ThermoLift

THE ULTIMATE HEAT PUMP™

NECPUC Symposium, Hartford, Connecticut – June 4, 2019

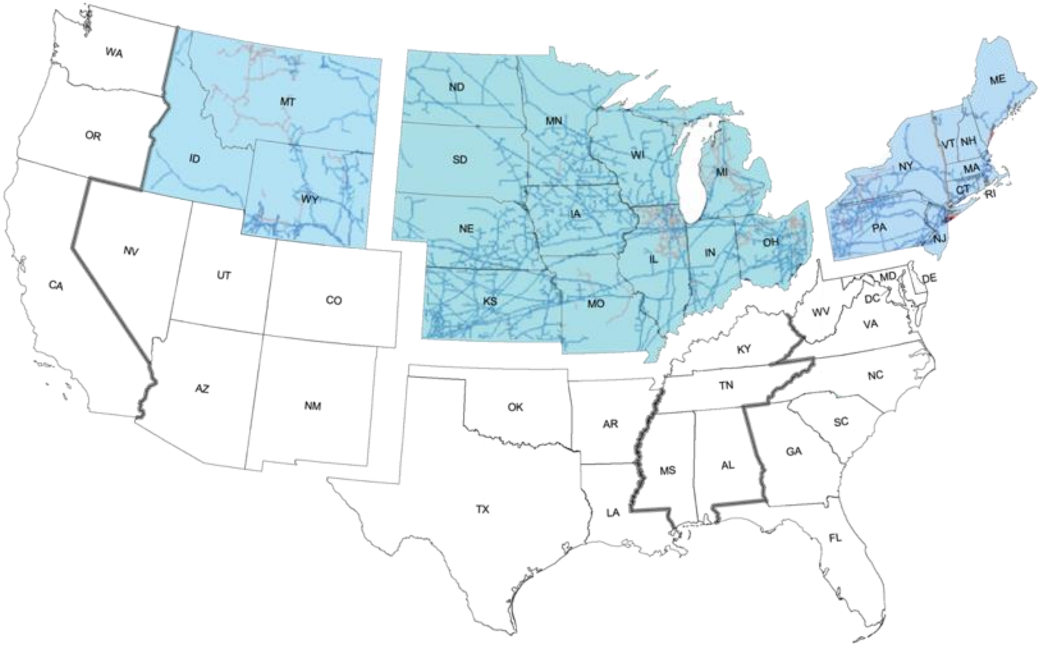
New England Conference of Public Utility Commissioners

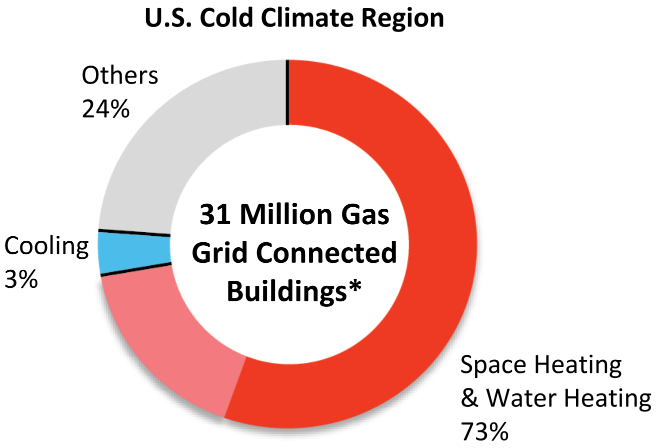
Decarbonization through Energy Efficiency

ENERGY EFFICIENCY GAMECHANGER

- ***Natural Gas-Powered Heat Pump***
- ***50% Reduction*** *in Energy Use*
- ***Cooling with Natural Gas***
- ***One Appliance –*** *Heating, Hot Water, Air Conditioning and Refrigeration*
- ***Cold Climate Heating*** *with no additional heat source (even below 32 degrees F)*
- ***No Refrigerants*** *& No Toxic Emissions or Materials*

> 70% Cold Climate Building Energy = Heating



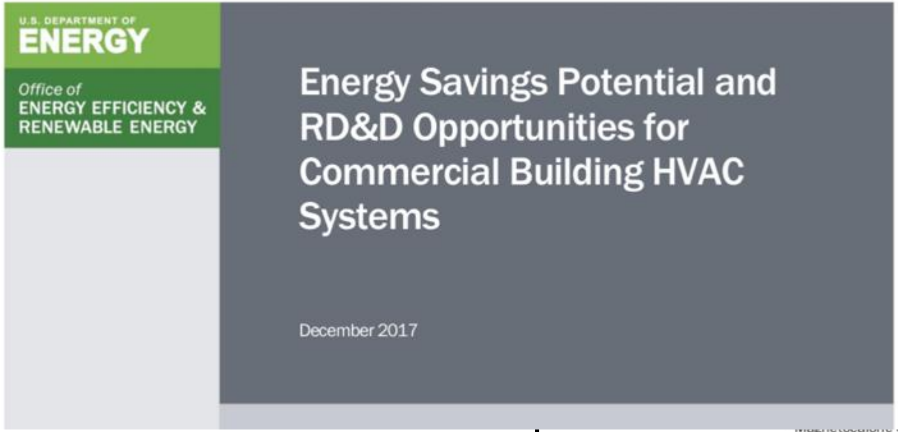


*Small Commercial Buildings & Residential, US Cold Climate Regions

THERMOLIFT: DOE #1 RANKED HVAC TECHNOLOGY

ThermoLift Heat Pump Highest Ranking

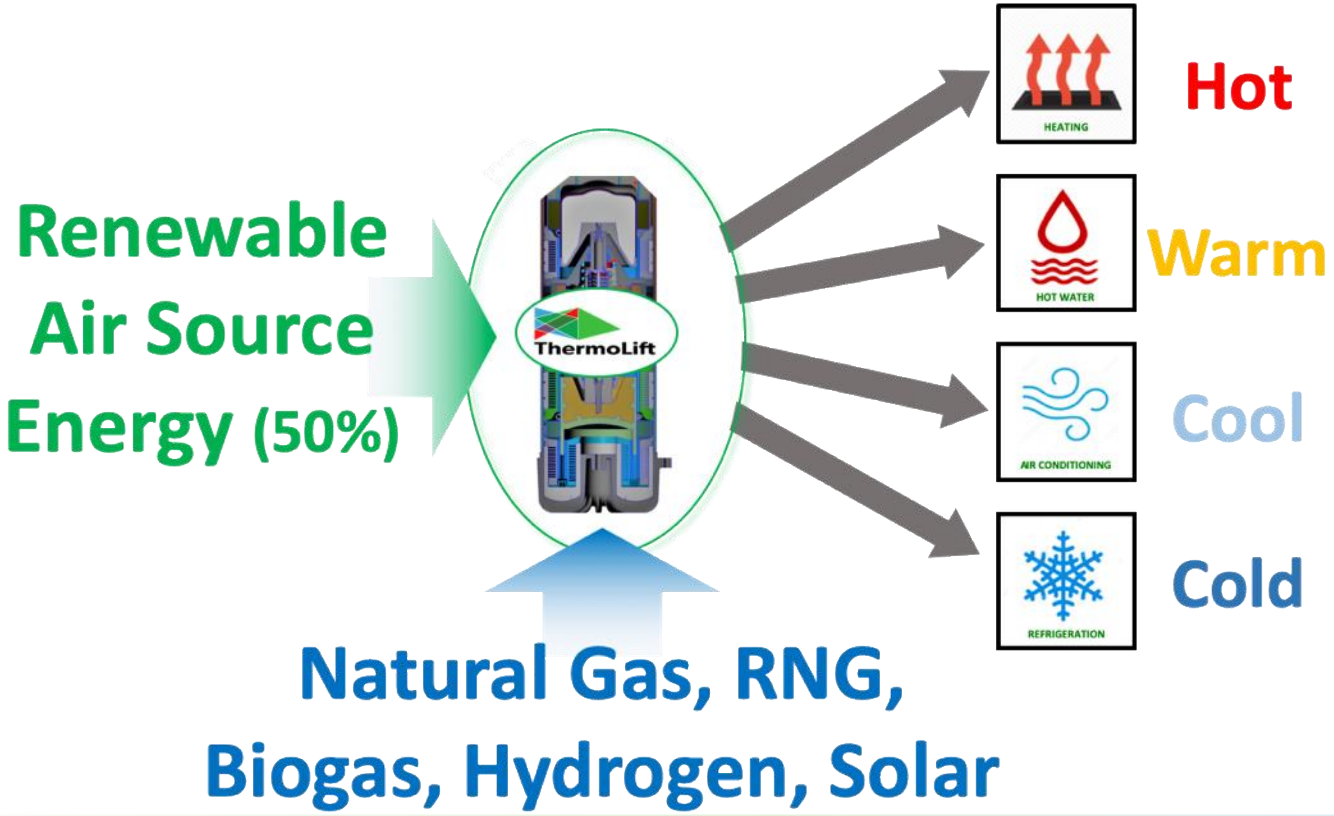
Figure 9: Final ranking of high priority technology options



Selection based on global review of 300 technologies.

ThermoLift

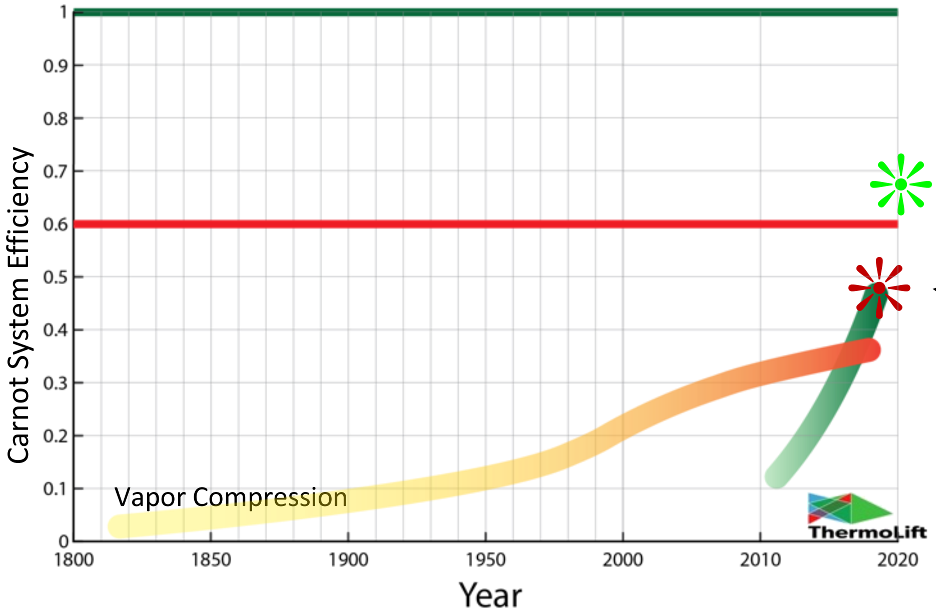
THERMAL COMPRESSION HEAT PUMP (TCHP™)



ACCELERATING ENERGY EFFICIENCY INNOVATION

Superior Efficiency with Zero Refrigerants, Zero HFCs

Already Surpassing 200 Years of Vapor Compression Technology

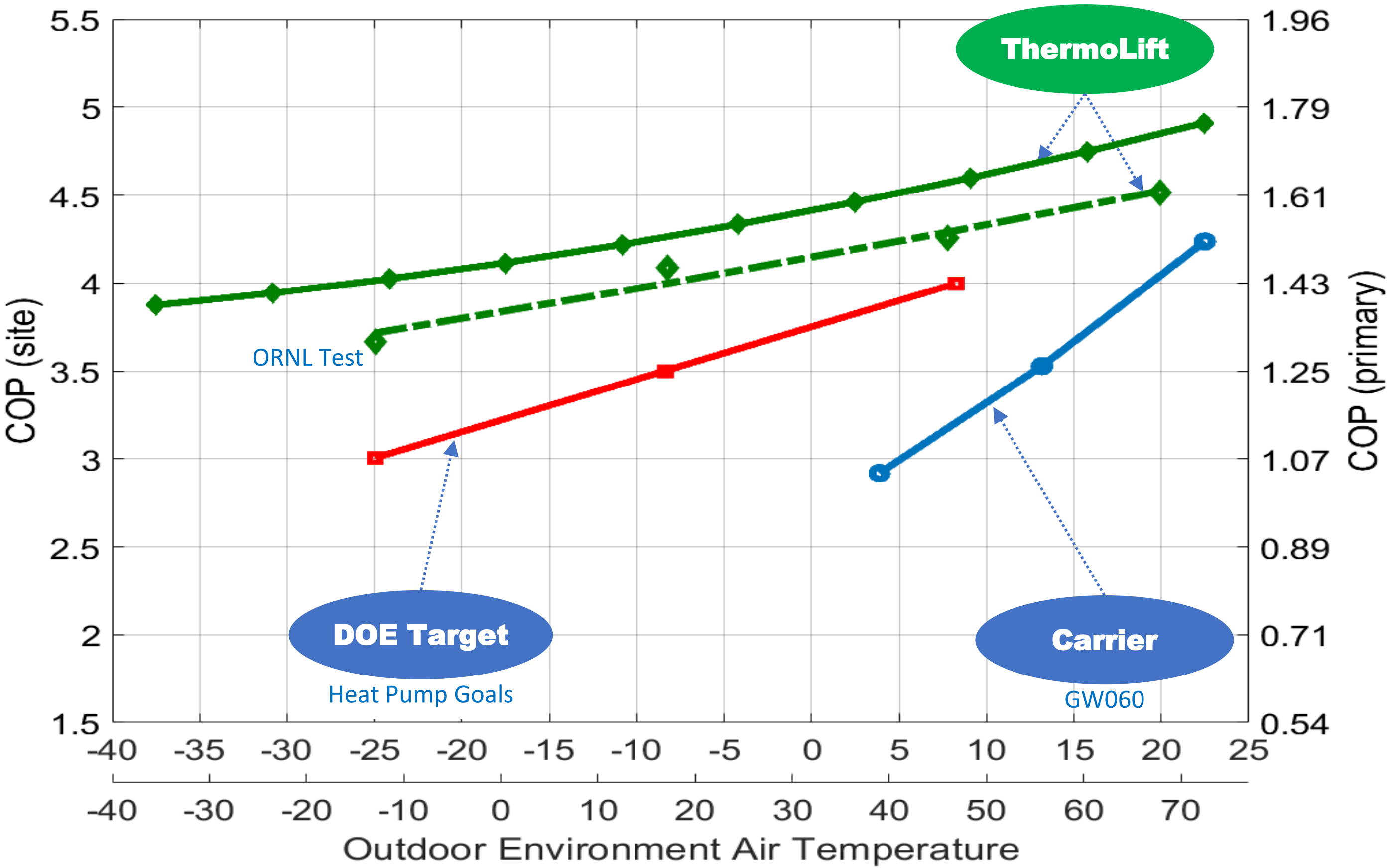


Soon: HCTC Exceeds Vapor Compression Theoretical Potential

Today: HCTC Exceeds Vapor Compression System Level Efficiency

SIGNIFICANTLY EXCEEDS STATE OF THE ART
- IN EFFICIENCY & PERFORMANCE

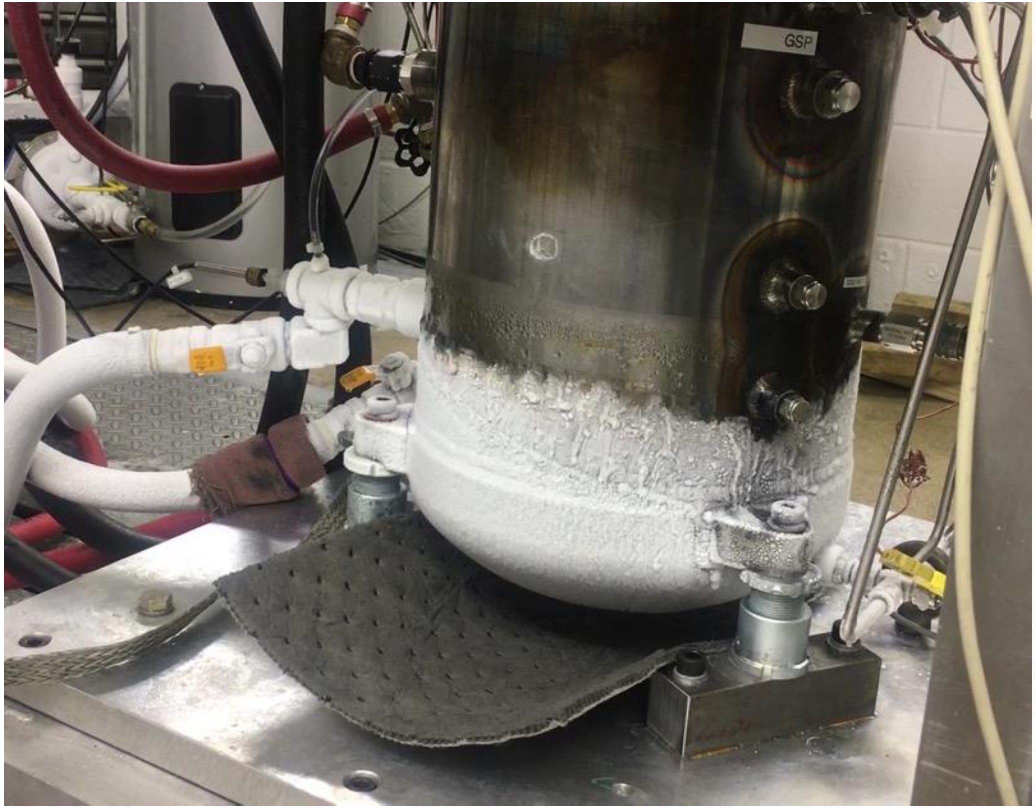
DOE Independent Testing at Oak Ridge National Lab



ThermoLift

LOW TEMPERATURE CAPABILITY – NO BACKUP

"Polar Vortex"
Compatible:
Constant Capacity at Cold Temperatures, No Backup System Needed.



Monovalent System

-150°F (-100°C) demonstrated at Oak Ridge National Lab

THERMOLIFT: NO REFRIGERANTS, NO HFCs, SAFE

- *ThermoLift* ***reduces by 100%*** *the greenhouse gas impact of refrigerants used by current technology ("Vapor Compression") or approximately 6 tons of CO2e over the units lifetime (due to no refrigerants; ThermoLift mitigates another 104 tons of greenhouse gas equivalents due to energy efficiency or 110 tons total).*
- *ThermoLift's Thermal Compression (TC-Cycle) uses No Refrigerants, No HFCs.*
- *Vapor Compression Heat Pumps – globally used for AC, Refrigeration and also Heating, require refrigerants and use HFCs*.*
- *HFCs by themselves, left unchecked, are predicted to contribute to a 0.5º C rise in global temperatures by 2100**.*

Appliance Type ****	Current Leak Rate	Leak Rate Effective 1/1/2019
Industrial process refrigeration[a]	35%	30%
Commercial refrigeration	35%	20%
Comfort cooling	15%	10%
All other appliances	15%	10%

HFCs, used mainly in refrigeration, air conditioning and heat pump equipment, are thousands of times more harmful to the climate than CO2. In response to the rapid growth of HFC emissions, the 197 parties to the Montreal Protocol adopted the Kigali Amendment in 2016 to reduce gradually their global production and consumption.**

KEY FIGURES ***

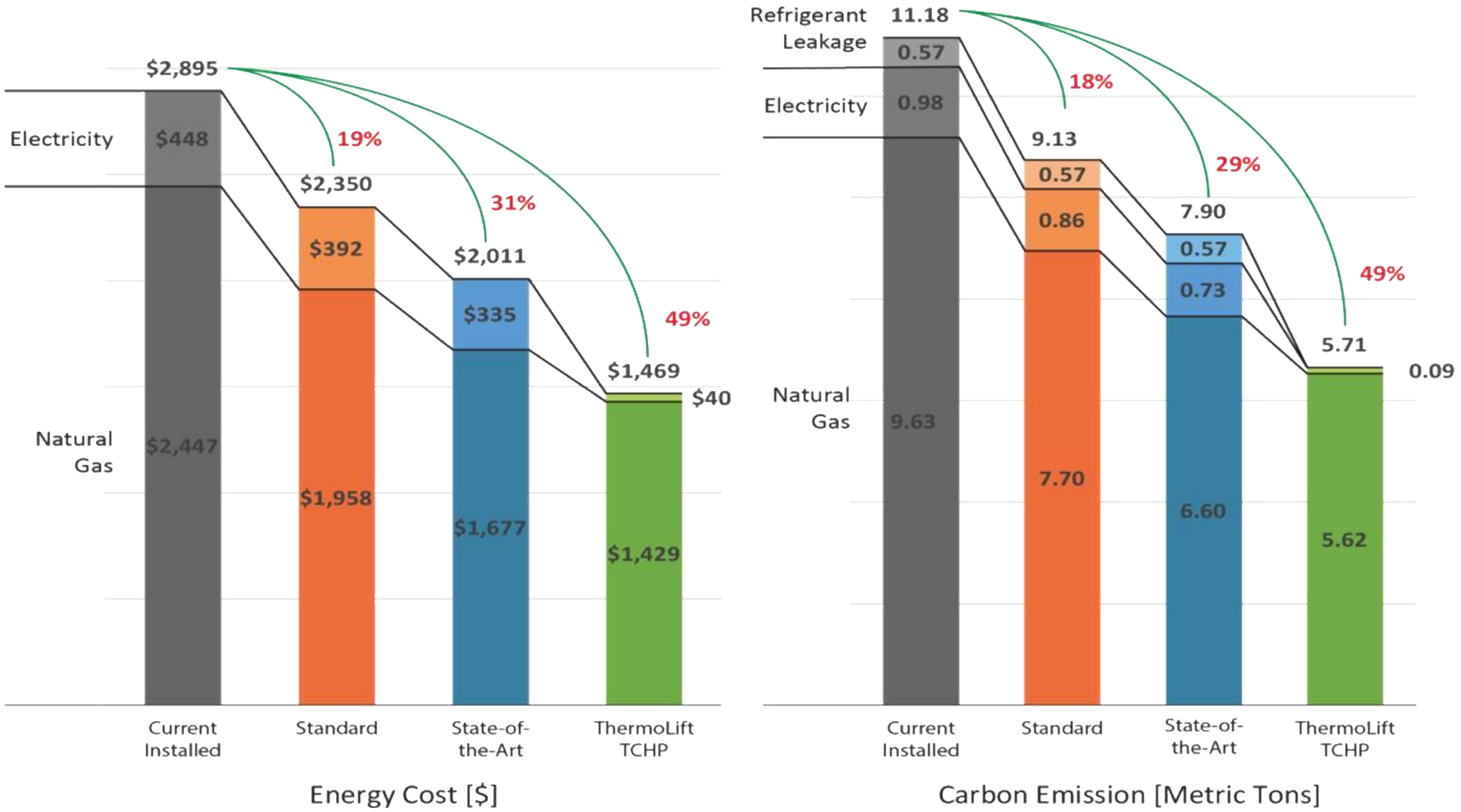
1,430x	10-15%	29 years	5.6 billion
The most abundant HFC is 1,430 times more damaging to the climate than carbon dioxide per unit of mass	Emissions of HFCs are growing at a rate of 10-15% per year	HFCs remain in the atmosphere for up to 29 years	The global stock of air conditioners in buildings will grow to 5.6 billion by 2050, which amounts to 10 new units sold every second for the next 30 years

ThermoLift Safety, Installation, Operations Benefits:

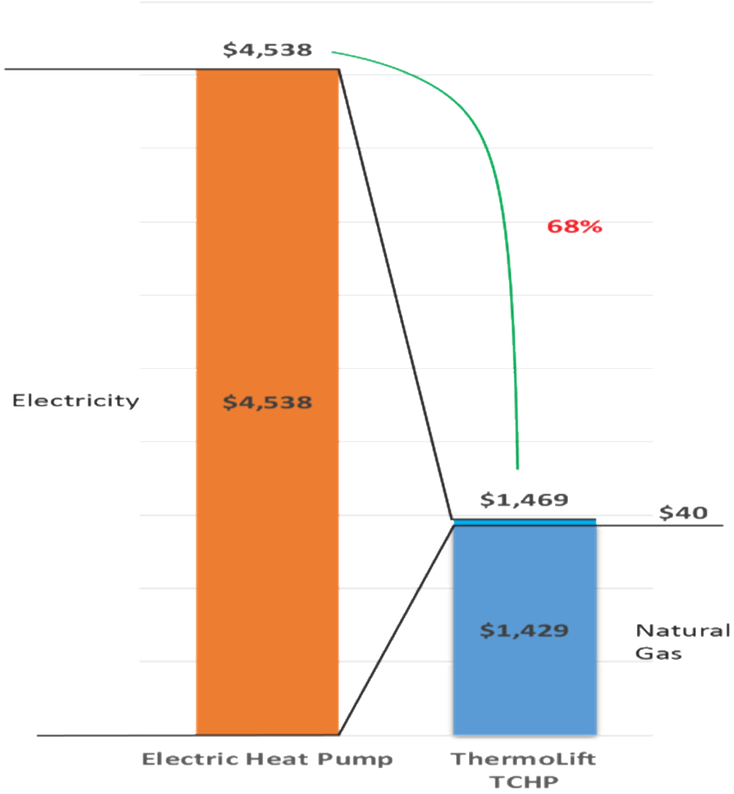
- Simplified operation & maintenance due to no refrigerants.
- Infinite zoning capability.
- No restrictions on cooling line lengths.
- No dangerous alternatives with indoor building code restrictions, such as flammables, ammonia, or high pressure CO2.
- ThermoLift resolves ASHRAE 15 & 34 compliance installation issues for safety.
- No EPA 608 installer certification needed.

* HFCs – Hydrofluorocarbons, are the most common type of refrigerant chemicals.
** Kigali Agreement: https://ec.europa.eu/clima/news/eu-ratifies-kigali-amendment-montreal-protocol_en
*** http://ccacoalition.org/en/slcps/hydrofluorocarbons-hfc
**** EPA allowed refrigerant leakage rates: https://www.epa.gov/section608/stationary-refrigeration-leak-repair-requirements

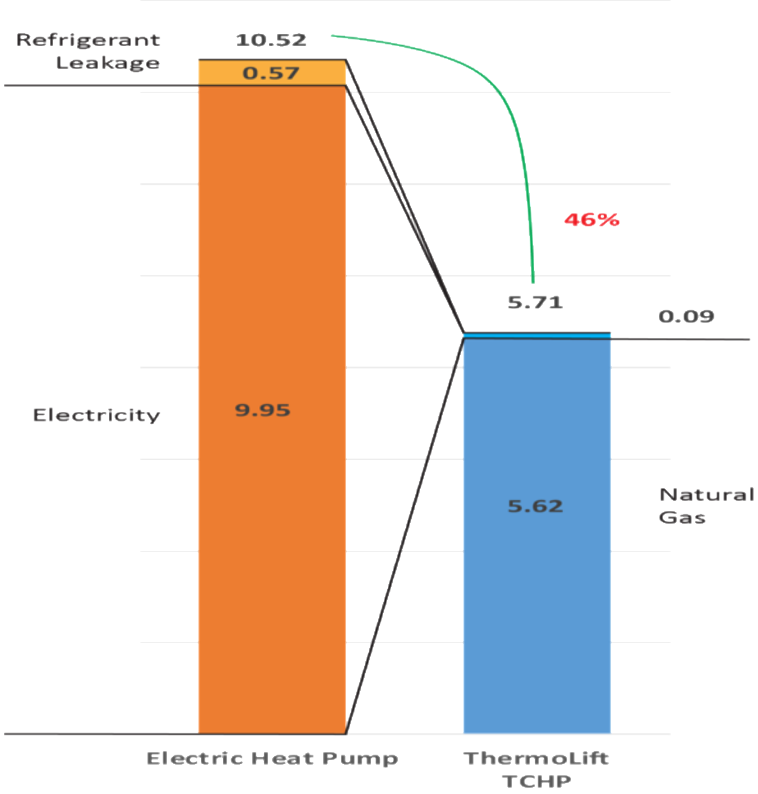
Hartford, CT – Residential Energy & CO2 Reduction



Hartford, CT – Residential Heat Pump Comparison



Energy Cost [$]



Carbon Emission [Metric Tons]

ThermoLift Competitive Landscape

	ThermoLift TCHP™	Condensing Boiler	High Efficiency AC (13 SEER)	Air Source Heat Pump (Minisplit VRF)	Water Source Heat Pump	Geothermal Source Heat Pump	Absorption Heat Pump
Heating	🟢	🟢	🔴	🟢	🟢	🟢	🟢
Cooling	🟢	🔴	🟢	🟢	🟢	🟢	🟢
No Refrigerants	🟢	🟢	🔴	🔴	🔴	🔴	🔴
Renewable Energy	🟢	🔴	🔴	🟢	🟢	🟢	🟢
Hot Water	🟢	🟢	🔴	🔴	🔴	🔴	🔴
Efficient Heating below 0℃ (32℉) Ambient Outdoor	🟢	🟢	🔴	🔴	🔴	🟢	🔴

ThermoLift System Benefits

ThermoLift

Consumer Benefits:

- ✓ *Lower Operating Cost*
- ✓ *High Performance*
- ✓ *Standard Installation Cost*
- ✓ *Renewable Energy*
- ✓ *Compact / Retrofit*
- ✓ *Support Fuel Switching from Oil*

Non-Pipe Solution for Capacity Constraints:

- ✓ *Expand Capacity through 50% End Use Efficiency*
- ✓ *No New Infrastructure Cost*
- ✓ *Address Seasonal Constraints and Moratoriums*

Cold Climate High Efficiency:

- ✓ *Constant Capacity even at Very Cold Outside Temperature*
- ✓ *No Need for Backup Heating*
- ✓ *Meet Peak Demand Heating without Additional Capacity - "Polar Vortex" Compliant*

Demand Response:

- ✓ *Gas Demand Response*
- ✓ *Variable Performance Range*
- ✓ *High Efficiency Modulation without Cycling On/Off*

No Refrigerants:

- ✓ *1,500x – 2,000x Worse Greenhouse Gas Impact*
- ✓ *Being Phased Out*
- ✓ *Leak Rates*

Decarbonizing through Energy Efficiency:

- ✓ *Lower Carbon Footprint*
- ✓ *Cost Effective GHG Reduction*
- ✓ *Important Solution towards Achieving Mandates, Regional GHG & Climate Impact Targets*

PARTNERS, COLLABORATION, SUPPORT

DEVELOPMENT AND DEMONSTRATION

U.S. DEPARTMENT OF ENERGY

NEW YORK STATE OF OPPORTUNITY. | NYSERDA Supported

NREL Transforming ENERGY | WELLS FARGO

IN² Program

gti

Clean Energy Business Incubator Program AT STONY BROOK UNIVERSITY

NATIONAL LABORATORIES

OAK RIDGE National Laboratory

NREL NATIONAL RENEWABLE ENERGY LABORATORY

BROOKHAVEN NATIONAL LABORATORY

ACADEMIC PARTNERS

Stony Brook University

ADVANCED ENERGY™ Research and Technology Center AT STONY BROOK UNIVERSITY

HOFSTRA UNIVERSITY

GLOBAL MANUFACTURING POWERHOUSE

LINAMAR Power to Perform

$7B Tier 1 Global Manufacturer

- *60 Plants Worldwide*
- *Reliability & Warranty*
- *Cost & Scale*

DISTRIBUTION, INSTALLATION AND SERVICE / SUPPORT RELATIONSHIPS

THE PAR GROUP

To Be Announced

PETRO

To Be Announced

STRONG IP PORTFOLIO & RECOGNITION

RECOGNITION

- DOE #1 Ranked HVAC Technology
- NREL IN² Incubator
- IEA Heat Pump Publication
- DOE Report on HVAC Technologies
- 2015 Long Island's Innovator of the Year
- American Gas Magazine
- NREL Industry Growth Forum
- Stony Book University Start-Up of the Year
- CEBIP Incubator Company of the Year

GRANTS

- Department of Energy
- NYSERDA
- Gas Technology Institute
- Wells Fargo IN^2
- NYS Manufacturing

STRONG INTELLECTUAL PROPERTY PATENT PORTFOLIO

17 patent families; 15 patents issued; 31 patents pending. Trademark protection has been filed and allowed.

PATENT FAMILIES	DATE	STATUS
Heat Pump with Electromechanical Actuated Displacers	4/11/2013	**Issued:** US, China, Canada **Filed:** Europe, India
Combination Solar and Combustion Heater	10/18/2013	**Issued:** Canada **Allowed:** China **Filed:** Europe, India, US
A Compact Heat Exchanger for a Heat Pump	11/25/2013	Filed: China, Germany, UK, US
A Combination Heat Exchanger and Burner	12/4/2013	**Filed:** China, Canada, Europe, India, US
A Four-Process Cycle for a Vuilleumier Heat Pump	11/18/2014	**Allowed:** China **Filed:** Canada, Europe, Korea, US
A Vuilleumier Heat Pump Having a HX Located Between the Displacers	2/21/2015	**Filed:** China, Denmark, US
A Heat Exchanger	6/10/2016	**Filed:** US
A Spring for an Electromagnetic Actuator System	9/15/2016	National phase filing 3/15/2018
Dome for a Thermodynamic Apparatus	10/15/2016	National phase filing 4/15/2018
Gas Spring and Bridge for a Heat Pump	10/18/2016	National phase filing 5/18/2018
Mechatronic Drivers in the Cold End of a Heat Pump	10/18/2016	National phase filing 5/18/2018
A Regenerator	3/16/2016	**Filed:** US
Spiral Extruded Heat Exchanger	2/22/2017	National phase filing 8/22/2018
A Linear Actuation System Having Face Coils and Side Coils for Armature Travel Assist	4/8/2017	File PCT or national phase by 4/8/2018
A Linear Actuation System Having Side Stators and a Permanent Magnet Armature	4/24/2017	File PCT or national phase by 4/24/2018
Centrally-Located Linear Motors for Driving Displacers in a Thermodynamic Apparatus Regenerator	9/25/2017	File PCT or national phase by 9/25/2018

WORLD CLASS LEADERSHIP

Paul Schwartz
CEO, Co-Founder

20+ years of experience in finance, investment banking.

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Prof. Dr.-Ing. Peter Hofbauer
President, Co-Founder

Former VP Viessman,

European Environmental Award,

Former Global Head of Engine & Powertrain VW

Robert Catell
Board of Directors

Former Chairman of National Grid (US) and CEO of KeySpan

Chairman of the American Gas Association and US Energy Association

Steve Winick
Board of Directors

Partner at Topspin Partners

Former CTO of Honeywell's $2B Home Security Group

David Parks, PhD
Board of Directors

HVAC Industry Leader

Former C-Level Positions in HVAC including Carrier, Haier America and Goodman

25 Full Time Team Members, including 9 PhDs, plus Extensive & Active Senior Advisor Network

THERMOLIFT: Energy Efficiency Gamechanger

Advanced Innovation to Meet Real Needs of NE Region:

- *Gas-Powered Air Source Heat Pump for Heating & Cooling*
- *DOE #1 Ranked HVAC Technology*
- *Up to 50% Reduction in Energy Use & Greenhouse Gas Emissions*
- *Deliver Significant Consumer & System Benefits*
- *No Refrigerants*

Seeking:

- *Rebate Program Participation*
- *Installation Incentives & Support*
- *Partnerships, Collaborations, Investors*

THANK YOU !

QUESTIONS ?

SUPPLEMENTAL SLIDES

ThermoLift

THE ULTIMATE HEAT PUMP™

Paul Schwartz, CEO
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ThermoLift at OGCI Climate Initiative, Houston, 2019

Peer Reviewed Principles of Operation

Detailed thermodynamic engineering analysis in Applied Thermal Engineering Journal


Applied Thermal Engineering 140 (2018) 553–563

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

ELSEVIER

Research Paper

Performance analysis of a free-piston Vuilleumier heat pump with dwell-based motion

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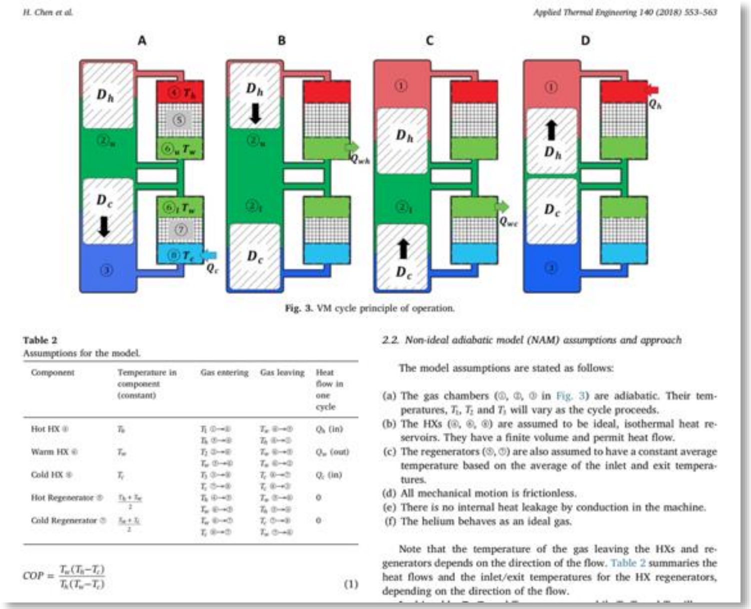

Fig. 3. VM cycle principle of operation.

Table 2
Assumptions for the model.

Component	Temperature in component (constant)	Gas entering	Gas leaving	Heat flow in one cycle
Hot HX ④	T_h			Q_h (in)
Warm HX ⑥	T_w			Q_w (out)
Cold HX ⑧	T_c			Q_c (in)
Hot Regenerator ⑤	$\frac{T_h+T_w}{2}$			0
Cold Regenerator ⑦	$\frac{T_w+T_c}{2}$			0

$$COP = \frac{T_w(T_h-T_c)}{T_h(T_w-T_c)} \quad (1)$$

2.2. Non-ideal adiabatic model (NAM) assumptions and approach

The model assumptions are stated as follows:

(a) The gas chambers (①, ②, ③ in Fig. 3) are adiabatic. Their temperatures, T_1, T_2 and T_3 will vary as the cycle proceeds.
(b) The HXs (④, ⑥, ⑧) are assumed to be ideal, isothermal heat reservoirs. They have a finite volume and permit heat flow.
(c) The regenerators (⑤, ⑦) are also assumed to have a constant average temperature based on the average of the inlet and exit temperatures.
(d) All mechanical motion is frictionless.
(e) There is no internal heat leakage by conduction in the machine.
(f) The helium behaves as an ideal gas.

Note that the temperature of the gas leaving the HXs and regenerators depends on the direction of the flow. Table 2 summaries the heat flows and the inlet/exit temperatures for the HX regenerators, depending on the direction of the flow.

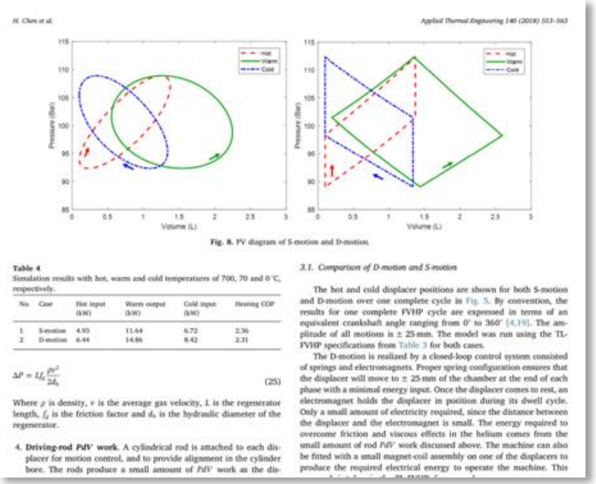

Fig. 8. PV diagram of S-motion and D-motion.

Table 4
Simulation results with hot, warm and cold temperatures of 700, 70 and 0 °C, respectively.

No	Case	Hot input (kW)	Warm output (kW)	Cold input (kW)	Heating COP
1	S-motion	4.93	11.64	6.72	2.36
2	D-motion	6.44	14.86	8.42	2.31

$$\Delta P = L f_r \frac{\rho v^2}{2 d_h} \quad (25)$$

Where ρ is density, v is the average gas velocity, L is the regenerator length, f_r is the friction factor and d_h is the hydraulic diameter of the regenerator.

4. **Driving-rod *PdV* work.** A cylindrical rod is attached to each displacer for motion control, and to provide alignment in the cylinder bore. The rods produce a small amount of *PdV* work as the dis-

3.1. Comparison of D-motion and S-motion

The hot and cold displacer positions are shown for both S-motion and D-motion over one complete cycle in Fig. 5. By convention, the results for one complete FVHP cycle are expressed in terms of an equivalent crankshaft angle ranging from 0° to 360° [4,19]. The amplitude of all motions is ± 25 mm. The model was run using the TL-FVHP specifications from Table 3 for both cases.

The D-motion is realized by a closed-loop control system consisted of springs and electromagnets. Proper spring configuration ensures that the displacer will move to ± 25 mm of the chamber at the end of each phase with a minimal energy input. Once the displacer comes to rest, an electromagnet holds the displacer in position during its dwell cycle. Only a small amount of electricity required, since the distance between the displacer and the electromagnet is small. The energy required to overcome friction and viscous effects in the helium comes from the small amount of rod PdV work discussed above. The machine can also be fitted with a small magnet-coil assembly on one of the displacers to produce the required electrical energy to operate the machine. This

ThermoLift Delivers 2.4x More Heat per Unit of Natural Gas

ThermoLift delivers *__more value for energy__*.

Average Current Installed Base

ThermoLift

Units: all on equivalent MMBtu basis

COP: Coefficient of Performance
= Heat Delivered / Fuel Input

ThermoLift Renewable Energy ‘Capacity Factor’*

	Wind	Solar	ThermoLift Heat Pump	Electric Heat Pumps
Capacity Factor	*37%***	*26%***	*100%****	*~ 50%****
Renewable Energy	*100%*	*100%*	*50% - 100%*	*50% - 100%*
Refrigerants or HFCs	*No*	*No*	*No*	*Yes, Refrigerants @ up to 2,000x CO2 GHG Impact*

* Though Heat Pumps are renewable energy devices, calculating their Capacity Factor (as with wind and solar) is not yet standardized. This analysis considers Heat Pump Capacity Factor (for Heating) as the % of time that the device delivers Renewable Energy for Heating (i.e. does not rely on a secondary heat source, or does not utilize renewable energy for heating) during heating days, following the similar logic for wind and solar.

**US Energy Information Administration (EIA), 2018

*** Calculated from National Oceanic and Atmospheric Administration (NOAA) Data for 2018, Albany Airport Weather Station Temperature Data

ThermoLift Comparative Analyses

- The building energy simulations are performed using EnergyPlus. EnergyPlus[1] is DOE's flagship whole building energy modeling engine. It is certified by *ASHRAE 140: Standard Method of Test for the Evaluating of Building Energy Analysis Computer Programs*.

- The residential case refers to a typical standalone residential house complying with IECC 2006 code. This building model is developed by DOE under Building Energy Code Program[2].

- For carbon reduction, the direct carbon emission from natural gas end use and indirect carbon emission from electricity consumption are calculated based on *Greenhouse Gas Emissions*[3] from Energy Star Portfolio Manager. Due to the weather related nature of air conditioner, its consumption is regarded as non-baseload and calculated accordingly.

- Other data based on Energy Information Agency (EIA) and similar databases. Further details available upon request.

1. EnergyPlus: https://www.energy.gov/eere/buildings/downloads/energyplus-0
2. DOE Building Energy Codes Program: https://www.energycodes.gov/development
3. Energy Star Portfolio Manager: https://www.energystar.gov/buildings/tools-and-resources/portfolio-manager-technical-reference-greenhouse-gas-emissions