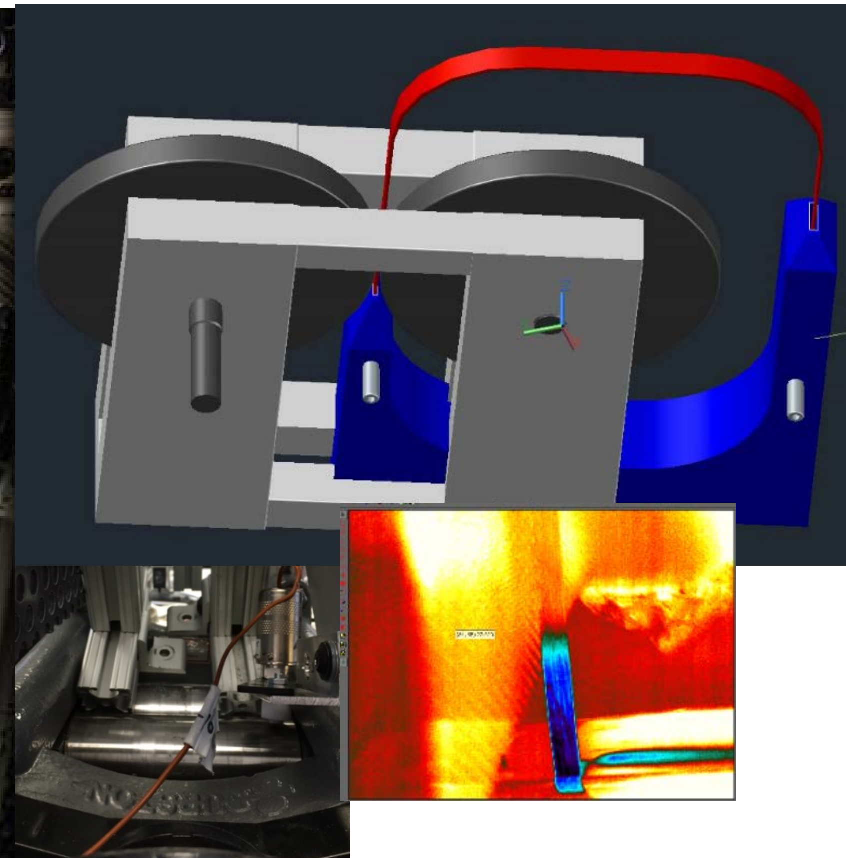
Compact Thermoelastic Cooling System

2017 Building Technologies Office Peer Review



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Maryland Energy and Sensor Technologies, LCC

Project Summary

MEST

Timeline:

Start date: 7/01/15

Planned end date: 12/31/17

Key Milestones

1. Direct
2. 400 W system with COP > 4, < $2000 system cost; 27 months

Budget:

Total Project $ to Date:

- DOE: $307,497
- Cost Share: $82,742.69

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 400 W 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 400 W TEC prototype. A limited number of units will be sold to partners.

Technology History

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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 Advanced Research Projects Agency • ENERGY

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

University of Maryland 1856

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

MEST

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

New Developments in the Field of Thermoelastics

MEST

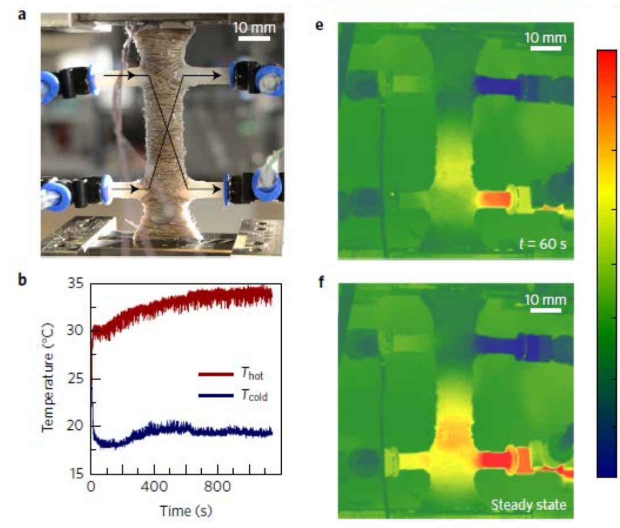
nature energy

ARTICLE

PUBLISHED: 5 SEPTEMBER 2016 | ARTICLE NUMBER: 16134 | DOI: 10.1038/NENERGY.2016

A regenerative elastocaloric heat pump

Jaka Tušek[1,2]*, Kurt Engelbrecht[1]*, Dan Eriksen[1], Stefano Dall'Olio[1], Janez Tušek[2] and Nini Pryds[1]



SCIENTIFIC REPORTS

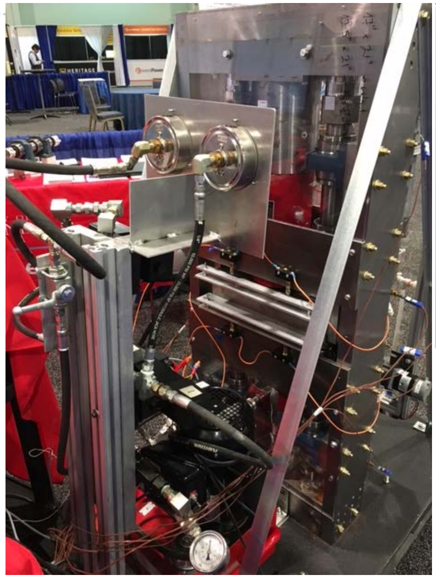
OPEN

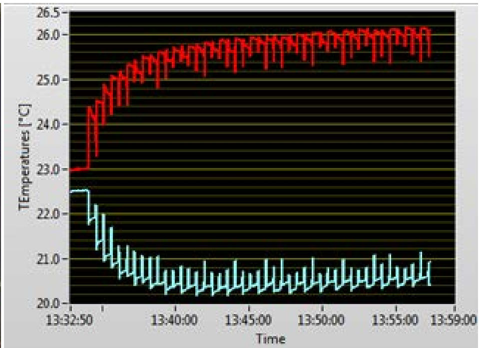
Giant and reversible room-temperature elastocaloric effect in a single-crystalline Ni-Fe-Ga magnetic shape memory alloy

Received: 07 January 2016
Accepted: 15 April 2016
Published: 03 May 2016

Yang Li[1,2,3], Dewei Zhao[1,2] & Jian Liu[1,2]

CaloriCool™
CALORIC MATERIALS CONSORTIUM





UMD group

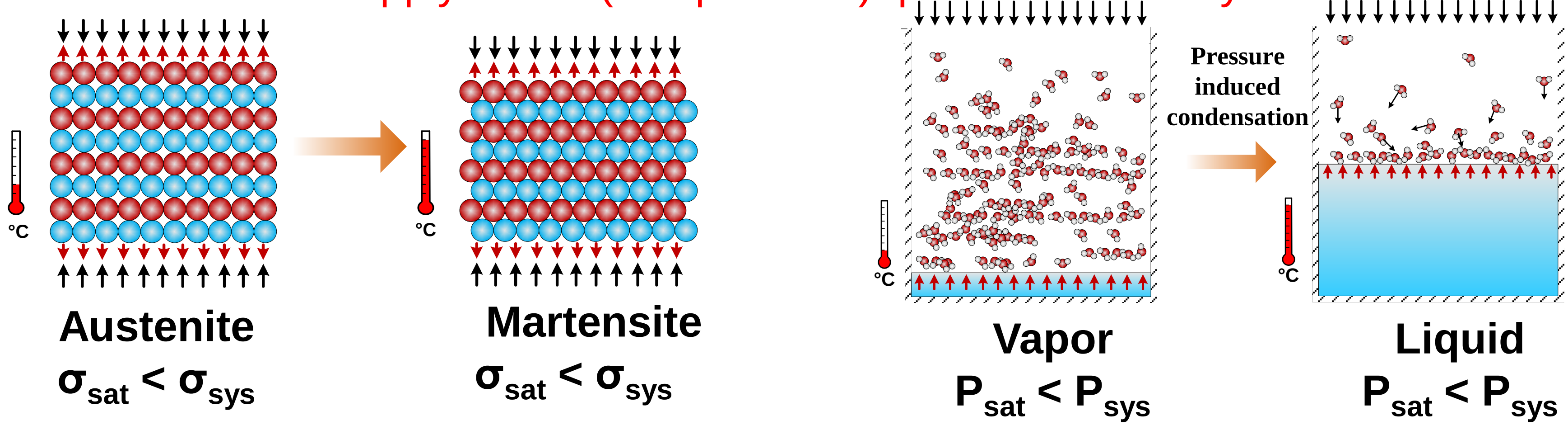
400 W (6' x6'x2')

ARPA-E Summit 2017

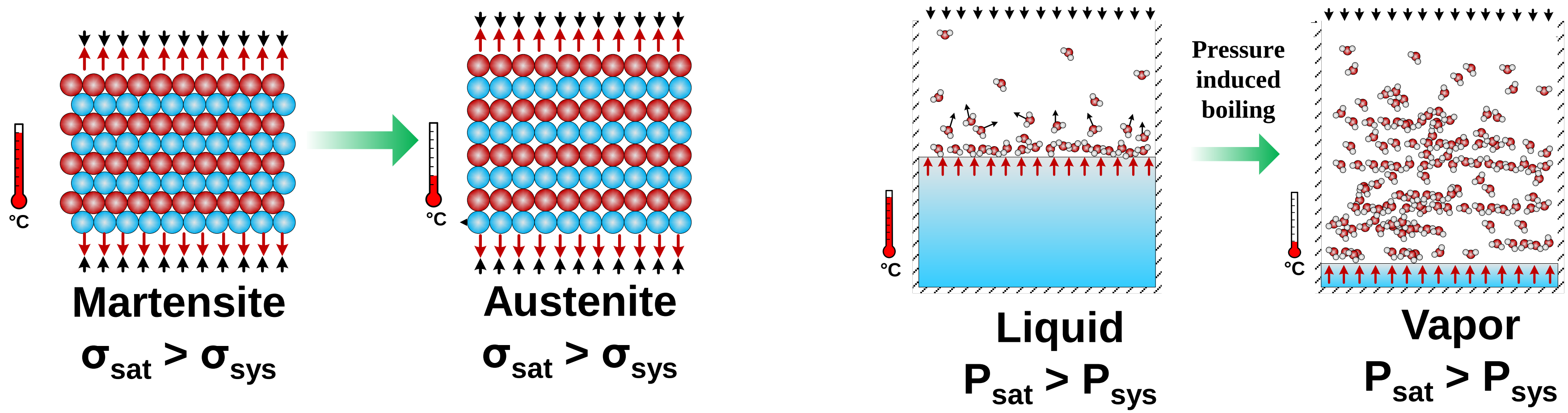
From Materials to Systems

Comparison: Thermoelastic vs Vapor Compression

Apply stress (compression) /pressure to the system



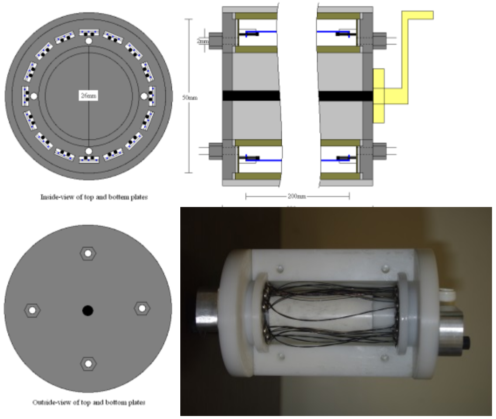
Remove stress/pressure to the system



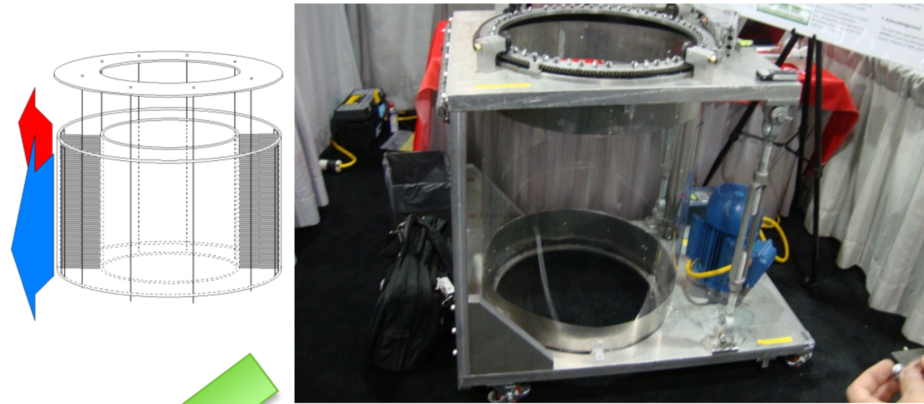
Large force (400 MPa) with small displacement (5% strain)

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

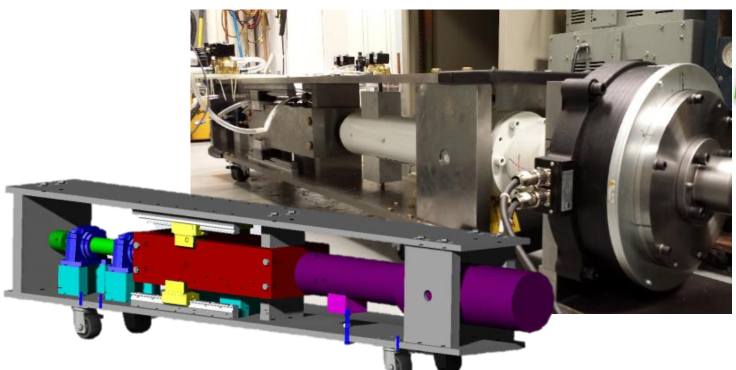
Previous Projects (UMD/UTRC/PNNL)



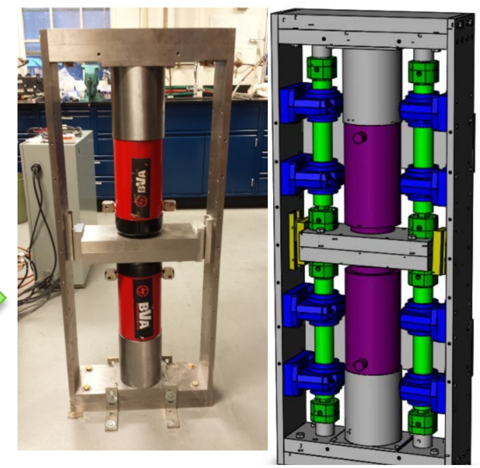
GEN-0: hand crank/tension
35 W (2010)



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



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



Issues:

Large load;

Large footprint

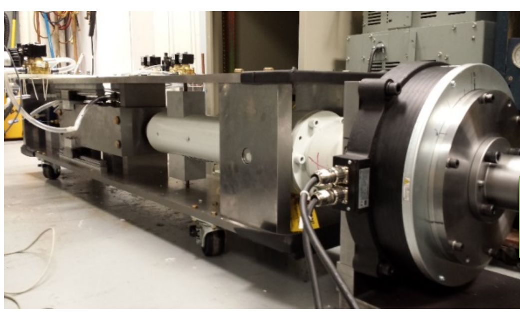
GEN-3: compression based
400 W water cooling (2017)

Approach

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

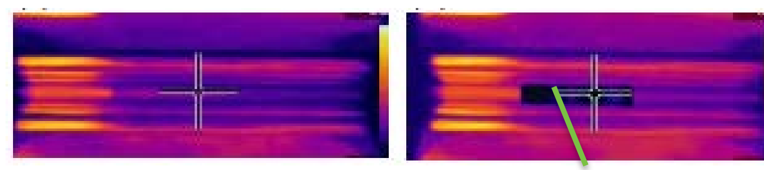
Key Issues: Effective means to feed refrigerants into the roller; heat exchange between the roller and the refrigerants; between the refrigerant bars and water; optimization of the rolling parameters.

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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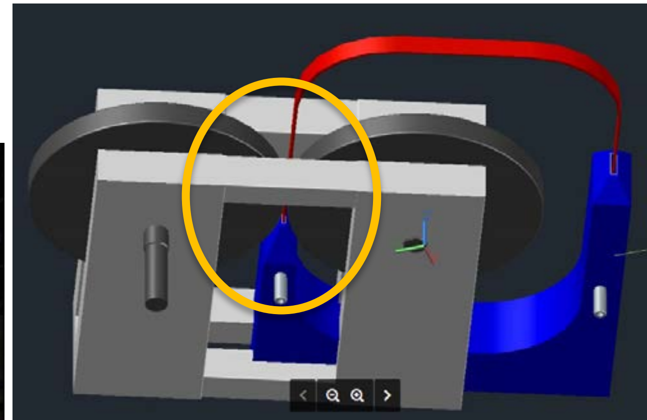
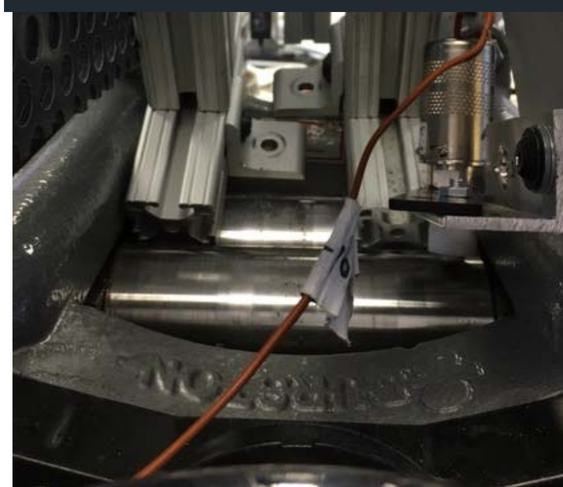
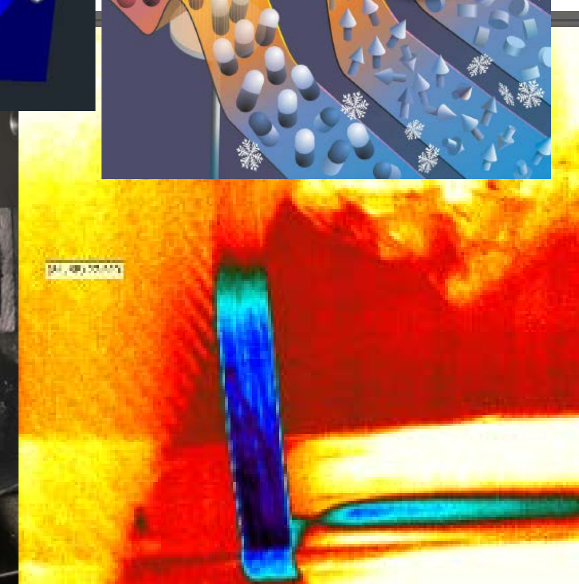
Roller compresses and releases the refrigerants

Latest prototype: 80 W moving towards 400 W

Continuous operation demonstrated







Rolling thermocouple and IR camera used to measure temperatures of moving ribbons

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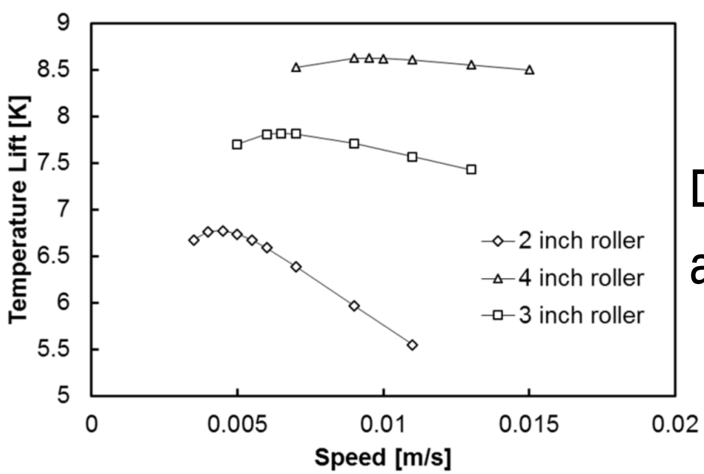
Progress and Accomplishments (started July, 2015) MEST

Accomplishments: Direct cooling of water demonstrated at 40 W. Continuous operation demonstrated. Some components for the 400 W are ready.

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.



Dependence of the temperature lift on rolling speed and roller diameter (simulation)

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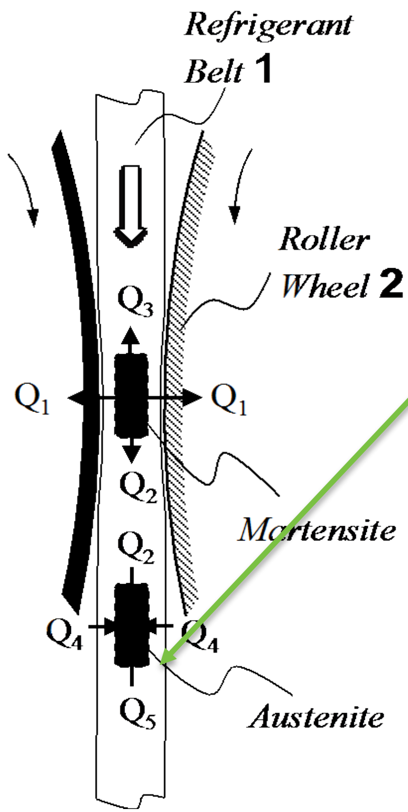
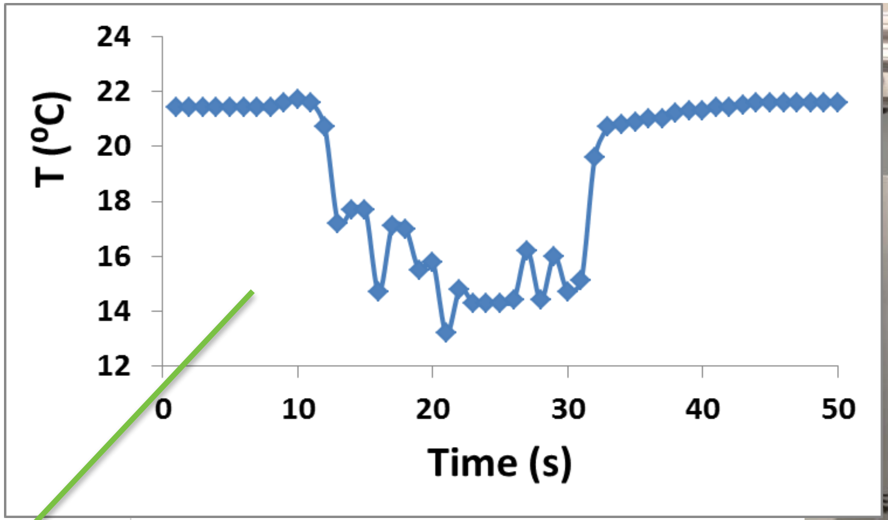
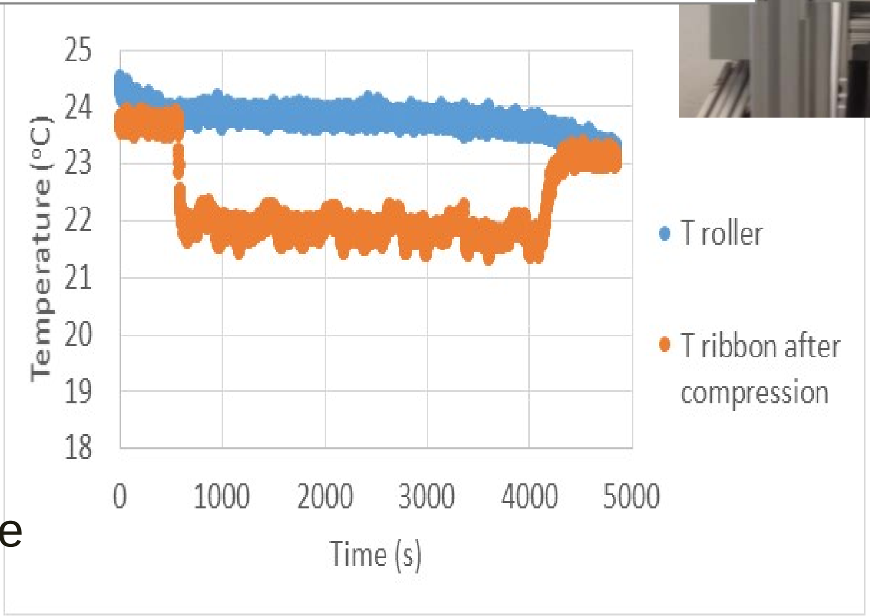
Measurement of Cooled Refrigerant

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







Any heat release/absorbed will be conducted through the ribbon

Direct Cooling of Water

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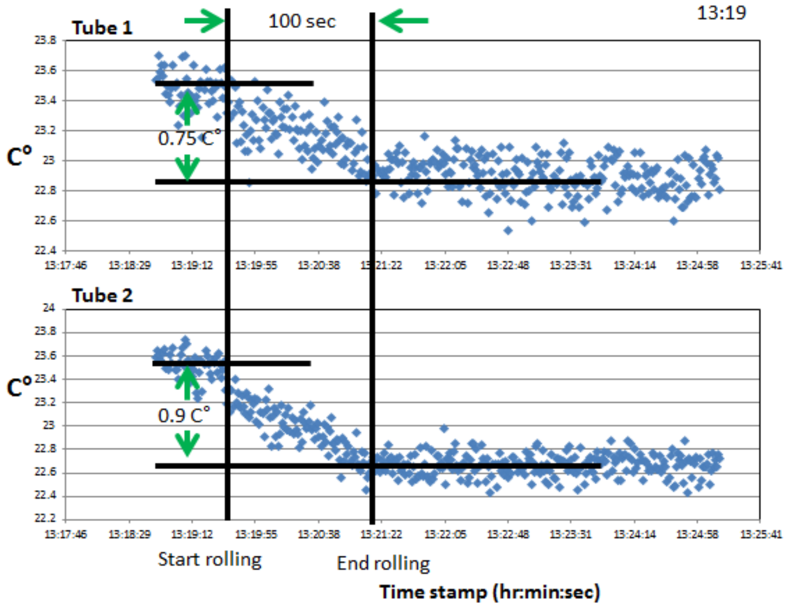
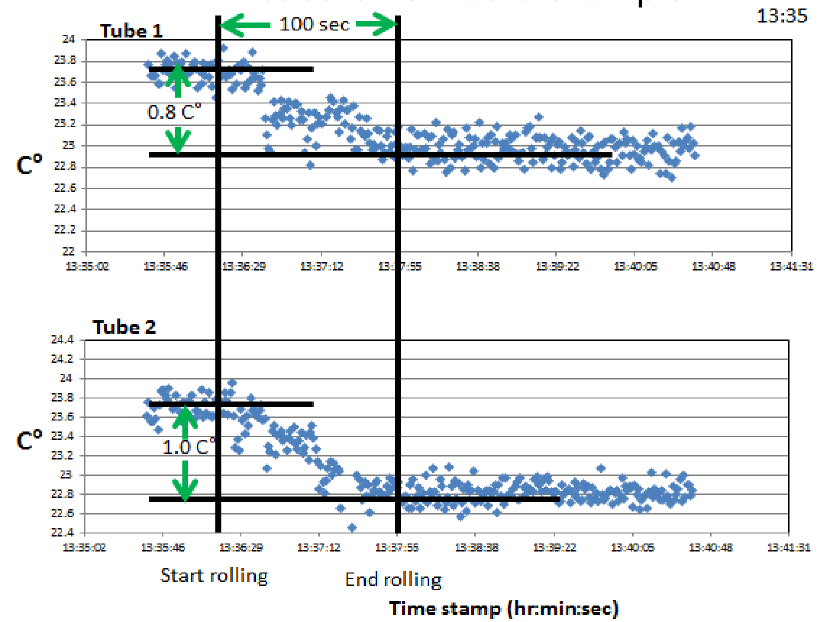
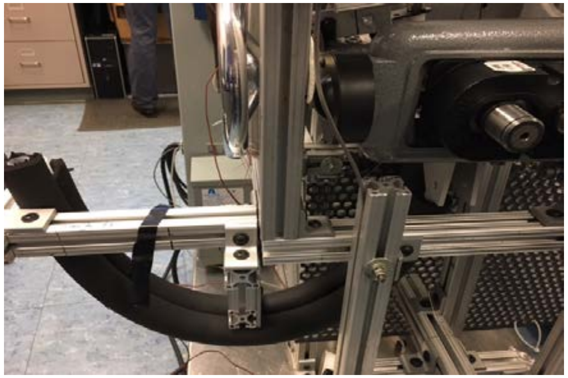
Measurement data example 1



Measurement data example 2





Ribbons enter the loops containing water as they exit the roller

300 ml x 1 cal/(deg ml) x 1 deg x 4 J/cal x 2 ~ 2400 J in 100 sec

Thermoelastic Cooling: Simulation

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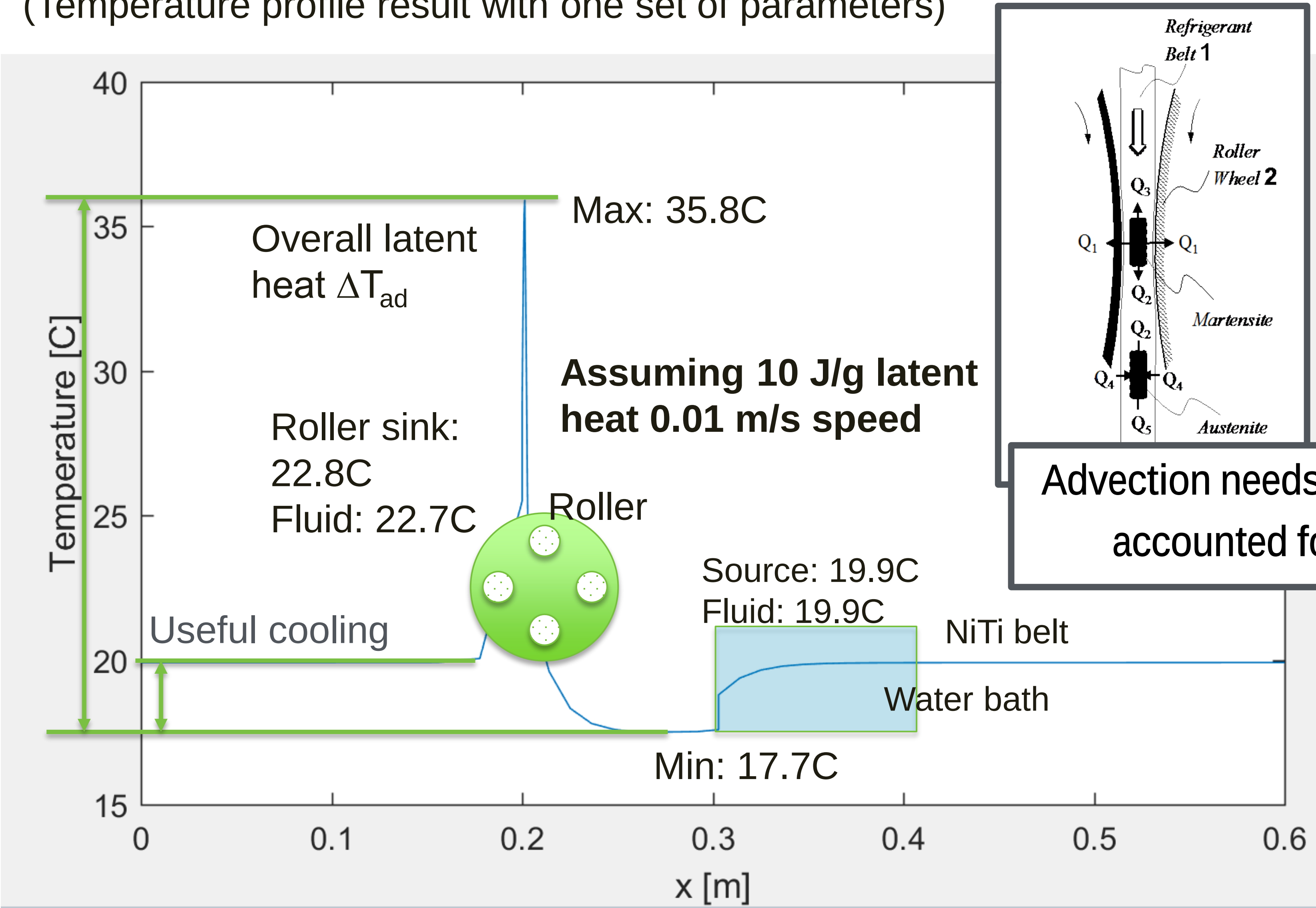
(Temperature profile result with one set of parameters)



Advection needs to be accounted for

SIMULINK is used to guide parameter optimization

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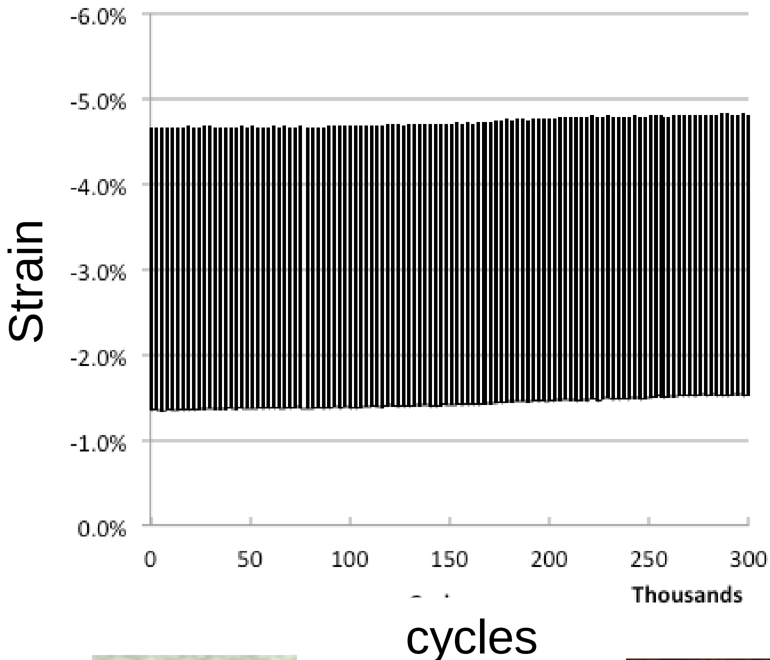
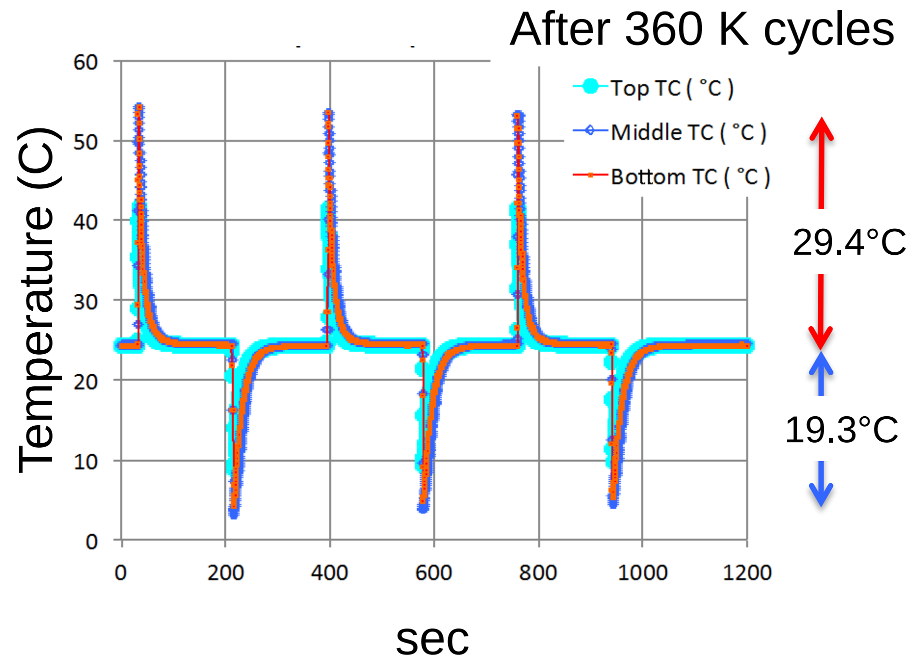
Thermoelastic Cooling: Material Fatigue Test





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:

- MRS Spring 2016 Symposium: Caloric Materials for Renewable Energy Applications (Phoenix, April 2016).
- Ferroic Cooling Convention (Meersburg, Germany, October 2016)
- MRS Spring 2017 Symposium: Caloric Energy Conversion Materials (Phoenix, April 2017)

Ferroic Cooling
A DFG PRIORITY PROGRAMME

Next Steps and Future Plans

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Next Steps and Future Plans:

(Short term)

Optimize design parameters for the 400 W unit

Finish constructing parts for the 400 W unit (roller and the heat-exchanger)

Assemble and test the prototype

Carry out further simulations

(~ 1 yr)

Optimized operation of the 400 W unit

Next-step scale up

(In parallel)

Explore new refrigerant materials and vendors

Refine commercialization plans

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Project Budget

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Project Budget: The official BP1 ended in July 2016; delayed meeting BP1 milestones due to lack of materials
Variances: No-cost extension for 6 months
Cost to Date: We have spent half of the project budget.

Budget History					
7/01/15 – FY 2015 (past)		FY 2016 (current)		FY 2017 – 12/31/17 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
50,210.3	12,662.6	257,635.11	70,080.09	307,094.00	70,905.31

Project Plan and Schedule

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- Project commenced: 7/1/15; end date: 12/31/17
- Key milestones: operation of 400 W prototype operation
- Likelihood evaluation: COP > 4, size < 2 ft^3, < $2K/unit