Benefits of Thermoelectric Technology for the Automobile

Francis Stabler
General Motors & Future Tech LLC

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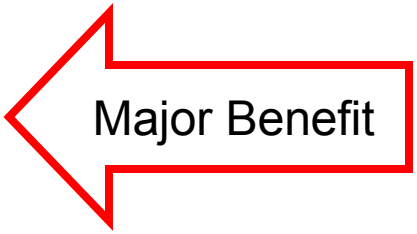
Major applications of Thermoelectric Technology on Automobiles (cars and light trucks)

- Thermoelectric Generators (TEG) have been a major focus for Automotive applications
- HVAC applications are starting
  - Heated and cooled seats, contributing to HVAC, have over a decade of production
- Battery thermal management is a field of growing opportunity

Why develop automotive TEG's?

- **Improve vehicle fuel efficiency**
  - Customer driven requirement
  - Government driven requirements
- Requirements to lower CO_2 emissions
- Green image to help vehicle sales
- Support increased vehicle electrification
- Simpler than alternative systems:
  - Rankine, Stirling, thermo-acoustic, etc.



How will a TEG provide fuel economy improvement?

- On the FTP driving cycle
  - Replace the generator load (160 – 500 W)
  - TEG/Exhaust heat used for faster warm-up of the engine and transmission
  - Minimize added mass (a loss of FE)
  - Convert selected vehicle mechanical functions to electrical functions and provide electrical power with TEG
- Real world driving? Could be more / less

Fuel Economy due to vehicle alternator replacement

- Power usage on FTP: 160 to 500 W
  - Small Car (Chev Aveo 1.6L 4 Cyl) ~ 160 W
  - Full Size Truck (6.0L V8) ~ 500 W
- Fuel Economy penalty estimates for alternator: 1 to 4 %
- Examples of Fuel Economy
  - Mid size cars with V-6 engine ~ 1 to 2 % FE
  - Small Car (~4%) or full size truck (~ 3%) FE

FE due to faster engine and transmission warm-up

- Fuel economy is reduced by the parasitic loses of cold engine oil and transmission fluid
- The engine uses more fuel than normal for a given load until the coolant temperature reaches a calibrated condition
- Faster heating of the engine coolant can improve fuel usage by 0.2 to 1 %

FE due to added mass of TEG (loss)

- Energy analysis, supported by testing, predicts 1% fuel economy loss on the FTP for the following additional weight
  - Cars and small trucks =125 pounds
  - Large trucks and SUVs = 250 pounds
- This means that a TEG system weighing 125 Lbs will lower fuel economy
  - 1% on most cars
  - 0.5 % on a large SUV or truck

Fuel Economy gains by converting some loads from mechanical to electrical

- Why? - Efficient TEG's will generate more electric power than required to replace the alternator
- Example of conversion: replace coolant pump with
  - A full capability electric pump (400 to 800w max)
  - A small electric pump (25 to 50W max) and a clutched mechanical pump
- Other potential conversions: Oil pump, trans fluid pump, electric driven valve train, …

Summery of TEG FE changes

Fuel Economy Feature/Impact	Low	High
Alternator replacement	1%	4%
Faster engine & fluid warm-up	0.2%	1%
TEG Mass impact	-0.5%	-1%
Mech to Elect conversion of vehicle functions (ex. Coolant pump)	0.3%	4%

Thermoelectric heating & cooling benefits

- Heating & Cooling applications
  - Resolves greenhouse concerns of refrigerant use
  - Enables new design concepts for heating and air conditioning
  - Enables new features – heated or cooled storage
  - Improves reliability of selected components (battery, electronics, etc.)
- Unique opportunities for heating and cooling exist on hybrid, electric, and fuel cell vehicles
  - Intermittent or no direct mechanical power available for AC compressor operation
  - Intermittent or no ‘free’ heat availability
  - Increased electric power availability for heating or cooling
  - More potential for ‘clean sheet’ vehicle design
    - New heating and cooling design approaches – distributed systems

Thermoelectric HVAC
Case 1

- Direct replacement of centralized system
  - Operation with engine off
  - Faster operation
  - Some improved efficiency – Fuel economy improvement

Thermoelectric HVAC
Case 2

- Distributed system
  - New design
    - Integrated into passenger compartment
    - Use of heated / cooled seats and other contact areas
    - Heat / cool passengers only, not empty seat areas
  - Operation with engine off (electric)
  - Faster operation – heating and cooling
  - Remote operation capability without engine
  - Improved efficiency
    - Fuel economy gain in real world driving = TBD (could be up to 20 % in special situations with steady state driving)

Thermal management of batteries with thermoelectric technology

- Conventional vehicle starter batteries
  - Lead acid or alternate chemistry
- Hybrid vehicles
  - Parallel or series
- Electric vehicles
- Fuel cell vehicles (some designs)

How can thermoelectric technology improve battery operation?

- Very cold or hot batteries do not charge or discharge efficiently
  - Lead acid: 13.5 V charge at 70ºF (14.5 V at 20ºF)
- Battery life is extended if battery temperature is maintained in the optimum range for that battery chemistry
- Complimentary conditions: Battery packs need circuitry to balance the cell voltages
  - Power drawn from cells to maintain balance could power some or all battery pack heating and cooling

Summary

- Thermoelectric technology is likely to find application in several automotive systems
- Power generation and heating/cooling applications are equally attractive
- Improved efficiency of operation is the main pull for this change.
  - 1 to 8% fuel efficiency improvement for TEG
  - Estimated up to 5% fuel efficiency with thermoelectric HVAC
- None of the above will be possible without production quantities of new high-efficiency thermoelectric modules