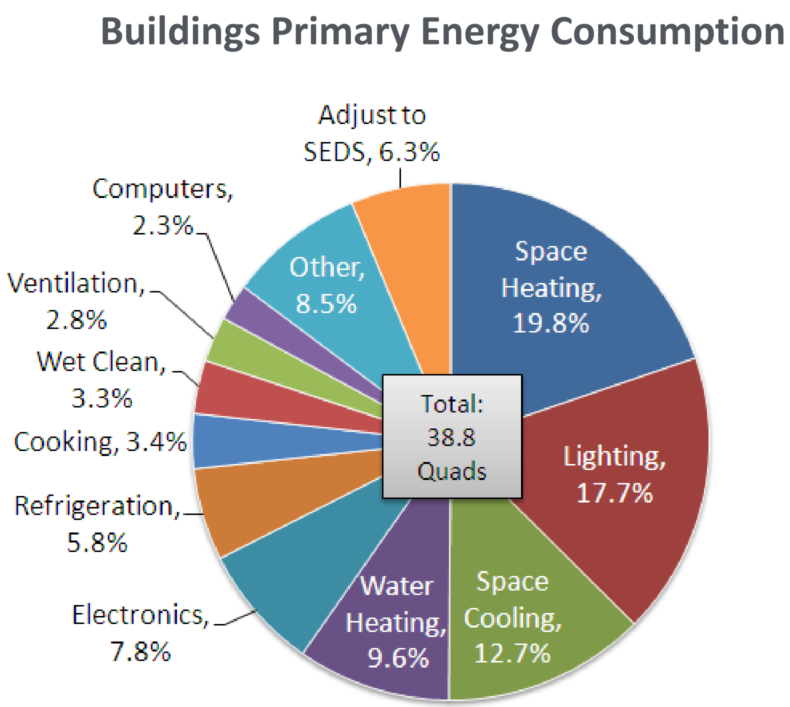
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

HVAC, Water Heating, and Working Fluids R&D

Antonio M. Bouza, DOE/BTP
Technology Development Manager

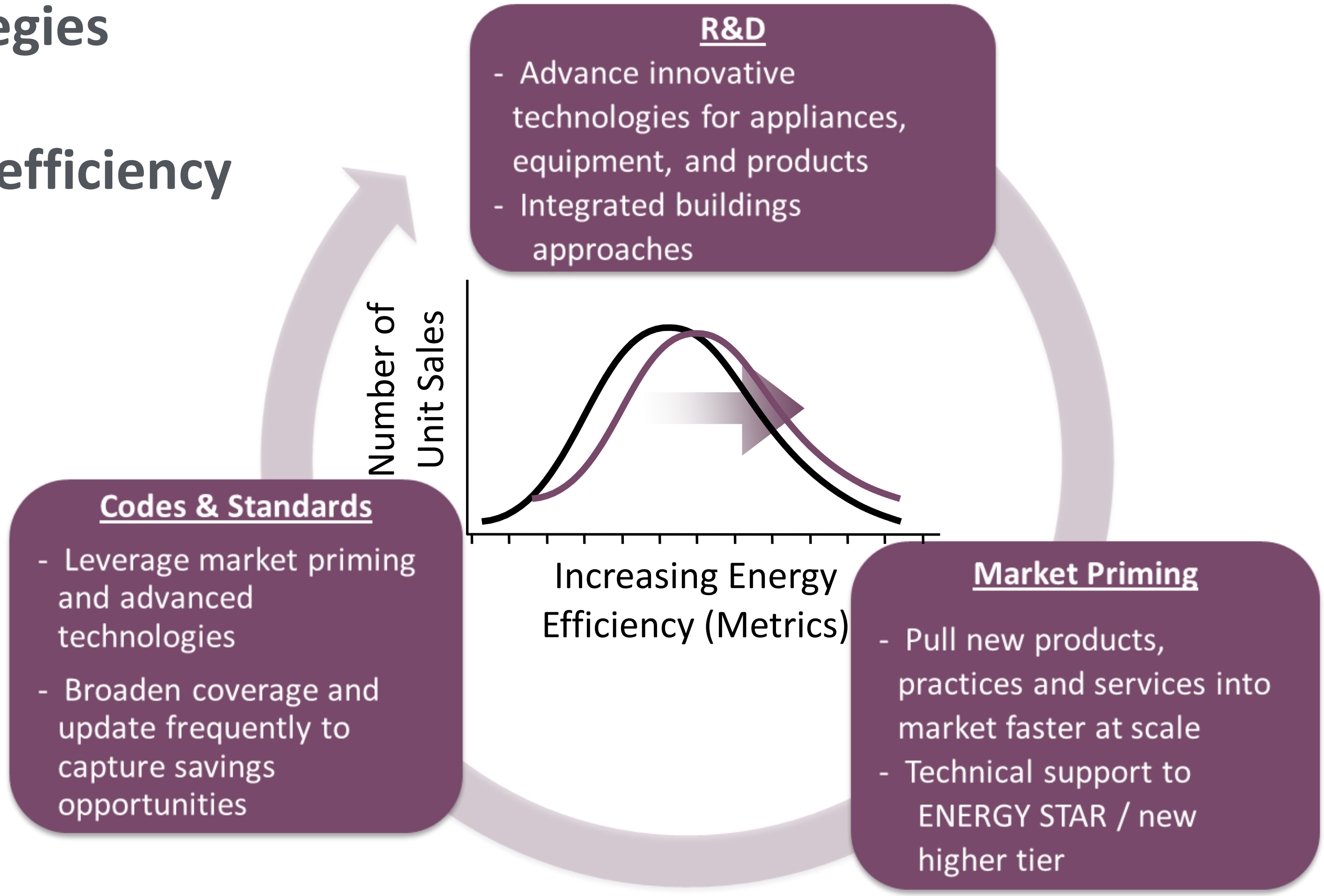
Van D. Baxter
Oak Ridge National Laboratory

Efforts focus on equipment for "drop-in" replacements



- HVAC (space heating, space cooling, and ventilation) is the largest end use for residential and commercial buildings, consuming approximately **35.3 percent of the total energy used in buildings**
- Following lighting, water heating is the third largest end use in buildings, using approximately **9.6 percent of primary energy**
- HVAC, WH and Refrigeration represent approximately **47.9 percent of primary energy use;** with appliances, the total is greater than 75%

Three strategies build a self-reinforcing efficiency ecosystem



HVAC, Water Heating, and Working Fluids R&D

R&D Road Maps

- Heating, Ventilation, and Air Conditioning (HVAC) - complete
- Water Heating - complete
- Next Generation Refrigerants (Low GWP) - complete
- Appliances - underway
- Solar Water Heating– complete
- Ground Source Heat Pump - underway

Road mapping process

Literature Review

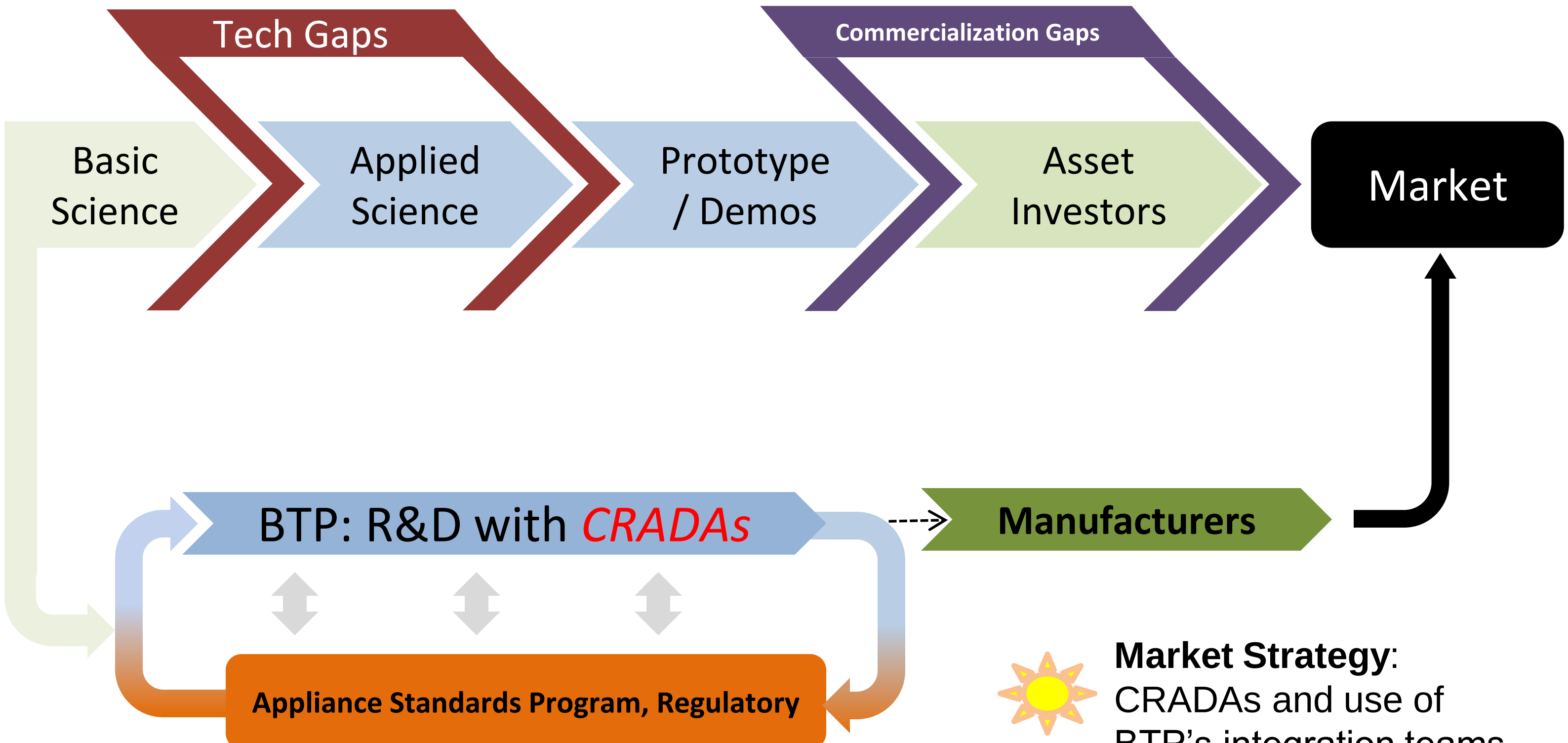
Stakeholder Discussions

- Individual Discussion
- Group Discussions
- Trade Associations
- Professional Organizations
- Manufacturers
- Utilities

National labs

- ORNL
- LBNL
- NREL
- ANL
- PNNL

HVAC, Water Heating, and Working Fluids R&D



Market Strategy: CRADAs and use of BTP's integration teams with research homes

CRADA : Collaborative Research and Development Agreement

Technology Approaches

HVAC&R Efficiency

- Nano lubricants
- Air Source IHP (CRADA)
- Ground Source IHP (CRADA)
- Cold Climate Heat Pump (CRADA)
- Radial Air Bearing HX
- HX Optimization Tool
- Variable Speed IHP (CRADA)
- Next Gen RTU (CRADA)
- Next Gen Window AC (CRADA)

Water Heating

- CO_2 HPWH (CRADA)
- Absorption HPWH (CRADA)

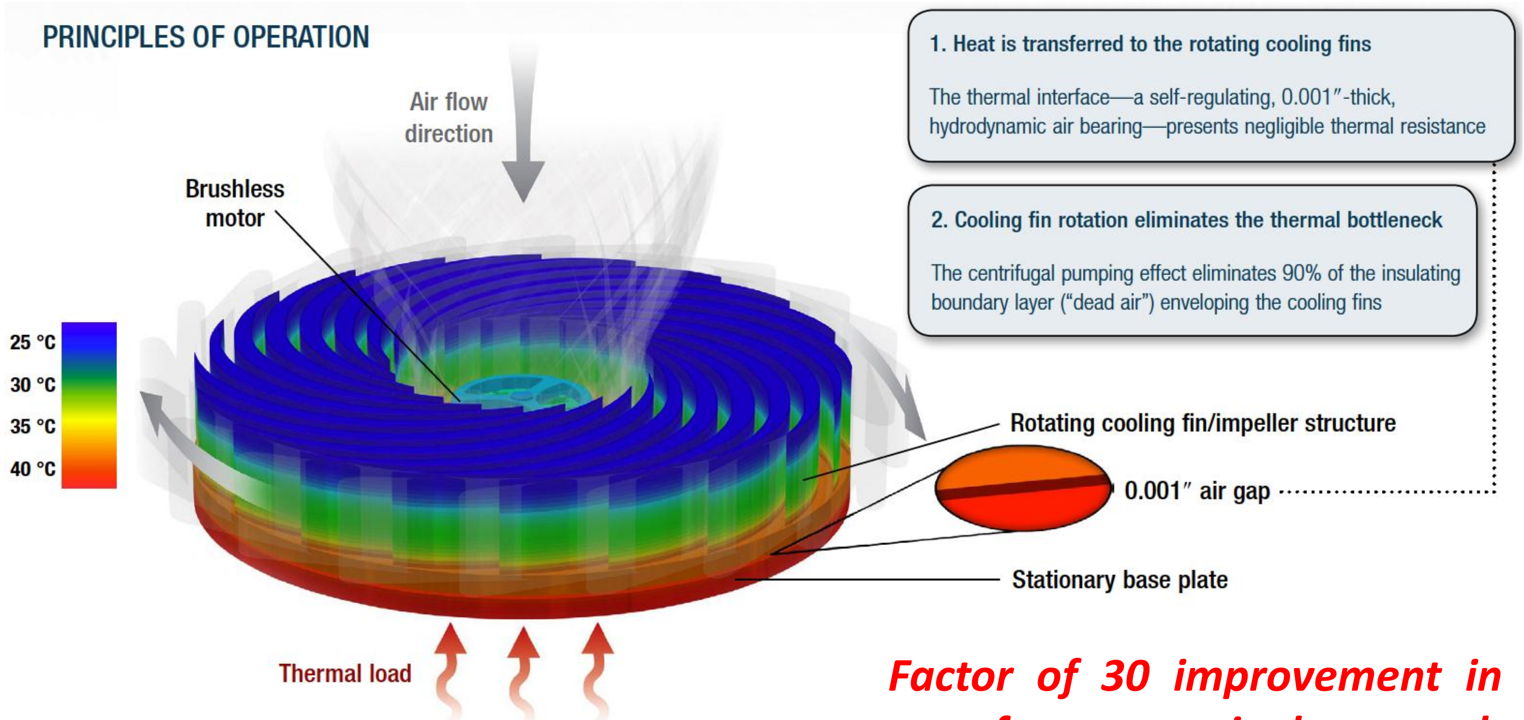
Efficient Alternative Cycle Cooling Systems

- Magnetocaloric RTU
- Multi-function Fuel Fired Heat Pump (CRADA)

Working Fluids

- Next-generation low- GWP and low life cycle climate performance (LCCP) refrigerants
- Development of new fluids
- Measurement of thermo-physical properties of new refrigerants
- Testing and evaluation of equipment with alternative refrigerants

Sandia's Air Bearing Heat Exchanger



Factor of 30 improvement in heat transfer per unit heat exchanger area demonstrated

- **Drastically reduced thermal resistance**
- **Drastically reduced device size**
- **Drastically reduced noise**

Technical white paper: http://prod.sandia.gov/techlib/access-control.cgi/2010/100258.pdf

Heat pump related projects covered today

Current projects	Energy Performance Improvement Targets
Electric HPWH	62 % energy savings vs. min eff electric storage WH
GS-IHP (variable speed)	55% to 65% energy savings vs. min eff equipment suite
AS-IHP (2-speed)	40% to 45% energy savings vs. min eff equipment suite
AS-IHP (variable speed)	45% to 55% energy savings vs. min eff equipment suite
Electric HPWH with low-GWP ref.	15% energy savings compared to Energy Star HPWH
Absorption HPWH	45% energy savings compared to Energy Star Gas Storage WH
Next Gen RTU (70 kW)	25% energy savings vs. ASHRAE 90.1 RTU minimum eff unit
Next Gen Window AC	30% energy savings vs. current min eff WACs
Cold Climate HP (10 to 17.5 kW)	50% to 70% energy savings at low ambient vs.. current min eff ASHP
Multifunction Gas-driven HP (10 to 17.5 kW)	70% peak demand savings; 40% source energy savings vs.. min efficiency electric heat pump
HP Coupled Washer/Dryer	40% energy savings vs. current min eff electric W/D

Integrated Heat Pump (IHP)
for Residential or Small Commercial Building Applications

Goal

Multifunction Electric Heat Pumps
(Space conditioning, water heating, dehumidification, and ventilation)

Conceptual designs: Air-Source and Ground-Source versions

- Two-speed and variable speed compressor versions; variable speed fans and pumps
- Potential 40% to 65% energy savings for HVAC/WH vs. suite of individual systems (13 SEER ASHP, 0.9 EF WH, 1.4 EF standalone dehumidifier, whole house ventilation per ASHRAE 62.2)

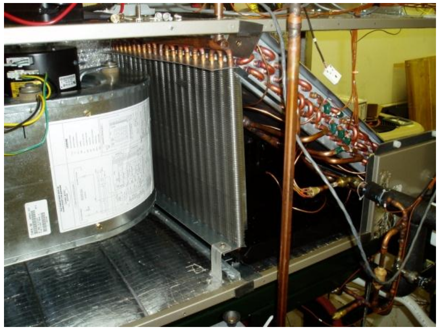
CRADAs in place with three major manufacturers to develop initial products *(two air-source and one ground-source)*

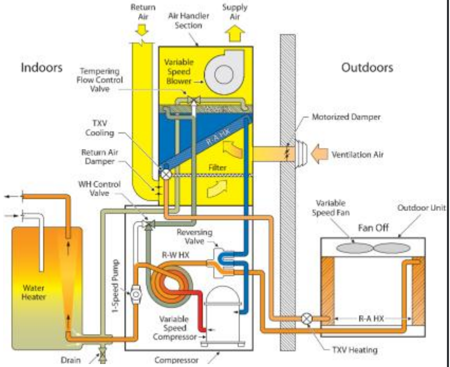
- CRADA => Collaborative Research and Development Agreement
- Ground-source version field testing underway – *2011-2012*
- 2-speed air-source version field testing expected in *2012/13*
- Vari-speed air-source version field testing expected in *2013/14*
- CRADA efforts targeted at 2-ton nominal cooling capacity systems

Integrated Heat Pumps (IHP)

- AS-IHP and GS-IHP development was basis of US contribution to Annex 32
- Field tests with 1st generation GS-IHP prototype in 2011
  - 2nd gen prototype under development incorporating "lessons learned" from 2011 testing
  - Field test results could be part of US contribution to NZEB Annex if we join

Lab prototype AS-IHP





Initial prototype GS-IHP

Prototype GS-IHP installed in test house

Develop Standard Test Method for IHPs to Facilitate Market Penetration

Draft test method for multi-function heat pumps like IHP

- ASHRAE standard project committee (SPC 206) formed – "Method of Test for Rating Multi-Purpose Residential Heat Pumps for Space Conditioning, Water Heating and Dehumidification"
- Work began spring 2011
- Goal to have draft for public review by late 2012
- Support future rating standard by AHRI

Principal US contribution to Annex 39

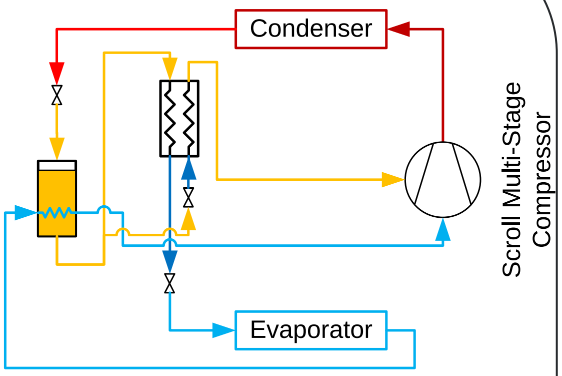
Improved Air-Source Heat Pumps for Cold Climates

Goal

- Develop advanced air-source heat pump system with enhanced heating capacity at low ambient temperatures and demonstrate in field test
- Capacity loss at -25°C outdoor temperature <25% vs. nominal capacity at 8.3°C rating point

Planned activities

- Modeling of VC cycles (multi-stage compression, ejector cycles, etc.) to identify preferred cycle options - underway
  - ➢ Optimize design and heat pump sizing to minimize performance degradation
- Engage manufacturer partner(s)
  - ➢ Investigate options to reduce equipment costs
  - ➢ Build lab test prototype based on preferred cycle option and conduct tests to refine design and verify analytical models
  - ➢ Build field test prototype and test in cold region of US



- *Analytical and experimental investigation of VC cycle options for improved cold ambient source performance*
- *Major part of US contribution to proposed Cold Climate HP Annex*

Residential Multi-Function Fuel-Fired Heat Pump

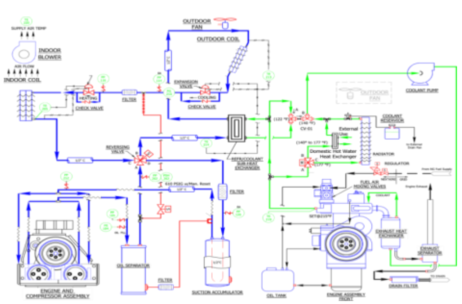
Goal

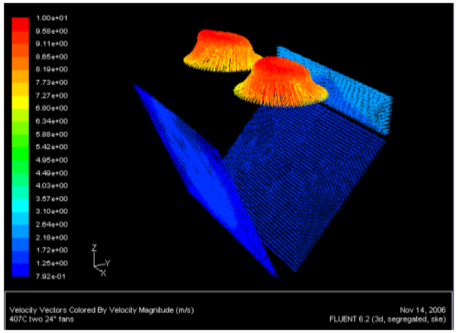
Develop a residential gas engine-driven integrated heat pump
- Space conditioning, dehumidification, water heating, up to 3 kW of electrical energy
- Single family or multi family applications

NEXTAIRE
PACKAGED GAS HEAT PUMP

- Builds on previous successful project for commercial rooftop AC application
  - 85% reduction in demand vs. electric HP
- CRADA project underway – prototype unit in lab testing phase
- Results could be contributed to proposed fuel-driven heat pump Annex (if we join)

NSPE New Product Award





High IEER Next Generation Rooftop

Goal

Develop commercial rooftop AC (RTU) with an integrated energy efficiency ratio (IEER) of 20.0 and 20-ton cooling capacity – integrated COP of ~5.9 and 70 kW capacity

Approach

- Use Modelica modeling language and HPDM to evaluate multiple technical solutions
- Variable-speed compressors, micro-channel HXs, condenser evaporative pre-cooling, desiccant and heat recovery wheels, etc.

High IEER Next Generation Rooftop

Planned activities

- Collect existing Modelica component libraries
  - variable speed compressor, fan, air-to-refrigerant HXs, desiccant wheel, etc.
- Develop additional required component modules with Modelica interface
  - interlaced HXs, micro-channel condenser, etc.
- Develop overall rooftop unit system model
  - interlaced refrigeration systems, vapor-compression cycle coupled with desiccant cycle
- Conduct design optimization by evaluating various component technology combinations
- Results could be applicable for potential Annex with commercial HVAC focus

Next Generation Window Air-Conditioner (WAC)

Goal

Develop WAC unit in 1.5 – 3.5 kW cooling capacity range with a rated cooling COP of 3.8 (energy efficiency ratio, EER, of 13)

Market & energy saving potential

- ~57 million in use in US
- Current DOE minimum COP is ~2.8
- Replacement of existing units with advanced WACs could save 2.6 Exajoules over next 20 years

Next Generation Window Air-Conditioner (WAC)

Planned activities

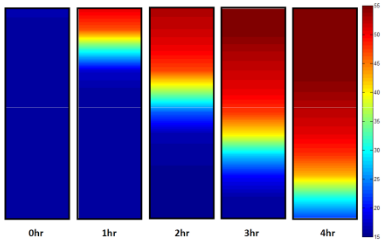
- Work with manufacturer partner to screen efficiency improvement options based on efficiency & cost impacts
- Conduct design optimization analyses to develop component specifications for WAC at target COP goal and within target capacity range
- Partner builds lab prototype
- Test prototype to verify COP
- Refine design as needed to achieve 3.8 COP target

Electric Heat Pump Water Heaters

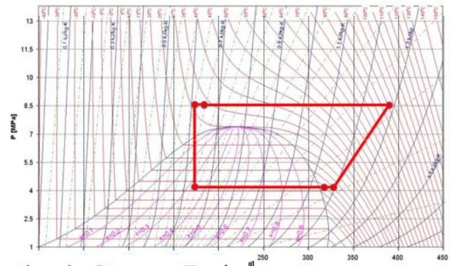
Replace high GWP refrigerants with low GWP alternatives (e.g. CO_2)

- Opportunities for efficiency improvements and lower LCCP/TEWI
- Challenges with CO_2:
  - Transcritical vapor compression cycle (high system pressure)
  - Compressor: high shell temperature, oil management
  - System operation and control strategy
- Initial breadboard unit lab tests resulted in COP of 2.5

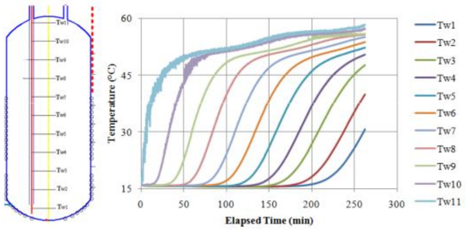
Temperature Stratification in Storage Tank



Average Cycle State Points For Entire Test



Temperature Stratification in Storage Tank

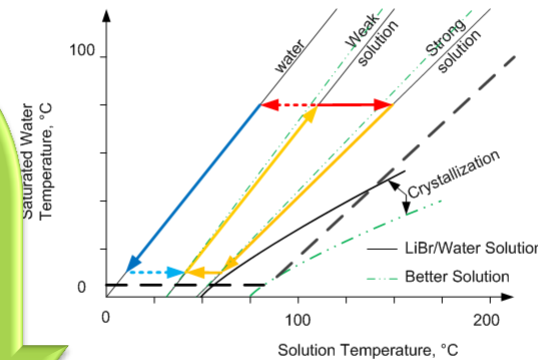


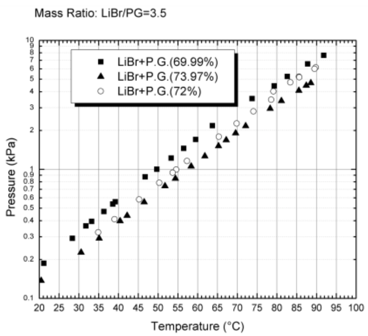
Low water circulation flow rate (11g/s) provides good stratification within tank

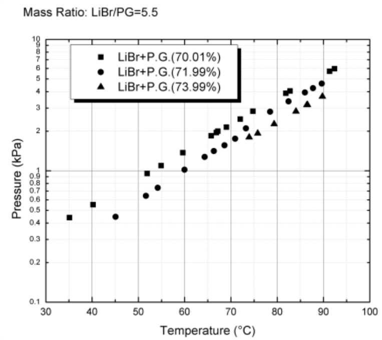
*Tw11, Tw9, Tw7, Tw5, Tw3, and Tw1 placed at locations required by DOE testing procedure

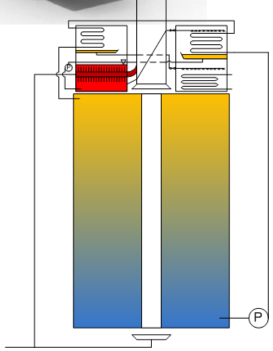
Fuel Driven Heat Pump Water Heater

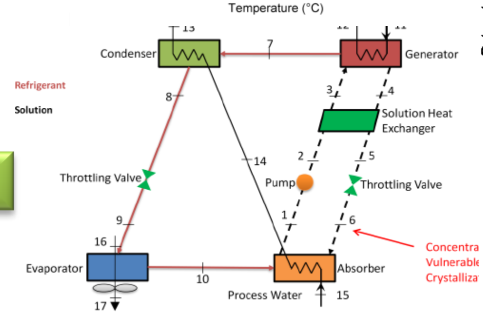
- **Fossil fuel to drive an absorption heat pump**
  - ➢Develop optimum working fluid (additives study)
  - ➢Develop best cycle configuration (patent applied)
  - ➢Demonstrate a working prototype and investigate commercialization potential
  - ➢Study additional thermally driven cycles (ejector)

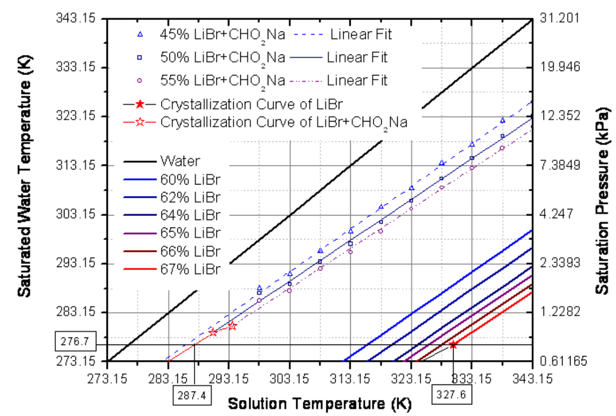












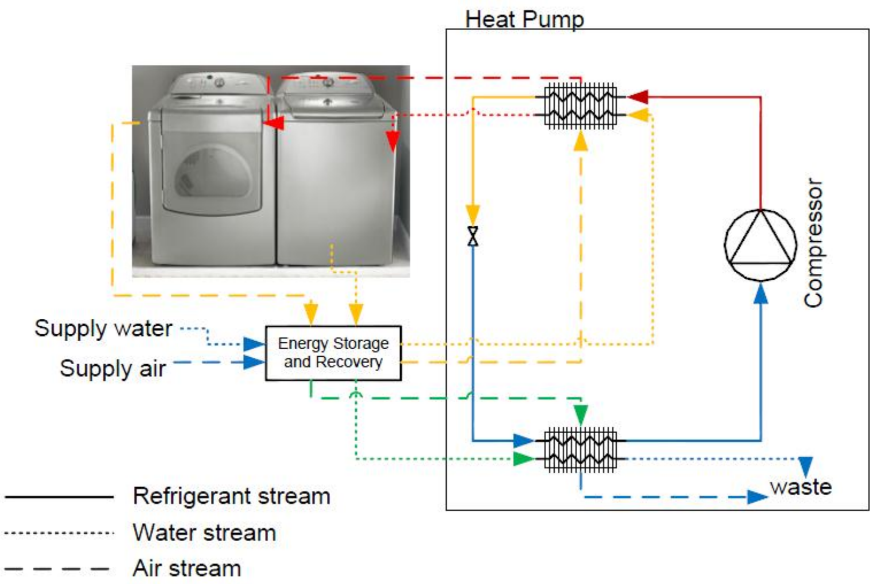
Heat Pump Coupled Washer/Dryer

Goal

Develop an advanced, washer/dryer utilizing heat pump technology with 40% energy savings vs. current minimum efficiency technology (energy factor of 2.1 vs. 1.5)

Approach

- Use heat pump cycle to facilitate intracycle heat recovery and minimize energy use
    - Waste wash cycle heat to preheat dryer air
    - Waste dryer heat to preheat entering water for washer
- 2011-2013 project time frame



Heat Pump Coupled Washer/Dryer

Planned activities

- Develop thermal storage/heat exchanger module to facilitate waste heat recovery for washing and drying processes
- Work with manufacturer partner to develop initial prototype heat pump system design; partner builds lab test unit
- Preliminary market study to assess potential cost and estimated national energy savings potential
- Conduct lab tests of initial prototype system
- Refine/optimize design concept based on initial test and assessment results
- Build 2nd generation lab prototype and conduct tests
- Update market and energy savings projections based on 2nd generation test results
- Proceed with prototype product development and field evaluations assuming positive outcome of R&D activities

Backup Slides

HVAC, Water Heating, and Working Fluids R&D

Current Activities (FY11 Funding):

HVAC	Water Heating	Working Fluids
• HVAC Technologies/Retrofit Barriers/Opportunities Roadmap • International HVAC&R Research Collaboration • Ground-Source Integrated Heat Pump • Air-Source Integrated Heat Pump • Standard Test Procedures for Integrated Heat Pumps • HVAC/Water Heating System Tests at ZEBRAlliance Research Houses • Residential Fuel-Fired Multifunction Heat Pump • Genetic Algorithm-based Optimization of Heat Exchangers for Energy Efficiency Gains • Multi-Zone HVAC Options for Residential Applications • Advanced HVAC/Water Heating Implementation in BEopt Optimization Analyses • High Performance Cold Climate Multi-stage Heat Pump • Radial Air Bearing Heat Exchanger Research and Development • Nano-graphitic Particulate Additives for Enhanced Heat Transfer and Lubricity of Refrigerant Systems • Evaluation of Magnetocaloric Refrigeration Cycles for Commercial HVAC	• Water Heating Roadmap • CO_2 Heat Pump Water Heater Development • Absorption Water Heater Development • Improving Efficiency of Fuel-fired Furnaces for Space and Water Heating Systems	• Next Generation Low Global Warming Potential Refrigerants Roadmap • Thermodynamic Evaluation of Low-Global Warming Potential Refrigerants • Nanolubricants to Improve Chiller Performance • R&D on Low Global Warming Refrigerants (CRADAs, 2)

HVAC, Water Heating, and Working Fluids R&D

Current Activities (ARRA):

HVAC	Water Heating	Working Fluids
• 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)*	• 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*.)	• 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)*

HVAC, Water Heating, and Working Fluids R&D

HVAC Road map	Gaps/Critical Barriers
Technical	• Higher efficiency (IEER>18) rooftop units • Integrated heat pumps that incorporate space conditioning, water heating, dehumidification, and ventilation with efficiency improvements > 50% • Higher efficiency fuel-fired equipment • EER 13 or higher window air conditioners • Cold climate heat pumps with higher efficiencies at low ambient temperature • Efficiency improvements of 10 to 15% for central chillers
Cost	• Lower cost technologies (engines, heat exchangers, controls, fan motors) for gas and electric heat pumps
Deployment	• Demonstrations of advanced technologies in large commercial/retail buildings • “Golden carrot” initiatives to encourage mass buy and market pull • CRADAs with manufacturers to develop and deploy high efficiency, cost-effective equipment to market

HVAC, Water Heating, and Working Fluids R&D

WH Road map	Gaps/Critical Barriers
Technical	• Higher efficiency (COP>1) gas-fired water heater options, such as absorption HPWH COP>3 electric HPWH with CO_2 or other low-GWP refrigerant • Distribution loss reduction approaches • Heat recovery integration technologies • Ensure sustained efficiency throughout product lifetime
Cost	• Lower cost electric HPWH options
Deployment	• Improve and demonstrate drain water heat recovery technologies • Demonstrations of novel technologies in large commercial/federal buildings • New test standards/metrics to improve upon EF test and capture advantages of new technologies • Novel marketing and deployment strategies to communicate benefits of “hybrid” water heaters

HVAC, Water Heating, and Working Fluids R&D

Appliances Road map	Gaps/Critical Barriers
Technical	• Integrated appliances with > 50% efficiency improvements • Advanced refrigeration cycles such as magnetocaloric, thermionic, and absorption • Improved insulations such as vacuum panels, phase change materials • Reduced demand clothes drying technologies (< 50%) • Reduced water consumption cleaning technologies
Cost	• Lower cost conventional technologies (heat exchangers, controls, fan motors) • Lower cost advanced technologies such as linear compressors, phase change materials, and materials
Deployment	• Standards that mandate high efficiency appliances • Energy STAR labeling of high efficiency appliances coupled with retailer education • CRADAs with manufacturers to develop and deploy high efficiency, cost-effective equipment to market

HVAC, Water Heating, and Working Fluids R&D

SHC Road map	Gaps/Critical Barriers
Technical	• More reliable, longer-lasting materials for low-cost SWH systems to compete against natural gas • Higher temperature collectors for solar cooling and process heat applications • Compact thermal storage – diurnal, seasonal, annual • Integration into combined PV/thermal systems, conventional HVAC systems, and building envelopes
Cost	• Lower cost polymer SWH systems for cold climates • Lower cost thermal storage for space heating • Lower cost polymer heat exchangers
Deployment	• Quality assurance through Solar Rating & Certification Corporation standards, e.g., durability ratings • Incorporate SWH in Residential Retrofit Guidelines and Weatherization Assistance Programs • Demonstrate polymer SWH systems in federal buildings and DoD facilities • Develop regional Energy Star criteria for SWH • Expand utility programs