Development of Thermoelectric Technology for Automotive Waste Heat Recovery

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Outline

- ❑ Introduction
- ❑ Project Issues, Goals & Metrics
- ❑ Engineering Highlights
- ❑ Project Status & Next Steps

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US Department of Energy
Energy Efficiency Renewable Energy (EERE)
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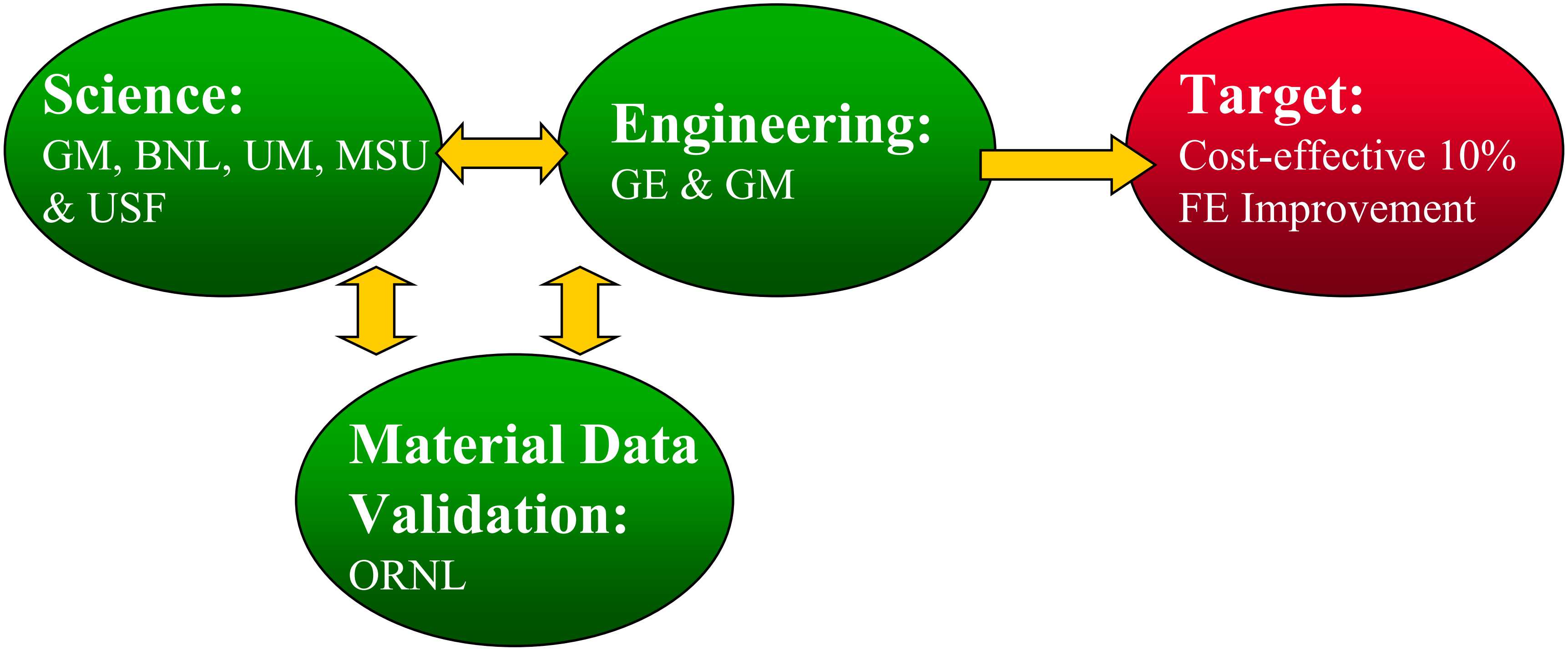
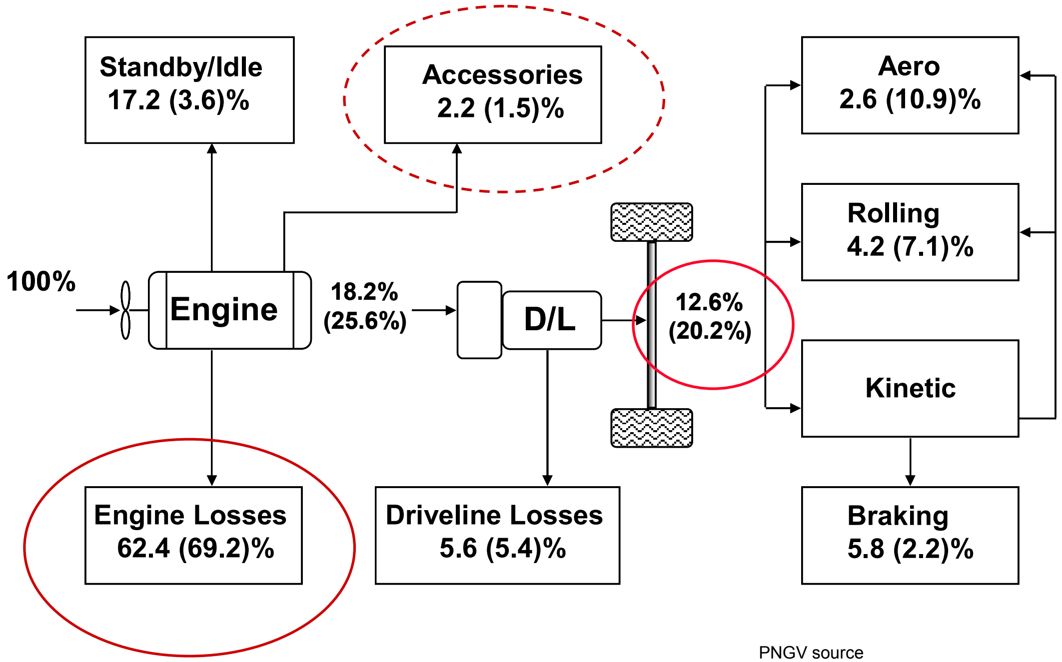
Development of Thermoelectric Technology for Automotive Waste Heat Recovery

- Target : 10% fuel economy improvement without increasing emissions
- Partnering:
  - **GM** – materials research, subsystem design, integration, modeling, and validation
  - **GE** – TE module, subsystem design and manufacturing
  - **Oak Ridge National Lab** – high temperature material property measurement and validation
  - **Brookhaven National Lab** – bulk materials: manufacturing processes
  - **University of Michigan** – bulk materials: filled skutterudites, nano-composites,…
  - **University of South Florida** – bulk materials: clathrates, nano-grain PbTe, …
  - **Michigan State University** – bulk PbTe-based materials …

DOE Program High-Level Process



Energy Distribution - Typical Mid-Size Vehicle on the Federal Test Procedure (FTP) Schedule Urban (Highway) % energy use



PNGV source

- Today's ICE-based vehicles: < 20% of fuel energy is used for propulsion
- > 60% of gasoline energy (waste heat) is not utilized

Issues

- Need variety of higher ZT materials
- Many thermoelectric material advances are recent, and not independently confirmed (several cases)
- Need to understand TE materials physical characteristics; are they sufficiently robust for the automotive environment
- Need engineering design for modules, subsystems and integration
- Uncertainty in materials, modules, subsystems & vehicle integration cost, and OEM market size

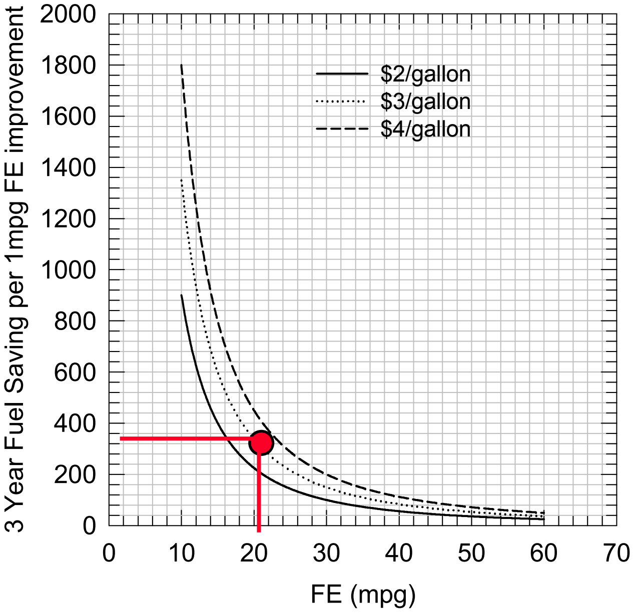
Key Milestones & Deliverables

- Develop & select TE materials for waste heat recovery devices
- Model & finalize TE waste heat recovery subsystem design
- Build & test the initial subsystem prototype generator
- Integrate, build & test a demonstration vehicle equipped with TE waste heat recovery subsystem
- Validate models & demonstrate fuel economy gain using TE waste heat recovery technology

$ / W – a Program Metric

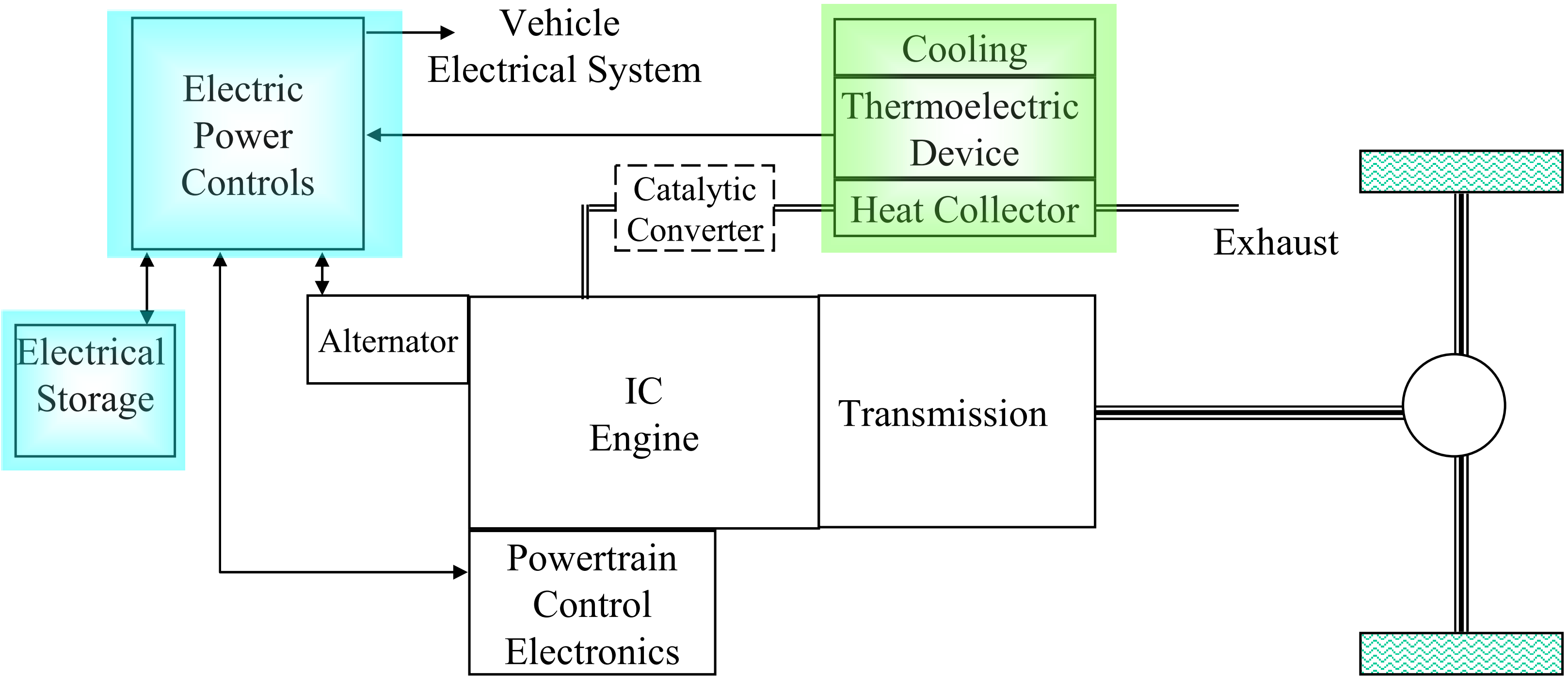
- $/W (not only ZT) is used for balancing various material, module, and subsystem options

- $/W can be readily converted to $/Δmpg, and $/Δmpg < Savings/Δmpg is necessary to provide consumer value



Consumer Fuel Savings/Δmpg ≈ $300-400/Δmpg (15000 mile/yr., 3yrs., 18-20 mpg)

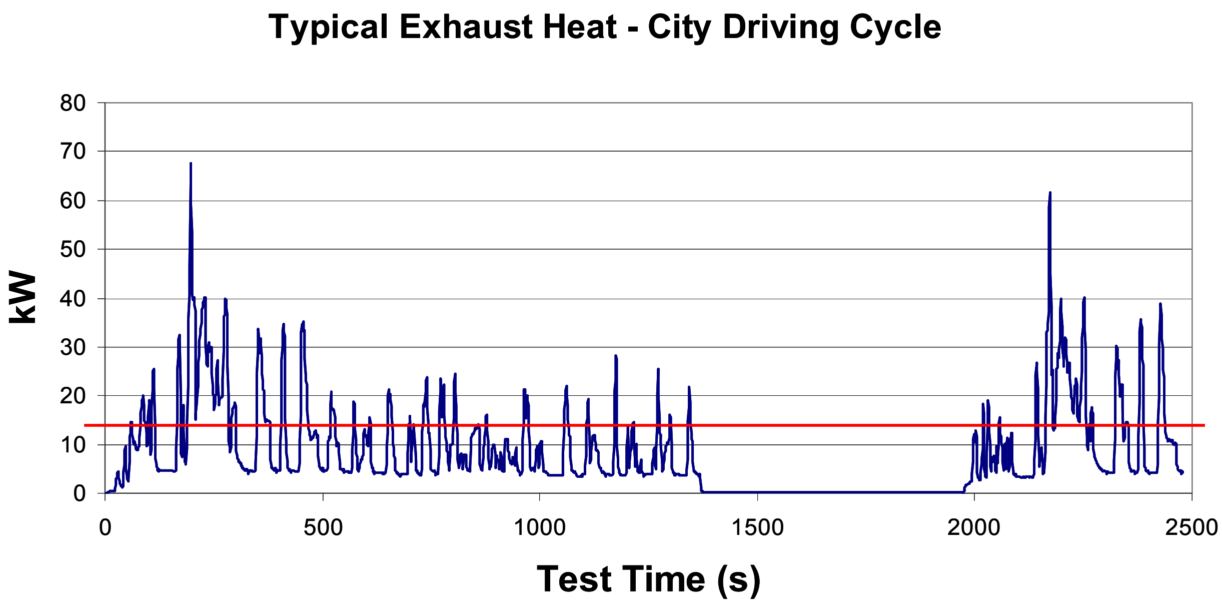
Thermoelectric Energy Recovery Augmented Electrical System



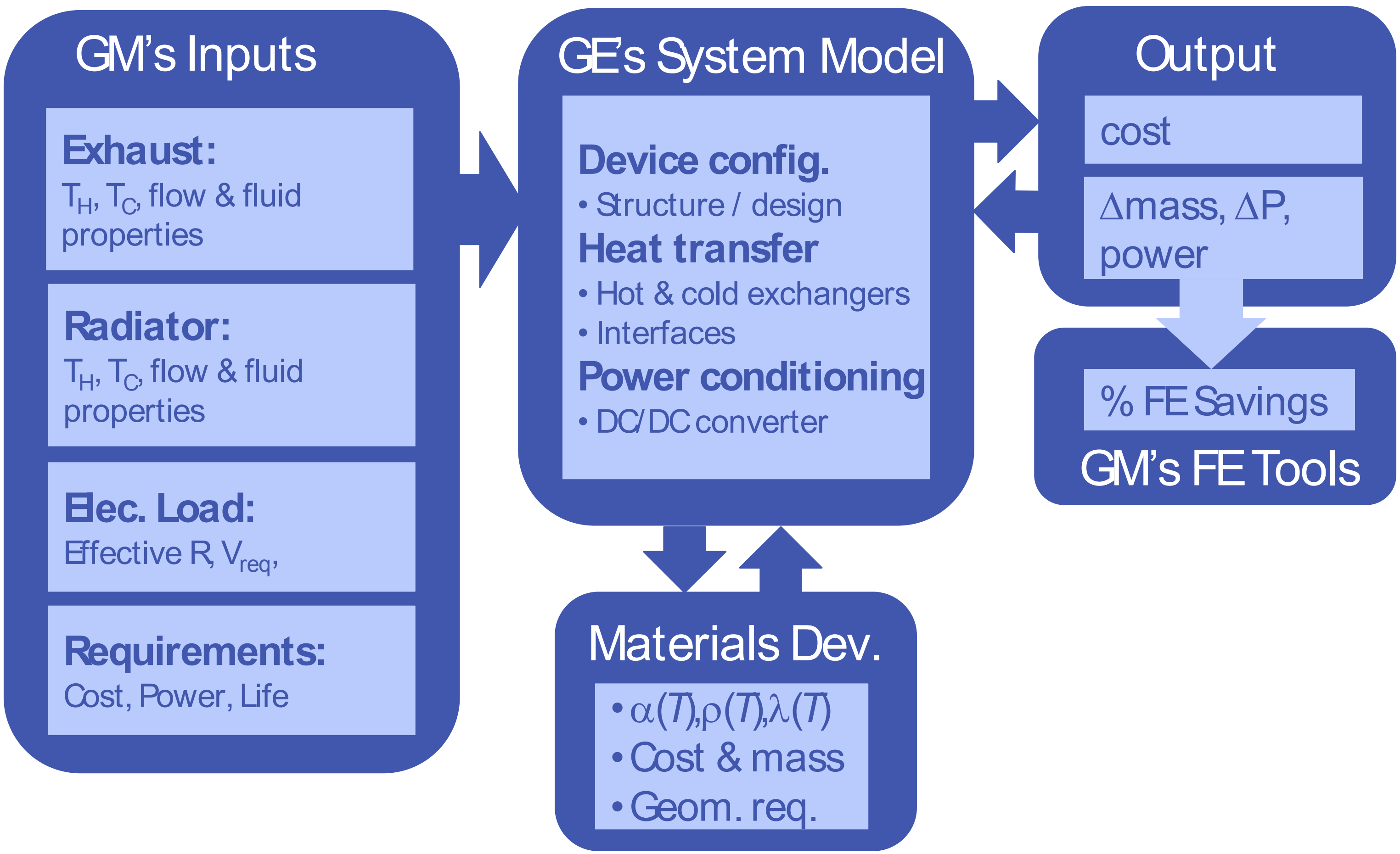
- Engine coolant is also a possible heat source, but smaller ΔT

Vehicle Selection – Full Size SUV

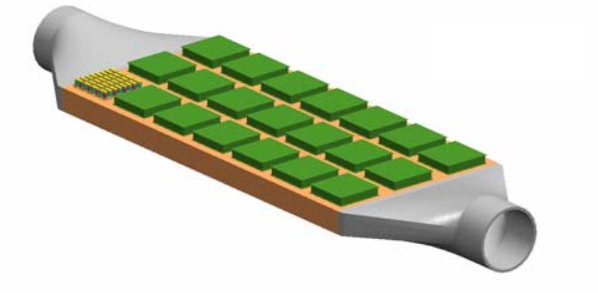
- plenty of space for accommodating TE subsystem
- a lot of waste heat: exhaust and radiator
- current muffler: 610 x 310 x235 (mm)
- available envelope: 840 x 360 x 255 (mm)

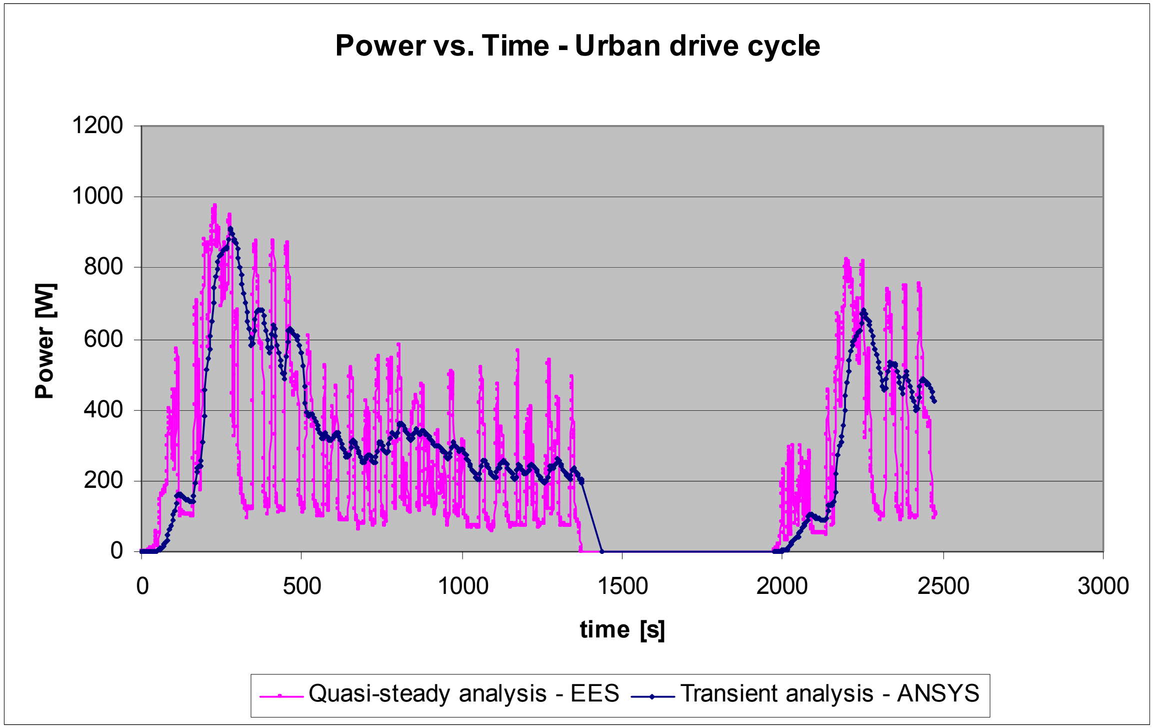


Subsystem Modeling



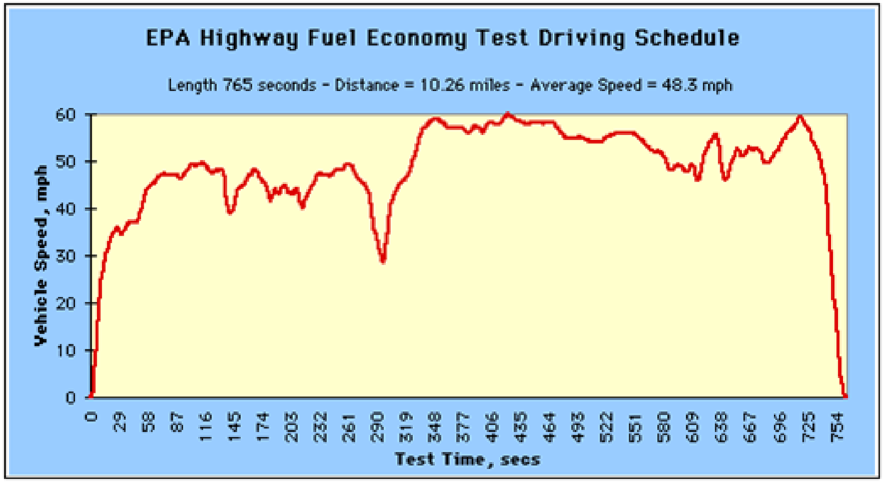
Subsystem Performance

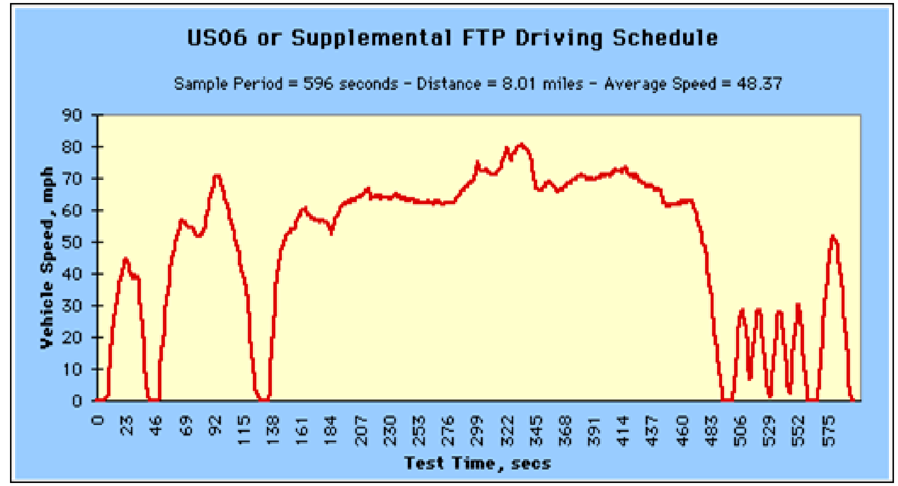




- Average output ~ 350 W and max. output ~ 914 W
- 350 W equals the base electrical load of today's generator on FTP, potential composite Urban/Highway fuel economy improvement of ~ 3%
- We expect an additional ~ 1% fuel economy improvement through vehicle integration

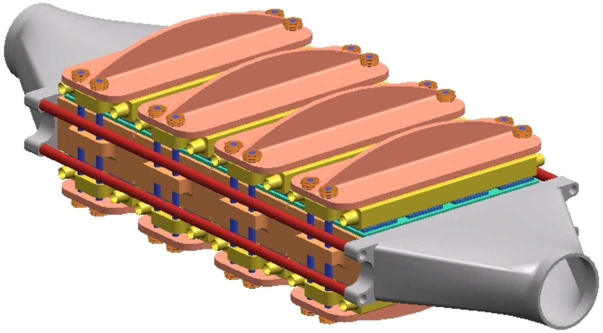
Fuel Economy Test Schedules



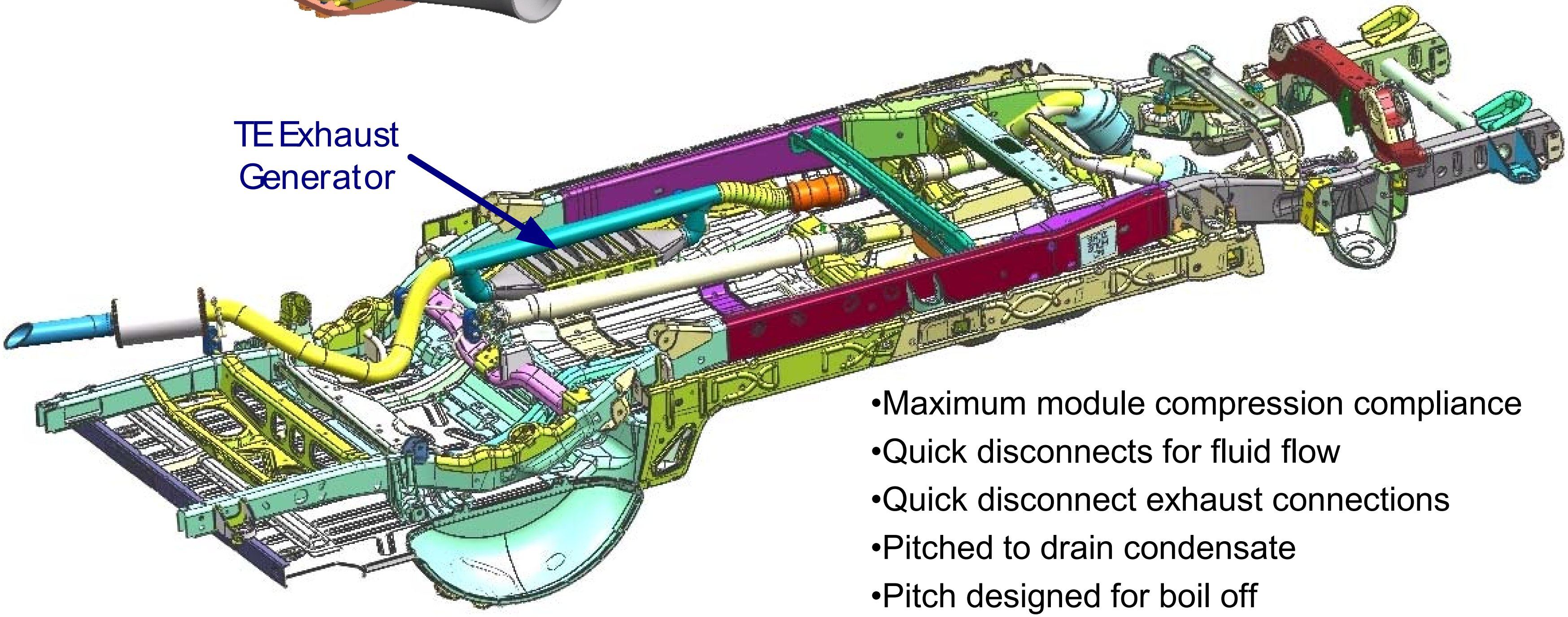


- FTP cycles represent very mild driving pattern (max. speed ~ 60 mph), therefore, does not accurately reflect real world scenario
- The US06 addresses this shortcoming with the FTP test cycles in the representation of aggressive, high speed and/or high acceleration driving behavior, and rapid speed fluctuations
- We expect a TE waste heat generator would generate > 350 W in real world

Subsystem Design - Preliminary



- Located where current muffler is placed; new muffler will be located behind the axle perpendicular to vehicle axis
- Axially compliant for thermal expansion mismatch

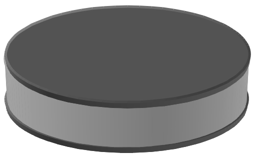


- Maximum module compression compliance
- Quick disconnects for fluid flow
- Quick disconnect exhaust connections
- Pitched to drain condensate
- Pitch designed for boil off
- Sealed electronics

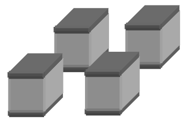
TE Subsystem Experiment Design

- 35 kW exhaust flow: 0-0.1kg/s mass flow rate between room temperature and 650 °C
- Closed-loop temperature / pressure control and computerized data acquisition

TE Module Construction

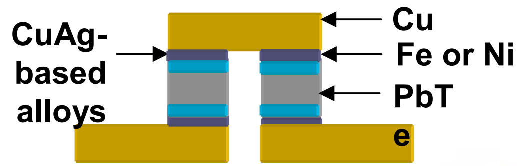


SPS PbTe with Fe or Ni barrier layers

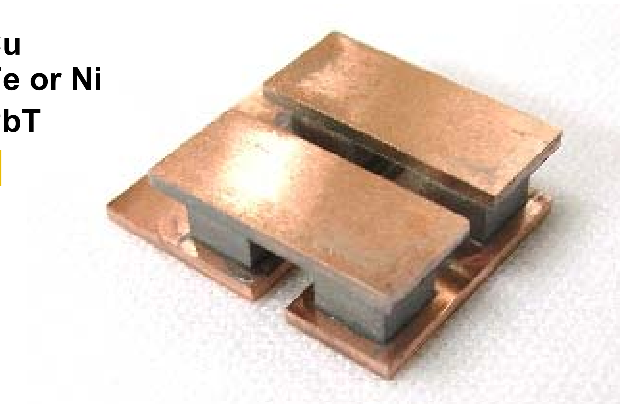


Singulation and surface preparation

Ag bearing Cu electrode

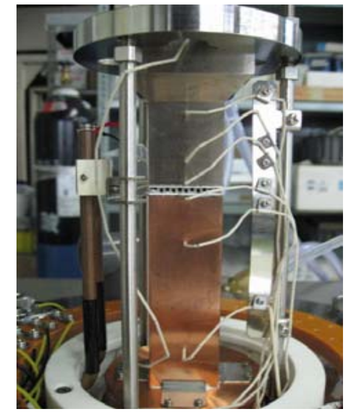


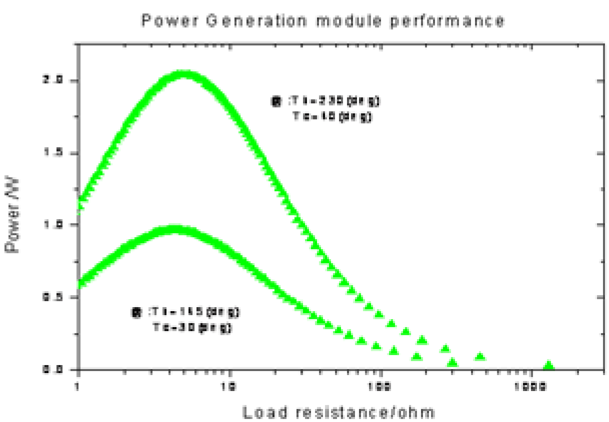
Brazing (in fixture)

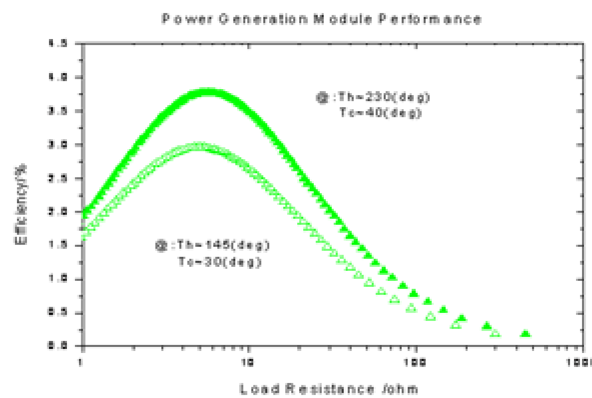


- 2x2 modules for initial process optimization
- Initial header-free design for manufacturability
- Ni diffusion barrier module with 600 °C braze; Fe diffusion barrier modules with 800 °C braze

TE Module Test

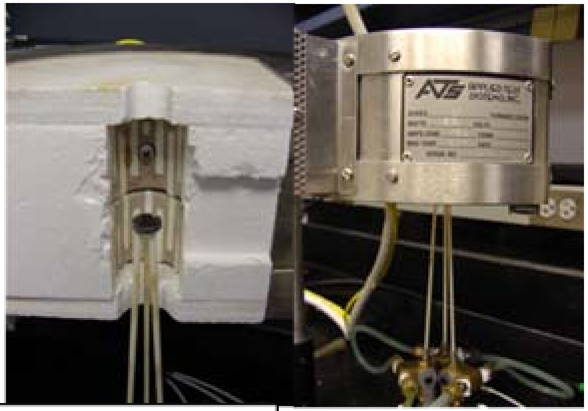


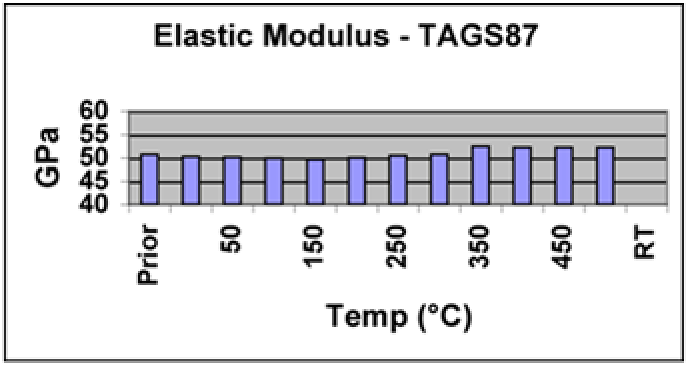


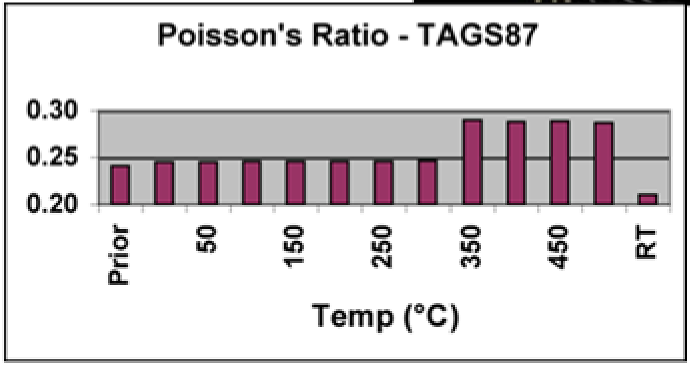


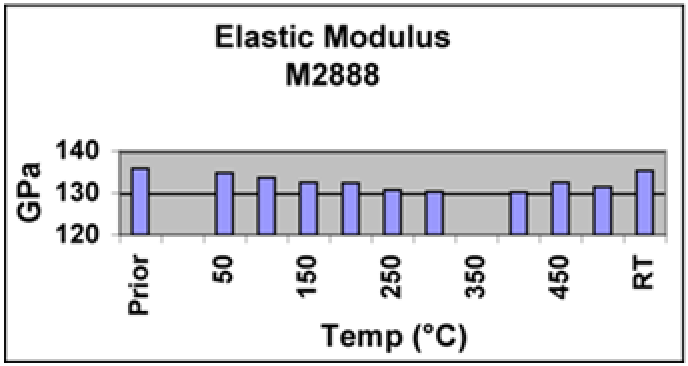
High Temperature Mechanical Properties Characterization

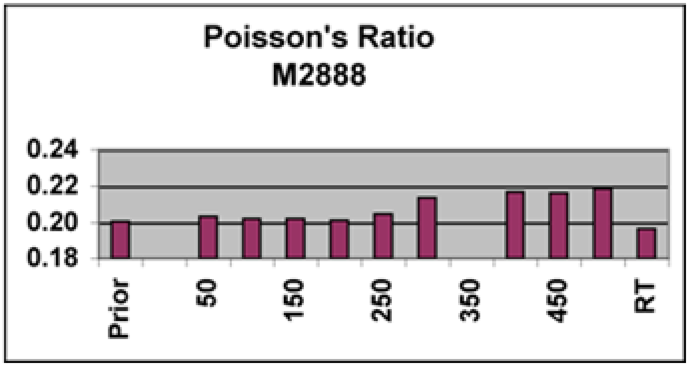
resonance ultrasound spectroscopy











Project Status & Next Steps

- Project is 60% complete
- TE materials and subsystem design have been selected
- Initial subsystem prototype generator available by next summer
- Fully integrated demonstration vehicle available summer 2010