HVAC, Water Heating and Appliance R&D: Magnetocaloric

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

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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.

Air Conditioning

World set to use more energy for cooling than heating, *theguardian.com Oct 26, 2015*

- Demand for air conditioning and refrigeration growing so fast that it threatens to smash pledges and targets for global warming.
- Worldwide power consumption for air conditioning alone is forecast to surge 33-fold by 2100 as developing world incomes rise and urbanization advances.
- Already, the US uses as much electricity to keep buildings cool as the whole of Africa uses on everything; China and India are fast catching up.
- By mid-century people will use more energy for cooling than heating.

“Nearly all of the world’s booming cities are in the tropics and will be home to an estimated one billion new consumers by 2025. As temperatures rise, they — and we — will use more air-conditioning.”, *NYTimes.com*

U.S. DOE low-GWP HVACR strategy

DOE envisions a future where low-GWP HVAC solutions are the new norm and non-vapor compression will be prevalent in several end uses.

Key Driver: DOE's goal to develop next-generation technologies that 'leapfrog' existing technologies and result in dramatically improved efficiency with near-zero GWP cooling fluids.

- **Short Term:** Develop and evaluate low-GWP alternative refrigerants, including flammability characterization and hot climate performance
- **Mid Term:** Develop HVAC&R systems that can handle low-GWP refrigerants
- **Long Term:** Develop non-vapor compression systems that use zero-GWP refrigerants

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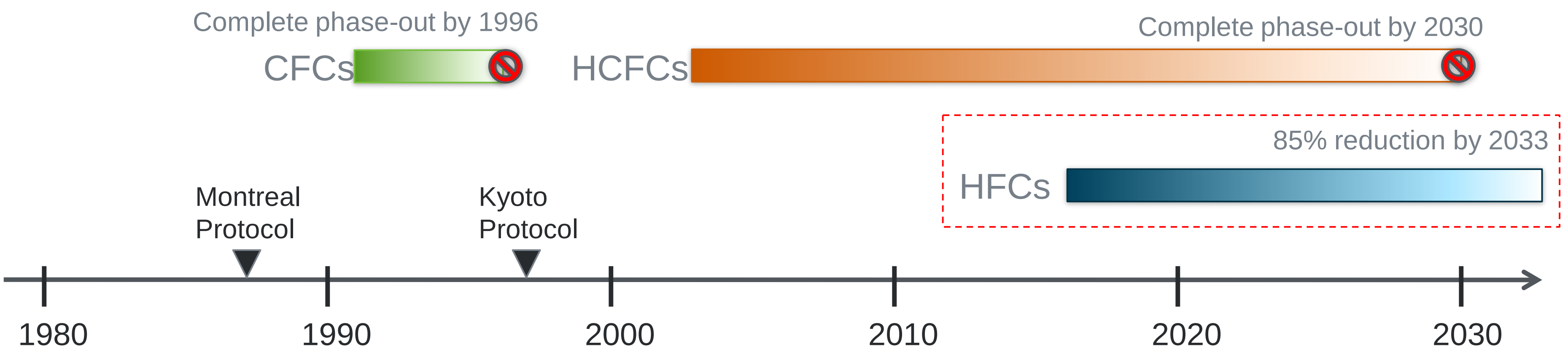
U.S. has successfully achieved similar phase-outs of CFC and HCFC refrigerants

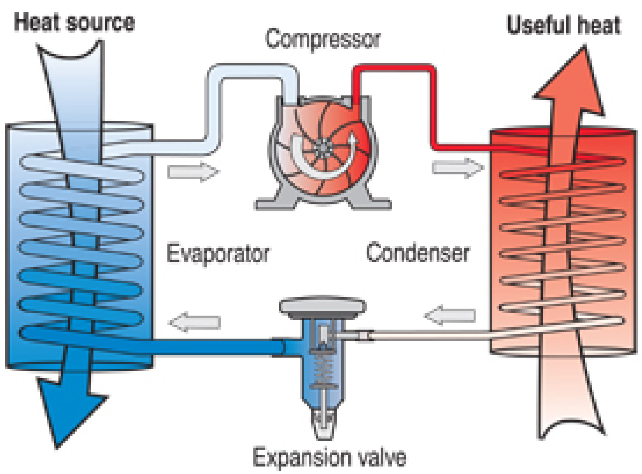


- HFC phase-out is more technically challenging than prior refrigerant transitions
- For some major applications, no HFC-alternatives have been identified that could be used today. (e.g. R-410a replacement for residential and commercial air conditioning)
- The proposed phase-down would plateau at an 85% reduction rather than a complete phase-out

Baseline technology: Vapor Compression Heat Pumps

Compressor: *Low pressure of the low-temperature refrigerant from the evaporator is raised to a pressure that is sufficiently high to match the desired condensing temperature in the condenser. During compression not only the pressure but also the temperature of the refrigerant will increase.*

Evaporator: Low-temperature heat exchanger where the refrigerant enters as a low-temperature liquid, absorbs heat from the heat source by evaporation at a low pressure and leaves as a low-temperature vapor.



Condenser: High-temperature heat exchanger where the refrigerant enters as a high-temperature vapor, rejects heat to the heat sink by condensation at a high pressure and leaves as a high-temperature liquid.

Expansion valve: *On its return to the evaporator from the condenser the high-temperature, high-pressure liquid refrigerant must be changed to the low-temperature, low-pressure liquid that enters the evaporator. This is usually achieved by a throttling device known as the expansion valve. When the hot liquid passes through this valve, not only will its pressure be reduced but at the same time its temperature will drop. As the pressure drops, refrigerant starts to evaporate in the valve and the heat of evaporation is taken from the refrigerant itself which causes its temperature to drop and the result is a low-temperature, low-pressure mix of liquid and vapor.*

http://www.heatpumpcentre.org/en/aboutheatpumps/howHPworks/Sidor/default.aspx

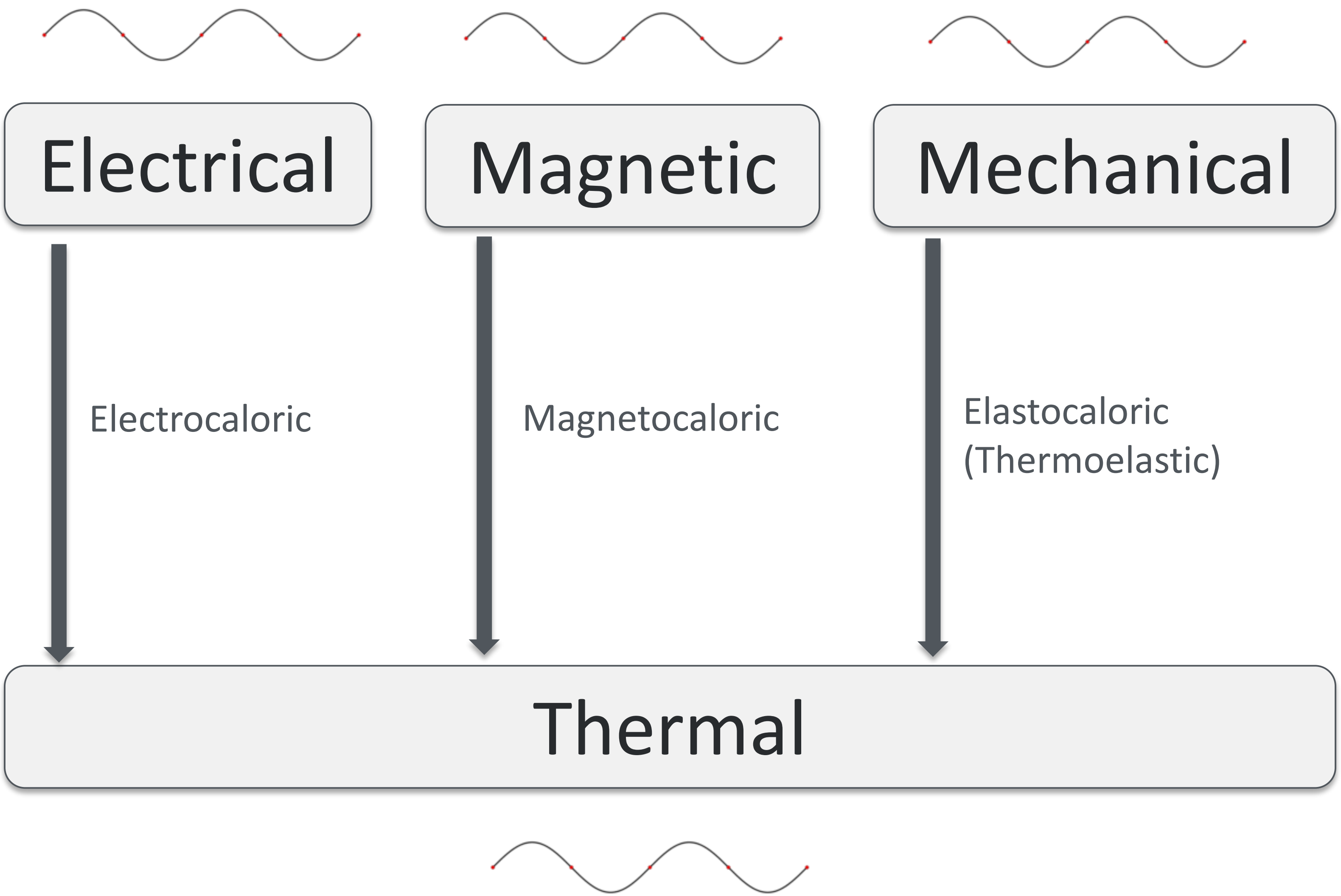
Residential Applications (example): Replacement Refrigerants Summary

Residential Application	Current (GWP)	Potential Future Replacement (GWP)	Status of Each Option
Home Refrigerators	HFC-134a (1430)	Isobutane (4)	Highly flammable; Commercialized in Europe; Approved with charge restriction in US, Some development needed
		HFO Flammable (4-100)	Moderately Flammable; Requires equipment development for commercialization
		HFO Non-Flammable (550-950)	Non-Flammable; Requires equipment development for commercialization
Window A/C	HFC-410A (2100)	Propane (3)	Highly Flammable; Approved by UL with Charge Restrictions but not EPA SNAP; Commercialized Abroad; Some development needed
		HFO Non-Flammable (950-1300)	Non-Flammable; Requires equipment development for commercialization
Central A/C	HFC-410A (2100)	HFO Non-Flammable (950-1300)	Non-Flammable; Requires equipment development for commercialization
		HFO Flammable (300-500)	Moderately Flammable; Requires equipment development for commercialization
		Propane (4)	Highly Flammable; Requires equipment development for commercialization; Safety concerns due to large charge sizes

Background

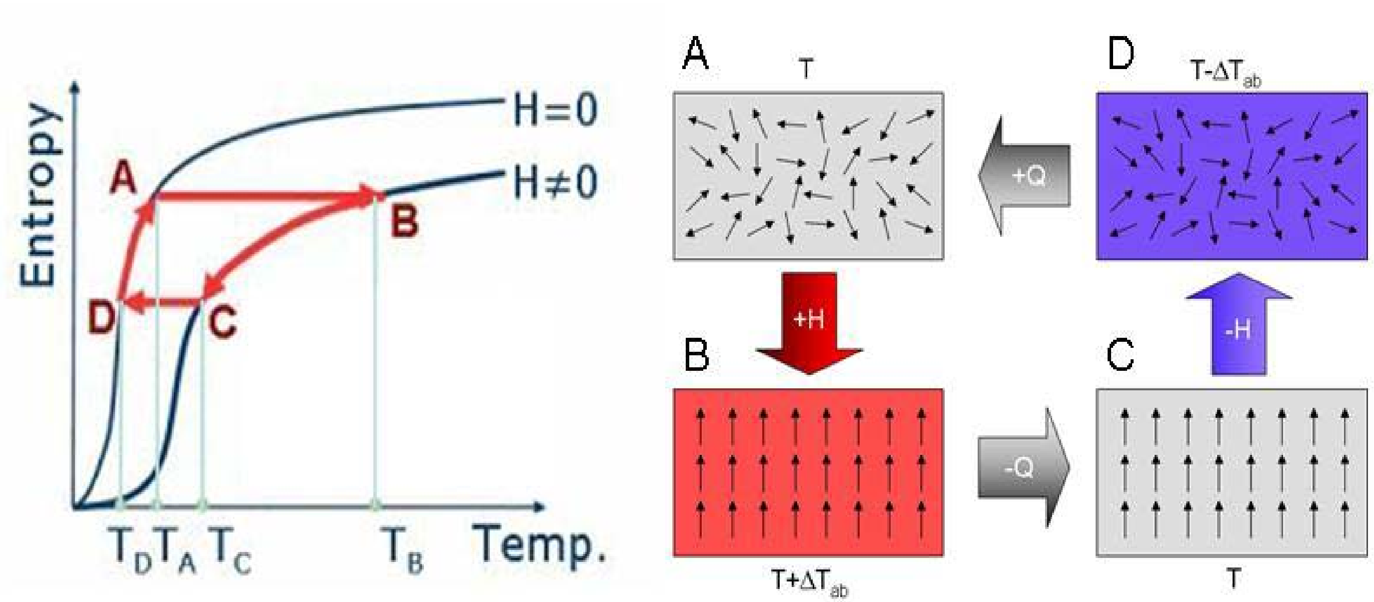
- Caloric materials are potentially environmentally friendly cooling technologies.
- Energy-efficient, environmentally-friendly refrigeration technologies based on reversible field-induced thermal change
- ***Caloric based systems: Coefficients of performance (COPs) scale proportionally to the magnitude of the caloric effects and inversely proportionally to the strength of the driving field***
- Benefits offered by caloric cooling include scalable, potentially energy-efficient and environmentally-friendly
- Caloric effects are maximized when a material is switched from a disordered into an ordered state, and/or from one ordered state to another
- Resulting effects may be enhanced when the transition is first-order, second-order ones require stronger fields
- Magnetocaloric, one of the three caloric technologies

Background



Electrical
Magnetic
Mechanical
Electrocaloric
Magnetocaloric
Elastocaloric
(Thermoelastic)
Thermal

Magnetic Cooling Cycle



Source: Goetzler et al. (2009)

A magnetic cooling system applies a magnetic field to a paramagnetic material. This aligns randomly oriented electron spins in the paramagnetic material (A→B), an exothermic process that raises the material's temperature and causes it to reject heat to its surroundings (B→C).

Upon removal of the magnetic field, the magnetic spins return to their randomized state, an endothermic process that cools the material (C→D). The material then absorbs heat from the space to be cooled (D→A). During this step, the paramagnetic material returns to its original state and the cycle starts again.

Magnetocaloric Projects in BTO

Residential Refrigerator/Freezer

PROJECT OBJECTIVE

This project is developing a residential refrigerator/freezer with 20% lower energy consumption relative to current U.S. Department of Energy minimum efficiency standards. The refrigerator will be designed to 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.

PROJECT IMPACT

ORNL estimates the potential savings to be 0.28–0.42 quads annually, assuming full market penetration.

http://energy.gov/eere/buildings/downloads/magnetocaloric-refrigeratorfreezer

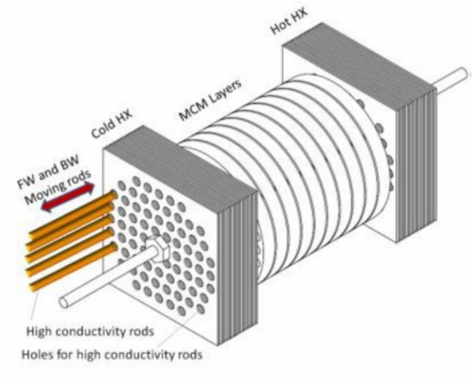
WINDOW AC UNIT

PROJECT OBJECTIVE

This project aims to develop a fully solid-state magnetocaloric AC that will result in significantly improved system efficiency and environmental friendliness (i.e., no use of GWP refrigerants) . The proposed AC will be a small-scale demonstration prototype (500W nominal capacity) similar to a window air conditioning unit for residential applications.

PROJECT IMPACT

Magnetocaloric air conditioning is an emerging technology with the potential for efficiency improvements of up to 25% over conventional vapor compression (VC) systems. This will make the U.S. the leader in the advanced HVAC industry and create new jobs in innovative technology. When fully deployed, this technology can save 1.06 quad (4.22 quad × 0.25) of energy for space heating and cooling in the U.S. residential sector alone.



http://energy.gov/eere/buildings/downloads/novel-solid-state-magnetocaloric-air-conditioner

Thank You and Contact Info…

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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