Development of a 100-Watt High Temperature Thermoelectric Generator

J. LaGrandeur, D. Crane, L. Bell

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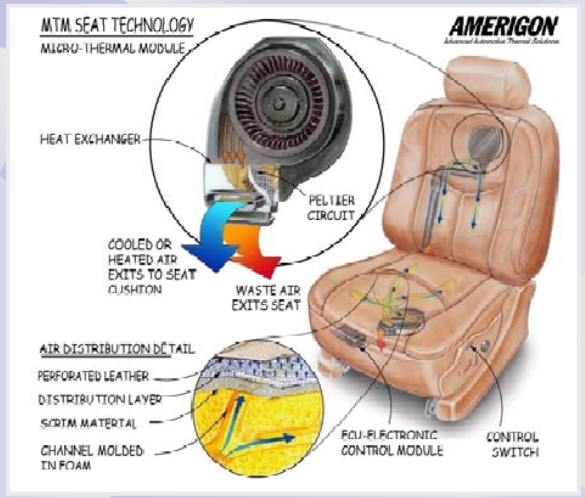
BSST Overview

BSST is a subsidiary of Amerigon and is located in Irwindale, CA (near Los Angeles)

BSST is developing advanced thermoelectric engines for heating, cooling and power generation



Sales & Technical Support

Amerigon Serves the Global Automotive Industry

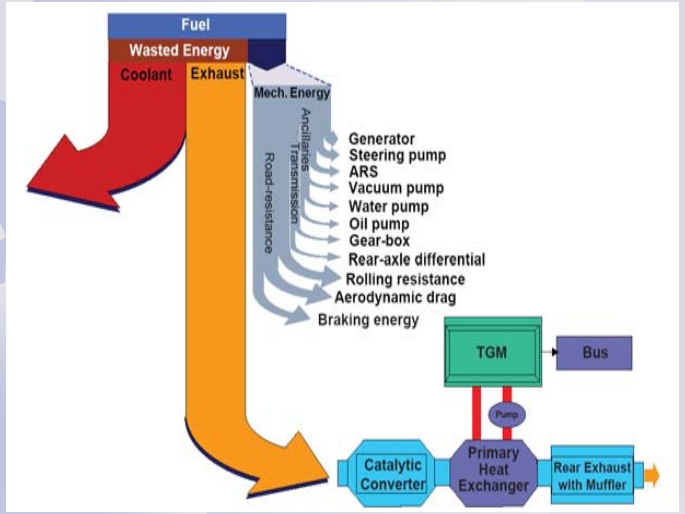
Amerigon CCS Customers include most major OEMs

freedomCAR & vehicle technologies program

In Q4 2004 the US DOE Office of Vehicle Technologies started 4 Thermoelectric Waste Heat Recovery Programs

The Program objectives include:

- 10% fuel efficiency improvement
- Reduced emissions
- A demonstrated path to commercialization and economic feasibility assessment



BSST Waste Heat Recovery Program Overview

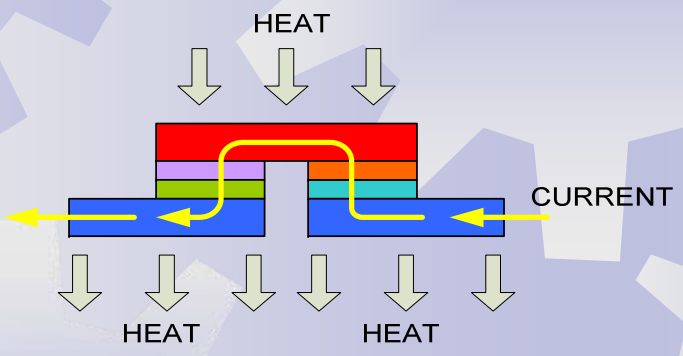
The program is organized into 4 development phases:

- **Phase 1** (Q3 04 thru Q2 05) A system architecture was created and bumper to bumper model created using ADVISOR. Initial system FE savings were shown to reach 12%
- **Phase 2** (Q3 05 thru Q4 06) Key subsystems (Primary Exhaust Gas Heat Exchanger, Thermoelectric Generator Module TGM), Power Conversion Electronics) were built and tested. BMW converted the bumper to bumper model to a Gamma Technologies modeling platform
- **Phase 3** (Q1 07 thru Q3 08) Low and high temp TEGs are being built and tested with other key subsystems:
  - A BiTe TGM, has been built and tested demonstrating > 500 watts electrical power output.
  - A high temperature TEG will be built and tested in Q3 2008 (>100 watts)
  - The Waste Heat Recovery System will be operated on a test bench using a hot gas torch in Q3 2008
- **Phase 4** (Q4 2008 – Q1 2009) A 500 watt high temperature TEG will be integrated and tested with BMW's in line 6 cylinder engine on an engine dynamometer at the Federal Laboratory in NREL Colorado

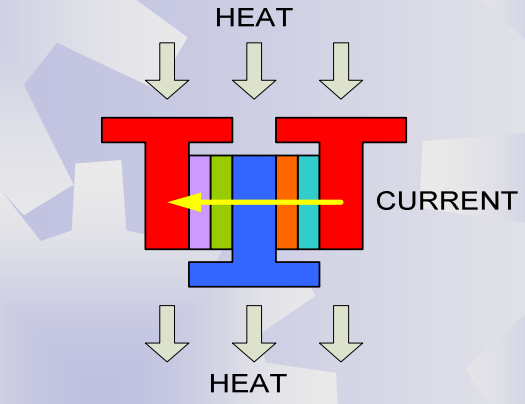
BSST TE Engine

BSST stack design allows:

- Optimum compressive loads for thermal and electrical interfaces
- Tailored n and p type element geometries for highest efficiency

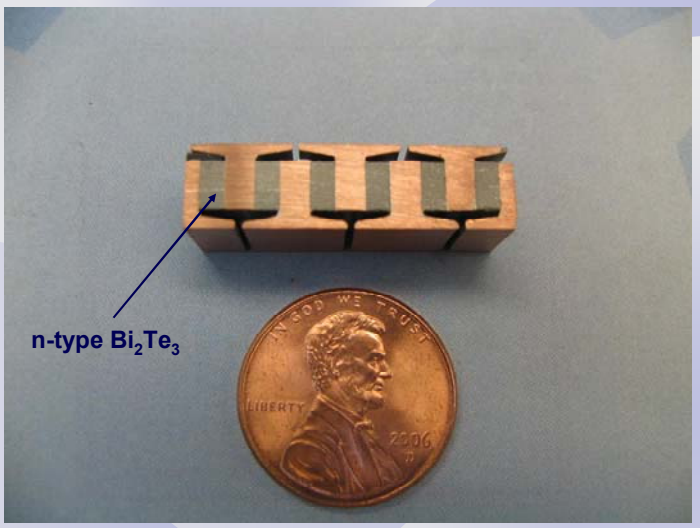


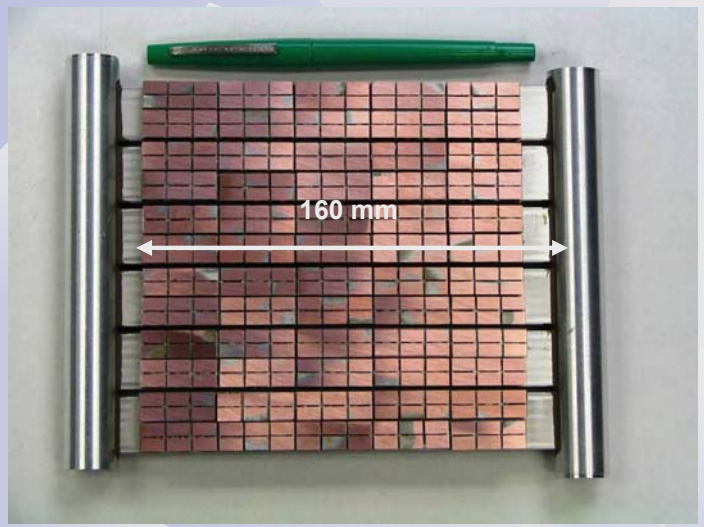
TRADITIONAL CONFIGURATION

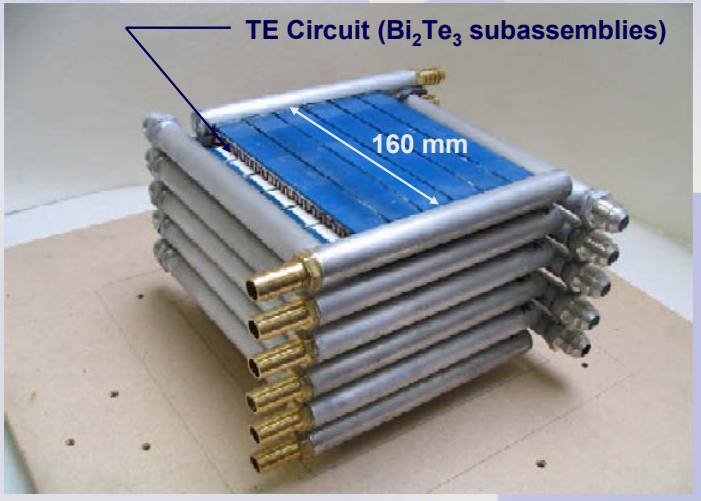


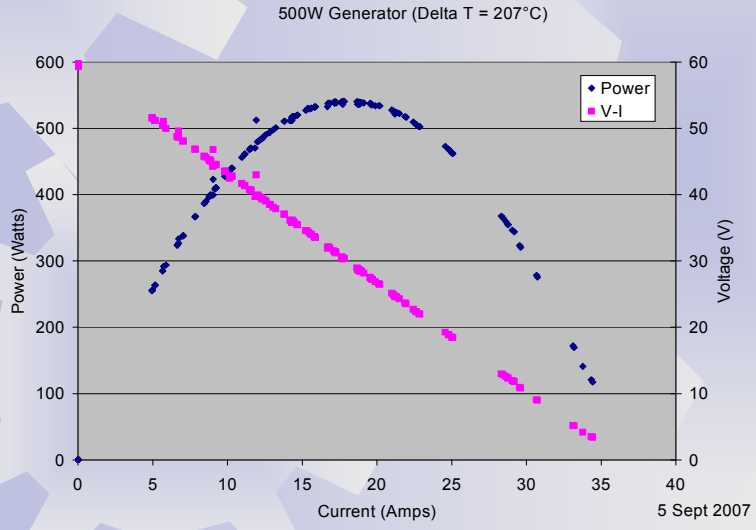
BSST HIGH POWER DENSITY CONFIGURATION

BiTe TEG

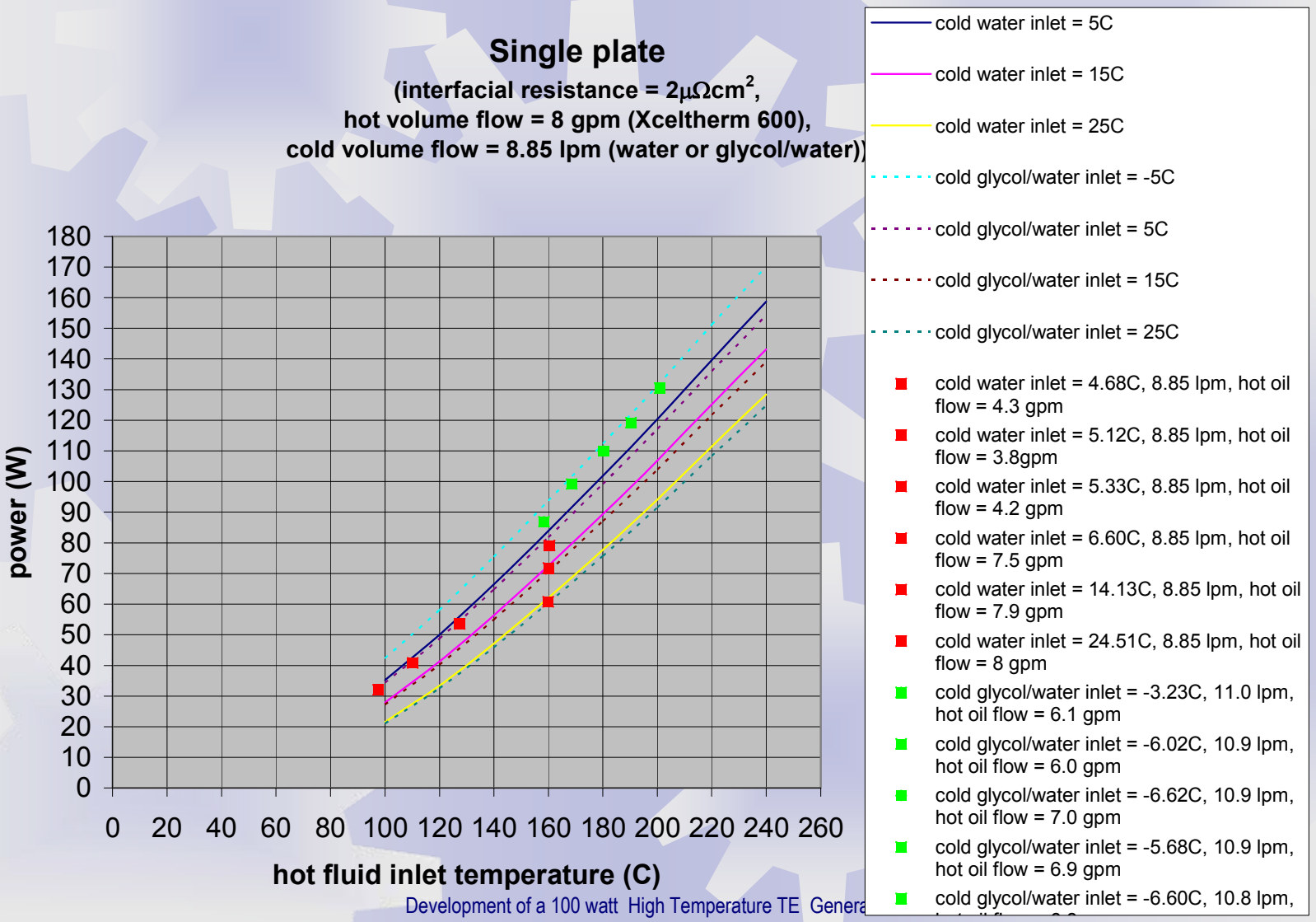

n-type Bi_2Te_3


160 mm


TE Circuit (Bi_2Te_3 subassemblies)
160 mm


500W Generator (Delta T = 207°C)
Power
V-I
Power (Watts)
Voltage (V)
Current (Amps)
5 Sept 2007
0
100
200
300
400
500
600
0
10
20
30
40
50
60
0
5
10
15
20
25
30
35
40

Peak Test Results Compared to Simulations
Measured to simulated values vary by < 5%



TEG Power Management

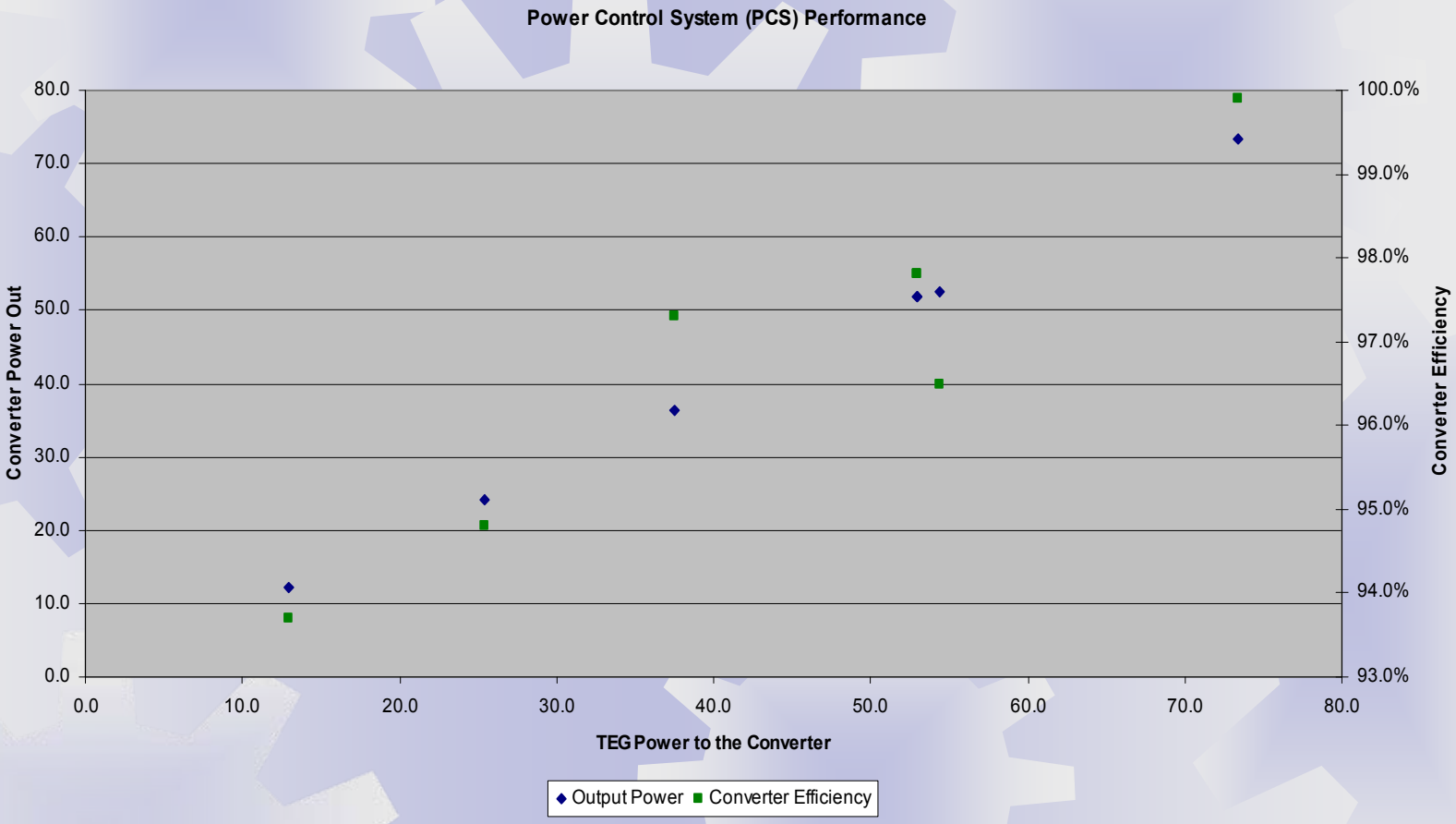
The 100 watt BiTe TEG was tested with a prototype Power Control System (PCS) and resistive load.

The prototype PCS includes:

- Boost and buck converters with microprocessor control to provide a maximum voltage of 12.8 VDC (resistive load maximum operating voltage)
- Serial data interface to report input and output voltage, current, power and converter efficiency

Three 50 watt automotive headlamps were used to test the PCS with the TEG.

PCS Performance- BiTe 100 Watt TEG



High Temperature TEG Design Summary

- Hot side heat exchanger redesigned for 500^0C exhaust gas (BiTe TEG used liquid heat exchangers with 200^0C oil)
- Three different TE subassemblies designed to match exhaust gas temperature gradient in the direction of flow to provide maximum TE material performance
- TEG thermal and electrical interfaces modified to withstand high temperature environment

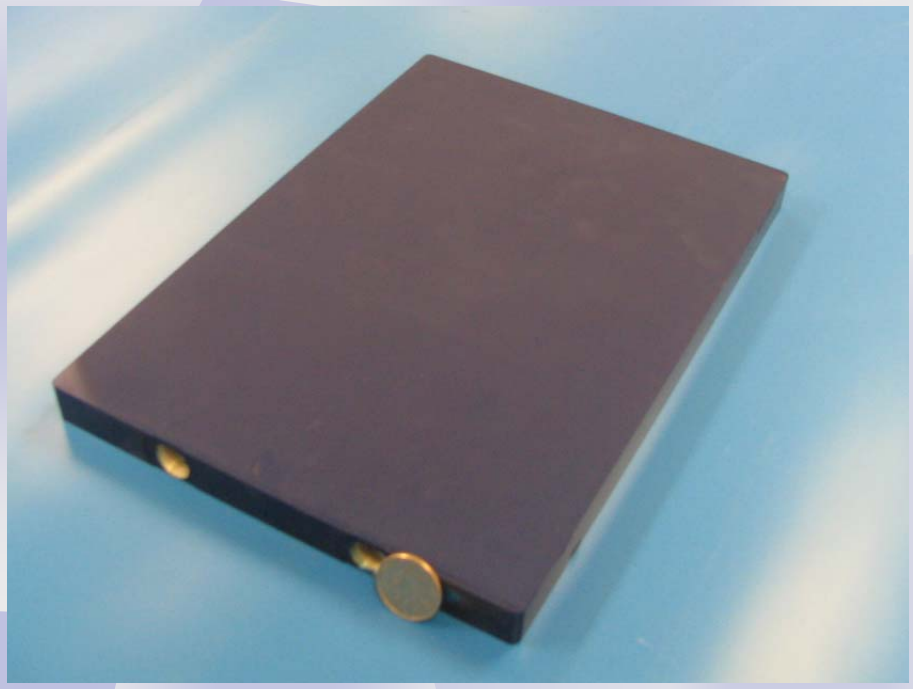
Prototype Exhaust Gas Heat Exchanger

- Stainless steel brazed construction with wavy fin
- Diamond surface coating for electrical isolation

Prototype Cold Side Heat Exchanger

Lytron off the shelf aluminum cold plate

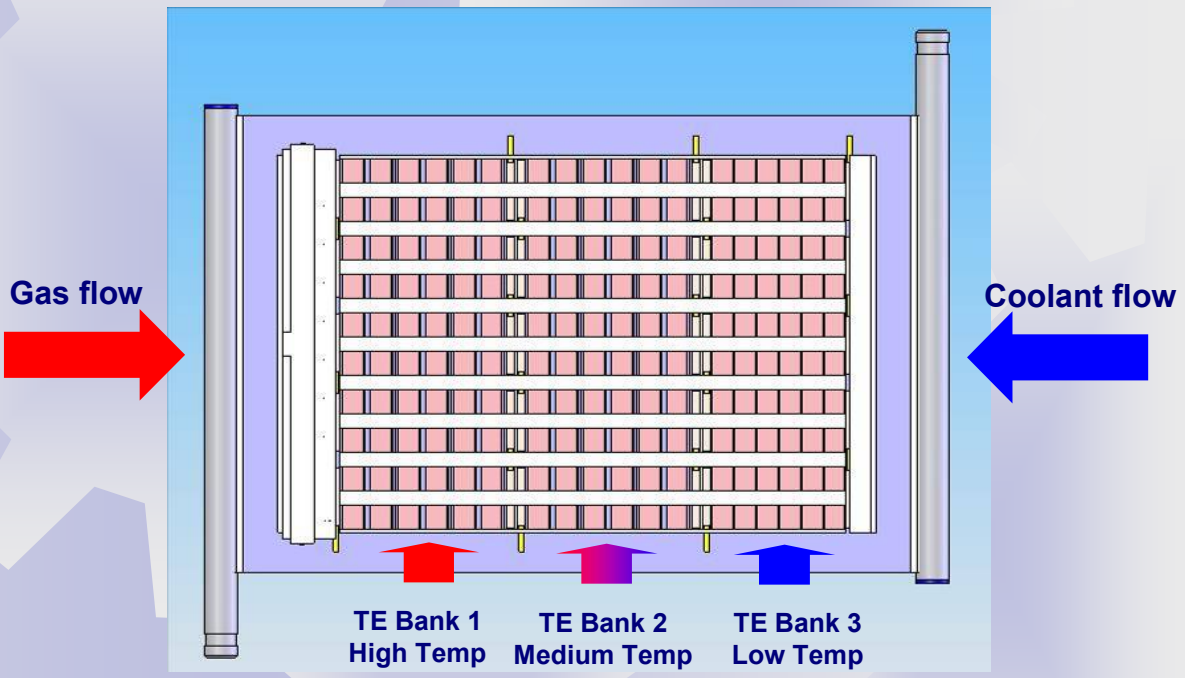
Surface finish: clear anodized for electrical isolation (blue die for anodize coating confirmation)



100 Watt High Temperature TEG

Counter flow design

Three configurations of TE subassemblies designed to match the temperature gradient in the heat exchanger for maximum TE performance

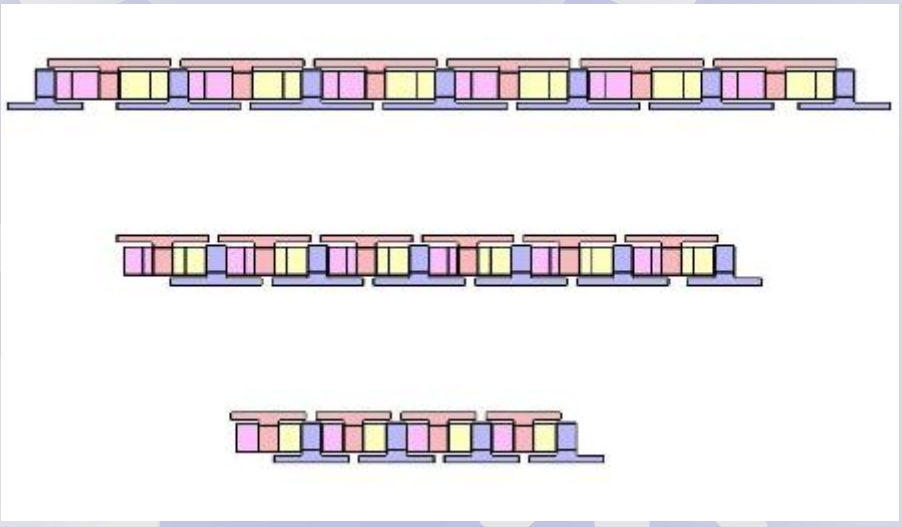


TE Subassembly Design and Construction

Hot and cold “T Shunts” provide electrical and thermal connections to TE elements

T shunts and elements designed to match thermal flux to optimize TE conversion efficiency

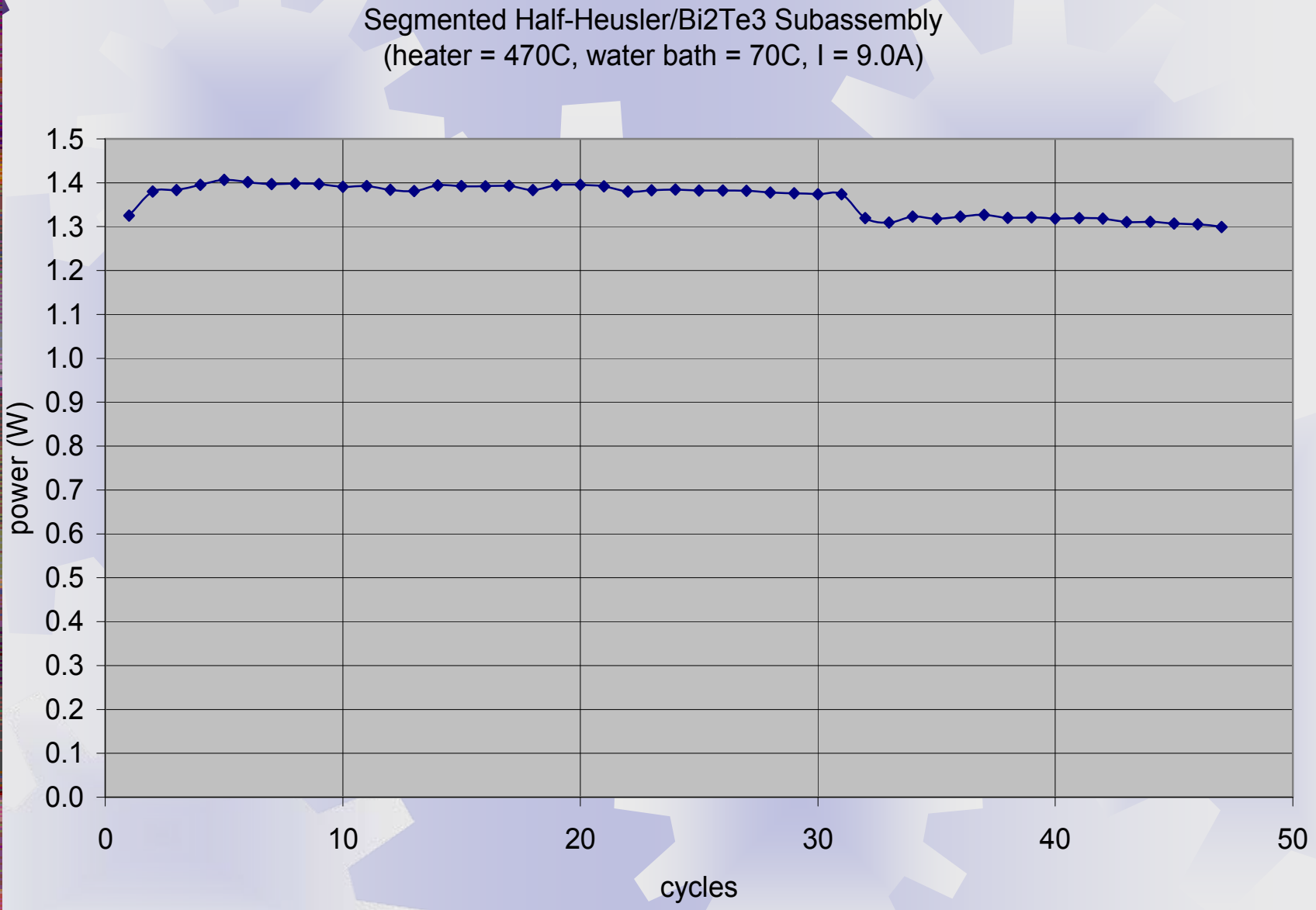
Proprietary Matlab Simulink computer tool simultaneously solves non linear equations to optimize performance and selected design parameters

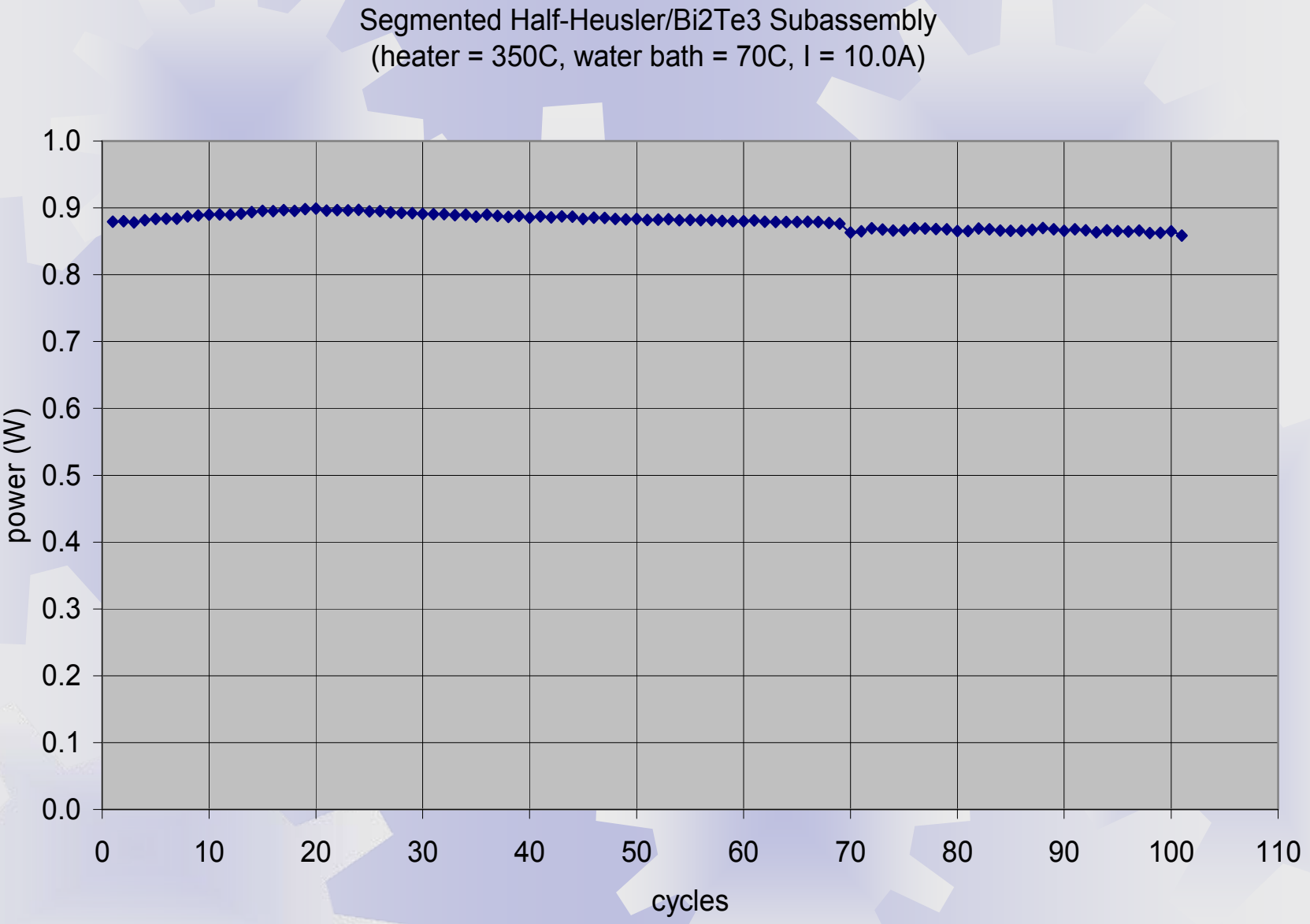


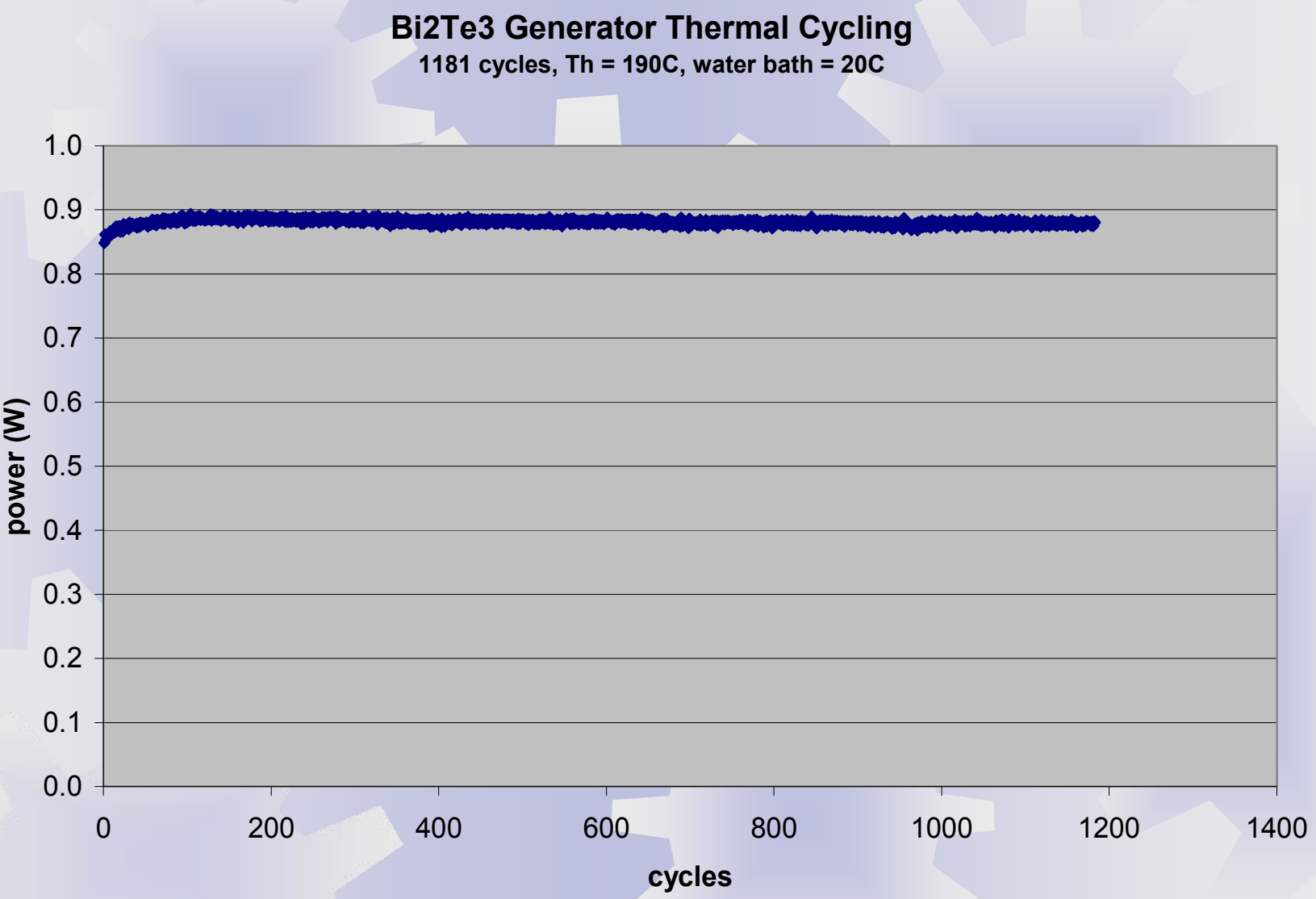
TE Subassembly Design and Construction

- TE subassemblies fabricated by BSST
- High and medium temperature sections include Half Heusler and BiTe segmented elements
- Low temperature TE subassemblies use BiTe only

TE Subassembly Thermal Cycling Results


Segmented Half-Heusler/Bi2Te3 Subassembly
(heater = 470C, water bath = 70C, I = 9.0A)
power (W)
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
10
20
30
40
50
cycles


Segmented Half-Heusler/Bi2Te3 Subassembly
(heater = 350C, water bath = 70C, I = 10.0A)
power (W)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
10
20
30
40
50
60
70
80
90
100
110
cycles


Bi2Te3 Generator Thermal Cycling
1181 cycles, Th = 190C, water bath = 20C
power (W)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
200
400
600
800
1000
1200
1400
cycles

Summary and Further Work

A low temperature TEG has been built and tested providing over 500 watts electric power at a ΔT of 200^0C

Prototype TE subassemblies for a high temperature TEG have been designed, built and tested

- A 100 watt high temperature TEG will be completed in Q3 2008
- A 500 watt high temperature TEG will be completed in Q4 2008 with Engine Dynamometer testing in Q1 2009

Testing of a low temperature TEG in a diesel engine vehicle is underway with results finalized in Q4 2008

Acknowledgements

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