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The Effects of an Exhaust Thermoelectric Generator on a GM Sierra Pick-up Truck

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Automobile Exhaust Thermoelectric Generator (AETEG) Project Overview

- Team – Clarkson University (Prime), Delphi Harrison Thermal System, GM Powertrain Division, Hi-Z Technology, Inc.
- Funding
  - New York State Energy Research & Development Authority (NYSERDA), PM Mr. Joseph R. Wagner
  - Department of Energy (DOE), PM Mr. John W. Fairbanks
- Deliverables
  - Phase I – AETEG Design
  - Phase II – AETEG Integrated into Pick-up Truck, AETEG Performance Test at Test Cell (Delphi), Test Results Analysis
- Vehicle – 1999 Sierra Pick-up Truck
- Engine – V8, 270 H.P., Gasoline

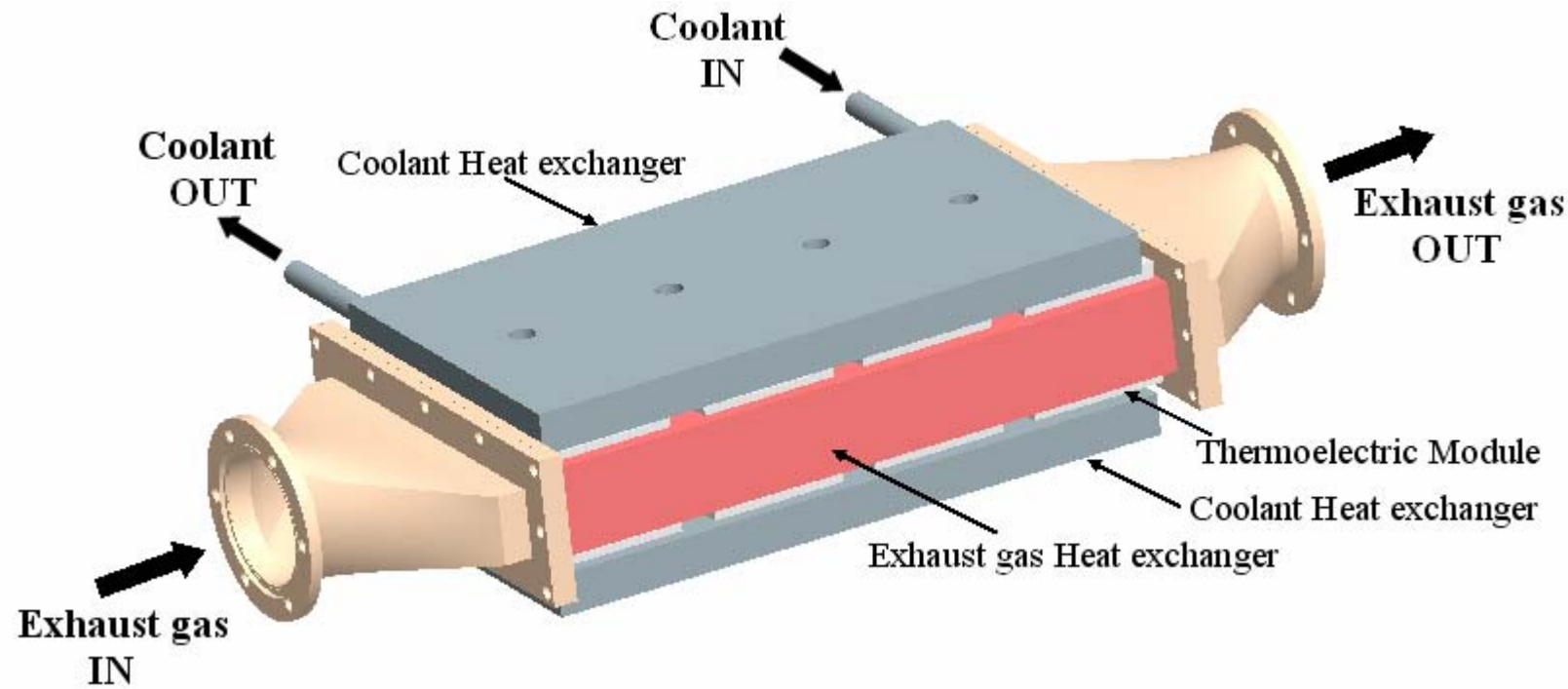
Project Objectives

- Design, Develop, Fabricate and Test 330 W Thermoelectric Exhaust Heat Recovery System for 1999 GMC Sierra Pick-up Truck
- Integrate the AETEG into the Truck Exhaust, Coolant and Electrical Systems
- Design, Develop, Fabricate and Test the AETEG Power Conditioning Unit (PCU)
- Demonstrate Capability of Supplying Electric Power at 12 and 42 V
- Perform Road Test of the AETEG and Estimate the Generator Performance Depending on Driving Conditions
- Develop Computer Model for Truck/ATEG System
- Investigate Opportunities for the AETEG Performance Improvement
- Develop Commercialization Plan for the AETEG System

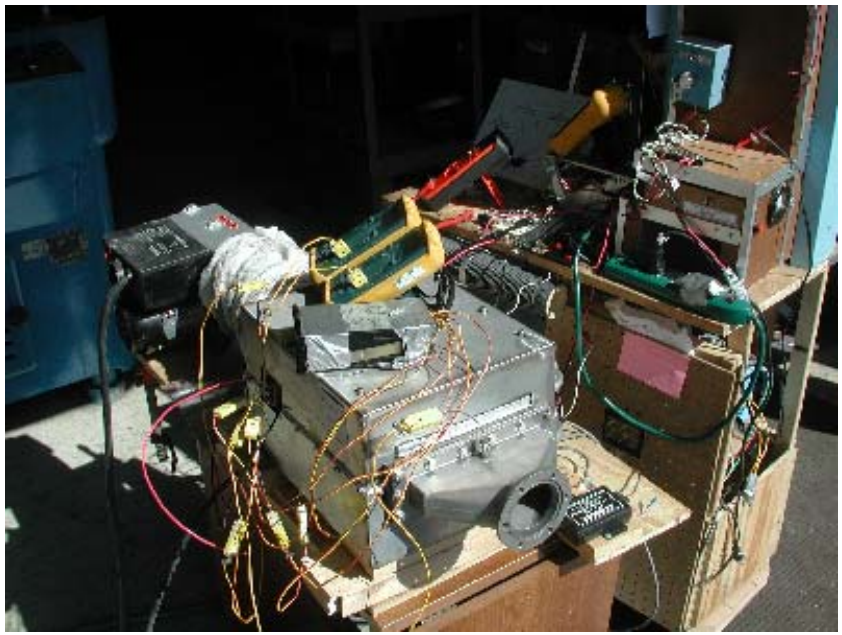
AETEG Design Parameters

- Electric Power Output
  - 300 to 330 W at hot/cold side $\Delta T = 200°C$ and $T_{cold} = 50°C$
  - 150-165 W is expected at $T_{coolant}$ about 90 ° C
- Type of TE Modules – HZ-20
- Number of Modules – 16 each (2 arrays; 8 modules per array)
- Output voltage
  - Suitable to charge 12 V battery
  - Adaptable to 42 V vehicle system
- Power Conditioning Unit (PCU)
  - Automatic match load device
  - DC/DC converter
- Dimensions – 13 inch x 10.75 inch x 8.5 inch

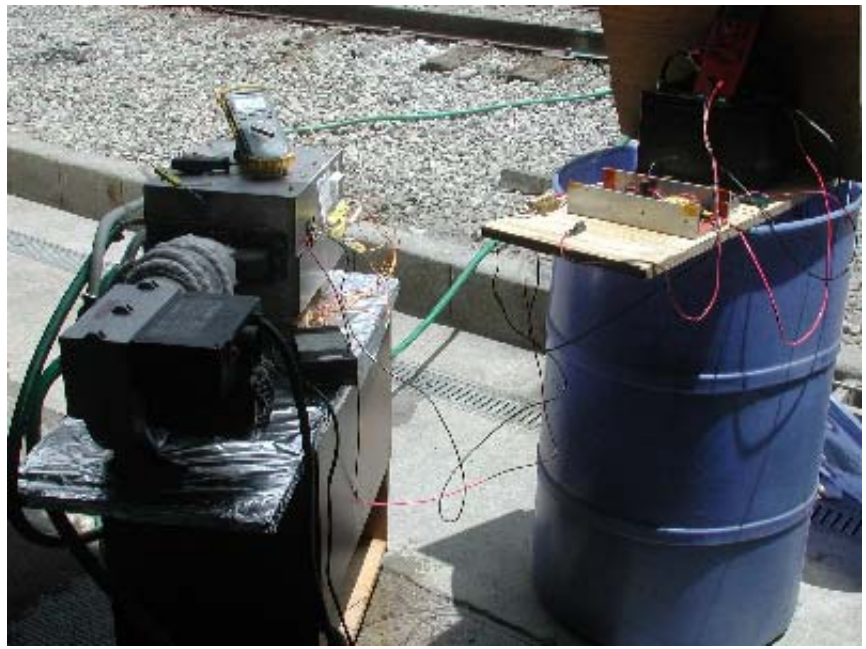
Assembled Thermoelectric Generator (TEG)



AETEG Hot Air Blower Test

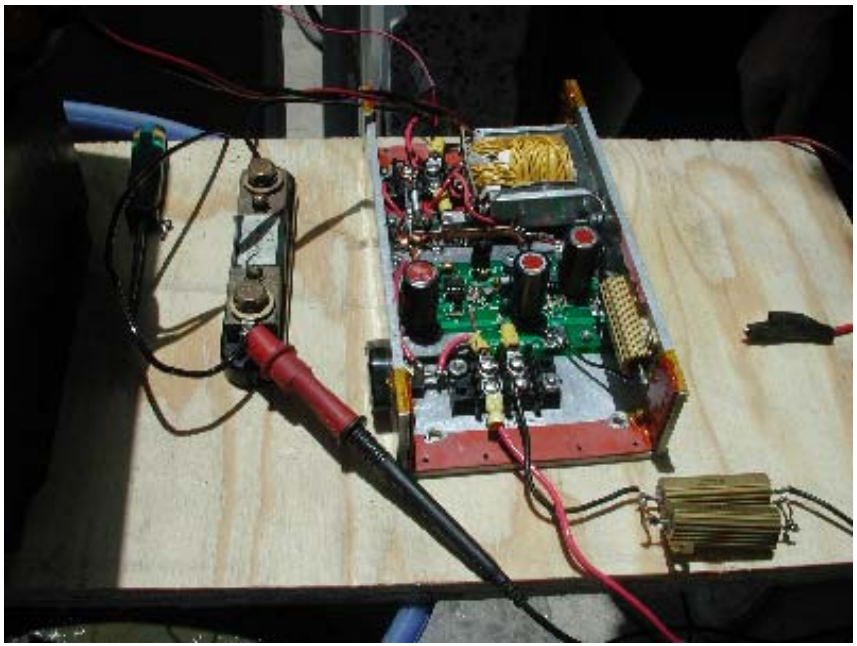


AETEG Hot Air Blower Test (Bench PCU Version)



AETEG Hot Air Blower Test(Final PCU Version

AETEG Power Conditioning Unit (PCU)



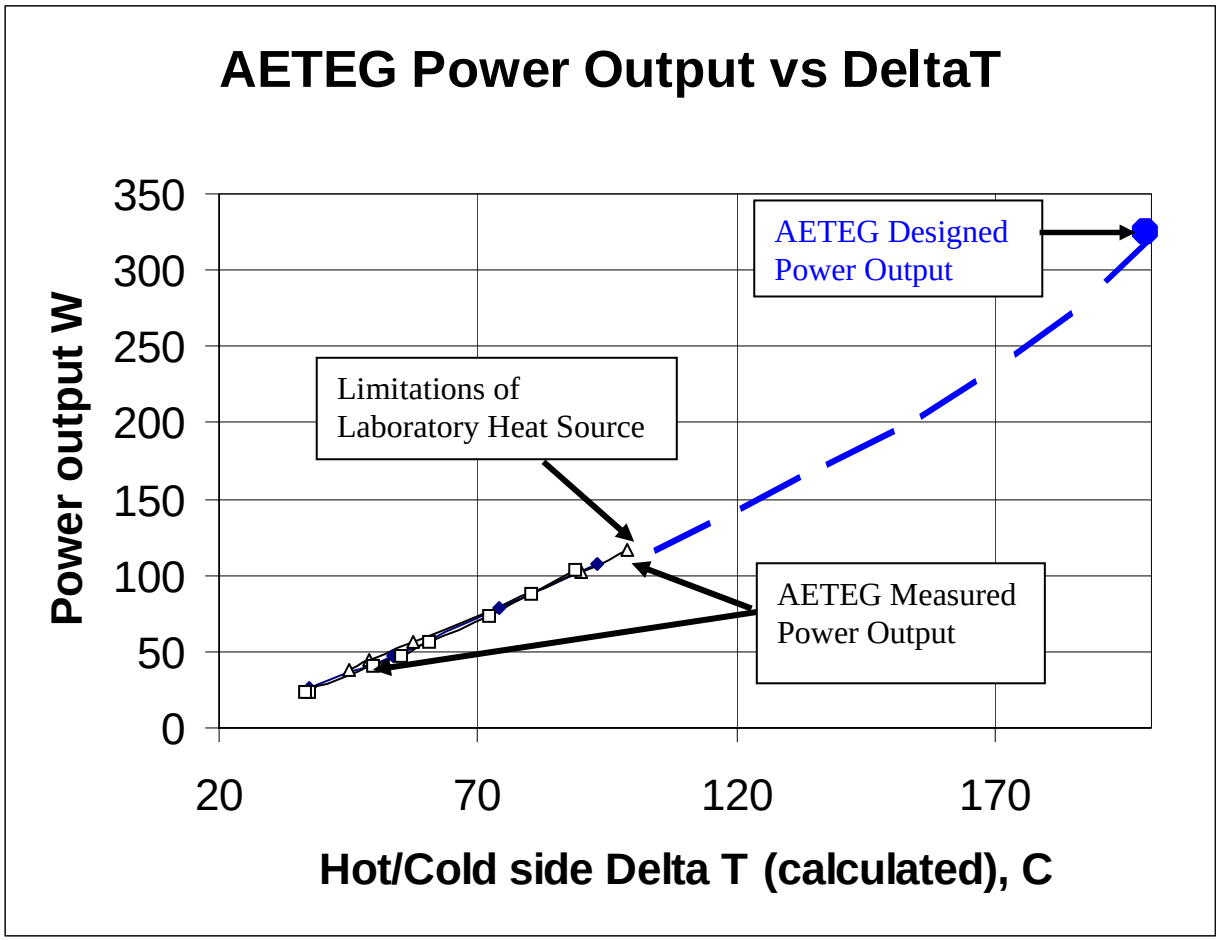
- Suitable for
  - 12 V (step down DC/DC converter)
  - 42 V (step down DC/DC converter) vehicle electrical system
- Configuration – combination of automatic match load device and DC/DC converter
- Dimensions – 5 in. x 9 in. x 2 in.
- Weight – 1.17 kg (2.6 lb)

PCU Parameters	Capacity	Voltage	Current	Efficiency
Input	330 W	14 – 30 V	(at 30 V) 10 A	88% Average
Output	290 W	11.5 – 15 V	(at 12 V) 24 A	

AETEG Hot Air Blower Test Results

Regime #	Tc ave, °C	Th ave, °C	ΔT*, °C	W_{AETEG}, W	W_{PCU}, W	EFF_{PCU}, %	VOC/VLOAD
March 24, 2004, Test #4 (Before shipping to Clarkson University). Load – bench test							
1	25	82.5	57.5	**26.60**	NA	NA	Not measured
2	25.4	99	73.6	**47.37**	NA	NA	Not measured
3	26.1	120	93.9	**78.45**	NA	NA	Not measured
4	27.4	140.3	112.9	**107.40**	NA	NA	Not measured
April 29, 2004. Test after received from Clarkson University. Before test at Delphi. Load – bench test							
1	28.2	93.5	65.3	**38.19**			2.34
2	28.4	97.5	69.1	**45.14**			2.42
3	29	106.5	77.5	**56.80**			1.92
4	30.4	140.5	110.1	**101.70**			2.02
5	31.6	150.5	118.9	**116.35**			1.98
June 10, 2004. Test after received from Delphi. PCU is fixed (TLC 555 chip failed). Load – PCU. Longer water hoses to the lab sink							
1	29.3	86	56.7	**24.00**	21.65	**90.2**	Not measured
2	30	99.8	69.8	**40.54**	36.12	**89.1**	1.52
3	30.3	105.3	75.0	**47.29**	41.76	**88.3**	1.55
4	31.1	111.8	80.7	**56.84**	50.23	**88.4**	1.60
5	31.6	123.8	92.2	**73.80**	64.70	**87.7**	1.68
6	31.6	132	100.4	**88.07**	77.12	**87.6**	1.79
7	32.5	141.3	108.8	**103.94**	90.76	**87.3**	1.88
8	29.3	86.8	57.5	**23.60**	21.31	**90.3**	1.36

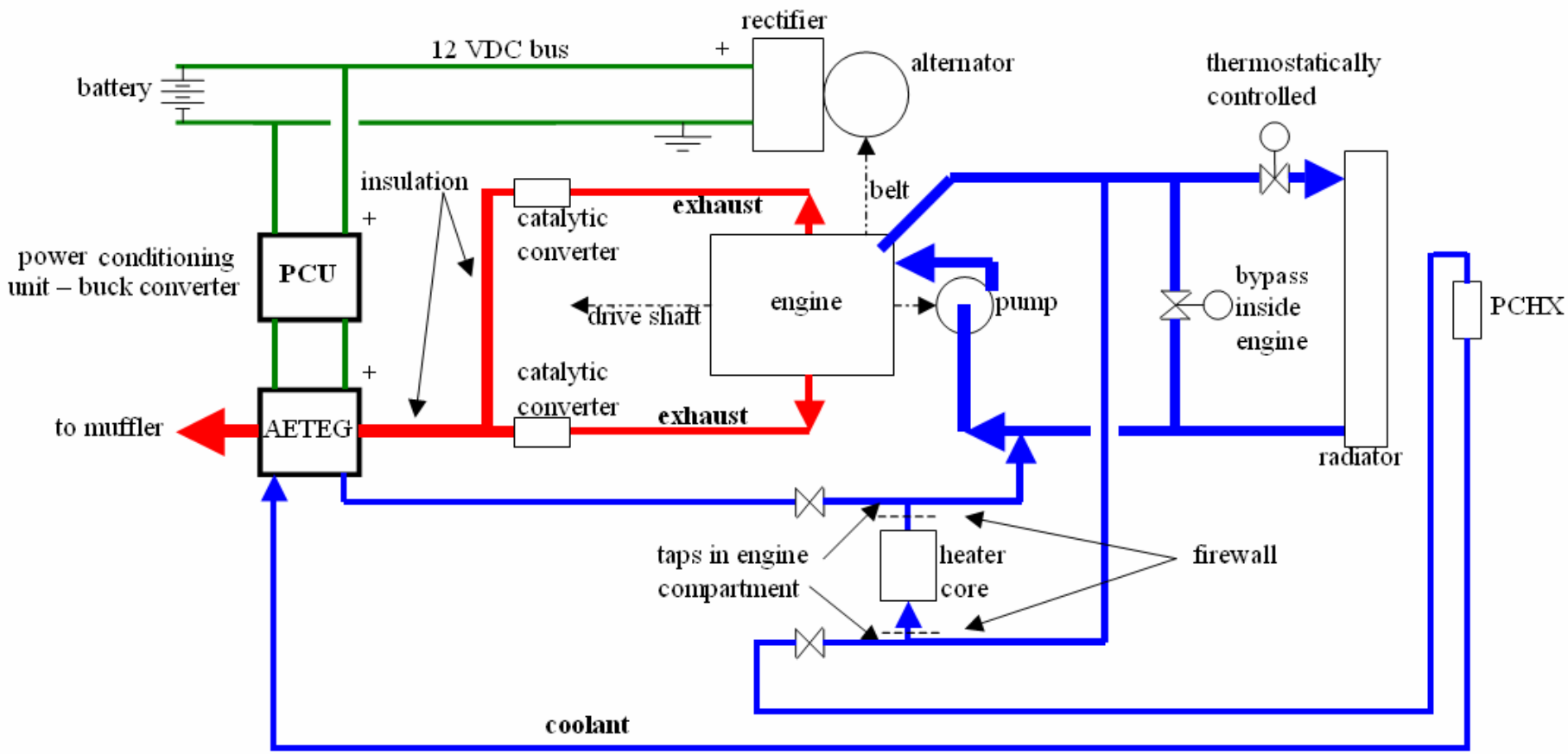
AETEG Hot Air Blower Test Results



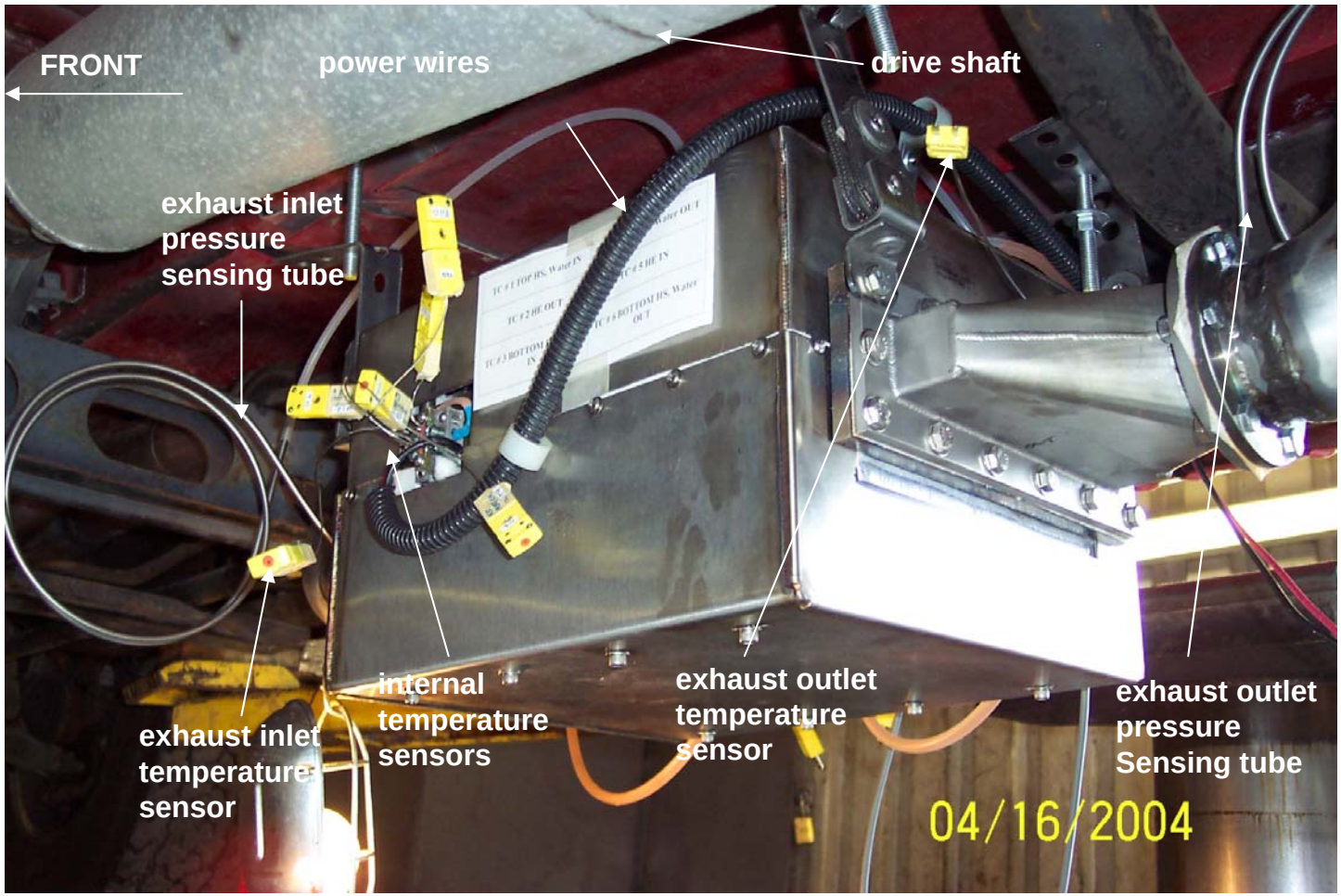
Test Vehicle – 1999 GMC Seirra Pick-up Truck

AETEG System Schematic

Systems: Exhaust Coolant Electrical



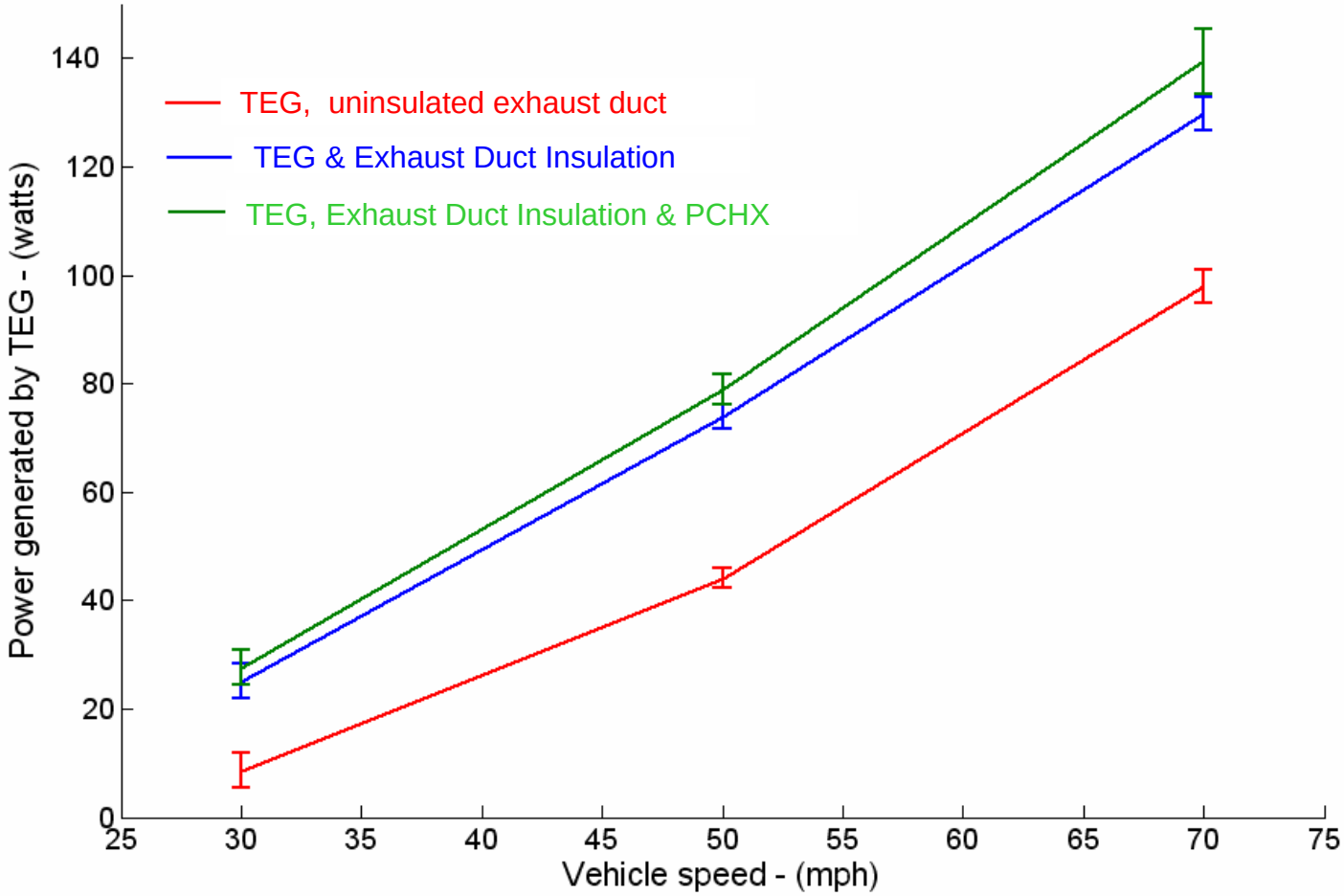
Left Side View of AETEG Installed in Test Truck



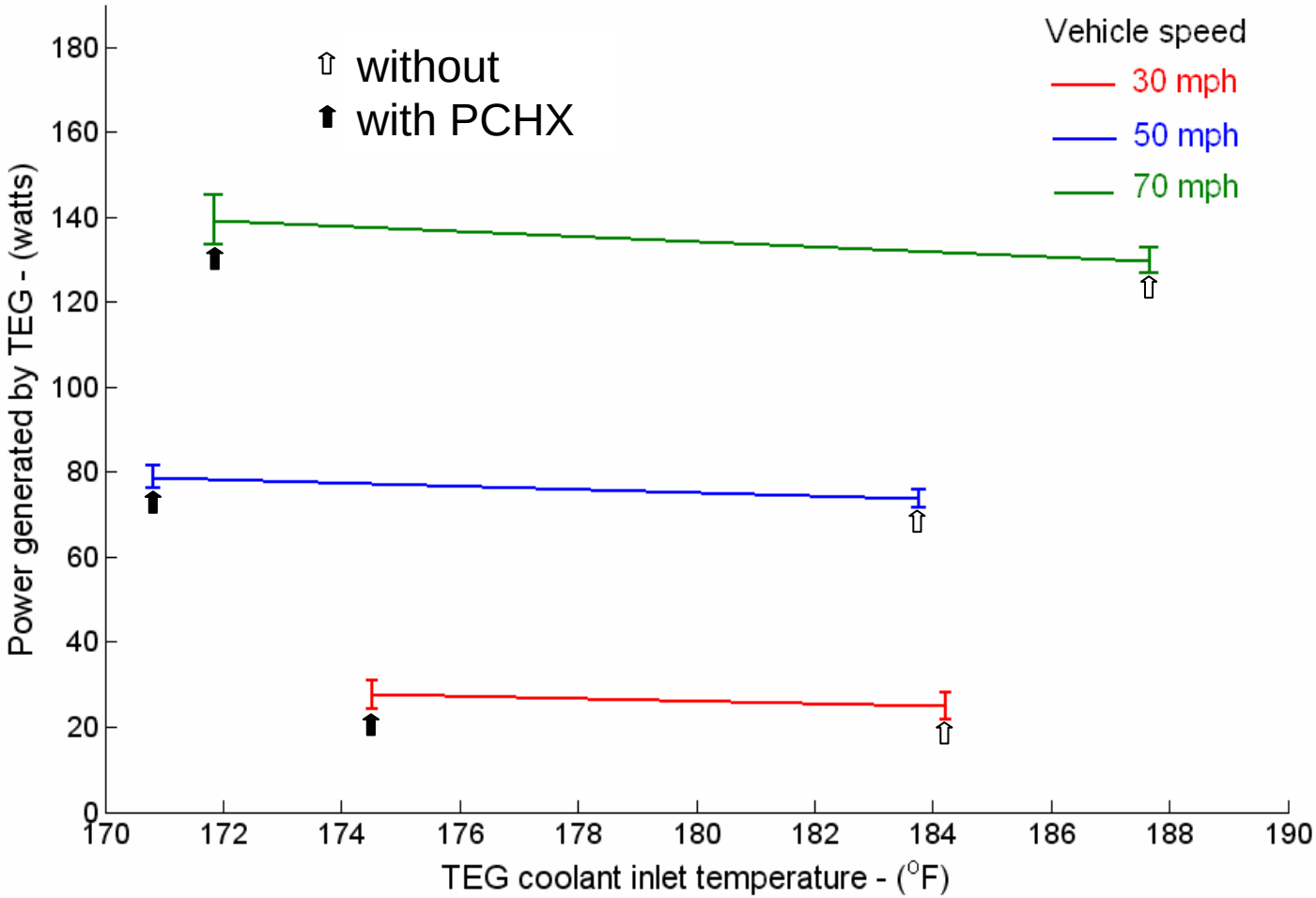
Test Matrix

- Test configuration
  - A: Baseline, No TEG
  - B: with TEG
  - C: with TEG & Exhaust insulation
  - D: with TEG, Exhaust insulation & PCHX
- Speeds
  - Idle
  - 30 mph
  - 50 mph
  - 70 mph
- Tunnel air inlet temperature
  - 40^{o} F
  - 70^{o} F
  - 100^{o} F
- Electrical load
  - Base
  - Base+25 amps
  - Base+50 amps

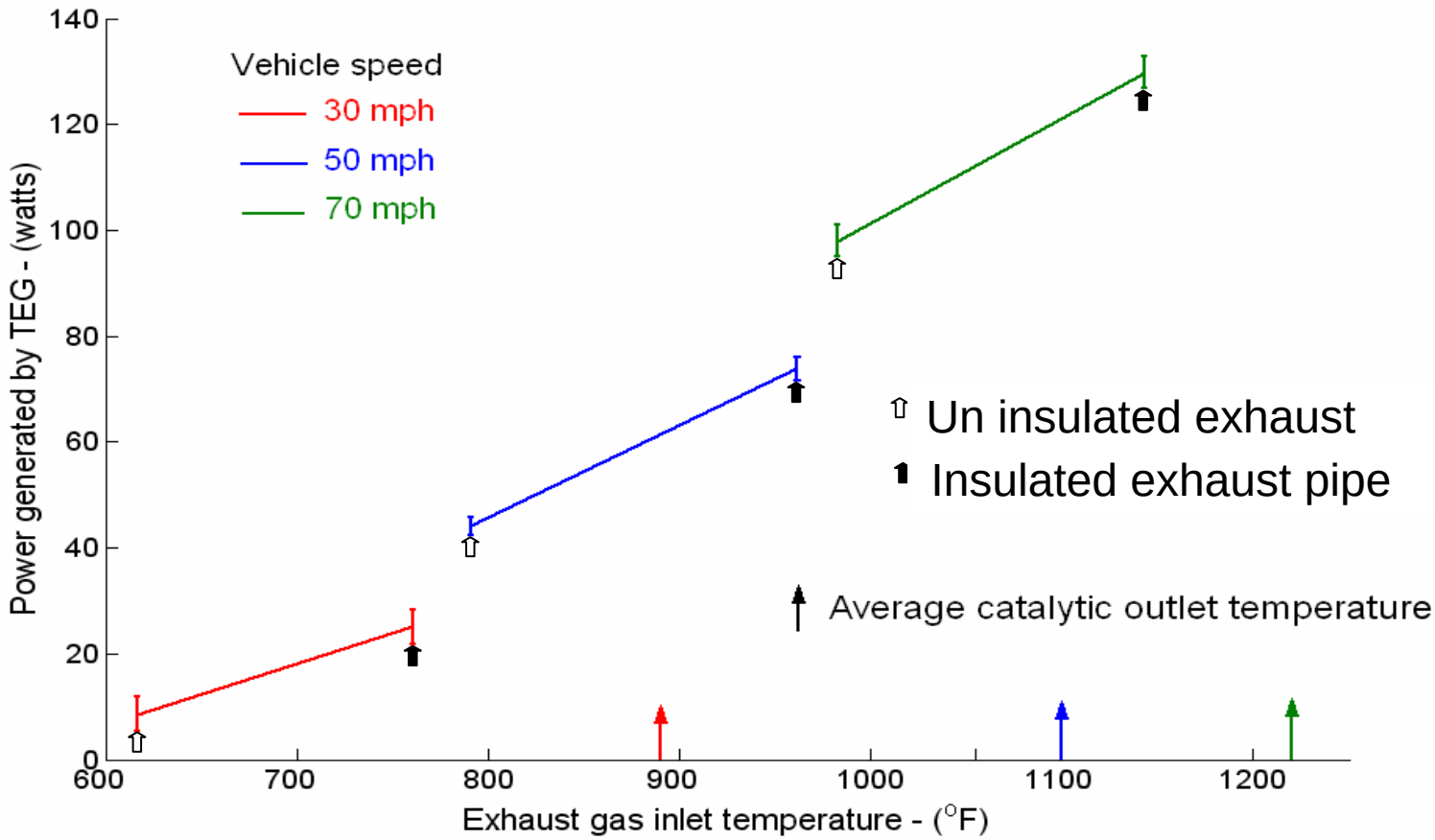
Power Generated by TEG as a Function of Vehicle Speed Meets Expected Power Production of 150 W



TEG Power as a Function of Coolant Inlet Temperature

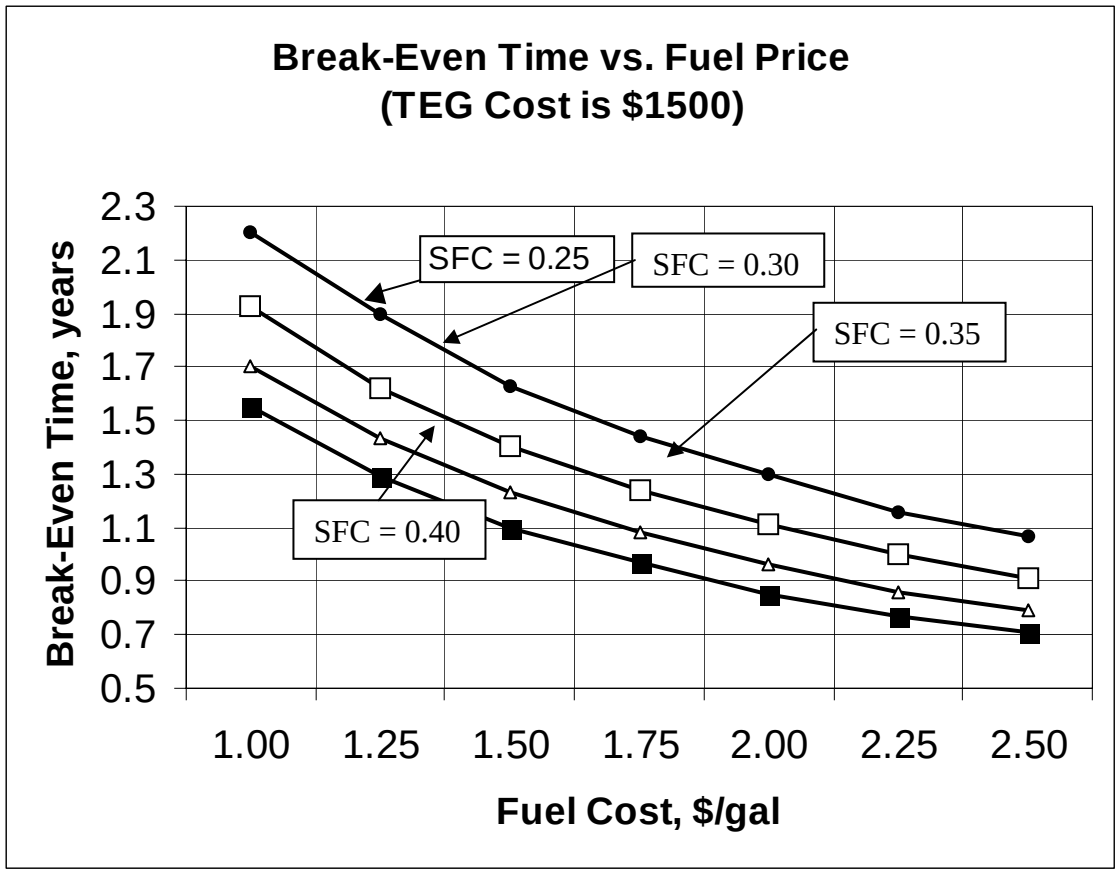


TEG Power as a Function of Exhaust Gas Inlet Temperature



AETEG Cost Effectiveness Considerations

(Approach for 1 kW Diesel Truck Cost Benefits Estimation)



Specific Fuel Consumption (SFC) presented in lb/H.P. - hr

Project Achievements

- Waste Heat Recovery System for the 1999 GMC Sierra Truck has been Designed, Developed, Fabricated and Tested
- Power Conditioning Unit Capable of Supplying Electric Power for a 12 V Truck System has been Designed, Developed, Fabricated and Tested (Clarkson and Hi-Z are in process of applying for a patent)
- PCU for a 42 V Vehicle Electrical System has been Designed
- AETEG/PCU System has been Integrated into the Sierra Truck
- AETEG/PCU System was Tested at Hi-Z with Hot Air Blower
- AETEG/PCU Performance was Evaluated Depending on Driving Conditions at Delphi Corporations' Thermal System Division at Lockport, NY

Project Achievements (Continued)

- Capability of Producing Designed Electric Power Output by the AETEG has been Demonstrated
  - Power Output Over 140 W has been Measured When $T_{coolant}$ was about 80°C (expected power production was about 150 W)
  - Power Output About 255 W has been Measured When $T_{coolant}$ was about 25°C (expected power production was about 300 W)
  - 300 W Power Production can be achieved with Upgraded PCU
- PCU Capability of Supplying 14-15 V to the Truck Electrical System has been Demonstrated
- PCU Average Efficiency of 88% has been Demonstrated. Lower efficiency measured during the test cell is associated with the defective PCU chip that was later replaced.
- AETEG Computer Model has been Developed and Evaluated Based on the Test Results Analysis

Next Steps

- Phase II B is Currently in Progress
- Evaluate the AETEG Performance (Computer Modeling) Based on Assumption of Using QW Thermoelectric Modules and Data Obtained During the AETEG Tests
- Develop Plan for Further AETEG Performance Improvement, Considering Following Steps:
  - QW Thermoelectric Materials Use
  - Heat Transfer Improvement via Design Optimization
  - Cooling System Enhancement (Separate AETEG cooling loop *vs* PCHX Upgrading Options)
  - AETEG Weight Reduction Through Innovative Materials Employment
- Manufacturability Enhancement via Design Simplification and Heat Exchanger Casting Instead of Machining Option
- Commercialization Plan Details Development

Acknowledgements

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Project members

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Hi-Z TECHNOLOGY, INC.

DELPHI
Driving Tomorrow's Technology

GM