DOE's Building Technologies Office:
HVAC, WH and Appliance R&D

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

Introduction

Program Goals:

Support BTO's goals to achieve 50 percent building energy savings

- By 2020, develop technologies enabling 10 percent energy savings in HVAC; 20 percent energy savings in water heating, and 15 percent energy savings in appliances
- By 2030, develop technologies enabling 25 percent energy savings in HVAC; 35 percent energy savings in water heating, and 30 percent energy savings in appliances
- Maintain the competitiveness of American industry

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

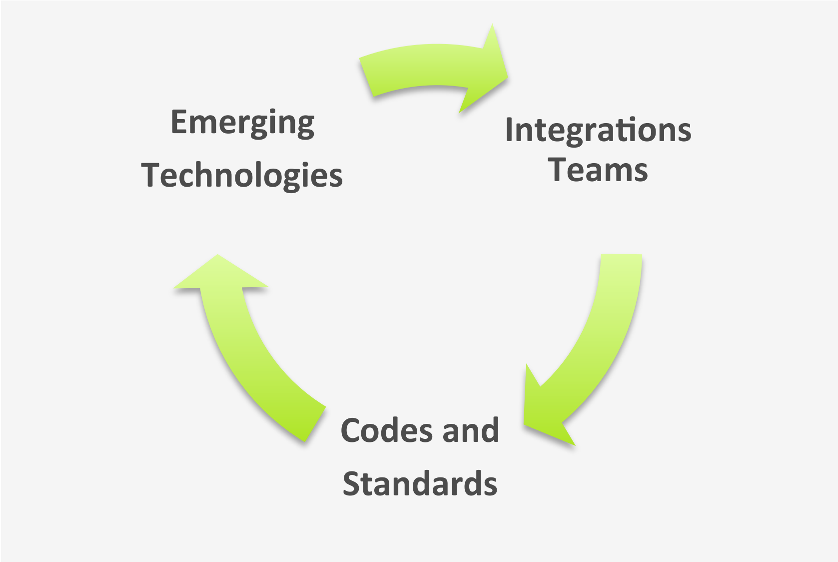
1) Accelerate the development of **near term** technologies that have the potential to save significant amount of energy (including cost reduction activities, bending the cost curve)
2) Accelerate the development of the **next generation** of technologies that have the potential of "leapfrogging" existing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

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

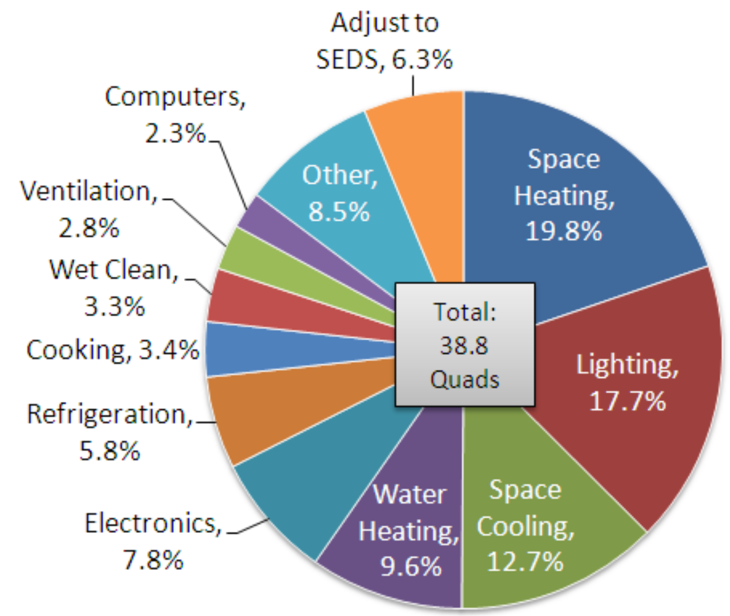
Codes and Standards

- 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

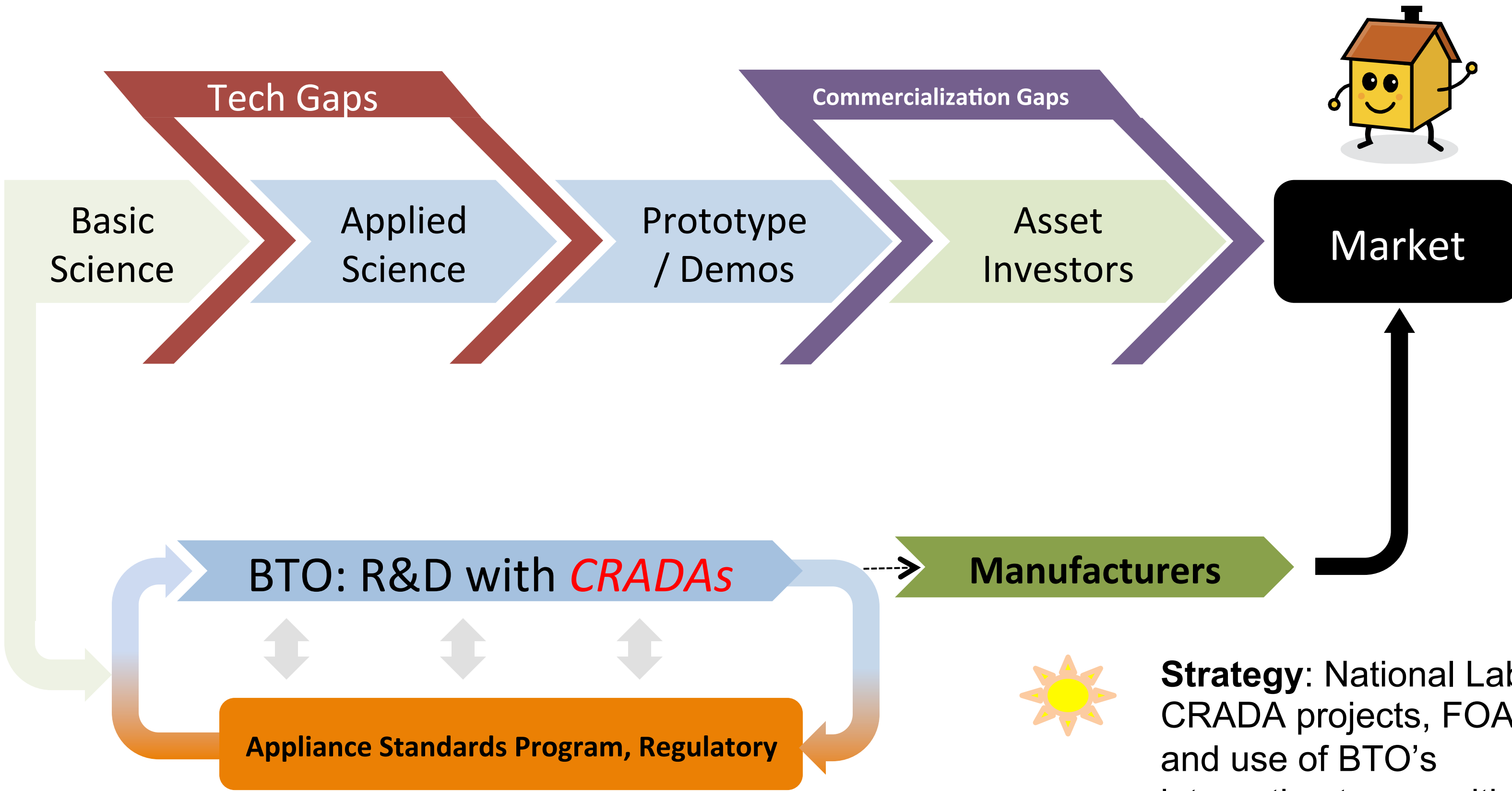
The challenge…

- 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 primes or as team members)
- Program seeks to build upon its past and speed the market availability and acceptance of new technologies that are economically viable
- **Not working in a vacuum**, most equipment is covered by appliance standards

Buildings Primary Energy Consumption



HVAC, Water Heating and Appliance R&D



CRADA : Collaborative Research and Development Agreement

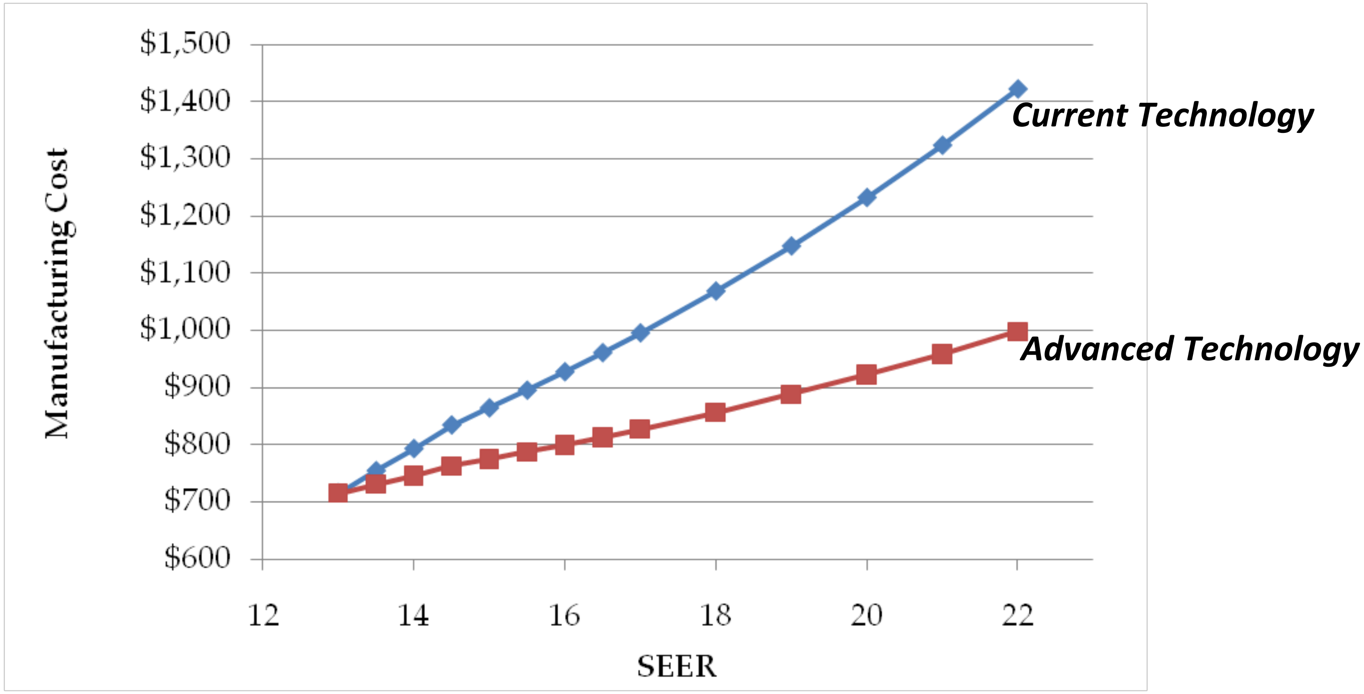
Strategy: National Labs CRADA projects, FOAs and use of BTO's integration teams with research homes

More than just discrete one-off projects but a continuum from a low TRL engineering efforts into a "market-ready" product

HVAC, Water Heating and Appliance R&D

Federal minimum efficiency standards are based on the relationship between incremental cost and higher efficiency …

Manufacturing Costs for Split-System Air Conditioners



… so "bending the cost curve", rather than reaching the ultimate in efficiency, is critical to making a large impact on national energy consumption. CRADAs can act as a catalyst in the process.

Integrated Heat Pump (IHP) Technologies

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 45 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 45 EER Barrier in the USA
- 80% reduction in electricity use
- Award Winning

R&D 100

2012 DEALER DESIGN AWARDS theNEWS GOLD

AHR EXPO Dallas, TX • January 28 - 30, 2013

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*

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
- FOA Topic

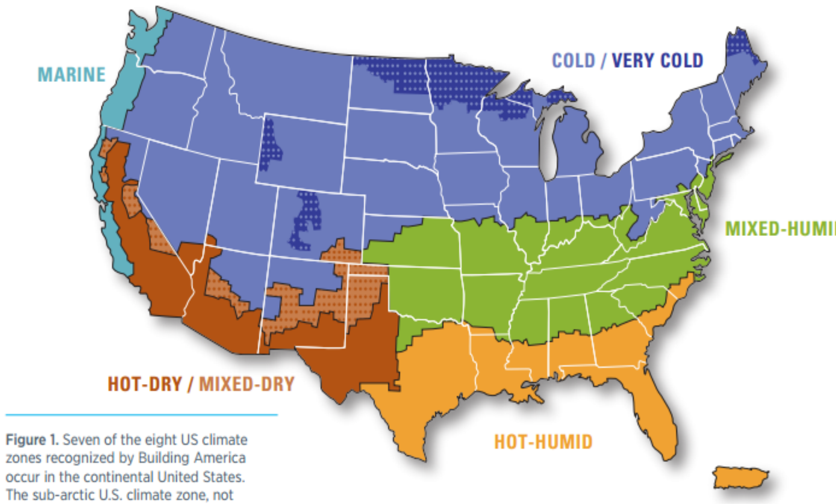


Figure 1. Seven of the eight US climate zones recognized by Building America occur in the continental United States. The sub-arctic U.S. climate zone, not shown on the map, appears only in Alaska.

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

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

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
- BENEFIT 2015 Projects

Water Heating: Advanced Technologies

CO_2 Heat Pump Water Heater (CRADA)

- Developing a carbon dioxide (CO2) heat pump water heater (HPWH) that meets ENERGY STAR® standards for HPWHs
- Low installed cost that will enable widespread acceptance in the U.S. residential market
- CO_2 has low global warming potential when compared to other refrigerants, has zero ozone depletion potential, is very inexpensive, and is not flammable

Sorption Heat Pump Water Heater Research

Ab/ad-sorption heat pump water heaters that will demonstrate an energy factor greater than 1.0 and at an installed cost low enough to enable widespread adoption, the technology has the potential for 40% energy savings over other gas-fired water heaters;

- **ADSORPTION HEAT PUMP WATER HEATER**
- **RESIDENTIAL ABSORPTION HEAT PUMP WATER HEATER**
- **COMMERCIAL ABSORPTION HEAT PUMP WATER HEATER**

Absorption *is a physical or chemical phenomenon or a process in which atoms, molecules or ions enter some bulk phase – gas, liquid or solid material.* ***Adsorption*** *is the adhesion of atoms, ions, or molecules from a gas, liquid, or dissolved solid to a surface.*

Water Heating: Next Generation Technologies

Combined Water Heater, Dehumidifier and Cooler (WHDC), University of Florida

- System dehumidifies the air and uses its energy for water heating
- Condensed water can subsequently be given back to the dried air in an evaporative cooling process; or, when only dehumidification is desired, it can be simply drained from the system
- Technology can utilize the A/C latent load for domestic hot water heating, resulting in significant energy savings for water heating and A/C
- Technology also benefits from a newly developed non-corrosive and non-toxic ionic liquid (IL) that does not crystallize

Advanced Hybrid Water Heater Using Electrochemical Compressor, Xergy

- Using water as the working fluid, rather than a refrigerant
- 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

Heat Pump Water Heater Using Solid-State Energy Converters, Sheetak

- Using thin film, thermoelectric technology to significantly reduce the electrical energy consumed in water heating—without affecting the cost

Appliance: Refrigerator Technologies

Next Generation Household Refrigerator

- Develop a next-generation variable-capacity household refrigerator using a linear compressor and other novel features
- Potential to reduce energy use by up to 25% compared with current refrigerators
- CRADA with Whirlpool

High-Performance Refrigerator Using Novel Rotating Heat Exchanger

- High-efficiency refrigerator with the Sandia rotating heat exchanger as an evaporator that can eliminate the defrost cycle, reduce fan power, and subcool the liquid refrigerant, as well as reduce the required cycle temperature lift
- Estimated that implementation of this novel HX can provide an estimated energy savings of 407 TBtu/year when implemented in both residential and commercial refrigeration
- Rotating heat exchanger has already won the Editor's Choice R&D 100 Award in 2012

Magnetocaloric Refrigerator (residential refrigerator/freezer)

- 20% lower energy consumption relative to current minimum efficiency standards
- Use the magnetocaloric (MCE) effect rather than a conventional vapor compression cycle and thus reduce greenhouse gas emissions by eliminating the use of high-global-warming-potential refrigerants
- Refrigeration technologies based on MCE are fluorocarbon-free and offer potential energy savings of 20%–30% over conventional vapor compression systems
- CRADA with GE

Appliance: Clothes Dryers

Heat Pump Clothes Dryer (CRADA)

- Design and develop a heat pump clothes dryer for the U.S. housing market.
- Lower energy consumption and no moisture disposal issues over the conventional electric dryers
- Heat pump clothes dryer has the potential of lowering the energy consumption by 60% as compared with the conventional resistance heaters

Novel Ultra-low Energy Consumption Ultrasonic Clothes Dryer

- Develop a clothes dryer prototype, using ultrasonic transducers, with an EF above 10 lb/kWh
- Parting from conventional heat-based drying methods, the technique used here relies on using piezoelectric transducers to generate high frequency mechanical vibration to mechanically extract moisture from the fabric as cold mist

Novel Energy Efficient Thermoelectric Clothes Dryer

- Develop and demonstrate a proof-of-concept prototype dryer based on drum-integrated thermoelectric technology, with an EF above 6 and drying time comparable to conventional technology.
- Thermoelectric technology has the potential to be much less expensive at scale than vapor compression-based heat pump dryers

Energy Efficient Clothes Dryer with IR Heating and Electrostatic Precipitator (GE)

- Dryer is unique as it uses an electrostatic precipitator (ESP) to remove humidity from the air stream