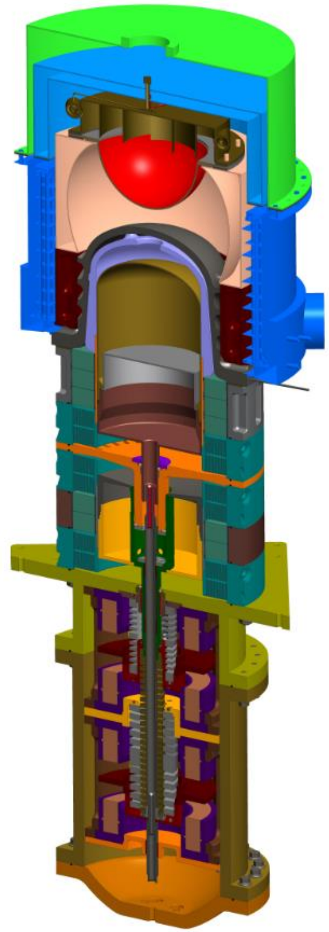
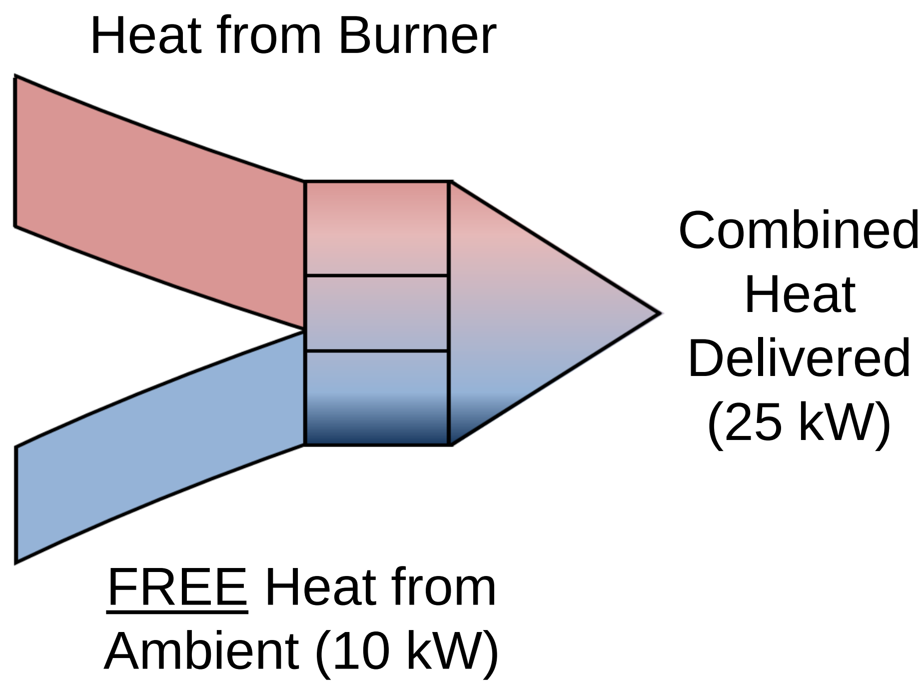
The Natural Gas Heat Pump and Air Conditioner

2016 Building Technologies Office Peer Review





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THERMOLIFT

Paul Schwartz, CEO
pschwartz@tm-lift.com

DE-FOA-0000823

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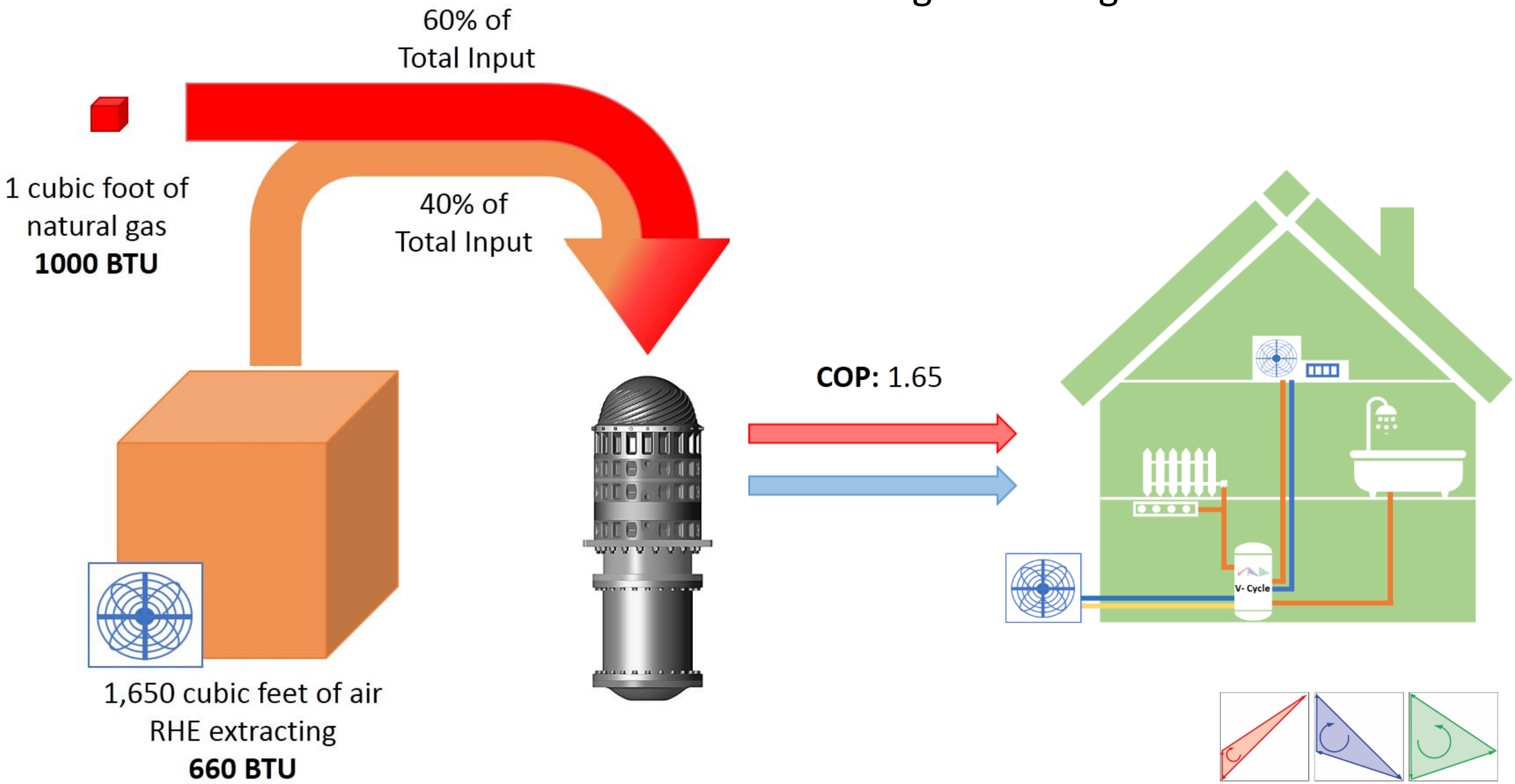

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Project Summary

Timeline:

Start date: 10/1/2013 (8/1/2013)

Planned end date: 9/31/2016

Key Milestones

1. Concept & CAD model; Q1 FY2014
2. Thermal Simulation; Q2 FY2014
3. 20kW Demonstrator; Q3 FY2015
4. Testing at Oak Ridge; Q2 FY2016

Budget: **$750,000**

Total spent to date: $525,331

Total future: $224,669

Target Market / Audience:

Residential and Small Commercial Buildings & Specialized Industrial Applications

Key Partners:

DOE	NYSERDA
Stony Brook Univ.	Oak Ridge Natl. Lab.
National Grid	Fala Technologies
GTI	Star Gas
Par Group	

Project Goal:

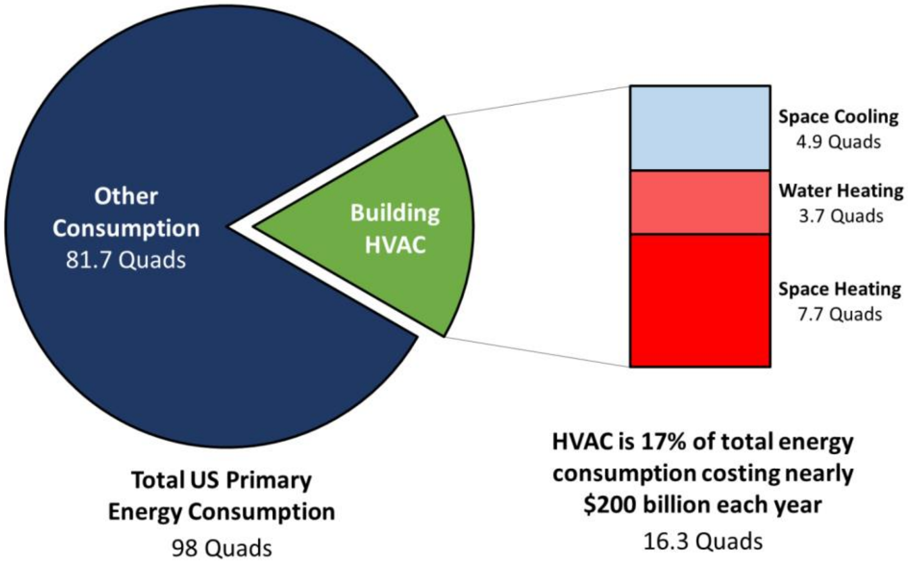
To develop a Vuilleumier heat pump (VHP) which includes novel improvements that will yield higher performance than the already high COP results of previously developed VHP. The heat pump will use natural gas to provide heating, cooling, and hot water with a single device.

Purpose and Objectives

Problem Statement:

- In cold weather climates, typical heat pumps are prohibitively costly to operate.
- In warm climates, peak electricity is very expensive.
- Common HVAC devices (compressors, furnaces, boilers, etc.) are outdated / inefficient.

Target Market and Audience:



Impact of Project:

1. The project goal is a 20kW device, capable of delivering complete heating and cooling demand (2,000 sqft. building).
2. Growth and Impact Plan:
   a. Near-term (<1 yr after project) – Incorporate manufacturing design refinements and conduct durability studies. Begin demonstration projects and pilots through partners including national laboratories, gas utilities, DoD, and others.
   b. Intermediate-term (1-3 yrs) – Product launch, 5k units installed during the first year, 15,000 in year two.
   c. Long-term (3+ yrs) – Expansion / global adoption, Target: 150k-250k unit production.

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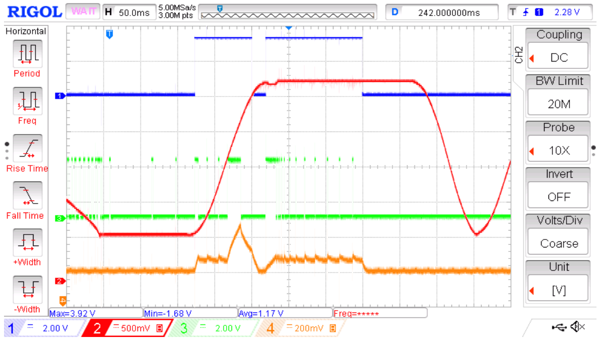
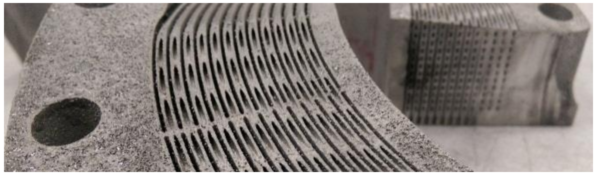
Approach

Approach: ThermoLift is modernizing a proven Vuilleumier cycle device for heating, cooling, and hot water. The end product will be a single 20kW natural gas-driven device for residential and commercial applications. Engineering development is focused on incorporating innovative improvements, optimizing device performance, and reducing the complexity and manufacturing costs.



Key Issues:

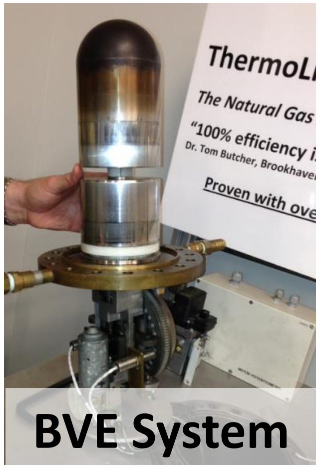
- Design of novel electromechanical drive.
- Design of optimized heat exchangers.
- Concerns due to high temperatures & pressures.



Distinctive Characteristics:

- Single natural gas-driven device
- Minimal electricity → grid independence
- No refrigerants – No compressors
- High cold climate performance

Temp °F	DOE Target	BVE Demonstrator
-13	1	1.3
17	1.15	1.45
47	1.3	1.65



ThermoLift 1st-Generation Prototype


Nov. 2013

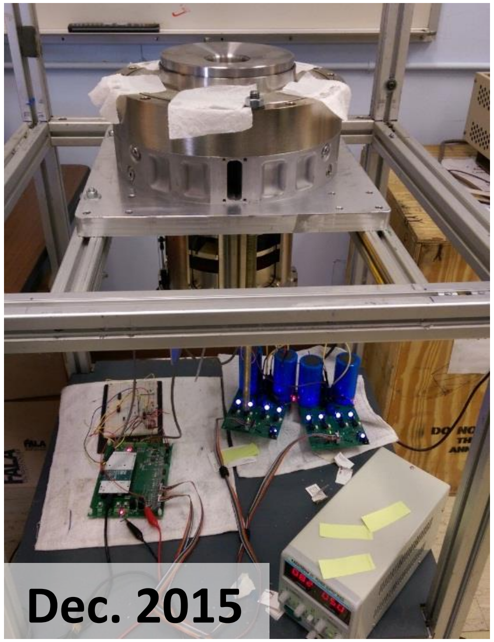
ThermoLift first developed a benchtop proof-of-concept for the novel independent mechatonic design.
A complete heat pump prototype was designed, simulated, and built by late 2014.


Sept. 2014

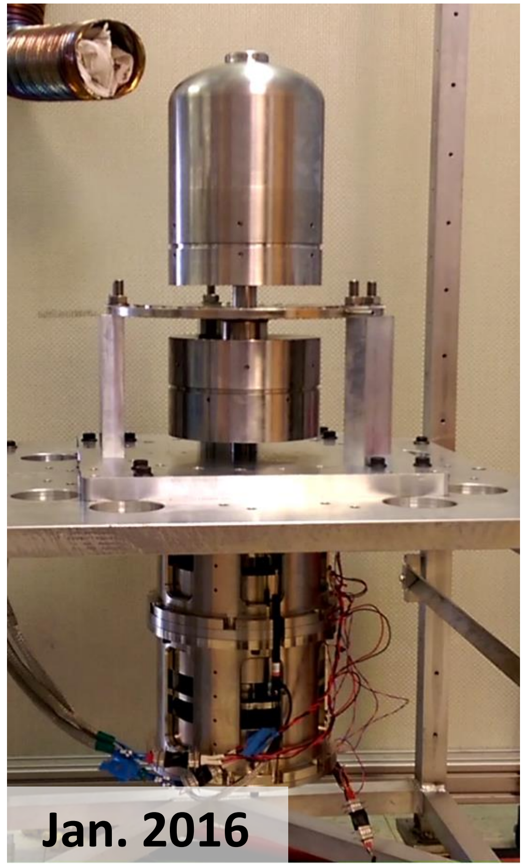
ThermoLift began testing and generated numerous iterations & simulations in order to develop improved components.


Mar. 2015

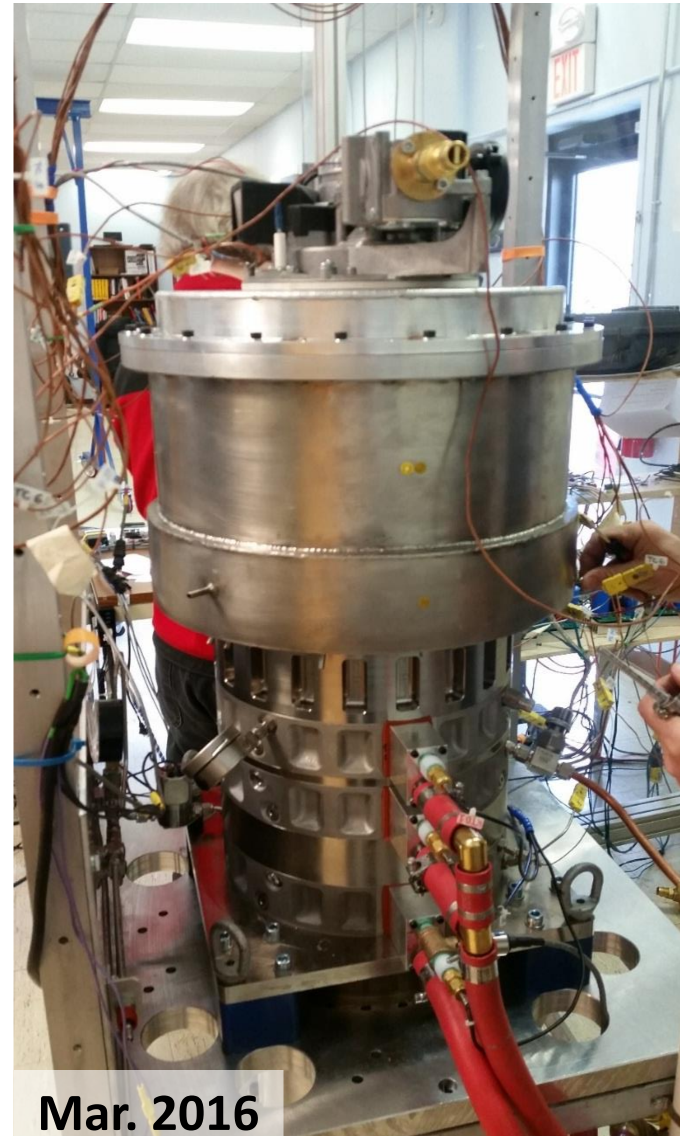
ThermoLift 2nd-Generation Prototype


Dec. 2015

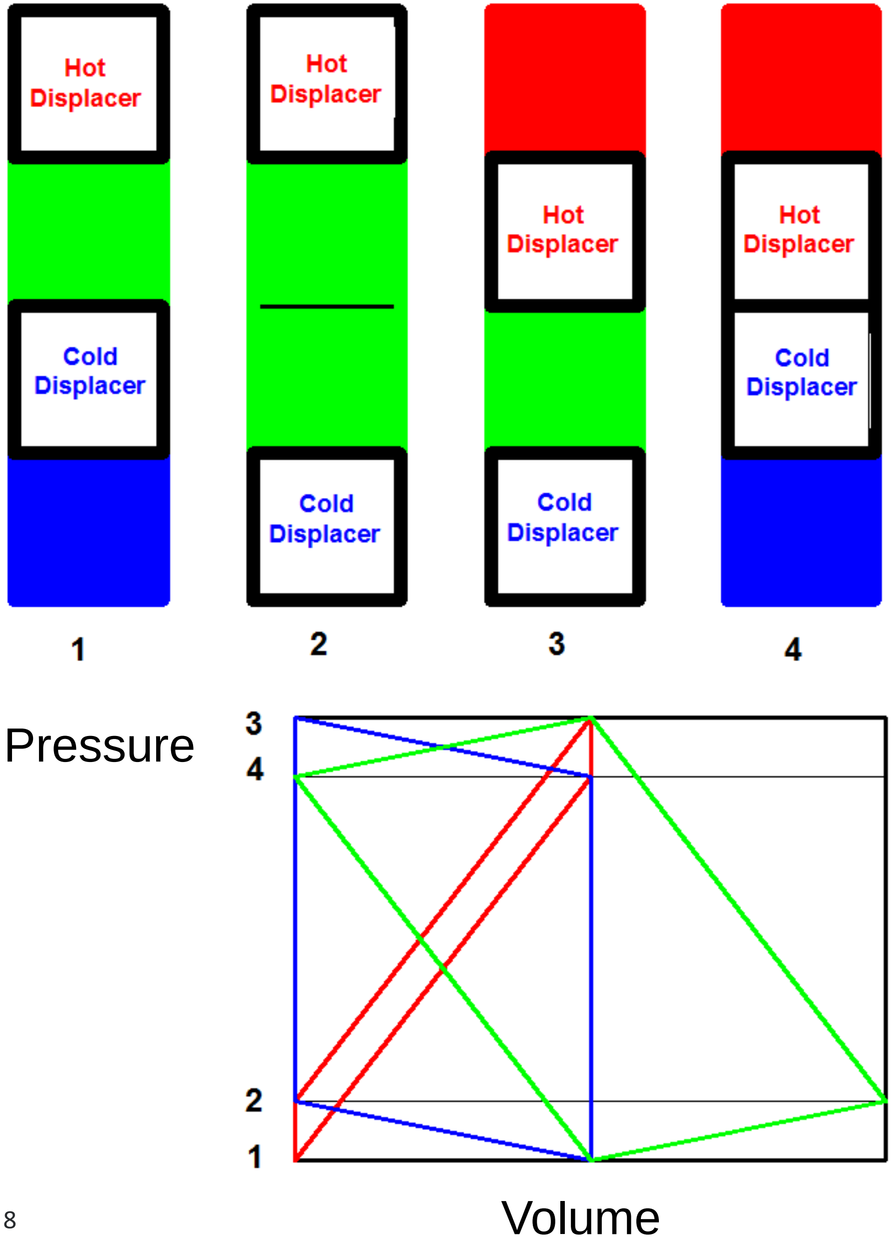
ThermoLift started mechatronics testing with actual Gen 2.0 machine parts. Focus was on incorporating major improvements to control strategy and adaptability to different operating conditions.


Jan. 2016

ThermoLift is currently conducting full thermodynamic testing in our Ann Arbor lab with encouraging results.


Mar. 2016

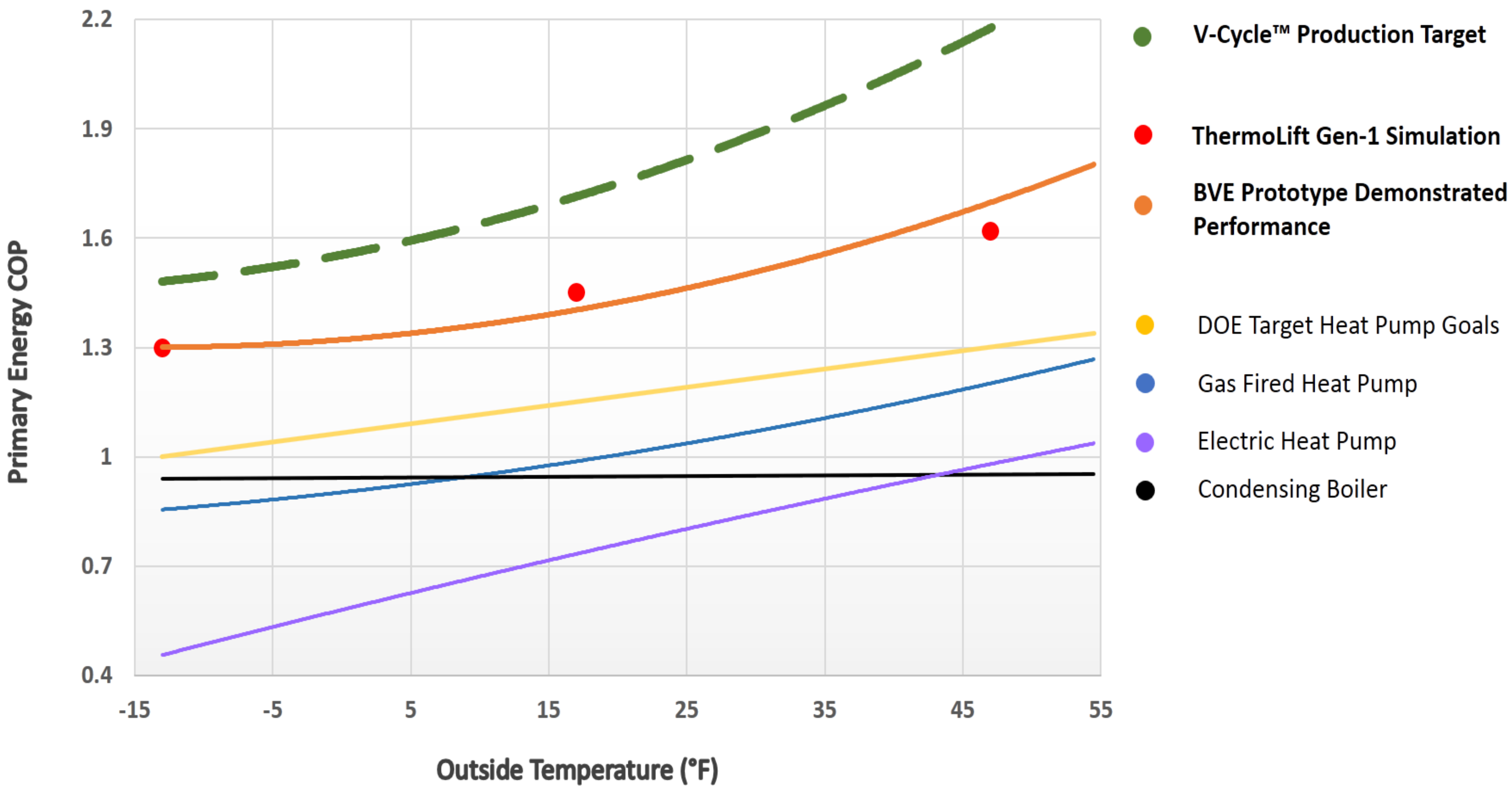
ThermoLift 4 Phase Process (Patent Pending)



<u>Novel displacer system incorporating electronic controls:</u>

- Enables independent and discontinuous motion.
- Thermodynamic advantages based on ability to control gas flow differently.
- This advancement was unachievable with mechanically-linked displacers in previous Vuilleumier devices.
- Enables customization and optimization at partial load conditions and for cooling applications.

Comparison to State-of-the-Art



Team & Progress (5 PhDs & 9 Masters)

THERMOLiFT

Leadership

Steve Winick
Partner, TopSpin Partners

Dr-Ing. Prof. Peter Hofbauer
Co-Founder & Inventor

Bob Catell
Chairman, Advanced Energy Center

Paul Schwartz
Founder & Chief Executive Officer

Engineering

Dr-Ing. Adrian Tusinean
Chief Technology Officer, Co-Founder

David Yates
Lead Designer

Erik Kauppi
Program Manager

Seann Convey
Materials, M.S.

Dennis Lin
Thermodynamic, M.S.

Matt Duthie
CAD Engineer

Andrew King
Mechanical Engineer

Tom Litow
Electronics, M.S.

Jim Cambell
Electronics Engineer

Business Development

Jonathan Haas
Senior Vice President, M.S.
Grants – DOE, NYSERDA

Rachel Falor
Admin / Accounting

Christina Convey
Research / Marketing

Intellectual Property

Diana Brehob, Ph.D.
VP Operations & IP Counsel, J.D.

Advisors

Michael Faltichek
Long Island Angel Network

Jon Longtin, Ph.D.
SBU Mechanical Engineering

Col. Paul Roege
Army Chief Operation Energy

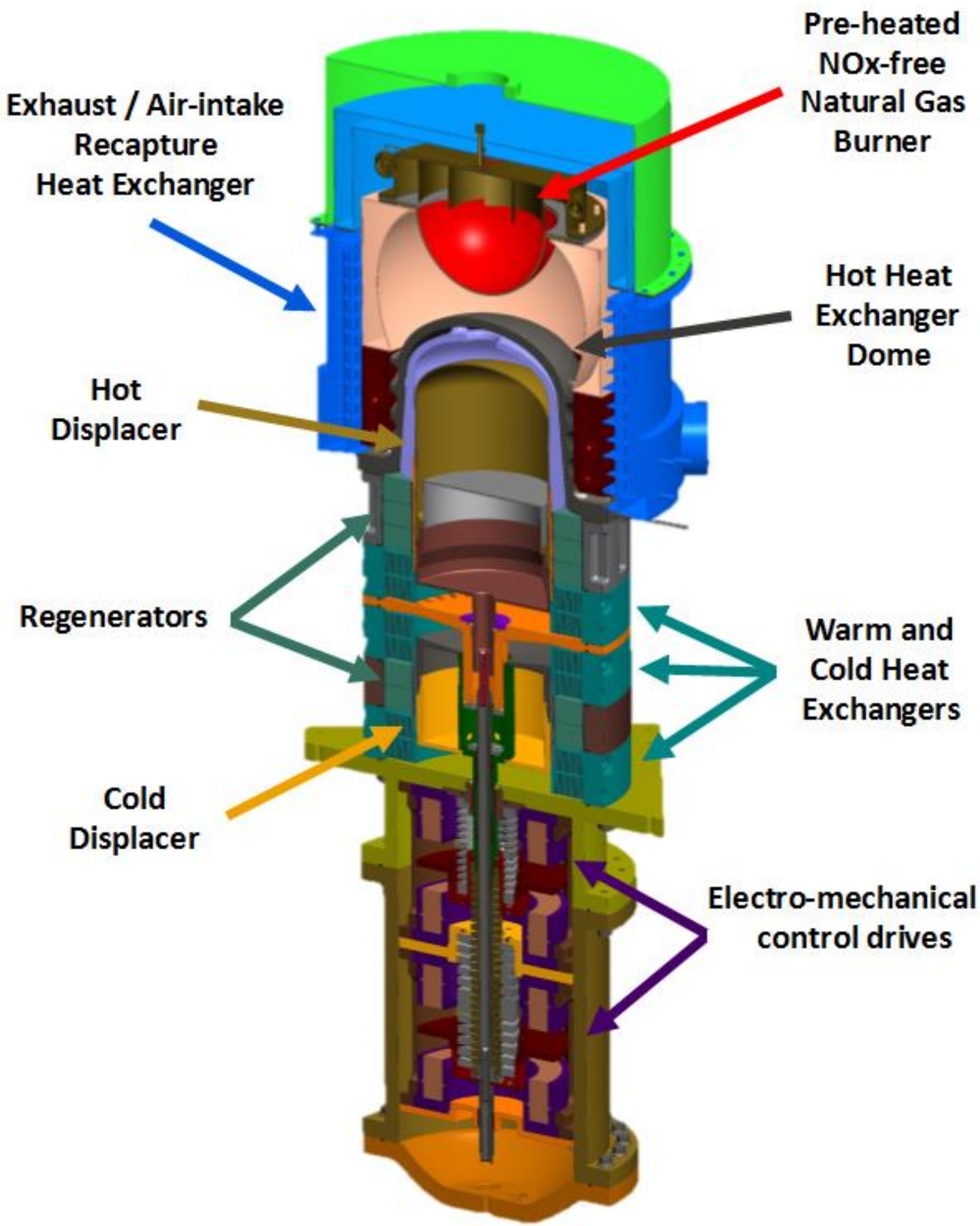
Michael Danaher
WSGR

David Hamilton
Clean Energy Incubator (CEBIP)

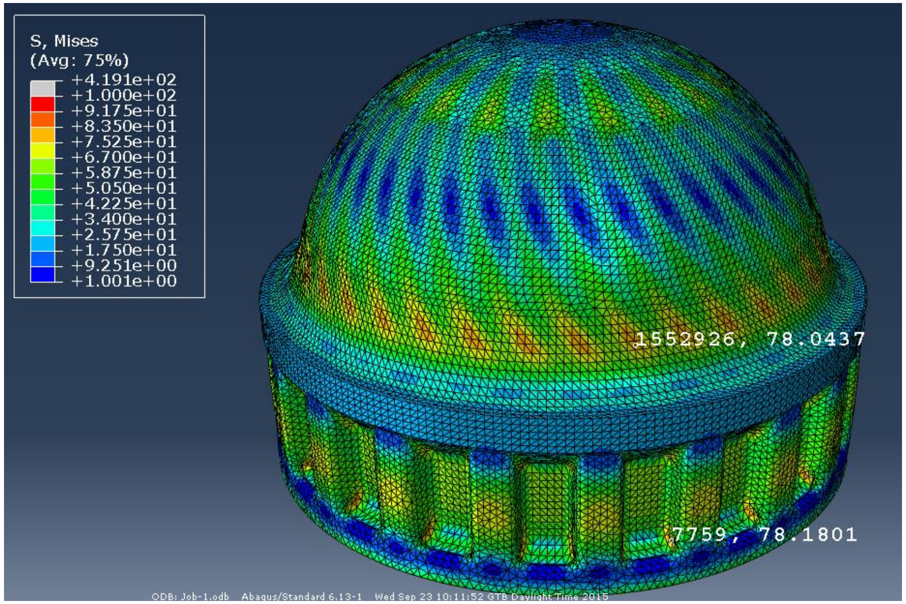
Mark Austin
NYSERDA / Bright Capital

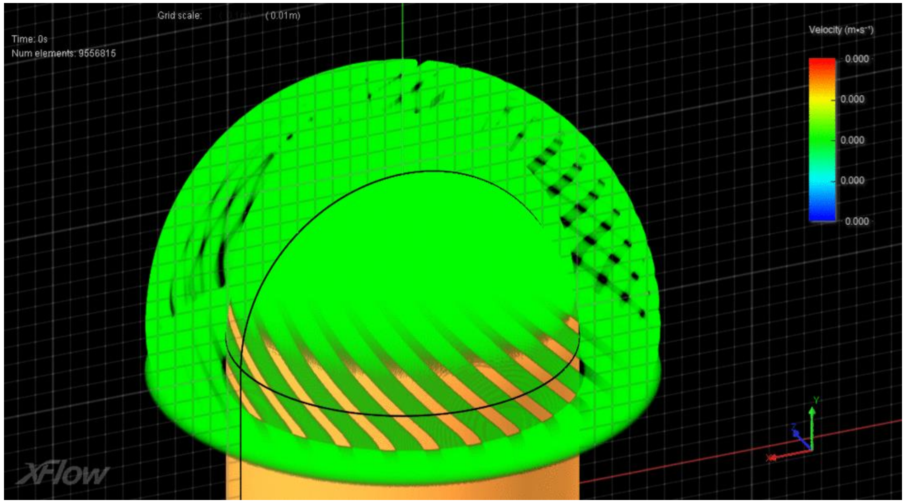
Design Improvements

Animation of
Moving Displacers

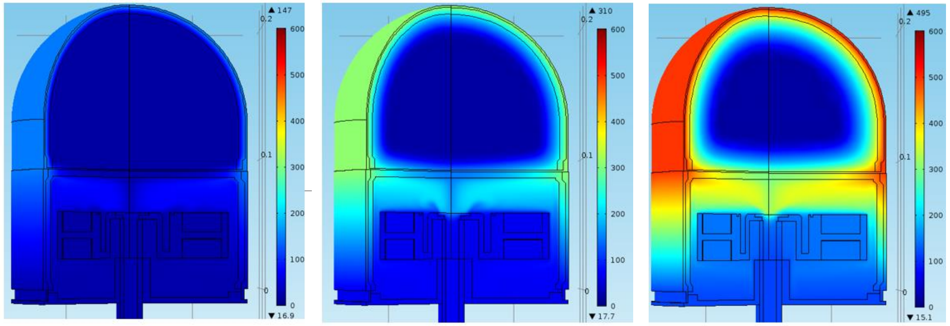


Improved Thermo-Mechanical Simulation





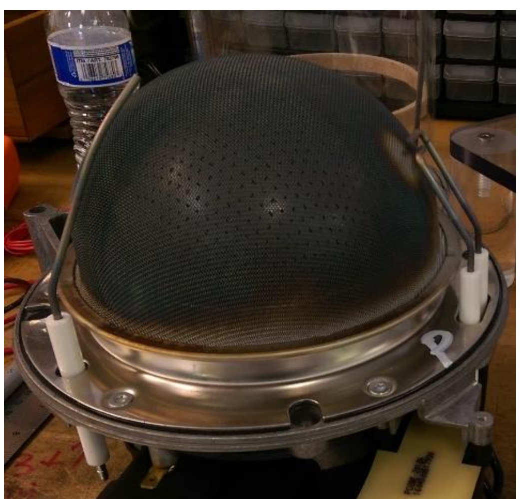
- In the past 12 months, we have been able to dramatically improve our modeling robustness and agility with more sophisticated 3D CFD and mechanical FEA simulation.
- Currently working with Stony Brook University to utilize high performance computing cluster for enhanced iteration



1 min 9 mins 18 mins

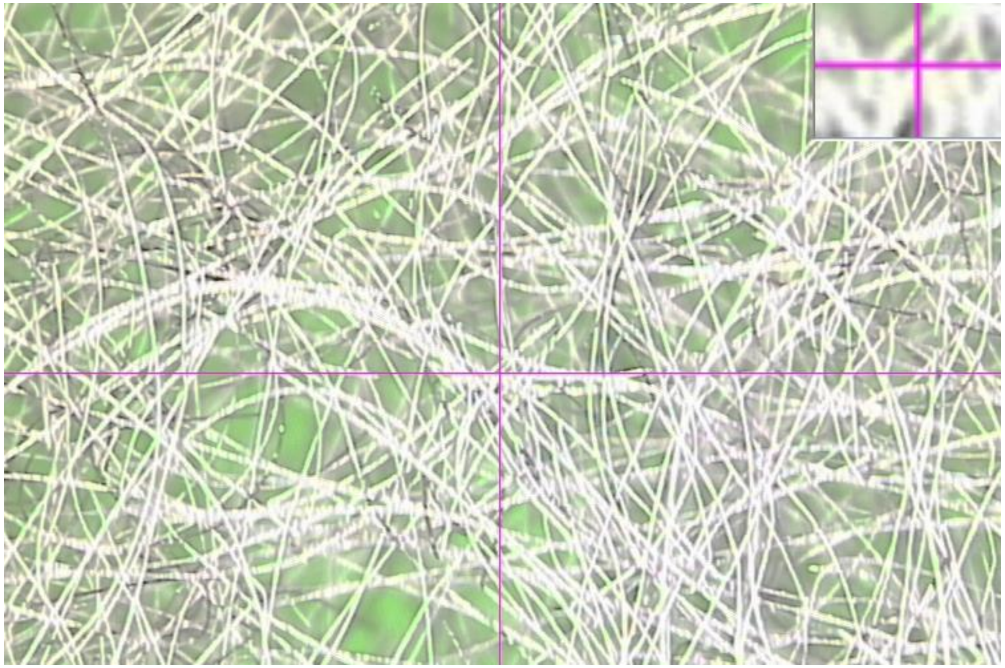
Hot Heat Exchanger + Exhaust Recovery

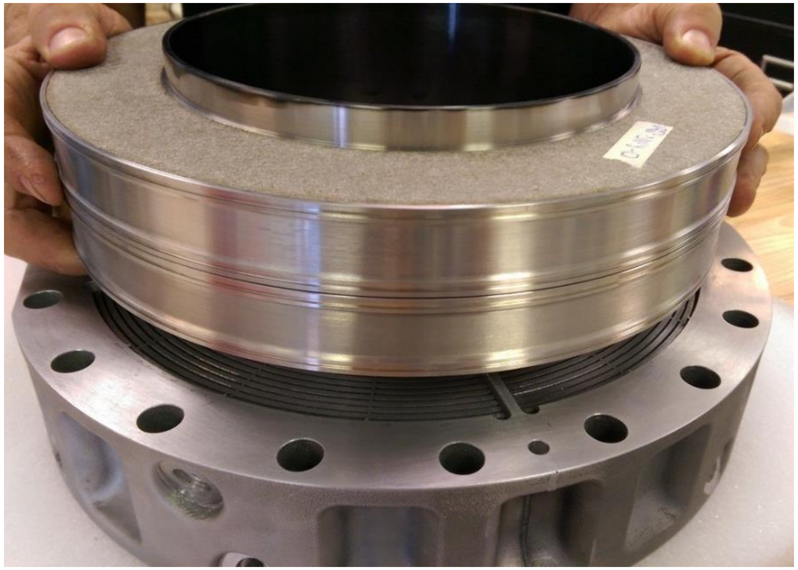
- Working with Gas Technology Institute to optimize integration of NOx-free radiation burner.
- Testing mixing equipment, reflector designs, and modulation.
- Developed air-to-air heat exchanger for recovery of convective heat from exhaust gas to pre-heat mixture of natural gas and intake air prior to combustion.
- Incorporated condensing heat exchanger to recover additional heat from exhaust; will be further refined.

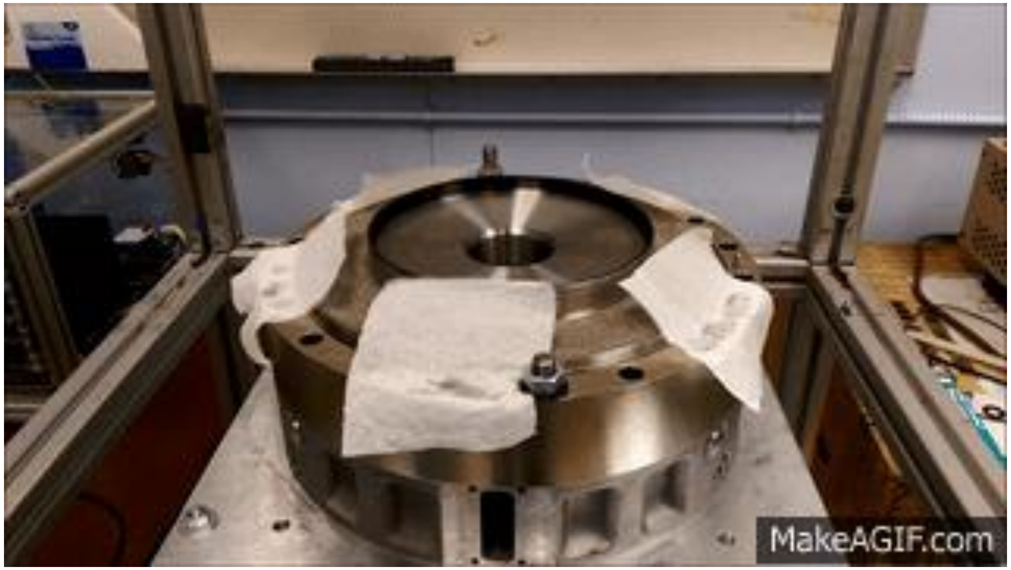


Improved Regenerators

- Regenerators are crucial to the thermal compression concept of V-Cycle device
- Random fiber has greater uniformity of gas flow properties and heat transfer
- Need to consider optimization for large scale production



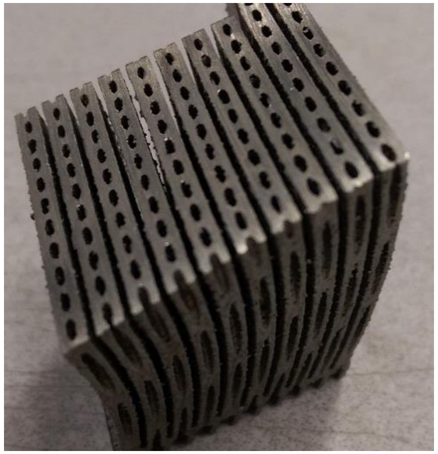


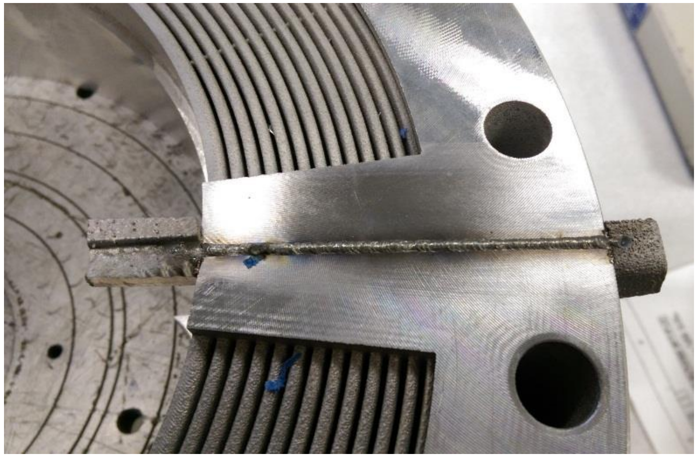


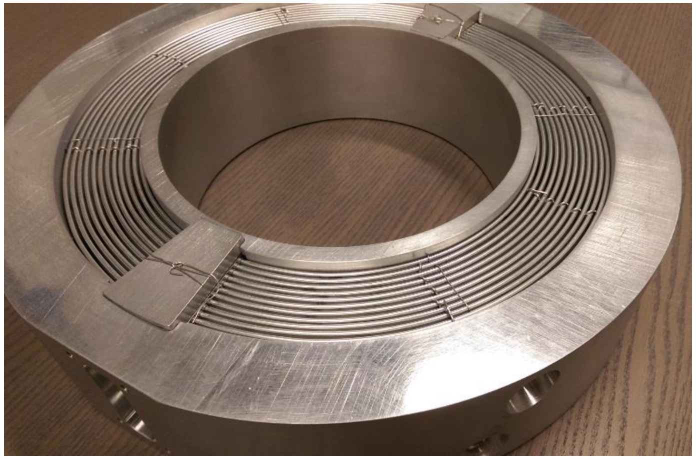
Microchannel Heat Exchanger

Novel Microchannel Design for Helium / Water / Glycol HXs:

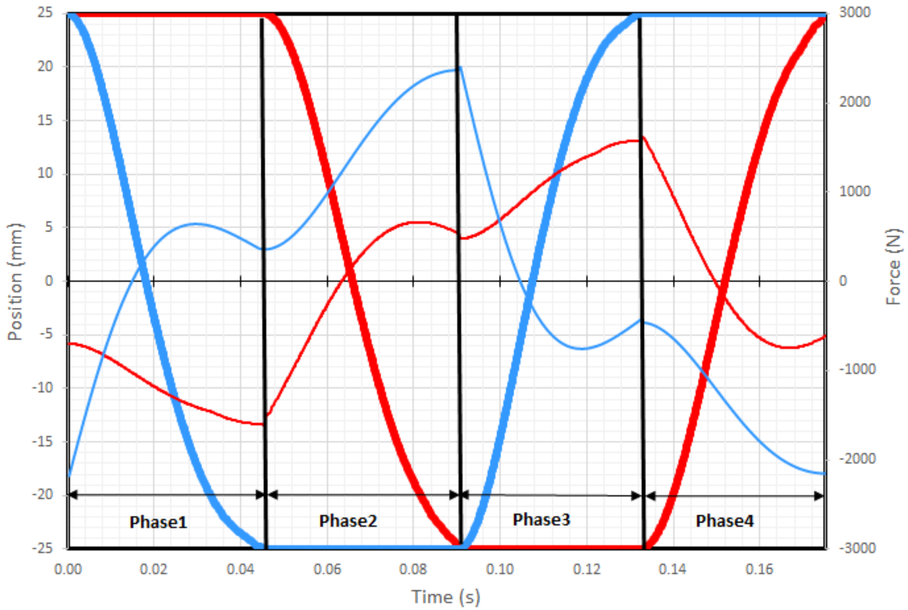
- Prototype:
  - 3 heat exchangers were assembled from 12 quadrants fabricated using DMLS 3D-printing of Aluminum (ALSi10Mg).
  - Quadrants were e-beam welded and showed no leaks at 100 bar.
- Production Intent Concept:
  - Built multiple sample HXs using aluminum extrusions and brazed together at inlet and outlet; further improvements identified.

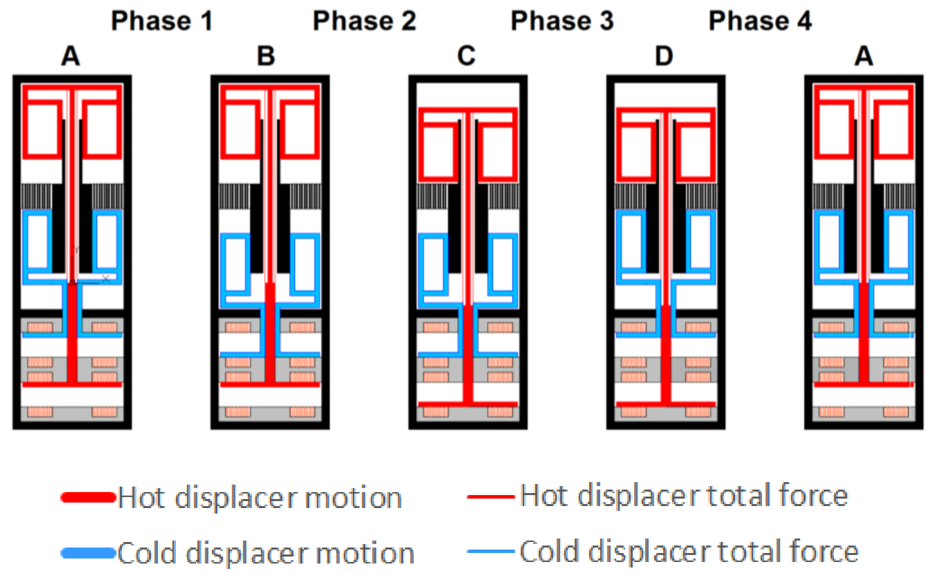


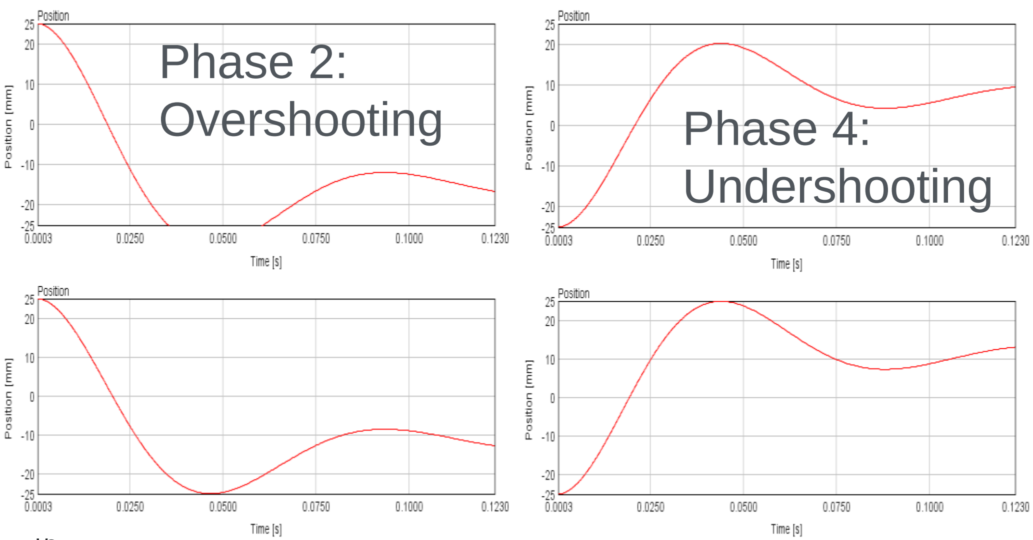




Mechatronic Controls and Simulation







Developed Comprehensive Gas Dynamics Solver:

- Models the total forces on each displacer including gas pressures, mechanical spring forces, and damping forces.
- Allows for detailed prediction of motion and operation in different conditions.
- Enables customization and optimization of alternate electromagnetic control strategies.

Anticipated Performance

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Ambient Temp.	Heating COP	Heating Capacity
-25 ^{o}C -13 ^{o}F	1.48	18.0 kW
-8 ^{o}C 18 ^{o}F	1.59	17.0 kW
8 ^{o}C 46 ^{o}F	1.73	16.2 kW

Ambient Temp.	Cooling COP	Cooling Capacity	Heating Capacity
20 ^{o}C 68 ^{o}F	0.88	7.4 kW	15.6 kW
30 ^{o}C 86 ^{o}F	1.00	7.7 kW	15.2 kW
40 ^{o}C 104 ^{o}F	1.13	7.9 kW	14.7 kW

1D Thermodynamic Simulation Notes:

- Freq. = 5.5 Hz, T_{hot} = 700 ^{o}C, T_{warm} = 60 ^{o}C, Pressure = 100 bar
  - Target Freq. = 7.5 Hz; strategies to improve identified
- COP includes estimation of loses from burner exhaust (70%) to hot heat exchanger but not auxiliary equipment (fans, pumps)
- Working with NREL to build HVAC system model for full building energy model as part of Wells Fargo IN^2 Incubator

Letters of Support / Interest in Commercialization

THERMOLIFT

Development & Demonstration

- U.S. Department of Energy
- New York State of Opportunity – NYSERDA Supported
- gti
- ALCOA
- FEV
- CPC Composite Prototyping Center
- Department of Defense, United States of America

Institutional Investors

- tOpspin
- Long Island Angel Network
- Wells Fargo

Academic Partners

- Stony Brook University
- Clean Energy Business Incubator Program at Stony Brook University
- Advanced Energy Research and Technology Center at Stony Brook University

Domestic & International Utility and Distribution Relationships

- nationalgrid
- conEdison
- British Gas
- PSEG Long Island
- PETRO
- Gaz de France
- DTE Energy
- SoCalGas
- The Par Group

National Laboratories

- Oak Ridge National Laboratory
- NREL National Renewable Energy Laboratory
- Brookhaven National Laboratory

International Organizations

- ehpa european heat pump association
- Sustainable Development Technology Canada
- Department of Energy & Climate Change
- Fraunhofer

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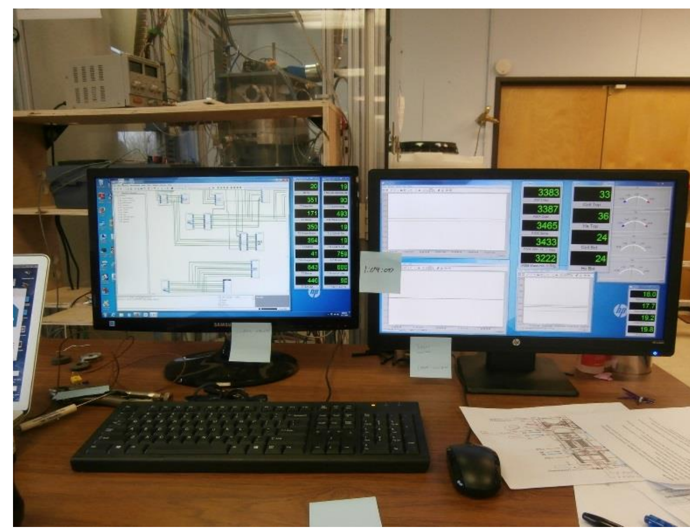
Progress and Accomplishments

Lessons Learned:

- Mechatronics have a high sensitivity to flow resistance, dead volume, and thermal considerations.
- Refinement of mass-spring system and coil geometry can dramatically improve reliable operation and performance.
- Manufacturing process engineering and precision are crucial to helium temperature and pressure concerns.

Accomplishments:

- Built and began testing 2nd generation prototype.
- Re-designed numerous improved components.
- Developed baseline simulations for tuning, validation, and future enhancements.



Market Impact:

- Assembled an experienced organization.
- Built extensive network of advocates, partners, suppliers, and qualified customers.

Awards/Recognition:

- 2016 Clean Energy Trust Challenge – *Finalist*
- 2015 Wells Fargo IN2 Innovation Incubator – *Winner*
- 2014 CleanTech Open NE People's Choice Award
- 2014 Fraunhofer 4 Startups to Watch at NY Energy Week
- 2014 ARPA-E Future Energy – *Winner*
- 2014 & 2013 Defense Energy Summit – *Winner*

Project Integration and Collaboration

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Project Integration:

- Stony Brook University - AERTC
- Engineering expertise in Detroit & Ann Arbor
- Gas utilities domestically and abroad
- Established advocates in numerous organization (DOD, European Heat Pump Assoc.)

Advanced Energy Center

Partners, Subcontractors, and Collaborators:

- Oak Ridge National Labs
- Gas Technology Institute (GTI)
- National Grid, Star Gas, Par Group
- Fala Technologies, LoDolce, MicroTube, HandyTube, Bruce Diamond

Communications:

Exhibits:

2014-16 ARPA-E, 2013-14 New England Venture Summit, 2013-14 Defense Energy Summit, 2013-16 Advanced Energy Conference , 2012-14 National Academy of Sciences

Publications:

2015 IEA Heat Pump Centre Newsletter, 2014 American Gas Magazine, 2014 DOE Non-Vapor Compression HVAC Technologies, China Lake High Tech. Association Journal, Newsday, LI Business News, CBS News Affiliate

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Next Steps and Future Plans

Project Schedule												
Project Start: 10/1/2013	(light blue)	Completed Work										
Project End (originally planned): 9/1/2014	(dark blue)	Active Task (in progress work)										
Project End (anticipated): 9/1/2016	red ◆	Milestone / Deliverable (Originally Planed)										
	◆	Milestone / Deliverable (Actual)										
	FY 2013	FY 2014				FY 2015				FY 2016		
Task	Q4 (Oct. - Dec.)	Q1 (Jan. - Mar.)	Q2 (Apr. - Jun.)	Q3 (Jul. - Sept.)	Q4 (Oct. - Dec.)	Q1 (Jan. - Mar.)	Q2 (Apr. - Jun.)	Q3 (Jul. - Sept.)	Q4 (Oct. - Dec.)	Q1 (Jan. - Mar.)	Q2 (Apr. - Jun.)	Q3 (Jul. - Sept.)
Past Work												
Q4 Milestone: Concept Definition	completed ◆											
Q1 Milestone: Simulation and Design		completed ◆										
Q2 Milestone: Procurement and Build			completed, red ◆	completed	completed ◇				◆			
Current / Future Work												
Q3 Milestone: Testing				completed, red ◆	completed	completed	completed ◇	completed	completed	completed	completed ◆	
Q4 Milestone: Testing ORNL					red ◆						completed	completed ◆

- Further optimized design:
    - Analysis of improved heat input
    - Investigate joining technologies for high pressure sealing
    - Simplified manufacturing design
    - System integration and improved modulation
    - Focus on cost reduction and durability
- Full scale demonstration / Pilot tests


Oak Ridge Natl. Lab

REFERENCE SLIDES

Project Budget

Project Budget: Total budget of $1,103,810 including $200,000 allocated to ORNL for 3rd party testing and validation ($903,810 operating budget).
Total DOE / ThermoLift cost share of 60.85% ($550,000) / 39.15% ($353,810).

Variances: Development program was extended from proposed completion date of Sept. 2014 to Sept. 2016. No changes to the budget were undertaken.

Cost to Date: Total spent = $863,280 / $1,103,810 ≈ 78.1% of total budget.

Additional Funding: ThermoLift has been awarded an additional $582,000 in NYSERDA funding and approximately $5,100,000 in private capital (TopSpin Partners, Long Island Angel Network, and others).

Budget History					
10/1/2013 – 9/30/2014 (past)		10/1/2014 - Current (current)		Current – 9/31/2016 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$525,331	$337,949	$0	$0	$24,669	$15,861

+ $200,000 (ORNL)

Project Plan & Schedule

Project Schedule										
Project Start: 9/1/2013		Completed Work								
Project End (originally planned): 9/1/2014		Active Task (in progress work)								
Project End (anticipated): 3/31/2016		Milestone/Deliverable (Originally Planed)								
		Milestone/Deliverable (Actual)								
	FY 2013	FY 2014				FY 2015				FY 2016
Task	Q4 (Oct - Dec)	Q1 (Jan - Mar)	Q2 (Apr - Jun)	Q3 (Jul - Sep)	Q4 (Oct - Dec)	Q1 (Jan - Mar)	Q2 (Apr - Jun)	Q3 (Jul - Sep)	Q4 (Oct - Dec)	Q1 (Jan - Mar)
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Q1 Milestone: Simulation and Design										
Q2 Milestone: Procurement and Build										
Current/Future Work										
Q3 Milestone: Testing										
Q4 Milestone: Testing ORNL										