BTO's Heat Pump Research Efforts

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

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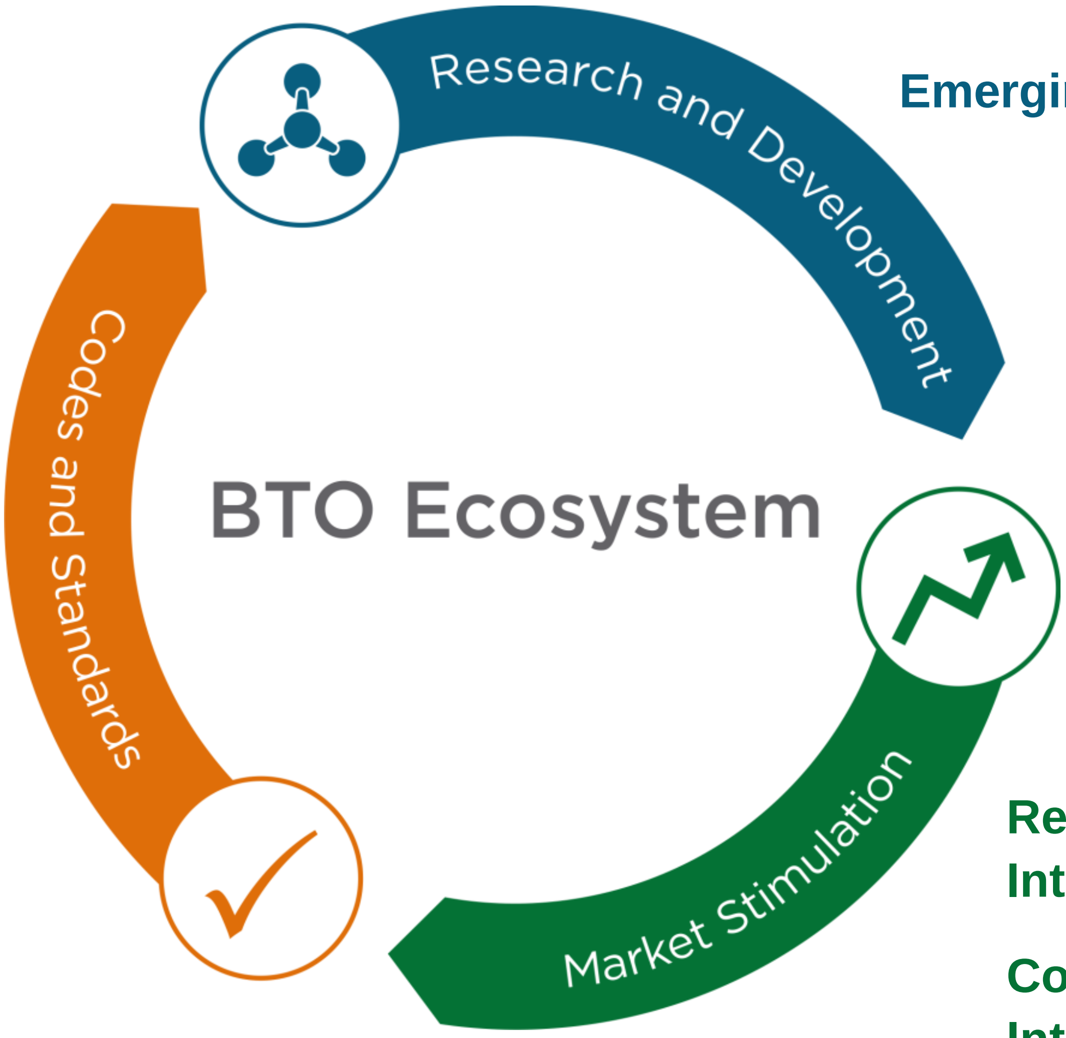
Outline

- BTO Ecosystem
- Introduction
- Cold Climate Heat Pump Research Projects
- Heat Exchangers
- Future Technologies

Building Technologies Office (BTO) Ecosystem

Codes and Standards



Emerging Technologies

Residential Buildings Integration

Commercial Buildings Integration

http://energy.gov/eere/buildings/building-technologies-office-2016-peer-review

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Introduction

Program Goals:

BTO's ultimate goal is to reduce the average energy use per square foot of all U.S. buildings by 50% from 2010 levels. Emerging Technologies Program's goal is to enable the development of cost-effective technologies capable of reducing a building's energy use per square foot by 30% by 2020 and cutting a building's use by 45% by 2030, relative to 2010 high-efficiency technologies.

HVAC/WH/Appliances goals require by 2020 that the potential energy use intensity (EUI) for:

- HVAC would be 60% lower
- WH would be 25% lower
- Appliances would be 15% lower
- All relative to 2010 energy-efficient baseline

Two-pronged approach to accelerate the development of new technologies:

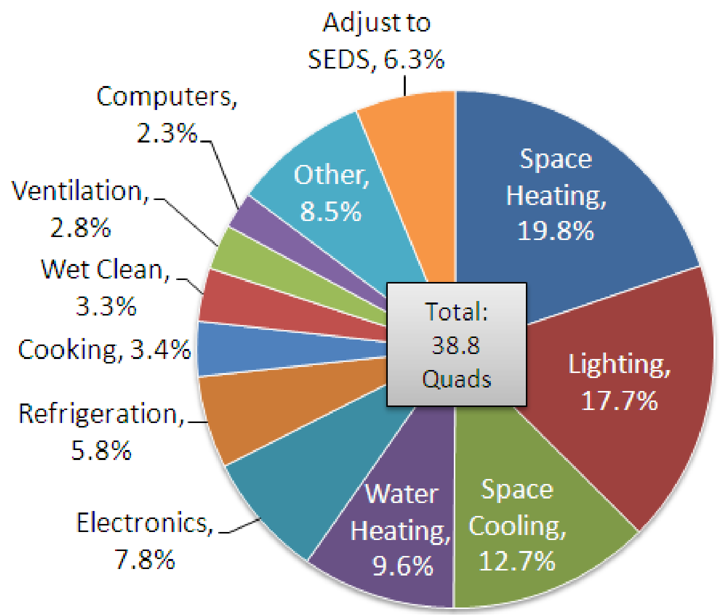
1) Accelerate the development of **near term** technologies that have the potential to save significant amount of energy (including cost reduction activities, bending the cost curve)
2) Accelerate the development of the **next generation** of technologies that have the potential of "leapfrogging" existing technologies by pursuing entirely new approaches (including crosscutting efforts)

The goal is to develop technologies that save energy and reduce our environment burden while introducing them in the simplest application first, highest probability of success.

The challenge…

- In addition to individual end-use solutions, integrated solutions are also pursued
- Energy cascading (using the waste heat from one process as the source of energy for another) is utilized
- Optimizing energy use in a building, an optimum point instead of just a local minimum (single end-use)
- Broad approach includes pursuing crosscutting technologies that enable better HVAC, water heating and appliances
- A **fast way to develop new technologies** and get them into the market is through CRADAs and FOAs (with manufactures as primes or as team members)
- Program seeks to build upon its past results and speed market availability and acceptance of economically viable new technologies
- **Not working in a vacuum**, most equipment is covered by appliance standards
- Engage manufacturers and BTO deployment teams
- ***Efficiency first***

Buildings Primary Energy Consumption



CRADAs: *Collaborative Research and Development Agreements*

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HVAC: Innovative and Economically Viable Solutions, *Efficiency first*

Regional Solutions

- *Low Ambient Heat Pump Research*
  - Where natural gas is unavailable or want to displace oil heat
  - Unlike standard heat pumps, can maintain capacity and efficiency (COP) at low ambient temperatures
- *Regional Solutions (Hot, Humid and Mixed)*
  - Air conditioning (AC) is more than just cooling air
  - Significant savings, on the order of 50-90%, are possible for technologies optimized for specific climates and applications
  - Large portion of the current building stock is located in hot and humid environments, which have the potential to create large latent (humidity) loads within buildings

Integrated Heat Pump (IHP) research, energy saving potentials approaching 50% when HVAC and water heating is coupled

Non-vapor compression research, no refrigerants (saving energy while reducing environment burdens)

- Potential of "leapfrogging" existing HVAC technologies by pursuing entirely new approaches
- Examples: Ab/Ad-sorption Heat Pumps, Electrocaloric, Electro Chemical Compression (ECC) technology, Magnetocaloric, Membranes, Thermoelastic, Thermoelectric, etc

Crosscutting technologies

- Heat exchanger research
- Compressor research
- Refrigerant research (Low-GWP solutions)
- Motors
- Materials Joining Technologies

Cold Climate Heat Pump Research Projects

Heat Pump Technologies: Regional Solutions (Cold Climates)

Cold Climate Heat Pump Technology

- Target markets: Cold climate regions
  - Where natural gas is unavailable or want to displace oil heat
  - Improving the performance of natural gas systems
- Unlike standard heat pumps, can maintain capacity and efficiency (COP) at low ambient temperatures
- Technology includes multi-stage compressors, non-HFC refrigerants (e.g. CO_2) and absorption systems.
- If electricity generated from low carbon sources, can reduce carbon emissions from gas heating

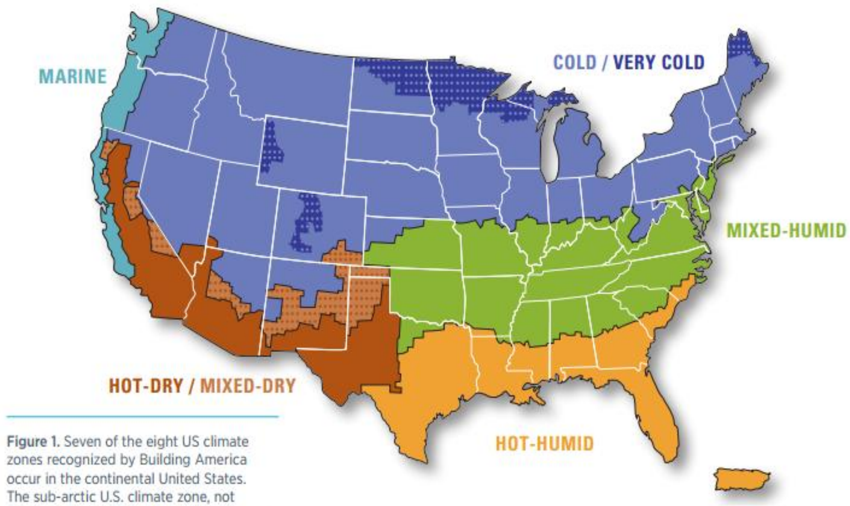

Figure 1. Seven of the eight US climate zones recognized by Building America occur in the continental United States. The sub-arctic U.S. climate zone, not shown on the map, appears only in Alaska.

Image Source: "High Performance Home Technologies – Guide to Determining Climate Regions by County." PNNL and ORNL. August 2010.

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Heat Pump Technologies: Regional Solutions (Cold Climates)

DOE's targets

- Setting the standard for cold climate performance
- Targets for both electrical and natural gas systems

Current BTO Activities

- IEA Annex 41, Cold Climate Heat Pumps
- Development of a High Performance Cold Climate Heat Pump (Purdue University)
- Supercharger for Heat Pumps in Cold Climates (Mechanical Solutions, Inc.)
- Cold Climate Heat Pump (CRADA Project at ORNL)
- High Performance Commercial Cold Climate Heat Pump (CCCHP) , (United Technologies Research Center)
- Residential Cold Climate Heat Pump with Variable Speed Boosted Compression, (Unico)
- Natural Refrigerant High Performance Heat Pump for Commercial Applications, (S-RAM Dynamics)
- Natural Gas Air Conditioner and Heat Pump, (ThermoLift, Inc., Vuilleumier cycle)
- Low-Cost Gas Heat Pump For Building Space Heating, (Stone Mountain Technologies, Inc.)

DOE Cold Climate Heat Pump R&D Performance Targets (Electricity, Residential)

Ambient Temperature (°F)	COP	Maximum Capacity Decrease from Nominal (%)
47	4	0
17	3.5	10
-13	3	25

DOE Cold Climate Heat Pump R&D Performance Targets (Natural Gas, Residential)*

Ambient Temperature (°F)	COP	Maximum Capacity Decrease from Nominal (%)
47	1.3	0
17	1.15	20
-13	1.0	50

DOE Cold Climate Heat Pump R&D Performance Targets (Electricity, Commercial)

Ambient Temperature (°F)	COP	Maximum Capacity Decrease from Nominal (%)
47	4	0
17	3	10
-13	2.5	25

**COP based on higher heating value of natural gas*

Stone Mountain Technologies, Inc.: Low-Cost Gas Heat Pump for Building Space Heating

- Develop and demonstrate a gas-fired absorption heat pump, with heating COP's greater than 1.0 at low ambient. Design simplicity and volume manufacturing requirements emphasized from conception. Achieving a projected 2-5 year economic payback to drive market penetration is a higher priority than ultra-high efficiency.
- Optimized Simple Single-Effect Cycle That Predicts Target Performance (ammonia).
- Low-Cost Solution Pump Successfully Scaled Up Factor of 10.
- Alpha Packaged Prototype Fabricated & Lab Tested
- Preliminary manufacturing cost estimate within target range.

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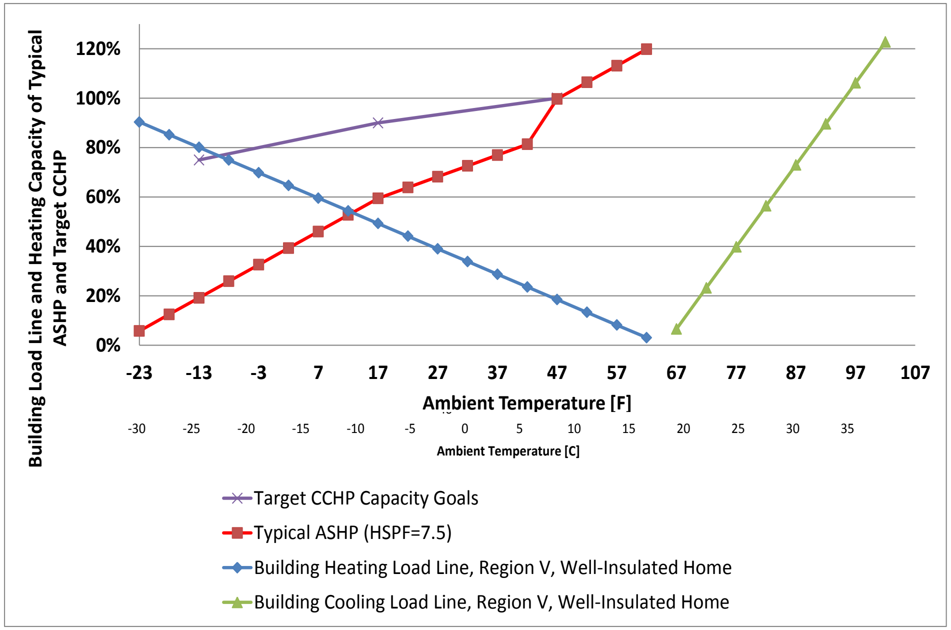
ORNL and Emerson Climate Technologies, Cold Climate Heat Pump

Between 2011 and 2015, researchers at DOE's Oak Ridge National Laboratory (ORNL) and Emerson Climate Technologies engaged in a Cooperative Research and Development Agreement (CRADA) to develop a high efficiency, Cold Climate Heat Pump (CCHP) for the U.S. residential market.

- Exhaustive technology survey and conducted in-depth engineering design and building energy modeling, using the ORNL Heat Pump Design Model (HPDM) and EnergyPlus
- Ultimately, a system was chosen that utilized tandem compressors in combination with a compressor discharge temperature control
- Tandem compressors, i.e. two parallel, equal-size, single-speed compressors, provided by Emerson Climate Technologies, were optimized for heating operation and can tolerate discharge temperatures up to 280°F
- Team developed both lab and field prototypes, which successfully met DOE's performance targets
- Lab prototype featured the tandem single-speed compressors, and reached a 4.2 coefficient of performance (COP) at 47°F, 76% of rated heating capacity, 1.9 COP at -13°F, and 2.9 COP at 17°F, with a rated heating seasonal performance factor (HSPF), as defined in AHRI 210/240, of 11.2



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ORNL and Emerson Climate Technologies, Cold Climate Heat Pump

Prototype was built based on the tandem compressors concept and used in a field investigation in an occupied home in Ohio for 12 months, beginning in 2015.

- During the heating season, a measured HSPF of 10.8 was achieved, and the HP was able to operate in temperatures as low as -13°F with no resistance heat use
- CCHP maintained an acceptable comfort level through the heating season, and achieved a measured seasonal energy efficiency ratio (SEER) 17.7 during the cooling season
- In comparison to the homeowner's previous conventional air-source heat pump (ASHP), >40% energy saving was achieved by the prototype CCHP in a peak heating load month with overall average ambient temperature around 20°F.
- As part of this CRADA, a second "premium" prototype CCHP design using tandem vapor injection (VI) compressors was also developed
  - Laboratory tests, the "premium" prototype reached 4.4 COP at 47°F; 88% heating capacity and 2.0 COP at -13°F, and 3.1 COP at 17°F, with a rated HSPF of 11.8.
  - "Premium" prototype performance is uniformly 5% higher than that of the field-tested prototype with non-VI single-speed compressors.

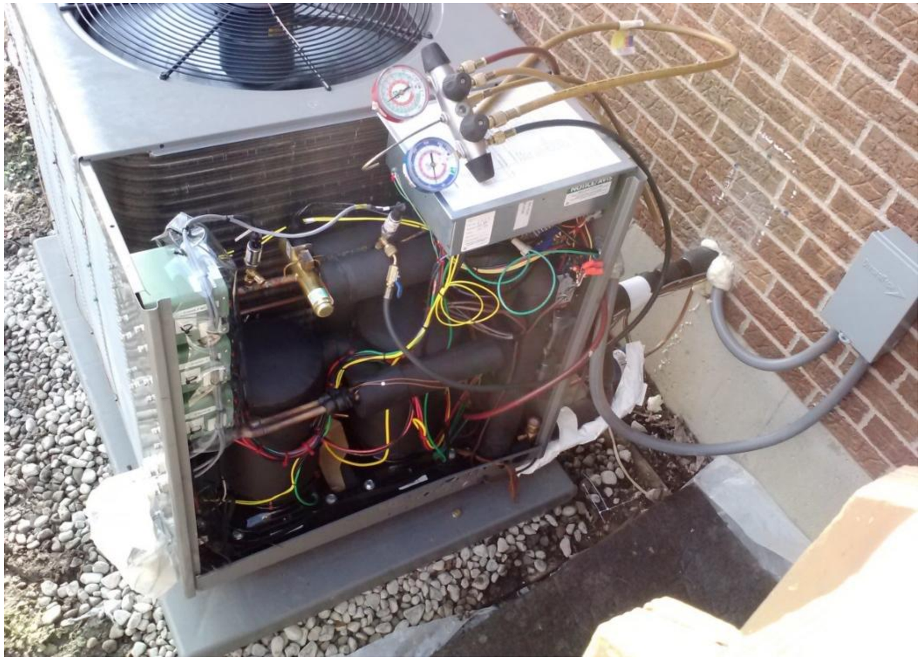


Figure: Photo of the prototype CCHP outdoor unit as installed at the Ohio field test site in January 2015

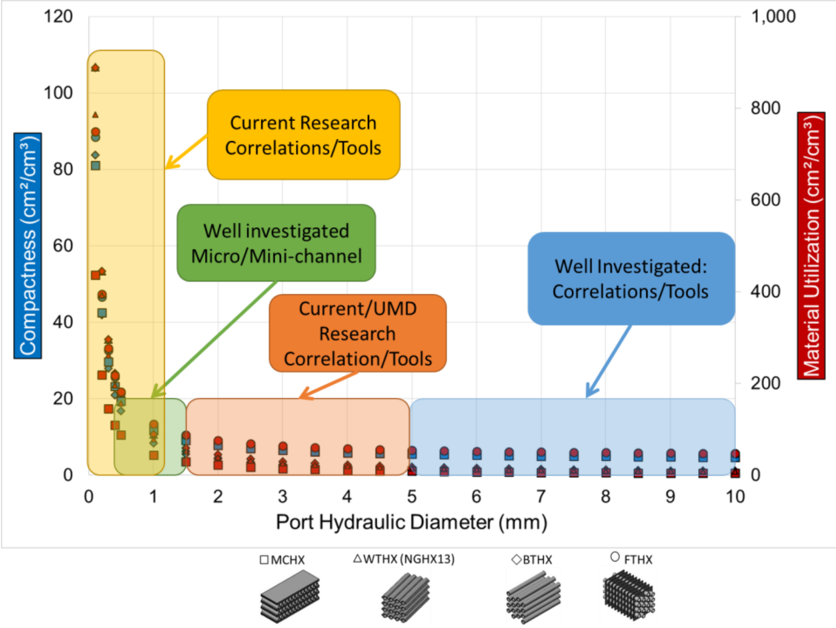
This project resulted in the development of a split system, CCHP, providing a nominal 36,000 Btu/hr (10.6 kW) heating capacity with a COP > 4.0 (at the 47°F AHRI rating condition) and maximum efficiency degradation of 50% and capacity loss of 25% at -13°F ambient conditions.

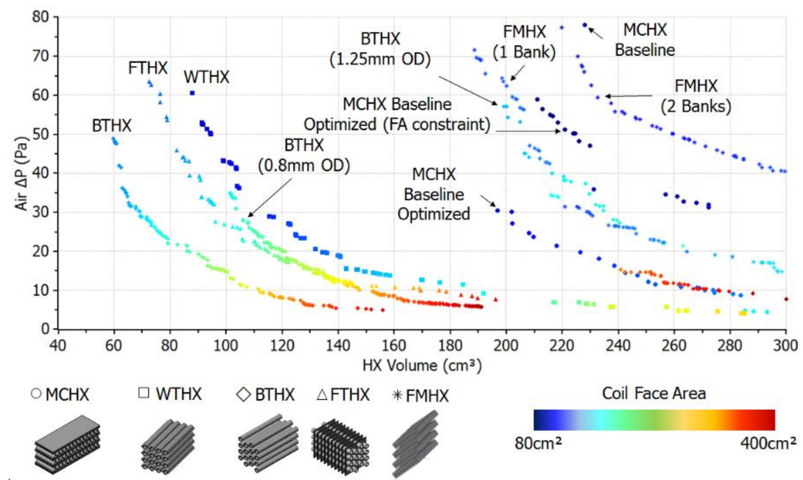
Heat Exchangers

BTO HVAC Program: Heat Exchangers

Miniaturized Air-to-Refrigerant Heat Exchangers (UMD)

- Develop miniaturized air-to-refrigerant heat exchangers that are 20% better, in size, weight and performance, than current designs AND in production within 5 Years
- HVAC&R industry have used tube-fin heat exchangers
- Started transitioning to multi-port flat tubes, also known as microchannel heat exchangers
- Development of microchannel heat exchangers and introduction in the HVAC&R industry took more than 20 years due to challenges in water drainage, fouling, and perceived risks by design engineers.
- Project aims at developing the next generation of air-to-refrigerant HX that would improve the ***heat transfer, reduce pressure drop, increase robustness, and improve cost competitiveness***.



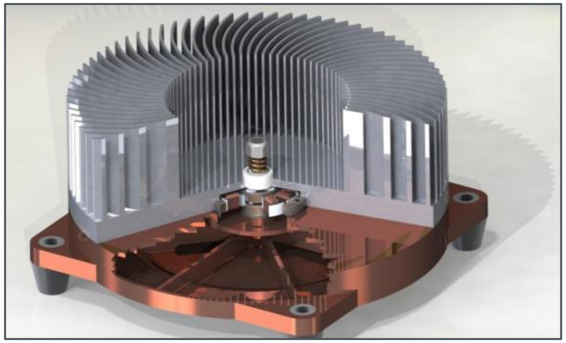


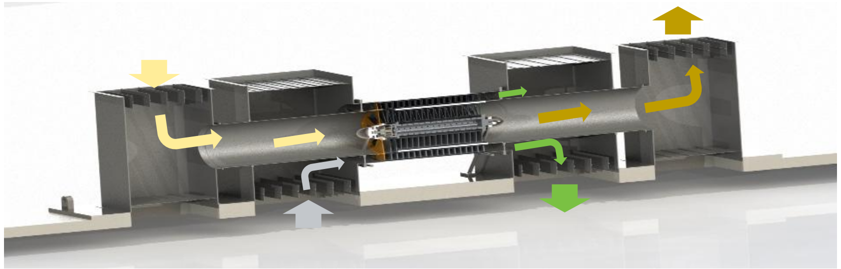
http://energy.gov/eere/buildings/downloads/miniaturized-air-refrigerant-heat-exchangers

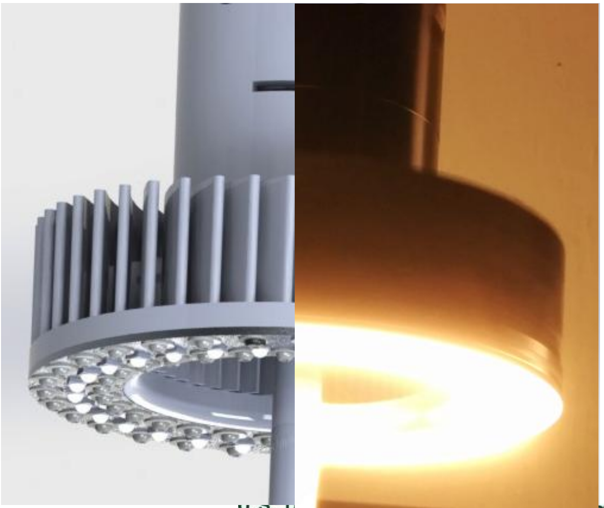
BTO HVAC Program: Heat Exchangers

Sandia Cooler Technology

- Rethink Heat Exchanger (HX) technology entirety
- Attack the boundary layer, noise, and heat sink fouling problems simultaneously with a rotating HX
- Use hydrodynamic air bearing technology to transmit heat to rotating frame
- Numerous applications of this new heat exchanger technology are now being explored
  - Computer chip cooling first (CPU/GPU)
  - Thermoelectric heat pumps
  - HVAC Heat Pumping (Rotary Vapor Compression Cycle Technology)
  - LED lighting and others







Future Technologies

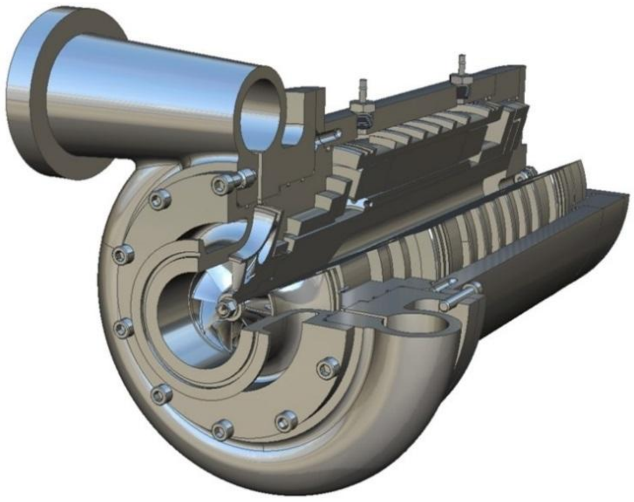
Advanced Vapor Compression:

Mechanical Solutions, Inc. (MSI) and **Lennox Industries, Inc.** will receive $1 million to develop a low-Global Warming Potential (GWP) HVAC system featuring ultra-small centrifugal compression to meet DOE's requirement for more efficient HVAC systems. The developed system will be in the 2- to 20-ton range.

- Achieve system-level integration of a low-GWP refrigerant and an ultra-small compressor, including heat exchanger, control methodology, "drop in" replace-ability, and more flexibility in product packaging
- Produce the compressor for a cost that is equal to or less than current heavier, bigger and less efficient solutions
- Ultra-small compressor will feature increased efficiency and oil-free operation
- All in a form factor less than 1/10th the size of a comparable scroll compressor
- Heat exchanger system will also be optimized for the oil-less, very low-GWP refrigerant

United Technologies Research Center (UTRC) will receive $975,000 to demonstrate a high efficiency centrifugal compressor design.

- Enable high efficiency small commercial rooftop systems in the 1.5- to 10-ton range
- Compared to units operating in the 50-ton range
- Could provide 30% annual energy savings with less than two years payback by 2020
- If fully commercialized, could save 2.5 quads of energy by 2030 (USA only)



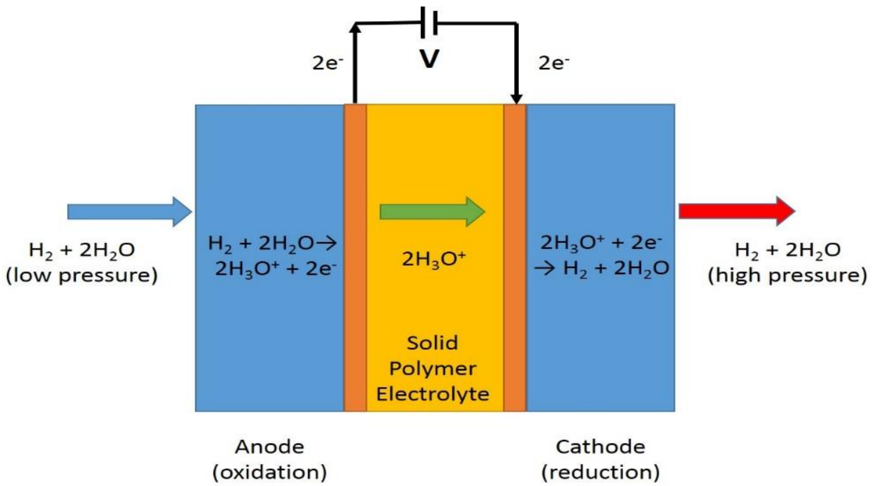
Mechanical Solutions, Inc.'s ultra-small centrifugal compressor concept will facilitate low-GWP refrigerant adoption.
Photo Credit: Mechanical Solutions, Inc.

BTO HVAC Program: Platforms to innovate from

Xergy's Low-Cost Electrochemical Compressor Technology

- Electrochemical compressor (ECC) to replace mechanical compressors
- Use water as the working fluid, rather than a refrigerant, which contributes to climate change and is used by vapor-compression systems
- Electrochemical compressor creates a refrigeration cycle by producing a small volume of lightly pressurized hydrogen from electricity
- Leveraging hydrogen's excellent thermodynamic characteristics, as well as existing proton-exchange-membrane (PEM) technology
- Numerous applications of this new compressor technology are now being explored
  - Water Heaters
  - HVAC systems, with improved management of latent and sensible heat loads with unprecedented efficiency
  - Document dehumidification system
  - Compact fuel cells
  - Membrane could potential be used for desalination applications

Electrochemical compressor for HVAC schematic.



Individual electrochemical compressor cells are arranged in stacks. (Cary Zachary, 2015)

Thank You

The HVAC/Water Heating/Appliance subprogram develops cost effective, energy efficient technologies with national labs and industry partners. Technical analysis has shown that heat pumps have the technical potential to save up to 50% of the energy used by conventional HVAC technologies in residential buildings. Our focus is on the introduction of new heat pumping technologies, heat exchanger technologies, and advanced appliances, e.g., refrigerator and clothes dryers. Heat exchangers are used not only in air conditioning, heating, water heating and refrigeration but also in nearly every application that generates waste heat, a major crosscutting research opportunity. We are also pursuing non-vapor compression technologies, which have the potential to replace or be integrated with conventional vapor compression technologies, can provide 50% reductions in energy consumption, and have extremely low-global warming potential.

http://energy.gov/eere/buildings/hvac-water-heating-and-appliances

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