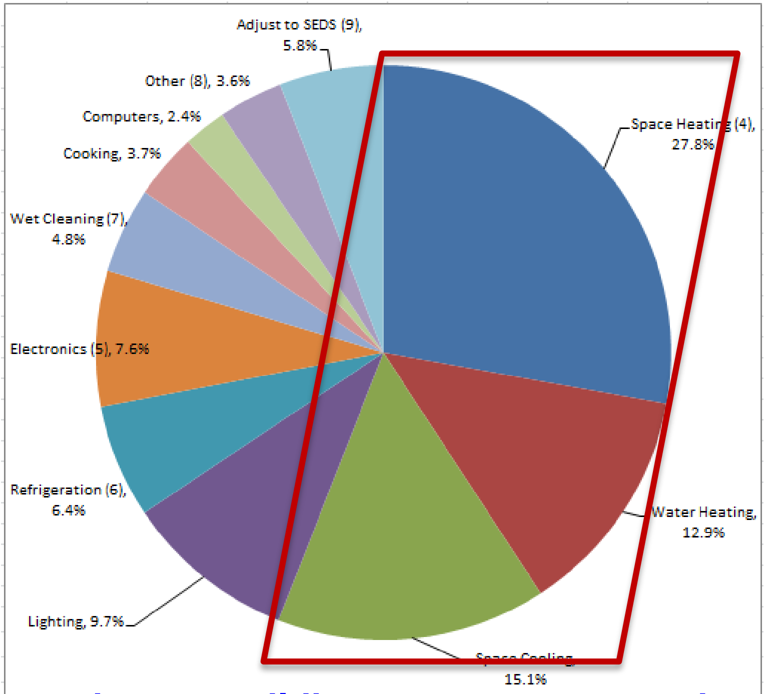
1) **1.2 cooling COP**
2) **1.5 heating COP**
3) **80% primary energy savings for water heating**
4) **1 to 2 kW electricity generation capability for ancillary loads**
5) **5 year payback**
6) **Off-grid operation**

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%**



March 2012 Buildings Energy Data Book

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

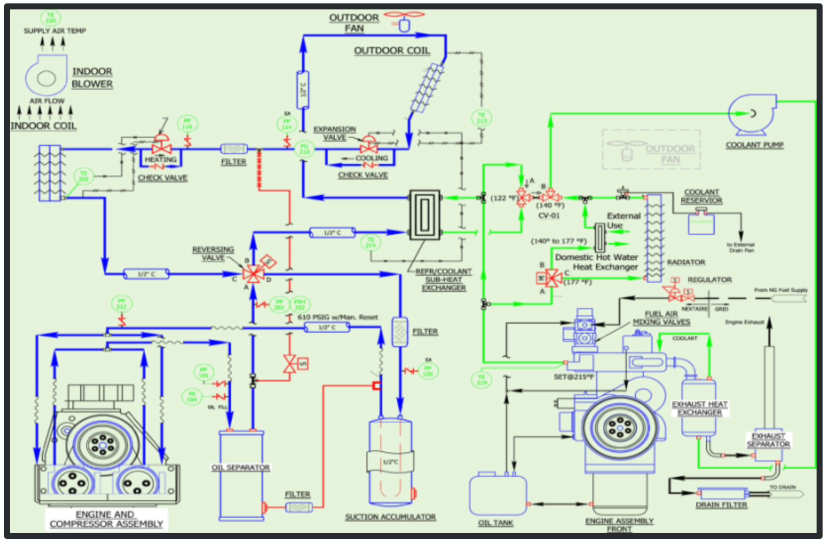
Determine Project Goals

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**

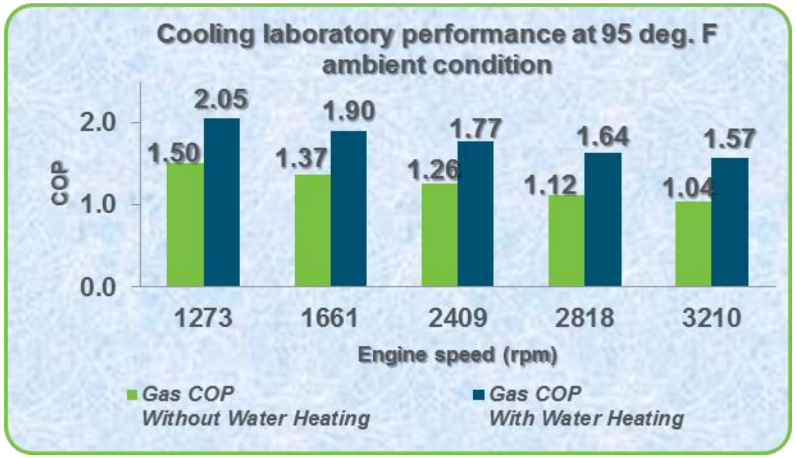
Design for Southwest Gas utility market

- **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)**

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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

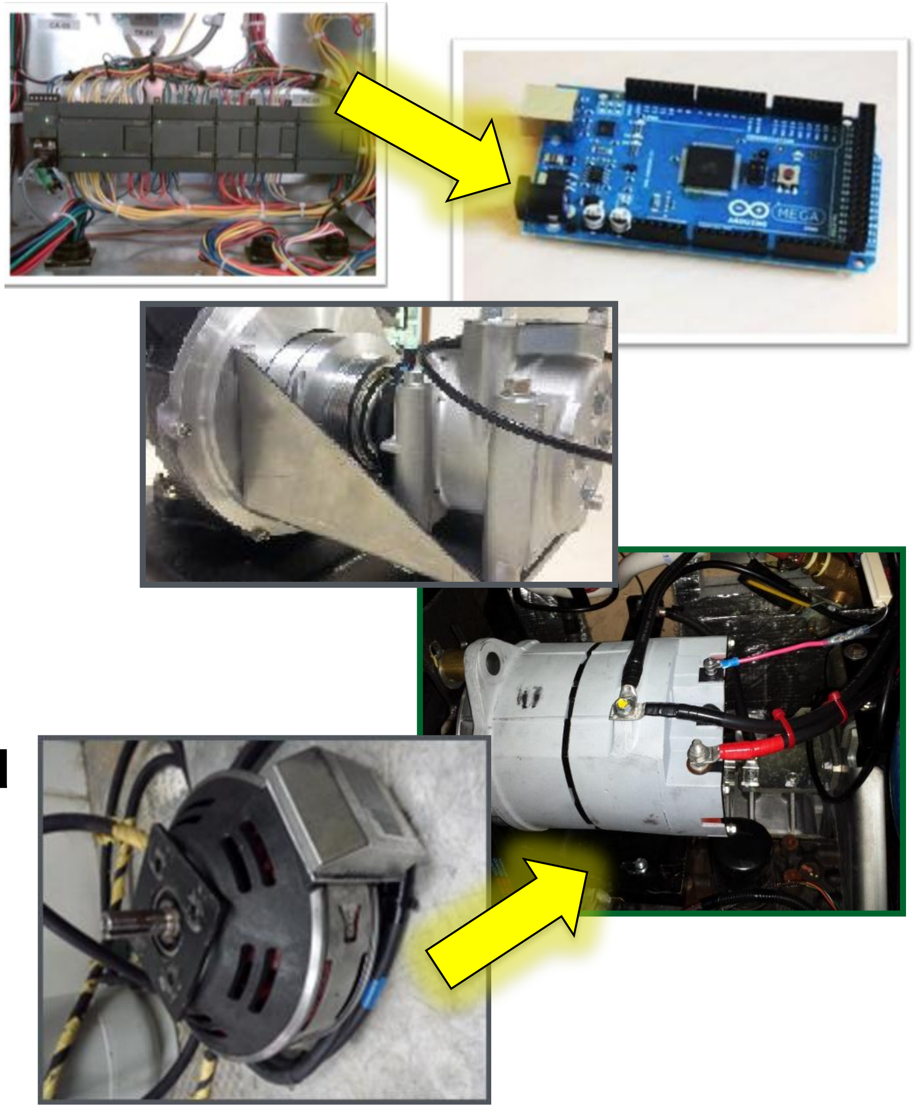
- **electric consumption**
- **gas consumption**
- **water heating capability**
- **reliability**
- **maintain comfort levels**
- **noise**
- **vibration**
- **installation issues**
- **maintenance issues**

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**

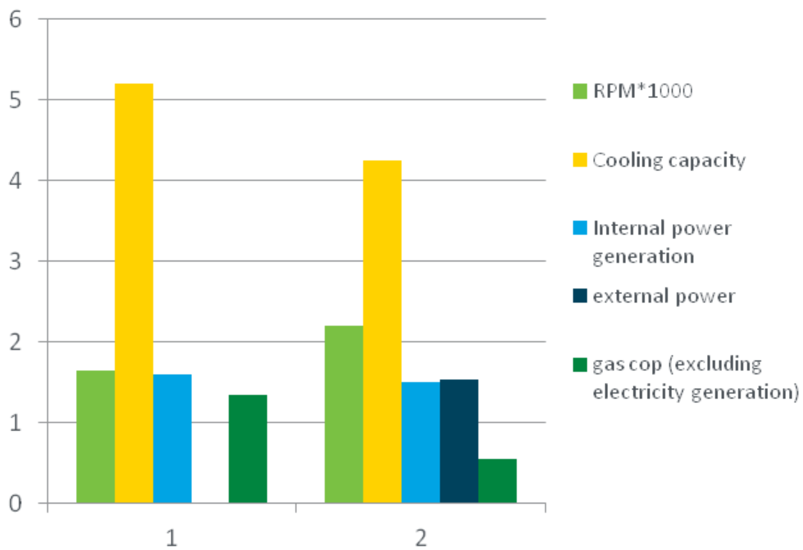


Approach

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

ORNL goals @ 95ºF	**Test results**
Cooling Cap. = 3 ½ - 5 tons	✓ 4.1 tons
Cooling COP = 1.3	✓ 1.28 COP
Heating Cap. = 50-70,000 btuh	✓ 72,000 btuh
Heating COP = 1.5	✓ 1.48 COP
Domestic H2O = 60 gal.	✓ 60+ gal.
Water temp. = 140º F	✓ ~ 140º F
Ancillary loads = 0.75 – 1.0 kW	✓ ~ 0.95 kW

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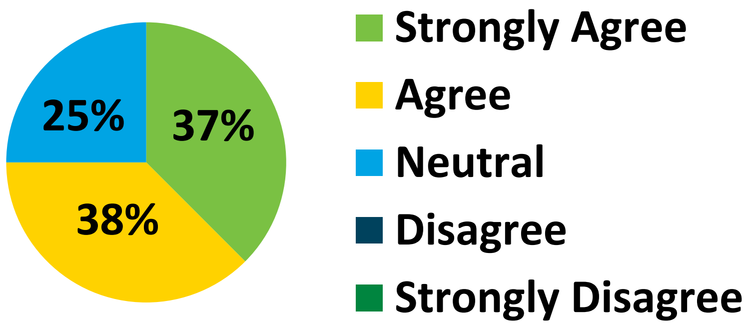
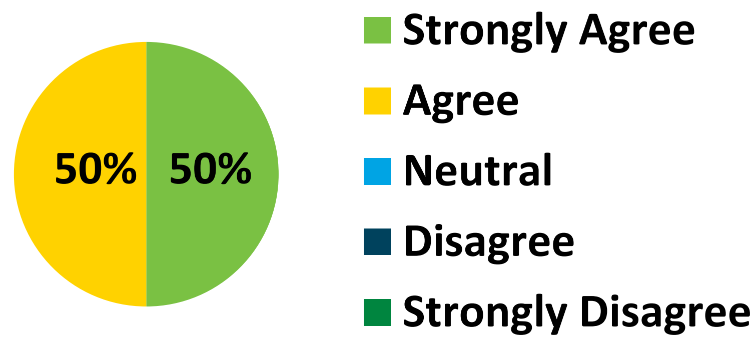
Alpha Unit Customer Survey Results

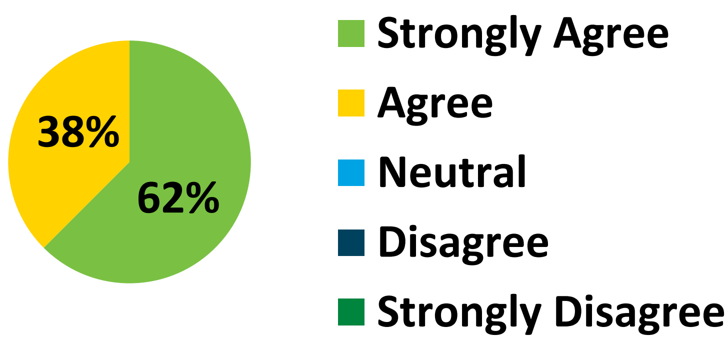
System/Unit operation is not intrusive



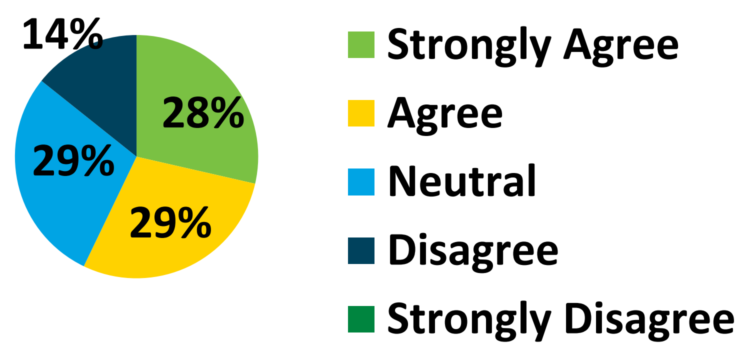
System/Unit operation meets your expectations



Comfort level provided is the same or better



Noticeable difference *(improvement)* in water heating



Cost Targets for a Viable Product

Item	Cost for 1,000 units	Priority	Achieved
Controls (Engine/System)	1,000	1	★
Recuperator	600	3	
Compressor	500	5	
Insulation	200	6	
Radiator/fan	450	9	
Drive assembly	250	10	
Outdoor coil	800	8	
Cabinet	1,300	7	
Alternator	500	2	★
Refrigerant assembly (w) parts	1,100	4	
Engine	2,300	11	
Total	9,000		

Simple Payback

Years using 14 SEER	Years using 18 SEER	Location
5.3	5.8	National Avg
3.9	3.7	Elko, NV
7.3	8.9	Las Vegas, NV
7.5	11.7	Phoenix, AZ
3.6	3.9	New York, NY
4.0	4.1	Chicago, IL

Based on $9,000 first cost

Progress and Accomplishments

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**

Market Impact: Product introduction in 2016

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**

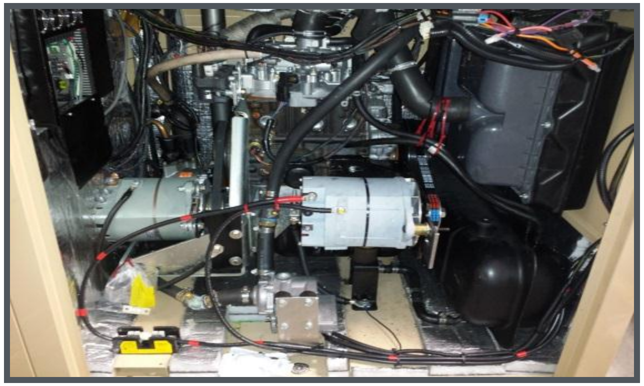
Partners, Subcontractors, and Collaborators: **CRADA partner Southwest Gas/IntelliChoice Energy. Marathon Engine Systems has a subcontract with Southwest Gas to provide engines and construct prototypes. Mestek is the manufacturing partner.**

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

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**



REFERENCE SLIDES

Project Budget

Project Budget: **DOE total $2,804k FY11-15**
Variances: None
Cost to Date: $2,227k through February 2014
Additional Funding: None expected

Budget History					
FY2011 – FY2013 (past)		FY2014 (current)		FY2015 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$1854k	*	$450k	*	$500k	*

*** 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)

Project Start: 01-October-2010		Completed Work
Projected End: 30-September-2015		Active Task (in progress work)
		Milestone/Deliverable (Originally Planned) use for missed
		Milestone/Deliverable (Actual) use when met on time

	FY2013				FY2014				FY2015			
Task	Q1 (Oct-De	Q2 (Jan-Ma	Q3 (Apr-Jur	Q4 (Jul-Sep	Q1 (Oct-De	Q2 (Jan-Ma	Q3 (Apr-Jur	Q4 (Jul-Sep	Q1 (Oct-De	Q2 (Jan-Ma	Q3 (Apr-Jur	Q4 (Jul-Sep
Past Work												
Complete proof of concept controller development												
Complete Alpha unit lab testing												
Complete Beta unit design with power generation module												
Complete lab tests of Beta unit with power generation capability												
Complete development of lower cost power generation module												
Current/Future Work												
Complete pre-commercial design w/low cost PG module												
Construct pre-commercial unit and initiate lab testing												