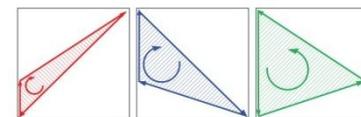
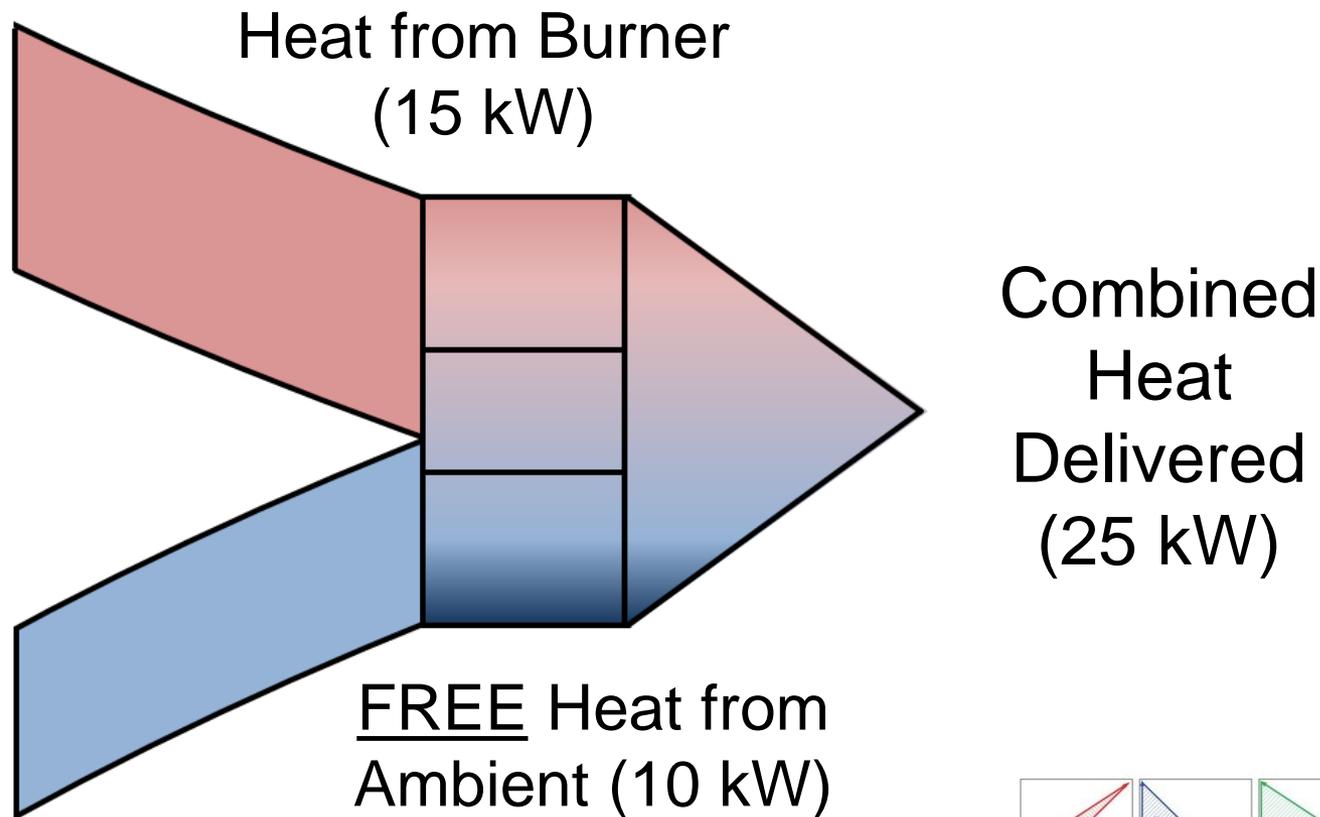
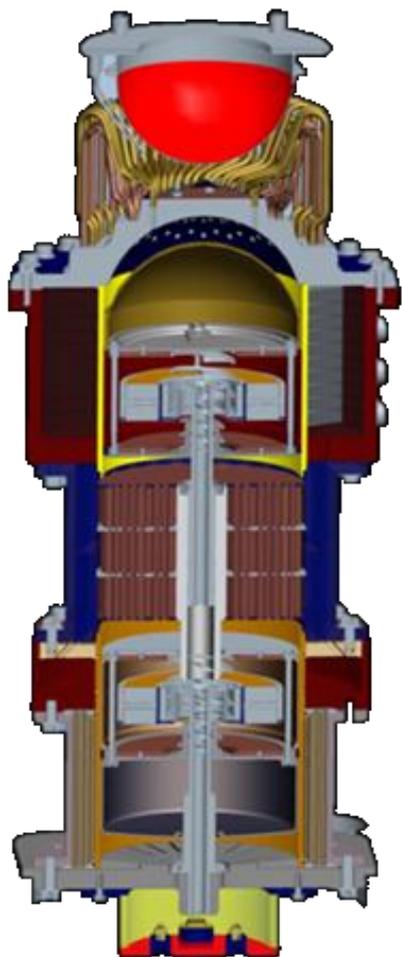


# The Natural Gas Heat Pump and Air Conditioner

2014 Building Technologies Office Peer Review

New Project



ThermoLift, Inc.

U.S. DEPARTMENT OF  
**ENERGY**

Energy Efficiency &  
Renewable Energy

Paul Schwartz, [pschwartz@tm-lift.com](mailto:pschwartz@tm-lift.com)

DE-FOA-0000823 Grantee

# Project Summary

## Timeline:

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

Planned end date: 9/30/2014

## Key Milestones

1. Concept & CAD model; Q1 FY2014
2. Thermal Simulation; Q2 FY2014
3. 20kW Demonstrator; Q3-Q4 FY2014
4. Testing at Oak Ridge; Q4 FY2014?

## Budget: \$750,000

Total spent to date: \$397,000

Total future: \$353,000

## Target Market / Audience:

Residential and Small Commercial Buildings  
& Specialized Industrial Applications

## Key Partners:

DOE	NYSERDA
Stony Brook Univ.	Oak Ridge Natl. Lab.
National Grid	Par Group
ATA	STAR Energy
Fala Technologies	LoDolce

## 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

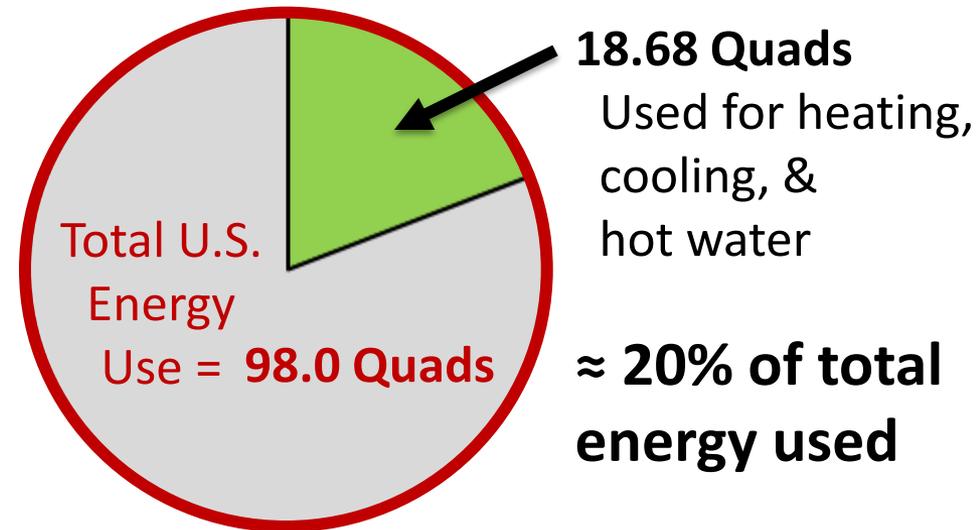
## Problem Statement:

- 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 are outdated / inefficient.

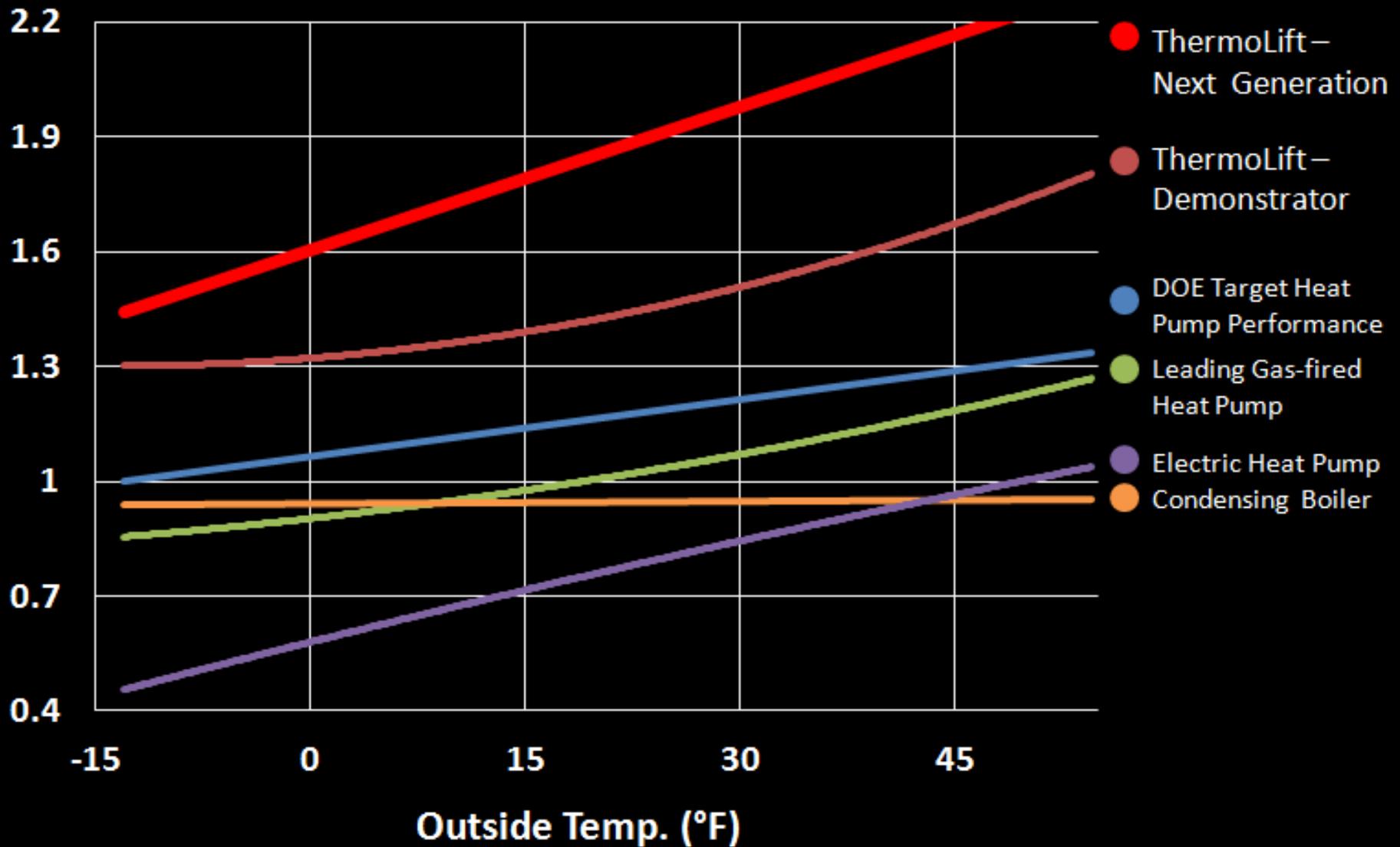
## Impact of Project:

1. The project goal is a 20kW device, capable of delivering complete heating and cooling demand with scalable 2,000 sqft. units.
2. Growth and Impact Plan:
  - a. Near-term (<1 yr after project) – Incorporate manufacturing design refinements and conduct durability studies, Begin demonstration through DOD ESTCP program and pilots through gas utility partnerships.
  - 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.

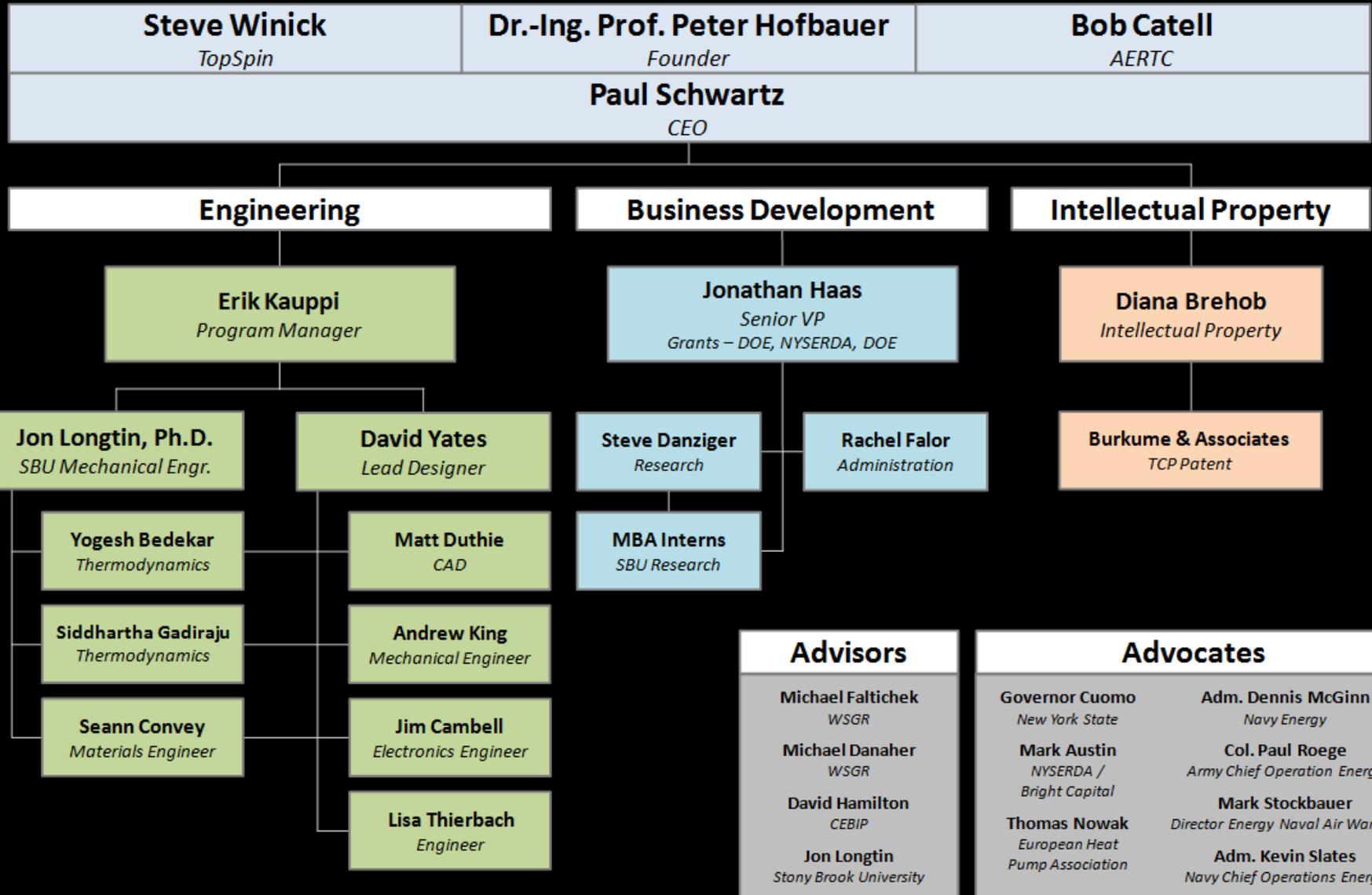
## Target Market and Audience:



# Comparison to State-of-the-Art



# Team



# Approach

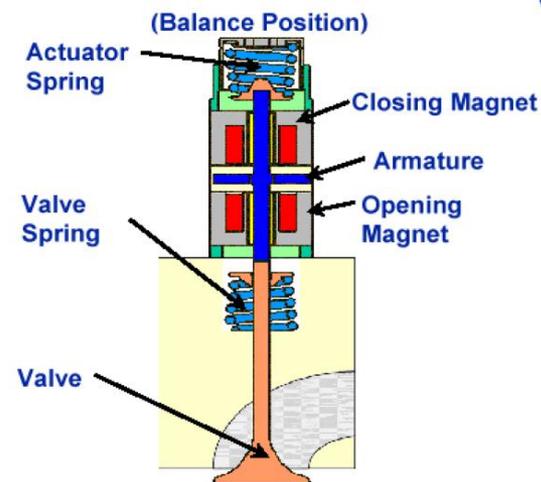
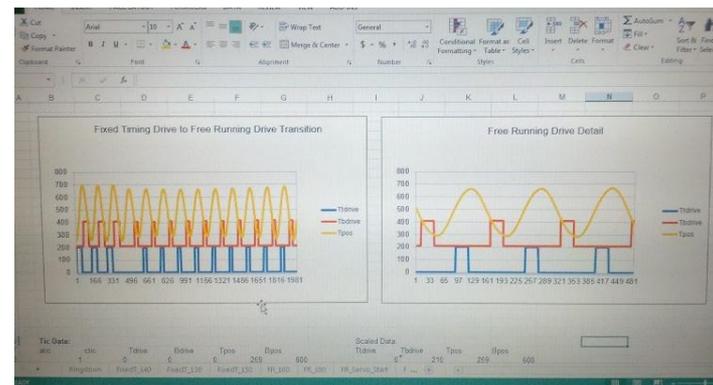
**Approach:** ThermoLift is modernizing a proven Vuilleumier cycle device for heating, cooling, and hot water. The end product will be a single 20kW natural gas-driven device for residential and commercial applications. Engineering development is focused on incorporating innovative improvements, optimizing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

## Distinctive Characteristics:

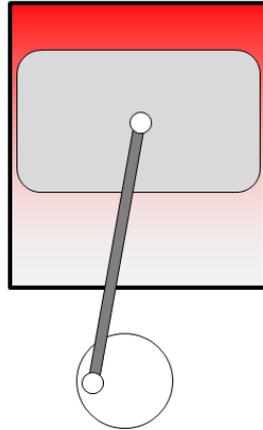
- Single Natural gas-driven device for heating, cooling, and hot water
- No electricity meaning grid independence
- No refrigerants - Helium working gas
- Cold climate performance



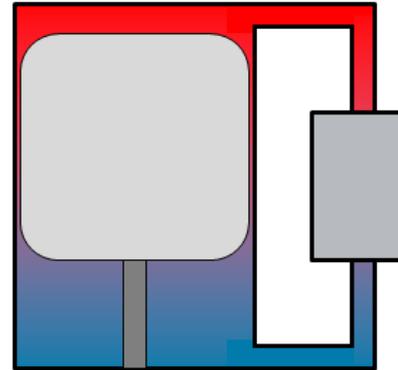
Temp °F	DOE Target	BVE Demonstrator
-13	1	1.3
17	1.15	1.45
47	1.3	1.65

# Thermally Driven Cycles (Vuilleumier & Stirling)

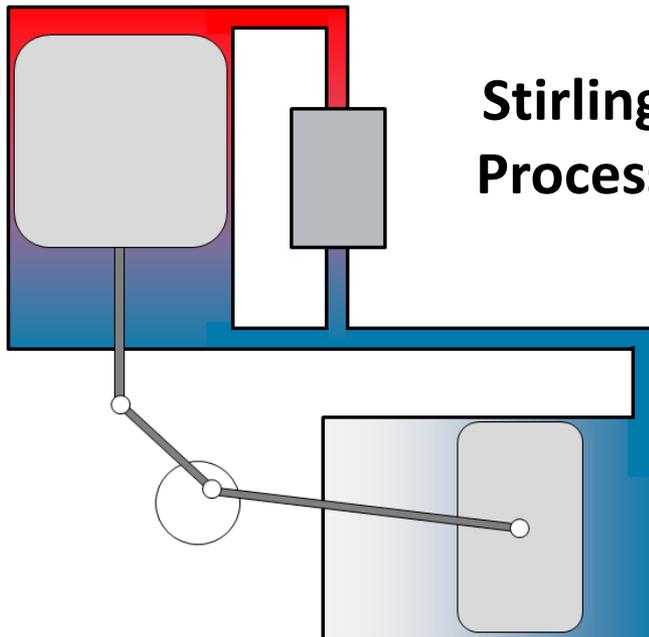
**Mechanical  
Compressor**



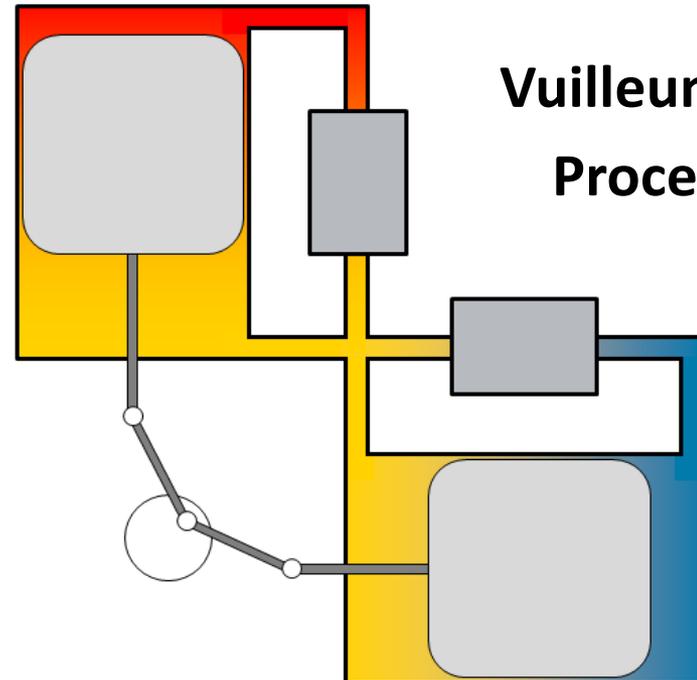
**Thermal  
Compressor**



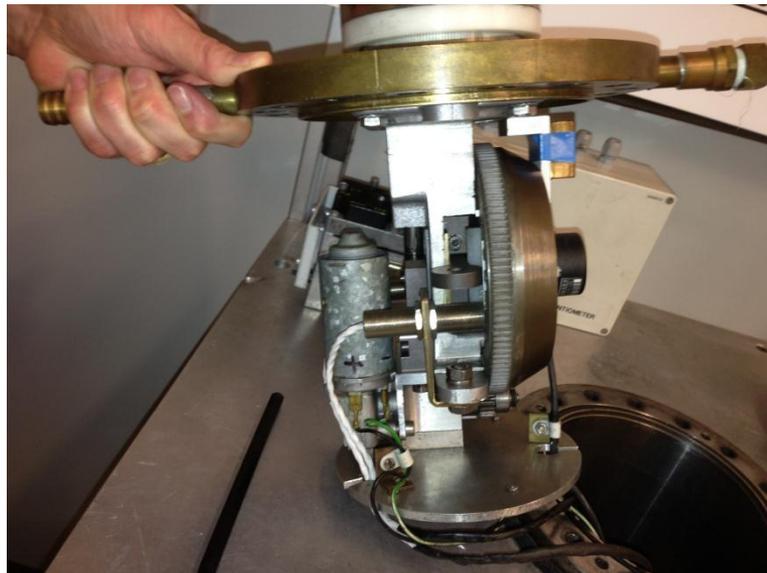
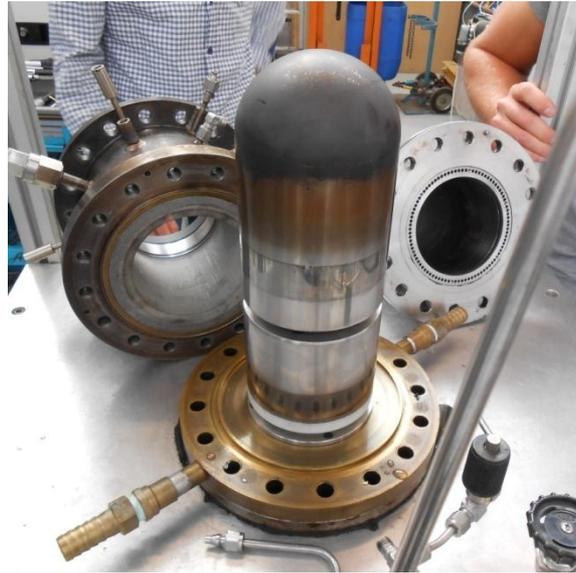
**Stirling  
Process**



**Vuilleumier  
Process**



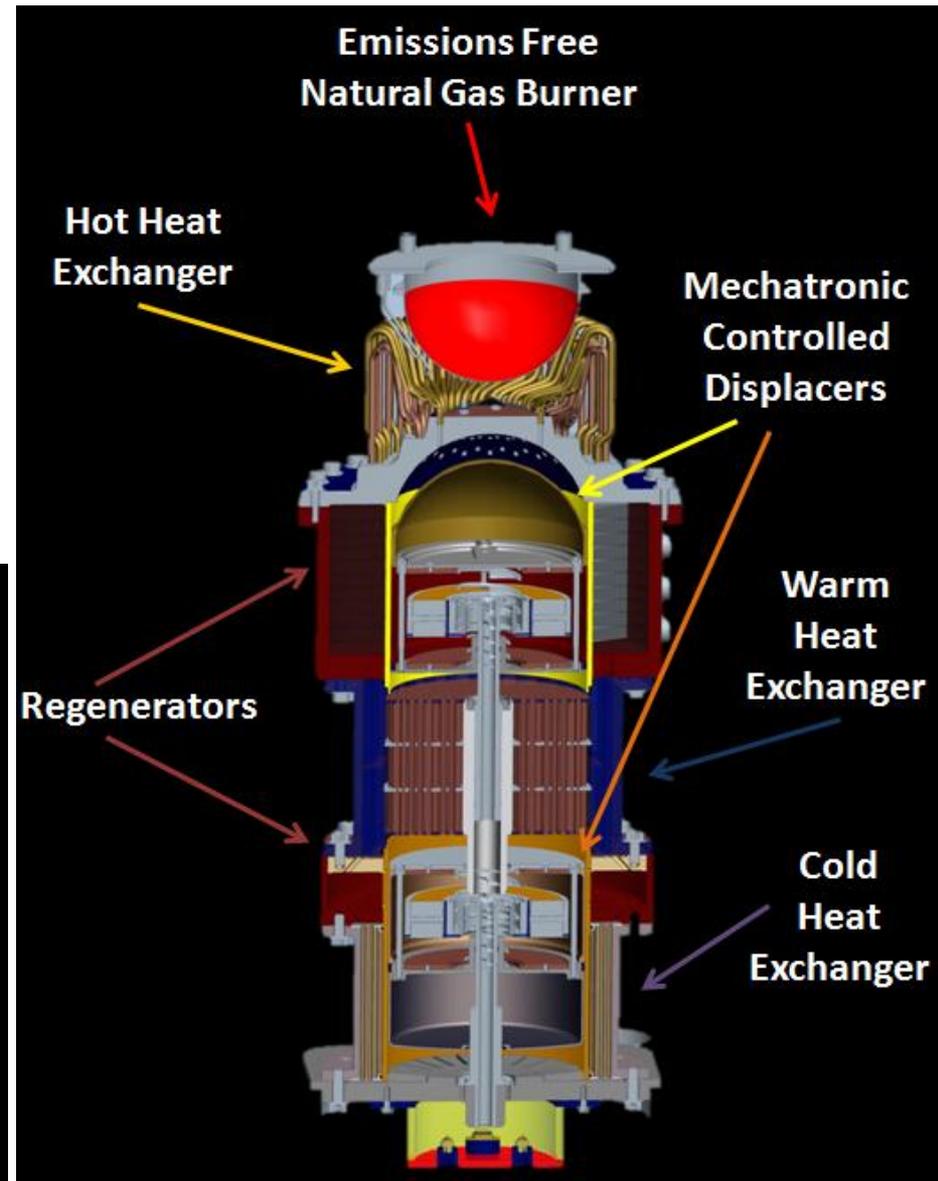
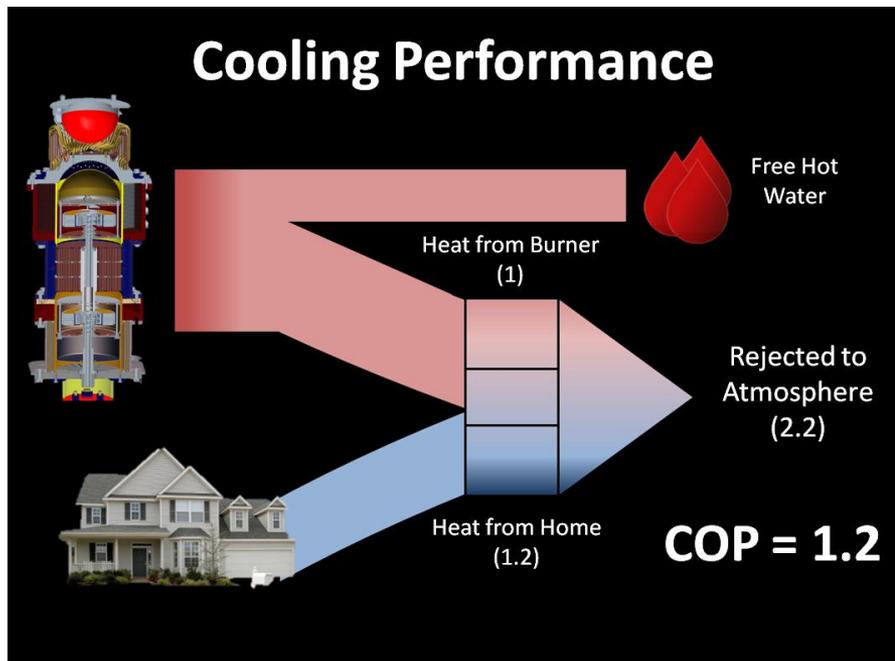
# BVE Energy Demonstrator 1991



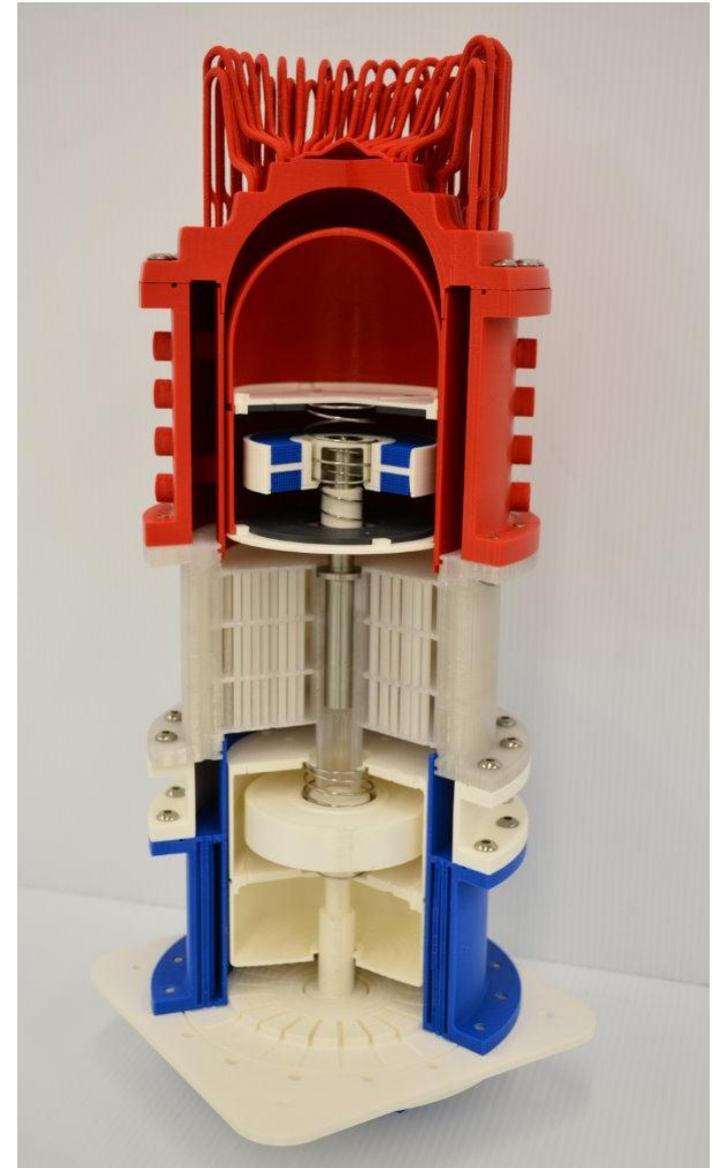
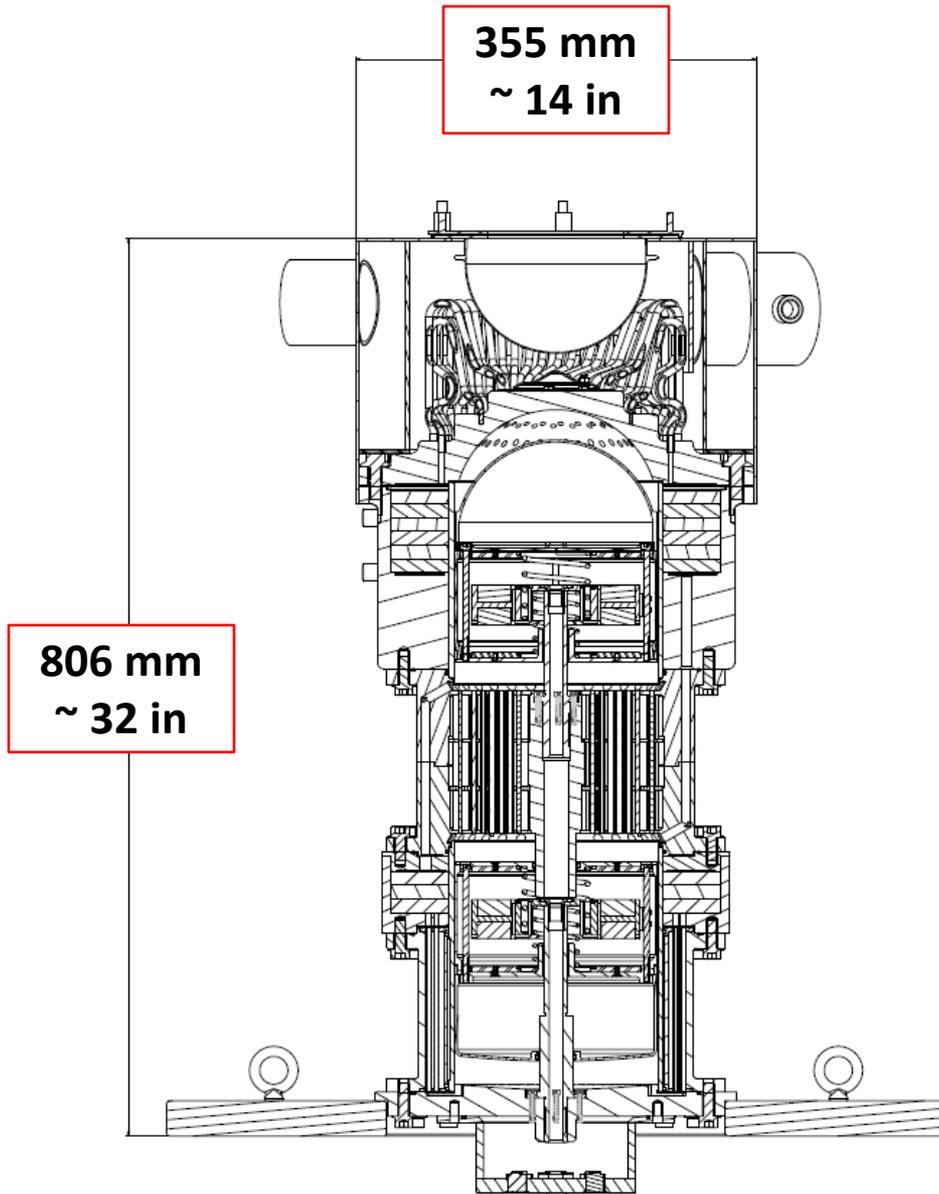
# ThermoLift First Generation

## Benefits:

- Single device for complete HVAC
- 30-50% reduction in energy used
- No electricity / Grid Independent
- No refrigerants
- Cold climate performance
- Fuel agnostic
- Simple retrofit & installation
- Smaller footprint / Fully scalable units
- Smart grid enabled controls
- Full efficiency at partial loads



# 3D Printed Prototype



# Thermodynamic Cycle Analysis & Simulation

Two different 1D simulation tools

## Tested effects of:

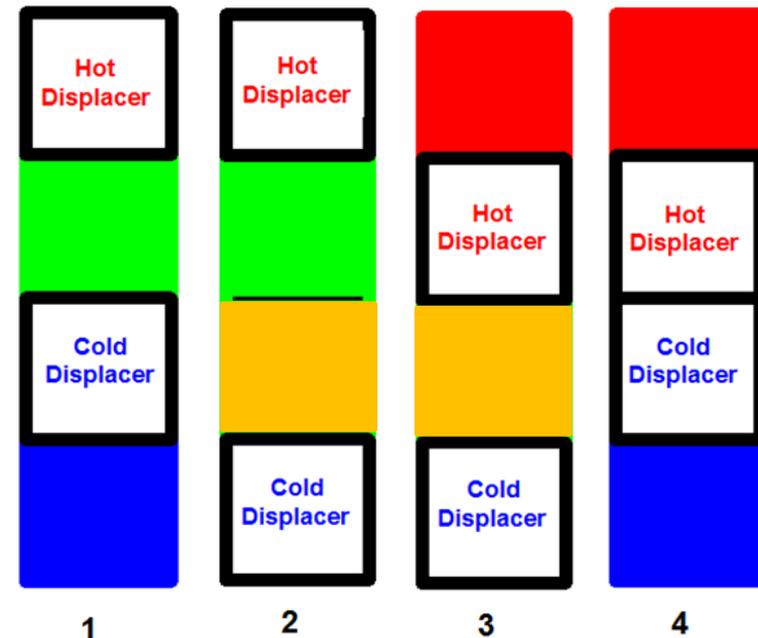
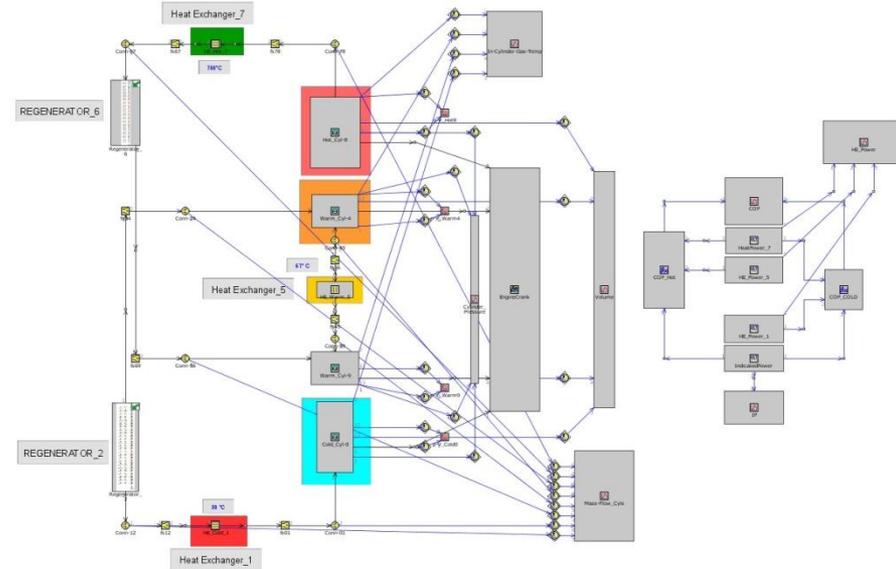
- Non-traditional displacer motion
- Geometry changes
- Different temperatures

## Results:

- Found potential issues with flow resistance leading to improved design

## Next steps:

- Integrate and validate simulation with CFD and prototype test data
- Define critical loss mechanisms



**COP**  
**2.26**  
←

Case	Bore8	Bore4	Bore9	Combine d Energy Rate Out of Fluid; Part HE_Hot_7	Combine d Energy Rate Out of Fluid; Part HE_Hot_Warm_5	Combine d Energy Rate Out of Fluid; Part HE_Cold_Warm_3	Combine d Energy Rate Out of Fluid; Part HE_Cold_1	Output; Part COP_Hot
No Unit	mm	mm	mm	kW	kW	kW	kW	-
4	180	180	120	-13.102	11.140	12.378	-9.492	1.80
5	180	180	140	-14.136	11.646	15.933	-12.120	1.95
6	180	180	160	-15.131	12.132	19.697	-14.518	2.10
7	180	180	180	-16.028	12.819	23.409	-16.332	2.26

# Heat Exchanger CFD

## Using 2D CFD:

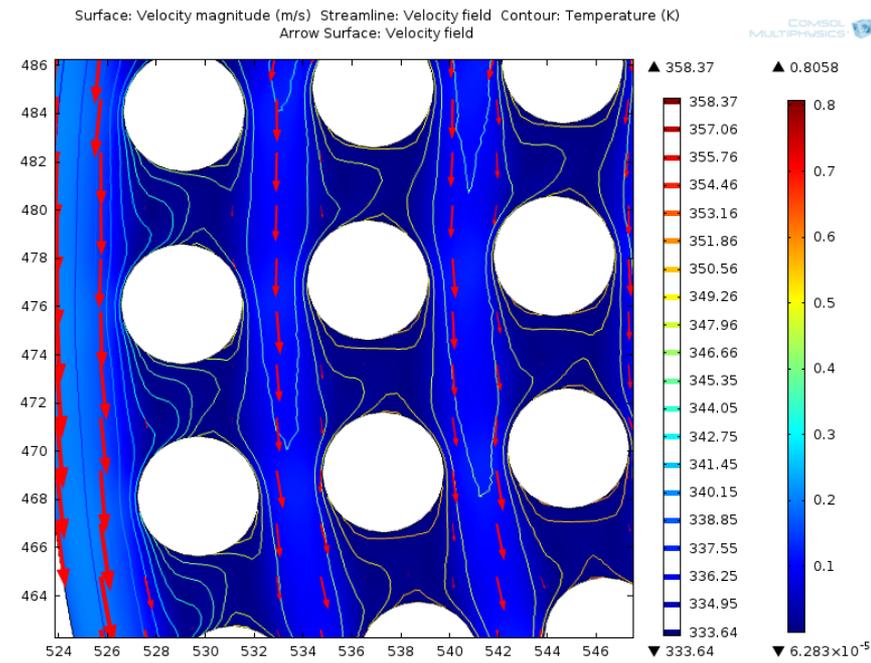
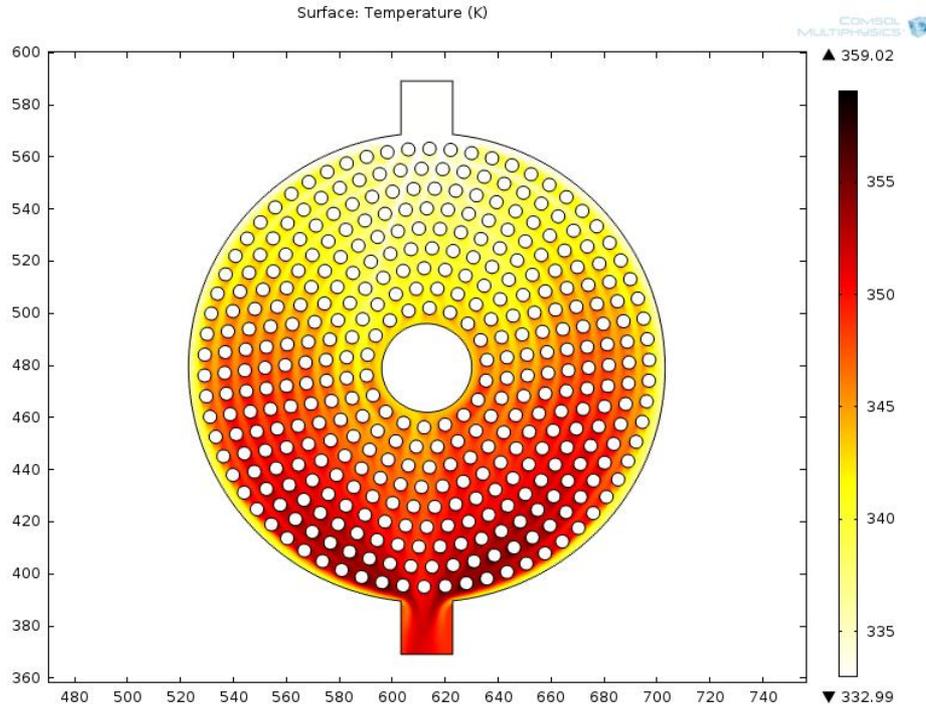
- Simulated fluid flow and heat transfer between helium working gas and hydronic distribution system

## Results:

- Required design changes (length, # tubes, baffles) to ensure sufficient heat transfer with acceptable pressure drops

## Next steps:

- Validate simulation data including losses (e.g. entrance / exit effects)
- Further analyze flow resistance versus dead volume performance tradeoff
- Develop more effective HX designs for future generations including alternative fuels



# Mechanical FEA

## Simulation:

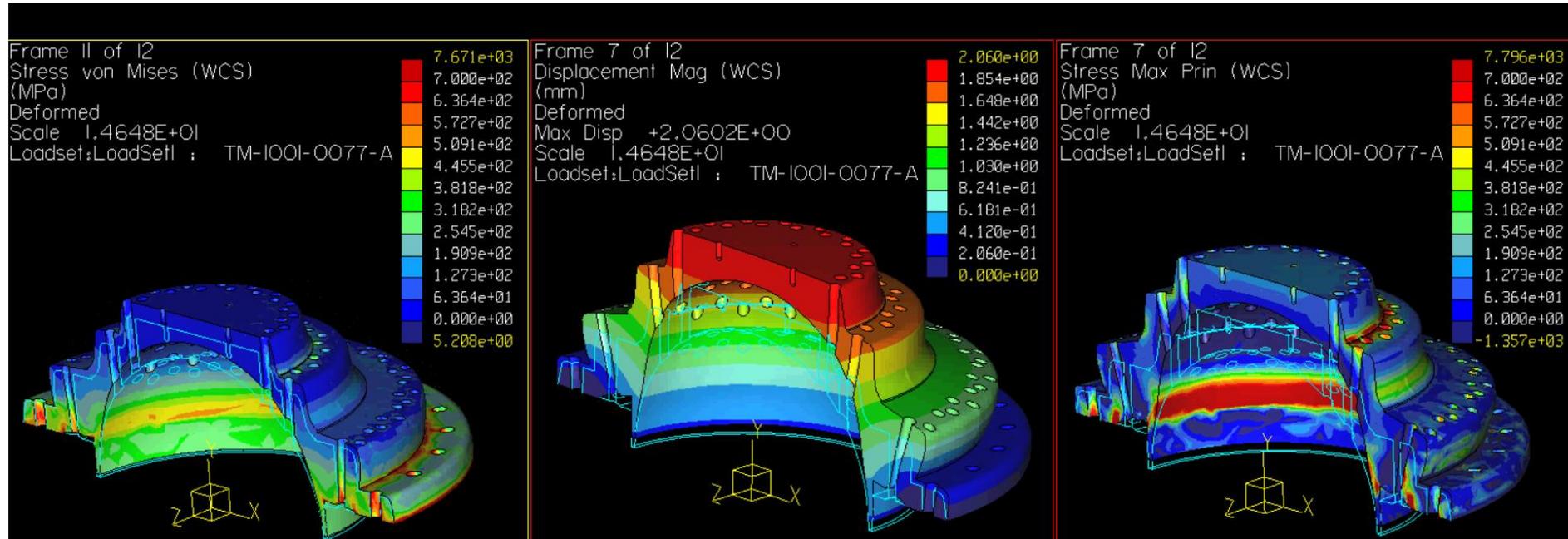
- Found unacceptable stress and strain on the heater head

## Results:

- Designed thicker plate and changed flange locations for proper sealing
- Developed method for better creep evaluation

## Next steps:

- Evaluate materials with superior mechanical properties at high temperatures
- Investigate alternative design structures for thermal stress mitigation



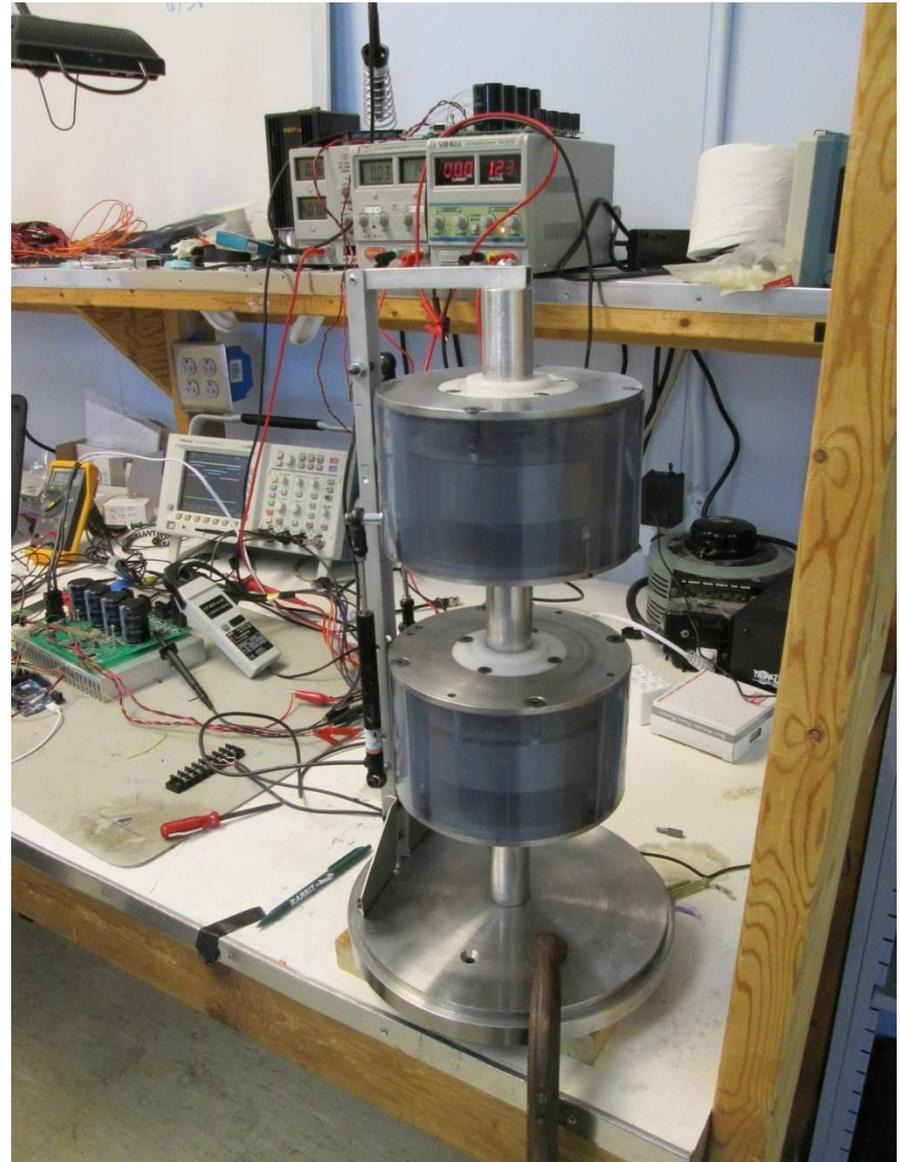
# Mechatronic Demonstrator

## Development:

- Determined frequency and novel displacer motion
- Built test apparatus
- Tuned spring based on masses and flow resistance
- Developing control software
- Added position sensors for increased feedback
- Tested in ambient air

## Next steps:

- Testing in operational environment



# Progress and Accomplishments

## Lessons Learned:

- There is a high sensitivity to flow resistance and regenerator performance
- The complexity of regenerators provides opportunity for study and innovation particularly manufacturing
- Address high temperature and pressure concerns
- Simulation will be further tuned with initial test data

## Accomplishments:

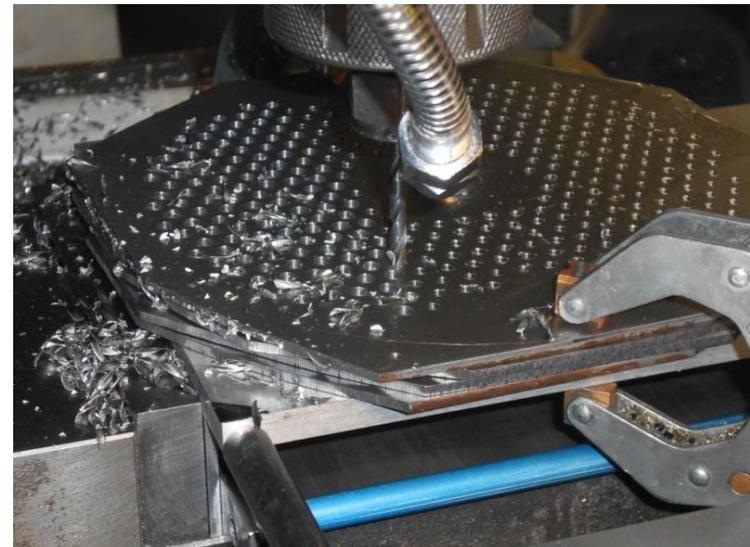
- Built and begun testing on mechatronic controls
- Sourcing and receiving components for first prototype
- Developed a baseline simulation for tuning and validation

## Market Impact:

- Assembled an experienced organization
- Built extensive network of advocates, partners & suppliers

## Awards/Recognition:

- 2013 Defense Energy Summit – *Winner*
- 2013 New England Venture Summit – *Best Presenter*
- 2014 ARPA-E UltraLight Startups Future Energy Pitch Competition – *Winner*



# Project Integration and Collaboration

## Project Integration:

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

## Partners, Subcontractors, and Collaborators:

- Applied Thermodynamic Apparatus (ATA)
- Oak Ridge National Labs
- Brookhaven National Labs
- Fala Technologies, LoDolce, MicroTube, HandyTube, Bruce Diamond

## Communications:

### Exhibits:

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

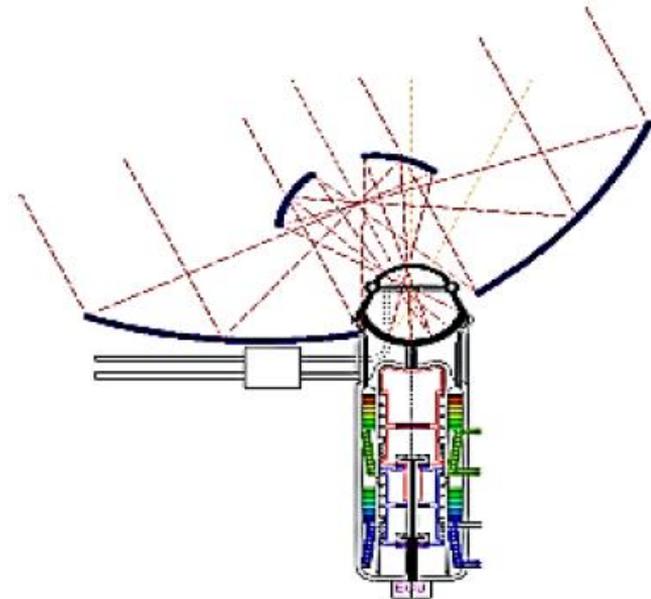
### Publications:

2014 American Gas Magazine, China Lake High Technology Association Journal, Newsday, LI Business News, CBS News Affiliate



# Next Steps and Future Plans

- Large scale demonstration
- Further optimized design:
  - Analysis of flow resistance and dead volume of critical components
  - Simplified manufacturing design
  - Analysis of innovative technologies & materials
- Development of novel heat exchanger components
- Optimization for alternative technologies and industrial applications
- Development of fuel agnostic capabilities using alternative fuel sources including heating oil, biofuels and solar thermal



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# REFERENCE SLIDES

# Project Plan and Schedule

Project Schedule								
Project Start: 10/1/2013	Completed Work							
Projected End: 9/30/2014	Active Task (in progress work)							
	◆ Milestone / Deliverable (Original Planned)							
	◆ Milestone / Deliverable (Actual)							
	FY2014				FY2015			
Task	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
<b>Past Work</b>								
Q1 Milestone: Concept Definition (CAD Model)	◆							
Q2 Milestone: Simulation and Design (Model Output)		◆						
<b>Current/Future Work</b>								
Q3 Milestone: Procurement & Build (Prototype Analysis)			◆	◆				
Q4 Milestone: Testing (Oak Ridge Natl. Lab)				◆				

# Project Budget

**Project Budget:** \$1,103,810 (DOE \$750,000 / ThermoLift \$ 353,810)

**Cost to Date:**

- Total spent = \$651,862 ≈ 59.1% of total project budget

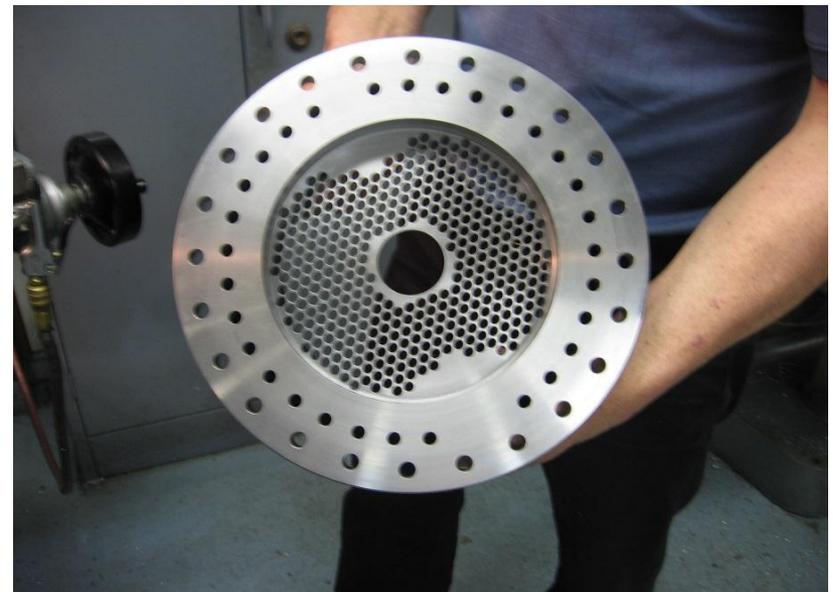
**Additional Funding:**

- NYSERDA – \$482,722
- Private Capital – \$1.63M (TopSpin, LI Angel Network).

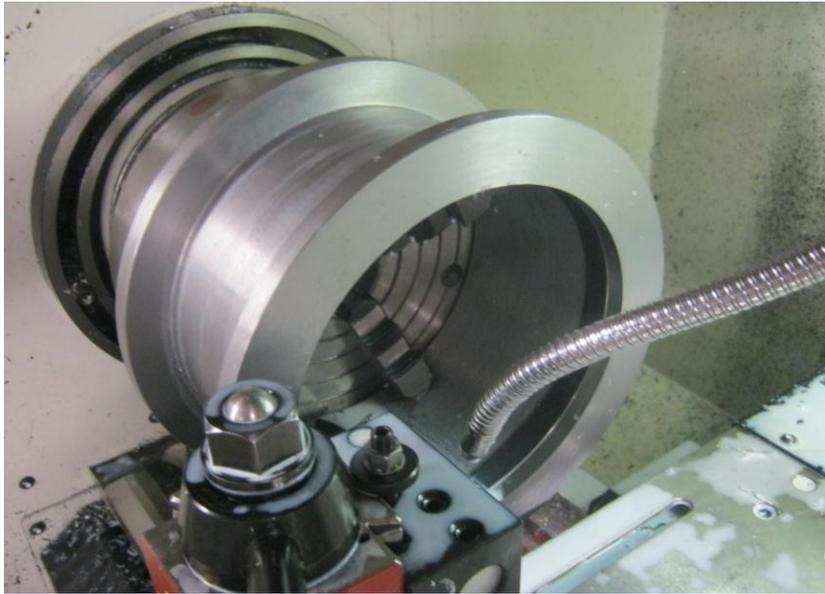
## Budget History

Q1 FY2014 (past)		Q2 FY2014 (current)		Q3-Q4 FY2014 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
\$ 299,681	\$ 192,782	\$ 97,000	\$ 62,399	\$ 353,319	\$ 98,629

# Team & Progress

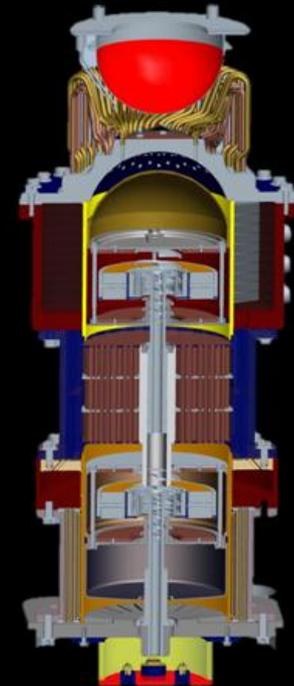
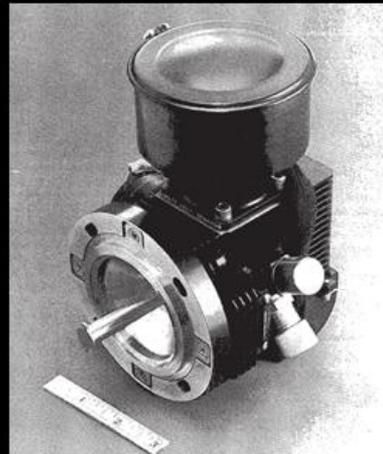
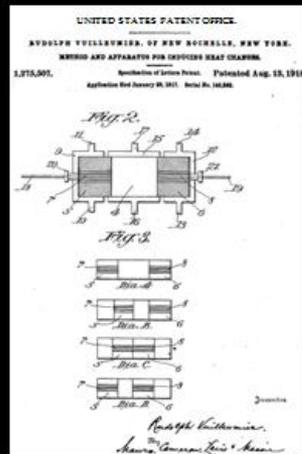


# Additional Progress Pictures



# Vuilleumier Development

## Proven & Demonstrated



1975-76: USAF, NASA

2012: ThermoLift

1920

1930

1940

1950

1960

1970

1980

1990

2000

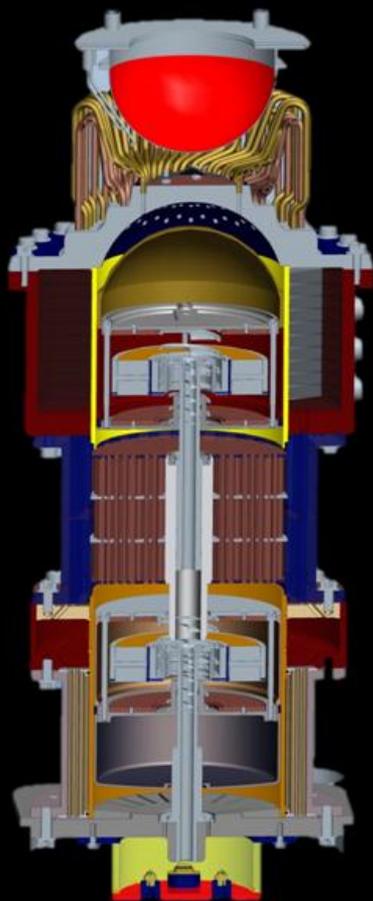
2010

1918: First Patent

1991-98: Demonstrator

# Heating Pump

## Operational Advantage



Heat from  
Burner  
(15 kW)

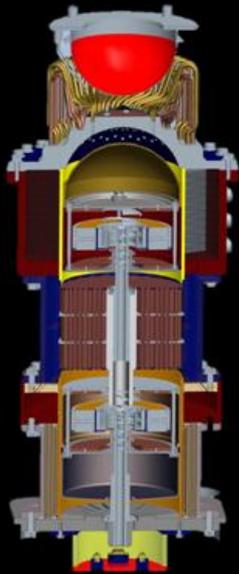
**COP = 1.65**

Combined  
Heat Delivered  
(25 kW)

FREE Heat from  
Ambient (10 kW)

# Cooling Pump

## Cooling Performance



Free Hot  
Water

Heat from Burner  
(1)

Rejected to  
Atmosphere  
(2.2)

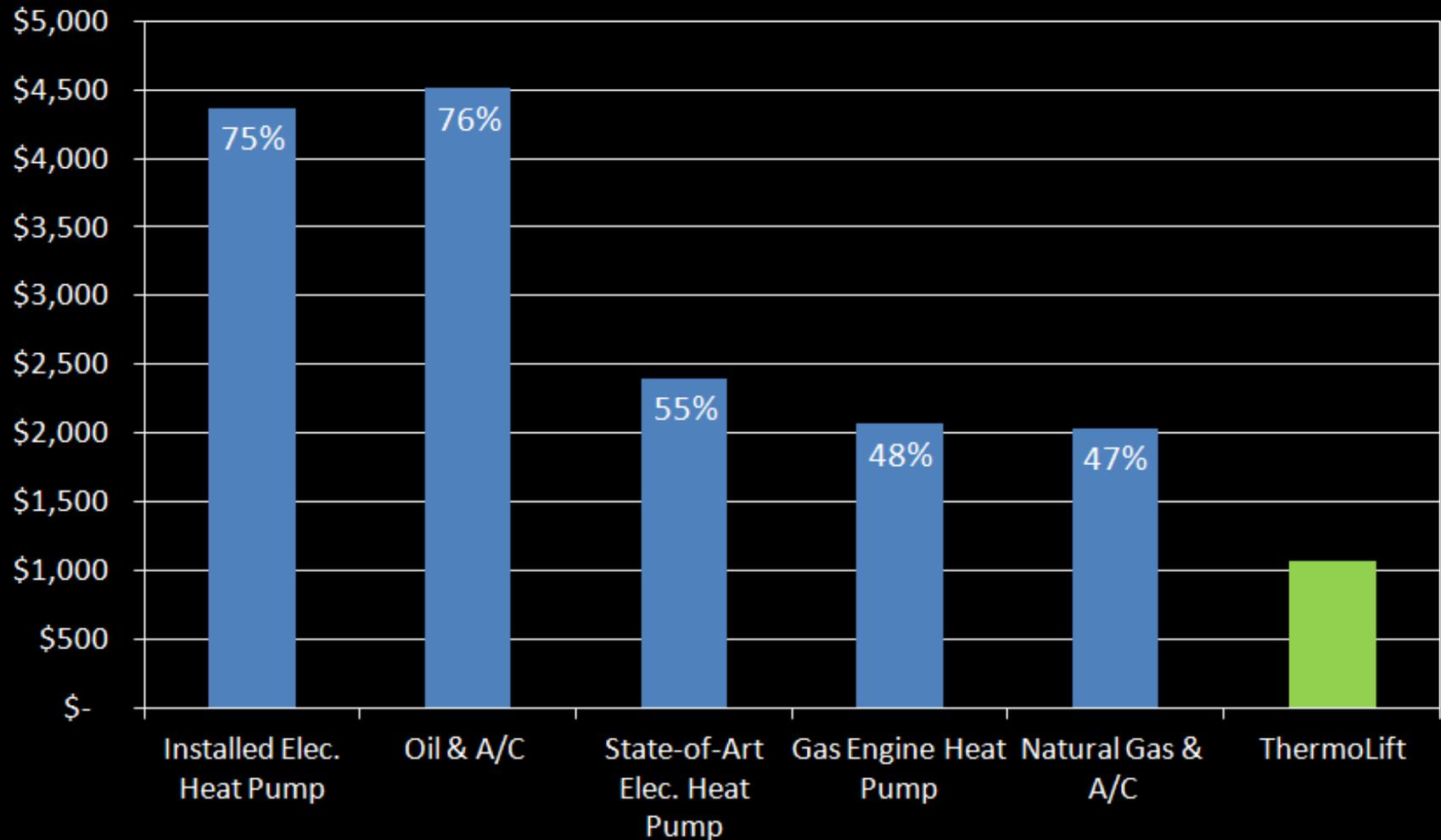
Heat from Home  
(1.2)

**COP = 1.2**



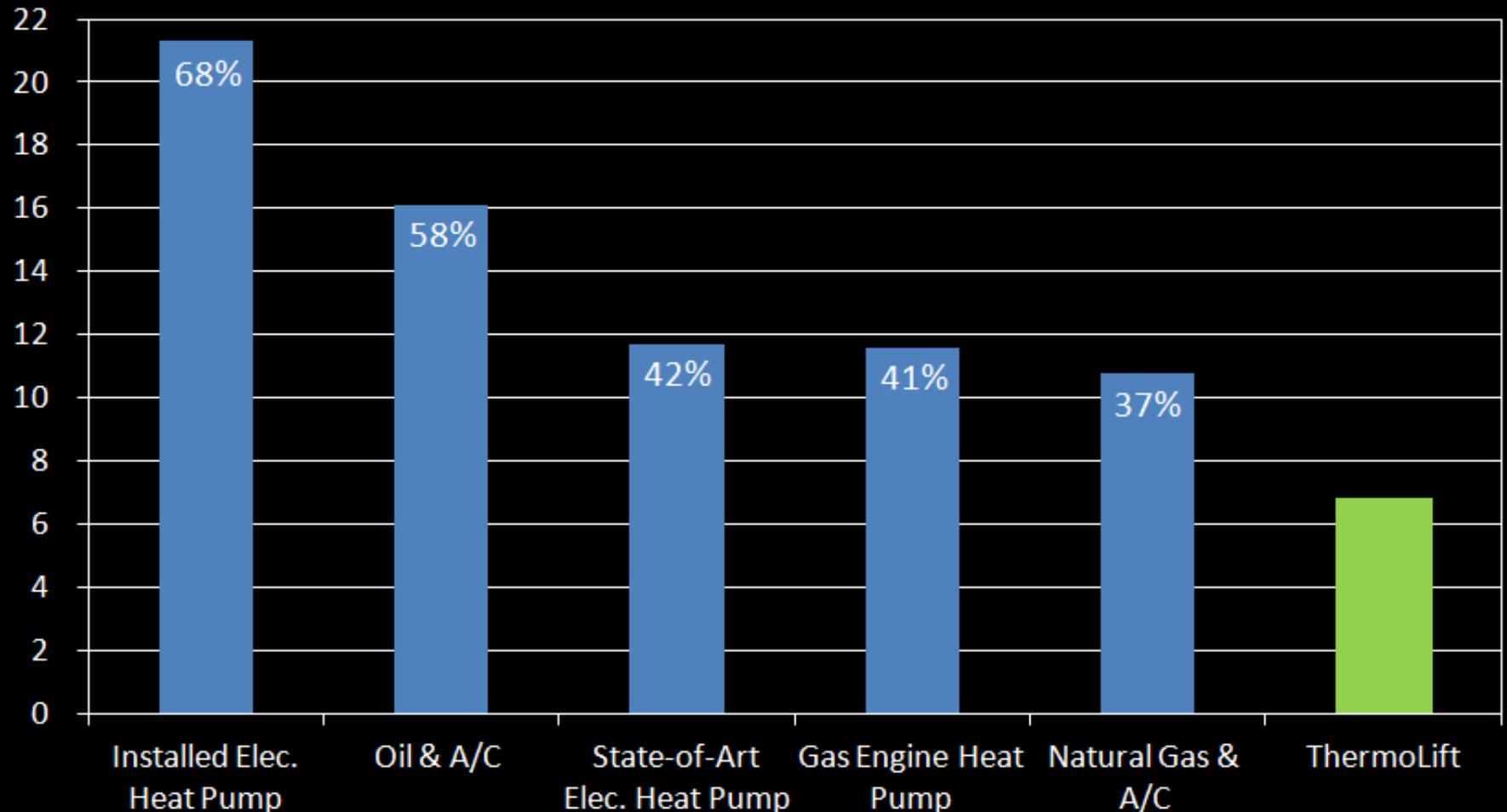
# Energy Savings

## Annual Cost of Energy (Heating, Cooling and Hot Water)



# Emissions Reduction

## Annual CO<sub>2</sub> Emissions (Tons)



## Customer Value Proposition

### Lower Capital Expense:

System Function	Efficiency	State of the Art Equipment Cost	ThermoLift Equipment Cost
Space Heating	0.96 (AFUE)	\$2,446	\$5,500
Water Heating	0.98 (EF)	\$1,625	
Space Cooling	16 (SEER)	\$3,162	
<b>TOTAL</b>		<b>\$7,233</b>	<b>\$5,500</b>

### Lower Life Cycle Cost:

System	Efficiency (AFUE)	State of the Art Operational Cost	ThermoLift Operational Cost	Annual Cost Savings	20 Year Savings
Gas Furnace	0.96	\$1,220	\$732	\$488	\$9,760
Oil Boiler	0.86	\$2,824	\$1,129	\$1,694	\$33,888