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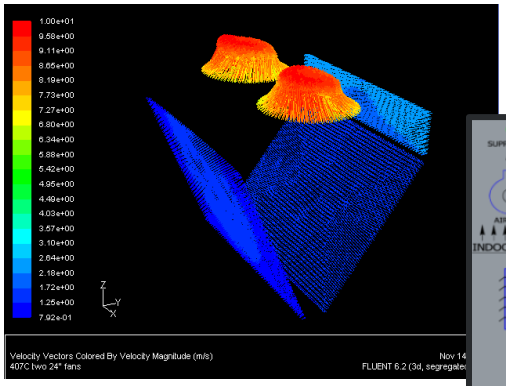
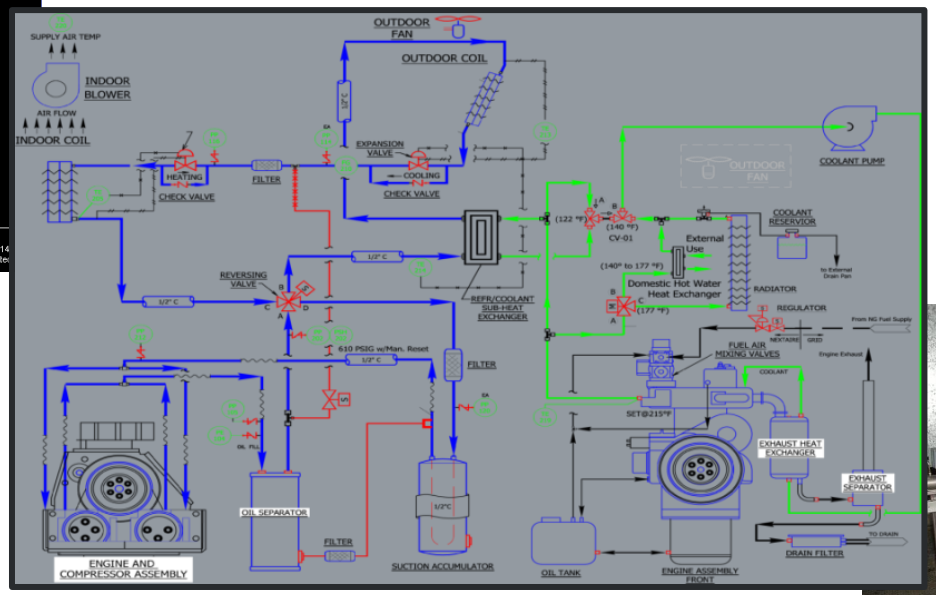
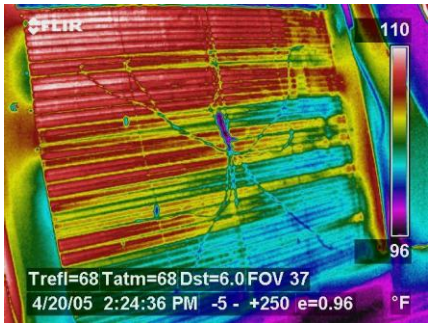
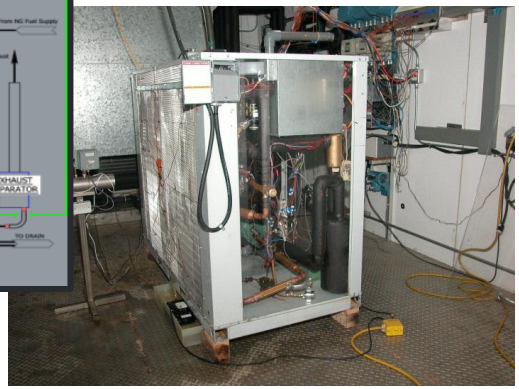








Multi-Function Fuel-Fired Heat Pump CRADA

Ed Vineyard

Oak Ridge National Laboratory, Building Equipment Research

vineyardea@ornl.gov, 865-576-0576

April 2, 2013

Purpose & Objectives

Problem Statement: 55% residential building energy use for space conditioning & water heating; highly efficient systems needed to facilitate DOE/BTO goal for 50% reduction in building energy use by 2030

Impact of Project: Cumulative energy savings potential of 0.25 Quads per year based on a penetration rate of 10% for a residential multifunction heat pump that provides space conditioning, water heating, and power generation compared to separate HVAC and water heating equipment at minimum efficiency levels

Project Focus: Supports/facilitates achievement of DOE/BTO goal of 50% reduction in building energy use by 2030; Develops and promotes market introduction of a residential fuel fired multifunction heat pump to help achieve the 20% HVAC and 60% water heating energy savings required to meet the Uber goal

Approach

Approach:

- Building on success of commercial heat pump, develop residential unit with additional features (water heating, power generation)

Distinctive Characteristics:

- Natural gas engine-driven compressor
- 1.5 kW power generation
- Waste heat recovery for space heating/water heating
- Smart controller to achieve optimal efficiency

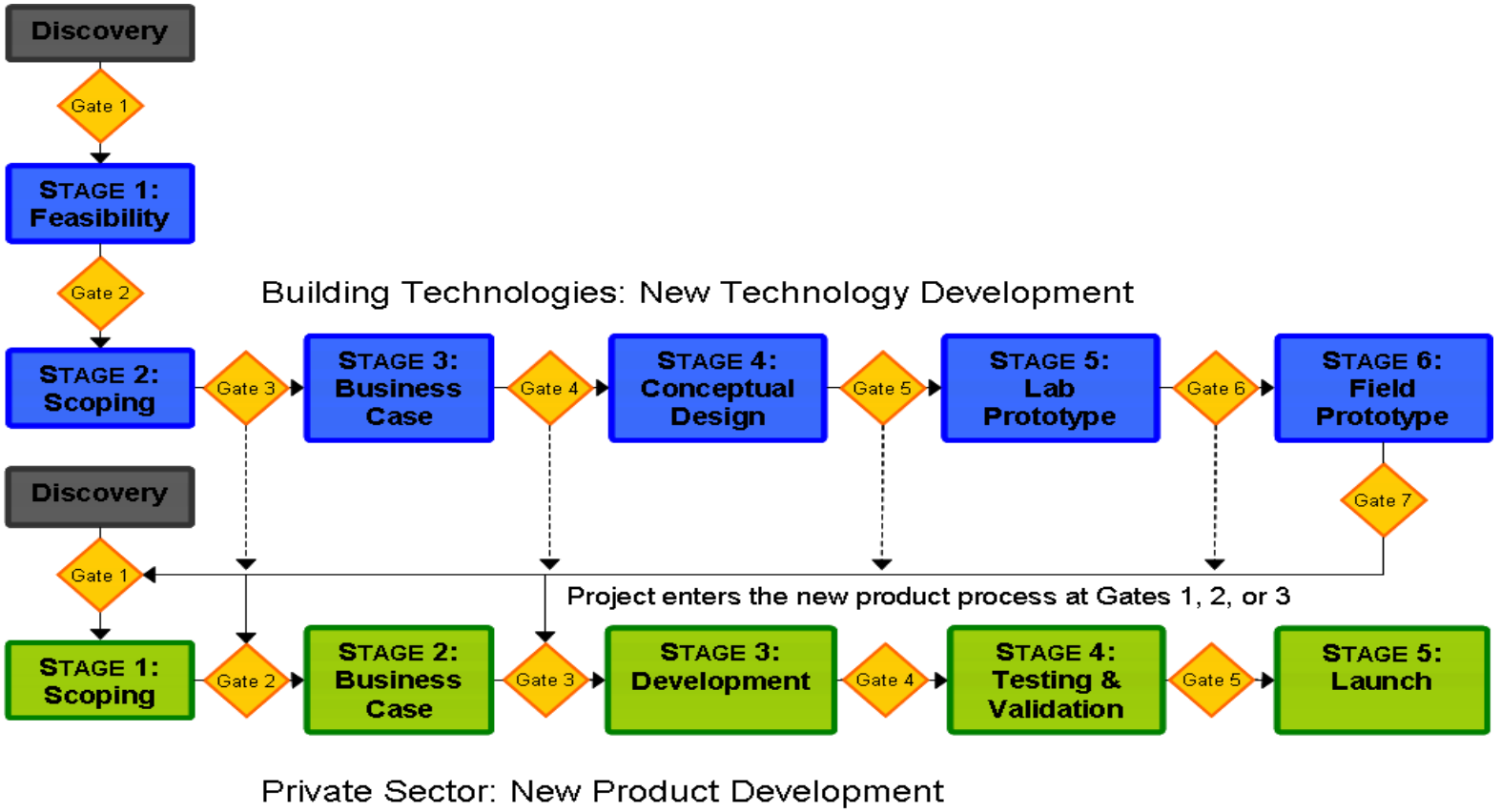
Approach

Project Goals:

Reduce primary energy consumption	• Cooling source COP of 1.3, heating source COP of 1.5 • Reduce water heating energy consumption by 80% • 30% primary energy savings
Protect the environment	• Reduce carbon emissions by 30% • Reduce nitrogen oxide by 30% • Reduce sulfur dioxide by 95%
Improve energy security and support U.S. economy	• Improves reliability of electric grid by reducing peak power demand by 85% • Uses natural gas as a fuel, an abundant U.S. energy resource • Energy cost savings for the consumer

Approach

- Stage-Gate process is used to reduce risk



Approach

Key Issues: Cost ($8000 target), overall size, optimal control of space conditioning, water heating, and power generation, and selection/development of power generation module

- Increase current (PLC) system controller capabilities to reduce engine and system controls and reduce costs

$1500 → $150

Low cost commercially available open source control board with 54 digital I/O points, 16 analog inputs

- Reduce components and decrease maintenance intervals

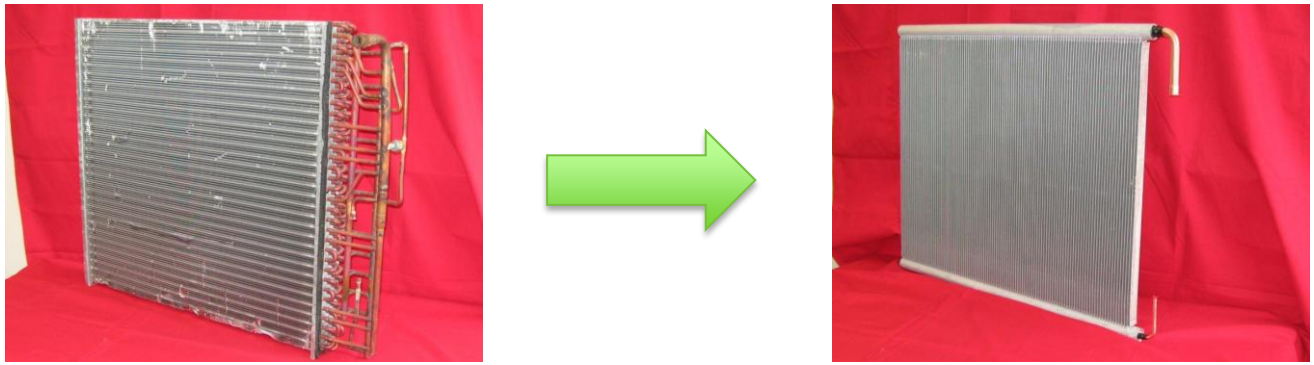
Direct coupling the engine/compressor assembly eliminated pulley and belt

Replace multiple mixing valve with simpler valve and circuiting

Approach

Key Issues: (cont.)

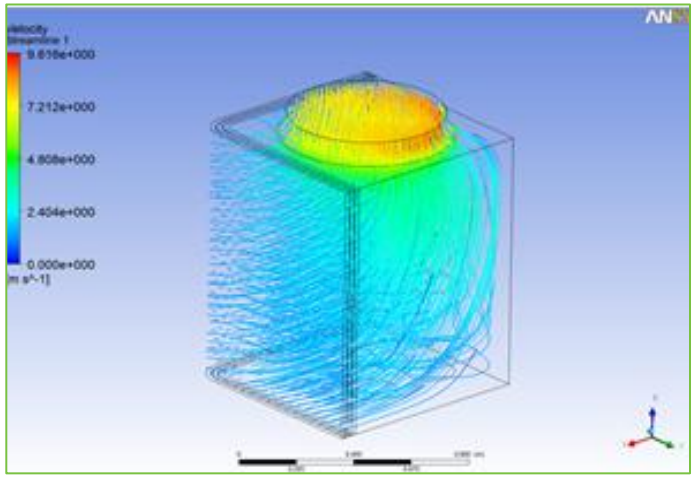
- Reduce unit cost by replacing specialty items with “off the shelf” components (heat exchangers, fan blades, valves)
- Reduce unit size and cost by replacing specially manufactured copper fin and tube heat exchangers with micro-channel heat exchangers



- Replace existing 1 hp outdoor fan motor with ¼ hp fan motor; enabled by micro-channel coil w/ lower pressure drop
- Determine control strategy to optimize waste energy stream utilization between water heating load and space heating load
- Reduce power draw from fans, pumps, and controllers (1200w to 600w)

Accomplishments and Progress

- Completed the design and development of alpha prototype
  - Selection of small, long life engine
  - CFD modeling of heat exchangers, flow paths
  - Water heating (heat recovery from engine)



Control panel

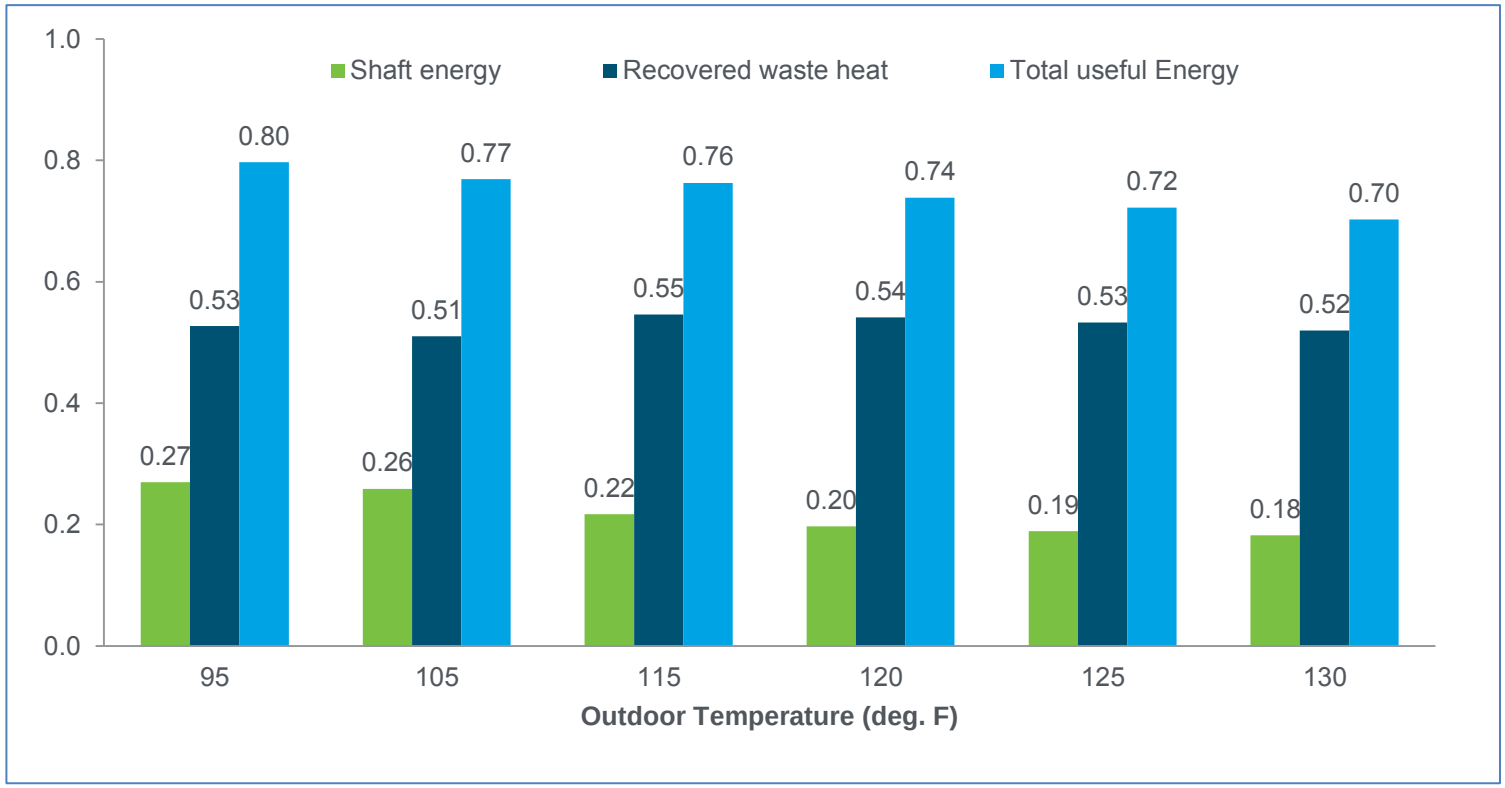
IC engine – Marathon (U.S. manufacturer)

Open drive scroll compressor

Heat recovery

Accomplishments and Progress

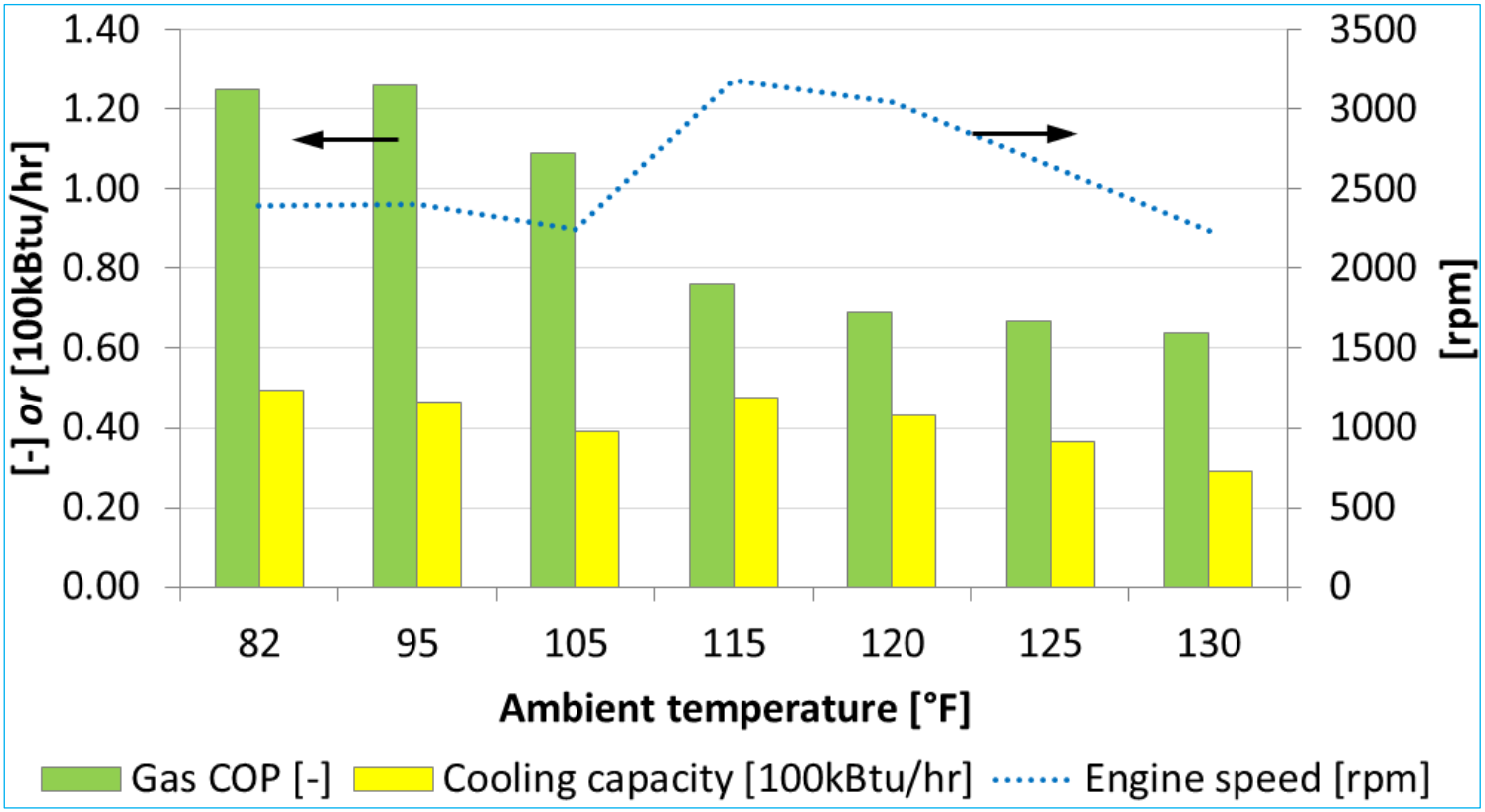
- Completed performance testing of the alpha prototype



Fraction of fuel input converted to useful energy

Accomplishments and Progress

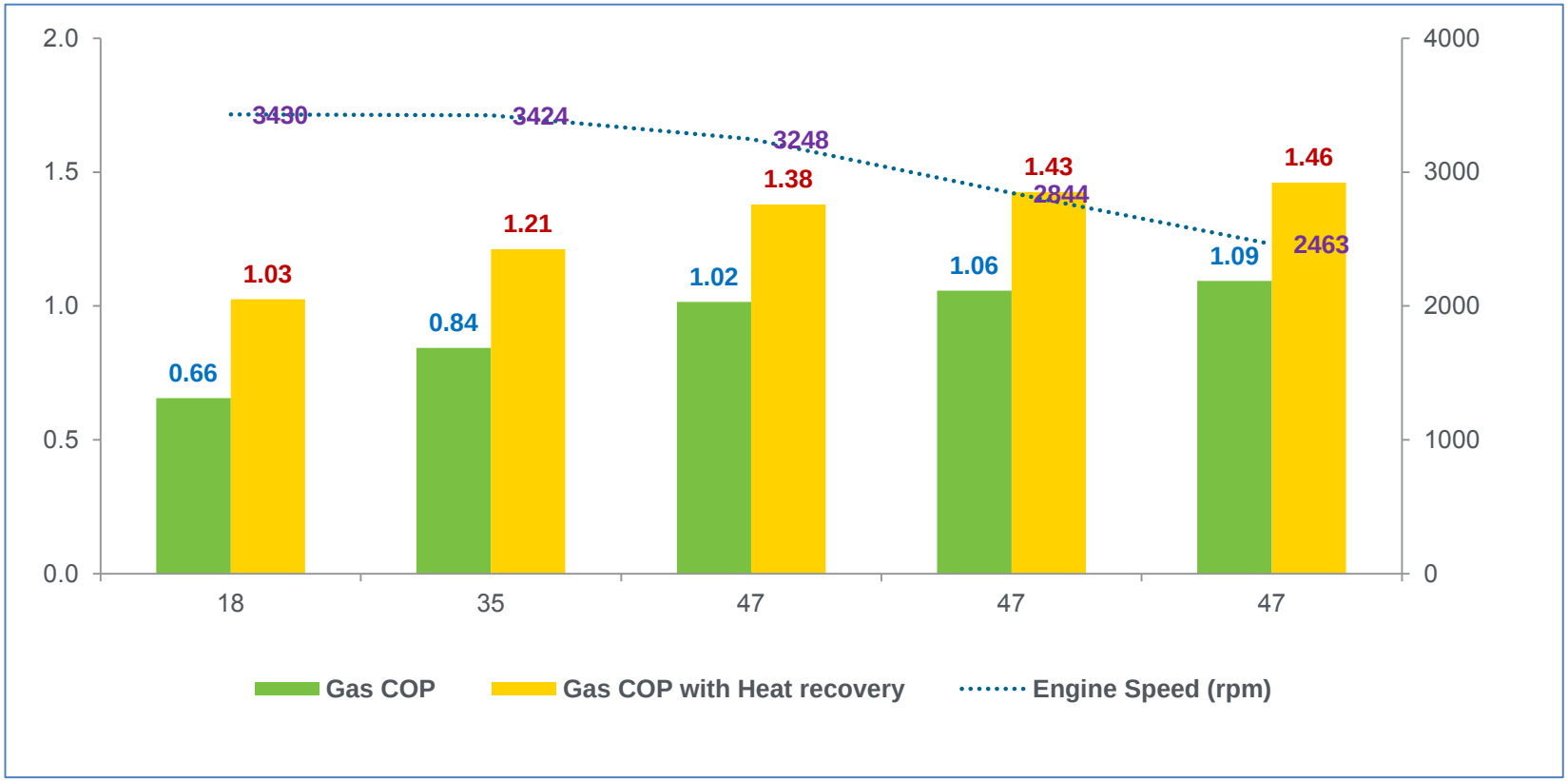
- Completed cooling performance testing of the alpha prototype



Cooling COP and Capacity as a function of ambient temperature

Accomplishments and Progress

- Completed heating performance testing of the alpha prototype



Heating COP as a function of ambient temperature

Progress on Goals:

Project Goals	Achieved results with Alpha prototype
Cooling source Gas COP of 1.30	Cooling COP 1.26, combined cooling/water heating COP 1.77
Heating source Gas COP of 1.50	Heating COP 1.46
80% reduction in water heating energy consumption	Over 80% achieved
Reduce peak electrical power demand by 85%	Over 85% achieved

Project Plan & Schedule

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Original initiation date: September 1, 2010
Planned completion date: September 30, 2014
Project on schedule to meet FY13 project milestones

Go/No-Go decision plans
12/2011-proceed to full scale unit; **passed**
11/2013-proceed to field testing

Summary	
WBS Number or Agreement Number	
Project Number 18810	
Agreement Number 6800	

Legend
Work completed
Active Task
Milestones & Deliverables (Original Plan)
Milestones & Deliverables (Actual)

Task / Event	FY2012 Q1	FY2012 Q2	FY2012 Q3	FY2012 Q4	FY2013 Q1	FY2013 Q2	FY2013 Q3	FY2013 Q4	FY2014 Q1	FY2014 Q2	FY2014 Q3	FY2014 Q4
Project Name: Multi-Function Fuel-Fired Heat Pump												
Milestone: Complete breadboard unit testing	◆											
Milestone: Complete alpha unit design			◆									
Milestone: Complete alpha unit testing				◆								
Current work and future research												
Milestone: Develop control strategy and controller						◆						
Milestone: Complete beta unit testing							◆					
Milestone: Develop power generation module								◆				
Milestone: Complete lab tests of Beta unit with power generation module									◆			
Milestone: Perform design review with CRADA partner and build field test units										◆		
Milestone: Develop field test plan and instrumentation package										◆		
Milestone: Install units in field and complete testing												◆

Project Budget

Project Budget: Total - $2000k (DOE)

Partner (SWGAS) Budget - $2400k

Variances: None

Cost to Date: $1453k

Additional Funding: FY14 - $800k

Budget History					
FY2011		FY2012		FY2013	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$500k	$600k	$600k	$600k	$900k	$600k

Project Integration, Collaboration & Market Impact

Partners and Collaborators:

- Southwest Gas (CRADA partner), natural gas service provider in Nevada, California and Arizona
- IntelliChoice Energy, subsidiary of Southwest Gas
- Marathon Engine Systems (MES), manufacturer of the IC engine

Communications:

Conference paper and presentation: Mahderekal, I, Shen, B., Vineyard E. A., (2013), "Development of Fuel Fired Multi-function Heat Pump", Conference CD of ASHRAE 2013 Winter Conference, Dallas, TX.

Next Steps and Future Plans:

- Incorporate a power generation feature on the Beta unit
- Complete development of Beta version including control strategy
  - space conditioning
  - water heating
  - 1.5kw power generation
- Perform laboratory tests using AHRI and ANSI performance testing and rating of gas-fired heat pumps
- Develop field test plan, install units, and complete field test
- Work with partner to commercialize multi-function fuel-fired heat pump