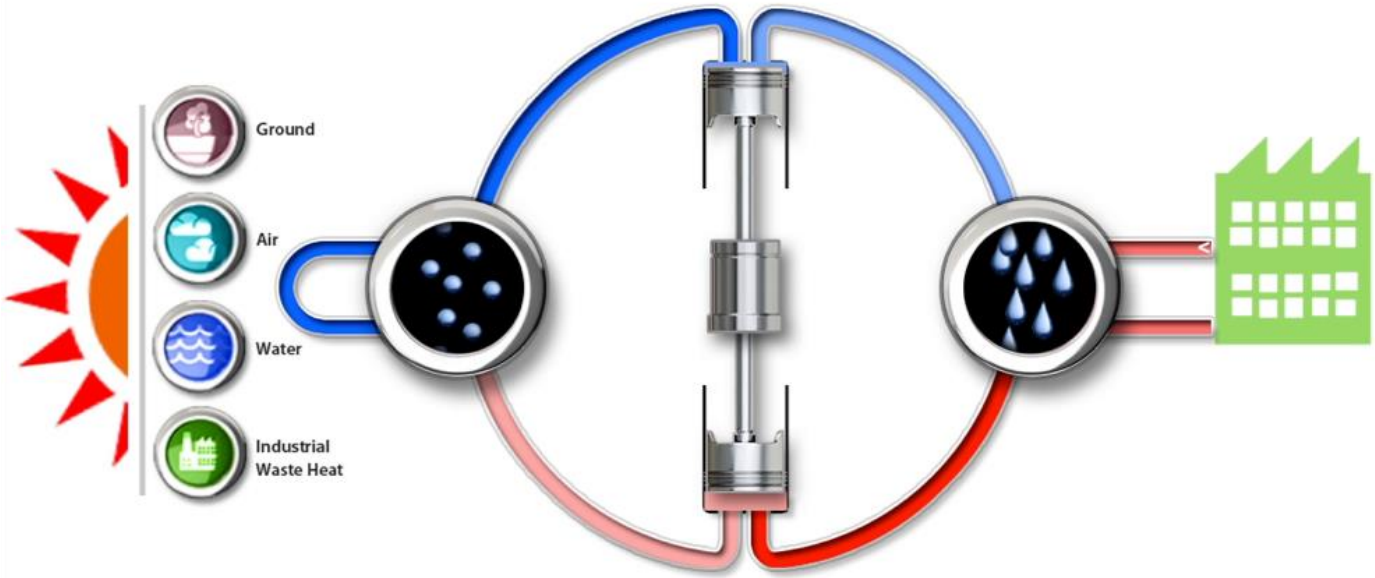
Natural Refrigerant (R-729) Heat Pump

2016 Building Technologies Office Peer Review



Lee Jestings (lee@S-RAM.com),

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

S-RAM DYNAMICS

Project Summary

Timeline:

Start date: 12-2013

Planned end date: 12-2017

Key Milestones:

1. S-RAM CO2 compressor
2. Compressor test stand (5/2014)
3. Compressor testing (7/2014)
4. Expander/compressor unit (air) (3/2016)
5. Fabricate heat pump prototype (7-2016)
6. Complete prototype testing (12-2016)

Budget:

Total Project $ to date:

- DOE: **$197,000**
- Cost share: $**245,000**

Total Project $:

- DOE: **$400,000**
- Cost share: $**320,000**

Key Partners:

ReGen Power
Purdue University
Oak Ridge National Labs

Project Outcome:

- 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

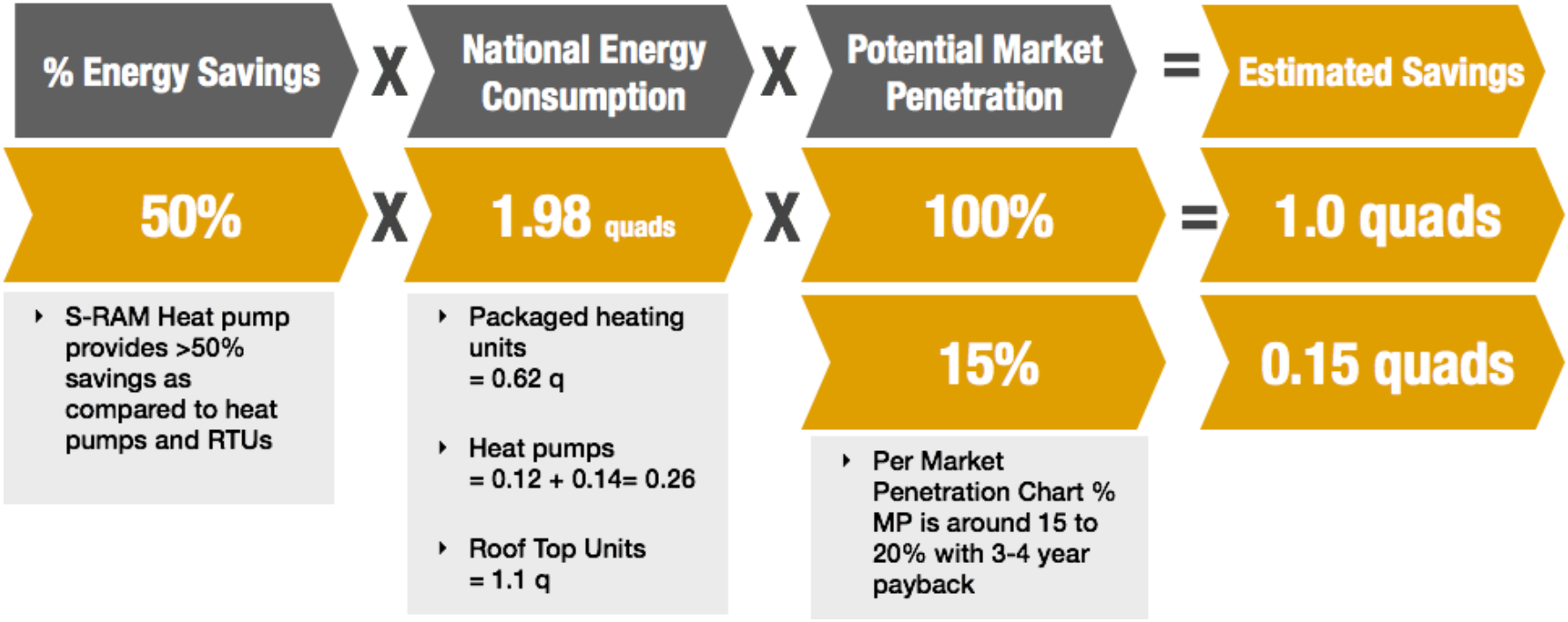
Project Objectives

- 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.

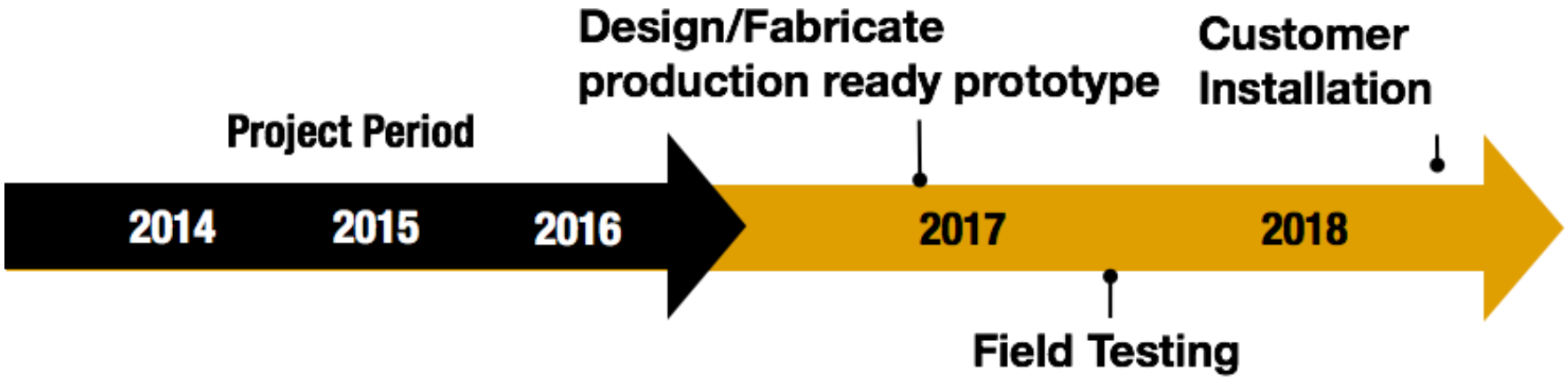
Target Market/Impact of Project

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

Based on E.E.R.E. Guide for Evaluation of Energy Savings Potential

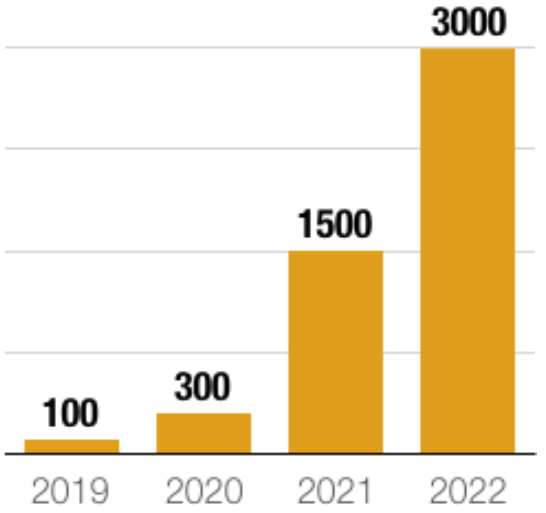


Commercialization Plan



Key Success Factors

- **ERC efficiency**
- **2016 testing**
- **Demonstration partners/customers**



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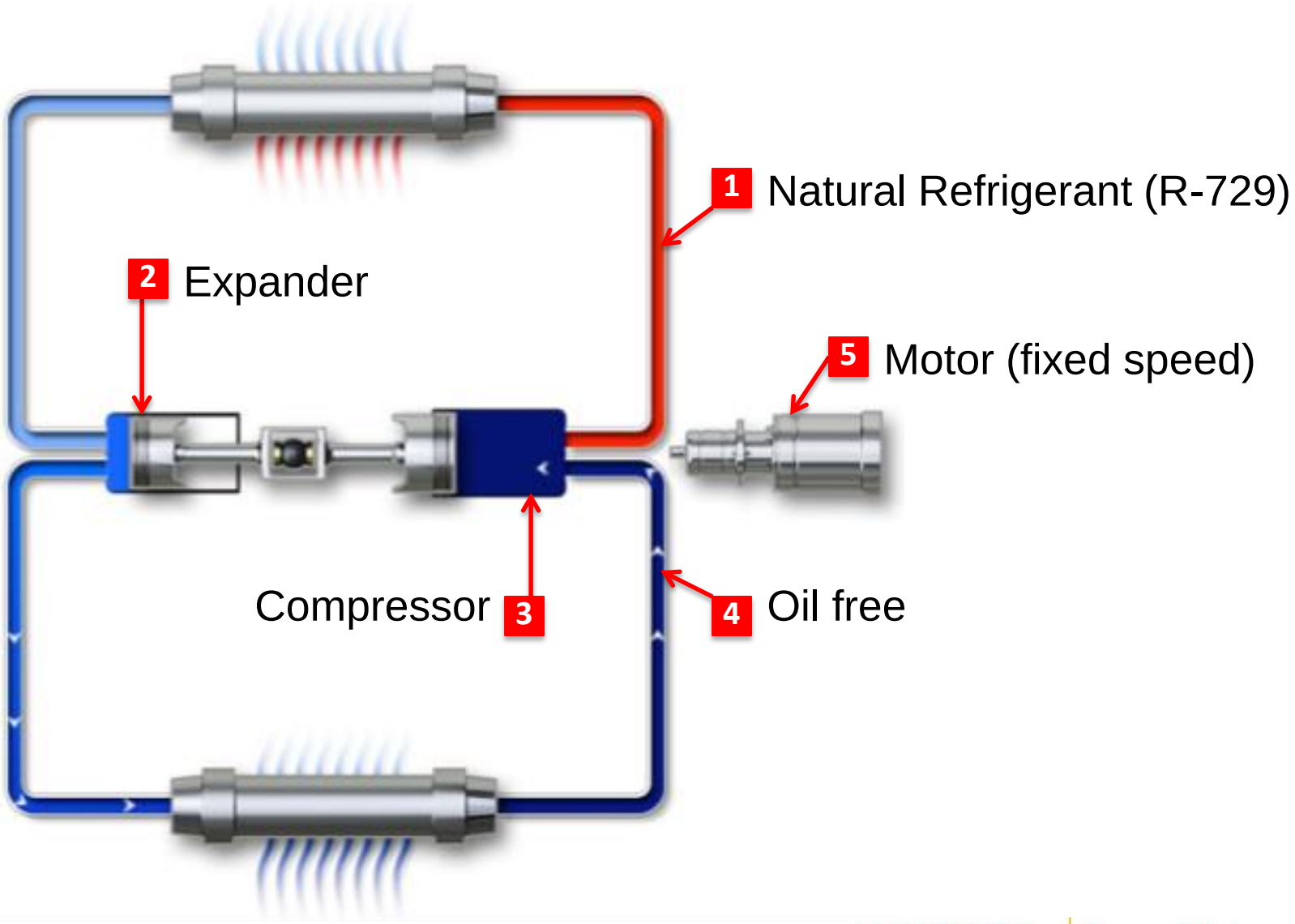
Proposed System and Approach



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

DOE Project	
R-729 Heat Pump	R-729 heat pump targeted for cold climate commercial/industrial buildings > 10 tons
Heat-to-power Engines	Low temperature heat-to-power engine for biomass and waste heat applications (50 and 100 kW units)
R-744 Compressor Rack	Variable capacity R-744 compressor rack for industrial and supermarket refrigeration.
Simultaneous heating & cooling	R-744 simultaneous heating/cooling unit for thermal battery for smart grid applications.
Pressure recovery to power	Pressure recovery to power expander for natural gas distribution systems.

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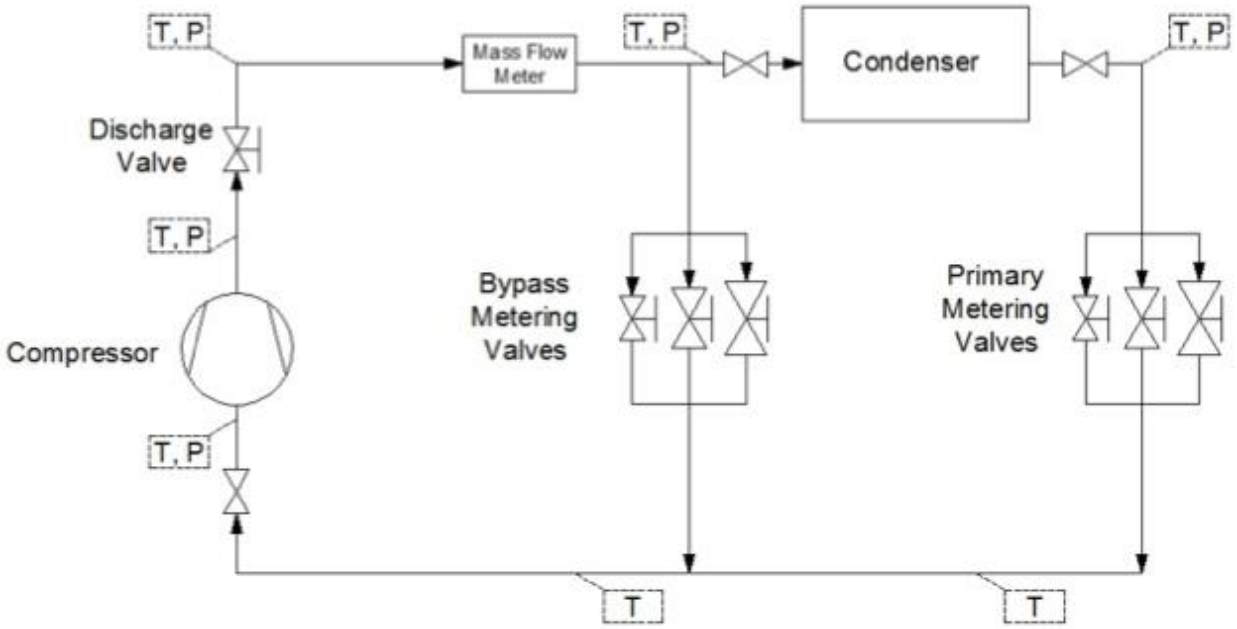
Progress-to-date: CO^2 compressor test stand

- Built CO^2 compressor test stand at Purdue
- Transcritical CO^2 up to 2,000 psi
- 50^+ kW cooling capacity

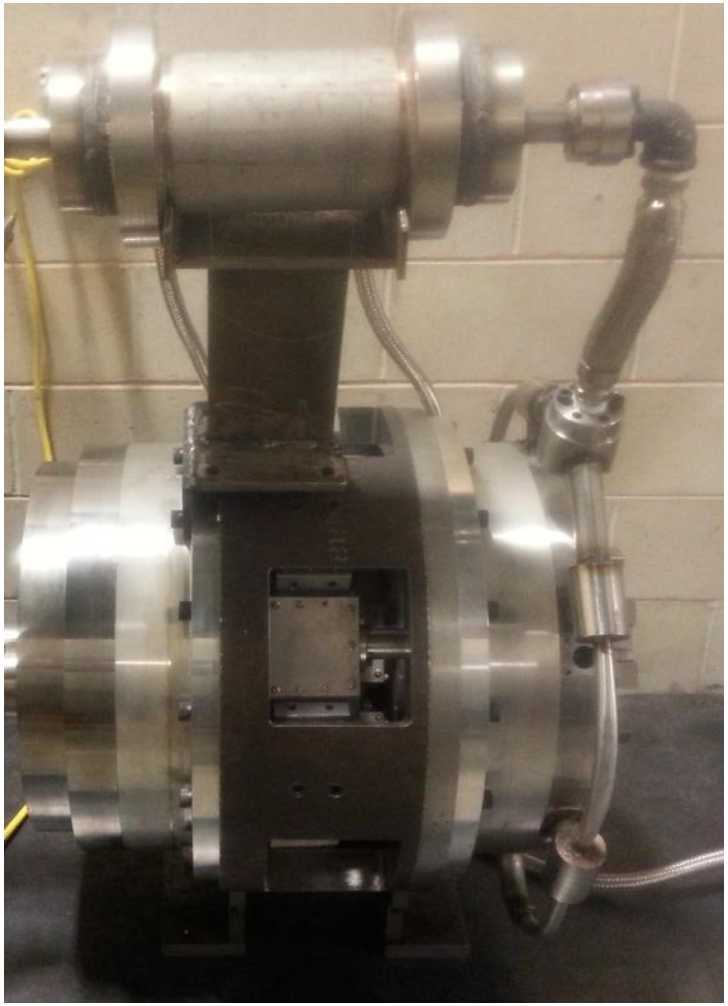


Progress-to-Date: Variable CO^2 compressor

- 345 cc (30 m^3/hr. or 17.7 cfm)
- Variable displacement (25% to 100%)
- Oil free refrigerant
- Testing (600-1200 RPM pressure ratio of 1.5-4.0
- High volumetric efficiency and good isentropic efficiency

Progress-to-Date: Expander/Compressor Unit

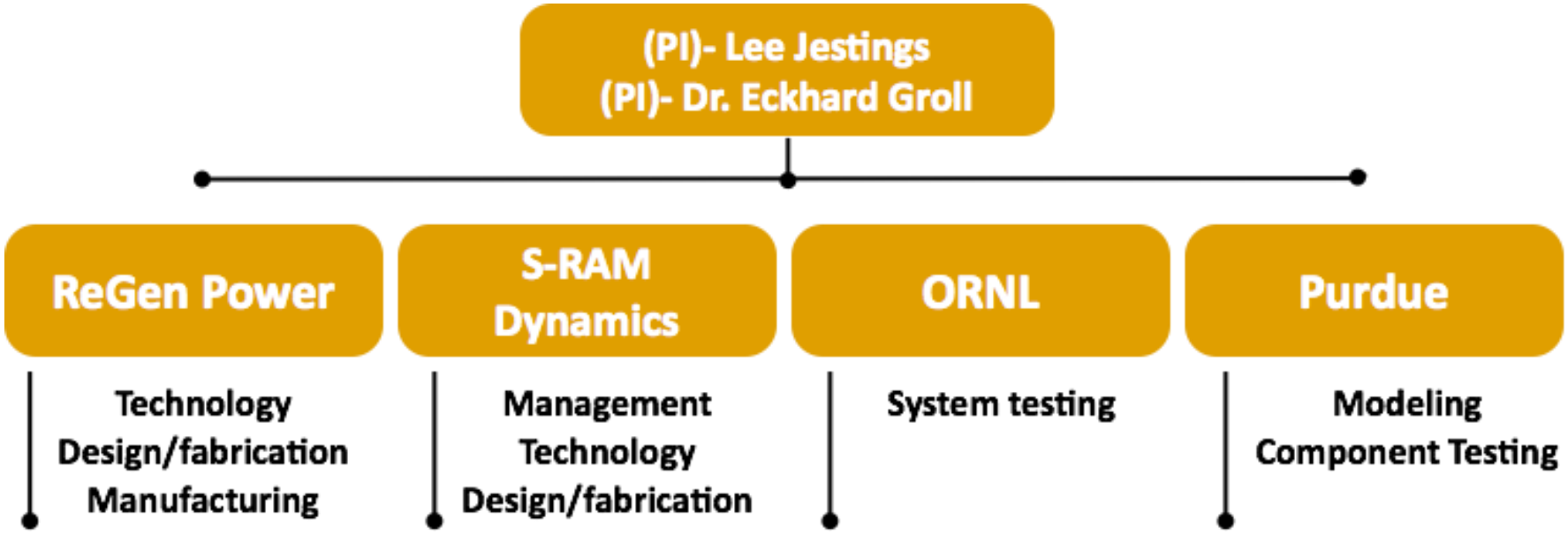
- Expander/compressor on opposed pistons.
- Oil free refrigerant
- 240,000 BTU/ 20 tons
- Fabrication completed on 1-30-2016



Progress-to-Date: Heat Pump Unit

- Printed titanium regenerator at Oak Ridge National Labs
- Current testing of the drive, compressor and expander components are ongoing
- Final modifications are in progress
- Heat pump testing to begin by 7-1-2016

Project Collaboration



Next Steps

Plans for next quarter

- Complete heat pump component testing
- Fabricate modifications to heat pump
- Complete heat pump testing
- Final testing at Oak Ridge National Labs

Project Budget

Project Budget: $573,000 ($400,000 from DOE)
Variances: N/A
Cost to Date: $197,000 of $400,000 of DOE funds spent-to-date
Additional Funding: N/A

Budget History					
12-15-2013 FY2016 (past)		FY2016 (current)		FY2017 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$197,000	**$245,000**	**$203,000**	**$75,000**	**$0**	**$0**

Project Plan and Schedule