U.S. Department of Energy
Energy Efficiency and Renewable Energy

"**Thermoelectric Waste Heat Recovery Program for Passenger Vehicles**", 2012 Vehicle Technologies Program Annual Merit Review

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Project ID # ACE080

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BSST Program Overview

Timeline

Program Start Date:	Oct ‘04
Program End date:	Sept ‘11
Percent Complete:	100%

Budget

Total Project spend:	$ 11,874,538
DOE Share:	$ 7,156,109
Contractor Share:	$ 4,718,429 (39.7%)
FY2011 Funding Received:	$ -

Barriers

Economic manufacture of TE engines and TEG subsystem

Vehicle system integration for optimum usage of TE power

Vehicle TEG system on-cost

Targets

FE Improvement: 10%

Partners

Project Lead:	BSST
OEM Partners:	BMW & Ford
Tier 1 Partners:	Faurecia, Visteon
University/Fed’l Lab Partners:	Caltech, JPL, NREL Virginia Polytechnic

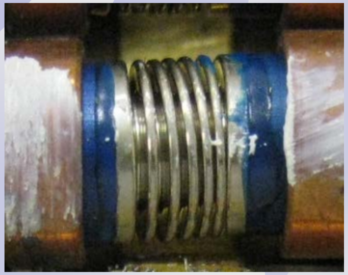
Phase 5 Objectives

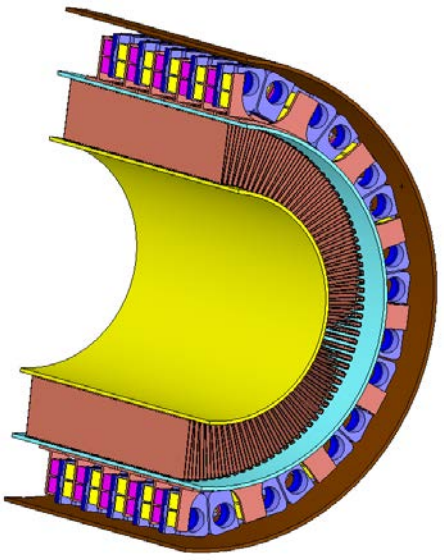
- Improve cylindrical TEG prototype manufacture with improved tooling and subassembly component manufacture
- Integrate TEGs into BMW and Ford vehicles for road testing
- Address series production manufacturability/ usability issues with the cylindrical TEG

BSST 2011 Program Milestones

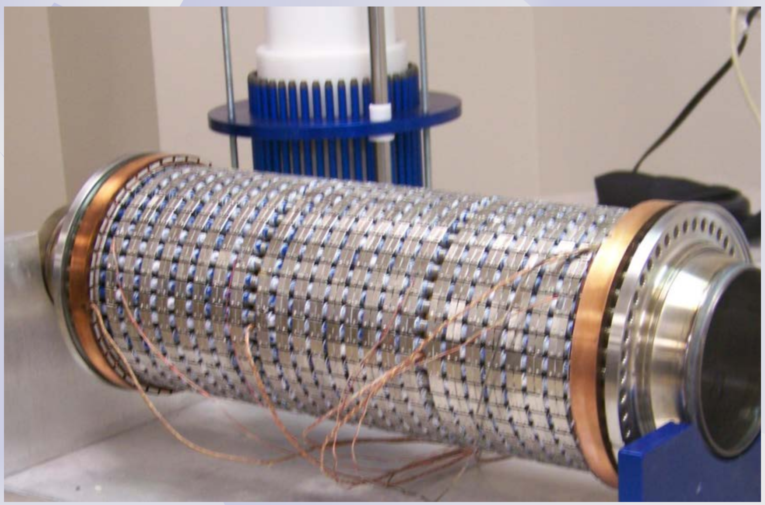
Date	Milestone	Actual
May 7	Complete TEG build and test at BSST	Completed
June 11	Complete engine/TEG dyno testing at NREL	Completed
August 15	Deliver TEGs for BMW and Ford Vehicle installations	Completed
October 15	Substantially complete TEG system evaluation in BMW and Ford vehicles	Completed

Approach: Improve TEG prototype manufacture





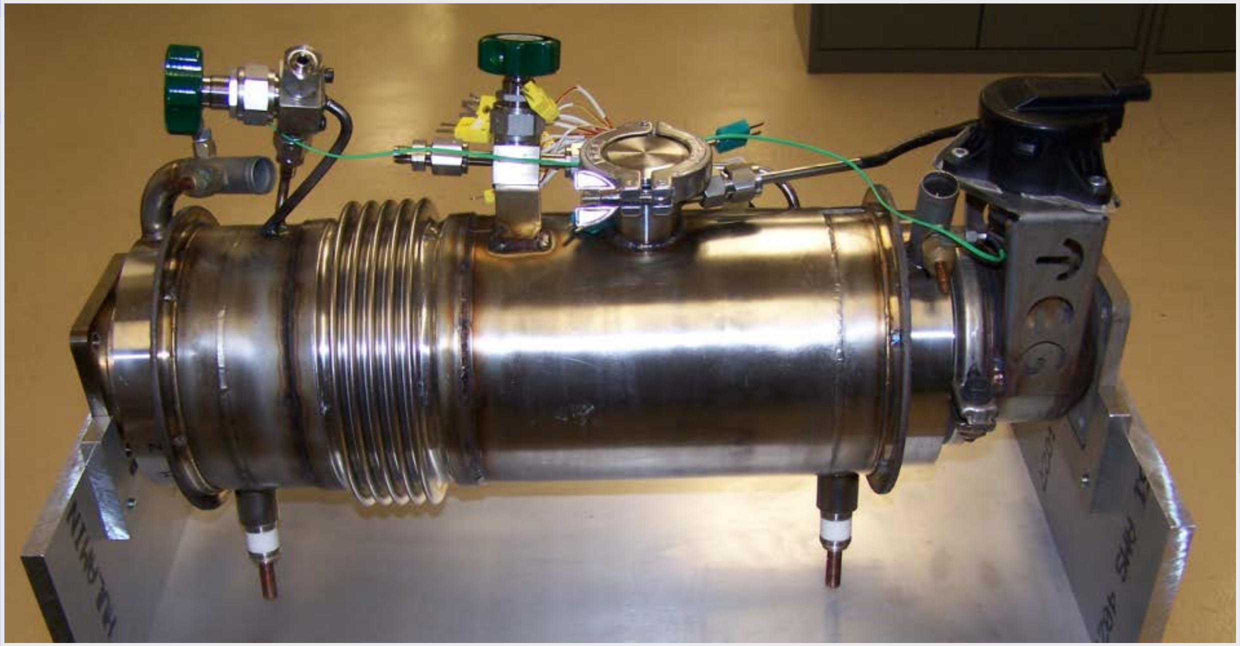
- The liquid cooling tube alignment along the length of the gas HEX (through many, collinear TE engines) was difficult to align
- Proposed solutions:
  - Carefully control the gas HEX OD and utilize tooling to precisely locate successive TE engines in the direction of flow



Approach: Integrate TEGs into BMW and Ford vehicles for road testing

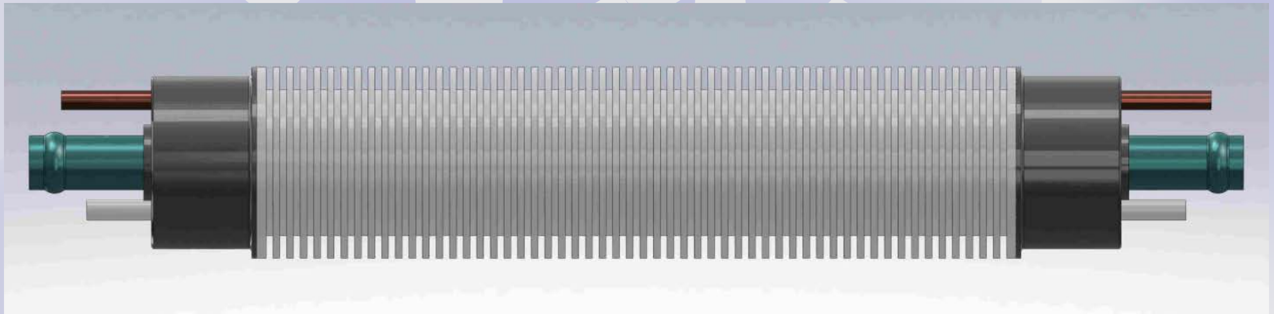
TEG atmospheric control (maintenance of O2 depleted atmosphere) was a high priority

Solution: Install gas ports in outer shell (hermetic enclosure) with pressure sensor to check and refill Argon gas as required



Approach: Address manufacturability/usability issues with the cylindrical TEG

- The Phase 5 TEG provides a proof of concept for stack-arranged TE engines in a cylindrical form factor.
- The current design has an inappropriate power form (high current, low voltage) and will be difficult to manufacture due to the complex liquid cooling circuit, number of parts and large hermetically enclosed volume.
- The next generation TEG will retain a cylindrical form factor and stack-designed TE engines but be comprised of a number of smaller cartridges.

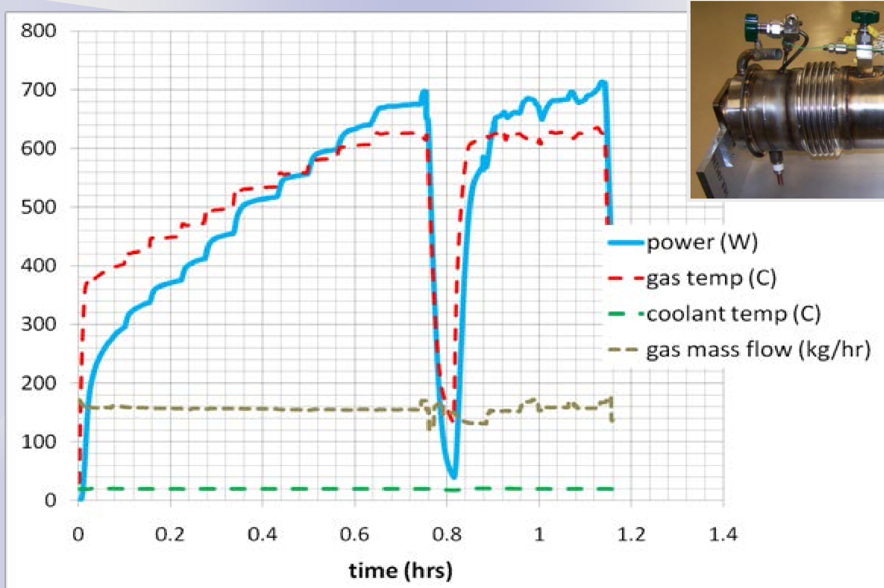


Accomplishment: Improve TEG prototype manufacture

Two Phase 5 Cylindrical TEGs were built using improved tooling and subassembly components

The TEGs were tested on the bench at Amerigon-Irwindale and in a peak performance test produced over 700 watts as a result of improving interfaces, thermal and electrical.

The hot side TE material temperature reached ~ 500C and the TEG has exhibited stable performance for > 6 months.

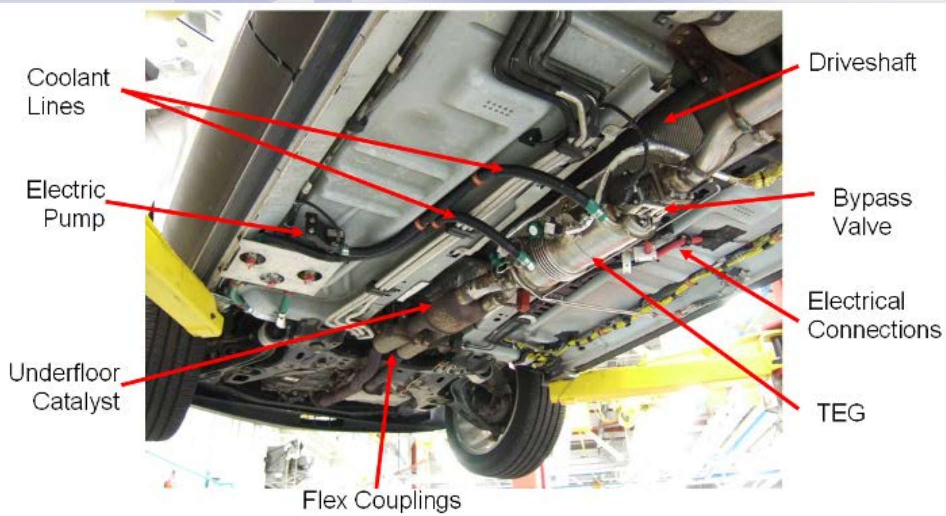


Accomplishment: Integrate TEGs into BMW and Ford vehicles for road testing

TEGs were installed in the BMW X6 and Ford Lincoln MKT.

The Ford installation is pictured at right.

- Powertrain coolant was circulated through the TEGs
- A resistive load was used to consumeTEG power

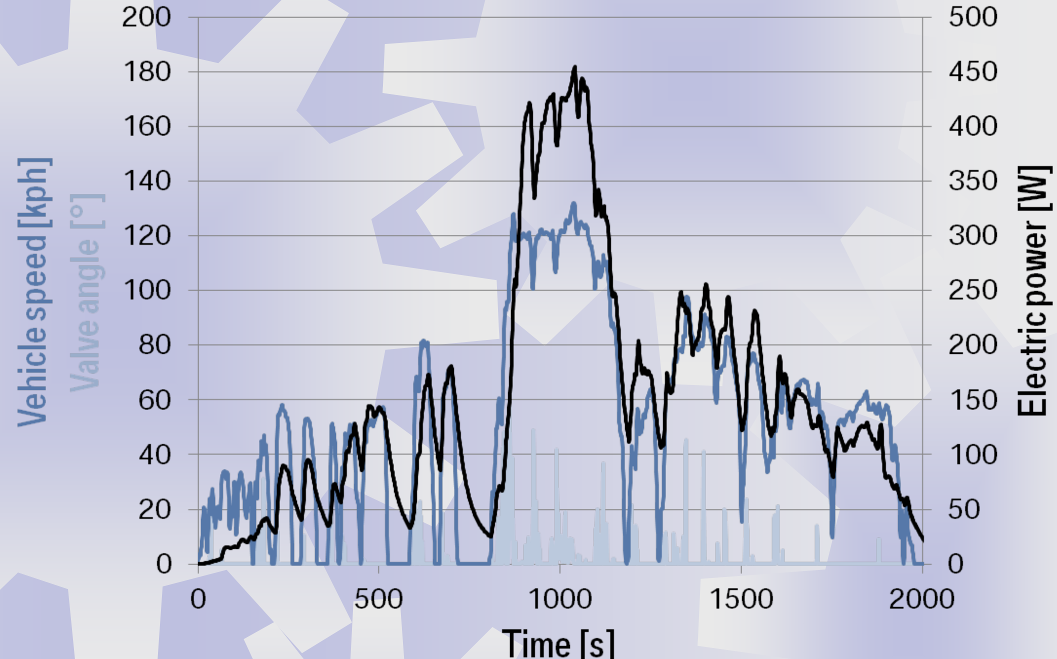


TEG Integration on Lincoln MKT

Accomplishment: Road test TEGs in BMW and Ford vehicles

The BMW X6 was put into service in July 2011.

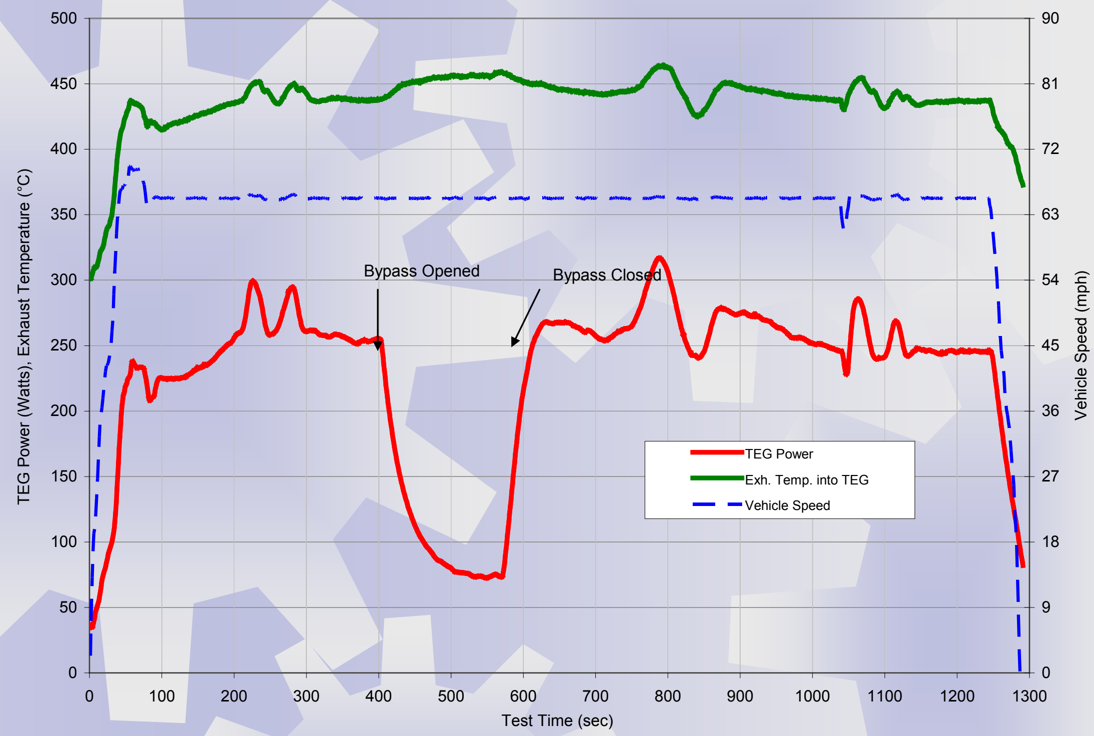
TEG power measured in the X6 is shown at right.



Accomplishment: Road test TEGs in BMW and Ford vehicles

The Ford Lincoln MKTwas put into service in August 2011.

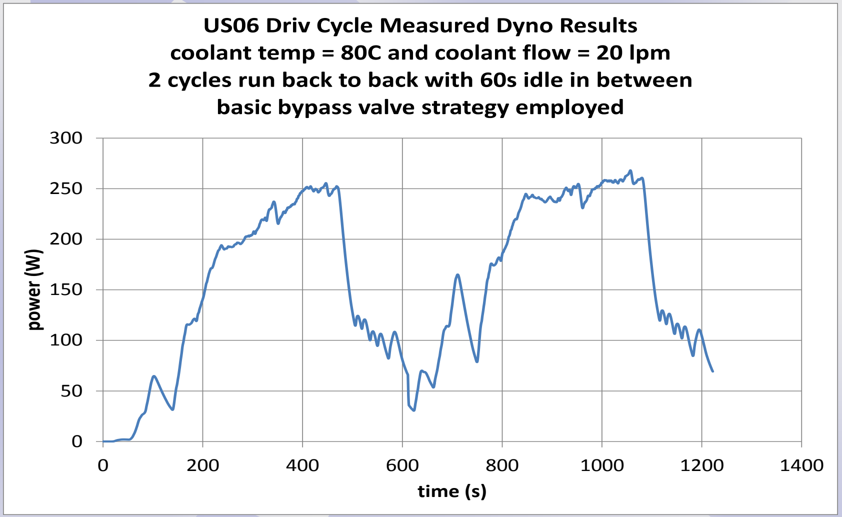
TEG power measured in the MKT for a 65 mph cruise condition is shown at right.

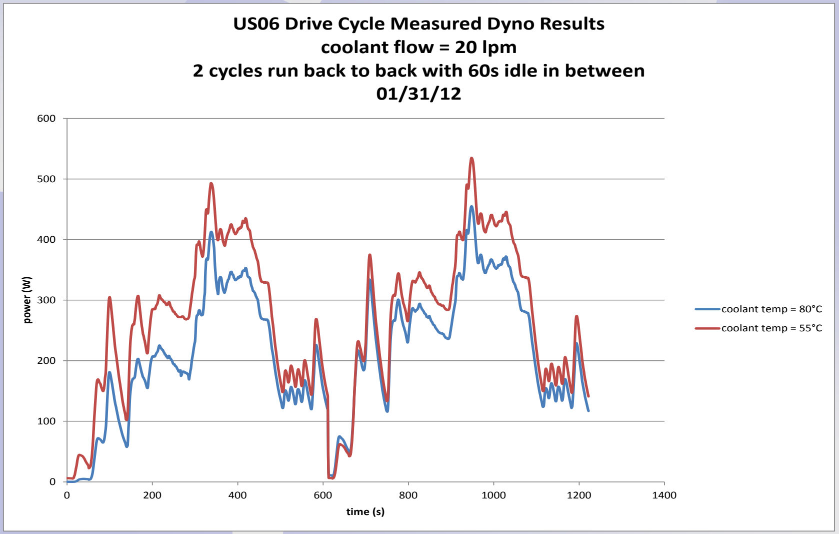


Accomplishment: Dynamometer test the TEG with BMW's 6 cylinder engine

The TEG was tested over steady state and drive cycle conditions at a designated NREL Lab

In preparation for the follow-on TEG program testing over US06 was performed.





Collaborations

- OEM leadership has been provided by BMW from program inception and Ford since Phase 3.
- Tier 1 support in the design-in of the cylindrical TEG for BMW and Ford vehicles was provided by Faurecia.
- TE Material characterization was provided by Caltech and ZT Plus.

Future Work

A follow-on TEG program for passenger vehicles began in October 2011. Objectives include:

- 5% FE gain over the US06 drive cycle
- Economic feasibility assessment for 100K/annum TEG system manufacture

Amerigon partners include BMW and Ford, Caltech and NREL.

Summary

Relevance

- Exhaust gas waste heat conversion to electric power reduces fuel consumption and is aligned with the increasing electrification of vehicles.

Approach/Strategy for Deployment

- An approach focused on optimizing vehicle level system performance while reducing the amount of TE material used to facilitate commercialization has been followed.

Technical Accomplishments and Progress

- Two prototype cylindrical TEGs were manufactured and have provided stabile performance since July, 2011. The TEGs operate with TE material temperatures reaching ~ 500C and have produced over 700 watts of electrical power. Carefully controlled testing under NREL's cognizance was performed on an engine dynamometer, and in bench testing at Amerigon the TEG computer performance model validated to within 5% to 10%.

Collaborations and Coordination with Other Institutions

- Faurecia, a Tier 1 global leader in exhaust systems, has joined BMW, Ford and BSST and is leading the TEG subsystem integration into the exhaust system. In parallel, Amerigon/BSST, through a self funded collaboration with OSU and Northwestern, has developed a pilot production facility ,ZT Plus ,for the manufacture of advanced TE material.

Proposed Future Work/Proposed Future Activities

- A follow on program has begun and Amerigon has made significant modifications to the TEG design to ready it for commercialization in the latter half of this decade.

Acknowledgements

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