Develop Thermoelectric Technology for Automotive Waste Heat Recovery

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Overview

Timeline
• Start date – May 2005
• End date – October 31, 2010
• Percent complete – 80%

Budget
• Total funding: $12,779,610
  – DOE share: $7,026,329
  – Contractor share: $5,753,281
• Funding received in
  – FY09: $920,987
  – FY10: $356,666 (10/09-2/10)

Barriers
• Barriers addressed
  – Integrating new advanced TE materials into operational devices & systems
  – Integrating/Load Matching advanced TE systems with vehicle electrical networks
  – Verifying device & system performance under operating conditions

Partners
• Interactions/collaborations
  ORNL – High temperature transport and mechanical property measurements
  UNLV – Computational materials development
  Marlow – TE module development and fabrication
  Faurecia – Exhaust subsystem fabrication and integration
• Project lead: GM R&D
Achieve 10% improvement in fuel economy (FE) by 2015 without increasing emissions

- Demonstrate FE improvement for the Federal Test Procedure driving cycle (~3%)
- Demonstrate that actual FE improvement for real world driving conditions is closer to DOE goal

Demonstrate commercial viability

- Assemble, install, and test prototype TEG on a production vehicle
- Collect performance data, show viability
- Identify specific design, engineering, and manufacturability improvements for path to production

Current Specific Objectives:

- Complete initial TEG prototype construction
  - Translate conceptual design from GE into buildable unit
  - Fabricate subsystem parts and complete assembly

- Complete test vehicle modification and integration
  - Exhaust system modification and bypass control for thermal management
  - Integration of electronic systems and controls for electrical power management
  - Install TEG on vehicle

- Collect performance data

- Improve material ZT and thermo-mechanical properties
  - Adjust composition and processing for best results
  - Synthesize material batches for TE module production

- TE module production
  - Complete metallization studies and fabrication method study
  - Fabricate modules for TEG
Relevance – Milestones

Previous Year
• Provide the initial TE waste heat recovery subsystem design
• Provide initial lab test data for TE modules
• Finalize TE waste heat recovery subsystem design

Current Year
• Provide initial production ready TE modules for application-based testing -- Mar 31, 2009
• Complete prototype TE generator subsystem parts fabrication and assembly – Oct 31, 2009
• Complete vehicle modification and system integration of controls and electrical system of test vehicle for first TE generator unit – Jan 2010
• Install first TE generator unit onto test vehicle – Feb 2010
Approach

- Develop models and computational tools to design TE generators which include heat transfer physics at heat exchanger and interfaces; TE material properties; and mechanical reliability
- Finalize design, fabricate, and assemble prototype TE generator
Approach (cont.)

- Develop power electronics design for power conditioning and vehicle control

- Develop control algorithms for improved thermal-to-electrical conversion efficiency

  Bypass valve for exhaust gas

- Improve TE materials (skutterudites) based on the concept of phonon engineering: \( ZT = 1.6 \) at 850 K, and \( ZT_{ave} = 1.2 \)
Approach (cont.)

- **Assess TEG Performance**
  - **Start-Cart**
    - First step in integration development
    - Provides a decoupled testing environment
    - Provides easy access for modification and debugging
  - **Chassis-Rolls Dynamometer**
    - Provide a realistic loading and repeatable environment, though not a realistic environment
    - Precise data collection
    - Standard test method for fuel economy and emissions measurements
  - **Environmental Dynamometer**
    - Chassis-rolls dynamometer which simulates grades, atmospheric environment
  - **Real World Driving**
Technical Accomplishments and Progress

• Completed thermoelectric generator design and began fabrication of heat exchanger subassemblies. First prototype completed, second one in progress.
Technical Accomplishments and Progress (cont.)

- Completed detailed design and assembly of power electronics for vehicle integration, installation and vehicle modification.

- Completed exhaust system modification: parts fabricated and installed
• Evaluated braze methods for electrical connections to PbTe.

(a) PbTe elements with a thick nickel end cap brazed to the metallization layer, and (b) shear test results with adhesion promoting heat treatment (failure is in bulk material.)

• Designed tooling for fabricating ceramic headers for TE modules.

• Synthesized several n-type PbTe ingots and explored processing variables to reduce cracking and fragility, and to improve adhesion of electrical and thermal contacts.

Prototype PbTe module
Technical Accomplishments and Progress (cont.)

- Validated measurements of transport and mechanical properties and performance at high temperature.
- Explored optimization of preferred materials for use in TE modules.
- Improvement in the synthesis, processing, and transport properties of Yb-filled skutterudites associated with specifically created nano-scale precipitates at grain boundaries and within grains.
- Achieved a figure of merit $ZT = 1.6$ for multiple filled skutterudites, highest value yet reached for any n-type filled skutterudite material.
- Improved TE properties of Type I clathrates by doping transition metals on the gallium sites.
- Investigated new TE materials: $\text{In}_4\text{Se}_3$, $\text{In}_4\text{Te}_3$, Cu-Ge-Se.
Conducted computational and experimental studies of the microstructure and nucleation mechanisms of nanoprecipitates that lead to the superior TE performance of (PbTe)$_{1-x}$(AgSbTe$_2$)$_x$.  

Atomic positions predicted by DFT calculations.
Collaboration and Coordination with Other Institutions

Current Collaborators (subcontractors):
- ORNL – High temperature transport and mechanical property measurements
- UNLV – Computational materials development
- Marlow – TE module development and fabrication
- Future Tech – Consultant (Francis Stabler)

Suppliers:
- Faurecia – Exhaust subsystem fabrication and integration
- HTI – Heat Exchangers

Previous Collaborators (subcontractors):
- General Electric – subsystem modeling and design
- University of Michigan, Michigan State University, Brookhaven National Lab, University of South Florida, RTI – TE materials development
Proposed Future Work
(Activities for the remainder of this project, ending October 31, 2010)

- Provide test results for initial TE generator (1st unit)
- Complete assembly of 2nd TE generator unit with full electrical system components.
- Finalize and implement vehicle integration with TE waste heat recovery system and complete the necessary vehicle modifications.
- Develop TE modules for 3rd TE generator unit.
- Carry out dynamometer tests and proving ground tests for vehicle equipped with the TE waste heat recovery system.
- Demonstrate fuel economy gain using TE waste heat recovery technology.
Summary

• Prototype TEGs are being assembled and installed on the test vehicle.

• Vehicle modifications and system integration are being completed as the TEGs are installed on the vehicle.

• Improvements in the performance of TE materials have been achieved, particularly for skutterudites.

• Skutterudite modules are being developed for the final prototype TEGs.