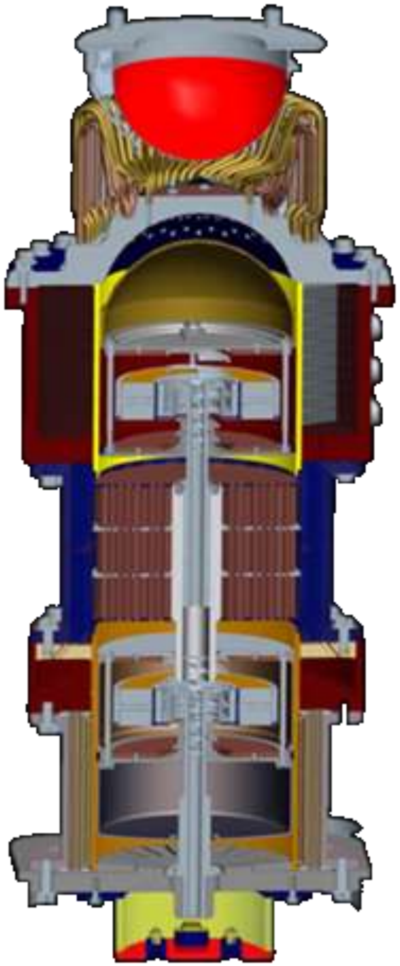
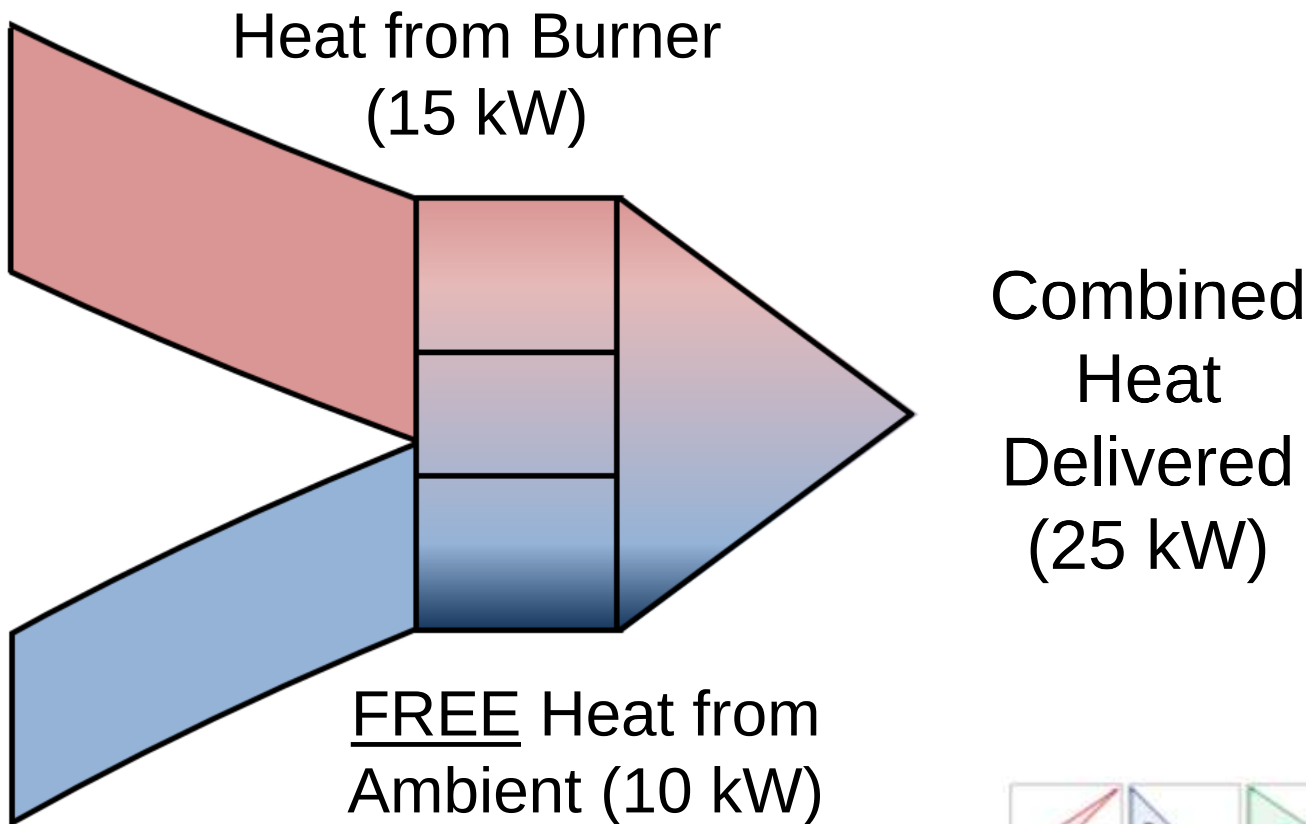
The Natural Gas Heat Pump and Air Conditioner

2014 Building Technologies Office Peer Review

New Project





U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

ThermoLift, Inc.

Paul Schwartz, 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:

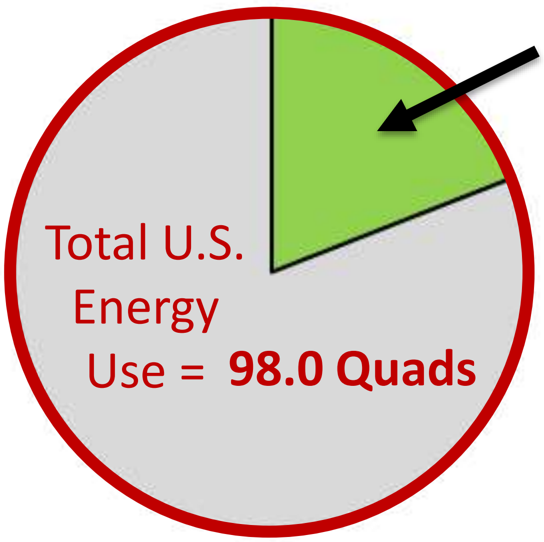
To develop a Vuilleumier heat pump (VHP) which includes novel improvements that will yield higher performance than the already high COP results of previously developed VHP. The heat pump will use natural gas to provide heating, cooling, and hot water with a single device.

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 are outdated / inefficient.

Target Market and Audience:

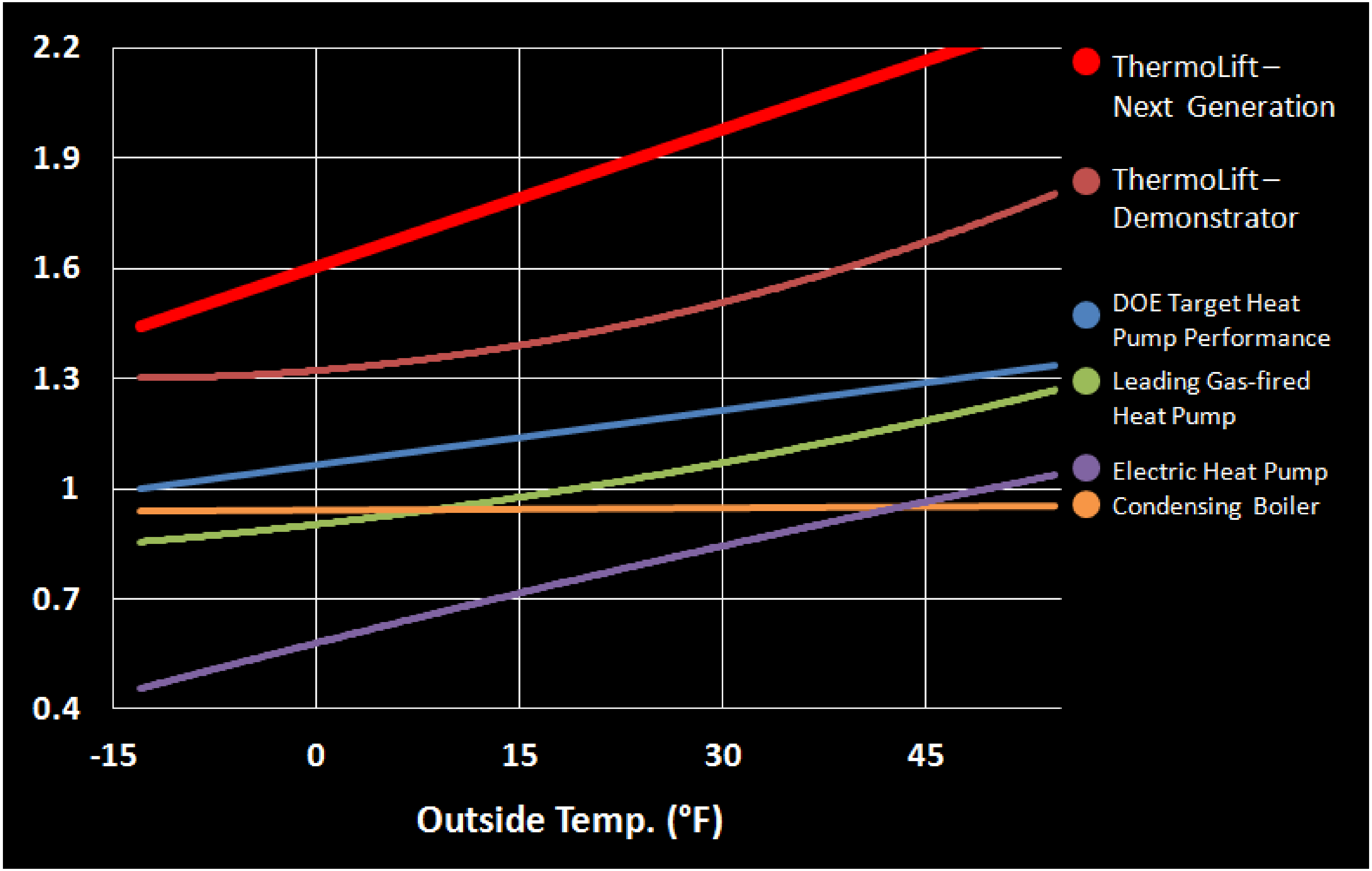


≈ 20% of total energy used

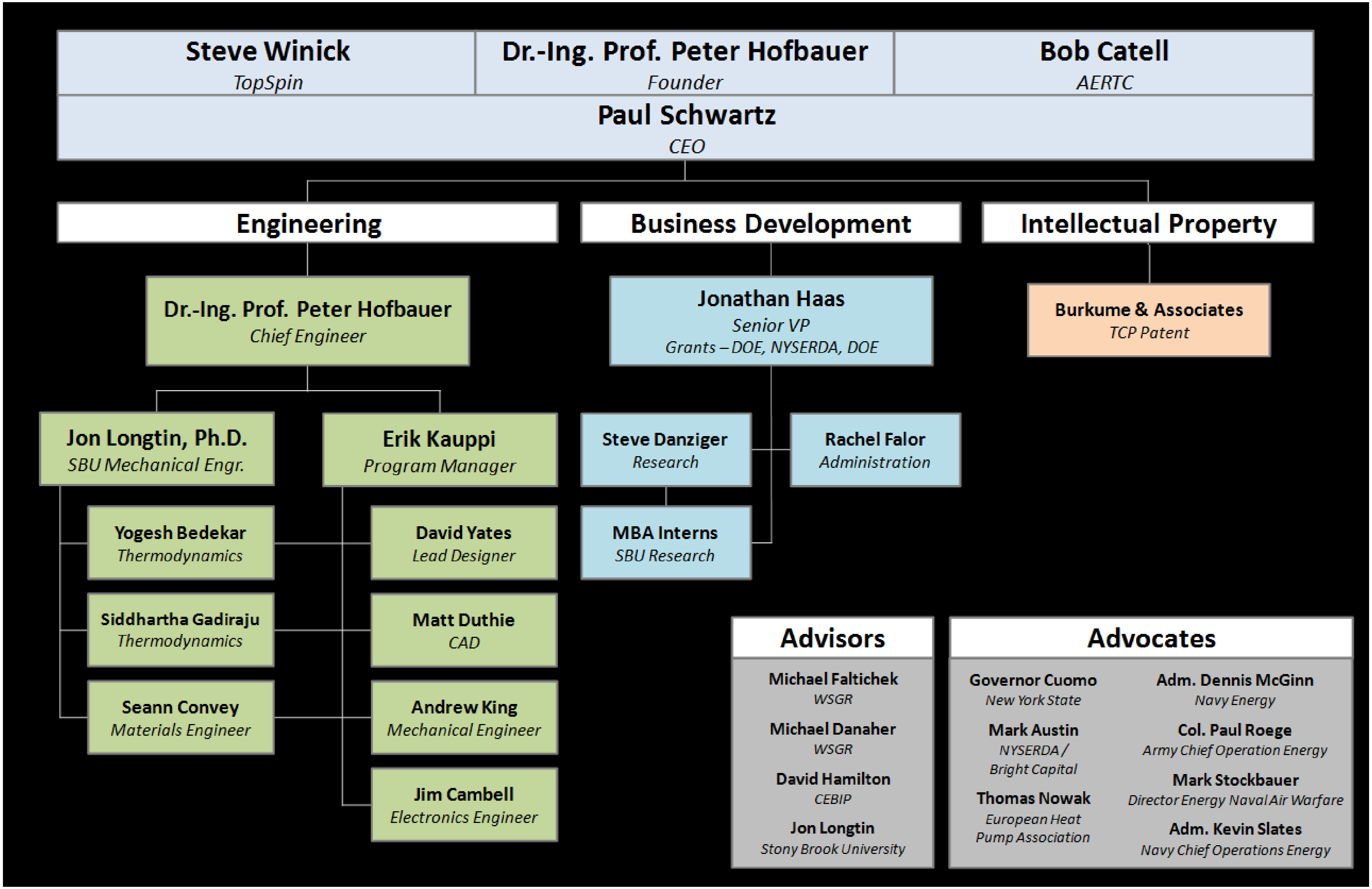
Impact of Project:

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.

Comparison to State-of-the-Art



Team



Steve Winick
TopSpin
Dr.-Ing. Prof. Peter Hofbauer
Founder
Bob Catell
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Paul Schwartz
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Grants – DOE, NYSERDA, DOE
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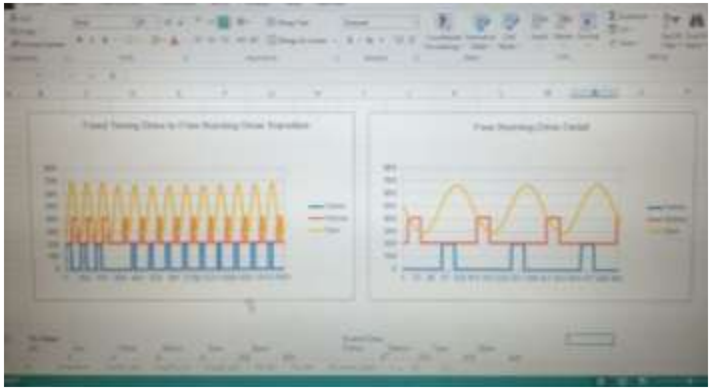
Adm. Dennis McGinn
Navy Energy
Col. Paul Roege
Army Chief Operation Energy
Mark Stockbauer
Director Energy Naval Air Warfare
Adm. Kevin Slates
Navy Chief Operations Energy

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

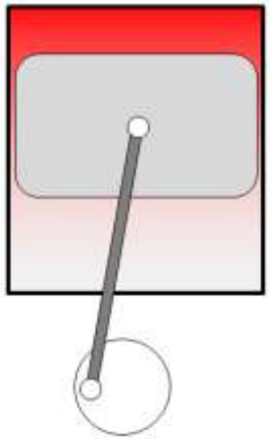
Distinctive Characteristics:

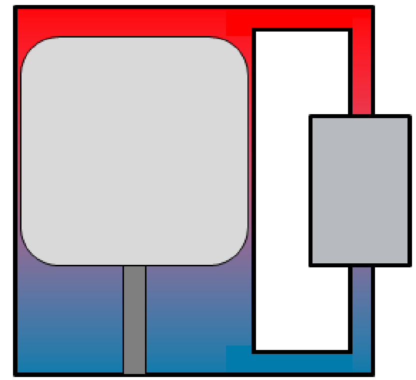
- Single Natural gas-driven device for heating, cooling, and hot water
- No electricity meaning grid independence
- No refrigerants - Helium working gas
- Cold climate performance

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

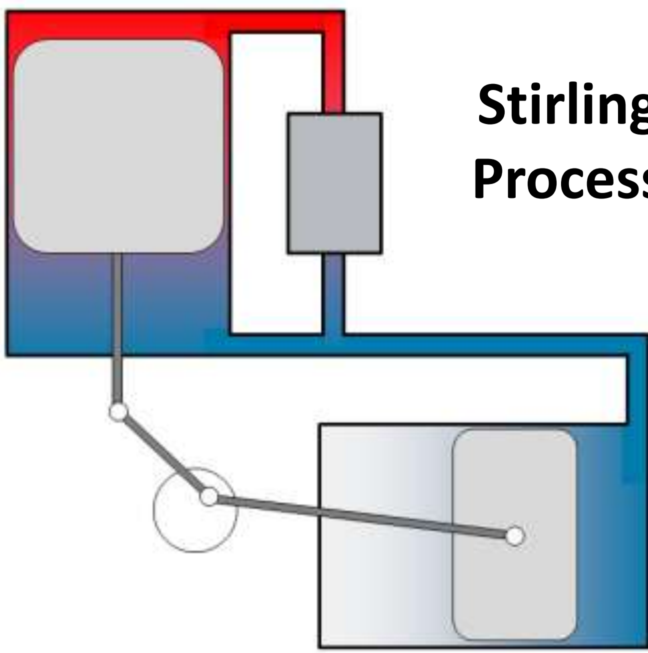
Thermally Driven Cycles (Vuilleumier & Stirling)

Mechanical Compressor

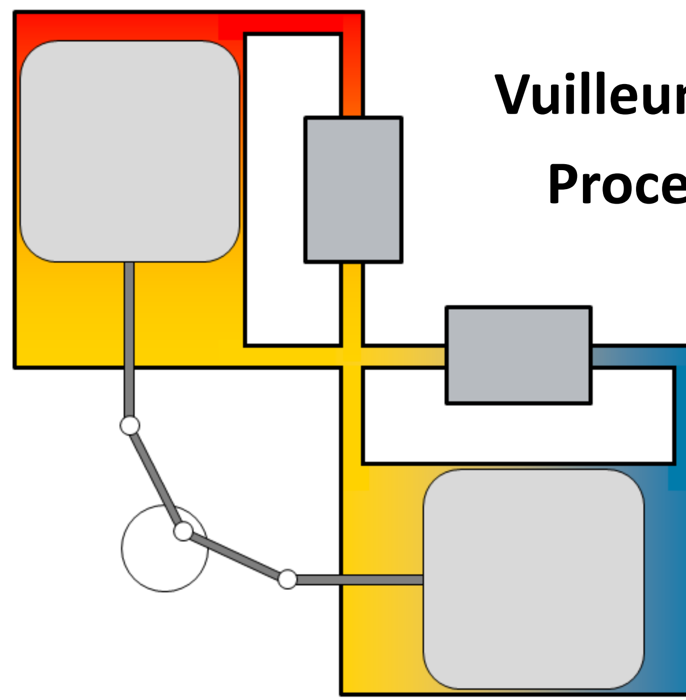




Thermal Compressor

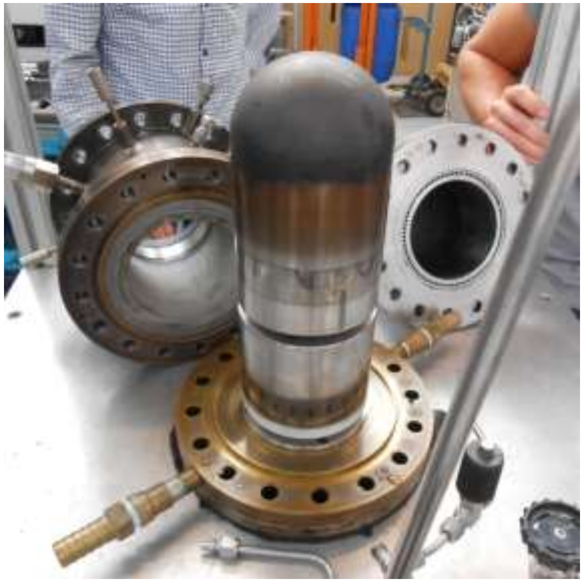


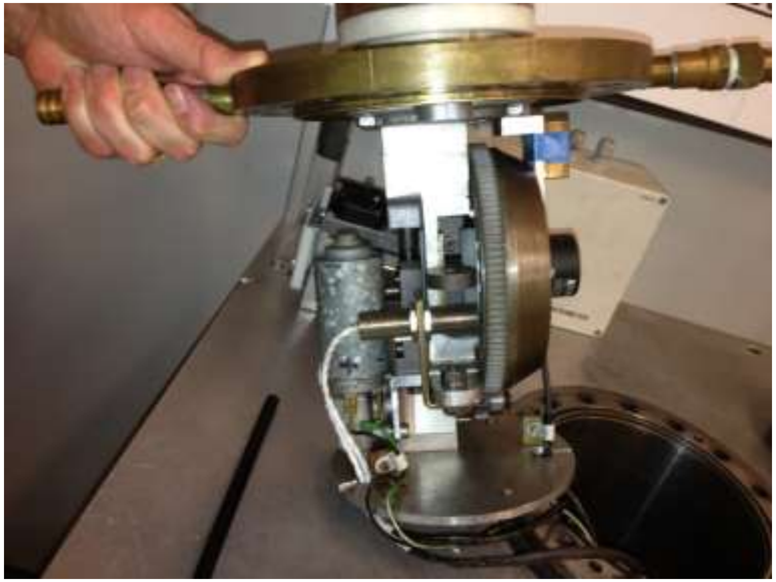
Stirling Process



Vuilleumier Process

BVE Energy Demonstrator 1991

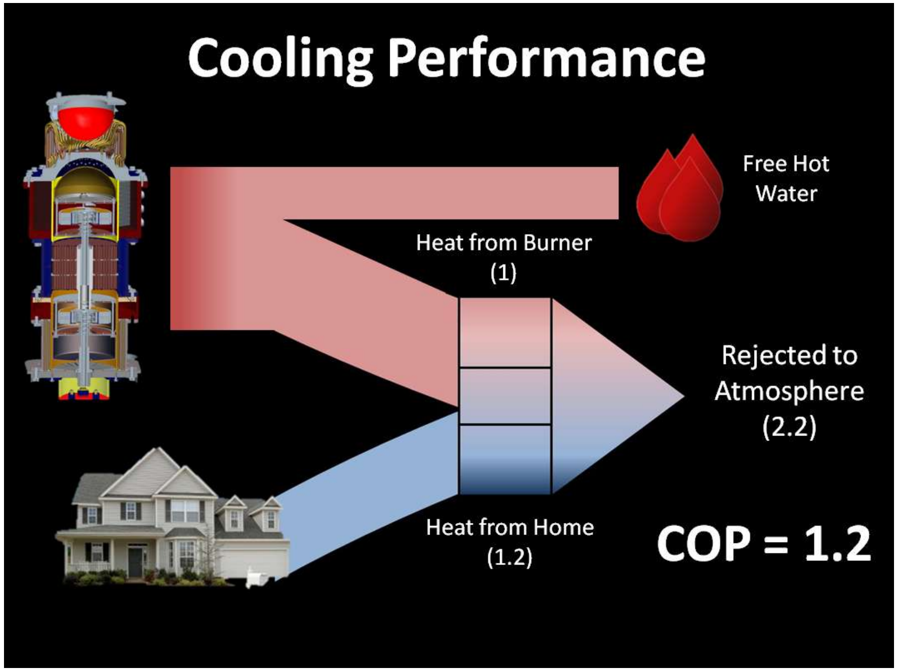


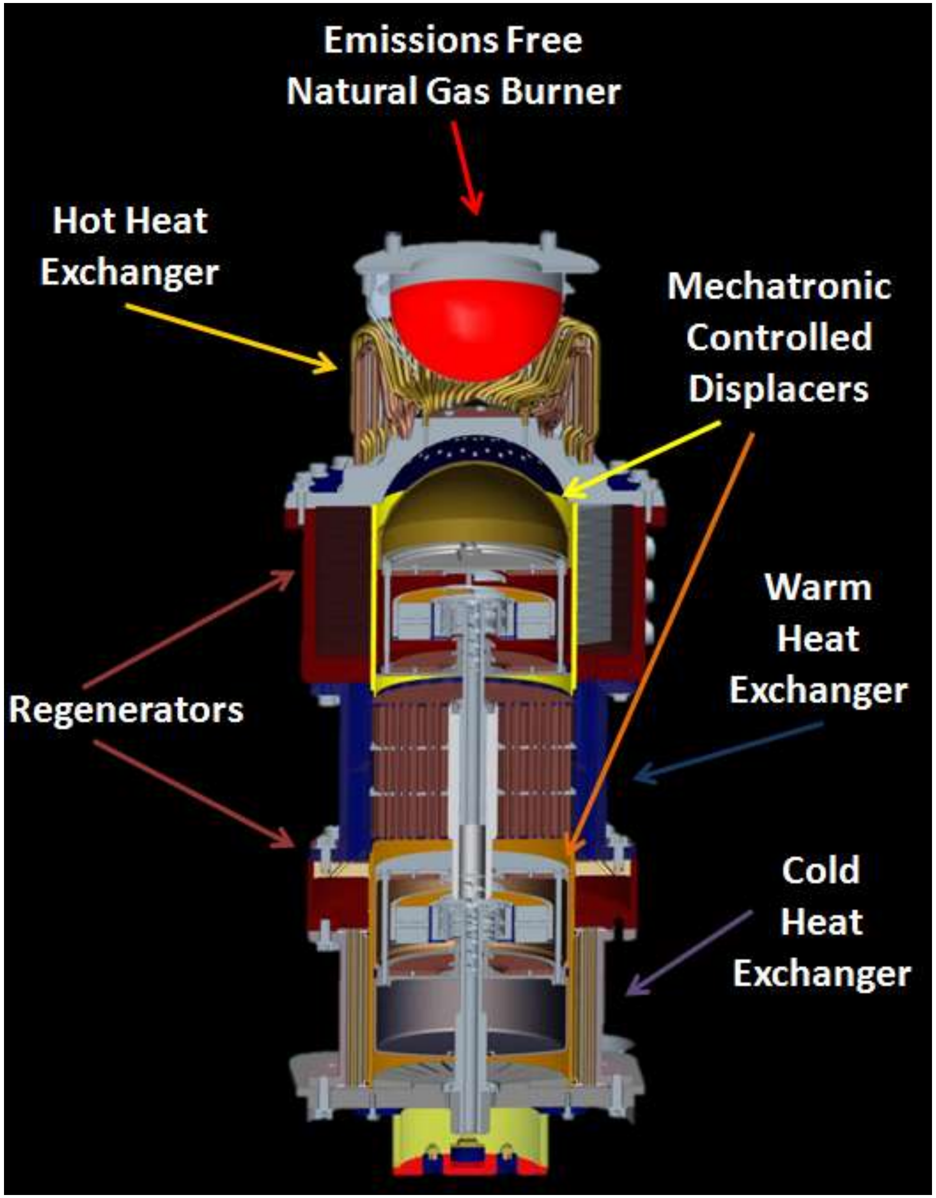


ThermoLift First Generation

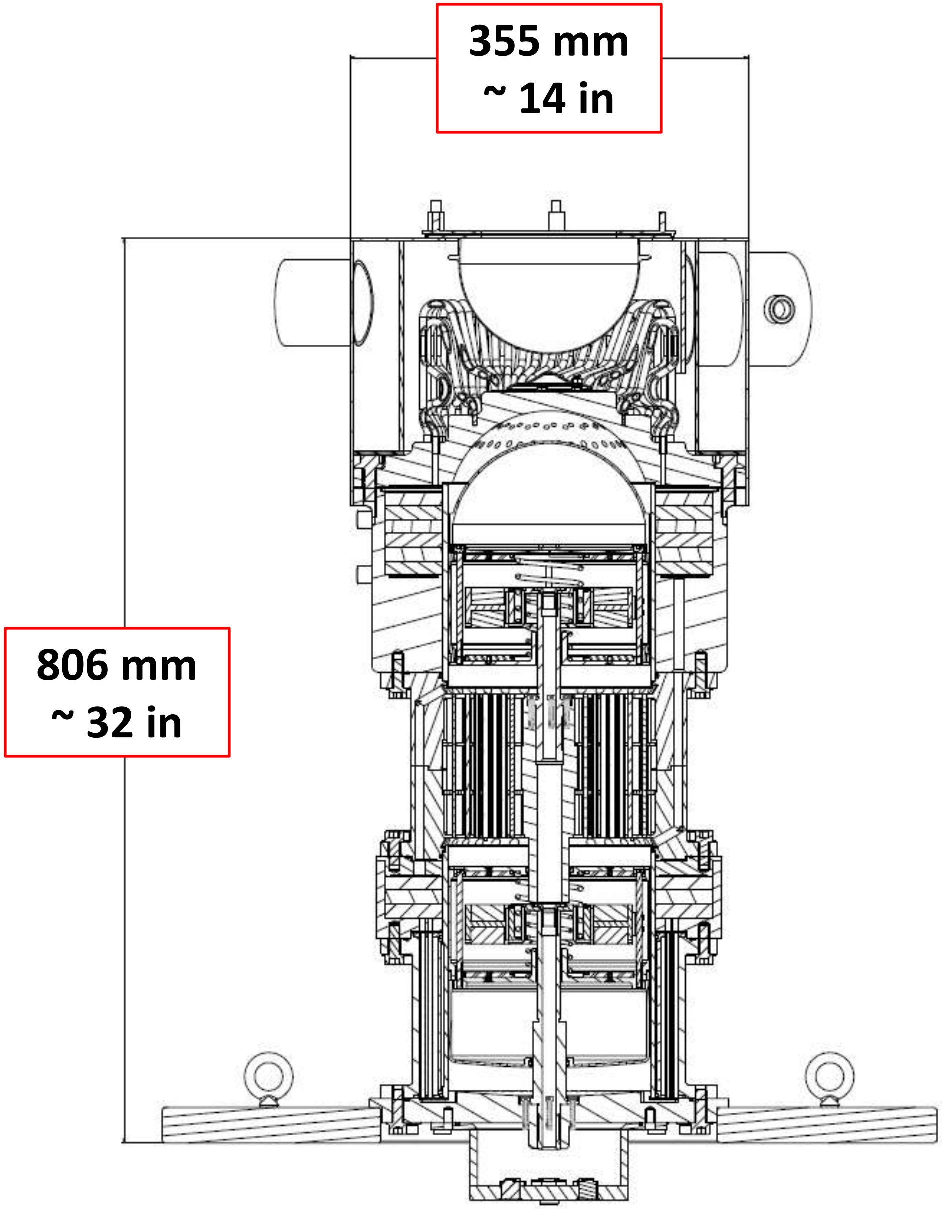
Benefits:

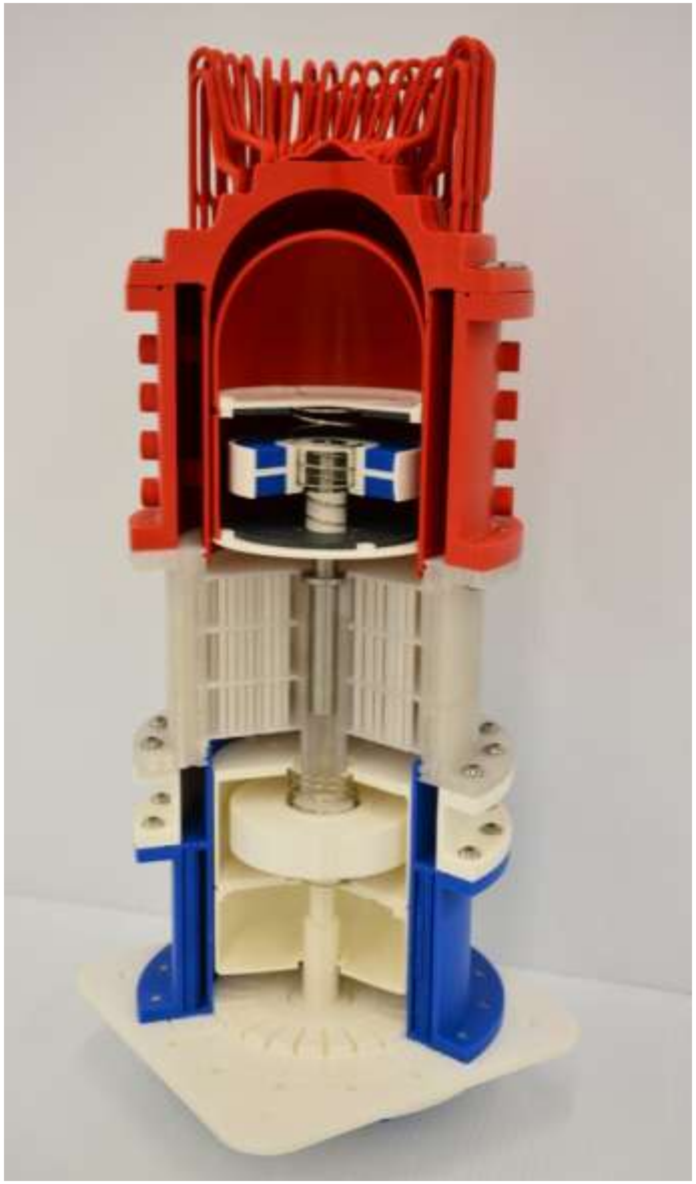
- Single device for complete HVAC
- 30-50% reduction in energy used
- No electricity / Grid Independent
- No refrigerants
- Cold climate performance
- Fuel agnostic
- Simple retrofit & installation
- Smaller footprint / Fully scalable units
- Smart grid enabled controls
- Full efficiency at partial loads





3D Printed Prototype





Thermodynamic Cycle Analysis & Simulation

Two different 1D simulation tools

Tested effects of:

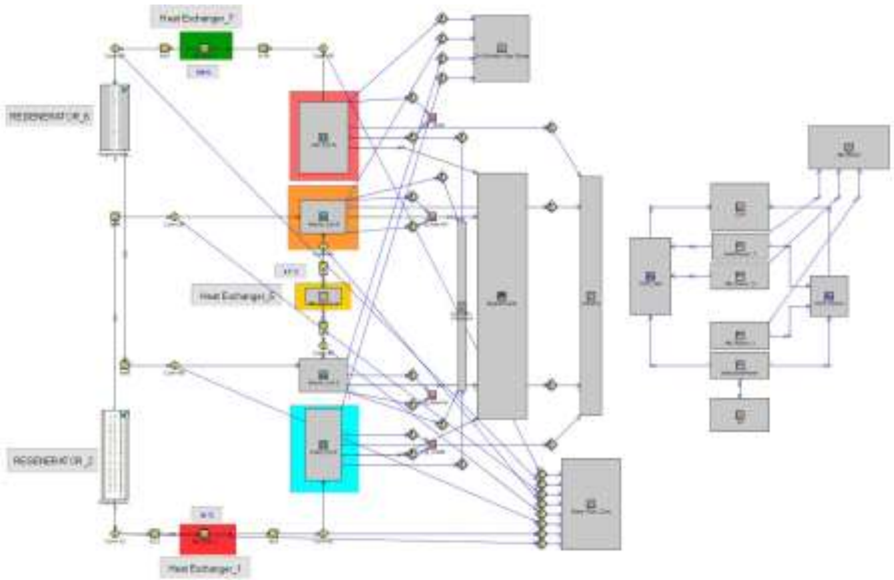
- Non-traditional displacer motion
- Geometry changes
- Different temperatures

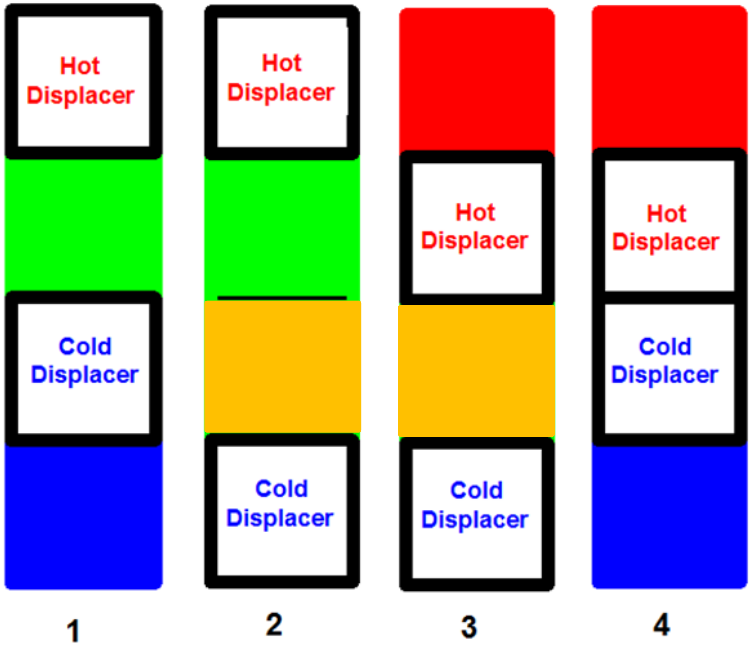
Results:

- 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





Case	Combined Energy Rate Out of Fluid; Part HE_Hot_7	Combined Energy Rate Out of Fluid; Part HE_Hot-Warm_5	Combined Energy Rate Out of Fluid; Part HE_Cold-Warm_3	Combined Energy Rate Out of Fluid; Part HE_Cold_1	Output; Part COP_Hot
No Unit	kW	kW	kW	kW	-
4	-13.102	11.140	12.378	-9.492	1.80
5	-14.136	11.646	15.933	-12.120	1.95
6	-15.131	12.132	19.697	-14.518	2.10
7	-16.028	12.819	23.409	-16.332	2.26

COP 2.26

Heat Exchanger CFD

Using 2D CFD:

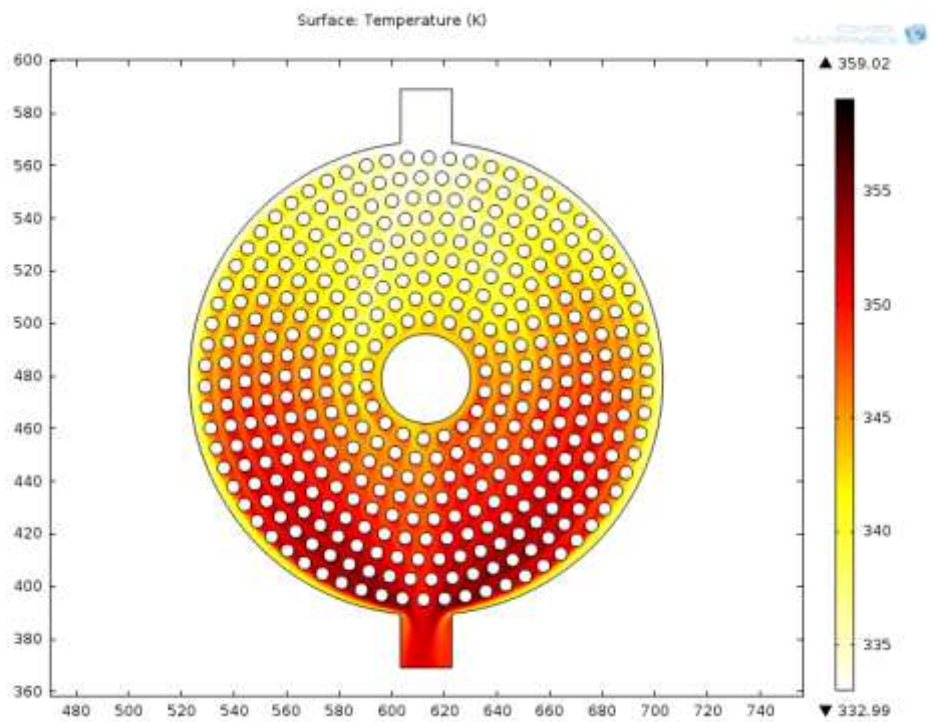
- Simulated fluid flow and heat transfer between helium working gas and hydronic distribution system

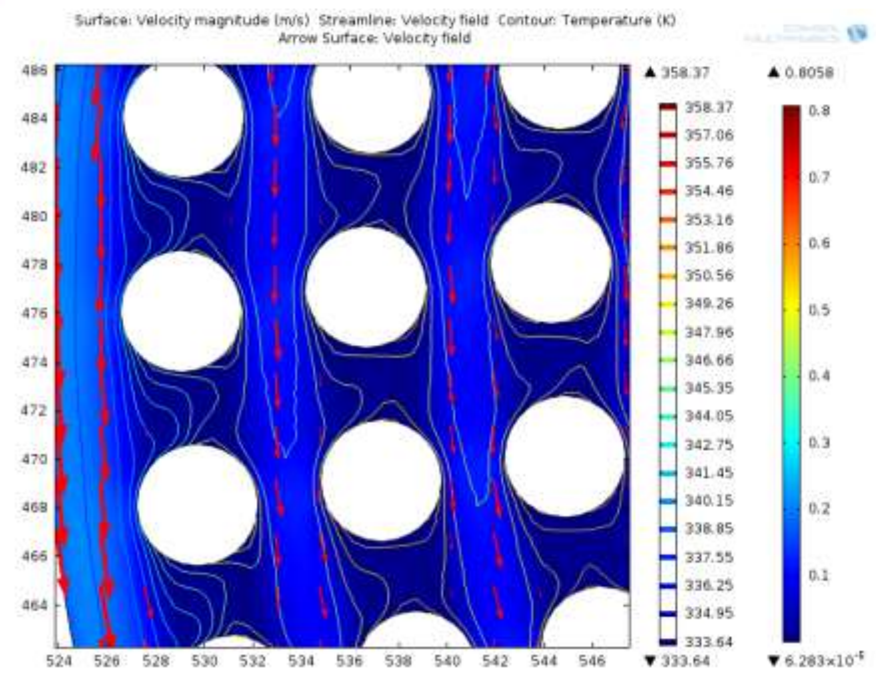
Results:

- 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:

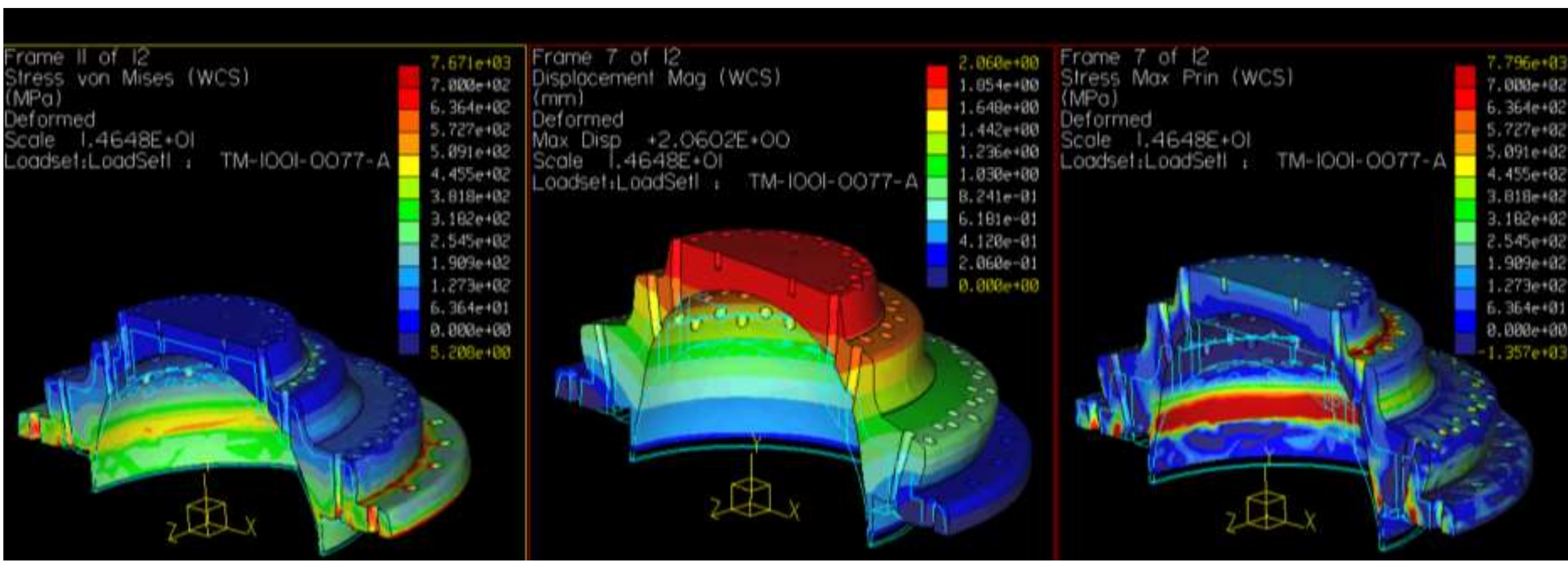
- Found unacceptable stress and strain on the heater head

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

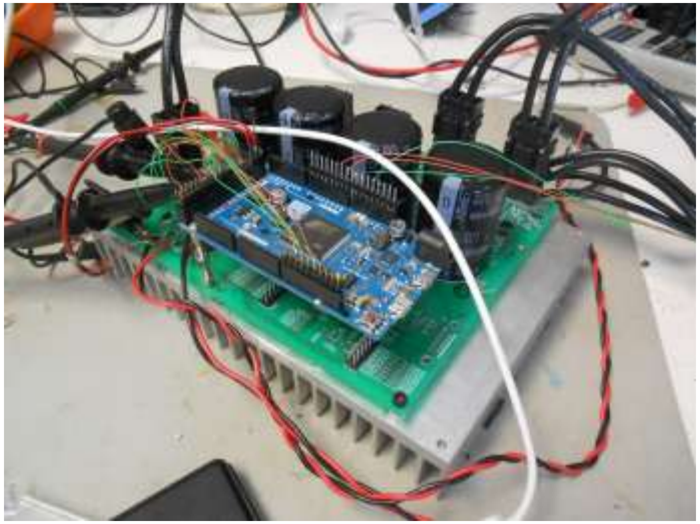
Progress and Accomplishments

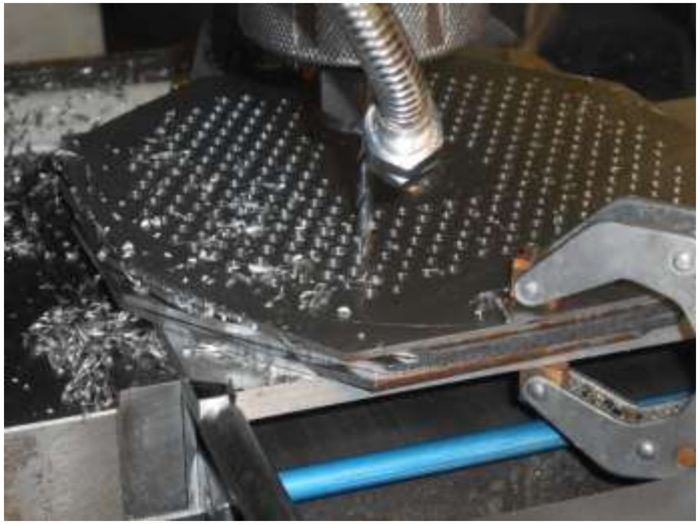
Lessons Learned:
- There is a high sensitivity to flow resistance and regenerator performance
- The complexity of regenerators provides opportunity for study and innovation particularly manufacturing
- Address high temperature and pressure concerns
- Simulation will be further tuned with initial test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

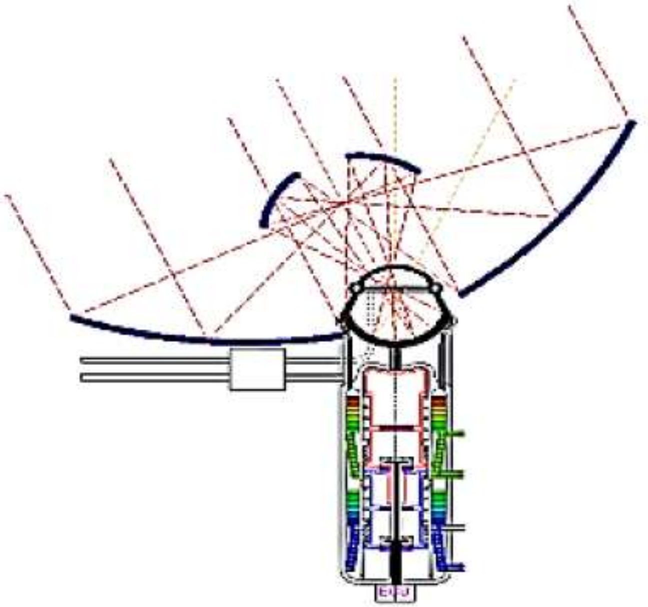
2014 ARPA-E, 2013 New England Venture Summit, 2013 Defense Energy Summit, 2013 Advanced Energy Conference NYC, 2012 National Academy of Sciences

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 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

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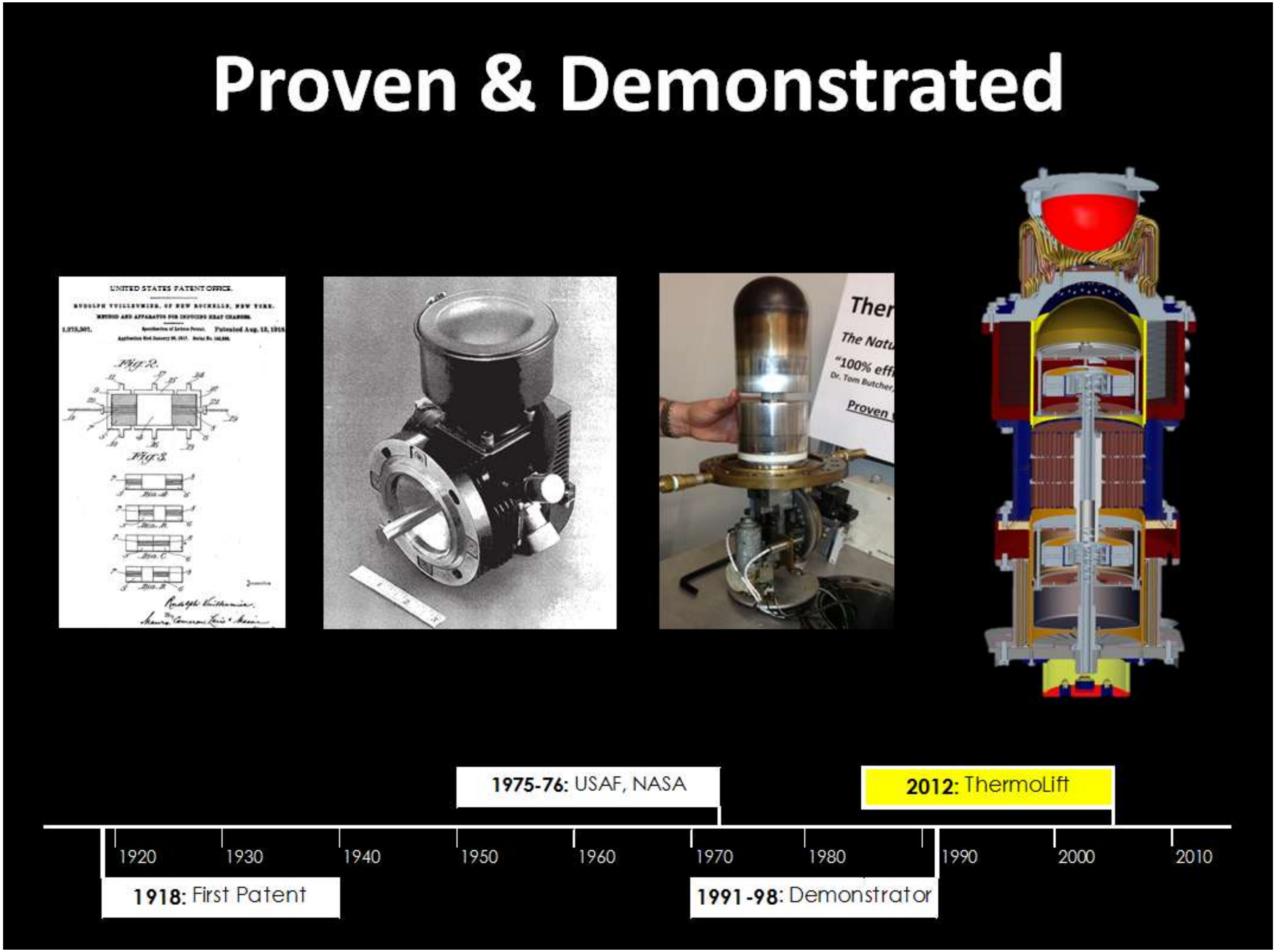
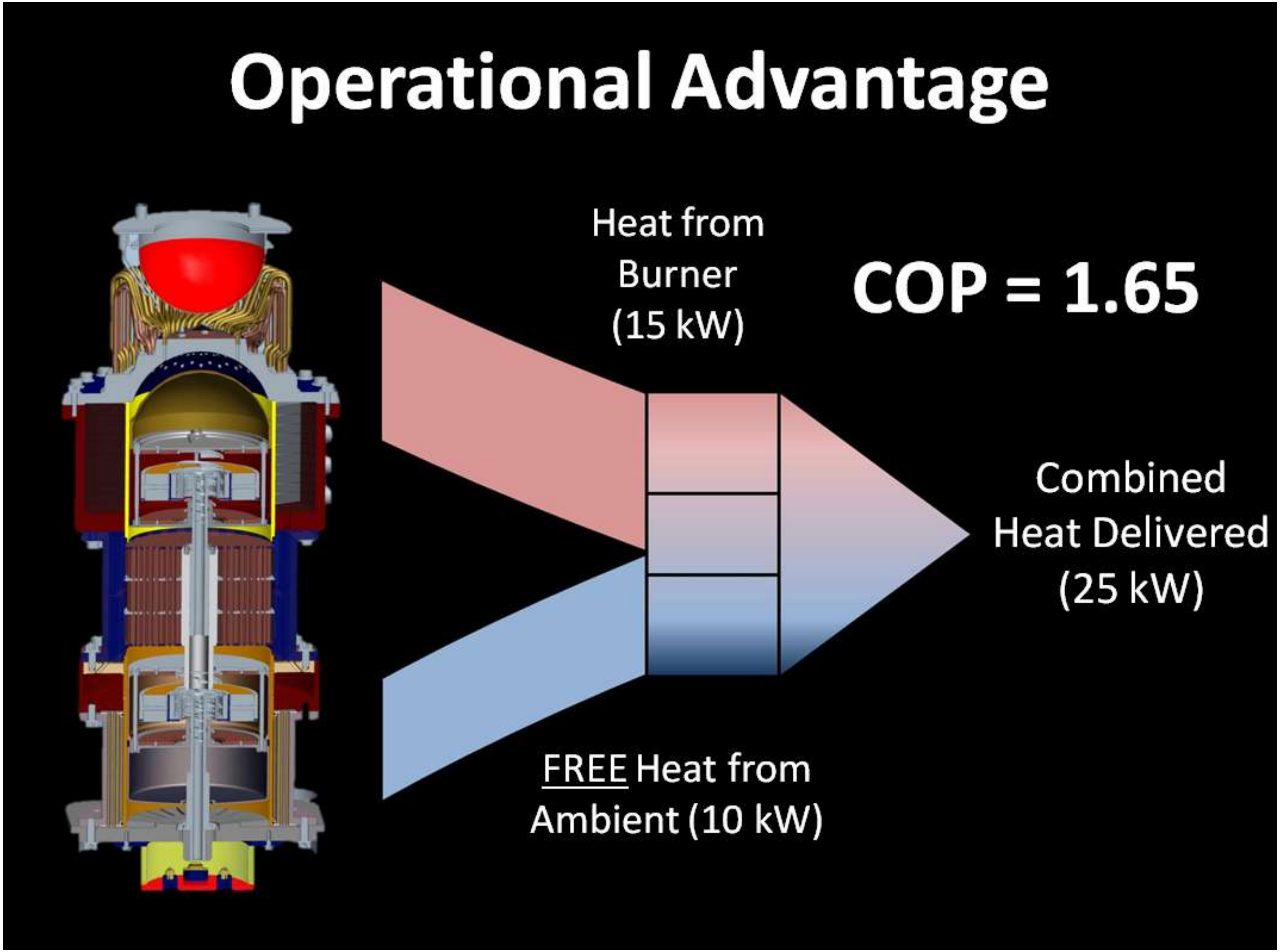
Team & Progress

Additional Progress Pictures

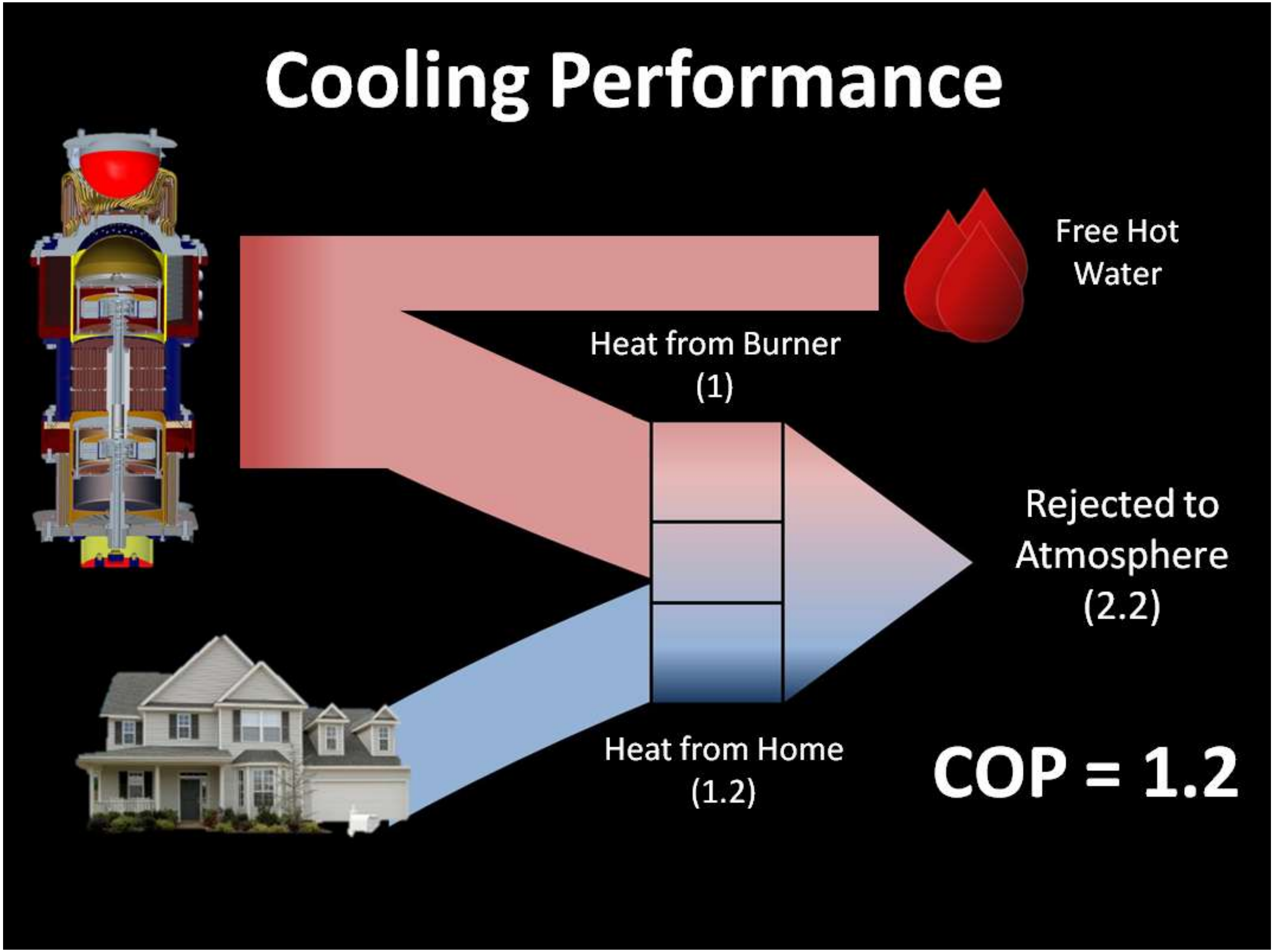
Vuilleumier Development



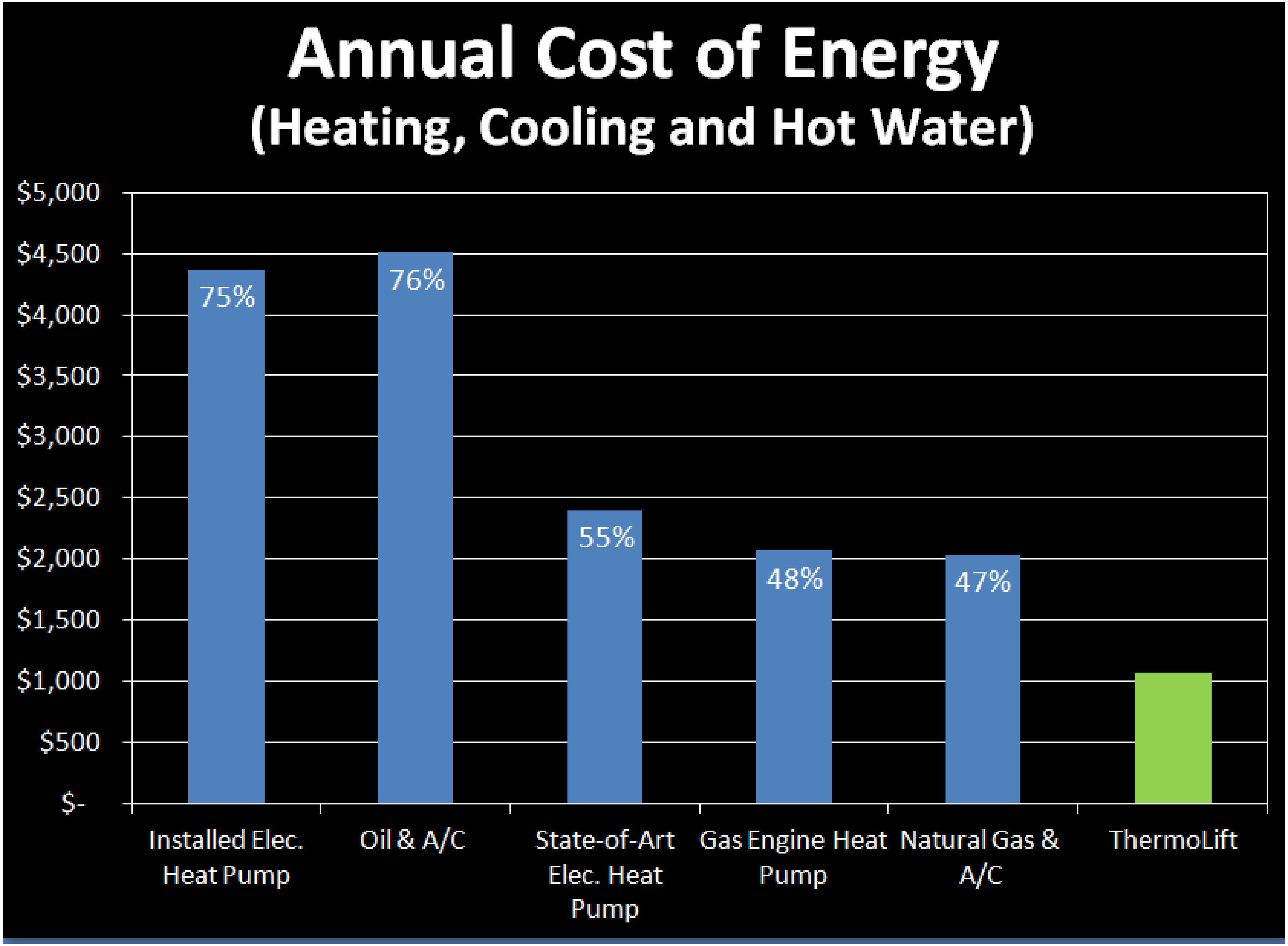
Heating Pump



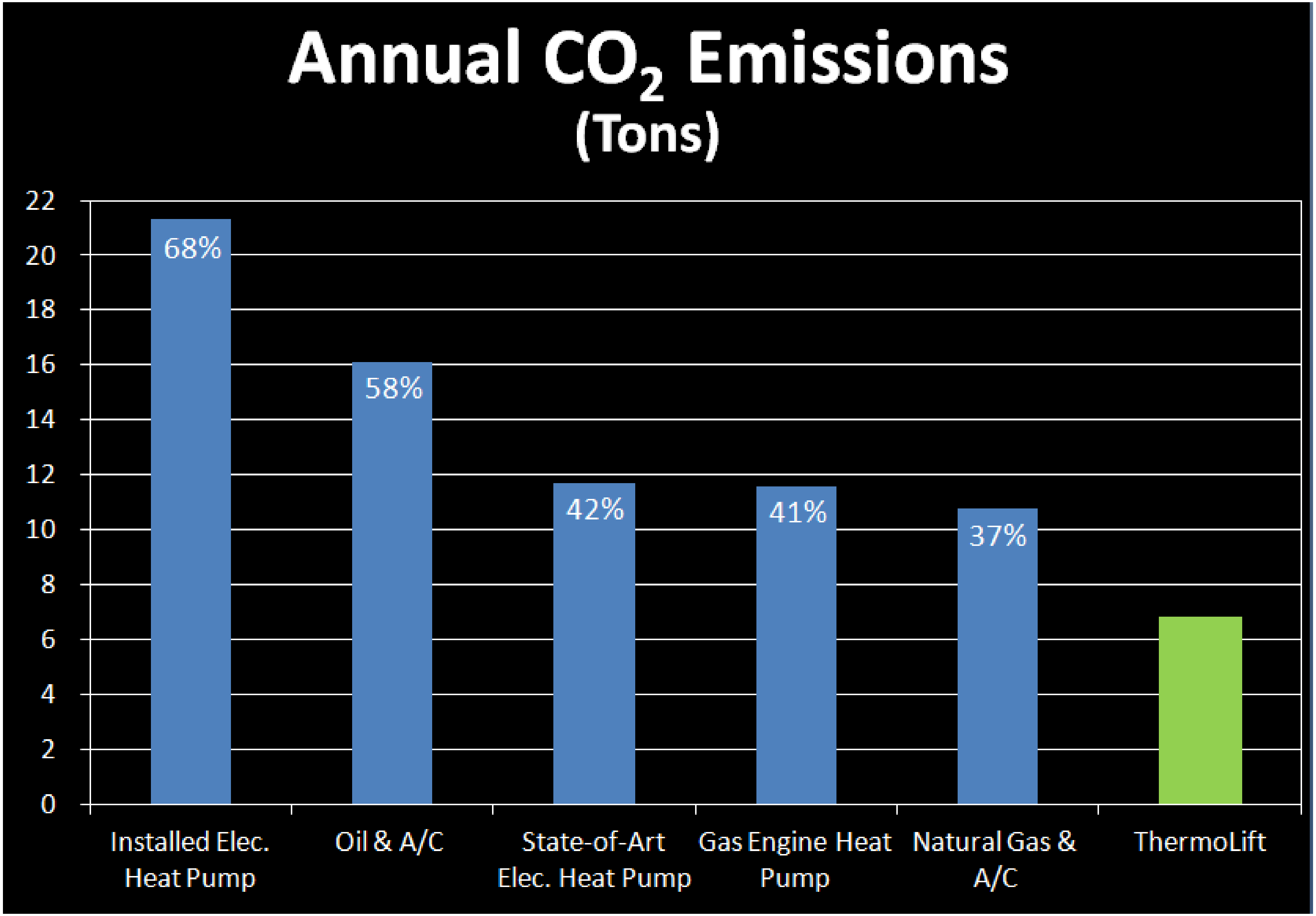
Cooling Pump



Energy Savings



Emissions Reduction



Customer Value

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	
TOTAL		$7,233	$5,500

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