Natural Refrigerant (R-729) Heat Pump

2014 Building Technologies Office Peer Review

New Project

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Project Summary

Timeline:
Start date: 12-2013
Planned end date: 1-2015

Key Milestones:
1. Test stand and S-RAM Compressor (1-20-2014)
2. Complete compressor testing (5-15-2014)
3. Fabricate heat pump prototype (10-1-2014)

Key Partners:
- Purdue University
- Oak Ridge National Labs
- ReGen Power

Budget:
Total DOE $ to date: $0
Total future DOE $: $400,000

Target Market/Audience:
- Commercial and industrial buildings
- Cold climate applications >10 tons

Project Goal:
- Develop and test high performance heat pump
  - Uses air(R-729) as refrigerant (No HFCs)
  - 50% energy savings
  - < 4 year payback
  - Commercialize within four years
  - Manufactured in the U.S.
Problem Statement

• Current commercial and industrial heat pumps
  – Poor coefficient of performance (COP) at low temperatures
    • HFC refrigerant temperature limitations
  – Reduced part-load efficiencies
    • compressor cycling
    • VFD or compressor staging required
  – Use of HFC refrigerants
    • High global warming potential (GWP)
    • High refrigerant costs
Project Objectives

• Demonstrate natural refrigerant heat pump prototype using S-RAM technology
  – 50% energy savings
  – Meet DOE cold climate COP targets
  – Use air (R-729) as the refrigerant (ODP=0 and GWP=0)
  – Cost effective < 4 year payback
• Commercialize within 4 years
• Manufacture in U.S.
Target Market/Impact of Project

- Commercial/industrial buildings
- Heat pumps, packaged heating and rooftop units
- > 10 tons


\[
\text{% Energy Savings} \times \text{National Energy Consumption} \times \text{Potential Market Penetration} = \text{Estimated Savings}
\]

- % Energy Savings: 50%
- National Energy Consumption: 1.98 quads
- Potential Market Penetration: 100%
- Estimated Savings: 1.0 quads

- S-RAM Heat pump provides >50% savings as compared to heat pumps and RTUs
- Packaged heating units = 0.62 q
- Heat pumps = 0.12 + 0.14 = 0.26
- Roof Top Units = 1.1 q
- Per Market Penetration Chart % MP is around 15 to 20% with 3-4 year payback
Commercialization Plan

Key Success Factors
- 2014 tests
- Demonstration partners/customers
Proposed System and Approach

1. Natural Refrigerant (R-729)
2. Expander
3. Compressor
4. Oil free
5. Motor (fixed speed)
S-RAM Compressor/Expander Technology

- Variable displacement, low-friction, axial piston drive technology
  - 47 patents and 4 pending
- Can mechanically change cylinder displacement while maintaining a fixed head clearance
- Can be integrated with an opposed expander
# S-RAM Target Applications

High value, high pressure, oil-free compressor/expander applications

<table>
<thead>
<tr>
<th>DOE Project</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>R-729 Heat Pump</strong></td>
<td>R-729 heat pump targeted for cold climate commercial/industrial buildings &gt; 10 tons</td>
</tr>
<tr>
<td><strong>Heat-to-power Engines</strong></td>
<td>Low temperature heat-to-power engine for biomass and waste heat applications (50 and 100 kW units)</td>
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<tr>
<td><strong>R-744 Compressor Rack</strong></td>
<td>Variable capacity R-744 compressor rack for industrial and supermarket refrigeration.</td>
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<tr>
<td><strong>Simultaneous heating &amp; cooling</strong></td>
<td>R-744 simultaneous heating/cooling unit for thermal battery for smart grid applications.</td>
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<td><strong>Pressure recovery to power</strong></td>
<td>Pressure recovery to power expander for natural gas distribution systems.</td>
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</table>
Progress-to-date: CO\textsuperscript{2} compressor test stand

- Built CO\textsuperscript{2} compressor test stand at Purdue
- Transcritical CO\textsuperscript{2} up to 2,000 psi
- 50\textsuperscript{+} kW cooling capacity
Progress-to-Date: Variable CO$_2$ compressor

- 345 cc (30 m$^3$/hr. or 17.7 cfm)
- Variable displacement (25% to 100%)
- Oil free refrigerant
- Testing
  - 750 to 1,500 rpm at 1.5 to 4.0 pressure ratios
Progress-to-Date: Expander/Compressor Unit

- Expander/compressor on opposed pistons.
- Oil free refrigerant
- 240,000 BTU/ 20 tons
- Fabrication completed by 5-1-2014
Test Results

Volumetric Efficiency

- S-RAM 345cc (750 rpm)
- Current CO² state-of-art

Pressure Ratio

Volumetric Efficiency

- S-RAM (750)
- Compressor 1
- Compressor 2
- Compressor 3
- Compressor 4
- Compressor 5
- Compressor 6
Test Results

Isentropic Efficiency

<table>
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<tr>
<th>Pressure Ratio</th>
<th>Isentropic Efficiency</th>
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<tr>
<td>1.5</td>
<td>100%</td>
</tr>
<tr>
<td>2</td>
<td>95%</td>
</tr>
<tr>
<td>2.5</td>
<td>90%</td>
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<tr>
<td>3</td>
<td>85%</td>
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<tr>
<td>3.5</td>
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<td>70%</td>
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</tr>
<tr>
<td></td>
<td>55%</td>
</tr>
<tr>
<td></td>
<td>50%</td>
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Current CO₂ state-of-art

S-RAM 345cc (750 rpm)
Project Collaboration

(PI)- Lee Jestings
(PI)- Dr. Eckhard Groll

ReGen Power
- Technology
- Design/fabrication
- Manufacturing

S-RAM Dynamics
- Management
- Technology
- Design/fabrication

ORNL
- System testing

Purdue
- Modeling
- Component Testing
Next Steps

Plans for next quarter

• Complete compressor testing
• Fabricate S-RAM ECU
• Fabricate titanium heat exchangers at ORNL
• International Compressor Conference Presentation (July)
Project Budget

Project Budget: $525,000 ($400,000 from DOE)
Variances: N/A
Cost to Date: $60,000 of DOE funds spent-to-date
Additional Funding: N/A

Budget History

<table>
<thead>
<tr>
<th>Date</th>
<th>FY2013 (past)</th>
<th>FY2014 (current)</th>
<th>FY2015 – 1-15-2015 (planned)</th>
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<tbody>
<tr>
<td>DOE</td>
<td>Cost-share</td>
<td>DOE</td>
<td>Cost-share</td>
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<td>$0</td>
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<td>$260,000</td>
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U.S. Department of Energy
Energy Efficiency & Renewable Energy
## Project Plan and Schedule

### Project Schedule

<table>
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<tr>
<th>Task</th>
<th>FY2013</th>
<th>FY2014</th>
<th>FY2015</th>
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<tbody>
<tr>
<td>Past Work</td>
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<tr>
<td>Q1 Milestone: Fabrication of variable compressor</td>
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<tr>
<td>Q1 Milestone: Fabricated CO2 compressor test stand</td>
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<tr>
<td>Current/Future Work</td>
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<tr>
<td>Q3 Milestone: Complete Compressor testing</td>
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<tr>
<td>Q3 Milestone: Fabricate heat pump</td>
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<tr>
<td>Q1 Milestone: Heat pump testing</td>
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<tr>
<td>Q1 Milestone: Final report</td>
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### Completed Work

- Project Start: 12-15-2013

- Active Task (in progress work)
- Milestone/Deliverable (Originally Planned)
- Milestone/Deliverable (Actual)