



# Potential of Thermoelectrics for Occupational Safety and Fuel Efficiency

## Gain and Applications

Lon E. ... , ... , Dan Coker

August 24, 2006



Detroit, Michigan- DEER 2006  
August 20-24, 2006

# Overview

Background on barriers to broader usage of thermoelectrics

TED heating

- First application in automotive engine exhaust gas pass
- Controlled engine temperature
- Liquid to air heat exchanger for cooling
- Liquid to air heat exchanger for supplemental heating/cooling passenger cabin

Roadmap

Electric devices in automotive; Climate

Waste heat recovery using thermoelectrics to increase fuel efficiency

Summary and conclusions



# **Background on Barriers to the Broader Usage of Thermoelectrics**

Detroit, Michigan- DEER 2006  
August 20-24, 2006



# Commercial Interest in Thermoelectrics

Solid-state cooling, heating and power generation

Small, light-weight. Potentially very reliable and rugged

Electrically powered with very few (or no) moving parts

Distributed (and spot) cooling/heating/temperature control

No gaseous pollutants

# What Has Limited Usage

Efficiency has been 1/4 that of 2 phase rectifier

- Inadequate for many high power applications
- Limited usage due to high cost of converter
- Too many components

Thermal

- Volumetric heat generation at high power levels
- Form factor not suitable to some applications
- Poor interface for high power density applications

Lack of design knowledge and effective simulation tools

- Performance often poorer than predicted
- Characteristics and hence response, can be a strong function of operating conditions

# Sources of TE System Performance Increase

## Materials

BiTe Thermoelectrics (1960s)

Heterostructures (2000-2002)

Baseline

+70 to 160%

## Materials/Design

Incremental improvements

(1960-2002)

5 to 15%

Accessory materials and  
components (1960-2002)

5 to 10%

## Thermodynamic Cycle

Isolated Element (2000-2002)

100 to 120%

Convection (2001-2002)

30 to 80%

## Power Density

Sintered micropower (2002)

Up to 25 X Increase

Heterostructure (2001)

30 to 300 X Increase

# Product Roadmap for Thermoelectric Heating/Cooling

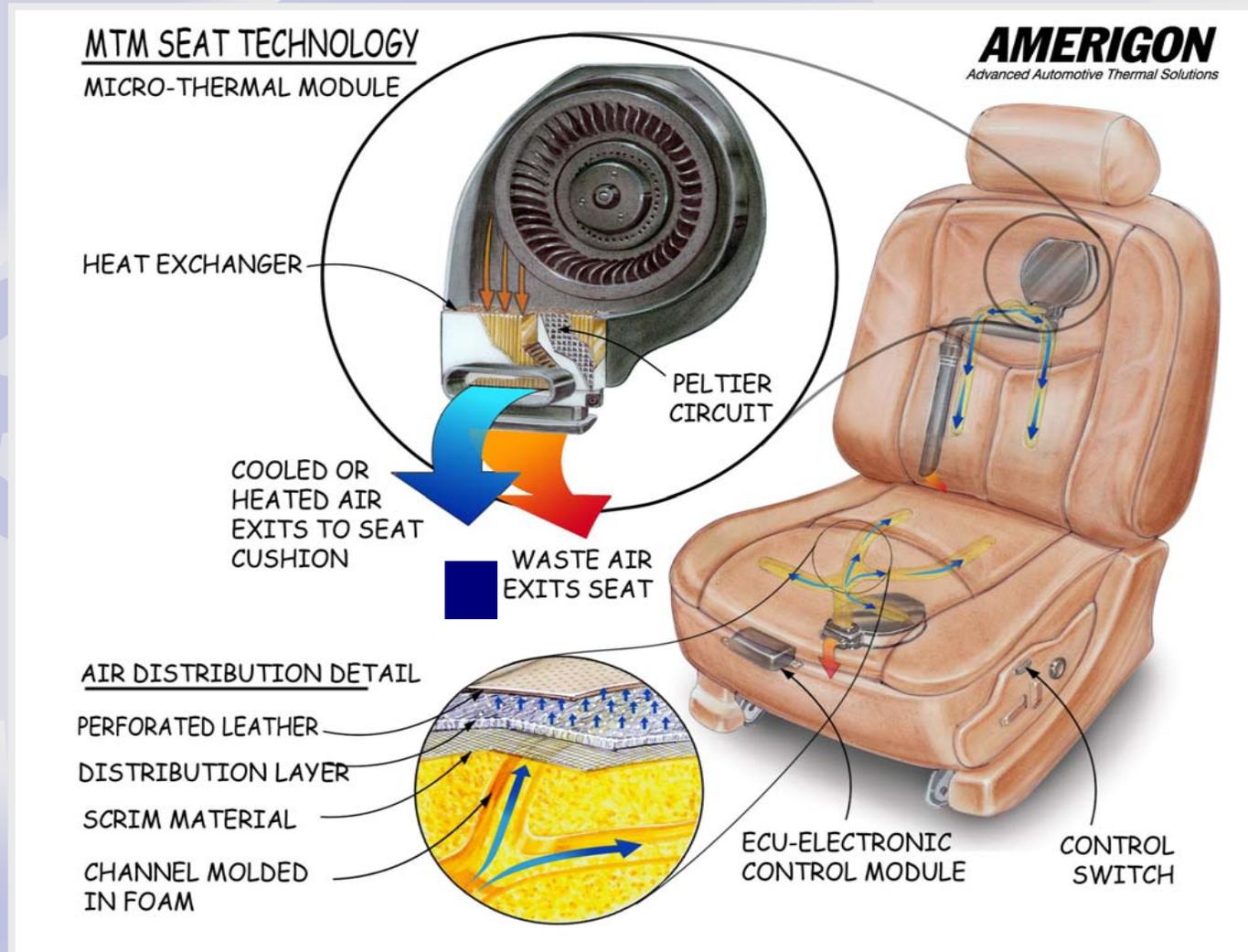
## Current applications

- Amerigo
- Cooling liquid to  $100^{\circ}\text{C}$   $\rightarrow$   $0^{\circ}\text{C}$
- Supplement air TEDs cooling using liquid to  $100^{\circ}\text{C}$   $\rightarrow$   $0^{\circ}\text{C}$
- Spot cooling air TEDs

## Long term goals

- Primary HVAC systems

# Product Roadmap: Amerigon's CCS



Detroit, Michigan- DEER 2006  
August 20-24, 2006

# Amerigon Current CCS™ Vehicle Lines



2007 Escalade (ESV, EXT)



Nissan Cima



Cadillac (XLR, DTS)



Toyota Century



Toyota Celsior\*



Lincoln LS



Lincoln Expedition



Nissan Fuga



2006 Buick Lucerne



Lincoln LS



Lincoln Aviator



Lexus LS 430\*



Hyundai Equus\*

Detroit, Michigan- DEER 2006  
August 20-24, 2006



2006 Lincoln Zephyr



Infiniti (Q45, M45)



Mercury Monterey

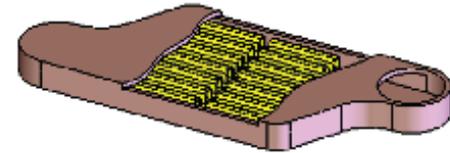
\* Four Seat Systems



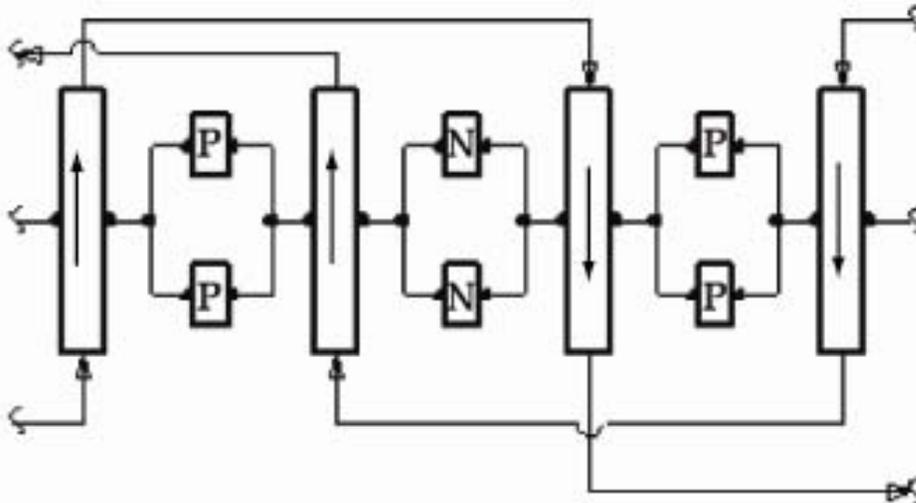
# Product Roadmap: Liquid to Liquid TED for Cooling Electronics

1. The device shall exhibit efficiencies at least 50% greater than that of current commercial TE technology;
2. TE material usage shall be less than 15% that of commercial TE modules
3. The device shall be rugged and have the prospect of being low cost and low system weight;
4. The design shall include electrical redundancy;
5. The design shall be scalable to larger and smaller sizes between 50 and 5,000 watt thermal capacity.

# Product Design



Heat Exchanger



Fluids and Current Paths

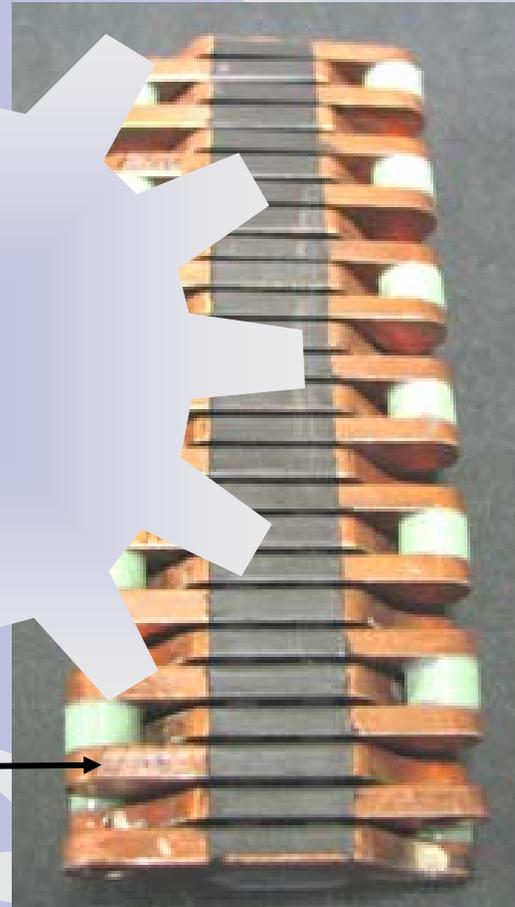
Detroit, Michigan- DEER 2006  
August 20-24, 2006

# TED Subassembly

TE element loc  
exchangers

Fluid duct  
heat exch

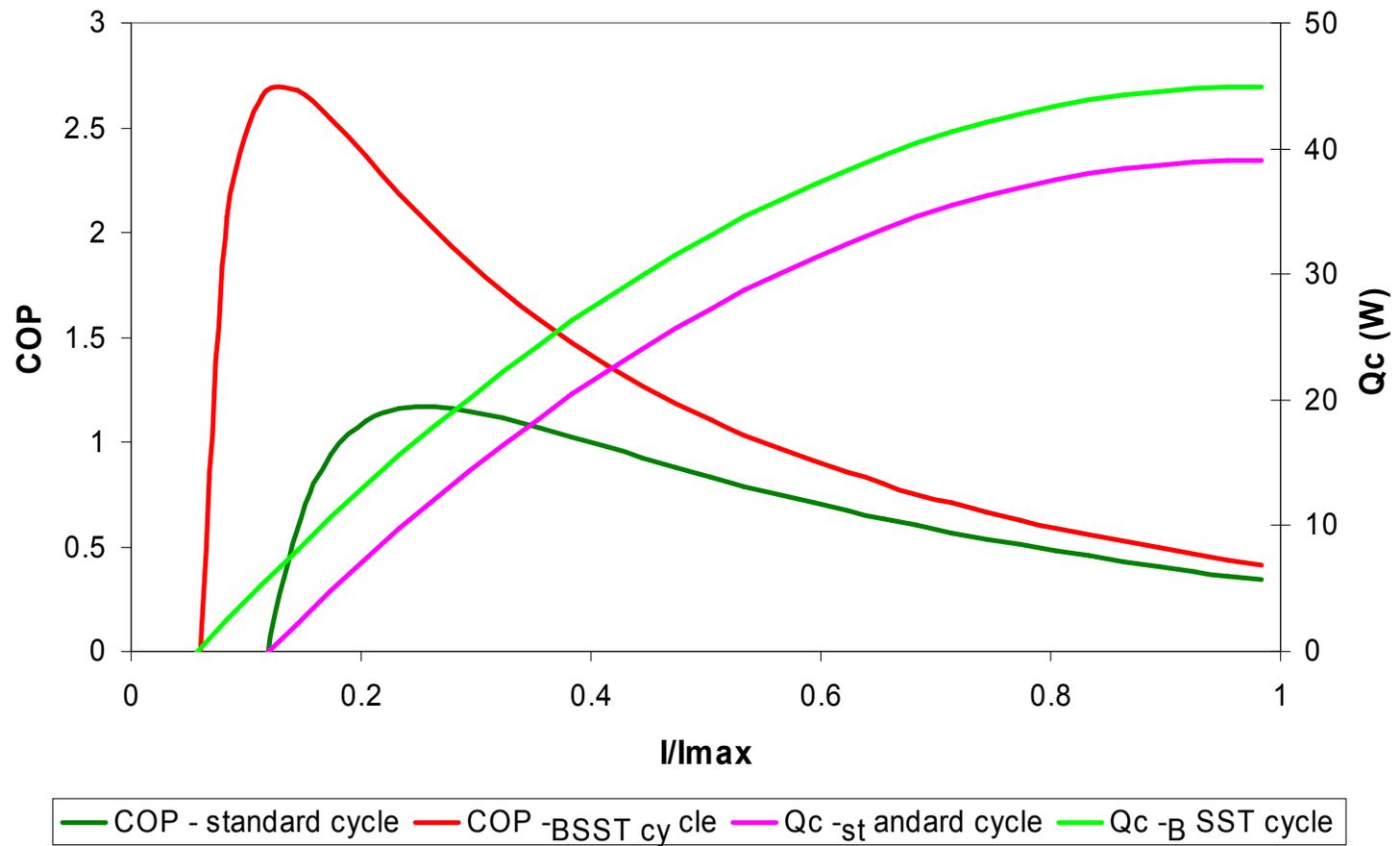
Heat exchangers  
(26 Total,



Breadboard subassembly.

# Power Density Characteristics

TE Performance ( $D_{Th} = D_{Tc} = 15C$ )



# Modeling Inputs (Properties)

stack\_gui
[-] [x]

SINGLE STACK

OPTIMIZATION

**FLOW**

counter

external

**POLARITY**

normal

**END CONDITIONS**

infinite\_heat\_sink

**BASE/FIN METAL**

copper

**HEX DIMENSIONS**

plate thickness  cm

side thickness  cm

TE pad thickness  cm

lincoln log configuration

**TEMPERATURES**

ambient temperature  C

hot inlet temperature  C

cold inlet temperature  C

hot DT  C

cold DT  C

total hot mass flow  cc/s

total cold mass flow  cc/s

hot wall temperature  C

cold wall temperature  C

**TE INFORMATION**

# of elements per stack

TE material

Seebeck coefficient  V/K

electrical resistivity  ohm-cm

thermal conductivity  W/mK

ZT

TE elect. inter. resist.  ohm - m<sup>2</sup>

**FLUID PROPERTIES**

hot fluid	cold fluid
water	water
density	density
997 kg/(m <sup>3</sup> )	997 kg/(m <sup>3</sup> )
thermal conductivity	thermal conductivity
0.613 W/mK	0.613 W/mK
dynamic viscosity	dynamic viscosity
0.000855 Ns/(m <sup>2</sup> )	0.000855 Ns/(m <sup>2</sup> )
specific heat	specific heat
4179 J/kgK	4179 J/kgK

**OTHER**

pump efficiency

thermal interfacial resistance  (m<sup>2</sup>)K/W

English Un...

Metric Units

**SOLDER**

bulk electrical resistivity  ohm-cm

electrical interfacial resistivity  ohm-cm<sup>2</sup>

bulk thermal conductivity  W/mK

thickness  cm

**BRAZE**

bulk electrical resistivity  ohm-cm

electrical interfacial resistivity  ohm-cm<sup>2</sup>

bulk thermal conductivity  W/mK

thickness  cm

SAVE CONDITIONS

filename

LOAD CONDITIONS

newport\_cond

# Modeling Inputs (Properties)

stack\_gui

SINGLE STACK

OPTIMIZATION

**FLOW**

counter

external

**POLARITY**

normal

**END CONDITIONS**

infinite\_heat\_sink

**BASE/FIN METAL**

copper

**HEX DIMENSIONS**

plate thickness: 0.0508 cm

side thickness: 0.0508 cm

TE pad thickness: 0 cm

lincoln log configuration

**TEMPERATURES**

ambient temperature: 42 C

hot inlet temperature: 41 C

cold inlet temperature: 38 C

hot DT: 10 C  total hot mass flow: 221 cc/s

cold DT: 6 C  total cold mass flow: 20 cc/s

hot wall temperature: 40.56 C

cold wall temperature: 38.33 C

**TE INFORMATION**

# of elements per stack: 25

TE material: Bi2Te3

Seebeck coefficient: 0.0002 V/K

electrical resistivity: 0.001 ohm-cm

thermal conductivity: 1.5 W/mK

ZT: 0.8

TE elect. inter. resist.: 2e-010 ohm-m<sup>2</sup>

**FLUID PROPERTIES**

hot fluid	cold fluid
water	water
density: 997 kg/(m <sup>3</sup> )	density: 997 kg/(m <sup>3</sup> )
thermal conductivity: 0.613 W/mK	thermal conductivity: 0.613 W/mK
dynamic viscosity: 0.000855 Ns/(m <sup>2</sup> )	dynamic viscosity: 0.000855 Ns/(m <sup>2</sup> )
specific heat: 4179 J/kgK	specific heat: 4179 J/kgK

**OTHER**

pump efficiency: 0.5

thermal interfacial resistance: 1e-007 (m<sup>2</sup>)K/W

English Un...  
 Metric Units

**SOLDER**

bulk electrical resistivity: .65e-005 ohm-cm

electrical interfacial resistivity: 3e-009 ohm-cm<sup>2</sup>

bulk thermal conductivity: 52.4 W/mK

thickness: 0.0051 cm

**BRAZE**

bulk electrical resistivity: 2.2e-006 ohm-cm

electrical interfacial resistivity: 3e-008 ohm-cm<sup>2</sup>

bulk thermal conductivity: 421.6 W/mK

thickness: 0.0076 cm

SAVE CONDITIONS filename

LOAD CONDITIONS newport\_cond

# Modeling Inputs (Properties)

stack\_gui

SINGLE STACK

OPTIMIZATION

**FLOW**

counter

external

**POLARITY**

normal

**END CONDITIONS**

infinite\_heat\_sink

**BASE/FIN METAL**

copper

**TEMPERATURES**

ambient temperature: 42 C

hot inlet temperature: 41 C

cold inlet temperature: 38 C

hot DT: 10 C  total hot mass flow: 221 cc/s

cold DT: 6 C  total cold mass flow: 20 cc/s

hot wall temperature: 40.56 C

cold wall temperature: 38.33 C

**TE INFORMATION**

# of elements per stack: 25

TE material: Bi2Te3

Seebeck coefficient: 0.0002 V/K

electrical resistivity: 0.001 ohm-cm

thermal conductivity: 1.5 W/mK

ZT: 0.8

TE elect. inter. resist.: 2e-010 ohm - m<sup>2</sup>

**FLUID PROPERTIES**

hot fluid	cold fluid
water	water
density: 997 kg/(m <sup>3</sup> )	density: 997 kg/(m <sup>3</sup> )
thermal conductivity: 0.613 W/mK	thermal conductivity: 0.613 W/mK
dynamic viscosity: 0.000855 Ns/(m <sup>2</sup> )	dynamic viscosity: 0.000855 Ns/(m <sup>2</sup> )
specific heat: 4179 J/kgK	specific heat: 4179 J/kgK

**OTHER**

pump efficiency: 0.5

thermal interfacial resistance: 1e-007 (m<sup>2</sup>)K/W

English Un...  
 Metric Units

**SAVE CONDITIONS** filename

**LOAD CONDITIONS** newport\_cond

lincoln log configuration

**HEX DIMENSIONS**

plate thickness: 0.0508 cm

side thickness: 0.0508 cm

TE pad thickness: 0 cm

**SOLDER**

bulk electrical resistivity: .65e-005 ohm-cm

electrical interfacial resistivity: 3e-009 ohm-cm<sup>2</sup>

bulk thermal conductivity: 52.4 W/mK

thickness: 0.0051 cm

**BRAZE**

bulk electrical resistivity: 2.2e-006 ohm-cm

electrical interfacial resistivity: 3e-008 ohm-cm<sup>2</sup>

bulk thermal conductivity: 421.6 W/mK

thickness: 0.0076 cm

# Modeling Inputs (Properties)

stack\_gui

SINGLE STACK

OPTIMIZATION

**FLOW**

counter

external

**POLARITY**

normal

infinite\_heat\_sink

**BASE/FIN METAL**

copper

**HEX DIMENSIONS**

plate thickness: 0.0508 cm

side thickness: 0.0508 cm

TE pad thickness: 0 cm

lincoln log configuration

**TEMPERATURES**

ambient temperature: 42 C

hot inlet temperature: 41 C

cold inlet temperature: 38 C

hot DT: 10 C  total hot mass flow: 221 cc/s

cold DT: 6 C  total cold mass flow: 20 cc/s

hot wall temperature: 40.56 C

cold wall temperature: 38.33 C

**TE INFORMATION**

# of elements per stack: 25

TE material: Bi2Te3

Seebeck coefficient: 0.0002 V/K

electrical resistivity: 0.001 ohm-cm

thermal conductivity: 1.5 W/mK

ZT: 0.8

TE elect. inter. resist.: 2e-010 ohm - m<sup>2</sup>

**FLUID PROPERTIES**

hot fluid	cold fluid
water	water
density: 997 kg/(m <sup>3</sup> )	density: 997 kg/(m <sup>3</sup> )
thermal conductivity: 0.613 W/mK	thermal conductivity: 0.613 W/mK
dynamic viscosity: 0.000855 Ns/(m <sup>2</sup> )	dynamic viscosity: 0.000855 Ns/(m <sup>2</sup> )
specific heat: 4179 J/kgK	specific heat: 4179 J/kgK

**OTHER**

pump efficiency: 0.5

thermal interfacial resistance: 1e-007 (m<sup>2</sup>)K/W

English Un...  
 Metric Units

**SOLDER**

bulk electrical resistivity: .65e-005 ohm-cm

electrical interfacial resistivity: 3e-009 ohm-cm<sup>2</sup>

bulk thermal conductivity: 52.4 W/mK

thickness: 0.0051 cm

**BRAZE**

bulk electrical resistivity: 2.2e-006 ohm-cm

electrical interfacial resistivity: 3e-008 ohm-cm<sup>2</sup>

bulk thermal conductivity: 421.6 W/mK

thickness: 0.0076 cm

filename

newport\_cond

# Modeling Inputs (Properties)

stack\_gui
[-] [x]

SINGLE STACK

OPTIMIZATION

**FLOW**

counter

external

**POLARITY**

normal

**END CONDITIONS**

infinite\_heat\_sink

**BASE/FIN METAL**

copper

**HEX DIMENSIONS**

plate thickness  
0.0508 cm

side thickness  
0.0508 cm

TE pad thickness  
0 cm

lincoln log configuration

**TEMPERATURES**

ambient temperature  
42 C

hot inlet temperature  
41 C

cold inlet temperature  
38 C

hot DT      total hot mass flow  
10 C       221 cc/s

cold DT      total cold mass flow  
6 C       20 cc/s

hot wall temperature  
40.56 C

cold wall temperature  
38.33 C

**TE INFORMATION**

# of elements per stack  
25

TE material  
Bi2Te3

Seebeck coefficient  
0.0002 V/K

electrical resistivity  
0.001 ohm-cm

thermal conductivity  
1.5 W/mK

ZT  
0.8

TE elect. inter. resist.  
2e-010 ohm - m^2

**FLUID PROPERTIES**

hot fluid water	cold fluid water
density 997 kg/(m^3)	density 997 kg/(m^3)
thermal conductivity 0.613 W/mK	thermal conductivity 0.613 W/mK
dynamic viscosity 0.000855 Ns/(m^2)	dynamic viscosity 0.000855 Ns/(m^2)
specific heat 4179 J/kgK	specific heat 4179 J/kgK

**OTHER**

pump efficiency  
0.5

thermal interfacial resistance  
1e-007 (m^2)K/W

English Un...

Metric Units

**SOLDER**

bulk electrical resistivity  
.65e-005 ohm-cm

electrical interfacial resistivity  
3e-009 ohm-cm^2

bulk thermal conductivity  
52.4 W/mK

thickness  
0.0051 cm

**BRAZE**

bulk electrical resistivity  
2.2e-006 ohm-cm

electrical interfacial resistivity  
3e-008 ohm-cm^2

bulk thermal conductivity  
421.6 W/mK

thickness  
0.0076 cm

SAVE CONDITIONS

filename

LOAD CONDITIONS

newport\_cond

# Modeling Inputs (Dimensions)

single\_analysis

**DESIGN VARIABLES**

hot-side
cold-side

fin density	<input type="text" value="18.5"/> fins/cm	<input type="text" value="18.5"/> fins/cm
fin height	<input type="text" value="0.18"/> cm	<input type="text" value="0.18"/> cm
fin length	<input type="text" value="0.625"/> cm	<input type="text" value="0.625"/> cm
fin thickness	<input type="text" value="0.0127"/> cm	<input type="text" value="0.0127"/> cm
heat exchanger width	<input type="text" value="1.5"/> cm	<input type="text" value="1.5"/> cm

switch hot/cold

TE leg width  cm

TE leg length  cm<sup>2</sup>

TE leg area  cm

TE leg thickness  cm

total elements

total desired flow  (cm<sup>3</sup>)/s

heating - main  
 cooling - main

current  A

(export for Simulink)

English Unit System  
 Metric Unit System

use entered current  
 use optimal current  
 use current for desired flow

use pump in COP  
 current for max heat pump  
 save results to file

**OUTPUTS**

COP

mass flow/stack hot DT (F)  g/s

mass flow/stack cold DT (F)  g/s

input power/stack  W

total voltage  V

power density  W/(cm<sup>3</sup>)

ZT

maximum current  A

accessory power  W

pressure drop - hot  Pa

pressure drop - cold  Pa

total TE volume  cm<sup>3</sup>

total hex volume  cm<sup>3</sup>

# Modeling Inputs (Dimensions)

single\_analysis

**DESIGN VARIABLES**

hot-side cold-side switch hot/cold

fin density: 18.5 fins/cm (hot-side), 18.5 fins/cm (cold-side)

fin height: 0.18 cm (hot-side), 0.18 cm (cold-side)

fin length: 0.625 cm (hot-side), 0.625 cm (cold-side)

fin thickness: 0.0127 cm (hot-side), 0.0127 cm (cold-side)

heat exchanger width: 1.5 cm (hot-side), 1.5 cm (cold-side)

TE leg width: 1.2 cm

TE leg length: 1.08 cm

TE leg area: 1.08 cm<sup>2</sup>

TE leg thickness: 0.06 cm

total elements: 675

total desired flow: 20 (cm<sup>3</sup>)/s

heating - main

cooling - main

current: 100 A

RESET PRINT LOAD CONFIGURATION

newport\_config

English Unit System

Metric Unit System

use entered current

use optimal current

use current for desired flow

use pump in COP

current for max heat pump

save results to file

filename.bt

**OUTPUTS**

COP: 0

mass flow/stack hot DT (F): 0 g/s, 0

mass flow/stack cold DT (F): 0 g/s, 0

input power/stack: 0 W

total voltage: 0 V

power density: 0 W/(cm<sup>3</sup>)

ZT: 0

maximum current: 0 A

accessory power: 0 W

pressure drop - hot: 0 Pa

pressure drop - cold: 0 Pa

total TE volume: 0 cm<sup>3</sup>

total hex volume: 0 cm<sup>3</sup>

RUN MAIN TRANSIENT (export for Simulink)

# Modeling Inputs (Dimensions)

single\_analysis

**DESIGN VARIABLES**

hot-side cold-side switch hot/cold

fin density 18.5 fins/cm 18.5 fins/cm

fin height 0.18 cm 0.18 cm

fin length 0.625 cm 0.625 cm

fin thickness 0.0127 cm 0.0127 cm

heat exchanger width 1.5 cm 1.5 cm

TE leg width 1.2 cm

TE leg length 0.9 cm

TE leg thickness 0.06 cm

TE leg area 1.08 cm<sup>2</sup>

total elements 675

total desired flow 20 (cm<sup>3</sup>)/s

heating - main

cooling - main

current 100 A

RESET PRINT

RUN MAIN TRANSIENT (export for Simulink)

LOAD CONFIGURATION

newport\_config

English Unit System

Metric Unit System

use entered current

use optimal current

use current for desired flow

use pump in COP

current for max heat pump

save results to file

filename.bt

**OUTPUTS**

COP 0

mass flow/stack hot DT (F) 0 g/s 0

mass flow/stack cold DT (F) 0 g/s 0

input power/stack 0 W

total voltage 0 V

power density 0 W/(cm<sup>3</sup>)

ZT 0

maximum current 0 A

accessory power 0 W

pressure drop - hot 0 Pa

pressure drop - cold 0 Pa

total TE volume 0 cm<sup>3</sup>

total hex volume 0 cm<sup>3</sup>

# Modeling Outputs

single\_analysis

**DESIGN VARIABLES**

hot-side cold-side switch hot/cold

fin density 18.5 fins/cm 18.5 fins/cm

fin height 0.18 cm 0.18 cm

fin length 0.625 cm 0.625 cm

fin thickness 0.0127 cm 0.0127 cm

heat exchanger width 1.5 cm 1.5 cm

TE leg width 1.2 cm

TE leg length 1.08 cm

TE leg thickness 0.06 cm

TE leg area 1.08 cm<sup>2</sup>

total elements 675

total desired flow 221 (cm<sup>3</sup>)/s

heating - main

cooling - main

current 100 A

RESET PRINT

RUN MAIN TRANSIENT (export for Simulink)

LOAD CONFIGURATION

newport\_config

English Unit System

Metric Unit System

use entered current

use optimal current

use current for desired flow

use pump in COP

current for max heat pump

save results to file

filename.bt

**OUTPUTS**

COP 4.469

mass flow/stack hot DT (F) 8.101 g/s 6.01

mass flow/stack cold DT (F) 3.671 g/s 10.8

input power/stack 20.593 W

total voltage 5.56 V

power density 2.305 W/(cm<sup>3</sup>)

ZT 0.953

maximum current 0 A

accessory power 0.119 W

pressure drop - hot 6166 Pa

pressure drop - cold 2506 Pa

total TE volume 43.35 cm<sup>3</sup>

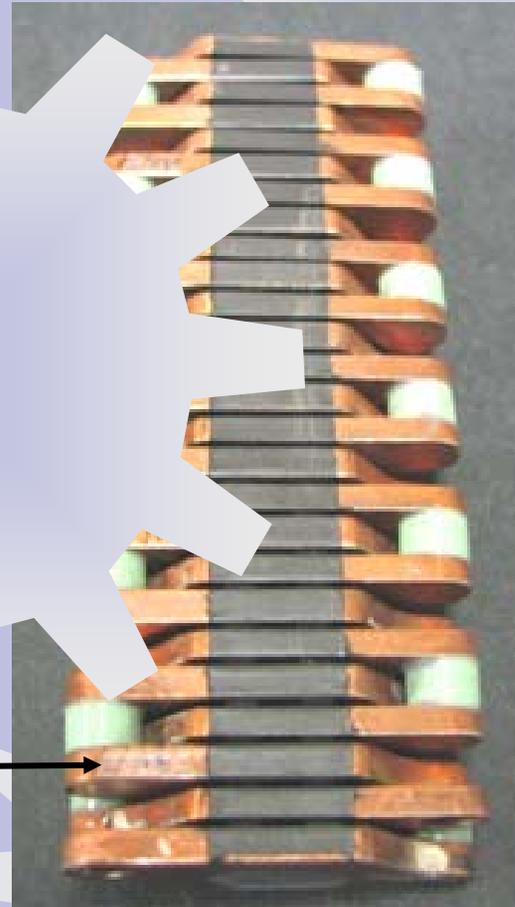
total hex volume 1077.84 cm<sup>3</sup>

# TE Subassembly

TE element loc  
exchangers

Fluid duct  
heat exch

Heat exchangers  
(26 Total,



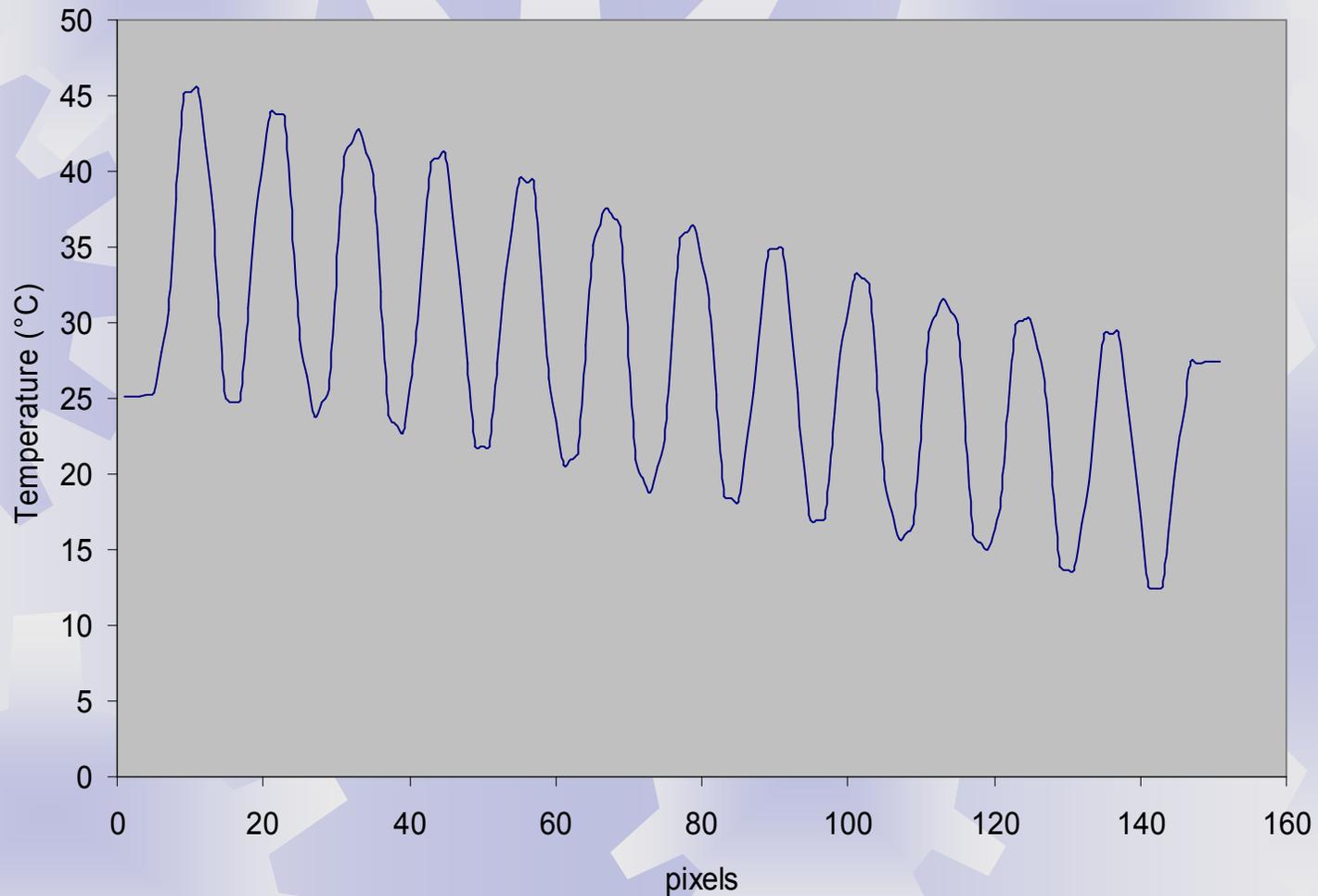
Breadboard subassembly.

# Infrared Camera Image of TED Subassembly



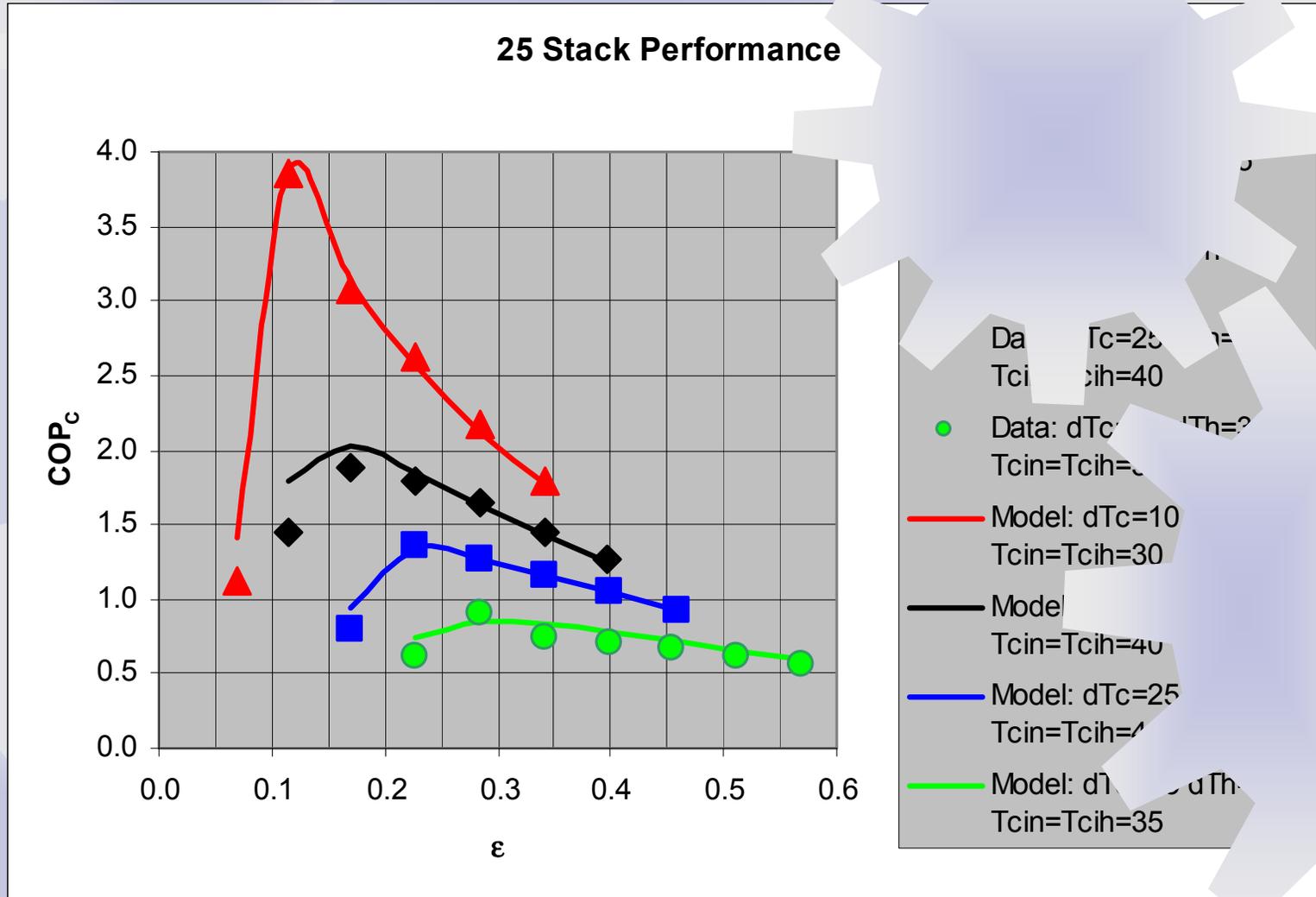
Detroit, Michigan- DEER 2006  
August 20-24, 2006

# Temperature Profile of TED Subassembly (using IR camera)



Detroit, Michigan- DEER 2006  
August 20-24, 2006

# TE Subassembly Simulated and Measured Performance Results



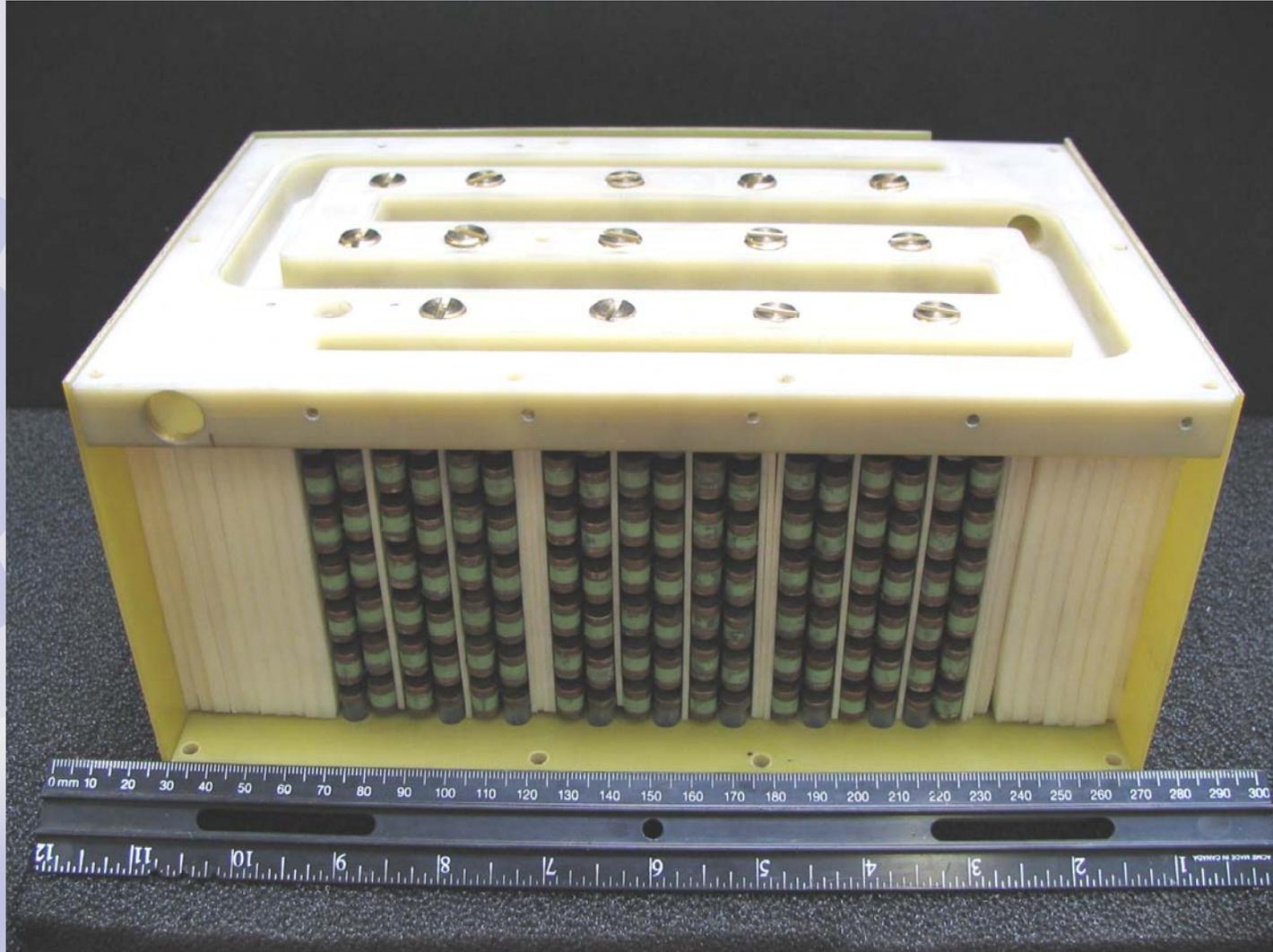
# Properties Comparison of Standard and Stack Design TE Modules

Parameter	Standard	Stack
Thermal cooling power (watts) $\Delta T_c = 10^\circ\text{C}; \Delta T_h = 5^\circ\text{C}$	10	10
TE material weight (grams)	290.0	129.4
Heat Exchanger weight (grams)	290.0	129.4
Weight of other materials (substrates, sealant, wires)		
Total subsystem weight (grams)	485.3	146.8
Volume (liters)	0.0616	0.0521
Power density (watts/liter)	1057	1250
Specific cooling power (watts/gram)	0.134	0.443
Peak efficiency (COP)	2.25	4.20

# Liquid to Liquid TED Design Objectives

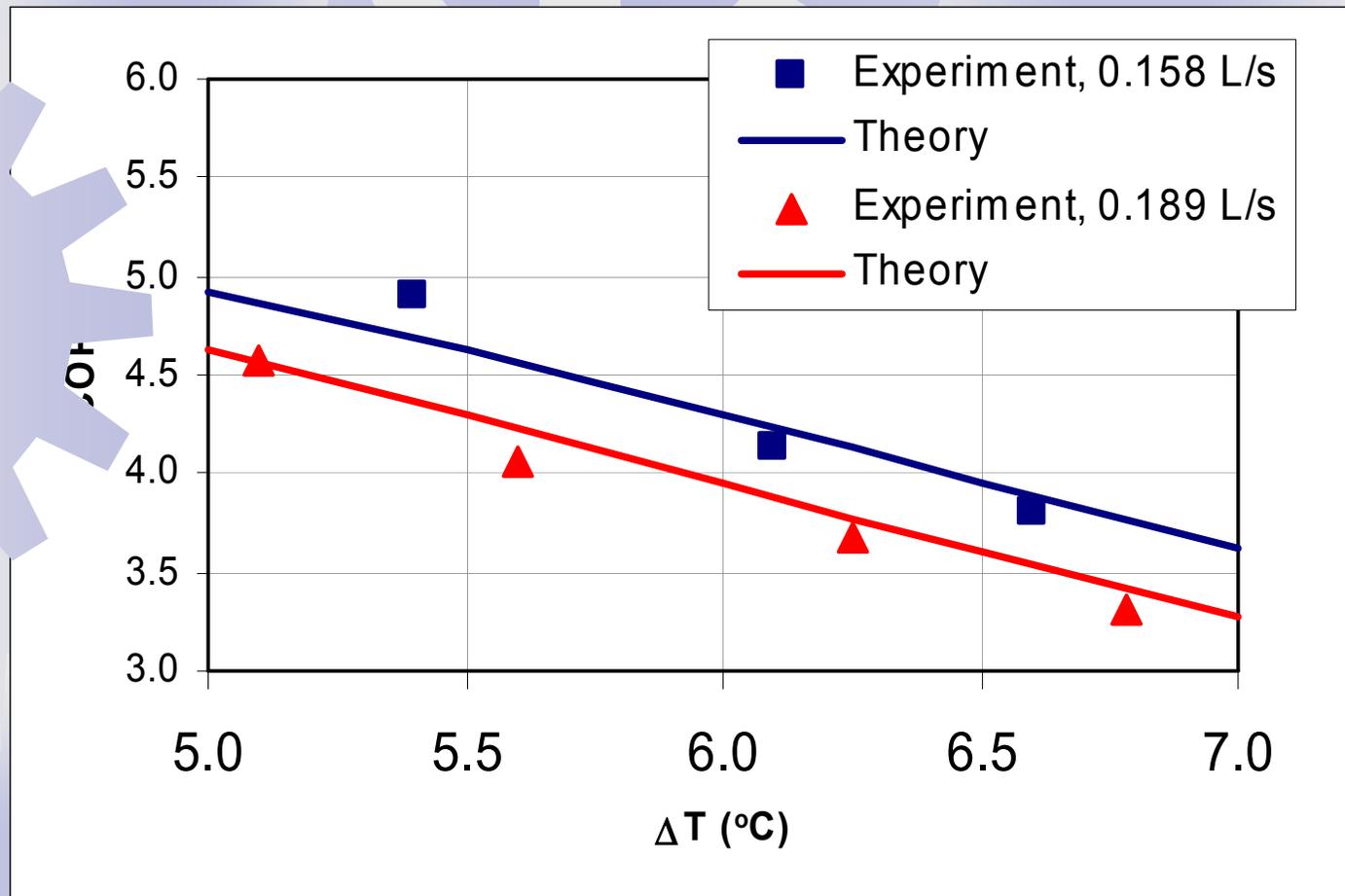
1. The device shall have a minimum cooling capacity of 1.0 Liters/sec
2. The system shall have a maximum cooling flow of 1.19 Liters/sec
3. Electrical power consumption shall be less than 1,000 watts
4. Maximum weight shall be 4.7 Kg
5. Maximum volume shall be 2.0 Liters

# 3500 W Cooler System



Detroit, Michigan- DEER 2006  
August 20-24, 2006

# Comparison of Computed and Experimental Results for 3,500W Cooler



# System Performance Results

Parameter	Final Design
Thermal cooling power at $\Delta T_c = 6^\circ\text{C}$ (watts)	3500
System weight (Kilograms)	4.4
Weight of other materials (shunts, substrates, sealants, wiring) (Kilograms)	C
Total system weight (Kilograms)	4.6
Volume (Liters)	
Power density (Kilowatts/liter)	2.26
Specific cooling power (watts/gram)	0.76
Peak efficiency (COP)	4.25

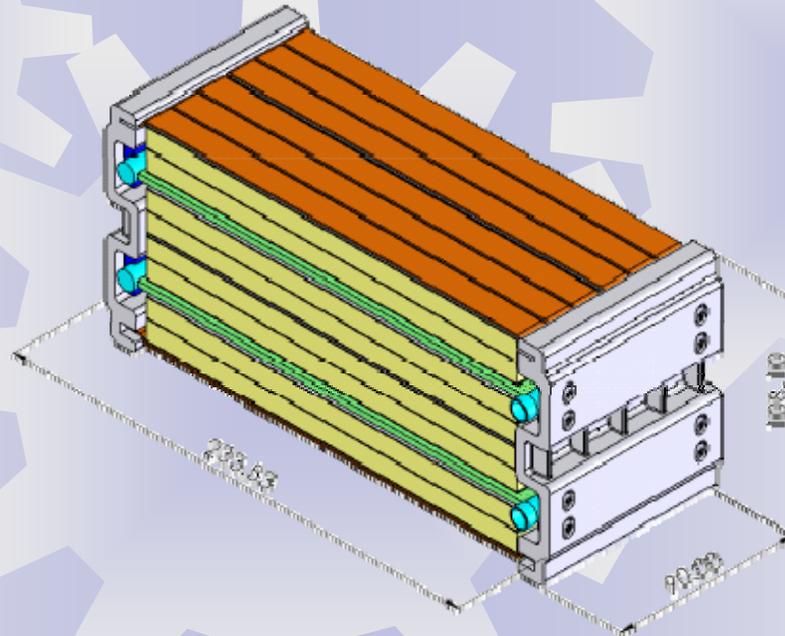
# Liquid to Air TED

Designed to provide efficient heating and cooling in vehicle compartments

## Performance

- In heating mode, provides 2500 watts of heat from liquid to the air achieving a nominal  $\Delta T$  of 20C (2500 watts @ 1000 watts electrical input power)
- In cooling mode, provides 1500 watts of heat from air to the liquid and achieves a nominal  $\Delta T$  of 15C (1500 watts of cooling @ 1000 watts electrical input power)
- Nominal  $\Delta T$  in air – 20C lift in heating and 15C depression in cooling

# Liquid-air thermoelectric heater/cooler



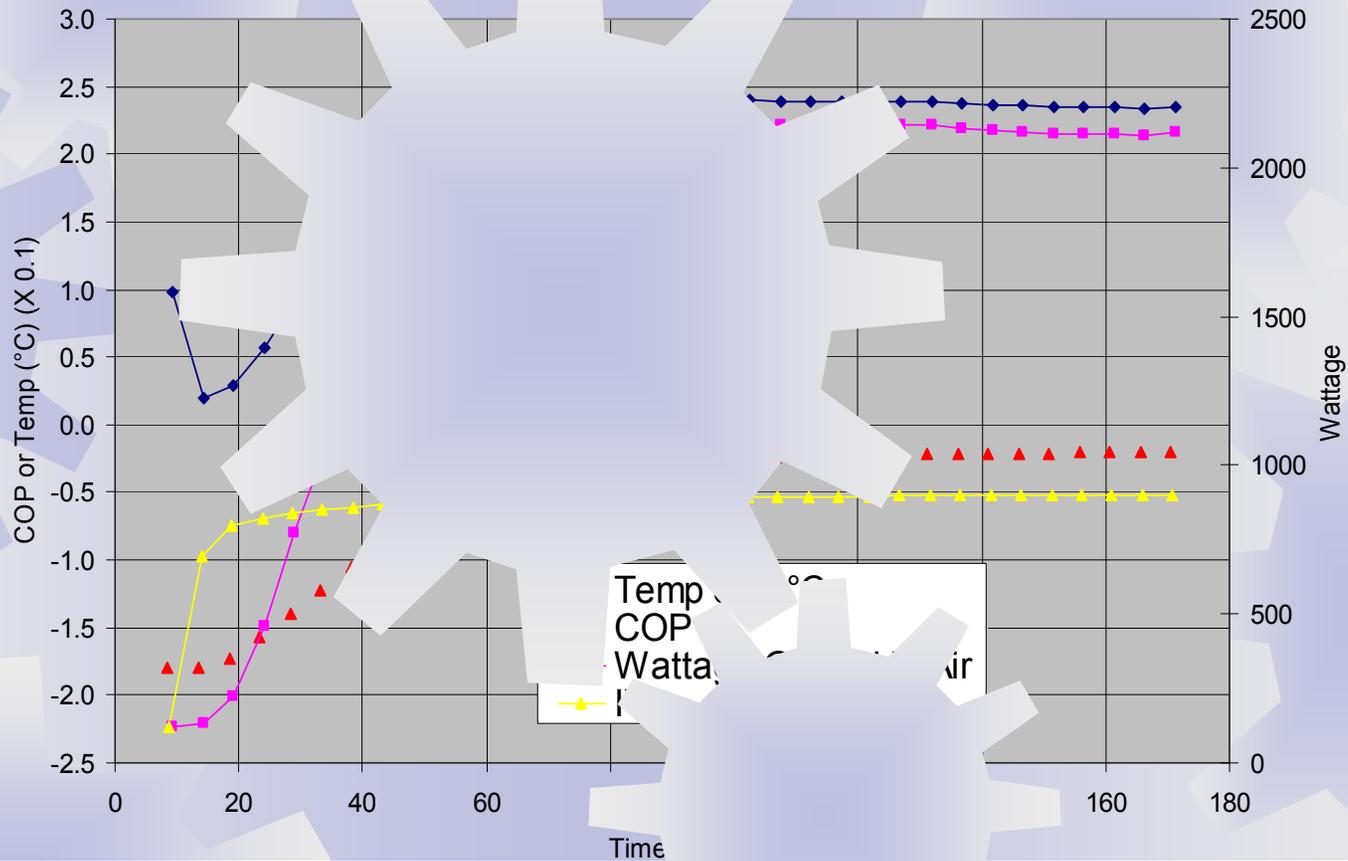
	Heating Mode		Cooling Mode
Qin (W)	820	Qout (W)	820
Qin (W)	240	Qin (W)	220
COP	2.8	COP	1.5
Airflow rate (Lit/s)	28.5	Airflow rate (Lit/s)	18.0
water flow rate (cool)	60	water flow rate (cool)	60
$\Delta T_{air}(C)$	28	$\Delta T_{air}(C)$	-18
$\Delta T_{water}(C)$	-1.4	$\Delta T_{water}(C)$	2.0
T <sub>air_inlet</sub> (C)	28	T <sub>air_inlet</sub> (C)	28
T <sub>water_inlet</sub> (C)	28	T <sub>water_inlet</sub> (C)	28
$\Delta P_{air}(Pa)$	0.255	$\Delta P_{air}(Pa)$	0.08
$\Delta P_{water}(Pa)$	0.1	$\Delta P_{water}(Pa)$	0.1

Volume: 234300

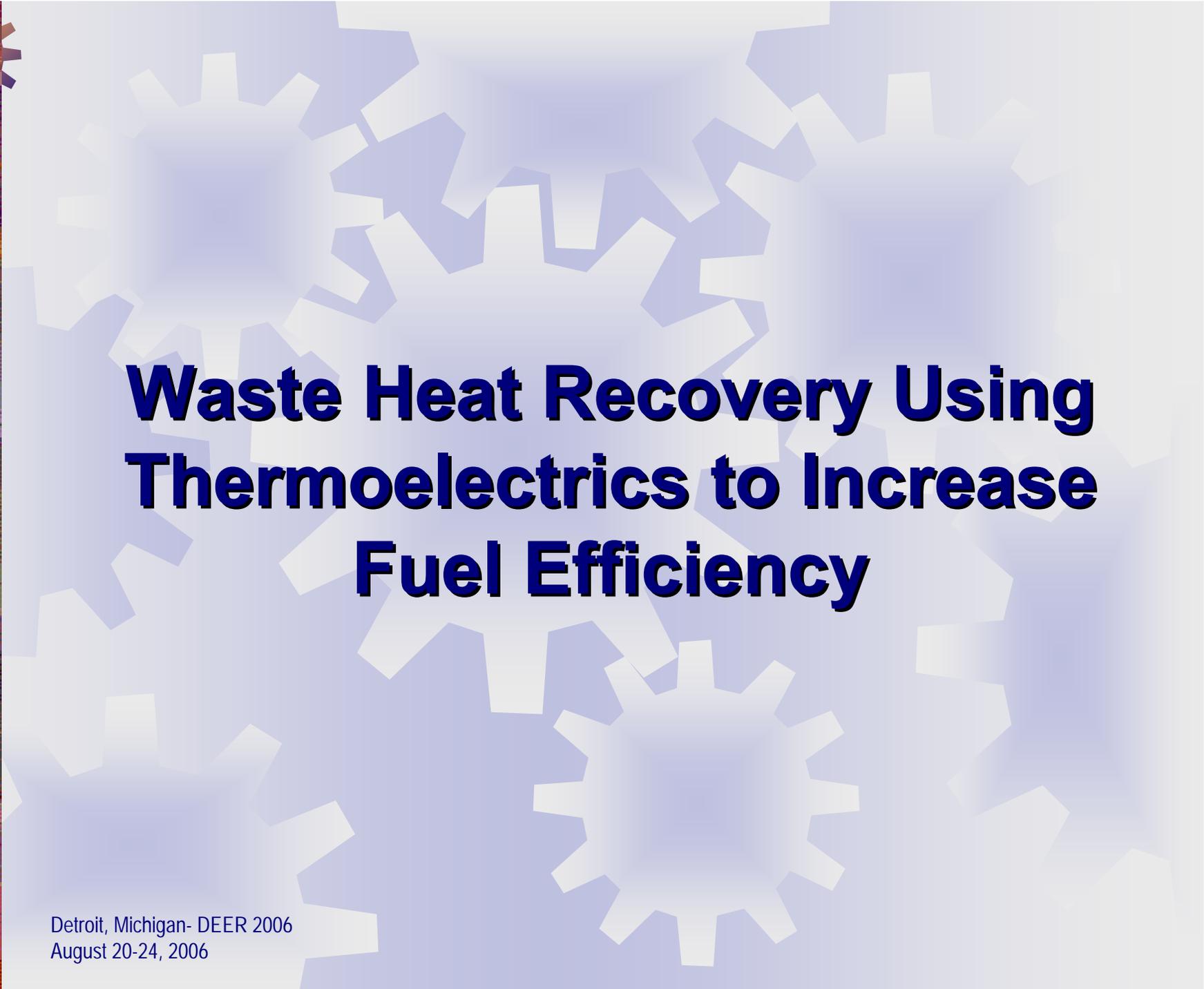
DWG NAME: TABLE TOP UNIT  
 DWG No: 060044036  
 REV: A  
 UNIT: mm  
 SCALE: 1:1  
 DATE: 3/1/06

# Liquid to Air Heating Performance

-20C Air, -20C Liquid, De Air = 18.5, Liquid Flow 10 L/ min, Air Flow 190 CFM



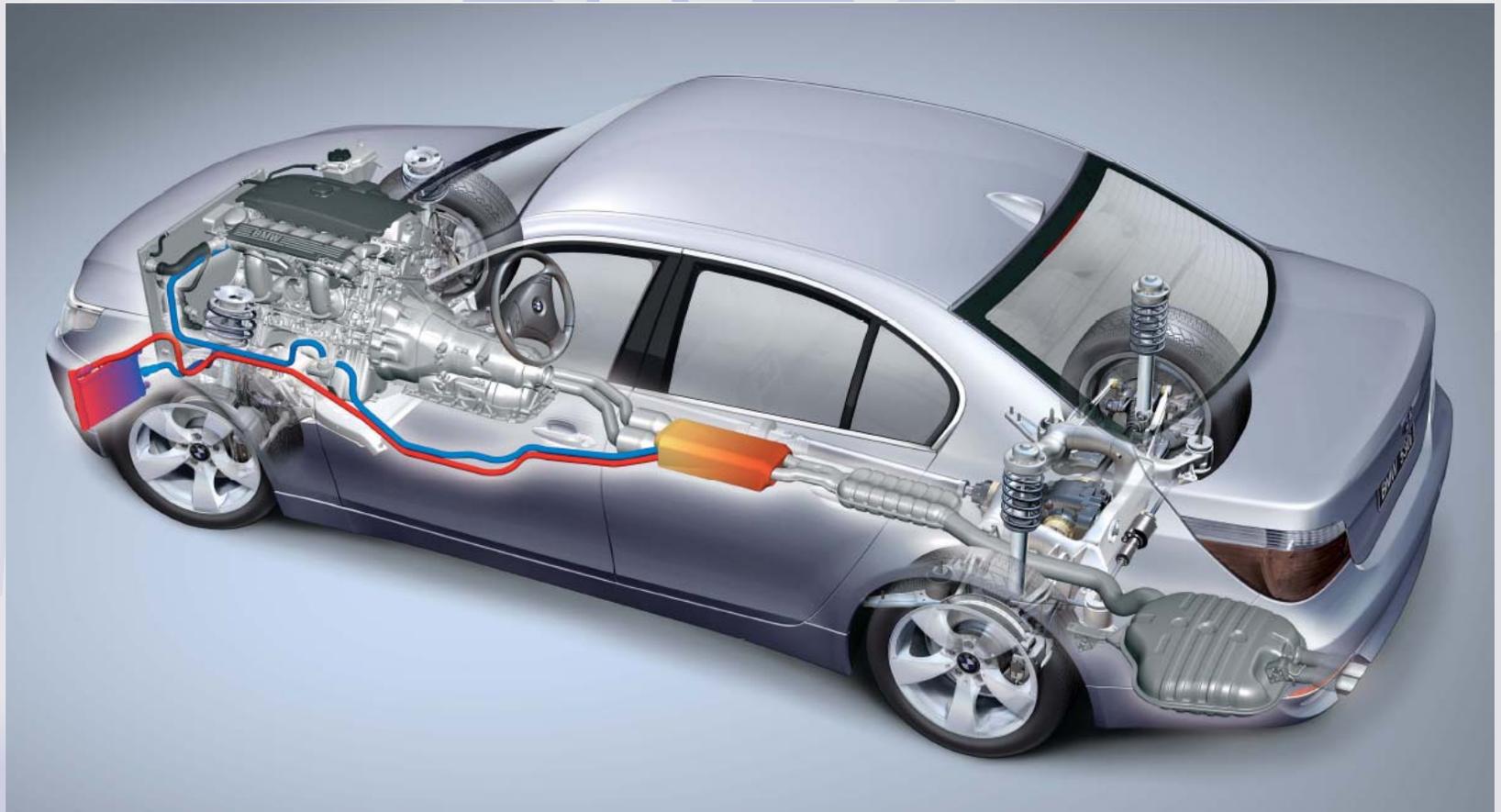
COP of 2.5 predicted and experimentally validated



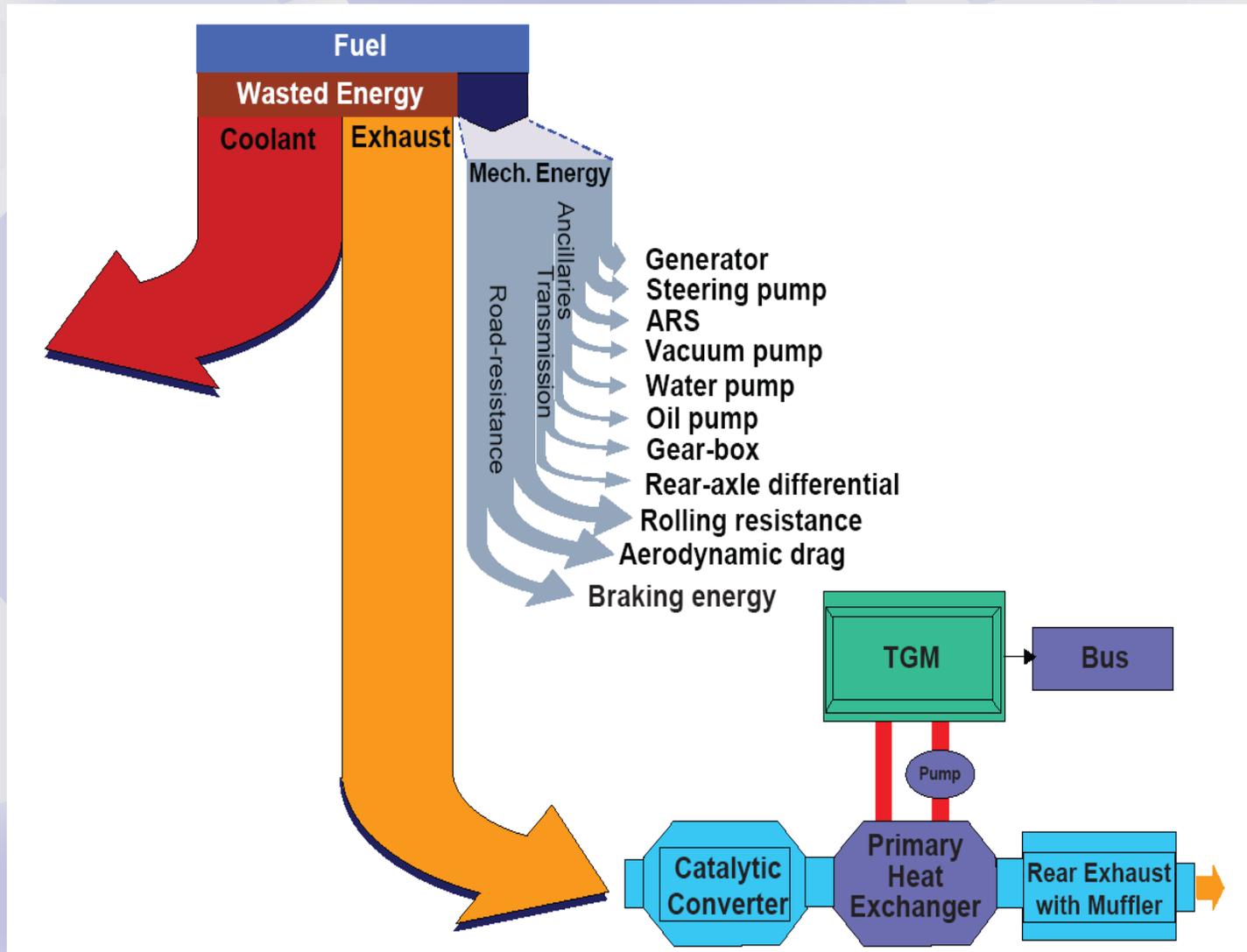
# **Waste Heat Recovery Using Thermoelectrics to Increase Fuel Efficiency**

Detroit, Michigan- DEER 2006  
August 20-24, 2006

# Thermal Management. Thermoelectric Generator.

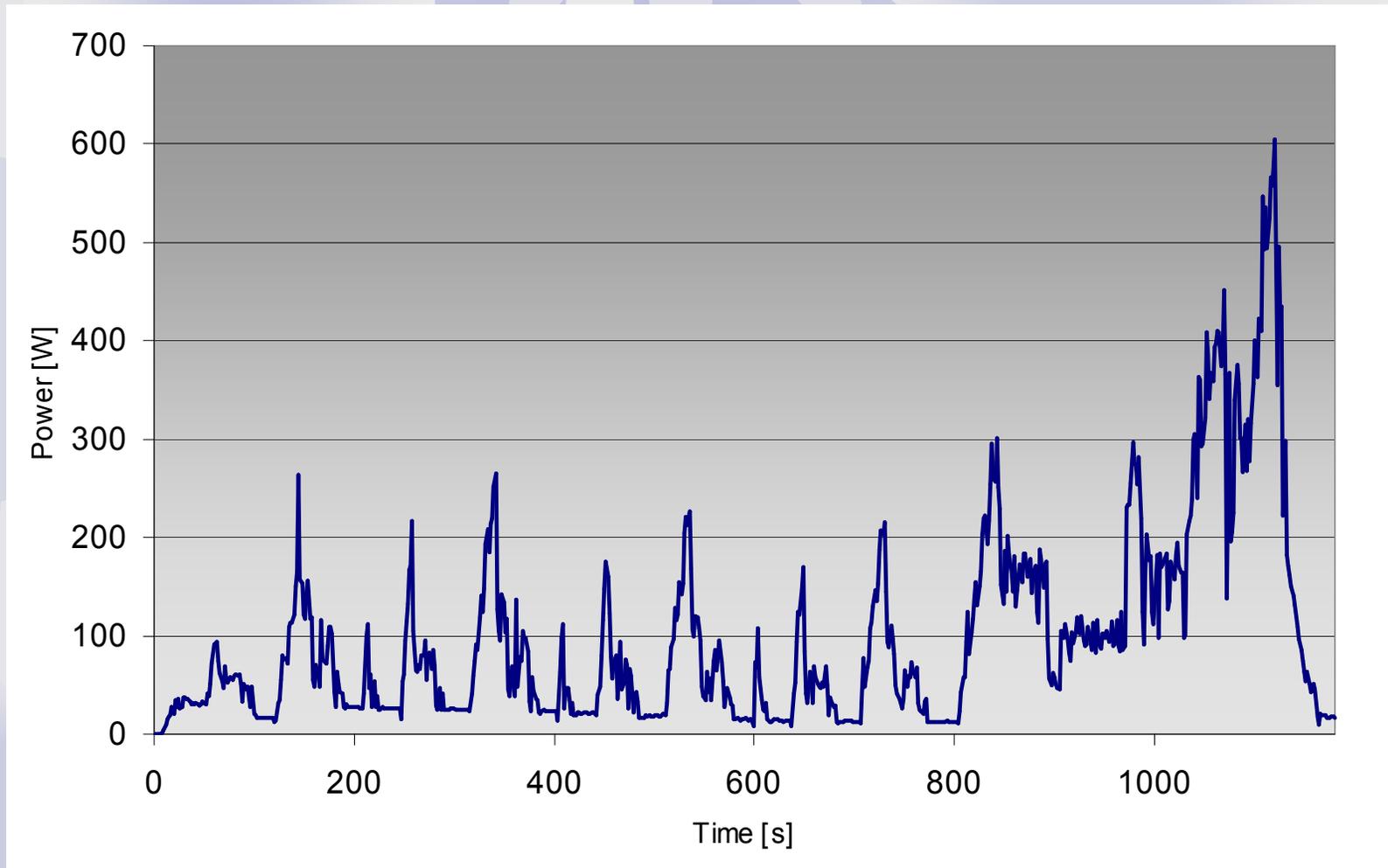


# System Block Diagram



# System Modeling

Electrical power output of the TGM (for NEDC)



Detroit, Michigan- DEER 2006  
August 20-24, 2006



# Summary & Conclusions

Amerigon's Climate Control Seat has validated the application of thermoelectrics in the automotive industry with over 1,000,000 devices sold in 2005 and scheduled volume increases in the next several years

New applications are in development at Amerigon and BSST that achieve improved performance by employing thermal isolation and high density design and construction

1. Performance is improved by about 90% by employing thermal isolation with thermodynamic cycle
2. TE material usage is reduced by a factor of 4 by;
  - a) Using stack design
  - b) Design optimization to reduce unnecessary parasitic losses

Compact, light weight, efficient cooler/heater/temperature devices can be produced with up to at least 5,000 thermal watt output

A thermoelectric waste heat recovery has been modeled to demonstrate 10% fuel economy improvement and key systems will be built and tested this year