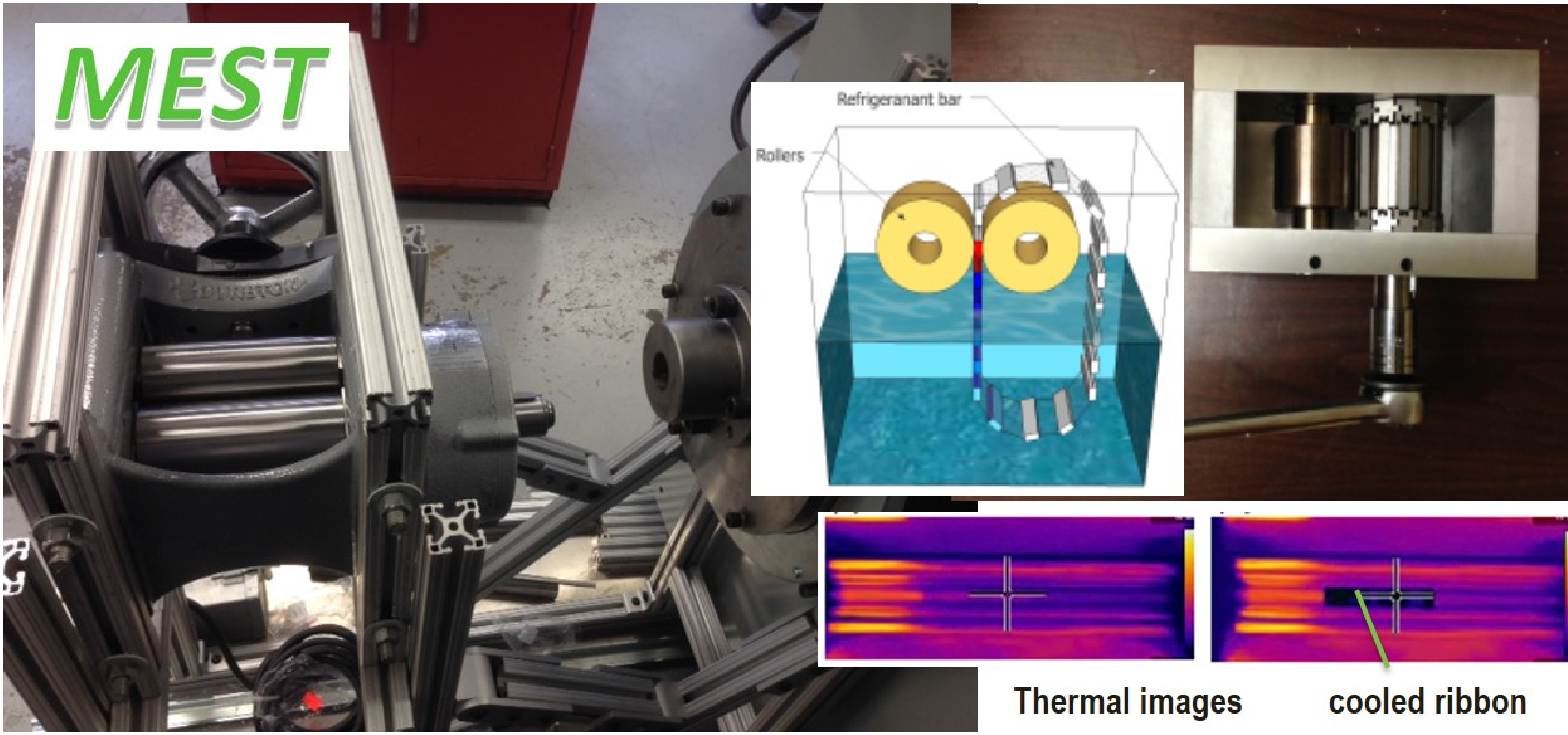
Compact Thermoelastic Cooling System

2016 Building Technologies Office Peer Review



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Maryland Energy and Sensor Technologies, LCC

Project Summary

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Timeline:

Start date: 7/01/15

Planned end date: 6/30/17

Key Milestones

1. Refrigerant $\Delta T > 10\ ^{\circ}C$ at 20 W; 9 months
2. 400 W system with COP > 4, < $2000 system cost; 18 months

Budget:

Total Project $ to Date:

- DOE: $122,845.4
- Cost Share: $30,980.54

Total Project $:

- DOE: $614,591
- Cost Share: $153,648

Key Partner:

Reinhard Radermacher,

University of Maryland

Project Outcome:

Demonstrate a pathway for thermoelastic cooling toward the cost target of $98/kBtu and the power density target of 50 kW/m^3.

Demonstrate compact thermoelastic cooling system with 1 kW cooling power, COP > 4, power density > 6250 W/m^3, lab scale production cost < $4000/kW

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Purpose and Objectives

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Problem Statement: Thermoelastic cooling (TEC), while recognized as one of the most promising non-vapor compression technologies, requires large compression load (~800 MPa) resulting in a large footprint of mechanism (~10 ft^3). We propose to develop a novel mechanism with reduced footprint and weight.

Target Market and Audience: The application of TEC is air-conditioning and refrigeration in residential and business sectors. 40% of commercial building sector's electricity consumption is for HVAC systems (7.3 quadrillion BTUs in 2011).

Impact of Project: If TEC is commercially accepted by the market with 50% penetration and 40% energy saving by 2025, the overall saving will be 1.48 quads of primary electricity and 74 MMT CO_2 emissions. The emission of greenhouse gases is equivalent to 146 MMT of CO_2. If 50% of HVAC units with GWP refrigerants are eliminated, saving of CO_2 emission is additional 73 MMT.

MEST is a Tier 1 OEM manufacturer. We plan to deliver a compact 1. 2 kW TEC prototype. A limited number of units will be sold to partners.

Technology History

Thermoelastic cooling was invented at the University of Maryland

APPLIED PHYSICS LETTERS **101**, 073904 (2012)

Demonstration of high efficiency elastocaloric cooling with large ΔT using NiTi wires

Jun Cui,[1,2] Yiming Wu,[1] Jan Muehlbauer,[3] Yunho Hwang,[3] Reinhard Radermacher,[3] Sean Fackler,[1] Manfred Wuttig,[1] and Ichiro Takeuchi[1,a)]

ARPA-E (DOE) has renewed the UMD contract to further develop fundamentals of thermoelastic cooling: total funding $3.3M (2010-2015)

Thermoelastic Cooling won the Invention of the Year Award, UMD, Office of Technology Commercialization (2011)

MEST licensed the technology in 2012 to develop and commercialize applications of thermoelastic cooling. To date: an NSF SBIR, State of Maryland investment, and a contract with a major manufacturer

Calorics: Materials to Commercial Products

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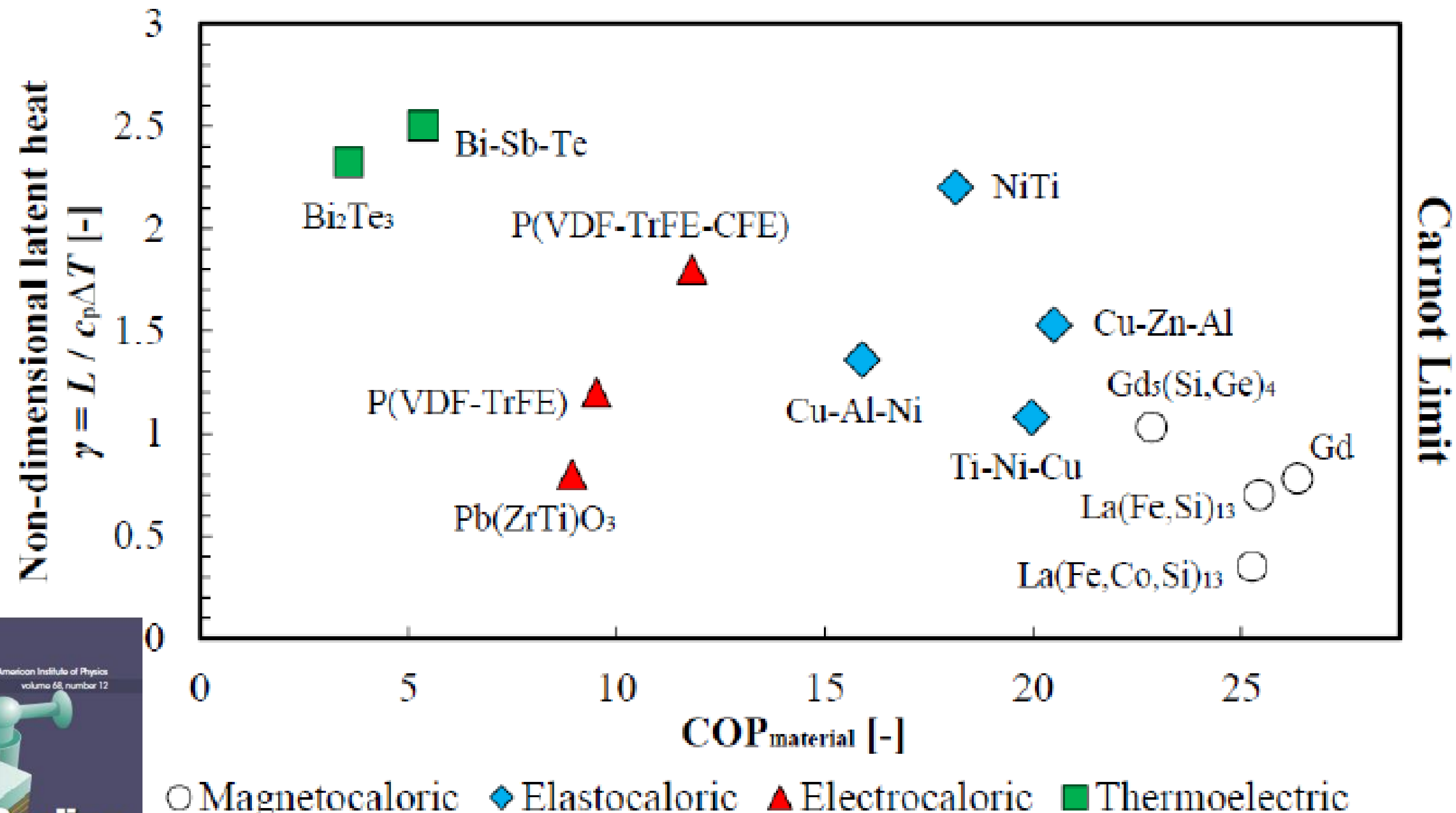

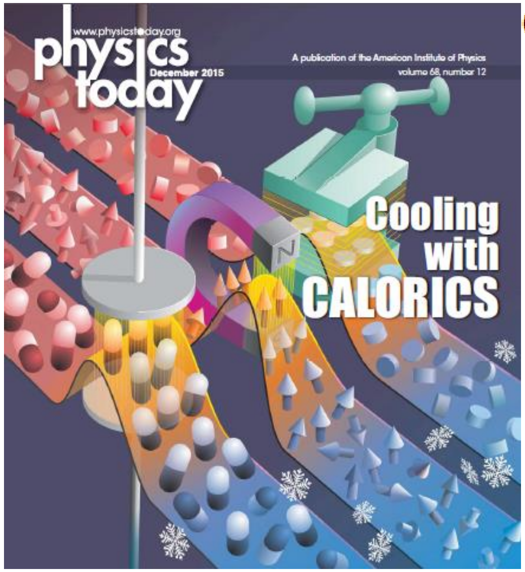

Comparison of various solid state cooling materials

Thermoelastic/elastocaloric materials are promising

Physics Today, Dec 2015

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Comparison: Thermoelastic vs Vapor Compression

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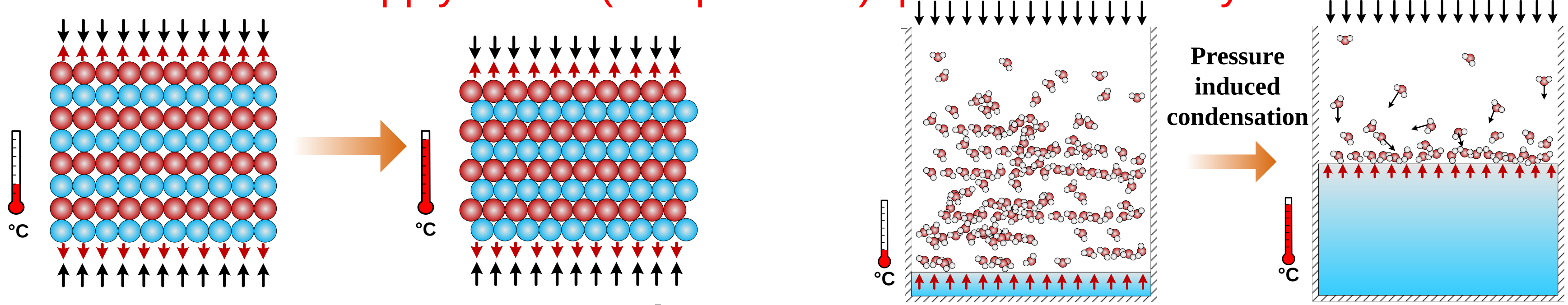
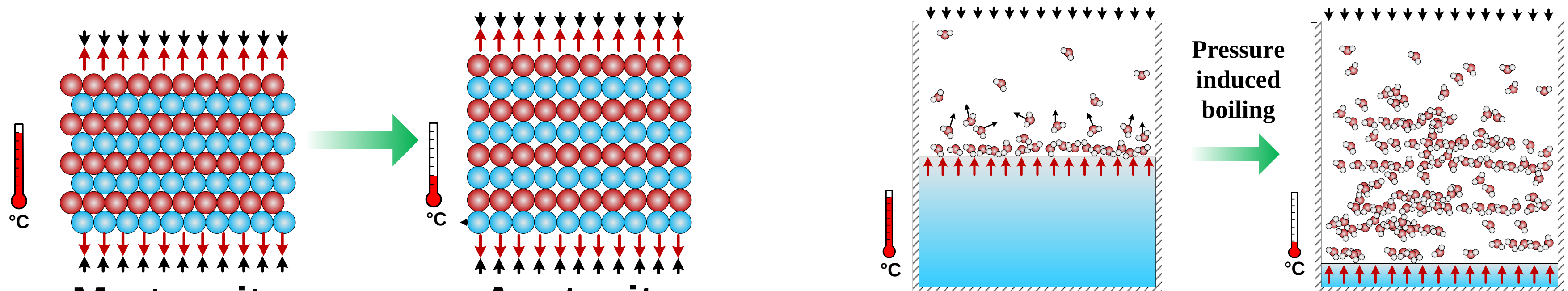
Apply stress (compression) /pressure to the system



Austenite $\sigma_{sat} < \sigma_{sys}$ | **Martensite** $\sigma_{sat} < \sigma_{sys}$ | **Vapor** $P_{sat} < P_{sys}$ | **Liquid** $P_{sat} < P_{sys}$

Remove stress/pressure to the system

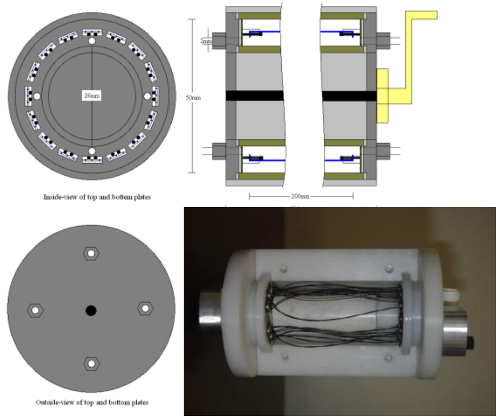


Martensite $\sigma_{sat} > \sigma_{sys}$ | **Austenite** $\sigma_{sat} > \sigma_{sys}$ | **Liquid** $P_{sat} > P_{sys}$ | **Vapor** $P_{sat} > P_{sys}$

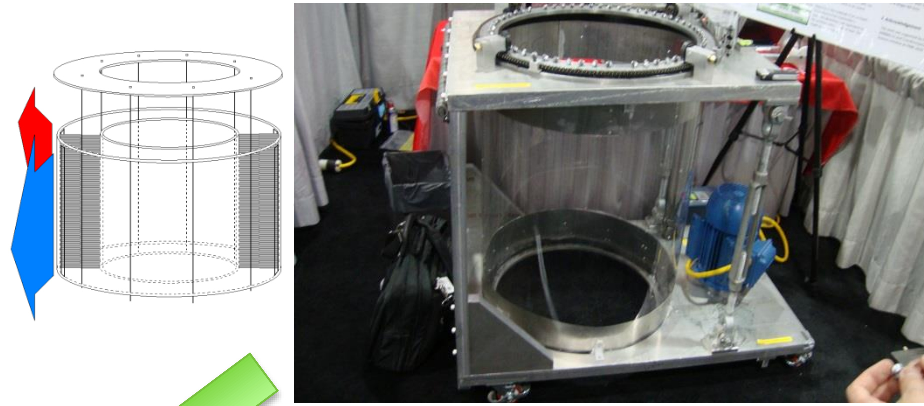
Large force (400 MPa) with small displacement (5% strain)

Relative small force (<5 MPa) and large volume change (>200%)

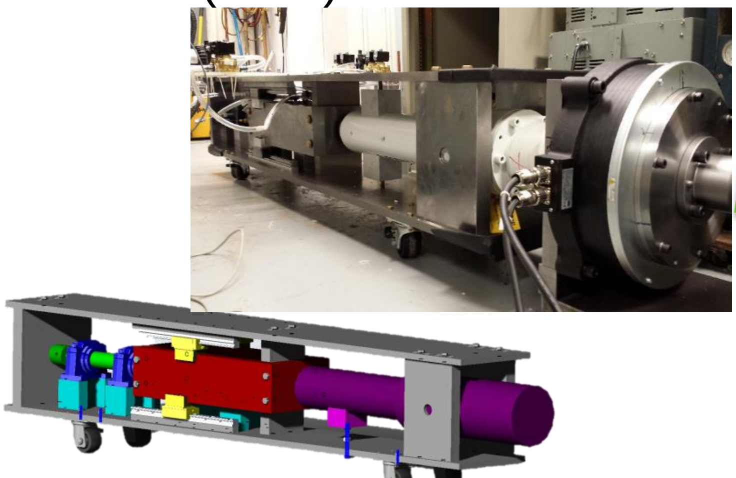
Previous Projects (UMD/UTRC/PNNL)



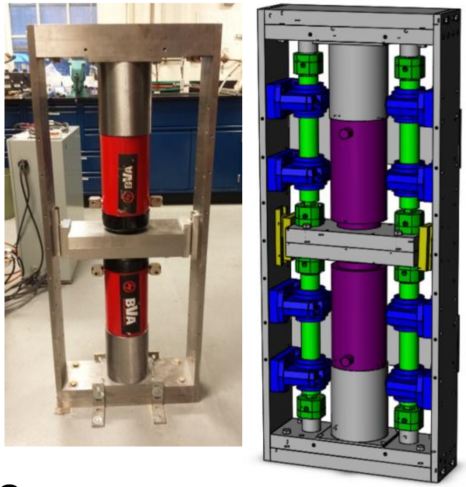
GEN-0: hand crank/tension
35 W (2010)



GEN-1: tension based 1 kW
Direct air cool (2012)



GEN-2: compression based
140 W water cooling (2014)



Issues:

Large load;

Large footprint

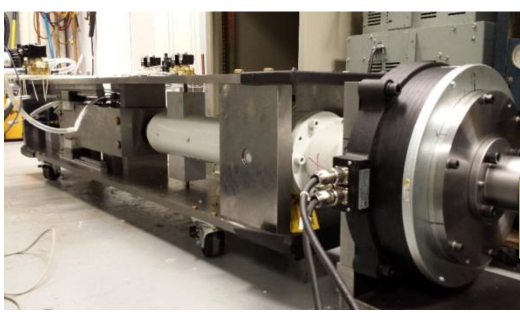
GEN-3: compression based
400 W water cooling (2015)

Approach

Approach: A novel mechanical loading mechanism with substantially reduced size and the weight of the overall system: the roller-belt design.

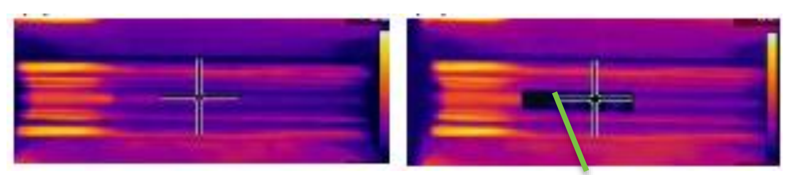
Key Issues: Effective means to feed refrigerants into the roller; heat exchange between the roller and the refrigerants; between the refrigerant bars and water; optimization of the rolling parameters.

Distinctive Characteristics: Continuous mode operation; simplified overall system design with minimized heat loss and footprint



large

small



Thermal images cooled ribbon

Roller-based Compressive Thermoelastic Cooling

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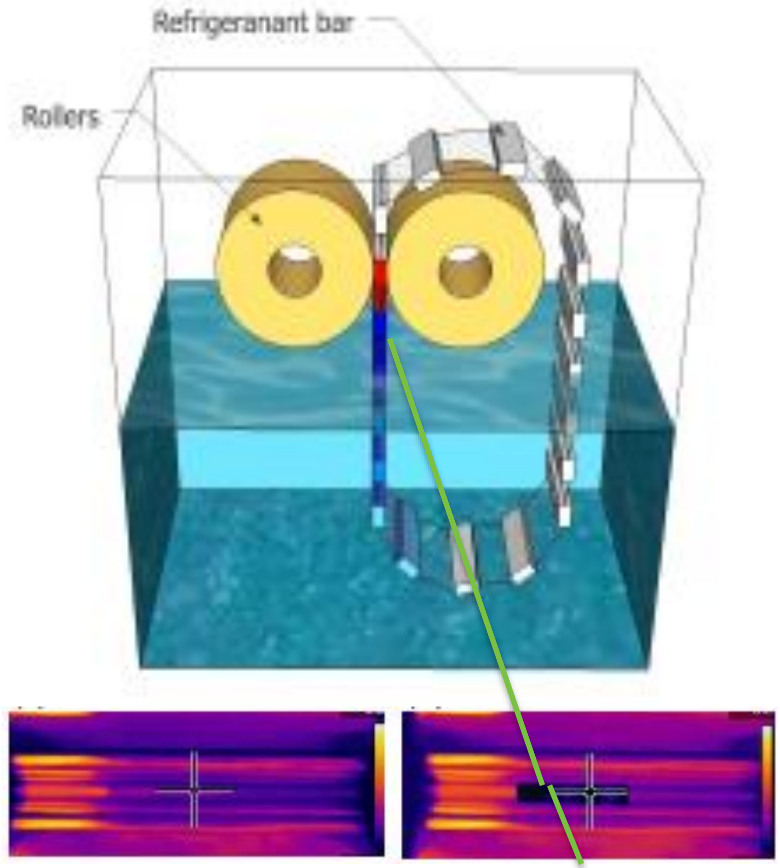
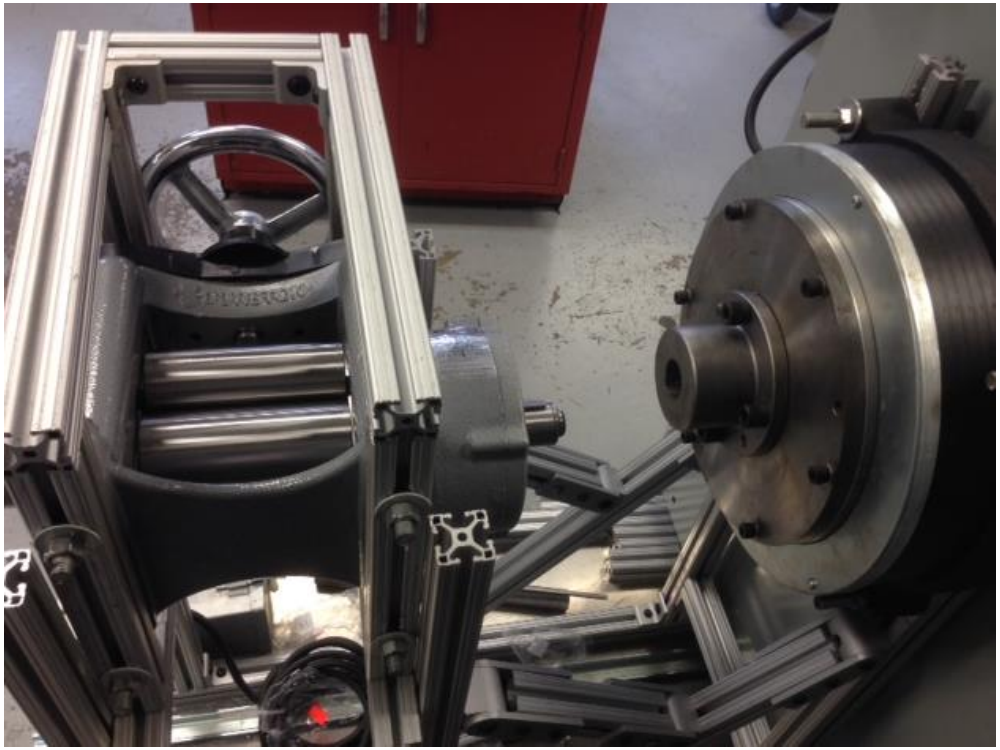
MEST GEN V
Prototype



Thermal images cooled ribbon

Latest prototype being constructed



Roller compresses and releases the refrigerants

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Progress and Accomplishments (started July, 2015)

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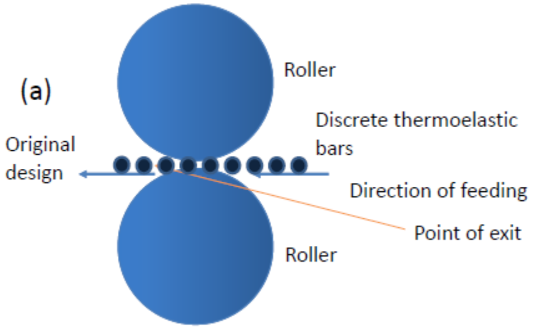
Accomplishments: Tested a large number of available materials to be used as bar/ribbon refrigerants, and identified several candidate materials; refined the design of the loading mechanism; developed a baseline simulation of the cooling set up.

Market Impact: We have attracted more interests from the HVAC industry. Performing simulations to increase energy efficiency and speed up the system optimization process.

Awards/Recognition: A provisional patent was recently filed.

Lessons Learned: Many parameters need to be simultaneously optimized. This has led to redesign of the loading mechanism.



Rolling mechanism

Direct Measurement of Refrigerant ΔT

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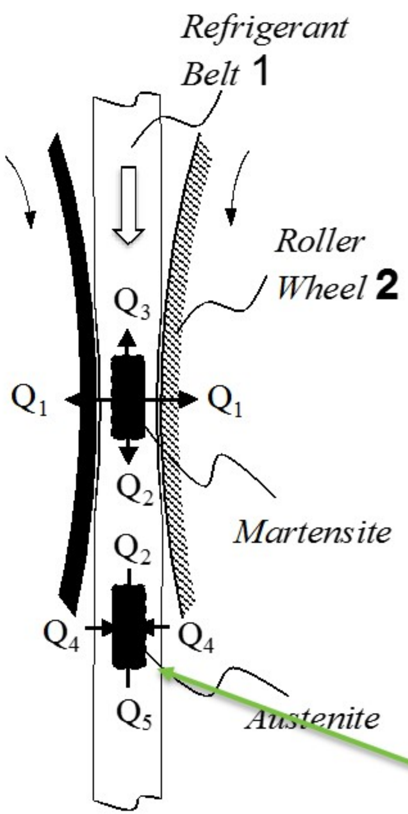
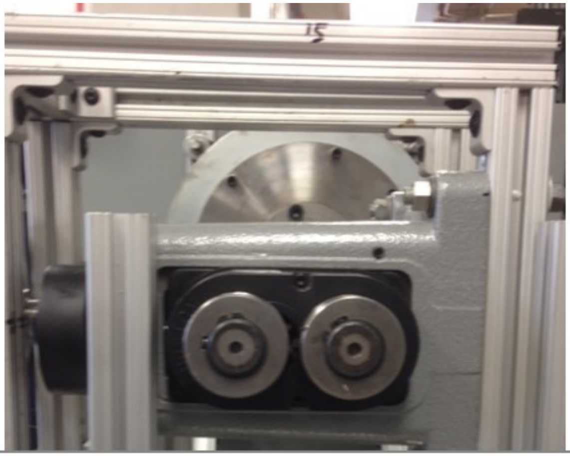
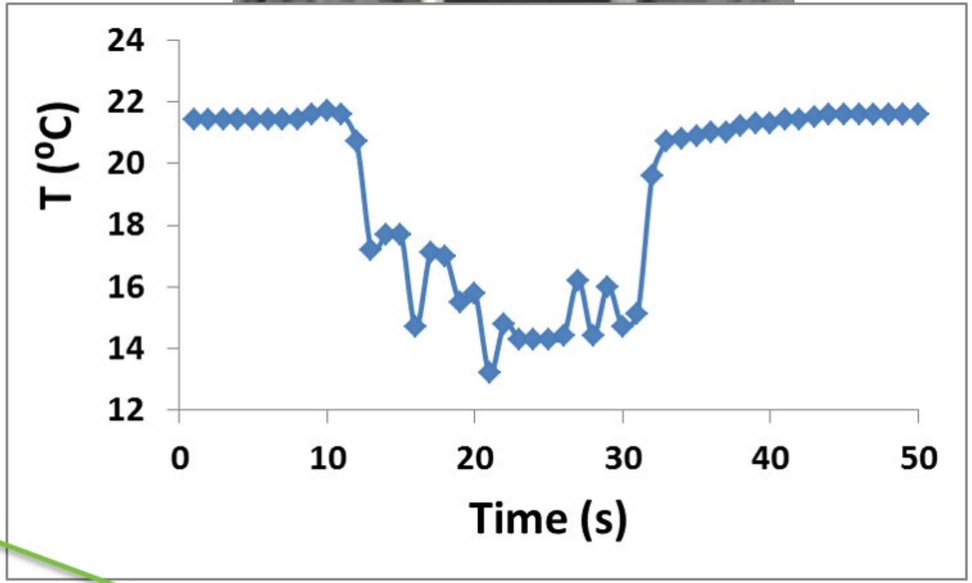




Prototype



Any heat release/absorbed will be conducted through the ribbon

Measured at the exit point of the ribbon: ΔT as large 8K

Thermoelastic Cooling: Simulation

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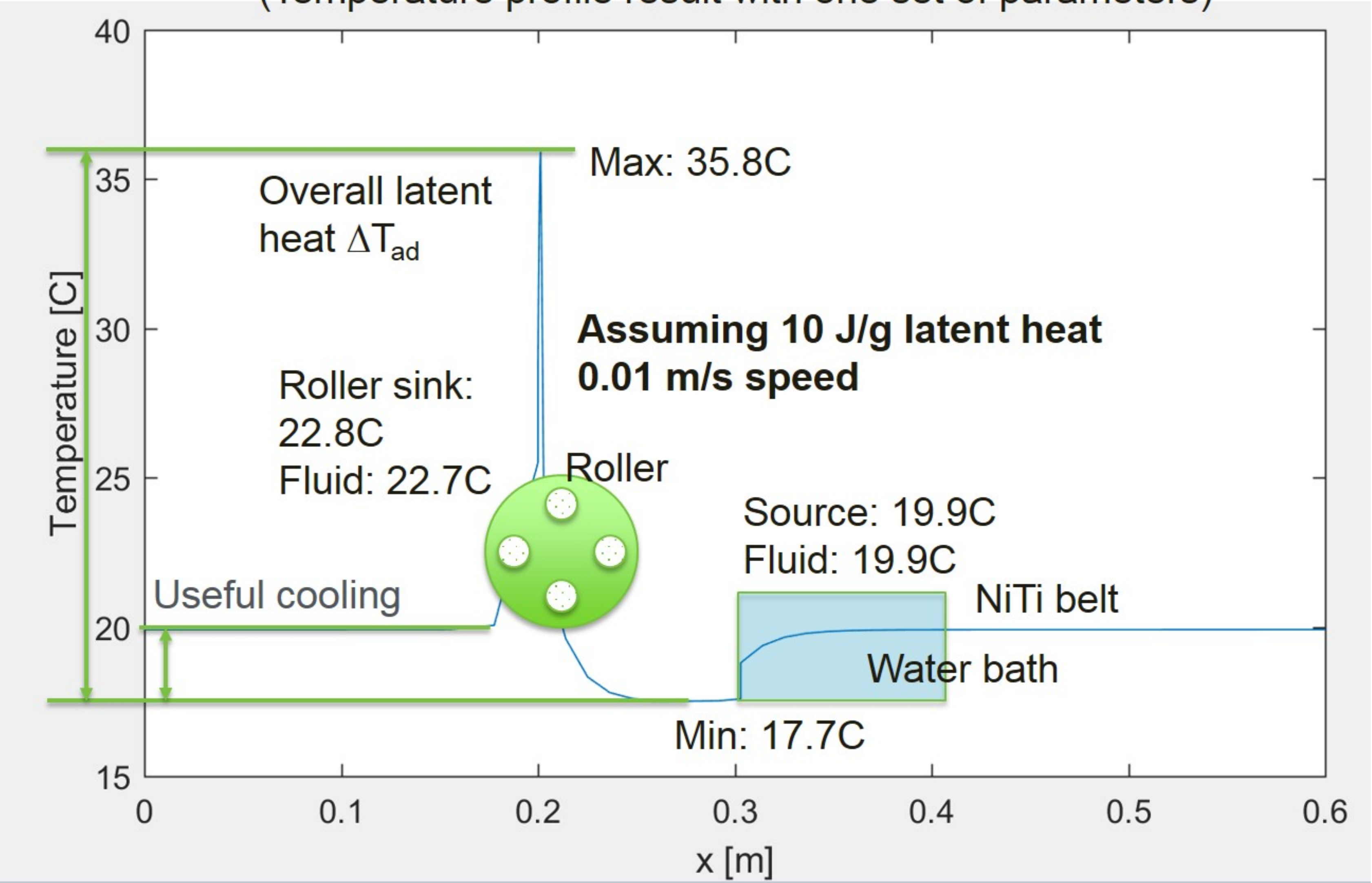
(Temperature profile result with one set of parameters)



SIMULINK is used to guide parameter optimization

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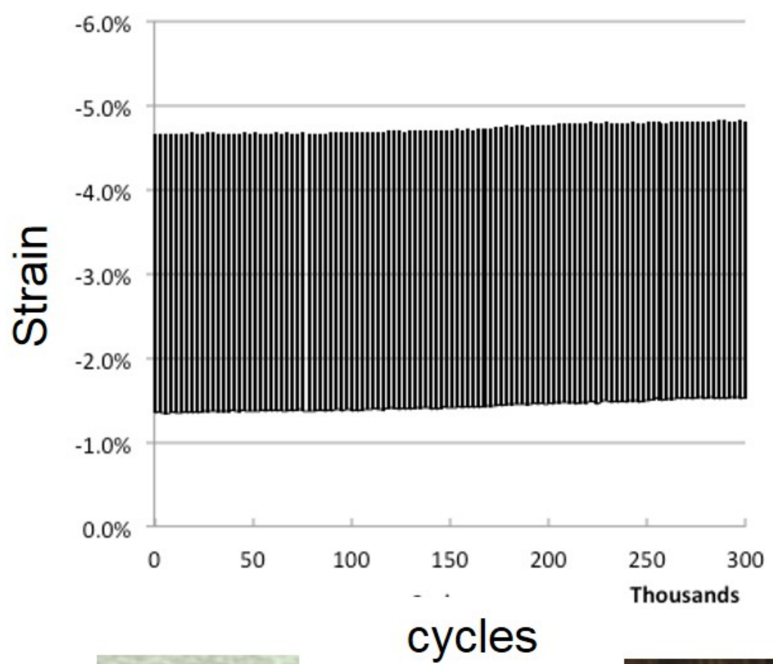
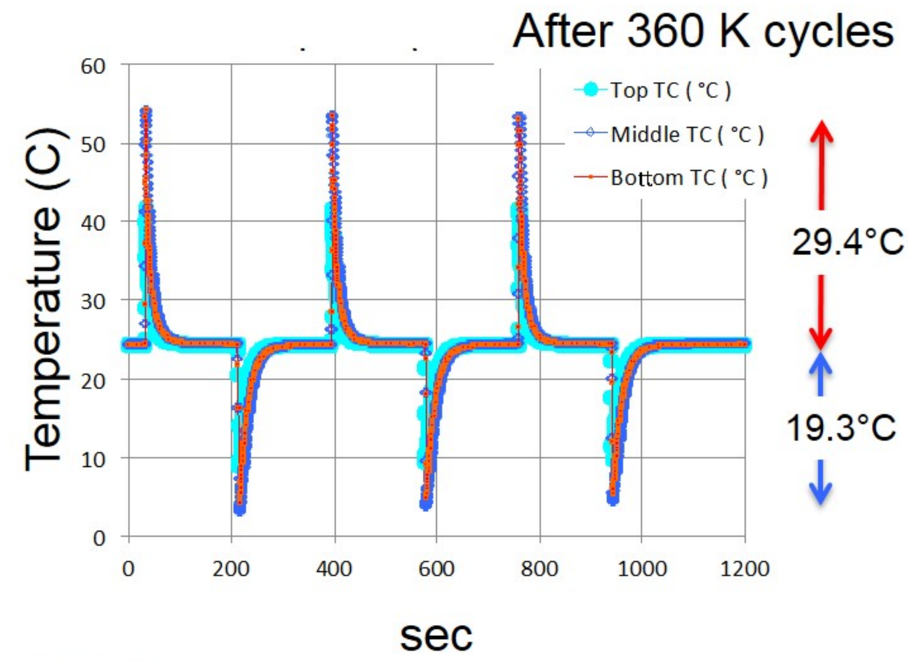
Thermoelastic Cooling: Material Fatigue Test





Compression test:
when properly loaded,
survives 360,000 cycles

J. Cui, PNNL

Thermoelastic Cooling: Relevance to BTO Goals

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Desired Characteristics	Relevance	Remarks
Good (LCCP) Life cycle climate performance	High, demonstrated	The TEC refrigerant is a solid, not containing any GWP chemicals
Integrated thermal storage potential	Low	There is a mechanism to use TEC materials to store cold
Grid integration capabilities	To be demonstrated by this effort	The roller-belt design requires high torque at low RPM, a distinct feature for DC motors. DC motors can run on batteries, fuel cells or a solar PV system without inverter, and therefore, it is micro-grid friendly.
Minimal water consumption	High, demonstrated	TEC does not use water for evaporative cooling; only uses water as heat exchange medium
Cost effectiveness (2017 target: $89 kBtu/hr)	To be demonstrated by this effort	The proposed effort will lead to $1176/Btu at lab scale. It could lead to $117/Btu with mass production
Potential to result in reduced size and/or weight	To be demonstrated by this effort	The proposed effort will lead to 50 kW/m^3 which is typical for vapor compression based units
Readily available materials & energy saving	High, demonstrated	The TEC system only uses common elements such as Fe, Ni, Ti, Cu, Al, and Zn.

Project Integration and Collaboration

Project Integration: We have regular visits from potential industrial partners (from U.S., Japan, China, and Europe). Some visit more regularly than others.

Partners, Subcontractors, and Collaborators: Key consultants:
R. Radermacher (UMD, Optimized Thermal System); Jan Muehlbauer

Communications:
- Workshop on Advanced Caloric Cooling for Efficient Cooling (UMD, April 2015) https://www.nanocenter.umd.edu/events/amec/2015.Workshop.Advancing_Caloric_Materials.REPORT.pdf;
- Discussion Meeting: Taking the temperature of phase transitions in cool materials (Royal Society of London, February 2016);
- MRS Spring 2016 Symposium: Caloric Materials for Renewable Energy Applications (Phoenix, April 2016).

Next Steps and Future Plans

Next Steps and Future Plans:

(Short term)

Demonstrate full continuous operation of roller-based TEC

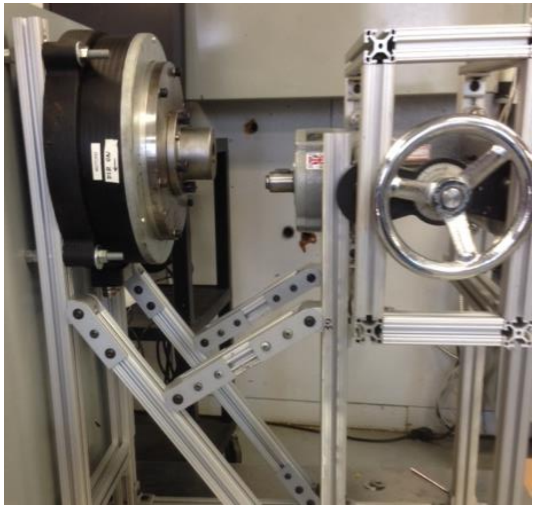
- Finish construction of the current prototype
- Design and test heat-exchange system
- Carry out further simulations

(~ 1 yr)

Optimize design parameters for scaling up to 400 W

- Modify initial designs of the drive and heat-exchanger

Build and test a 400 W prototype



(In parallel)

Explore new refrigerant materials and vendors

Refine commercialization plans

Project Budget

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Project Budget: Started with the preproposal period; still slowly ramping up the monthly spending.
Variances: Recent change in the personnel concomitant with a change in the technical approach; resulted in reduced spending rate to date. We plan to continue to pick up speed.
Cost to Date: We have spent about a little over a quarter of the project budget.

Budget History					
7/01/15 – FY 2015 (past)		FY 2016 (current)		FY 2017 – 6/30/17 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
50,210.3	12,662.6	72,635.11	18,317.94	491,745.59	122,667.46

Project Plan and Schedule

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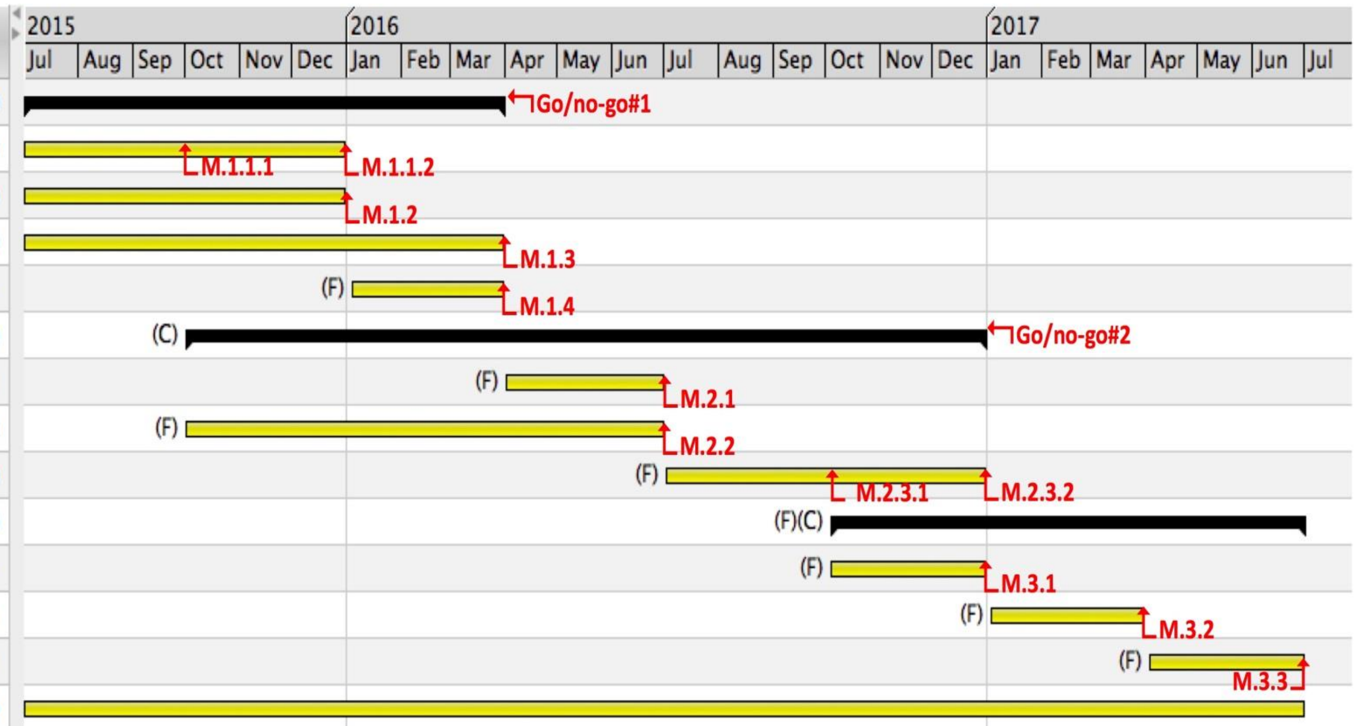
- Project commenced: 7/1/15; end date: 6/30/17
- Key milestones: 20 W with refrigerant $\Delta T > 10$ K; 400 W operation
- Go/no-go decision points: medium reservoir temperature: $\Delta T > 8$ K ; likelihood evaluation: COP > 4, size < 2 ft^3, < $2K/unit

Name	Days
1. GEN-V modification	**197.0**
1.1. Roller surface modification	132.0
1.2. Refrigerant bar procurement/machining	132.0
1.3. Roller temperature control	197.0
1.4. System integration & test	64.0
2. GEN-V scale up & test	**327.0**
2.1. Large roller	65.0
2.2. Bar connection mechansim	196.0
2.3. System Integration & test	131.0
3. GEN-V scale up & test	**195.0**
3.1. GEN-VI design	65.0
3.2. GEN-VI construction	65.0
3.3. GEN-VI evaluation	65.0
4. Project reporting and market analysis	**523.0**



Scaled up GEN-V: 400 W; Gen-VI: 1.2 kW