High Efficiency Low Emission Refrigeration System

2014 Building Technologies Office Peer Review

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

Brian Fricke, frickeba@ornl.gov
Oak Ridge National Laboratory

Project Summary

Timeline:

Start date: 1 October 2011

Planned end date: 30 September 2016

Key Milestones

1. Evaluate System Design Strategies; March 2013
2. Develop Prototype System; March 2013
3. Fabricate Prototype System; March 2014

Budget:

Total DOE $ to date: $700k

Total future DOE $: $1,000k

Target Market/Audience:

The primary market segment targeted by this project is large national food retailers.

Key Partners:

Hill Phoenix (CRADA Partner)

Danfoss

Luvata

SWEP

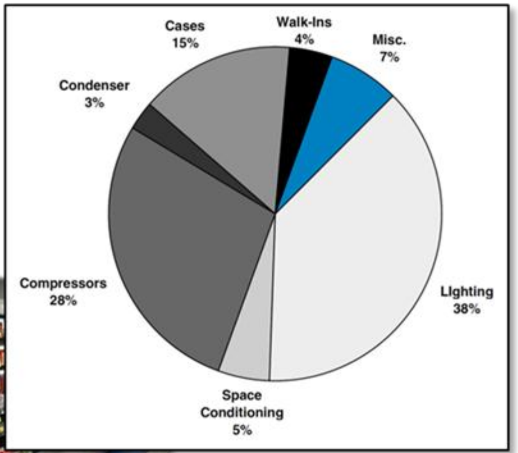
Project Goal:

The goal of this project is to develop a supermarket refrigeration system that reduces greenhouse gas emissions by 75% and has 25% lower energy consumption than existing systems.

Purpose and Objectives

Problem Statement:

- Develop supermarket refrigeration system:
  - Reduce greenhouse gas emissions by 75%
  - Reduce energy consumption by 25%
- Fabricate prototype systems for:
  - Laboratory evaluation
  - Field evaluation



Target Market and Audience:

- 37,000 supermarkets in the U.S.
- Average supermarket consumes ~2 million kWh per year:
  - Refrigeration represents ~50% of energy use
- Large refrigerant charge per store
  - 2000 to 6000 lb
  - High refrigerant leak rates (up to 25% per year)

Potential Savings:

Emissions: 30 $MMtCO_{2e}$/yr

Energy: 32 TBtu/yr

Purpose and Objectives

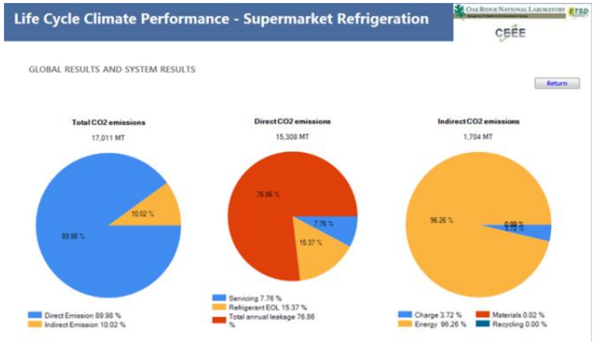
Impact of Project:

- Goal:
  - Develop low emission, high efficiency supermarket refrigeration system:
    - 25% energy savings, 75% emissions reduction
  - Demonstrate system performance:
    - In controlled laboratory setting
    - In third-party installation
- Impact:
  - Encourage implementation of new refrigeration technology:
    - Low emission, high efficiency systems in use in Europe and Canada
    - Encourage market penetration in the US
- Impact Paths:
  - Near term: Disseminate system performance data
    - DOE reports, conference proceedings, journal articles, trade shows
  - Intermediate term: Product launch by CRADA partner
    - Deploy low emission, high efficiency systems in 2014
  - Long term: Determine number of systems installed by industry partner
    - Feedback from owners/operators
    - Proven in-field performance

Approach

Approach:

- Analyze refrigeration system strategies:
  - System types (multiplex DX, secondary loop, CO_2), advanced display case designs, lower Global Warming Potential (GWP) refrigerants
  - EnergyPlus - evaluate energy consumption
  - Life Cycle Climate Performance (LCCP) modeling - evaluate emissions
- Select prototype refrigeration system:
  - Environmental impact, energy efficiency, cost-effectiveness, marketability, safety and reliability
  - Develop detailed design of prototype refrigeration system



Approach

Approach:

- Fabricate laboratory-scale prototype refrigeration system:
  - Characterize performance under controlled conditions
- Conduct field characterization of the prototype refrigeration system:
  - Develop guidelines for accurate field evaluations
  - Install full-scale refrigeration system in a third-party installation
  - Produce field characterization report:
    - Performance of the full scale refrigeration system operating under actual field conditions

Approach

Key Issues:

- Common multiplex direct expansion (DX) system:
  - Prone to refrigerant leaks:
    - Long piping lengths, high GWP refrigerants
    - High direct emissions
  - Significant energy consumption:
    - High indirect emissions
- Need system with reduced emissions and greater energy efficiency:
  - Lower direct and indirect emissions
  - Cost-effective, safe and reliable

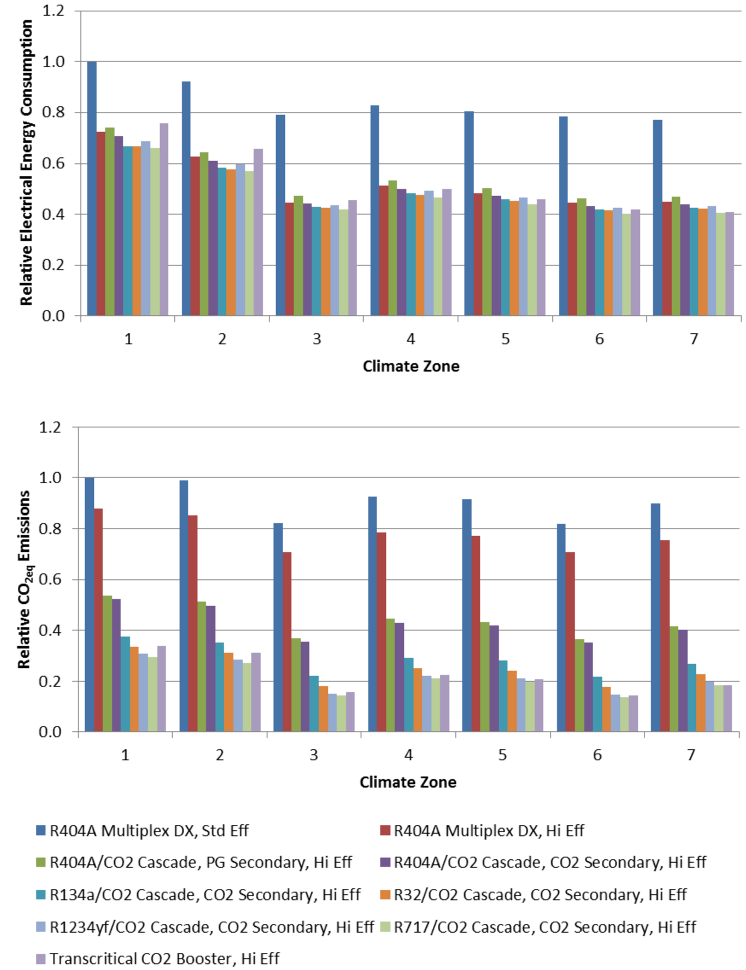
Distinctive Characteristics:

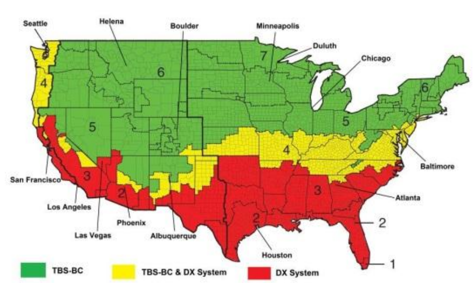
- Refrigeration system developed with industry partner
- System performance characterizations to be performed:
  - In lab, under controlled conditions
  - In field, under actual conditions

Progress and Accomplishments

Accomplishments:

– Analyzed energy consumption and environmental effects of various supermarket refrigeration systems
  - Multiplex DX, cascade/secondary, CO_2 transcritical, standard and high efficiency display cases
  - Added transcritical CO_2 booster system modeling to EnergyPlus
  - Evaluated energy consumption and LCCP of systems
  - Transcritical CO_2 system: 39% more efficient and 78% less emissions than baseline





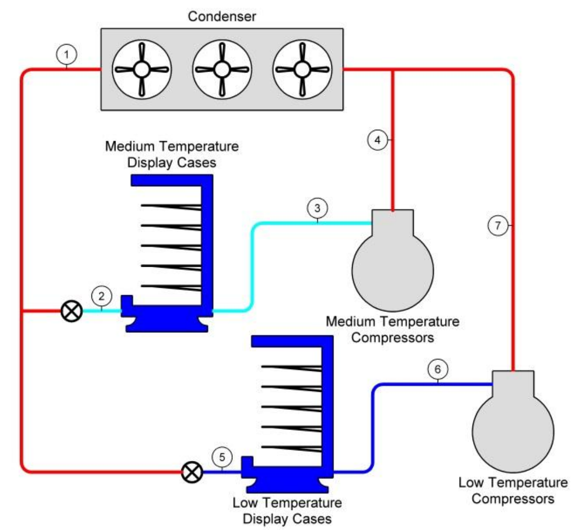
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

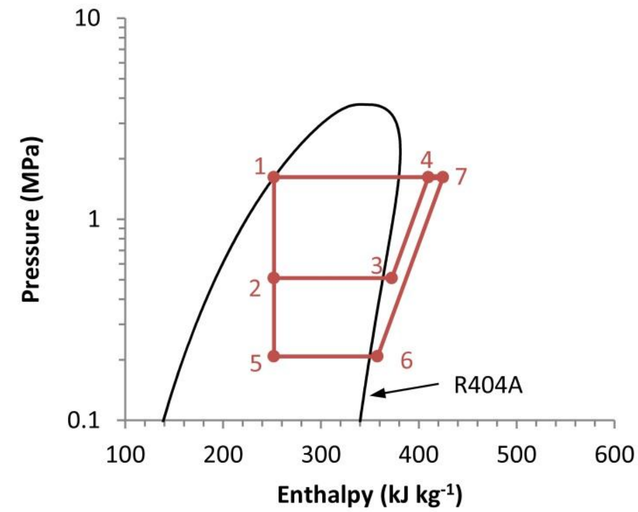
Progress and Accomplishments

Multiplex Direct Expansion (DX) System

Refrigerant: HFC

GWP: High (1600-4000)



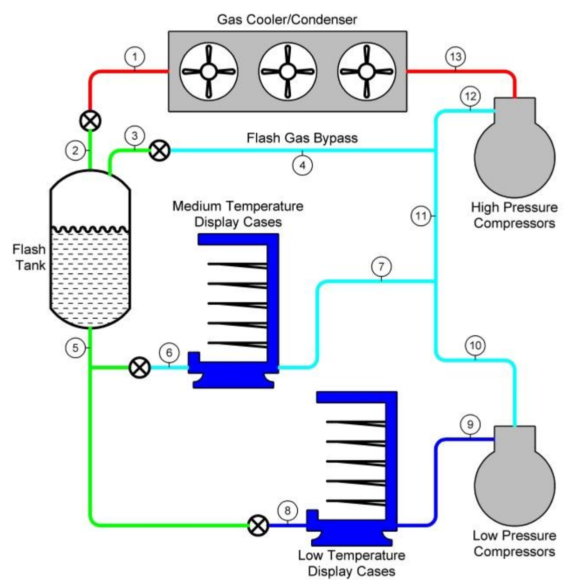


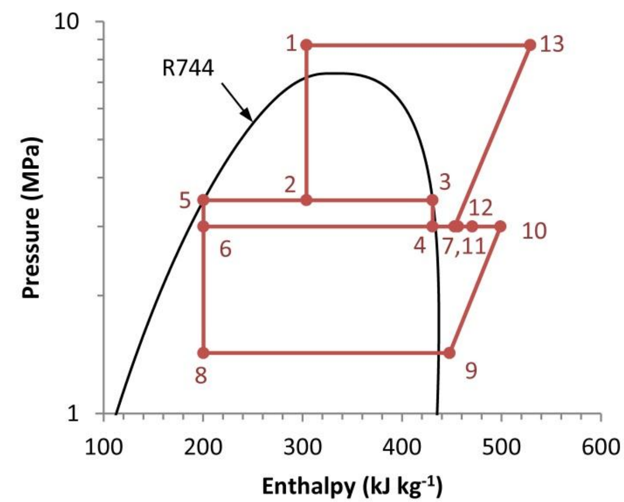
Transcritical CO_2 Booster System

Refrigerant: CO_2

GWP: Low (1)

In use in Europe and Canada, but not in US



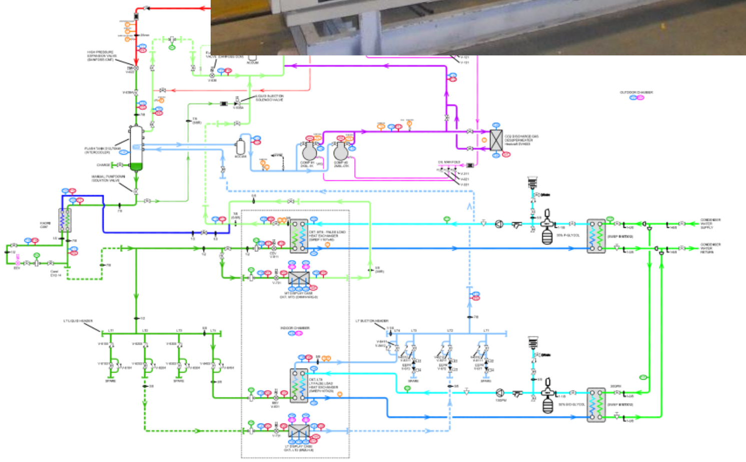


U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Progress and Accomplishments

Accomplishments:

- Developed prototype system
  - CO_2 transcritical booster
  - Based on results of energy and environmental analysis
  - Prepared design documents
- Fabricated prototype refrigeration system
  - Compressor rack
  - Gas cooler/condenser
  - Display cases
  - Fully instrumented
  - Installing system in ORNL's environmental chambers



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

Progress and Accomplishments

Market Impact:

- CRADA partner to deploy low emission high efficiency systems in 2014
- Conference presentations are raising interest in lower emission refrigeration systems, particularly CO_2 systems
  - Attendees are looking forward to seeing laboratory and field test results

Awards/Recognition:

- Not yet

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

Project Integration and Collaboration

Project Integration:

- Developing refrigeration system in collaboration with industry partners: Hill Phoenix, Danfoss, Luvata, SWEP
  - Collaborate via conference calls, email, site visits, meetings at conferences
- Professional organizations (ASHRAE, IIR, AHRI)
  - Interact with equipment manufacturers and end users at conferences

Project Integration and Collaboration

Partners, Subcontractors, and Collaborators:

- ORNL
  - Expertise in HVAC&R equipment performance evaluation and modeling
- Hill Phoenix
  - Supplier of commercial refrigeration systems and refrigerated display cases
- Danfoss
  - Supplier of refrigeration systems, sensors and controls
- Luvata
  - Supplier of heat exchangers, condensers and gas coolers
- SWEP
  - Supplier of brazed plate heat exchangers

Project Integration and Collaboration

Communications:

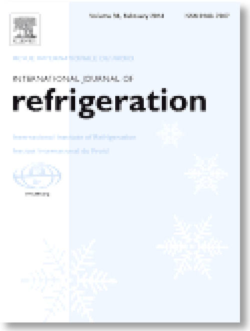
– PUBLICATIONS

- Fricke, Brian A., Pradeep Bansal, and Shitong Zha, "Energy Efficiency and Environmental Impact Analyses of Supermarket Refrigeration Systems," 2013 ASHRAE Summer Meeting, 22-26 June 2013, Denver, CO.

- Sharma, Vishaldeep, Brian A. Fricke, and Pradeep Bansal, "Thermodynamic Analysis of CO_2 Transcritical Supermarket Refrigeration Systems (NY-14-C012)," 2014 ASHRAE Winter Meeting, 18-22 January 2014, New York, NY.

- Sharma, Vishaldeep, Brian Fricke, and Pradeep Bansal, "Thermodynamic Analysis and Waste Heat Utilization of CO_2 Supermarket Refrigeration Systems," 11th International Energy Agency Heat Pump Conference, 12-16 May 2014, Montreal, Canada.

- Sharma, Vishaldeep, Brian Fricke, and Pradeep Bansal, "Comparative Analysis of Various CO_2 Configurations in Supermarket Refrigeration Systems," *International Journal of Refrigeration* (submitted).



Next Steps and Future Plans

Next Steps and Future Plans:

- Evaluate performance of prototype refrigeration system in laboratory
- Evaluate performance of refrigeration system in third-party installation
- CRADA partner to begin deploying systems by end of 2014
- Develop 2nd generation prototype system
  - Parallel compression
  - Evaporative gas cooler/condenser
  - Waste heat utilization

REFERENCE SLIDES

Project Budget

Project Budget: DOE total $1,700k FY12-16
Cost to Date: ~$586k through February 2014
Additional Funding: None expected.

Budget History					
FY2012 – FY2013 (past)		FY2014 (current)		FY2015 – FY2016 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$300k	*	$400k	*	$1,000k	*

* In-kind contribution from CRADA partner – exceeds DOE funding level; exact total is confidential information

Project Plan and Schedule

Project Schedule												
Project Start: 1 October 2011		Completed Work										
Projected End: 30 September 2016		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-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Past Work												
Q2 Milestone: Establish store/system criteria												
Q2 Milestone: Select/develop system models												
Q2 Milestone: Evaluate system design options												
Q2 Milestone: Develop prototype design												
Q4 Milestone: Develop lab test plan												
Current/Future Work												
Q2 Milestone: Fabricate/install prototype												
Q3 Milestone: Perform laboratory testing												
Q3 Milestone: Develop field test plan												
Q4 Milestone: Fabricate/install field system												
Q2 Milestone: Perform field testing												