U.S. DEPARTMENT OF ENERGY
Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

ARPA-E HVAC-DAC WORKSHOP

BTO: HVAC and Direct Air Capture (DAC)

Antonio M Bouza
Technology Manager
U.S. DOE Building Technologies Office
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DOE Goals and Research Strategy

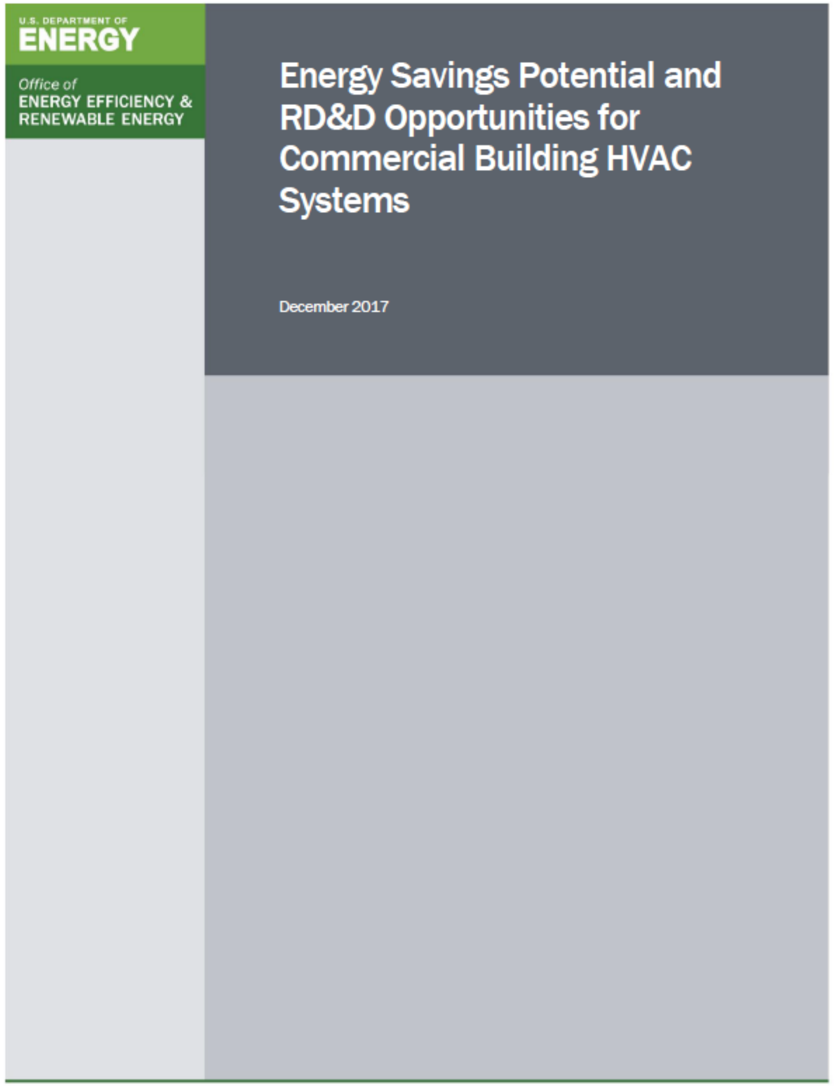
We Have a Clear Directive: **Put the U.S. on an irreversible pathway to achieve a carbon-free electricity sector by 2035 and a 100% clean energy economy by 2050**

At the same time, we will:

- Improve affordability, resilience and performance of buildings
- Provide workforce training and support creation of good-paying, quality clean energy jobs
- Advance diversity, equity, and inclusion in STEM
- Ensure overall benefits of investments are delivered to disadvantaged communities

Removing Carbon, Advanced Filtration Task

- BTO seeks to accelerate the development of next generation heating of HVAC systems with direct air capture capabilities
- Removing carbon is an advanced filtration task
- Two main air sources to remove carbon (CO2) from inside or outside air
- DAC components ***can not be parasitic***
- HVAC systems in the US will need to be able to meet current and future minimum HVAC efficiency standards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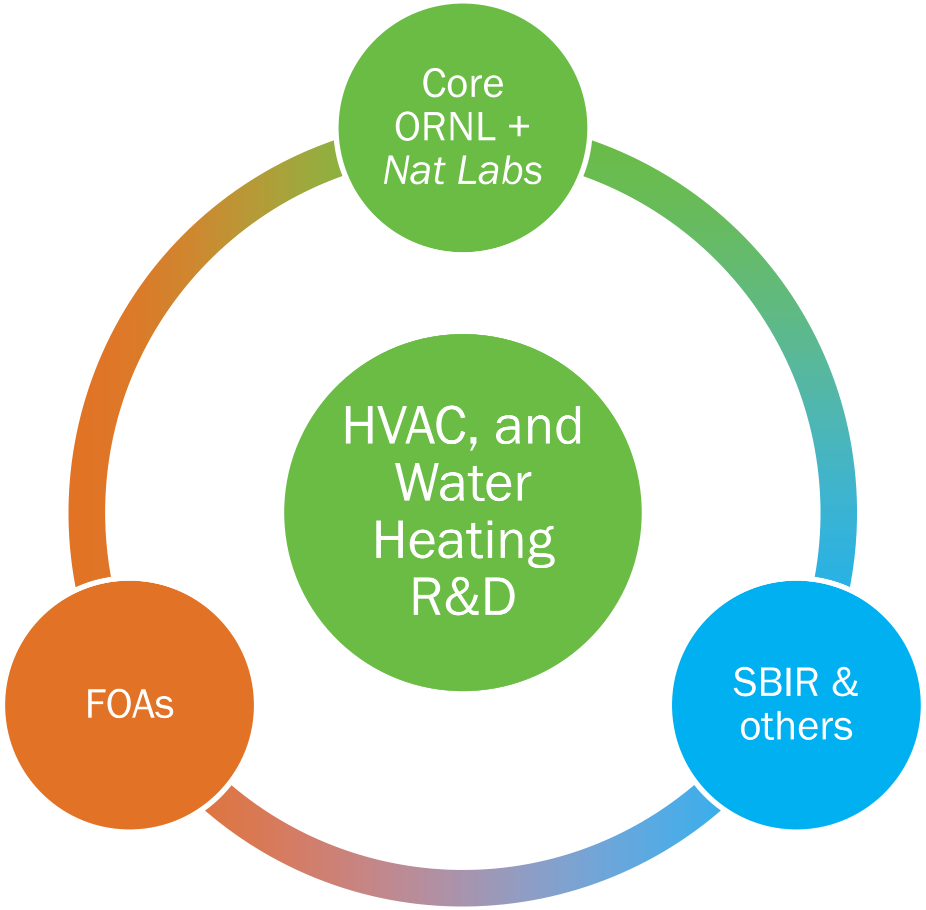
Energy Savings Potential and RD&D Opportunities for Commercial Building HVAC Systems

December 2017

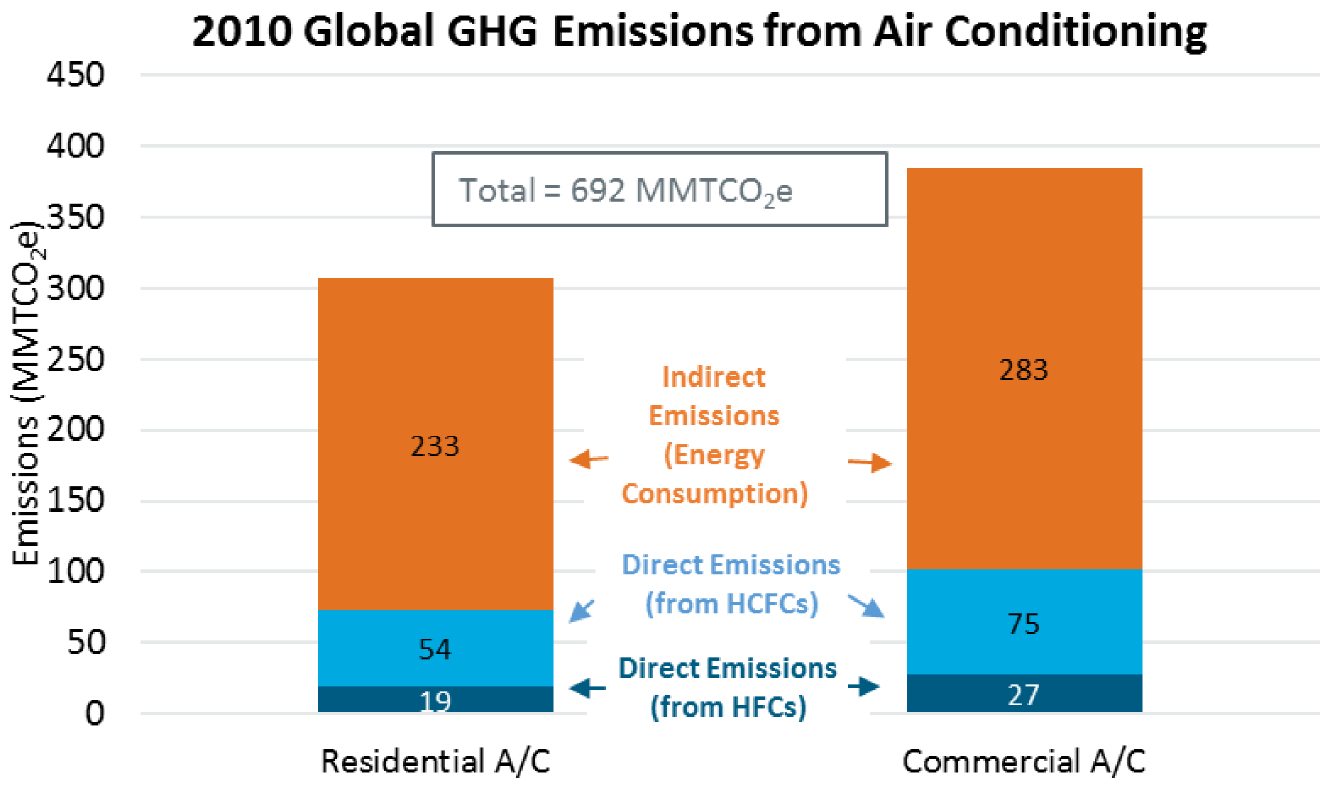
[Energy Savings Potential and RD&D Opportunities for Commercial Building HVAC Systems]

HVAC, and Water Heating R&D

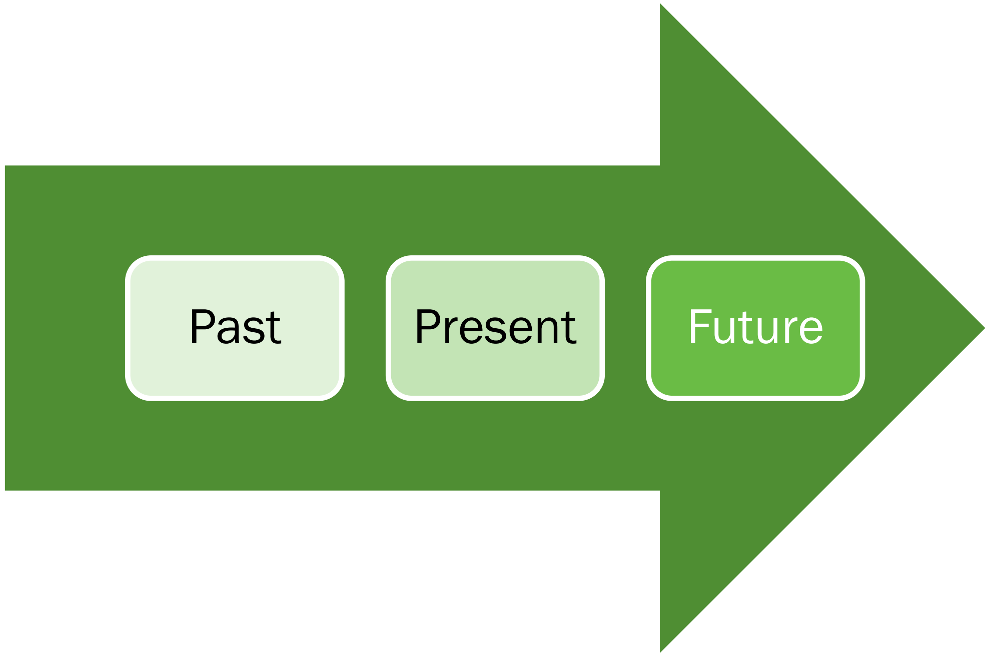


HVAC Research Strategy

- Enable and support the transition to heat pumping technologies
- Both emissions are critical
- Direct Emissions
  - Refrigerants
  - Reducing leaks
  - DAC technology
- Indirect Emissions
  - Efficiency
  - DAC impacts, positive



Timeline…



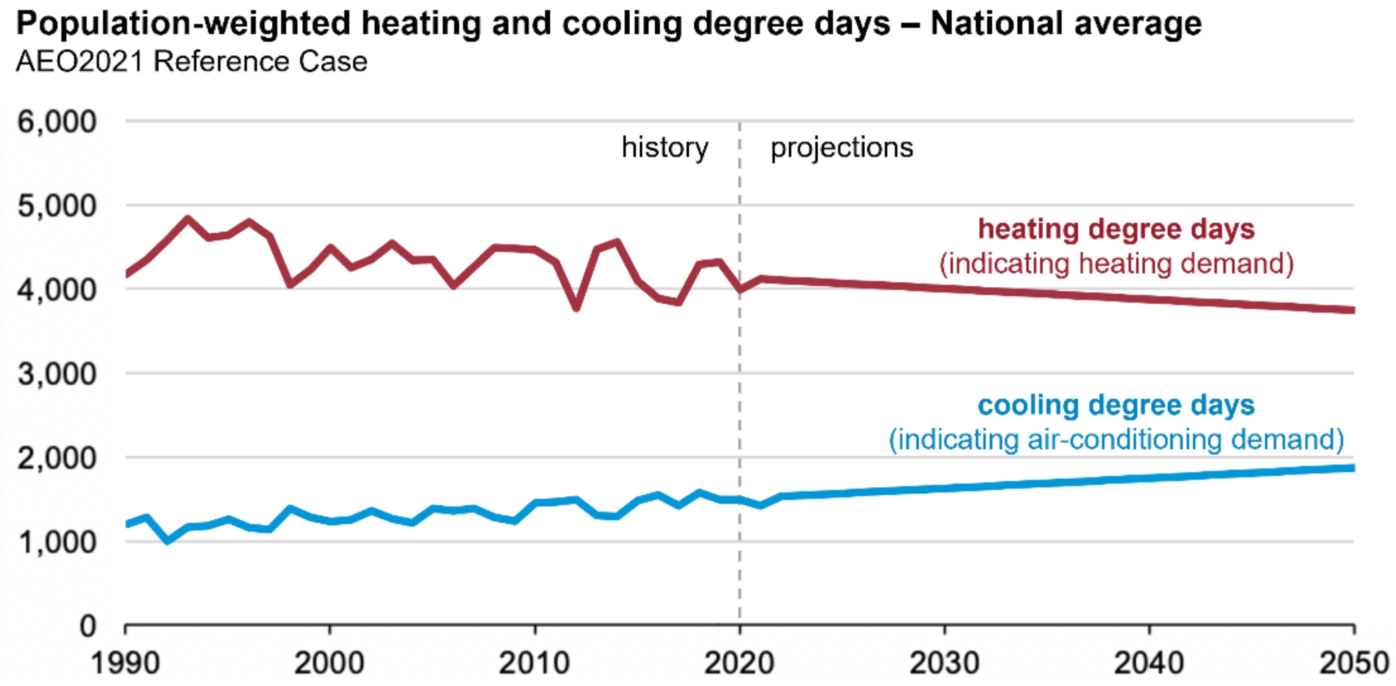
Timeline

	-10 years	-5 years	+5 years	+10 years
Regional HVAC solutions	Cold Climate Heat Pumps (CCHP), electrification	CCHP, electrification	• Hot, Humid and Mixed, SSLC • Commercialization, CCHP	• Hot, Humid and Mixed, SSLC • Commercialization, RTU CCHP and SSLC
Refrigerant R&D	• Modelling • Non-blends • Low-GWP alternative	• Low-GWP alternative • Transcritical CO_2 supermarket refrigeration • Alternatives for R-22 and R-410A • Flammable refrigerants, A2L/A3	• Low-GWP alternative • Alternatives for R-410A • Flammable refrigerants, A2L/A3 & sensors • Advanced compressors SSLC	• Commercialization, A2L systems • Low-GWP alternative • Advanced compressors SSLC, hybrid • Advanced compressors
Crosscutting technologies	• Heat Exchanger (HX)	• Heat exchanger research • Motors • Materials Joining Technologies • Energy Storage	• Commercialization, one technology • HX: Low GWP, and NVC • New materials, CABLE • Energy Storage	• HX: Low GWP and NVC • New materials • Energy Storage • Advanced compressors, hybrid

Timeline

	-10 years	-5 years	+5 years	+10 years
Integrated Heat Pump (IHP)	• Modeling • Updating HP design model	• Air Source (AS) and Ground Source (GS): 40% to 55% savings • Natural Gas • Developed Standard Method of Test (MOT)	• Cold Climate Heat Pump version • ABC focus • Hot, Humid and Mixed	• Commercialization • Low-GWP alternative • Hot, Humid and Mixed, SSLC • HVAC-DAC
HVAC and Direct Air Capture (DAC)		• Energy Savings Potential and RD&D Opportunities for Commercial Building HVAC Systems Report • Advanced filtration	• Metrics • R&D efforts • Integrated Solutions • Part of Separate Sensible and Latent Cooling (SSLC) HP systems	• Commercialization, HVAC-DAC systems

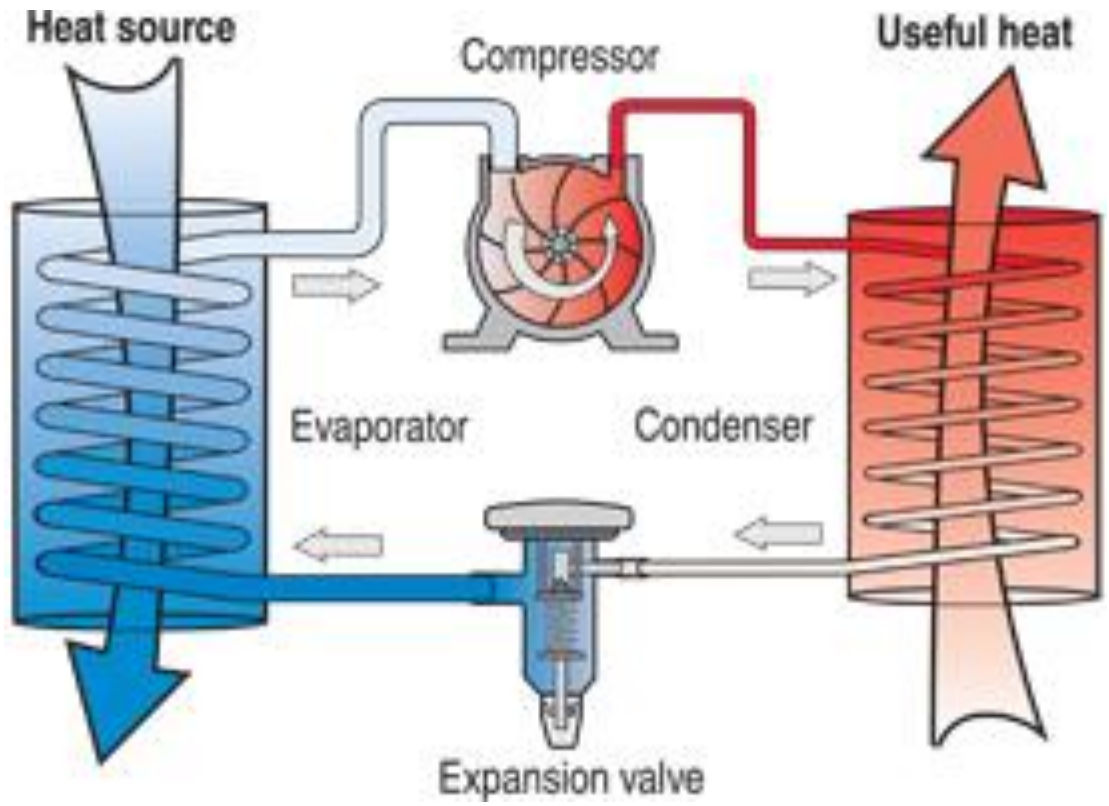
EIA projects… Space cooling increases



Waste heat from cooling is increasing

- Demand for space cooling will rise and demand for space heating will fall
- Heating demand is projected to remain higher than cooling

Heat Pumps and AC units: Cycle



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

- Technology relies on a vapor compression cycle that puts a refrigerant through a phase change
- HVAC-DAC technology can be integrated, potentially into the condenser

Integrated Heat Pump (IHP) Technologies

- 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
- Desuperheater can be used to transfers excess/waste heat generated from a vapor-compression cycle for heat watering or other uses
- IHP technologies can be expanded to HVAC-DAC applications

ClimateMaster

- 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

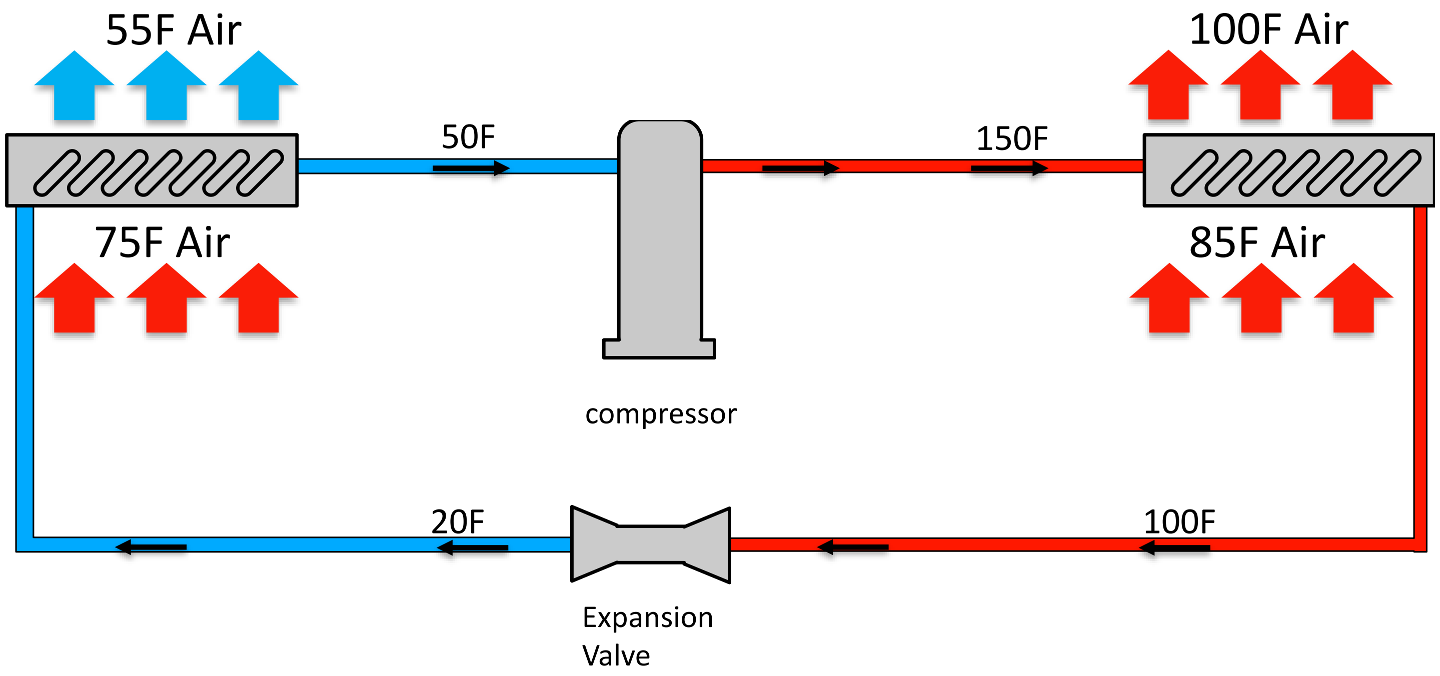
National Academies: Baselines, DAC systems

- Plant capture rate from air = 1 Mt/y CO_2
- Plant life = 10 years
- Concentration in air = 400 ppmv CO_2
- Volumetric flow rate ≥ 58,000 m3/s air
- Capture fraction from air ≥ 60+ CO_2
- Concentration of product ≥ 98 percent CO_2
- **Emission factors**
  - **Heat from natural gas = 227 g CO_2/kWh**
  - **Heat from coal = 334 g CO_2/kWh**
  - **Heat from nuclear = 4 gCO_2/kWh**
  - **Heat from solar = 8.3 gCO_2/kWh**
  - **Electricity from grid (U.S. average) = 743 gCO_2/kWh**
  - **Electricity from natural gas = 450 gCO_2/kWh**
  - **Electricity from coal = 950 gCO_2/kWh**
  - **Electricity from nuclear = 12 gCO_2/kWh**
  - **Electricity from solar = 25 gCO_2/kWh**
  - **Electricity from wind = 11 gCO_2/kWh**

Most approaches rely on heating or a combination of heat and vacuum to release captured CO_2 from its bound state. HVAC-DAC systems have the potential to use waste heat, low emission factor.

National Academies of Sciences, Engineering, and Medicine (2018), "Negative emissions technologies and reliable sequestration: a research agenda."

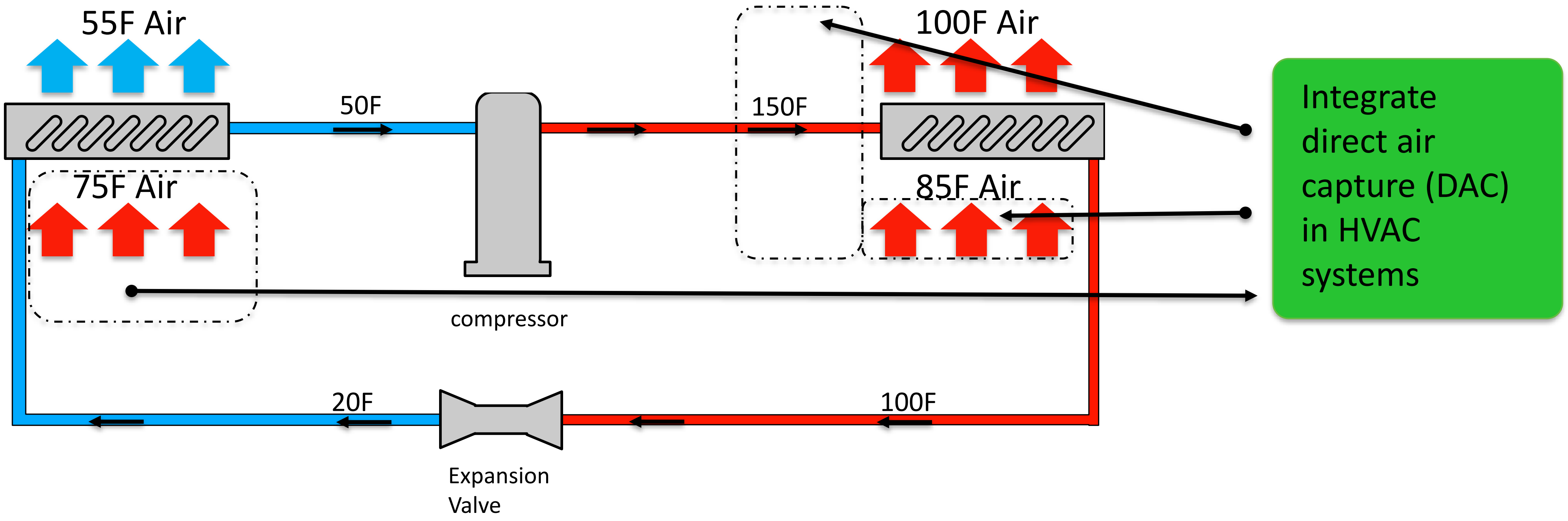
Heat Pump (Cooling Mode), Typical System



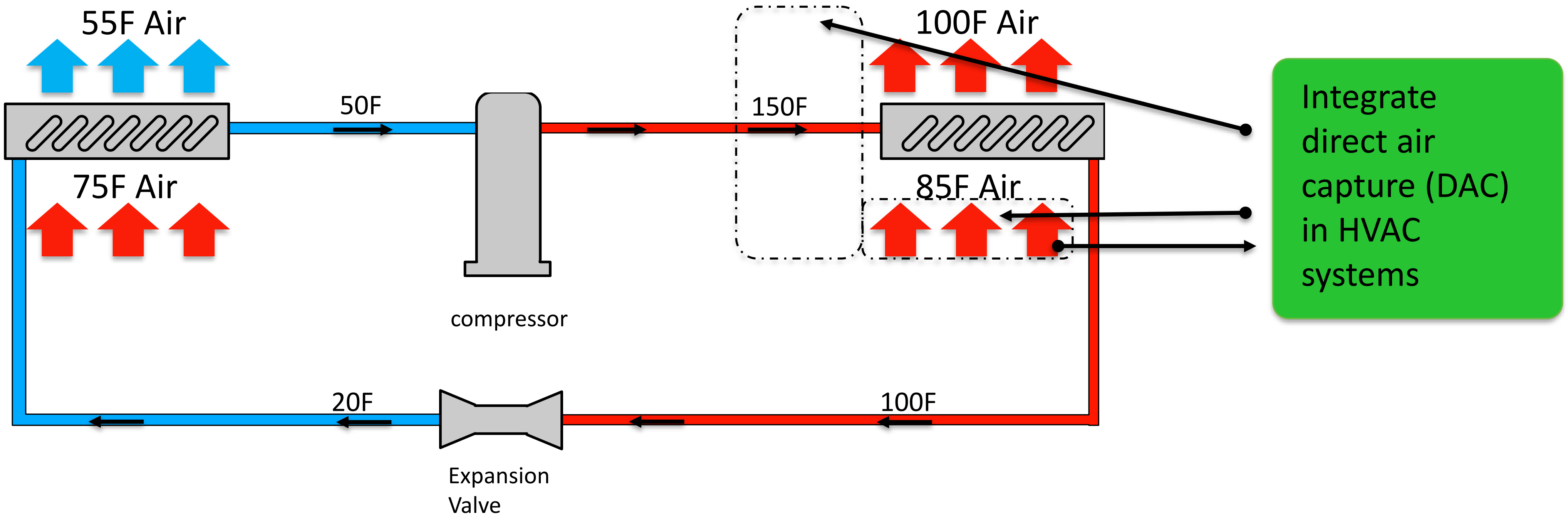
Direct air capture uses a chemical reactions to pull carbon dioxide out of air.

Thermal Energy Needs to release: 176-248F (Solid Sorbent) or ~1652F (Liquid Solvent)

Heat Pump (Cooling Mode), System Integration Indoor Air (Advanced Filtration Task)



Heat Pump (Cooling Mode), System Integration Outdoor Air (Non-Filtration)



BTO SBIR (C56-10): Decarbonizing Buildings, HVAC Direct Air Capture (DAC) systems

Objective/ Goal	Metric	Target	Stretch Target	Baseline Performance
Payback period, cost effectiveness	years	≤ 5 years	≤ 3 years	Applicant Defined
Energy efficiency improvements, HVAC	COP	5%, increase	15%, increase	Applicant Defined
Size and/or weight increases relative to today's current state of the art units. Volume important for system on the ground and weight critical for roof-based systems.	Volume (ft^3, m^3) or Weight (lbs., kg)	<50%, increase in volume and/or weight	<30%, increase in volume and/or weight	Applicant Defined
Carbon Capture metric	tCO_2/year	1.5 * rated system AC tonnage	2.0 * rated system AC tonnage	Applicant Defined
Lifetime	years	≥ 12	≥ 15	Applicant Defined
Service to maintain as-new performance	Yes/No	Little to no increase as compared to state-of-the-art HVAC design		Applicant Defined

Thank You

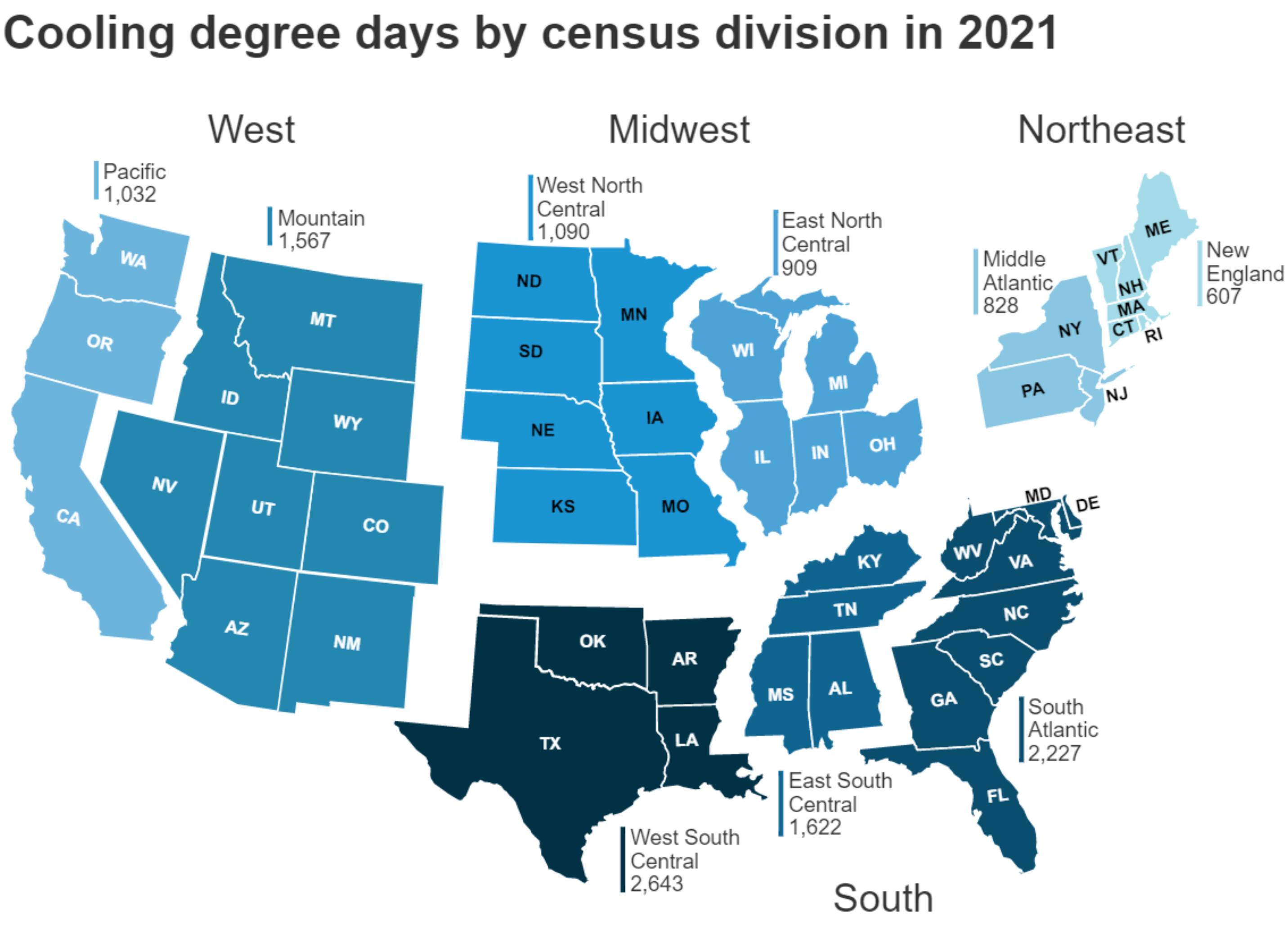
Antonio M Bouza

Technology Manager, HVAC & Water Heating R&D
U.S. Department of Energy, Energy Efficiency & Renewable Energy
Building Technologies Office
antonio.bouza@ee.doe.gov

Heat Pumps → Happy People → Happy Planet

Backup Slides

EIA: Cooling degree days by census division



Data source: U.S. Energy Information Administration, *Monthly Energy Review*, Table 1.10, June 2022
Note: Population-weighted degree days. Pacific division includes Alaska and Hawaii.

AS-Integrated Heat Pump (IHP) Technologies

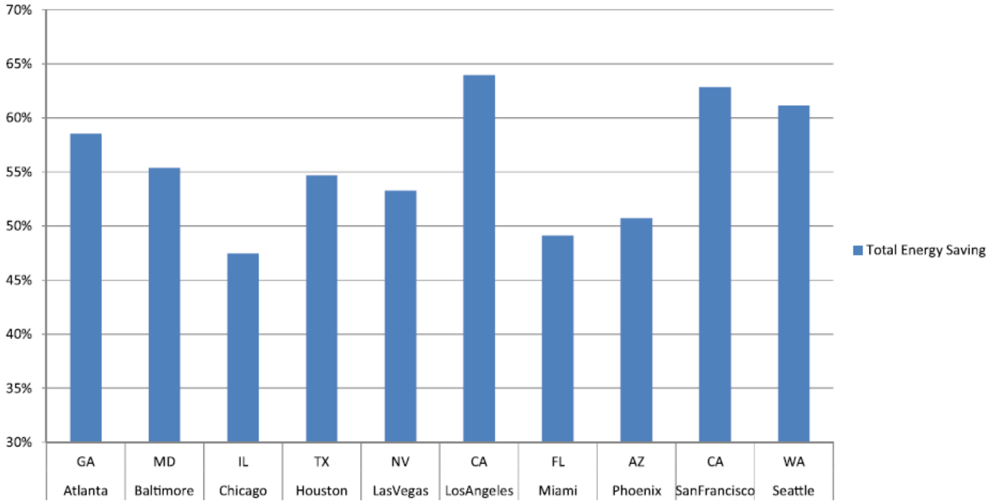


Fig. 6. Total Energy Saving Percentages in 10 US Cities.

Table 1
Building Energy Simulation Results of ASIHP versus a Baseline Heat Pump with Electric Water Heating.

City State		Atlanta GA	Baltimore MD	Chicago IL	Houston TX	Las Vegas NV	Los Angeles CA	Miami FL	Phoenix AZ	San Francisco CA	Seattle WA
Baseline	Total SC Delivery [kWh]	12617	9020	6438	27007	21111	1318	45187	31339	385	633
	Total WH Delivery [kWh]	15737	17311	18692	13735	13980	15349	11658	12541	17062	18129
	Total SH Delivery [kWh]	737	1356	3865	197	251	93	11	158	197	230
	Total Delivery [kWh]	29091	27687	28995	40939	35342	16761	56857	44038	17644	18993
	Total Energy Consumption [kWh]	18936	20176	23060	19461	20477	15678	20739	21796	17223	18393
	Total Electric COP [W/W]	1.5	1.4	1.3	2.1	1.7	1.1	2.7	2.0	1.0	1.0
ASIHP	Total SC Delivery [kWh]	11807	8482	6305	24143	19452	2694	40666	28096	766	1236
	Total WH Delivery [kWh]	15957	17473	18843	13900	14144	15516	11822	12704	17230	18301
	Total SH Delivery [kWh]	741	1362	3877	197	250	92	11	153	195	230
	Total Delivery [kWh]	28505	27318	29025	38241	33846	18302	52499	40953	18191	19768
	Total Energy Consumption [kWh]	7864	9000	12116	8817	9565	5648	10551	10739	6397	7148
	Total Electric COP [W/W]	3.6	3.0	2.4	4.3	3.5	3.2	5.0	3.8	2.8	2.8
Total Energy Saving Percentage (ASIHP vs. baseline)		58%	55%	47%	55%	53%	64%	49%	51%	63%	61%

Source: Energy and Buildings 156 (2017) 197–206, ORNL work