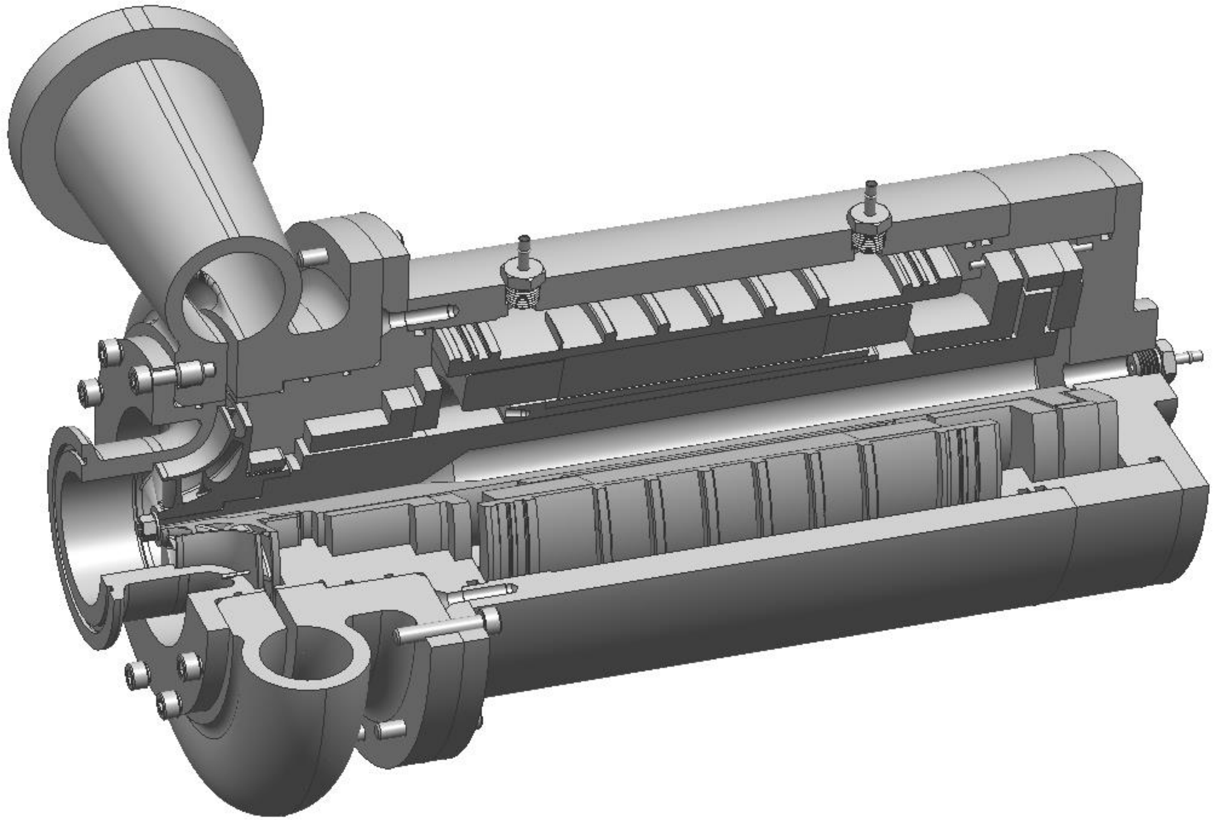
# LOW-GWP HVAC SYSTEM WITH ULTRA-SMALL CENTRIFUGAL COMPRESSION

2016 Building Technologies Office Peer Review

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

# Project Summary

**Timeline**:

Start date: 10/2015

Planned end date: 6/2017

Key Milestones

1. Milestone 3.3.1; 1/29/16
2. Milestone 2.1.1 ~40% complete; 1/29/16

**Budget**:

**Total Project $ to Date**:

- DOE: $134,406 + $56,776 (fy: 2016)
- Cost Share: $52,867

**Total Project $:**

- DOE: $999,921 ($362,794 Approved Budget)
- Cost Share: $251,525 ($125,886 Approved Budget)

**Key Partners**:

| | |
|---|---|
| Lennox International, Inc. | |
| TURBOCAM International, Inc. | |
| | |
| | |
| | |

**Project Outcome**:

Advance unrealized design potential of small centrifugal vapor compression in conjunction with advanced heat exchanger design to reduce environmental burdens with the use of low-GWP refrigerants while cost-effectively maintaining performance.

# Purpose and Objectives

**Problem Statement**: Advance unrealized design potential of small centrifugal vapor compression in conjunction with advanced heat exchanger design to reduce environmental burdens with the use of low-GWP refrigerants while cost-effectively maintaining performance.

**Target Market and Audience**: This project is targeted toward residential and commercial air conditioning. The market is approximately 3 quads of cooling for both residential and commercial. The audience is new units selected for low-GWP refrigerant capability.

**Impact of Project**:

- Project Output – Technical performance goals met, technical and manufacturing pathway established, and prototype for efficient use of low-GWP refrigerants in HVAC applications
- Near-term outcomes: Private sector aware of technology through investment/ collaboration, begin additional investment to refine technology/reduce cost
- Intermediate outcomes: Continued partnership with private sector system and component manufacturers to refine technology and reduce cost, introduce to market
- Long-term outcomes: Enable cost effective and energy efficient shift to low-GWP refrigerants in HVAC industry

# Approach

**Approach**: Develop conceptual model in collaboration with system vendor to determine efficiencies, system design and manufactured cost. Refine design and build/test prototype to validate solution.

**Key Issues**:

1. Efficiency – Low-GWP refrigerants are new and untested in this application. Early compressor studies are based on isentropic efficiency, but system efficiency results required.
2. System integration – Small centrifugal is a departure from current HVAC applications in this size range. Need good integration into system, including operating methodology, materials compatibility, etc. Heat exchanger is an integral component.
3. Cost – Technology will need to be cost effective to be adopted by industry and subsequently consumers.

**Distinctive Characteristics**: Determine system efficiency and cost estimates early in program

# Progress and Accomplishments

**Accomplishments**:

- Study of various low-GWP refrigerants performed and downselected
- Conceptual aero design completed
- Preliminary heat exchanger design completed, parts being sourced
- Conceptual bearing and motor design completed

**Market Impact**:

- Presenting findings to date at Purdue Compressor Conference Aug 2016
- Still early in project (Budget Period 1)

**Awards/Recognition**:

- None to date

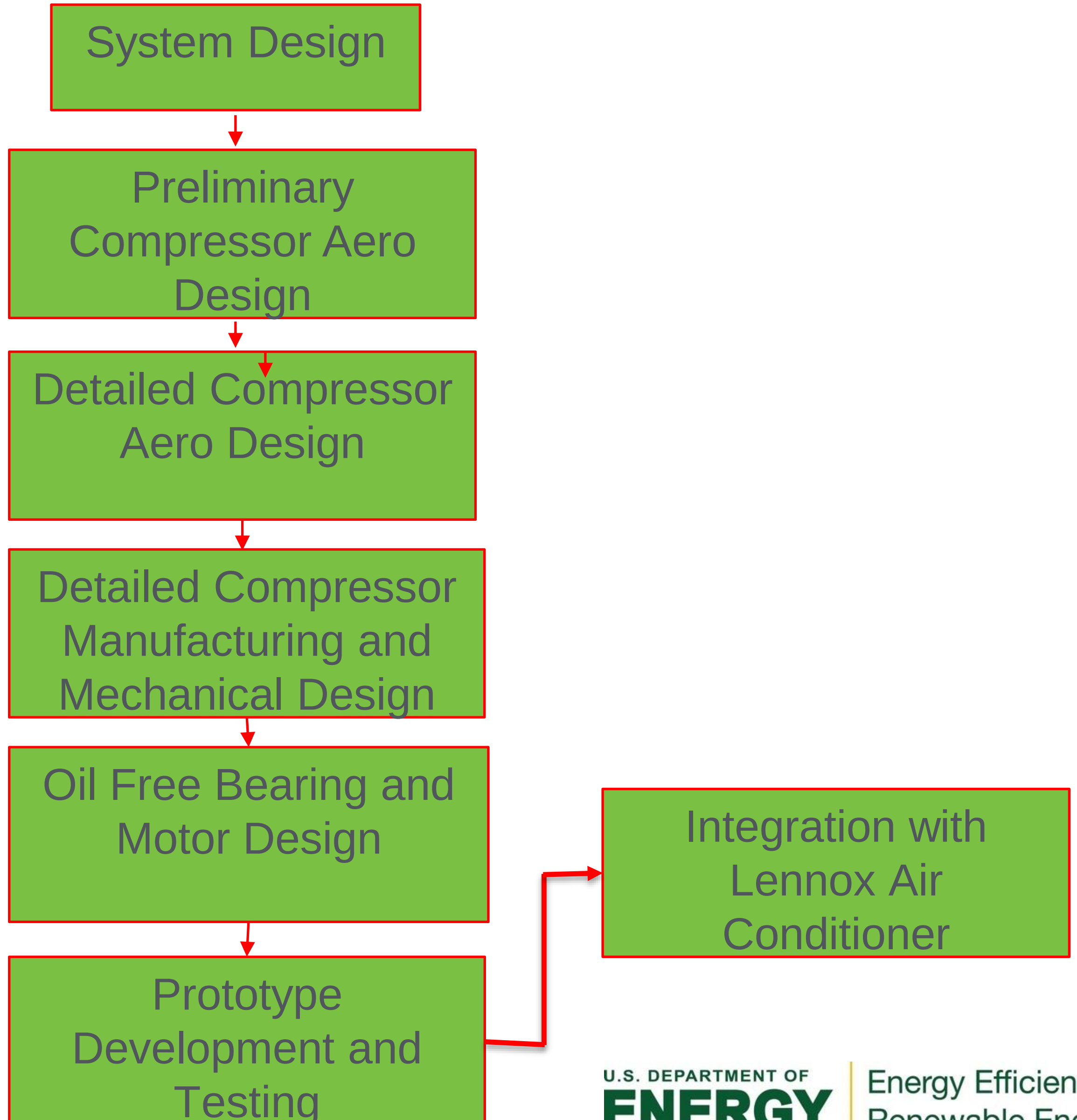
**Lessons Learned**:

- Business Development negotiations with partners can be very time consuming

# Project Objectives

- Design and development of an ultra-small, efficient, maintenance-free, oil-free, inexpensive centrifugal compressor, including aero components, rotor-bearing system, inverter and motor for a 5-ton air conditioning system
- Optimization for partial load efficiency, without sacrificing peak load performance
- Design for manufacturability and cost
- Validation and system integration of a high effectiveness heat transfer system, engineered for a very low-GWP refrigerant, e.g., microchannel heat exchanger
- Analysis of:
  - very low-GWP refrigerant compatibility with system materials
  - throughput benefits of centrifugal compression of lower density, very low-GWP's
- Quantification of beneficial lifecycle impacts of centrifugal technology, including installation, diagnosing, and servicing of systems
- Optimization for unitary "drop in" replacement, including flammability and safety risks, suction line pressure drop, and performance relative to outdoor temperature
- Testing of prototype system

# Design and Prototype Development Flowchart



# System Design

- Conducted by Lennox
  - System design consisting of all components(Compressor, heat exchanger, etc.), using Cycle_D code
- Multiple refrigerants examined
  - Several HFO blends were evaluated

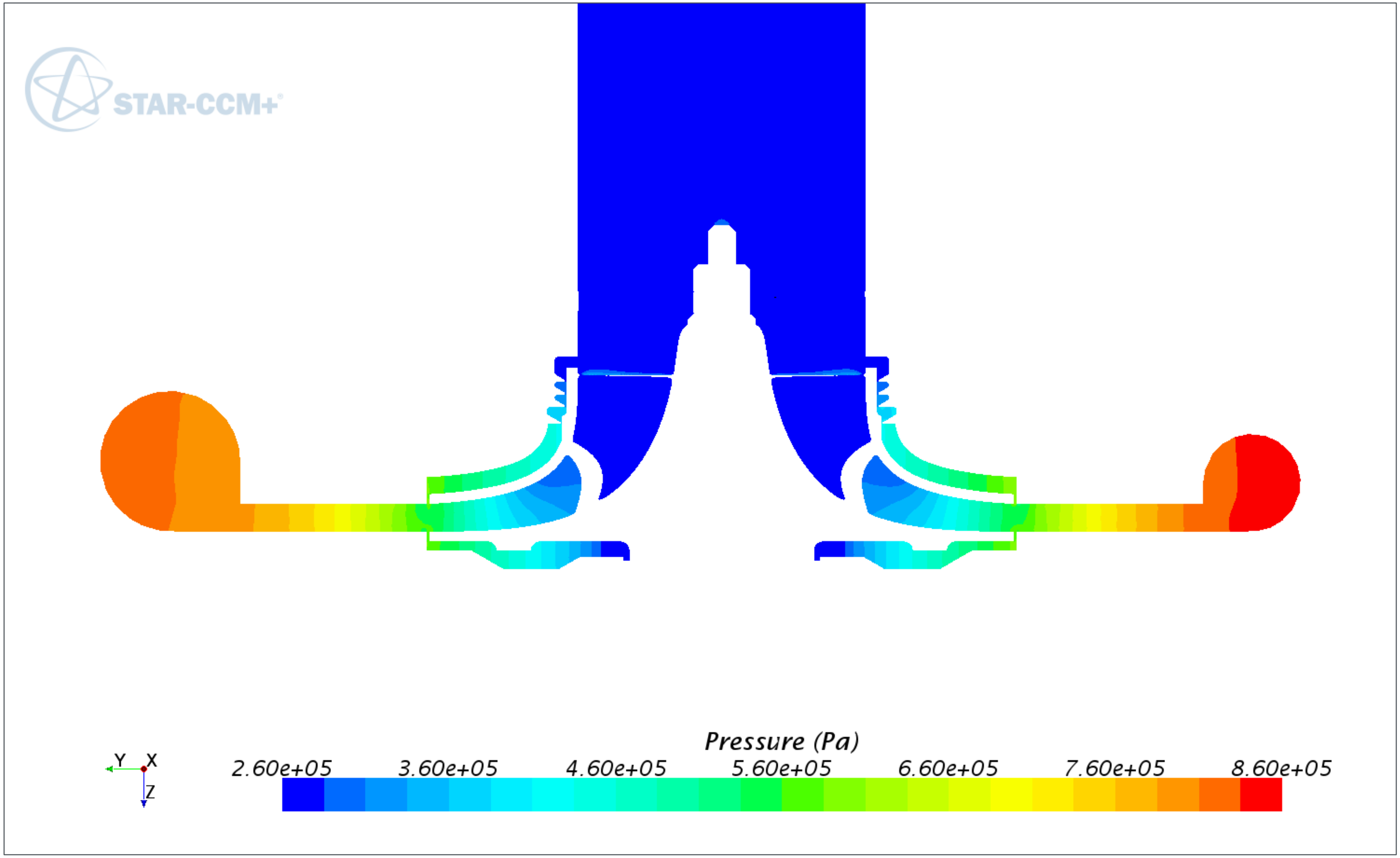
# Preliminary Aero Design

- Conducted using PCA Vista Design Code and CFturbo
- Both codes employed modified Redlich Kwong and Peng Robinson Equation of State(EOS) to simulate Refrigerant PVT behavior

# Detailed Aero Design

- Upon Completion of the preliminary design, a detailed 3-dimensional geometry of the centrifugal compressor was made using specific turbomachinery design software(ANSYS and CFturbo)
- The flowpath was analyzed using the real gas CFD code, STAR-CCM+
- A secondary flowpath was added to the system using the NX and Pro-Engineer CAD products to add fidelity to the analyses
- Complete analyses were conducted for subject refrigerants
- The analyses were completed at the rated condition, as well as a appropriate turndown condition to ensure proper off-design performance
- The effect of the foil bearings were considered in these analyses. A supply flow was taken from the impeller. This flow will feed the bearings, and provide motor cooling flow.

# Compressor Coupled CFD Analysis



# Project Integration and Collaboration

**Project Integration**:
MSI and Lennox are coordinating system design parameters to guide development. Lennox participates in requirements definition, design reviews, and parallel development.

**Partners, Subcontractors, and Collaborators**:
Project partner – Lennox International, Inc.

**Communications**:
Presenting findings to date at Purdue Compressor Conference Aug 2016

# Project Plan and Schedule

| Major Task Schedule | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Phase | SOPO Task # | Item: Task = T Milestone = M Deliverable = D | Task Title or Milestone/Deliverable Description | Performer (if different from recipient) | Task Completion Date | | | | Progress Notes |
| | | | | | Original Planned | Revised Planned | Actual | % Com-plete | |
| 1 | 1 | T | Program Management - Ongoing | Principal Engineer I | 9/30/2017 | 10/12/2017 | | 20% | Project Schedule has been shifted by 2 months due to late kickoff meeting |
| 1 | 2 | T | Requirements Definition | Vice President | 6/31/17 | | | 60% | |
| 1 | 2 | M | First version of Requirements Document complete | Vice President | 1/29/2016 | 2/28/2016 | | 40% | First Version Of Requirements Document To Be Finalized At Concept Design Review |
| 1 | 3 | T | Materials Comaptibility Investigation | Lennox | 4/30/2016 | | | 70% | |
| 1 | 3 | M | Preliminary materials selection complete | Lennox | 1/29/2016 | | | 100% | Refrigerant Selected |
| 1 | 3 | M | Final materials selection | Lennox | 7/30/2016 | | | 20% | |
| 1 | 4 | T | Market Transformation | | 6/30/2016 | | | 10% | Subtask 4.2 (Identified TURBOCAM) Conducting In Concert With Production Cost Estimate Effort |
| 1 | 4 | M | Obtain letter of interest from potential manufacturing partners | | 4/30/2016 | | | | |
| 1 | 5 | T | Conceptual Design | Vice President | 2/28/2016 | | | 60% | |
| 1 | 5 | M | Aerodynamic Design | | 1/15/2016 | | | 100% | Per DOE/MSI Aerodynamic Design Review (1/19/2016) |
| 1 | 5 | M | Motor Type Selected | | 3/1/2016 | | | 5% | |
| 1 | 5 | M | Economical bearing solution identified | | 2/28/2016 | | | 10% | |
| 1 | 6 | T | Preliminary & Critical Design | Vice President | 8/30/2016 | | | | |
| 1 | 6 | M | Final integrated compressor/motor design efficiency meets 78% | | 8/30/2016 | | | | |
| 1 | 6 | M | Refrigerant selection complete | | 8/30/2016 | | | | |
| 1 | | M | Go/No-Go Decision Point (Continuation Report) | | 6/30/2016 | | | | |
| 1 | 7 | T | Prototype Procurement and Assembly | Principal Engineer I | 3/31/2017 | | | | |
| 1 | 7 | M | LCCP improvement of at least 38% over typical A/C unit | | 9/30/2016 | | | | |
| 1 | 7 | M | Checkout test successful | | 3/31/2017 | | | | |
| 1 | 8 | T | Heat Exchanger Design | Lennox | 12/31/2016 | | | | |
| 1 | 8 | M | Heat exchanger types for evaluation selected | Lennox | 11/30/2015 | | | | |
| 1 | 8 | M | Achieve condenser HX cost parity vs. baseline R-410A condenser | Lennox | 12/31/2016 | | | | |
| 1 | 9 | T | Procure Heat Exchanger Prototype | Lennox | 1/30/2017 | | | | |
| 1 | 10 | T | Integrated compressor/motor and a/c system tests | Principal Engineer I | 4/30/2017 | | | | |
| 1 | 10 | M | 100% speed test for compressor | | 4/30/2017 | | | | |
| 1 | 11 | T | Final Design | Vice President | 6/31/17 | | | | |
| 1 | 11 | M | Final manufactured component cost still below $275 per unit (Go/No-Go Meeting) | | 6/31/17 | | | | |

**Project Dates**:

- Start: 10/2015
- End: 6/2017

**Current and Future Work**

- See Schedule

# Project Budget

**Project Budget**:
- DOE: $999,921 ($362,794 Approved Budget)
- Cost Share: $251,525 ($125,886 Approved Budget) - Lennox International, Inc

**Variances**:
- Currently no variances specific to project

**Cost to Date**:
- DOE: $134,406 (CY 2015) + $56,776 (Q1 CY 2016 – End Of Q1 CY 2016)
- Cost Share: $52,867 (CY 2015)

**Additional Funding**:
- Strategic Partner (Lennox International, Inc.) To Dedicate $251K Cost Share

**Budget History**

| 10/2015– CY 2015 (past) | | FY 2016 (Q1 CY 2016– through end of FY 2016) | | FY 2017 – 6/2017 (planned) | |
|---|---|---|---|---|---|
| DOE | Cost-share | DOE | Cost-share | DOE | Cost-share |
| $134,406 | $52,867 | $240,375 | $71,517 | $625,140 | $127,141 |

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# Next Steps and Future Plans

**Next Steps and Future Plans**:

- Consider 2-stage compressor
  - Longer lifecycle
  - More refrigerant options
  - Applicable to heat pumps, including cold climate
- Need to investigate higher resolution 3-d printing for various materials