ET's HVAC, WH and Appliance R&D

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Introduction

Program Goals:

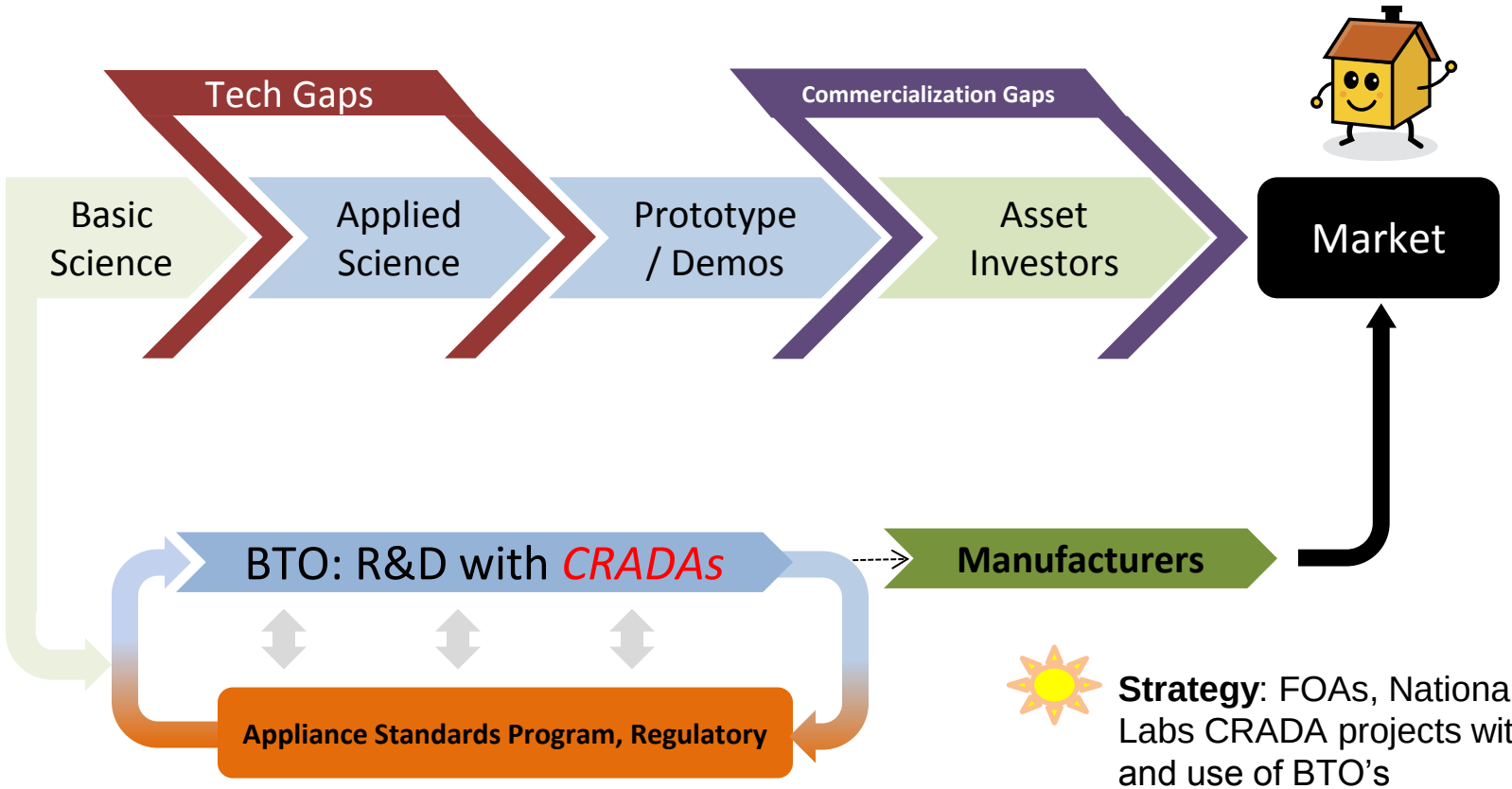
- *Support BTO's goals to achieve 50 percent building energy savings*
- By 2020, develop technologies enabling 20 percent energy savings in HVAC; 30 percent energy savings in water heating, and 10 percent energy savings in appliances
- By 2030, develop technologies enabling 40 percent energy savings in HVAC; 60 percent energy savings in water heating, and 20 percent energy savings in appliances
- Maintain the competitiveness of American industry (equipment and ***brains too***!)

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 (which may include cost reduction activities)
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*.

HVAC, Water Heating and Appliance R&D



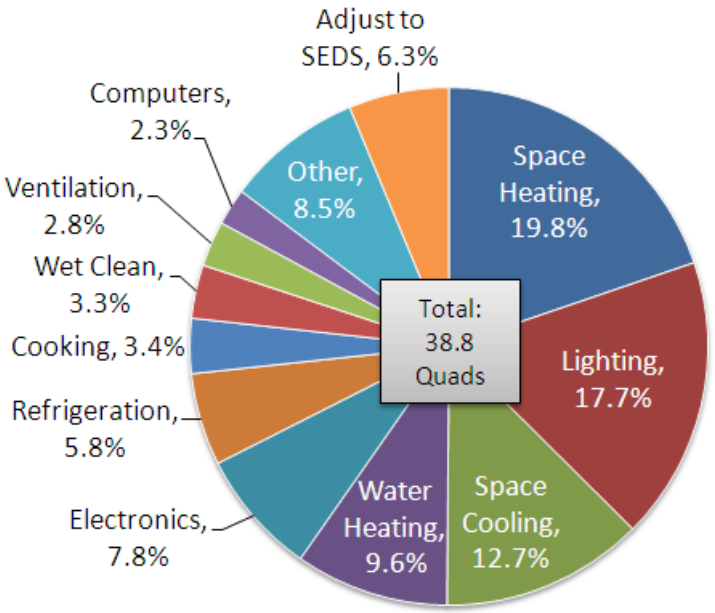
Strategy: FOAs, National Labs CRADA projects with and use of BTO's integration teams with research homes

CRADA : Collaborative Research and Development Agreement

The challenge…

- In addition to pursuing individual end-uses solutions integrated solution are also pursued
- In which energy cascading (using the waste heat from one process as the source of energy for another) is utilized
- Optimizing energy use in a building, a global optimum point instead of just a local minimum (single end-use)
- Board approach also includes pursing 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 team members)
- Program seeks to build upon its past and speed the market availability and acceptance of new technologies
- Not working in vacuum, most equipment is covered by appliance standards

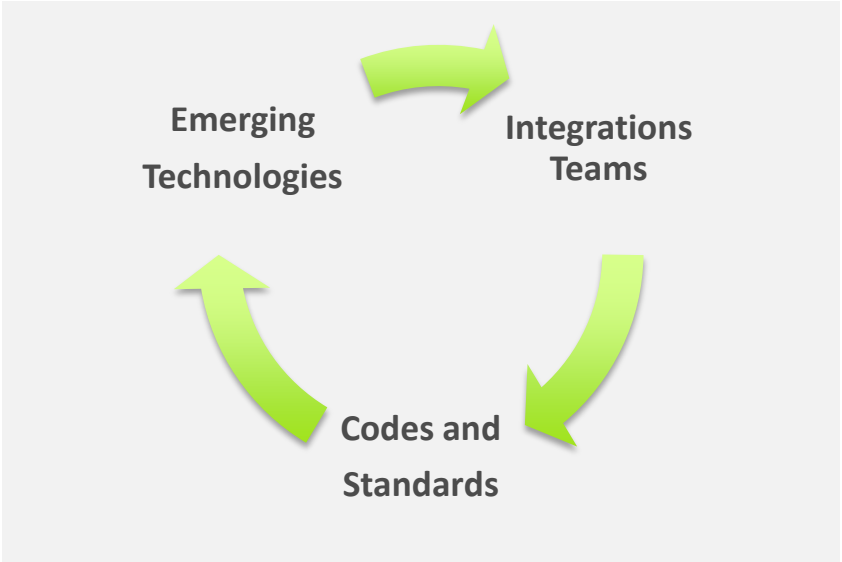
Buildings Primary Energy Consumption



The Building Technologies Office (BTO) uses an Integrated Approach to Deliver Savings

Emerging Technologies (Research & Development)

- Develop technology roadmaps and reports
- Prioritize opportunities for DOE
- Solicit and select innovative technology solutions
- Collaborate with researchers and market performers
- Solve technical barriers and test innovations to prove effectiveness
- Measure and validate energy savings



Integration Teams (Market Priming)

- Identify barriers to “speed and scale” adoption
- Develops solutions to policy, adoption, and financial barriers
  - Collaborate with industry partners to improve market adoption
  - Increase usage of products and services
  - Communicate the importance and value of energy efficiency
  - Provide technical assistance
  - Support development of workforce training and certification

Codes and Standards

- Establish minimum energy use in a transparent public process- raise the efficiency bar
- Protect consumer interests
- Reduce market confusion
- Enhance industry competitiveness and profitability
- Expand portfolio of energy efficient appliances and equipment

Wednesday, April 23, 2014: HVAC

Project	Area
Unico - Residential Cold Climate Heat Pump with Variable Speed Technology	Cold Climate Research
ORNL - Cold Climate Heat Pump	Cold Climate Research
UTRC - High Performance Commercial Cold Climate Heat Pump (CCCHP)	Cold Climate Research
Thermolift - The Natural Gas Heat Pump and Air Conditioner	Cold Climate Research
S-Ram - Natural Refrigerant High Performance Heat Pump for Commercial Applications	Cold Climate Research and Low GWP option
ORNL - Advanced Variable-Speed Air Source IHP	Integrated Heat Research
ORNL - 13 EER Window Air Conditioner	HVAC
SNL - Heat Exchanger Research	Crosscutting: Heat Exchanger Research

Thursday, April 24, 2014: HVAC

Project	Area
University of Maryland - Miniaturized Air to Refrigerant Heat Exchangers	Crosscutting: Heat Exchanger Research
Stone Mountain Technologies - Low-Cost Gas Heat Pump For Building Space Heating	Cold Climate Research and Natural Gas Technology
Architectural Applications Inc. - Building Integrated Heat and Moisture Exchange	SBIR, Regional Solutions (Hot, Humid and Mixed)
ORNL - Absorption Heat Pump Water Heater (HPWH)	Water Heating, Low GWP option and Natural Gas Technology
ORNL - CO2 Heat Pump Water Heater (HPWH)	Water Heating and Low GWP option
ORNL - Multi-Function Fuel-Fired Heat Pump	Integrated Heat Research
ORNL - Data Analysis from ARRA funded GSHP Demo Projects	Data Analysis of ARRA projects
ORNL - Working Fluids Low Global Warming Potential Refrigerants	Crosscutting: Heat Exchanger Research
NIST - Thermodynamic Evaluation of Low-Global Warming Potential Refrigerants	Refrigerant Research
CERC: Advanced ground source heat pump technology for very low energy buildings	GSHP
CBERD: Advanced HVAC w/ ORNL	HVAC

Wednesday, April 23, 2014: Appliances

Project	Area
ORNL - High Efficiency Low Emission Refrigeration System	Refrigeration and Low GWP option
ORNL - Magnetocaloric Refrigeration	Refrigeration and Non-vapor compression research
LBNL - Max Tech and Beyond	Appliances and training the next generation of appliance engineers

Integrated Heat Pump (IHP) Technologies, a huge opportunity

Integrated Approach

- Energy cascading is the process of using the waste (or residual) heat from one process as the energy source for another
- Concept is to merge several end-use together, generate a new solution, coupling things together
- Good example exists today from BTO's integrated heat pump work where the waste heat from the AC is used to heat water for free with energy saving potentials approaching 50% when HVAC and water heating is coupled
- HVAC Integrated Heat Pump (IHP) Technologies:
  - Air Source (AS)-IHP (2-speed), ***40% to 45%*** energy savings vs. min efficiency equipment suite
  - AS-IHP (variable speed), ***45% to 55%*** energy savings vs. min efficiency equipment suite
  - Multifunction Natural Gas-driven HP (10 to 17.5 kW), 70% peak demand savings; 40% source energy savings vs. minimum efficiency electric heat pump, with power generation
  - Thermolift, one year effort to demonstrate Vuilleumier heat pump (VHP) technology
  - Developing Standard Method of Test (MOT) for IHP, working with ASHRAE/AHRI

Today's IHP technology from BTO…
more products in the pipeline

ClimateMaster CRADA

- Multifunction Electric Heat Pumps, GS-IHP
- Space conditioning, water heating, dehumidification, and ventilation
- Trilogy 40 Q-Mode™ could save about 60% of annual energy use and cost for space conditioning and water heating in residential applications
- 30% more efficient than any other available ground-source heat pump
- Broke the 40 EER Barrier in the USA
- Award Winning

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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

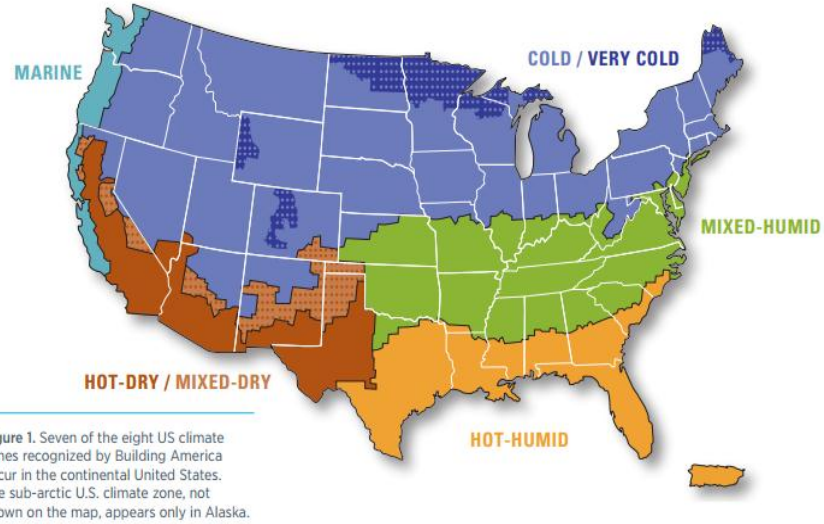


Figure 1. Seven of the eight US climate zones recognized by Building America occur in the continental United States. The sub-arctic U.S. climate zone, not shown on the map, appears only in Alaska.

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

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)

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)*

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

COP based on higher heating value of natural gas

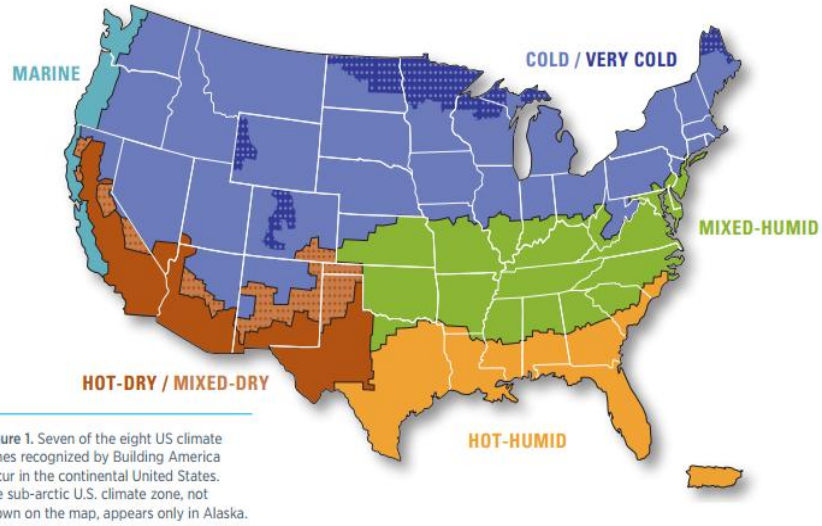
Heat Pump Technologies: Regional Solutions (Hot, Humid and Mixed)

Separate Sensible and Latent Cooling AC Systems

- Target markets: Large portion of the current building stock is located in hot and humid environments, which have the potential to create large latent loads within buildings
- HVAC was the largest energy end use for U.S. residential and commercial buildings, consuming approximately 37.3% (or ~15.05 Quads) of the total energy used in buildings.
- Significant savings, on the order of 50-90%, are possible for technologies optimized for specific climates and applications (DOE's QTR)
- Air conditioning (AC) is more than just cooling air
- Total cooling load, composed of both the sensible load (temperature) and the latent load (humidity)
- Conventional air conditioning (AC) systems have limited control of sensible cooling and latent cooling capacities

Current BTO Activities

- Max Tech and Beyond Design Competition for Ultra-Low-Energy-Use Appliances and Equipment Winner for 2012, University of Maryland Window Unit
- DOE workshop, Spring 2013
- Next Steps being worked on… FOA Topic?



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Climate Zone	Percentage of Homes with AC (2009), by Climate Zone
Very Cold / Cold	34%
Mixed-Humid	**31%**
Mixed-Dry / Hot-Dry	12%
Hot-Humid	**17%**
Marine	6%

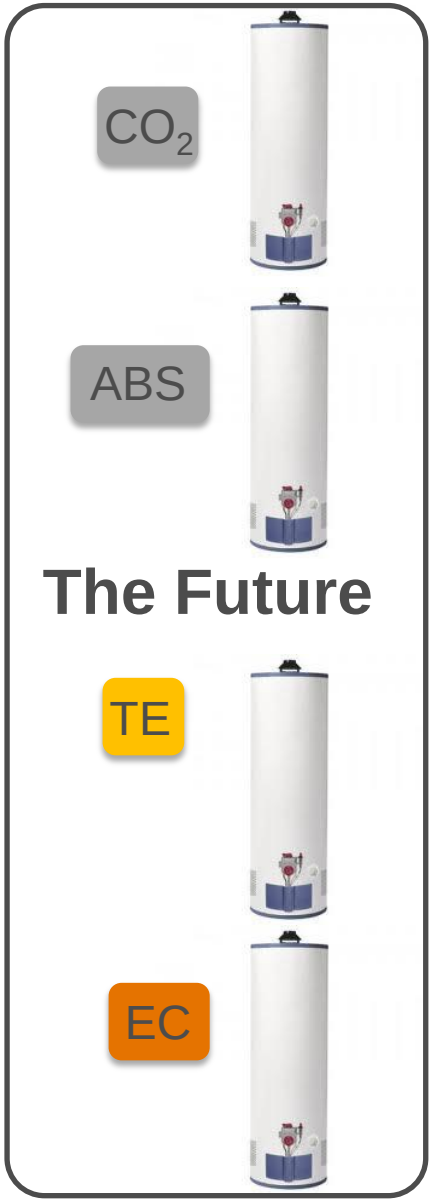
Source: 2009 Residential Energy Consumption Survey (RECS), U.S. Energy Information Administration, Table HC7.6

Heat Pump Technologies, still a huge opportunity for *Water Heating*

Heat Pump Water Heaters

- Electric Heat Pump Water Heater (HPWH) with low-GWP option (**CO_2**), 15% energy savings compared to Energy Star HPWH and better performance in colder climates
- Absorption (ABS) HPWH, 45% energy savings compared to Energy Star Natural Gas Storage WH
- Next generation of water heating solutions
  - Address the high first cost issue
  - Sheetak (Thermoelectric, **TE**) and Xergy (Electrochemical compressor technology, **EC**), SBIR projects are planting the seeds of change towards a non-vapor compression future
  - Modular designs for greater flexibility

Today's technology from BTO



HVAC, WH & Appliance: Non-vapor-compression technologies

What comes after vapor compression technology?

- Absorption Heat Pump, Adsorption Heat Pump, Bernoulli Heat Pump, Brayton Heat Pump, Critical Flow Refrigeration Cycle, Duplex Stirling Cycle, Ejector Heat Pump, Electrocaloric, Electro Chemical Compression (ECC) technology, Evaporative Cooling, Evaporative Liquid Desiccant A/C, Magnetocaloric, Membrane Heat Pump, Pulse Tube Refrigeration, Standalone Liquid Desiccant A/C, Standalone Solid Desiccant A/C, Thermoacoustic, Thermoelastic, Thermoelectric, Thermotunneling, Vuilleumier Heat Pump and Vortex Tube Cooling

Desirable characteristics:

- Good LCCP (Life Cycle Climate Performance), continuous response to part load conditions, integrated thermal storage, minimal/zero water consumption, cost effective, reduced size/weight and readily available materials

Moving towards non-vapor-compression air conditioning technologies

- Potential of “leapfrogging” existing HVAC technologies by pursuing entirely new approaches that offer better performance with reduced environment burden
- Use water heating as a starting point towards future AC technologies
  - Non-vapor compression water heating solutions, are near term viable solutions… while going beyond resistive heating
  - Xergy and Sheetak SBIR projects are planting the seeds of change towards a non-vapor compression future (will in next year’s peer review)

Backup Slides

HVAC, WH and Appliance R&D

Current Projects:

HVAC

- 13 EER Window Air Conditioner (ORNL)
- Advanced Variable-Speed Air-Source IHP (ORNL)
- Cold Climate Heat Pump (ORNL)
- Develop Standard Method of Test (ORNL)
- IEA Collaboration (ORNL)
- Multi-Function Fuel-Fired Heat Pump (ORNL)
- Next Generation RTU (ORNL)
- Advanced Rotating Heat Exchangers (ORNL and SNL)
- High Performance Commercial Cold Climate Heat Pump (CCCHP), (UTRC, DE-FOA-0000621)
- Residential Cold Climate Heat Pump, (Unico, DE-FOA-0000621)
- Low-Cost Gas Heat Pump For Building Space Heating (Stone Mountain Technologies, DE-FOA-0000621)
- Natural Refrigerant High Performance Heat Pump for Commercial Applications (S-RAM Dynamics, DE-FOA-0000823)
- Rotating Heat Exchanger Technology for Residential HVAC (SNL, DE-FOA-0000823)
- Natural Gas Air Conditioner and Heat Pump (ThermoLift, DE-FOA-0000823)
- Thermodynamic Evaluation of Low-Global Warming Potential Refrigerants (NIST)

Water Heating

- Absorption HPWH (ORNL)
- CO2 HPWH (ORNL)
- Adsorption Heat Pump Water Heater (ORNL)
- Sheetak (Thermoelectric, TE) and Xergy (Electrochemical compressor technology, EC), SBIR projects

Appliances, and other

- Heat Pump Dryer (ORNL)
- High Efficiency Low Emission Refrigeration System (ORNL)
- Working Fluids Low GWP Refrigerants (ORNL)
- Advanced Compressor Technologies (ORNL)
- Magnetic Refrigeration (ORNL)
- Miniaturized Air to Refrigerant Heat Exchangers (UMD, DE-FOA-0000621)

HVAC, WH and Appliance R&D

Past Activities (ARRA):

HVAC

- Development of a High Performance Cold Climate Heat Pump (*Purdue University and Emerson Climate Technologies*)
- Development of a Non-CFC-based, Critical Flow, Non-Vapor Compression Cooling Cycle (*PAX Streamline, Inc. and Kansas State University*)
- Improving Best Air Conditioner Efficiency by 20-30% through a High Efficiency Fan and Diffuser Stage Coupled with an Evaporative Condenser Pre-Cooler (*Florida Solar Energy Center*)
- Advanced Magnetic Refrigerant Materials (*GE Global Research*)
- Optimization of Regenerators for Active Magnetic Regenerative Refrigeration Systems (*University of Wisconsin Solar Energy Lab*)
- An Innovative Reactor Technology to Improve Indoor Air Quality (*TIAX, LLC)*

Water Heating

- Development and Validation of a Gas-Fired Residential Heat Pump Water Heater (*Stone Mountain Technologies, Inc.*)
- High Energy Efficiency R-744 Commercial Heat Pump Water Heaters (*Creative Thermal Solutions, Inc.)*
- Water Heater ZigBee Open Standard Wireless Controller (*Emerson Electric Co.*)

Working Fluids

- Energy Efficient Commercial Refrigeration with Carbon Dioxide Refrigerant and Novel Expanders (*TIAX, LLC*)
- Low Global Warming Potential Very High Performance Air-Conditioning System (*United Technologies Research Center and University of Illinois-Urbana Champaign*)
- Developing Next Generation Refrigeration Lubricants for Low Global Warming Potential/Low Ozone Depleting Refrigeration and Air Conditioning Systems (*Chemtura Corp.)*
- Experimental and Numerical Investigation to Enhance the Performance of Building Heating and Cooling Systems Using Nanofluids *(University of Alaska Fairbanks)*