Efficiency Vermont

FEBRUARY 2, 2017

Heat Pumps: The Past, Present and Future of this Transformative Technology

Jake Marin
HVAC Program Manager

Special Thanks

- Daikin – Naoki Fujita, Matt Lacey, Bill Paige
- DOE, BTO - Tony Bouza
- Fujitsu – Mike Psihoules
- Mitsubishi – Rick Nortz

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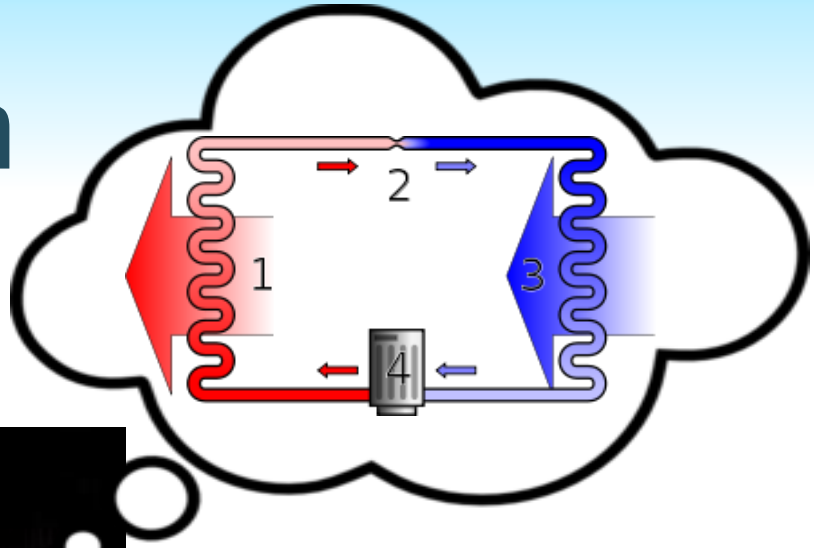
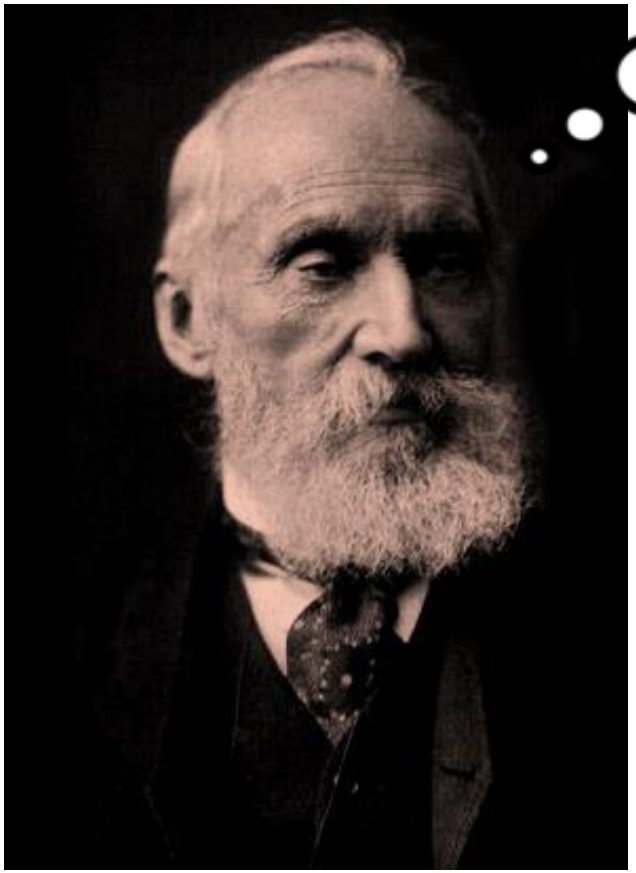
1852 – Lord Kelvin





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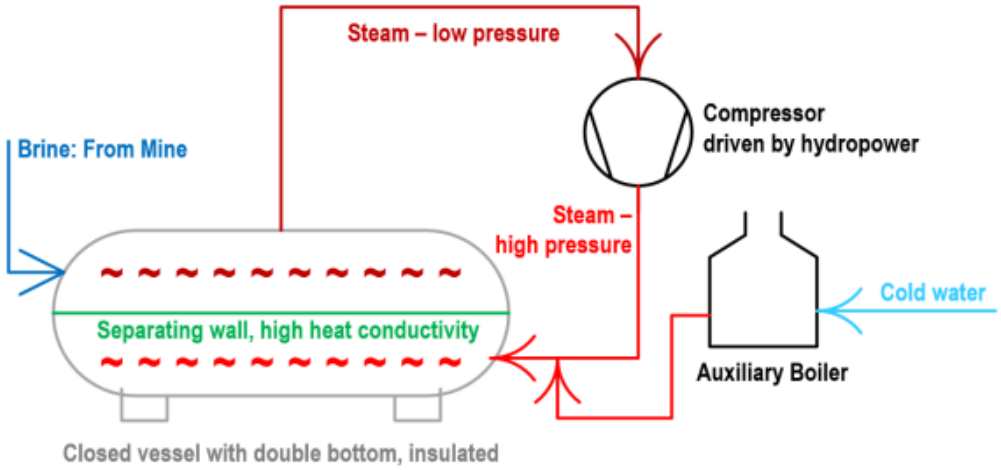
1856 – Peter von Ritting



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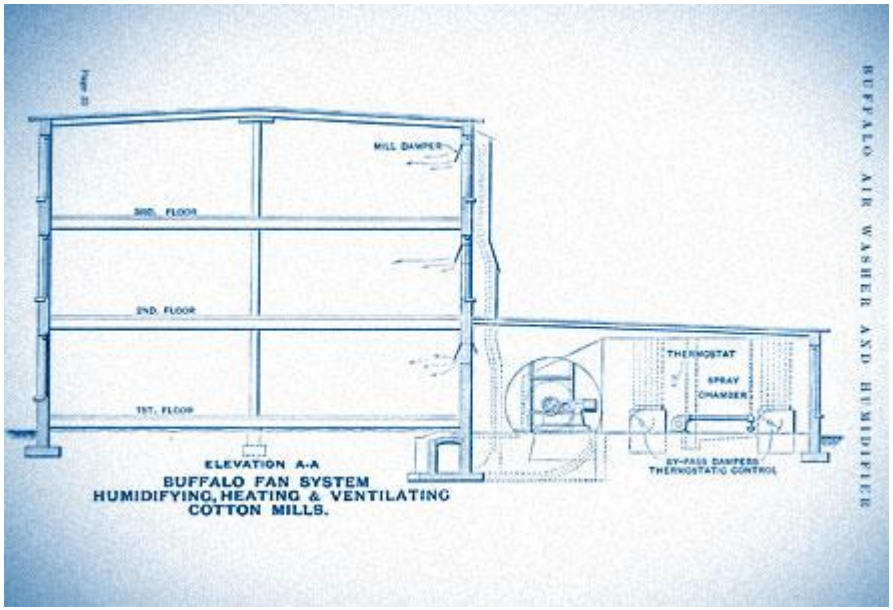
1902 Willis Carrier



- Inventor of modern air conditioning
- 1906 first installation of “Apparatus for Treating Air” at Cotton Mill in NC

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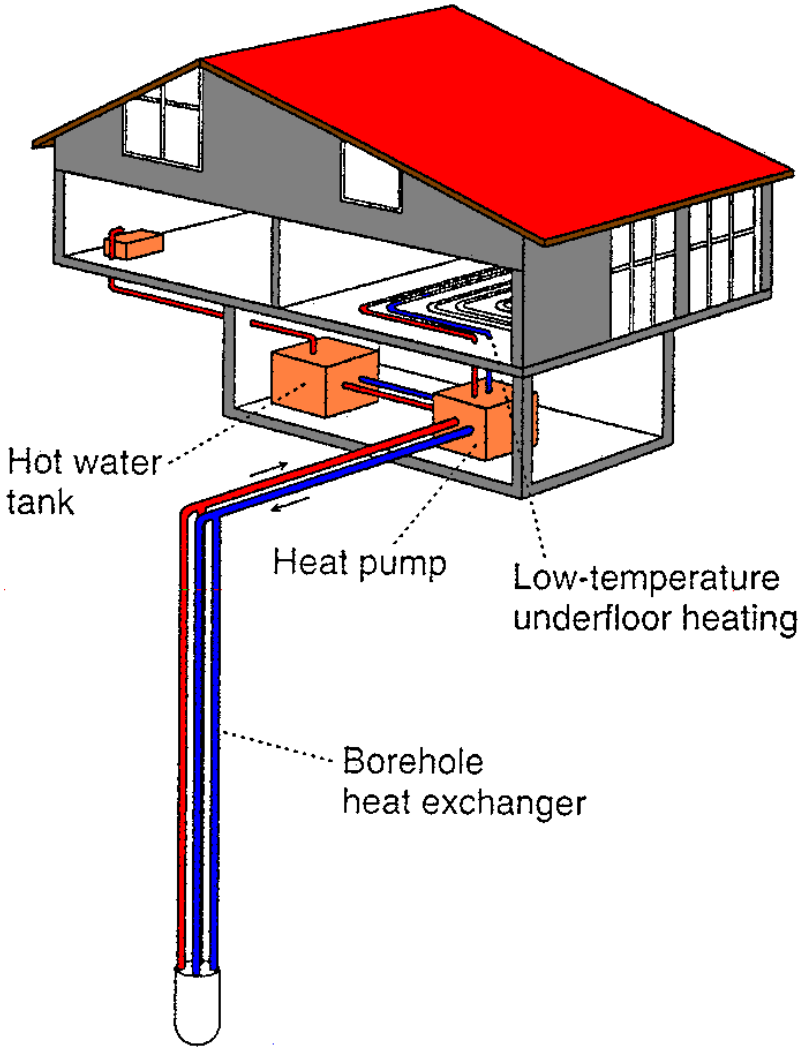
1940s – Ground Source HP



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1950-72 – Slow Time for HP

- Dropping oil prices
- Heat Pumps stagnate
- Mostly just cooling in warmer climates

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1973 – Oil Embargo

- … and a repeat in 1979
- First massive intro of heat pumps
- From 800,000 globally to **4,000,000!**

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70s and 80s – Asia and Ductless

- Ductless, good for masonry
- Small living units
- Historically kerosene heaters and window AC
- Ductless HP a great solution!

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Modern Innovations

- Refrigerants
- Microprocessors (80s)
- Electronic expansion valve (late 80s)
- Compressor technology (reciprocating to scroll to inverter)
- ECM fan motors
- Heat Exchangers (more efficient heat transfer with minimal surface area)
- Smaller, more efficient, quieter and more features

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Market and Industry

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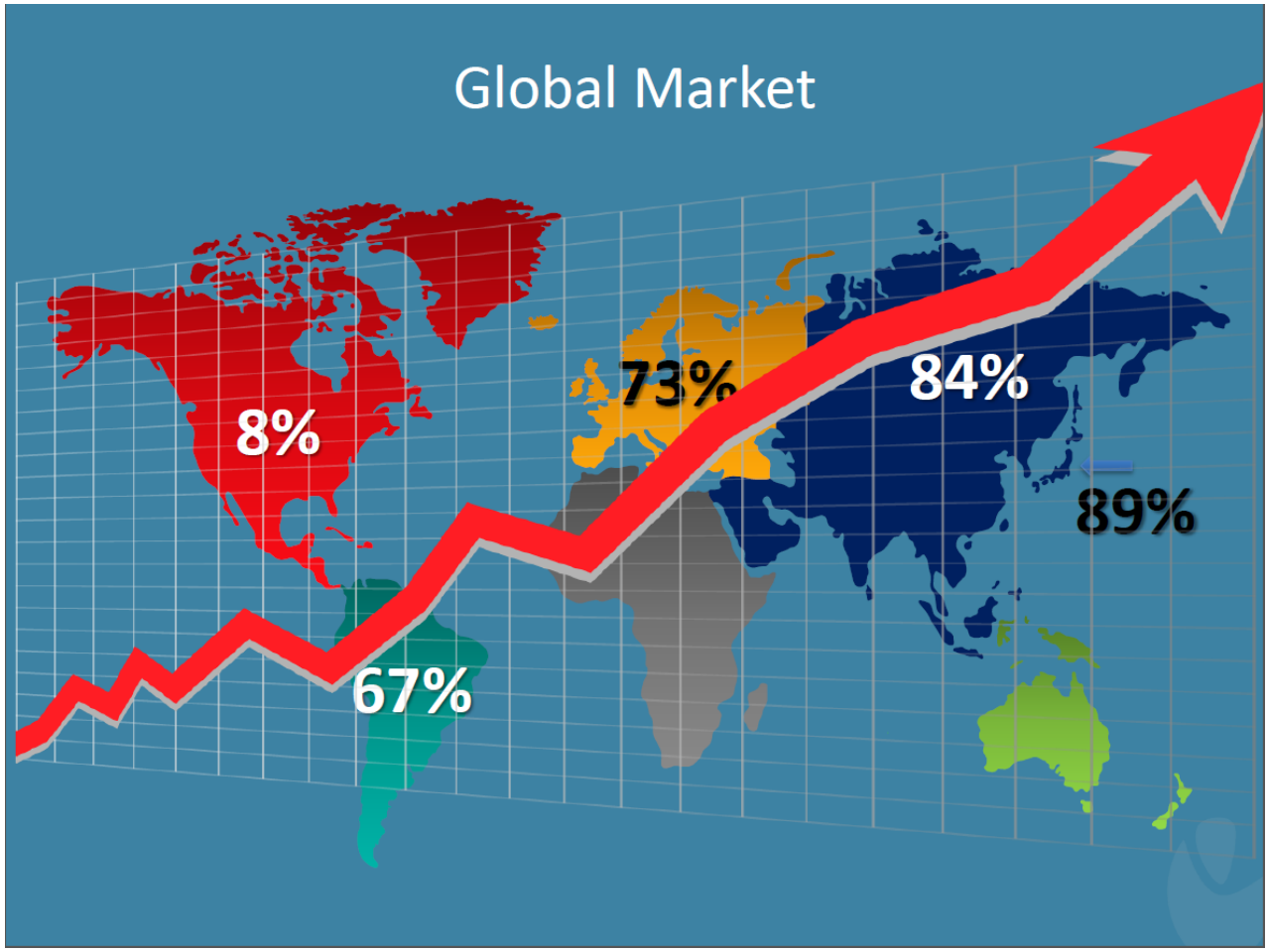
Global Ductless Adoption



Source: Nortz (Mitsubishi Electric) and Psihoules (Fujitsu), NJCEP Presentation

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Investment – Case Study

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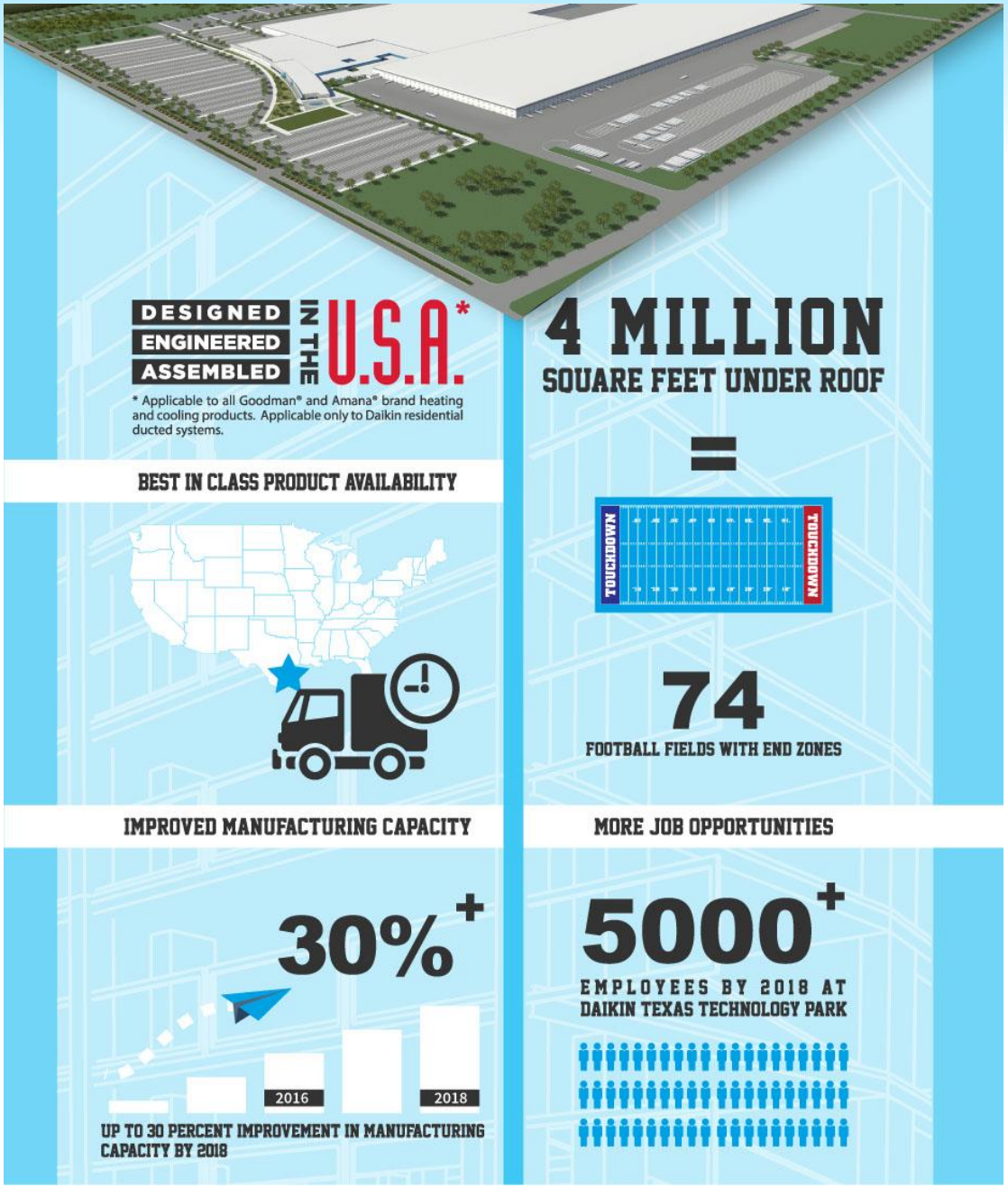

- $7B in US investments
- 2 other Parts Manufacturers have moved to US soil

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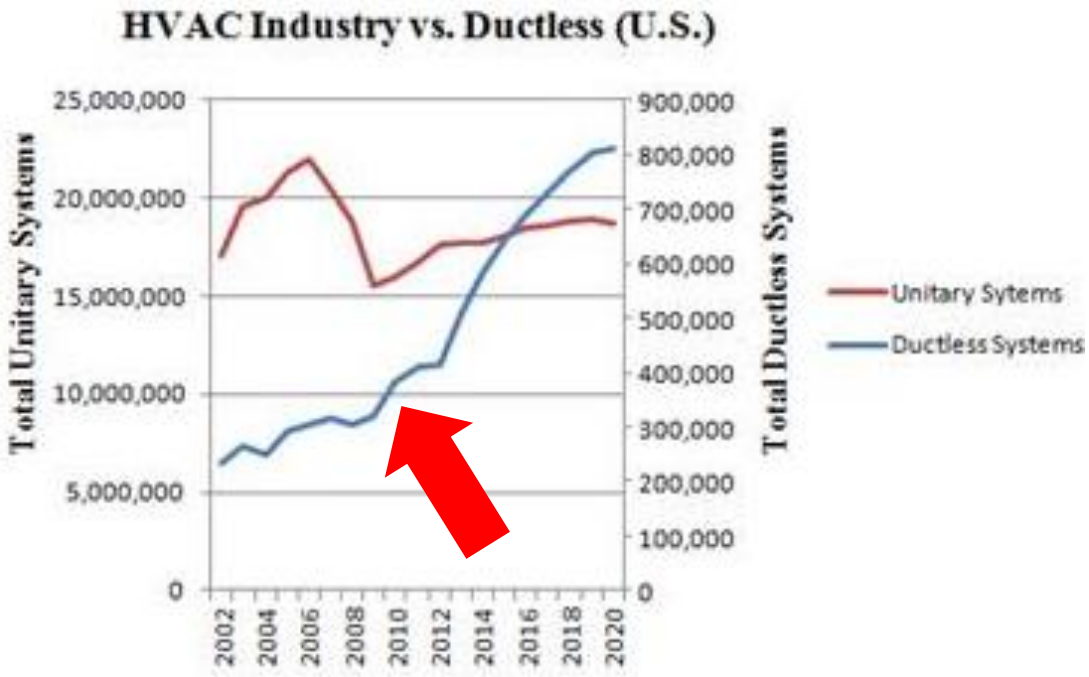
Market Growth

- 2015 - 2016 US Growth
  - **20% Ductless**
- EVT Program
  - 1824 (2015)
  - 2243 (2016)
  - **23%**



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Performance and Diversity

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How Low Can They Go?

- At least -13˚F
- Below -13?
- COP 2.0 @5˚F
- 100% of nominal capacity @5˚F

Pretty Low!

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Performance

- HSPF 12-15
- SEER 20-30, as high as 38!
- But…are HSPF and SEER good indications of performance?
- New Testing Standards
  - CSA
  - Dynamic vs. Static Testing

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Ductless – Single Zone

- EVT Supports 6 Manufacturers
- NEEP – 15 Manufacturers
- From 6,000-24,000 btu/h

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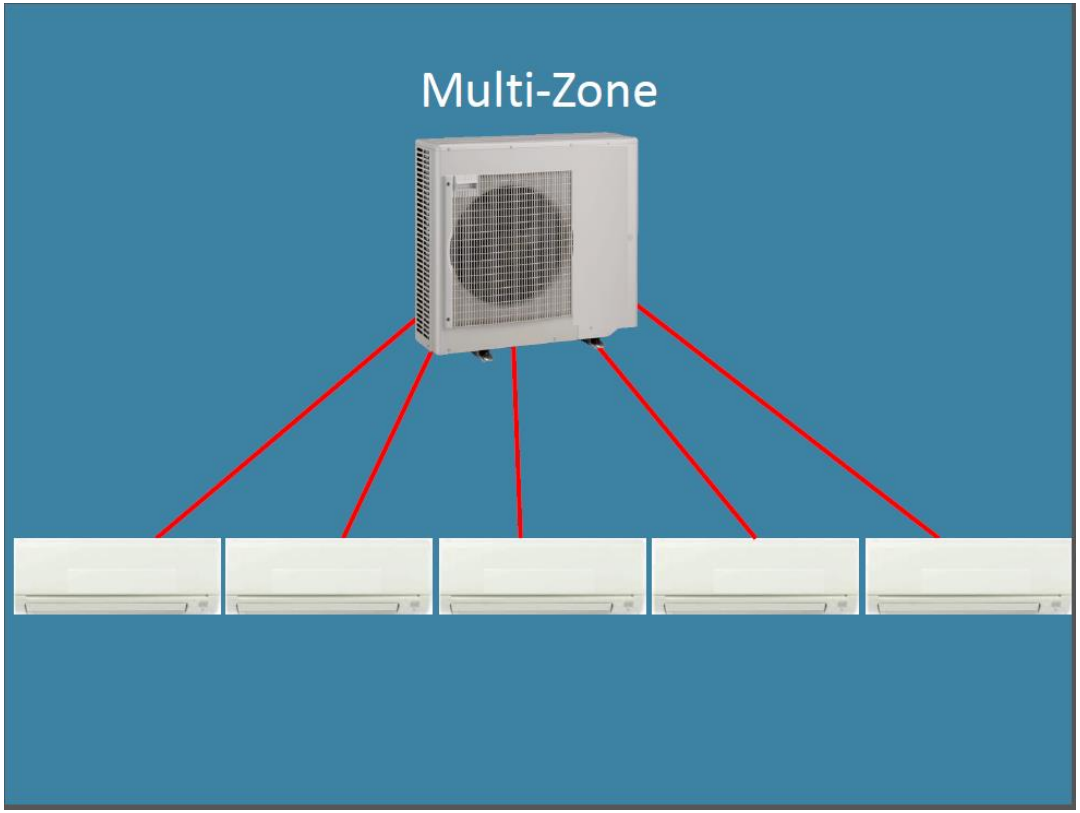
Ductless – Multi-Zone



- EVT – 3 Manufacturers
- NEEP – 6 Manufacturers
- 18,000 – 48,000 btu/h

Source: Nortz (Mitsubishi Electric) and Psihoules (Fujitsu), NJCEP Presentation

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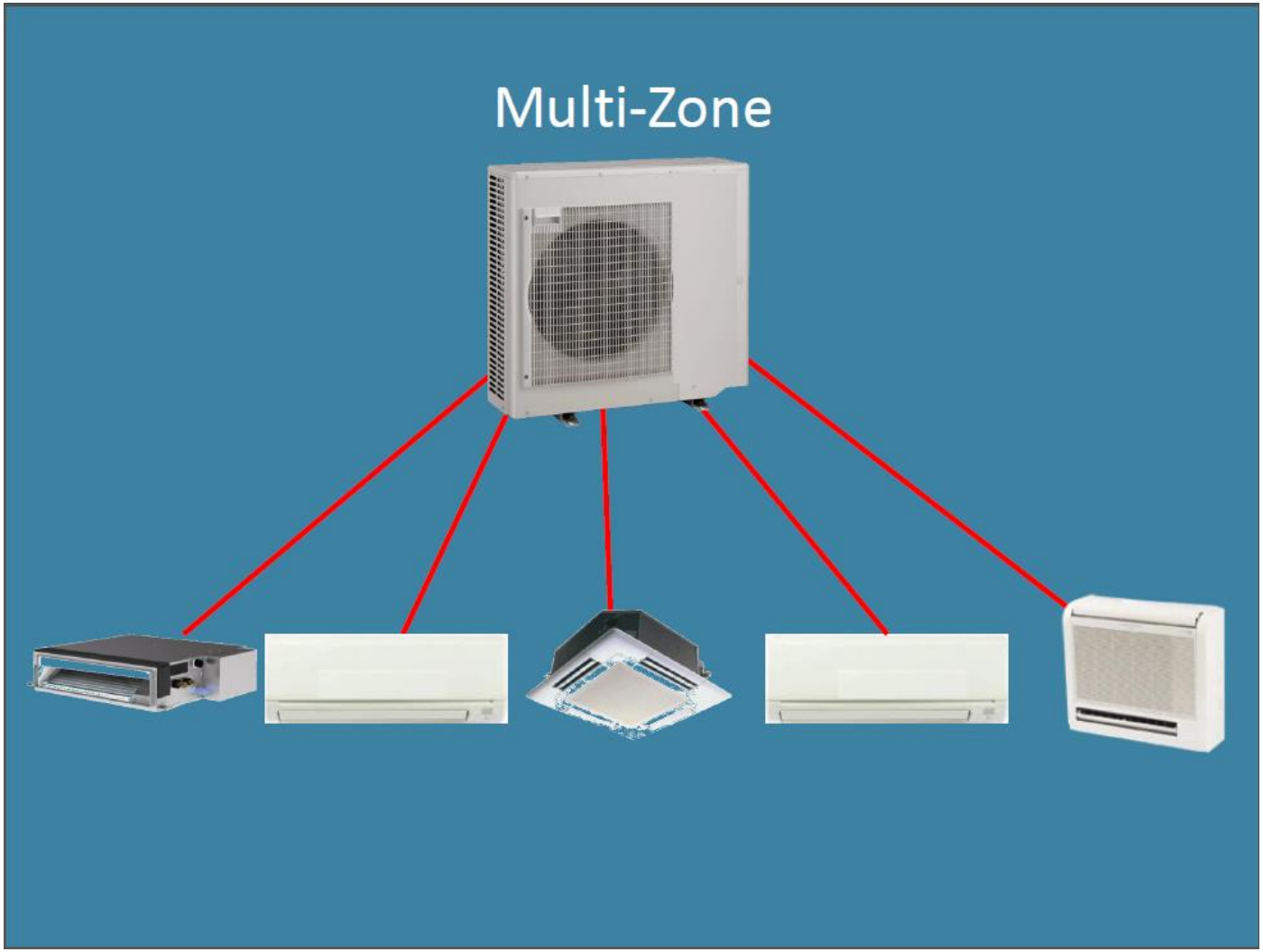
Ductless – More Choices!



Source: Nortz (Mitsubishi Electric) and Psihoules (Fujitsu), NJCEP Presentation

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Ducted

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Ducted

- Standard Heat Pump
- Not a lot of cold climate options
- Performance not at level of ductless
- Fully Distributed heating/cooling
- Excellent Integration with Backup System

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Ducted Ductless?

- Good for multiple small rooms
- Efficiency loss due to added fan energy

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Air to Water - Altherma

DAIKIN altherma™

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Air to Water

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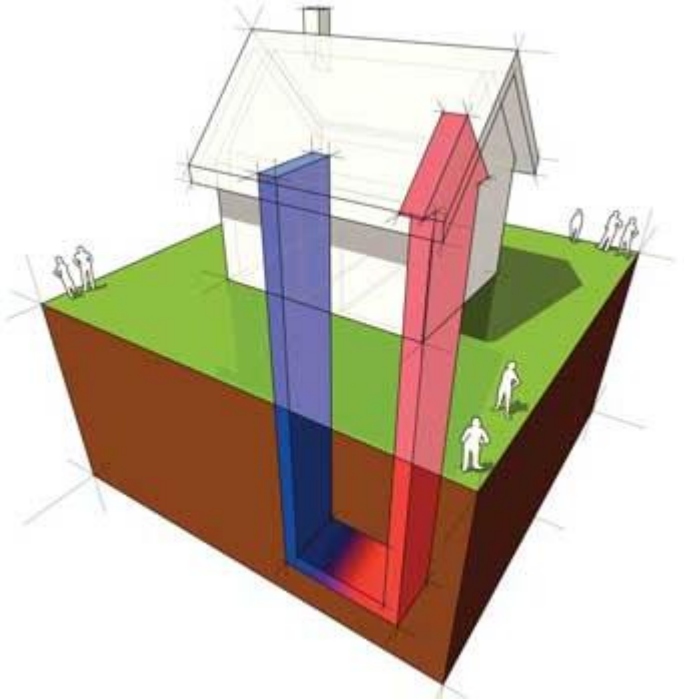
Ground Source

- Seasonal COPs up to 5
- Whole home heating/cooling
- No backup necessary
- Market growth, but still prohibitively expensive for most



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Commercial Heat Pumps

- VRF
  - Largest opportunity for growth in VT
- Hybrid Rooftop Units
  - Least involved option (direct swap-out)

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Other Applications

- Domestic Water Heating
- Clothes Dryers
- Industrial Heat Recovery
  - Drying, Washing, Pasteurizing, etc.

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Its All About Style…

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Current Trends

- Growth
- Investment in US market
- Development of products for US market
- Diversity of product offering
- Viable for most climates and market sectors

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System Impact & Integration

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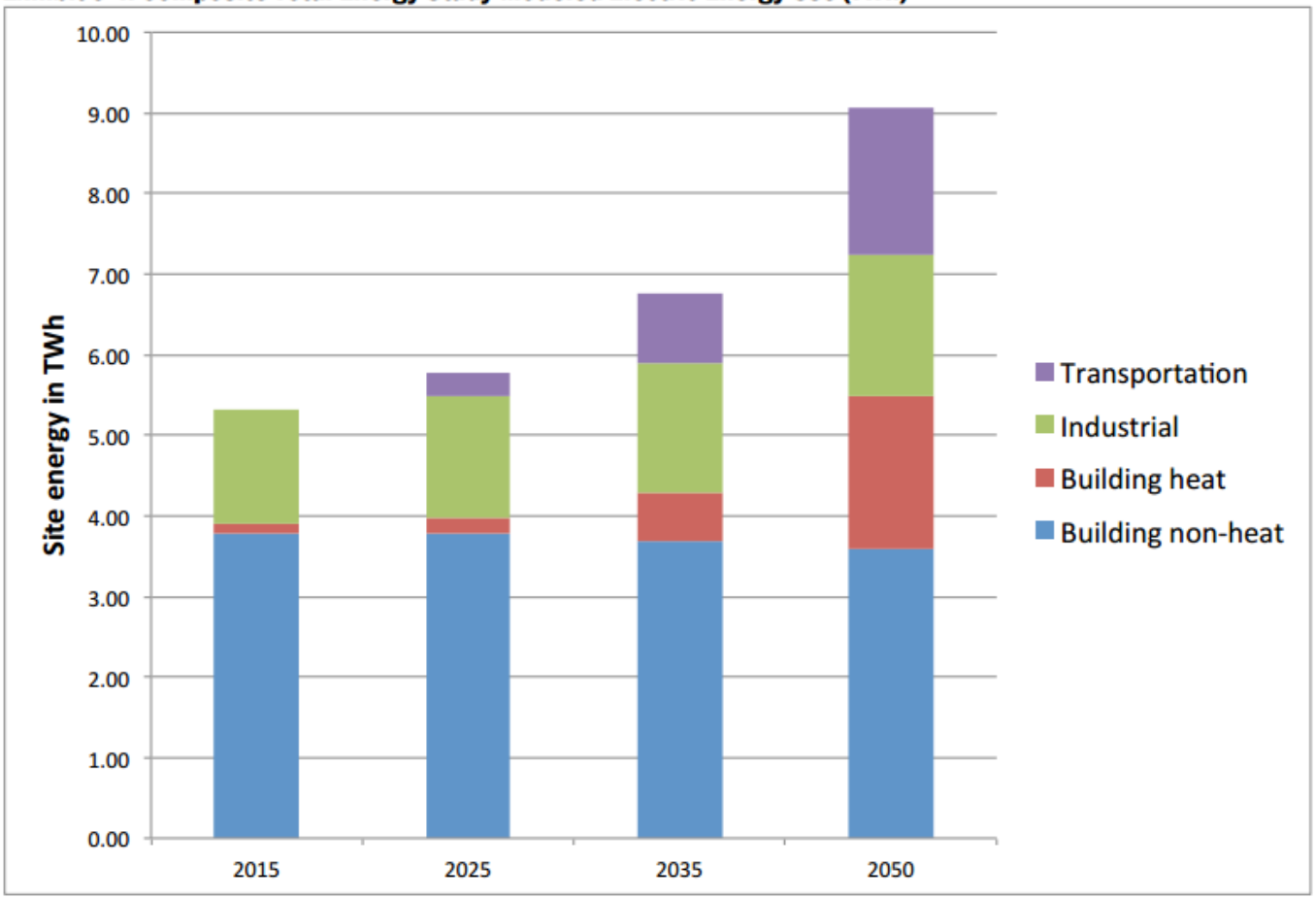
Modeled Electric Consumption

Exhibit 9-4. Composite Total Energy Study Modeled Electric Energy Use (TWh)



Source: VT Comprehensive Energy Plan 2016

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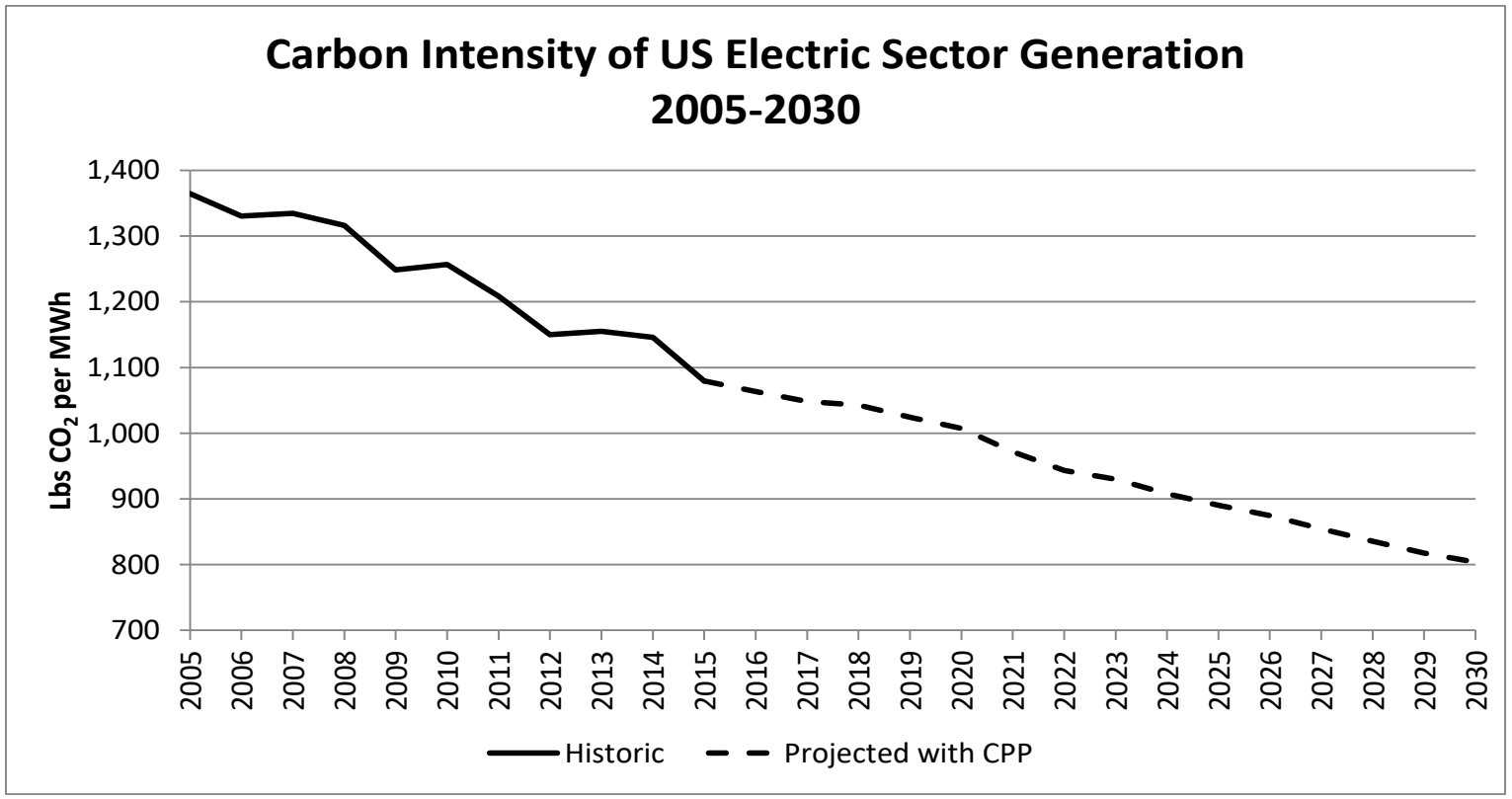
Improving “Emiciency”



Source: NRECA, RAP, “More Is Less: Environmentally Beneficial Electrification”

- Energy efficiency of installed equipment is static over time
- Emissions Efficiency (“emiciency”) improves over time

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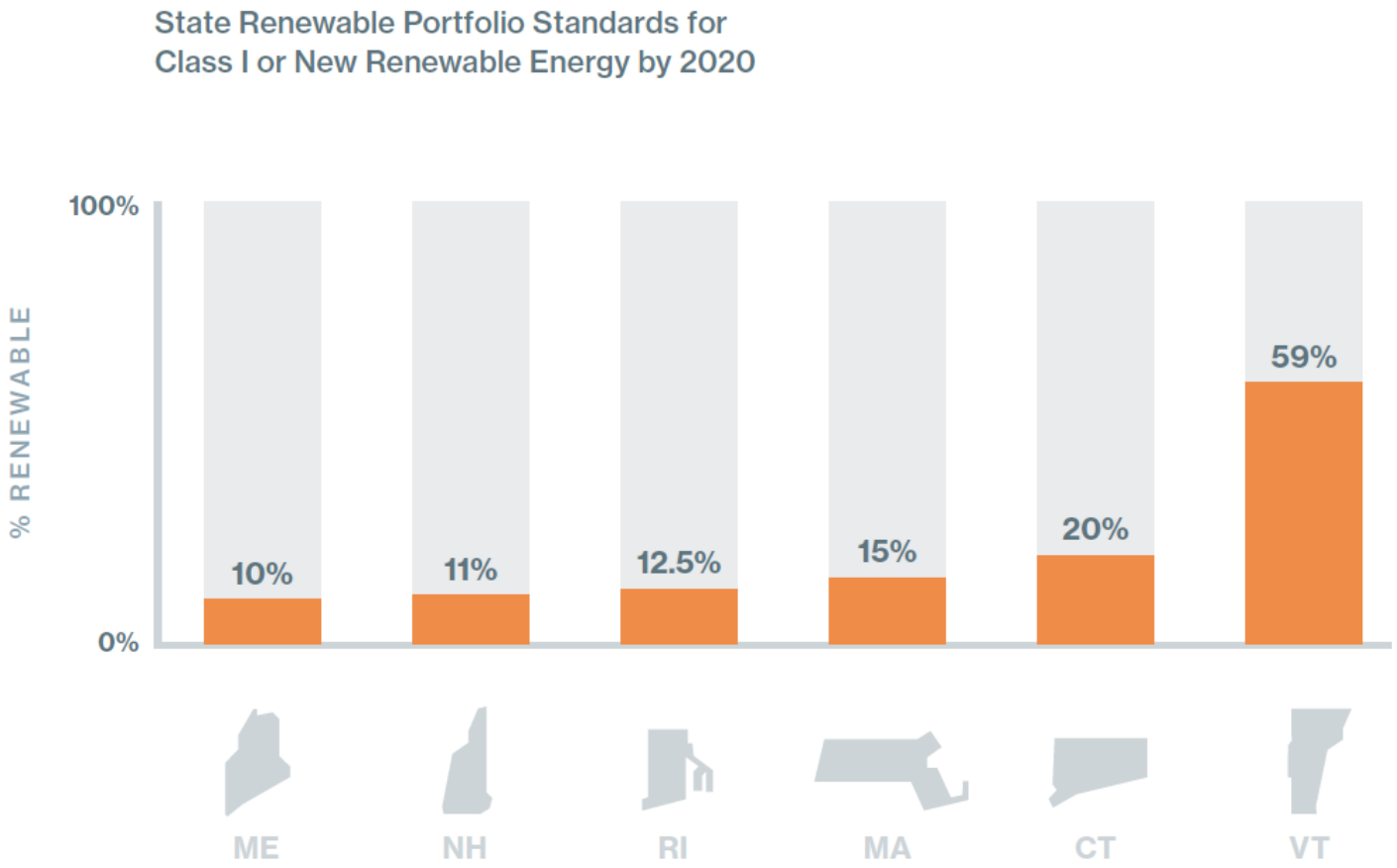
Renewable Penetration



Source: ISO-NE 2016 Regional Electricity Outlook

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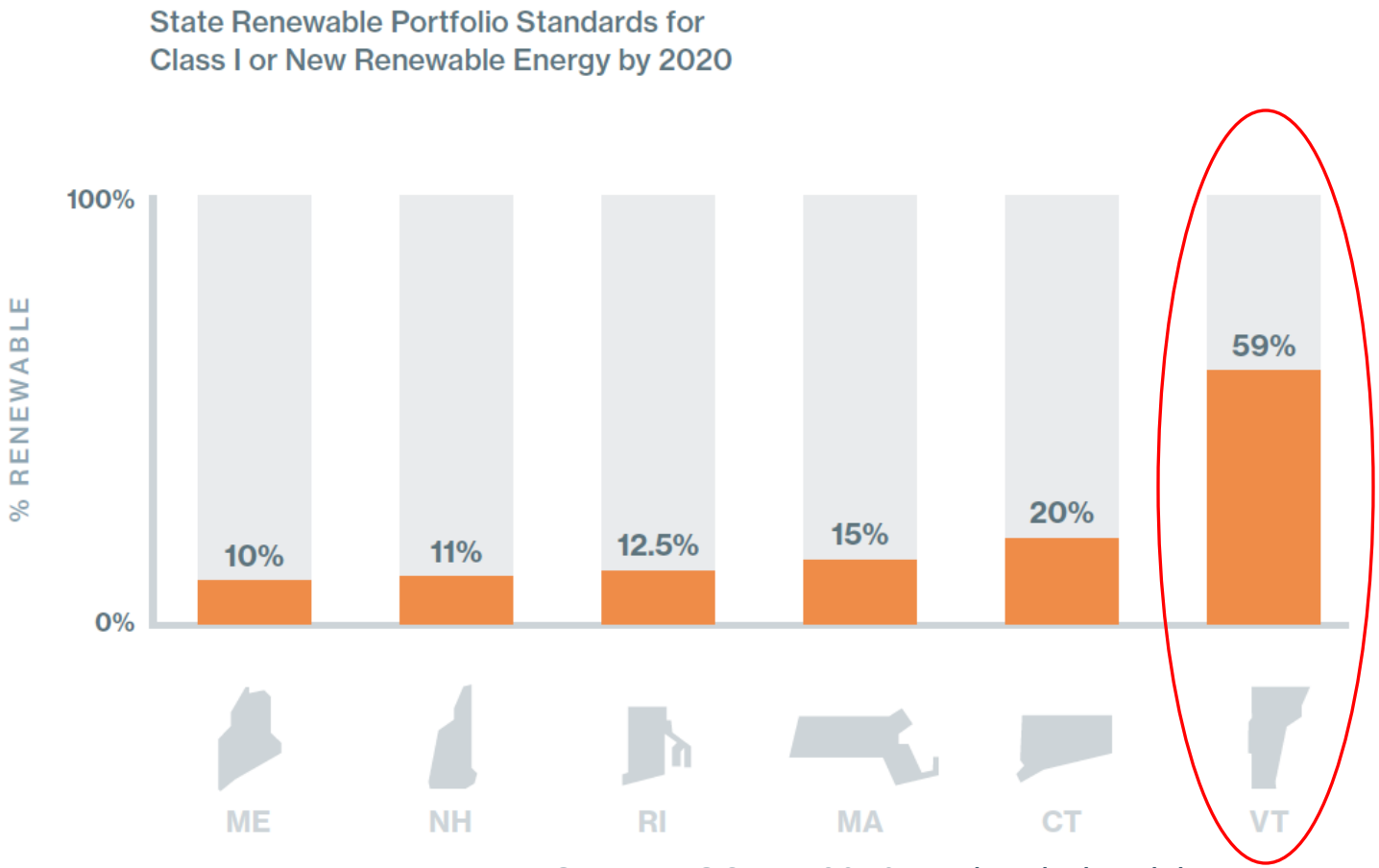
Renewable Penetration



Source: ISO-NE 2016 Regional Electricity Outlook

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75%

by 2032

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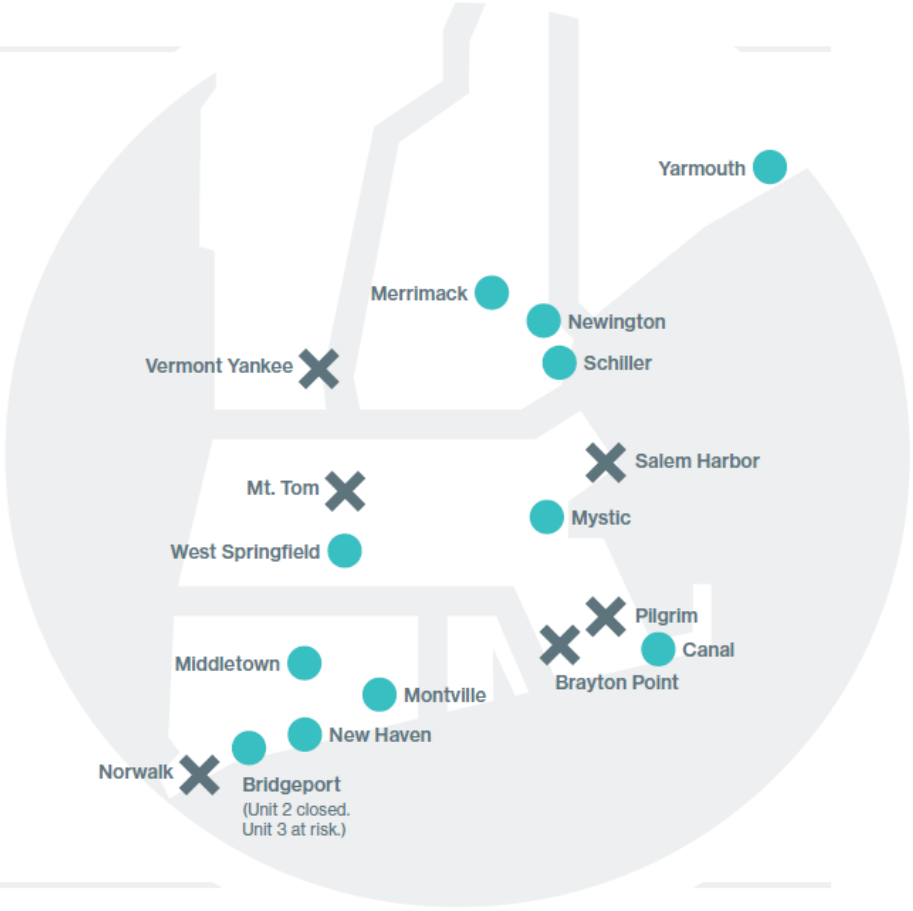
An Endangered Species

On the way out

More than 4,200 MW of the region's nongas generating capacity has retired or plans to retire soon. This includes several oil- and coal-fired units, as well as two nuclear plants that were part of the region's baseload generation. "At risk" for closing are another 6,000 MW from additional coal- and oil-fired generators, which are displaced from the electric energy market on most days by gas-fired units. But they are still critical for meeting the region's demand in winter, particularly when natural gas supplies are limited. In total, about 30% of the region's generating capacity could be gone by 2020. These retiring resources are likely to be replaced by more natural-gas-fired resources.



Source: ISO-NE 2016 Regional Electricity Outlook

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Enhanced Utilization of Renewables

- PV, Fuel Cells, and Battery Storage all operate using DC power
- Utilizing DC reduces losses due to:
  - Transmission/Distribution
  - Inversion

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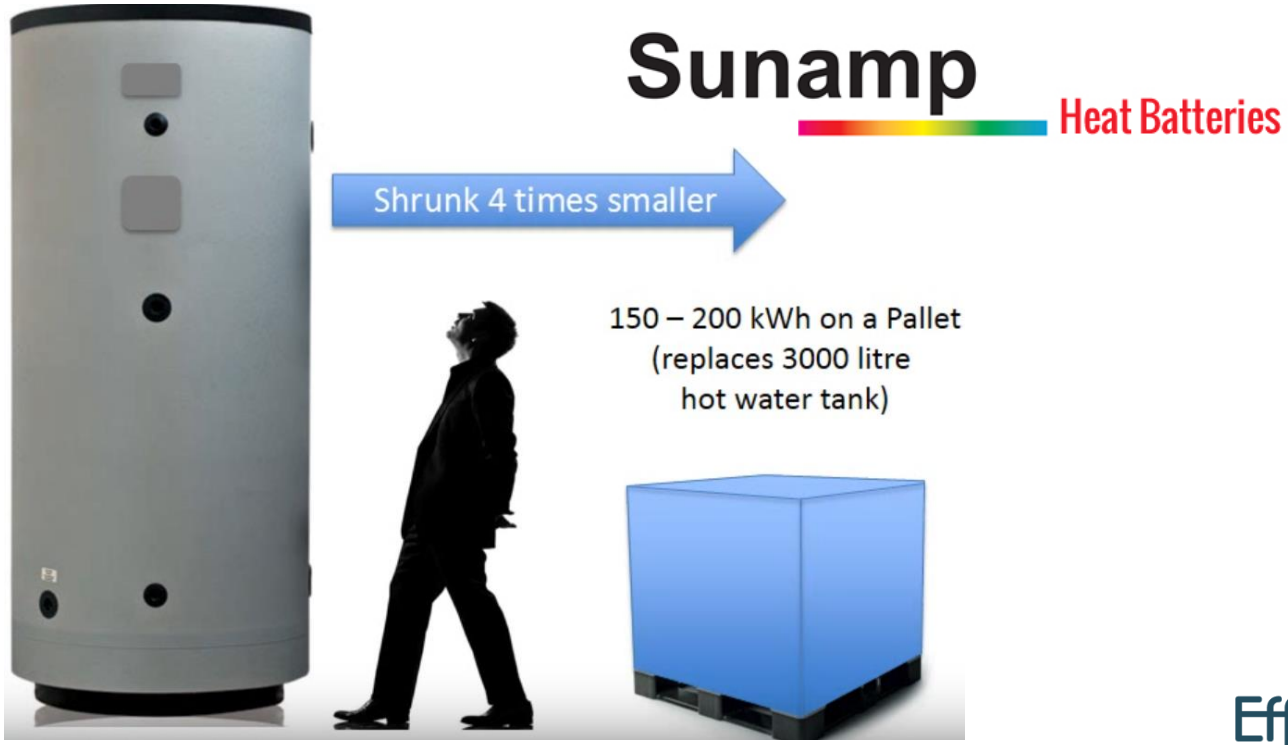
Thermal Storage

- Simple Water Storage, or
- Phase Change Materials (PCMs)



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Smart and Well Connected

- Demand Response
- Remote Firmware Updates
- Site-specific operation
- Occupancy and other sensors
- Integrated Controls

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Natural Refrigerants

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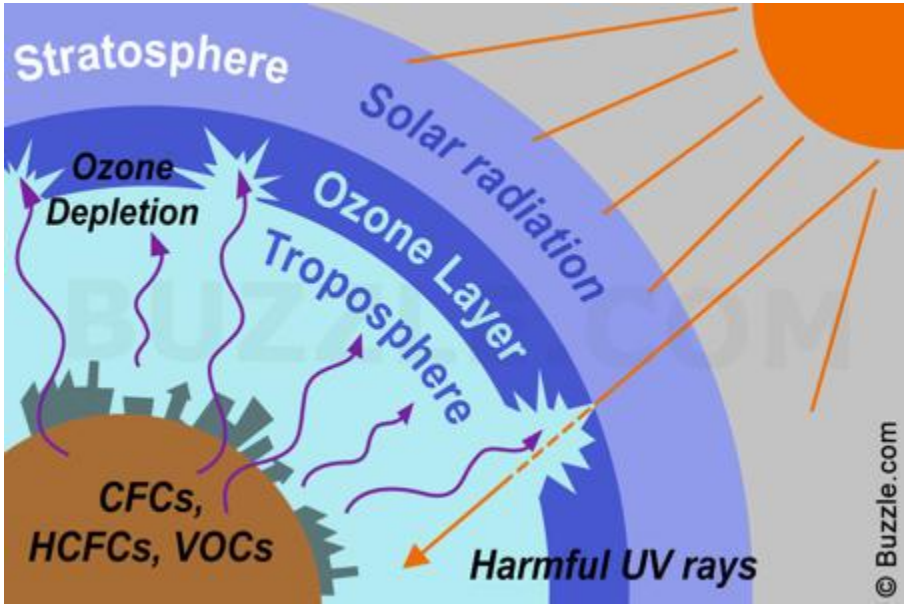
ODP

- **O**zone **D**epletion **P**otential
- Relative amount of ozone degradation compared to baseline R-11 (1.0)



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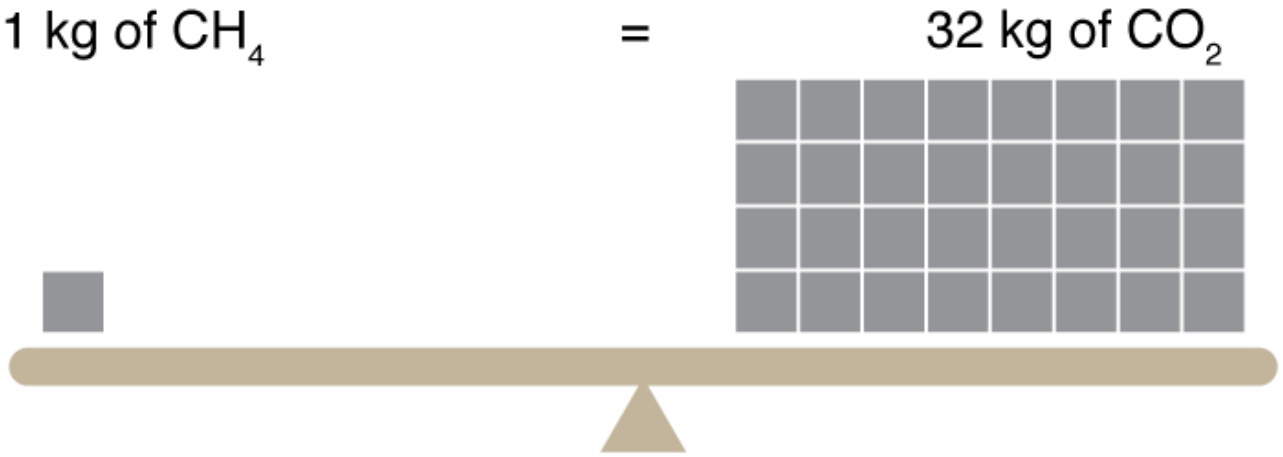
GWP

- **G**lobal **W**arming **P**otential
- Relative amount of heat trapped in the atmosphere by a gas (refrigerant) compared to a CO2 baseline (1.0)



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GWP and ODP

Figure 2: ODP and GWP for Various Refrigerants

REFRIGERANT	TYPE	ODP	GWP (100yr)
R-12	CFC	0.820	10,600
R-22	HCFC	0.034	1,700
R-404A	HFC	0	3,800
R-410A	HFC	0	2,000
R-290 (Propane)	Natural	0	~20
R-717 (Ammonia)	Natural	0	<1
R-744 (CO_2)	Natural	0	1
HFO-1234yf	HFO	0	4

Source: Calm & Hourahan, 2001

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Refrigerants

26%

Source: DOE, EERE, July 2016 *The Future of Air Conditioning for Buildings*

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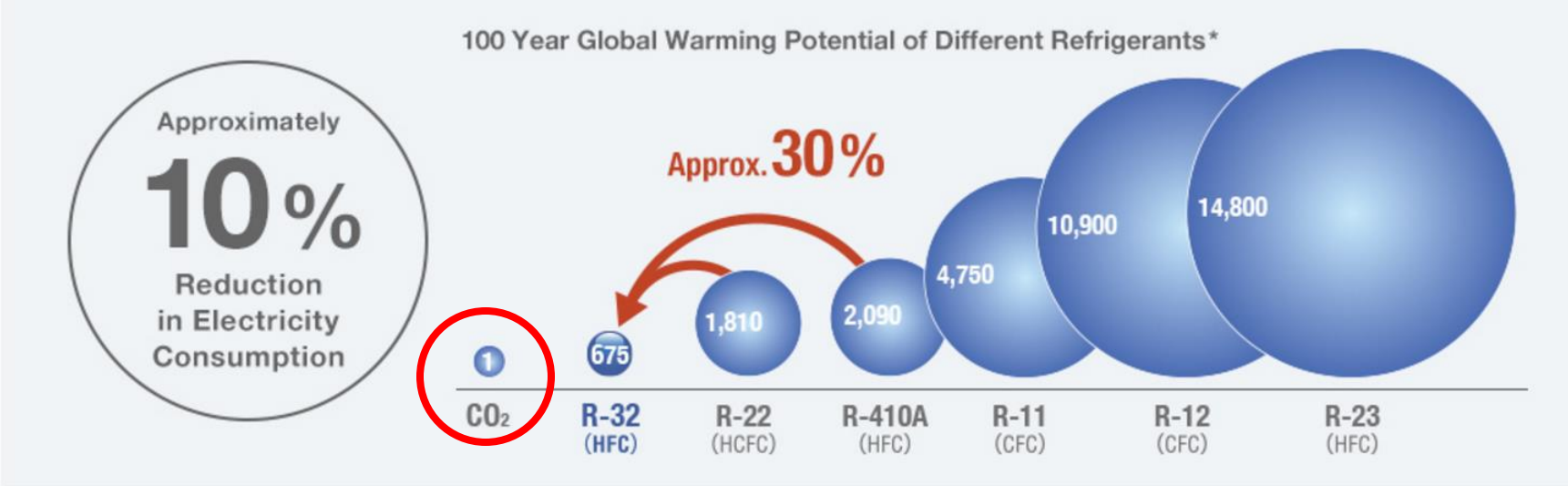
R-32



*Source: Values for 100 year global warming potential (GWP) from IPCC Fourth Assessment Report. Comparative 100 year GWP: HFC410A, 2,090; HFC32, 675.

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On a Mission

- Advancing Natural Refrigerants in order to shape a more sustainable future for refrigeration [and heat pumps!]

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New Ways to Skin the Cat

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The Pretty Sure Stuff

- Performance improving
- Smaller
- More features
- More options (manufacturer, delivery, etc.)
- More whole home

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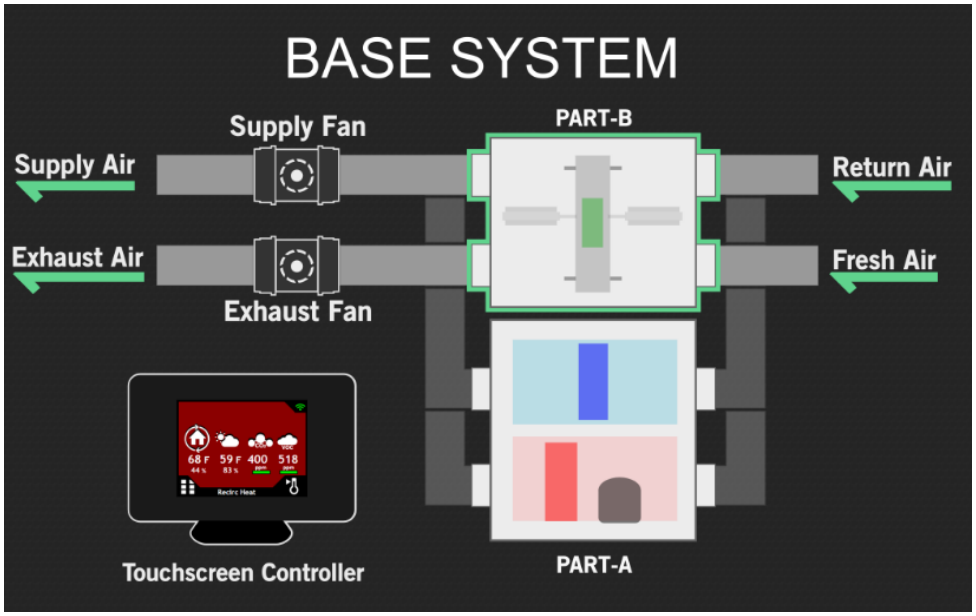
All-in-One

CERV



- Heat pump integrated ERV
- Integrated “smart” controls

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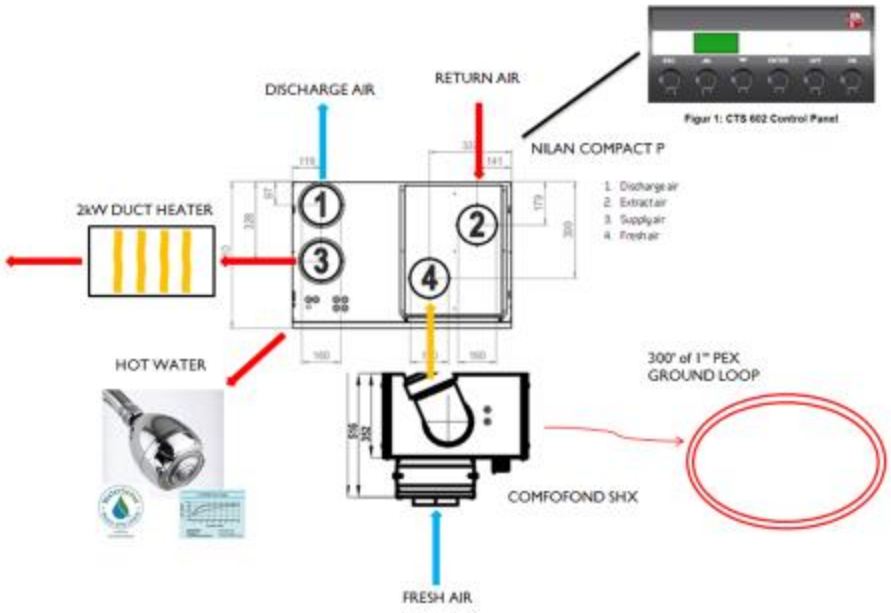
All-in-One

Nilan – Compact P

- Heat Recovery Ventilation
- DHW
- Heat Pump



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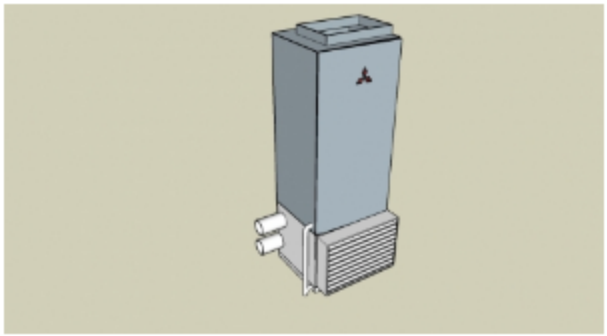
All-in-One

VICS

TEAM LEAD: STEVEN WINTER ASSOCIATES INC.—WASHINGTON, DC



Steven Winter Associates Inc. will develop a fully integrated, smart space conditioning and ventilation solution, referred to as VICS (a Ventilation Integrated Comfort System), for low-load dwellings (zero energy ready homes, multifamily apartments, etc.). This innovation is intended to address HVAC performance issues found in most low-load dwellings when space conditioning and whole-building ventilation are provided by separate mechanical systems. This lack of system integration can result in high equipment and installation costs, redundant components, and poorly or non-integrated controls. The VICS is intended to provide:

- A single device integrating an HRV or ERV with a low-capacity, split heat pump fan coil to provide efficient heating, cooling, dehumidification, and whole-house ventilation
- Filtration, heat recovery, conditioning, and distribution of outdoor air
- Installed cost savings of $1,000–$2,000 compared to separate, ducted ventilation and heating/cooling systems
- Separate control of supply and exhaust flows allowing for active makeup air for local exhaust fans
- Better humidity control by passing outdoor air through ERV and over a cooling coil.

- Full ventilation and space conditioning
- Designed for low load homes

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Complete Replacement

- No need for backup heating system
- Possible today in low load buildings
- Within 10 years (maybe 5!)

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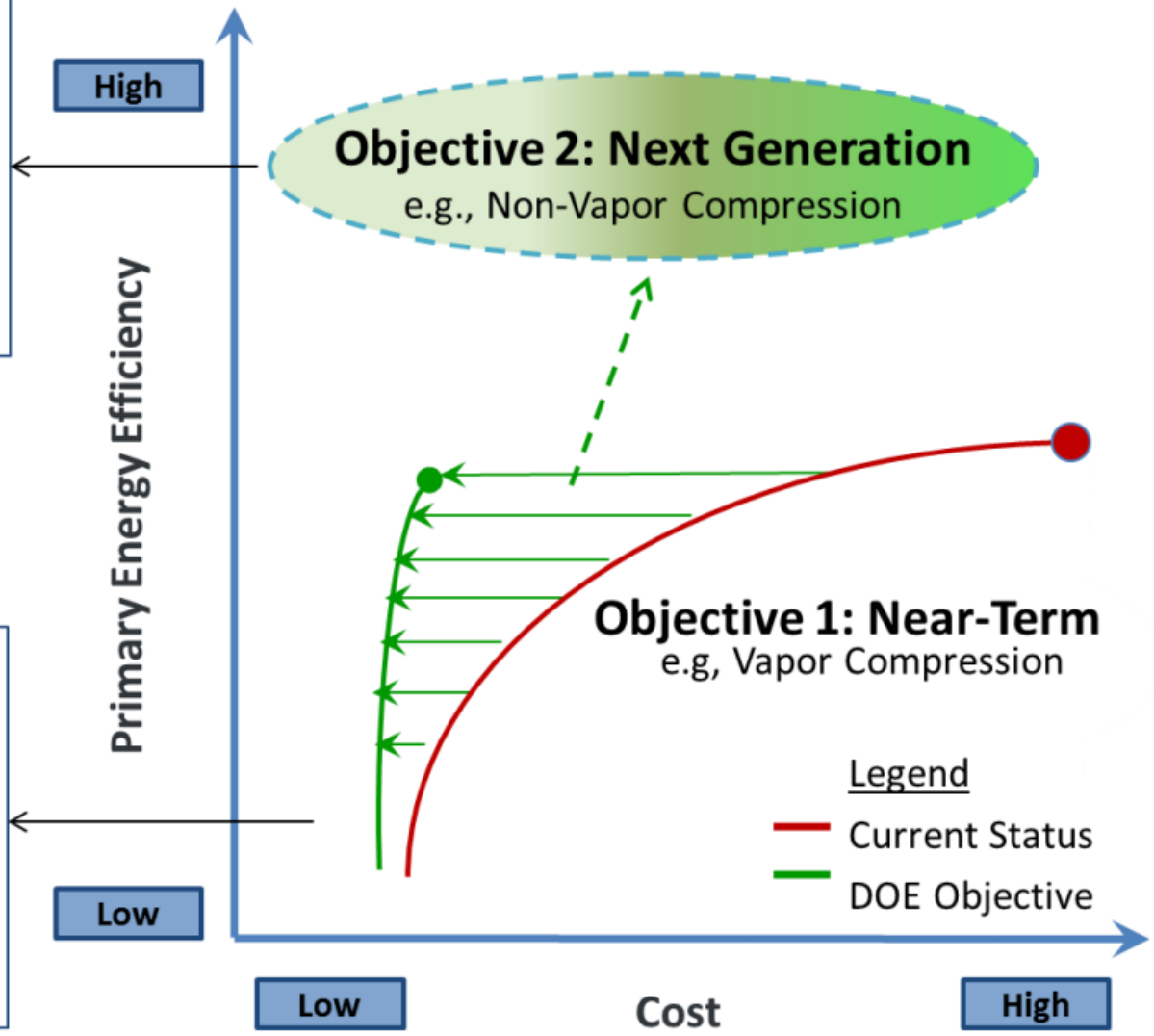
Objective 2: Next Gen

- Longer-term
- Potential to "leapfrog" existing technologies
- Entirely new approaches

Objective 1: Near-Term

- Improve efficiency of current technologies
- May include cost reduction activities



Source: Refined from BTO Presentation: energy.gov/sites/prod/files/2014/05/f15/HVAC_Overview_Bouza_042314_and_042414.pdf

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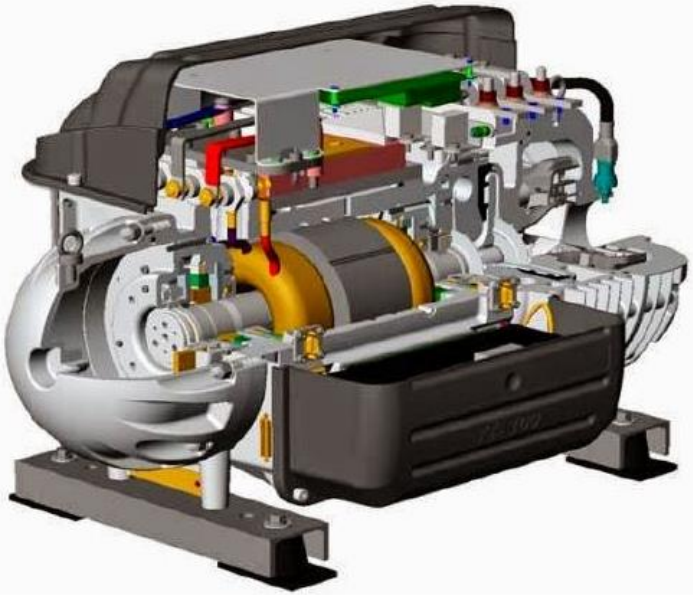
Compressors

The Heart and Soul of Heat Pumps

- Reciprocating, rotary vane, and screw
- Scroll currently used in efficient systems
- What's next? **Centrifugal**
- Used in Chillers
- Natural Refrigerant friendly
- Oil Free



Centrifugal Compressor

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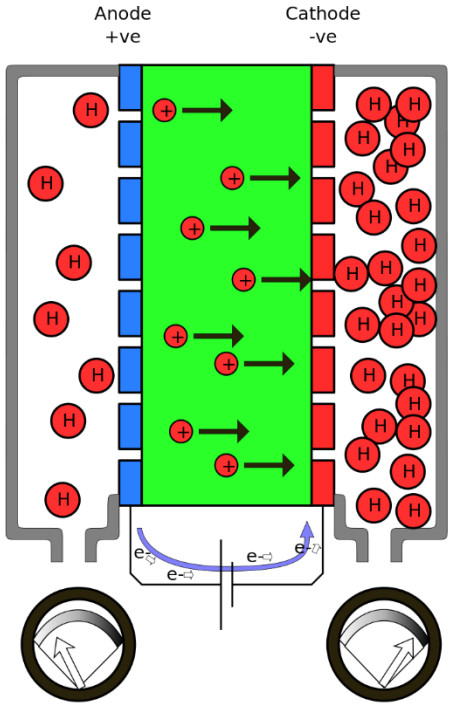
Compressors

The Heart and Soul of Heat Pumps

- Non-mechanical compression?
- Electro-chemical compressors
  - "Noiseless"
  - Low GWP refrigerants
  - Hydrogen combines with H20 and ammonia
  - Pressures up to 10,000 psi



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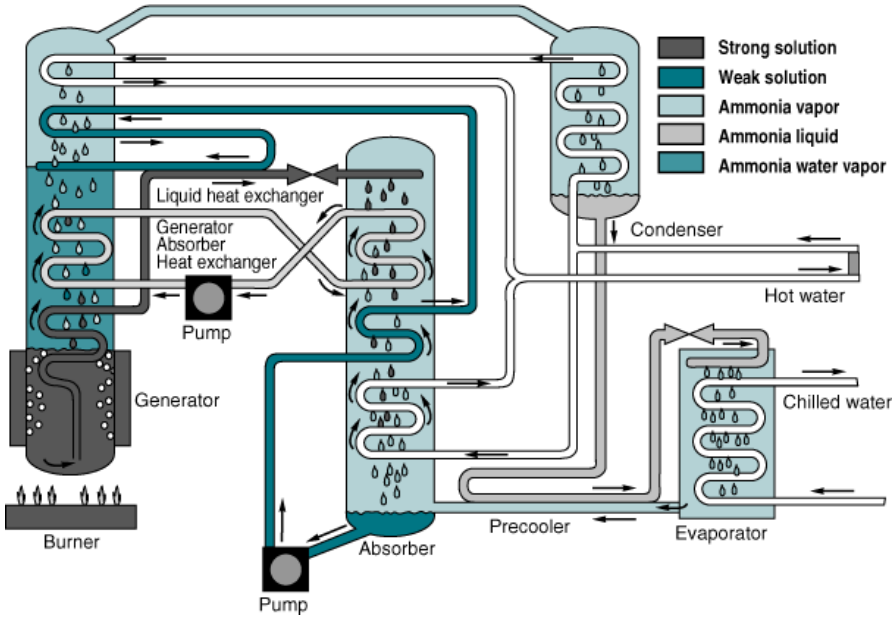
Non Vapor Compression

Absorption

- Cyclical absorption/desorption of refrigerant in secondary fluid
- Runs on Electricity or combustible fuels
- No compressor!
- Natural refrigerant
- New? - smaller and less expensive



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Non Vapor Compression

The really far-out stuff

- Thermo-electric
- Magneto-caloric
- Electro-caloric
- Elastic-caloric
- Thermo-acoustics

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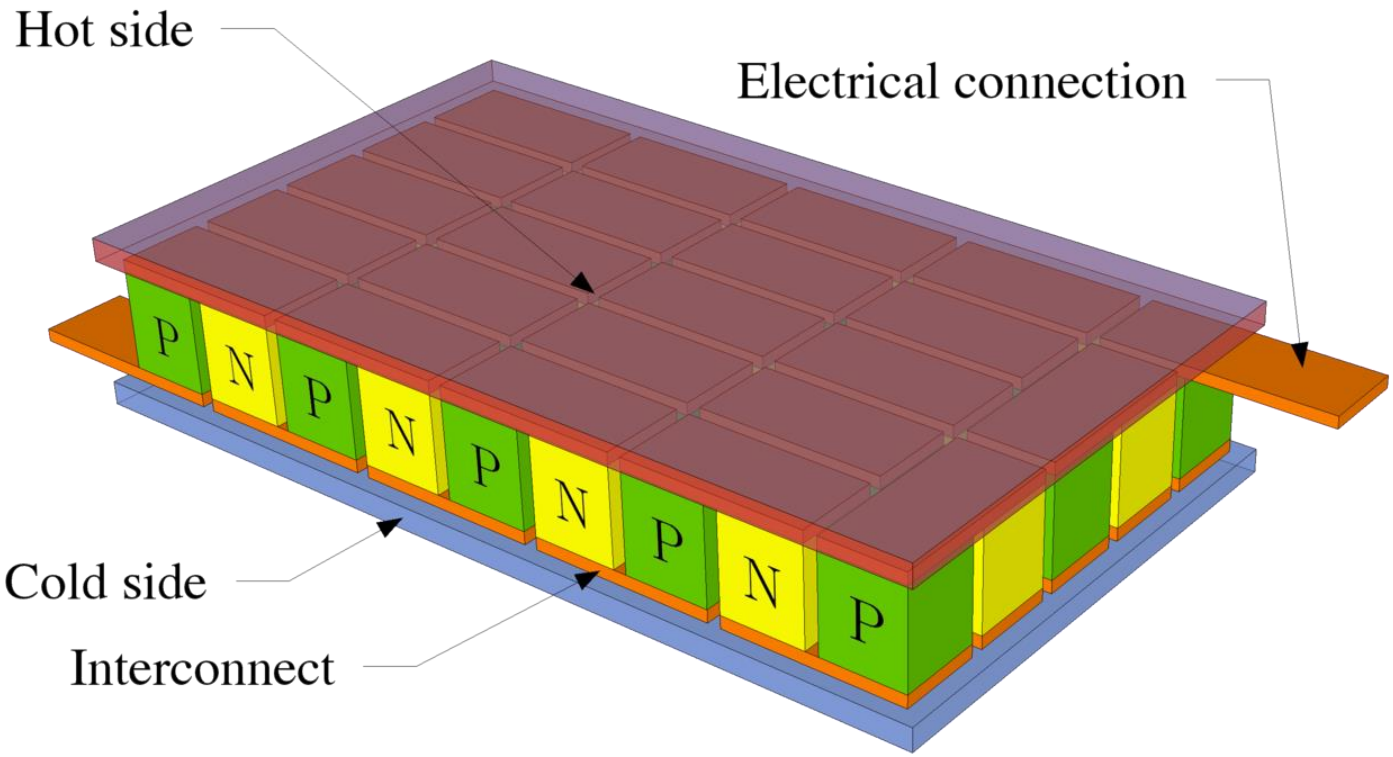
Thermo-electric



- Current induces temperature differential across 2 different materials (“peltier effect”)
- Solid State Heat Pump

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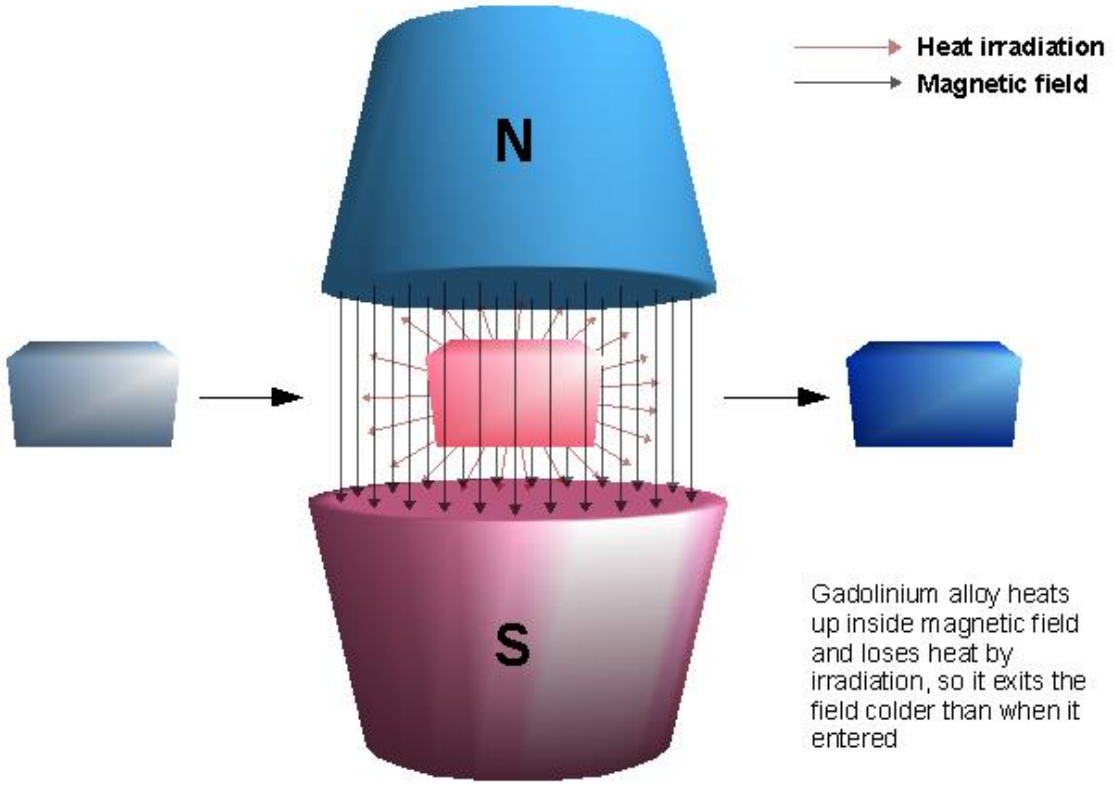
Magneto-caloric



- Some materials gain and lose heat when exposed to a magnetic field

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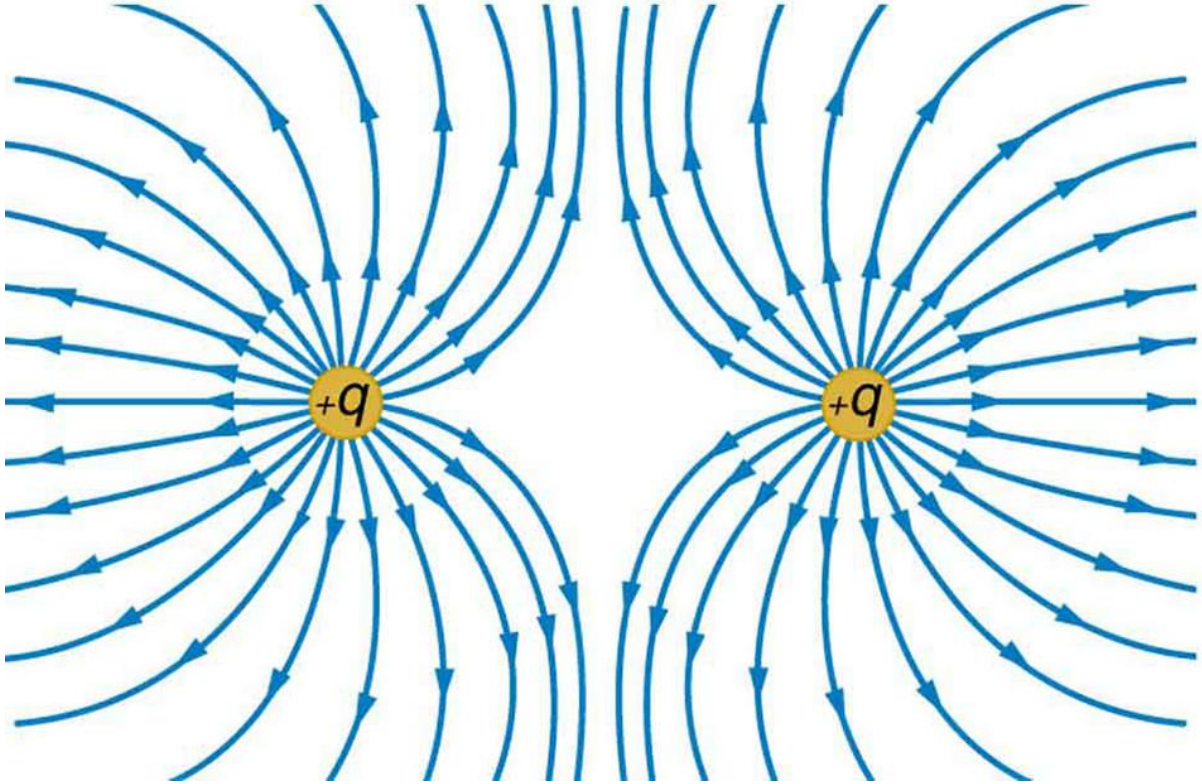
Electro-caloric



- Materials show a temperature change when exposed to an electric field

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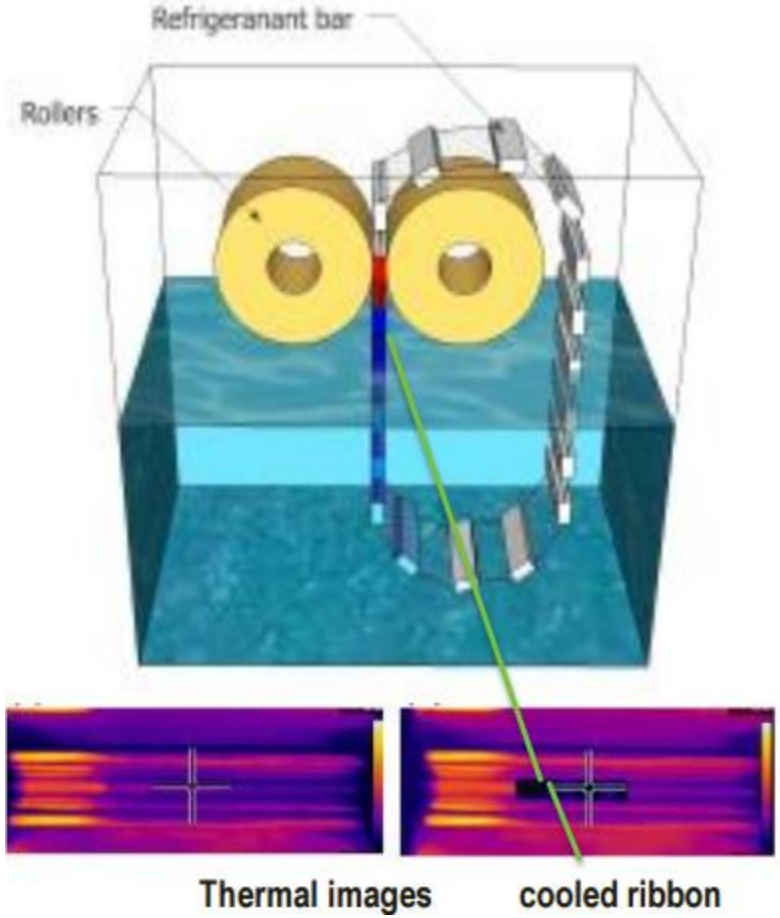
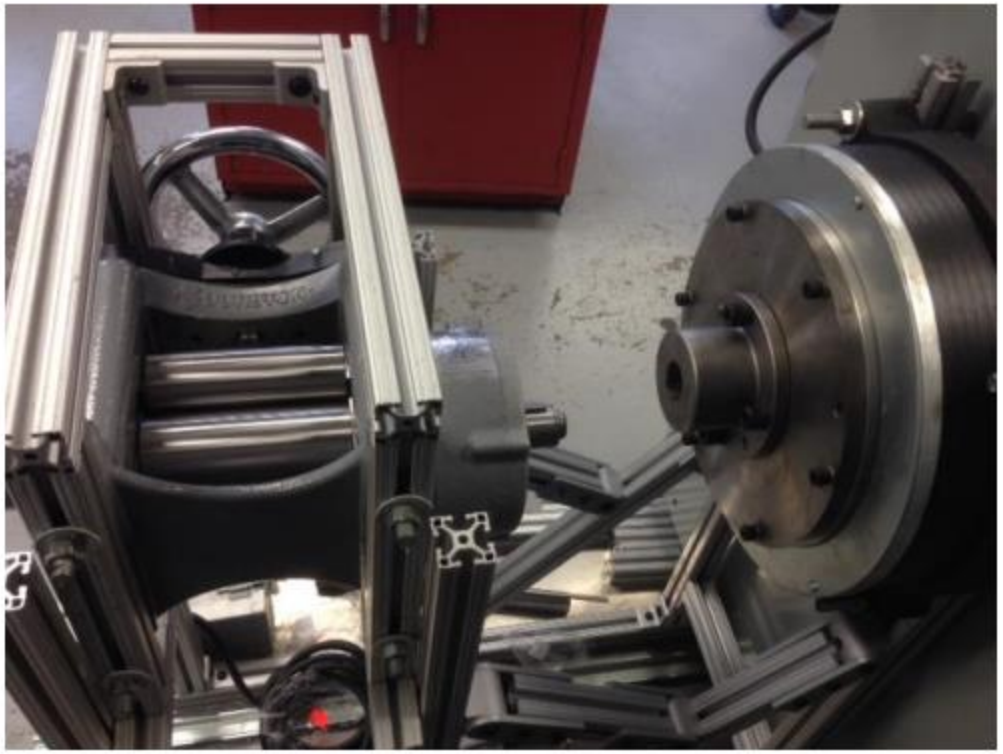
Thermo-elastic



Latest prototype being constructed



- Materials that give off heat when physically stressed
- Potential for COP ~11!

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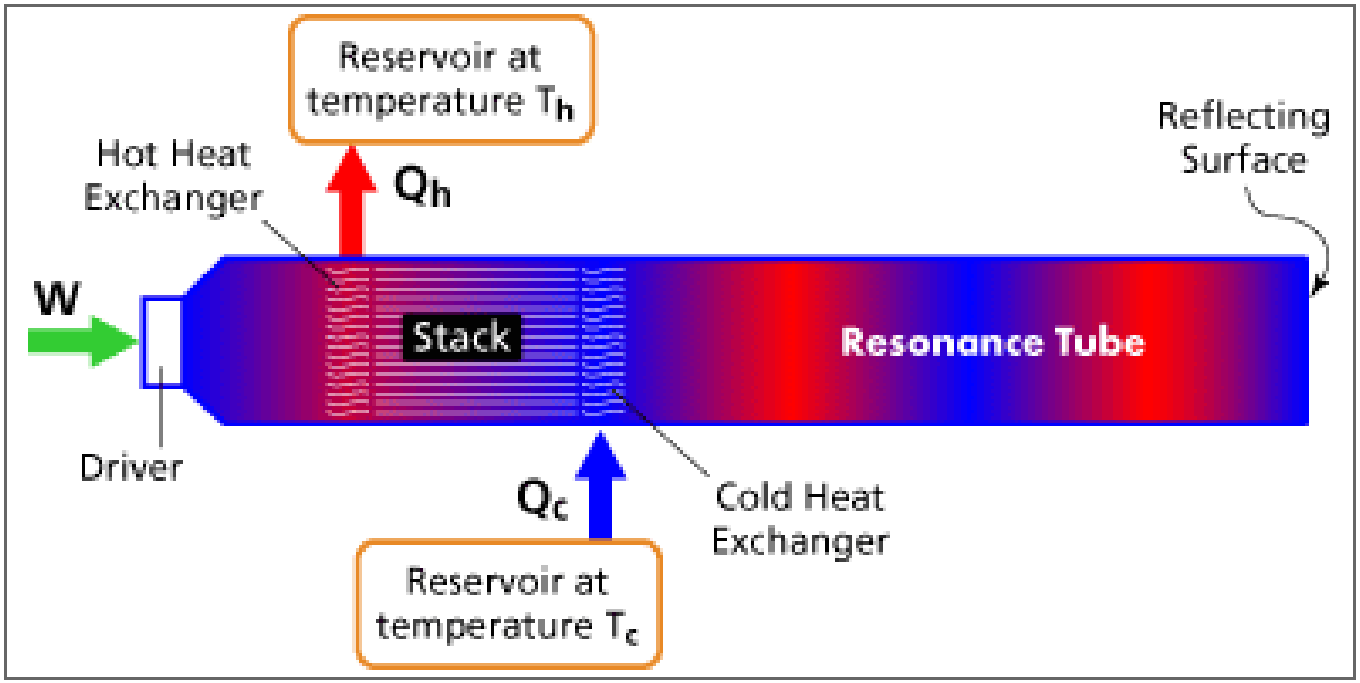
Thermo-acoustics



- Acoustic oscillations induce compression and expansion of a working gas (refrigerant)

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Conclusions

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100 SEER

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Conclusions

Its All About the Money

- Economics have driven innovations and adoption
  - Rittinger and Salt Brine
  - Oil Embargo
  - Disappearance of Altherma
  - Next Gen Tech

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Conclusions

Its All About the Money – Or Is It?

Type of Energy	BTU/unit	Typical Efficiency	$/unit	$/MMBtu	High Efficiency	$/MMBtu
Fuel Oil, gallon	138,200	80%	$2.23	$20.14	95%	$16.96
Kerosene, gallon	136,600	80%	$2.80	$25.65		
Propane, gallon	91,600	80%	$2.54	$34.64	95%	$29.17
Natural Gas, Ccf	100,000	80%	$1.41	$17.67 *	95%	$14.88
Electricity, kWh (resistive)	3,412	100%	$0.15	$43.46		
Electricity, kWh (heat pump)	3,412		$0.15	#	240%	$18.32
Wood, cord (green)	22,000,000	60%	$227	$17.21 ^		
Pellets, ton	16,400,000	80%	$275	$20.96 ^		

Source: November 2016 VT Fuel Price Report

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Conclusions

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Conclusions

Its All About the Money – Or Is It?

- Why?
  - Carbon footprint, being “green”
  - Comfort/Convenience - AC/Heat out of same install
  - Make use of solar (63% in EVT evaluation)
  - Getting away from bulk delivery
  - “Cool Gadget” high-tech thing

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Thank You!

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