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

U.S. Cold Climate Region

- Space Heating & Water Heating: 73%
- Others: 24%
- Cooling: 3%

31 Million Gas Grid Connected Buildings*

*Small Commercial Buildings & Residential, US Cold Climate Regions
Selection based on global review of 300 technologies.
THERMAL COMPRESSION HEAT PUMP (TCHP™)

Renewable Air Source Energy (50%)

Natural Gas, RNG, Biogas, Hydrogen, Solar

Hot
Warm
Cool
Cold
ACCELERATING ENERGY EFFICIENCY INNOVATION

Superior Efficiency with Zero Refrigerants, Zero HFCs

Soon: HCTC Exceeds Vapor Compression Theoretical Potential

Today: HCTC Exceeds Vapor Compression System Level Efficiency

Already Surpassing 200 Years of Vapor Compression Technology
SIGNIFICANTLY EXCEEDS STATE OF THE ART - IN EFFICIENCY & PERFORMANCE

DOE Independent Testing at Oak Ridge National Lab
LOW TEMPERATURE CAPABILITY – NO BACKUP

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

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

Monovalent System
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**.

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.**

<table>
<thead>
<tr>
<th>Appliance Type ****</th>
<th>Current Leak Rate</th>
<th>Leak Rate Effective 1/1/2019</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industrial process refrigeration*</td>
<td>35%</td>
<td>30%</td>
</tr>
<tr>
<td>Commercial refrigeration</td>
<td>35%</td>
<td>20%</td>
</tr>
<tr>
<td>Comfort cooling</td>
<td>15%</td>
<td>10%</td>
</tr>
<tr>
<td>All other appliances</td>
<td>15%</td>
<td>10%</td>
</tr>
</tbody>
</table>

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.
**** EPA allowed refrigerant leakage rates: https://www.epa.gov/section608/stationary-refrigeration-leak-repair-requirements
**** EPA allowed refrigerant leakage rates: https://www.epa.gov/section608/stationary-refrigeration-leak-repair-requirements
Hartford, CT – Residential Energy & CO2 Reduction

**Energy Cost [$]**
- **Current Installed**:
  - Electricity: $2,447
  - Natural Gas: $2,447
- **Standard**:
  - Electricity: $1,958
  - Natural Gas: $1,958
- **State-of-the-Art**:
  - Electricity: $1,677
  - Natural Gas: $1,677
- **ThermoLift TCHP**:
  - Electricity: $1,469
  - Natural Gas: $1,469
  - **% Reduction**: 31%

**Carbon Emission [Metric Tons]**
- **Current Installed**:
  - Refrigerant Leakage: 11.18
  - Electricity: 0.98
  - Natural Gas: 9.63
- **Standard**:
  - Refrigerant Leakage: 9.13
  - Electricity: 0.86
  - Natural Gas: 7.70
- **State-of-the-Art**:
  - Refrigerant Leakage: 7.90
  - Electricity: 0.57
  - Natural Gas: 6.60
- **ThermoLift TCHP**:
  - Refrigerant Leakage: 5.71
  - Electricity: 0.09
  - Natural Gas: 5.62
  - **% Reduction**: 49%
Hartford, CT – Residential Heat Pump Comparison

Energy Cost [$]

- Electric Heat Pump: $4,538
- Thermolift TCHP: $1,429
- Natural Gas: $1,469
- Refrigerant Leakage: 0.57
- Carbon Emission [Metric Tons]: 5.62
# ThermoLift Competitive Landscape

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Heating</strong></td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td><strong>Cooling</strong></td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td><strong>No Refrigerants</strong></td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td><strong>Renewable Energy</strong></td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td><strong>Hot Water</strong></td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td><strong>Efficient Heating below 0 °C (32 °F) Ambient Outdoor</strong></td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
</tbody>
</table>
# ThermoLift System Benefits

## 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

<table>
<thead>
<tr>
<th>U.S. DEPARTMENT OF ENERGY</th>
</tr>
</thead>
<tbody>
<tr>
<td>NEW YORK STATE OF OPPORTUNITY, NYSESDA Supported</td>
</tr>
<tr>
<td>NREL</td>
</tr>
<tr>
<td>IN² Program</td>
</tr>
</tbody>
</table>

### NATIONAL LABORATORIES

| OAK RIDGE National Laboratory |
| NREL |
| BROOKHAVEN National Laboratory |

### ACADEMIC PARTNERS

| Stony Brook University |
| Advanced Energy Research and Technology Center at Stony Brook University |
| Hofstra University |
|Clean Energy Business Incubator Program at Stony Brook University |
| gti |

### GLOBAL MANUFACTURING POWERHOUSE

<table>
<thead>
<tr>
<th>LINAMAR Power to Perform</th>
</tr>
</thead>
</table>

$7B Tier 1 Global Manufacturer
- 60 Plants Worldwide
- Reliability & Warranty
- Cost & Scale

### DISTRIBUTION, INSTALLATION AND SERVICE / SUPPORT RELATIONSHIPS

| THE PARGROUP |
| PETRO |
| To Be Announced |
| 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

STRONG INTELLECTUAL PROPERTY PATENT PORTFOLIO
17 patent families; 15 patents issued; 31 patents pending. Trademark protection has been filed and allowed.

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

GRANTS
- Department of Energy
- NYSERDA
- Gas Technology Institute
- Wells Fargo IN²
- NYS Manufacturing
WORLD CLASS LEADERSHIP

Paul Schwartz  
CEO, Co-Founder  
20+ years of experience in finance, investment banking.

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?

Paul Schwartz, CEO
pschwartz@tm-lift.com
+1-631-779-1370

SUPPLEMENTAL SLIDES

ThermoLift at OGCI Climate Initiative, Houston, 2019
Peer Reviewed Principles of Operation


Research Paper

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

HaiFei Chen¹, Chih-Chieh Lin², Jon P. Langholz³

¹ University of California, Berkeley, CA 94720, USA
² ThermoLift, Inc, Sunnyvale, CA 94086, USA
³ ThermoLift, Inc, Sunnyvale, CA 94086, USA

Table 2: Assumptions for the model.

<table>
<thead>
<tr>
<th>Component</th>
<th>Temperature in components (°C)</th>
<th>Gas entering</th>
<th>Gas leaving</th>
<th>Heat flow in</th>
<th>Heat flow out</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot HX 1</td>
<td>80</td>
<td>D₁</td>
<td>D₂</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Valve HX 1</td>
<td>80</td>
<td>E₁</td>
<td>E₂</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Cool HX 1</td>
<td>80</td>
<td>C₁</td>
<td>C₂</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Hot HX 2</td>
<td>80</td>
<td>D₃</td>
<td>D₄</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Valve HX 2</td>
<td>80</td>
<td>E₃</td>
<td>E₄</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Note: the temperature of the gas leaving the HX and re-entrance depends on the direction of the flow. Table 3 summarizes the heat flows and the inlet/outlet temperatures for the HX segments, depending on the direction of the flow.

$$ \text{COP} = \frac{\sum_{i} Q_{i} - \sum_{j} Q_{j}}{W_{in} + \sum_{k} Q_{k}} $$

Fig. B: VML cycle principle of operation.

Fig. 3: VM cycle principle of operation.

Fig. 4: PM diagram of power and efficiency.

Table 4: Computation of energy and exergy

<table>
<thead>
<tr>
<th>No.</th>
<th>Case</th>
<th>Power in</th>
<th>Power out</th>
<th>Exergy in</th>
<th>Exergy out</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Inlet</td>
<td>450</td>
<td>440</td>
<td>440</td>
<td>440</td>
</tr>
<tr>
<td>2</td>
<td>Outlet</td>
<td>300</td>
<td>290</td>
<td>290</td>
<td>290</td>
</tr>
</tbody>
</table>
ThermoLift Delivers 2.4x More Heat per Unit of Natural Gas

ThermoLift delivers more value for energy.

Average Current Installed Base

Units: all on equivalent MMBtu basis

COP: Coefficient of Performance = Heat Delivered / Fuel Input
## ThermoLift Renewable Energy ‘Capacity Factor’*

<table>
<thead>
<tr>
<th></th>
<th>Wind</th>
<th>Solar</th>
<th>ThermoLift Heat Pump</th>
<th>Electric Heat Pumps</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Capacity Factor</strong></td>
<td>37%**</td>
<td>26%**</td>
<td>100%***</td>
<td>~ 50%***</td>
</tr>
<tr>
<td><strong>Renewable Energy</strong></td>
<td>100%</td>
<td>100%</td>
<td>50% - 100%</td>
<td>50% - 100%</td>
</tr>
<tr>
<td><strong>Refrigerants or HFCs</strong></td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes, Refrigerants @ up to 2,000x CO2 GHG Impact</td>
</tr>
</tbody>
</table>

* 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.

2. DOE Building Energy Codes Program: [https://www.energycodes.gov/development](https://www.energycodes.gov/development)