Establishing Thermo-Electric Generator (TEG) Design Targets for Hybrid Vehicles

2013 DOE Hydrogen Program and Vehicle Technologies

Annual Merit Review

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&

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Project ID # VSS100

U.S. Department of Energy

Energy Efficiency and Renewable Energy

Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable

Project Overview

Timeline	Barriers
Start Date : Sep 2012 End Date : Sep 2013 Percent Complete: 40%	• Multiple hybrid architectures, control logics • TEG model with new materials • TEG configuration decisions • Limited availability of test data

Budget	Partners
Total Project Funding • DOE, Vehicle Systems: $75 K • DOE, Advanced Combustion: $75 K	• General Motors

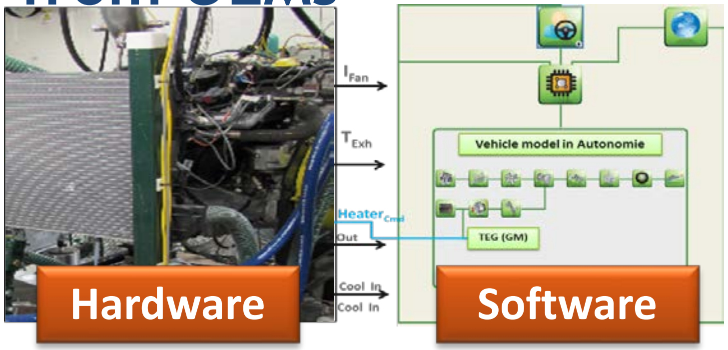
Relevance

Establish TEG requirements to provide cost effective power for hybrid vehicles.

- FY11 - Argonne demonstrated the ability to evaluate the benefits of TEG on a conventional vehicle using simulation techniques.
- TEGs may offer additional benefits for electric drive vehicles as the electrical energy can be fully utilized
- Cost benefit analysis can be used to determine the need of 'off-cycle credits'

Relevance: FY11 Work

Independent Evaluation of TEG using EIL & Simulation. Confirmed by Prototype Test Results from OEMs

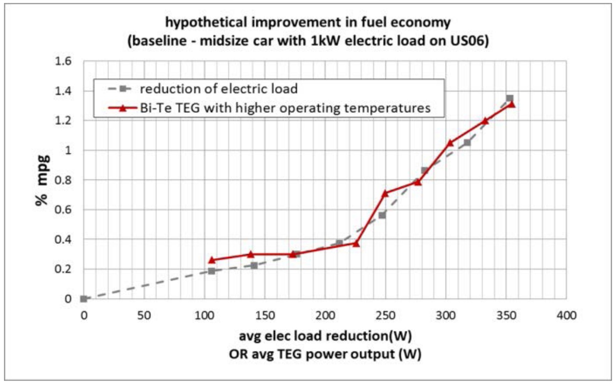


Objective:

Evaluate the fuel economy impact of thermoelectric devices ***on a conventional vehicle***, using engine-in-the-loop testing and simulation studies

Results:

- Cold & hot start conditions, effect of heat rejection by TEG and additional fan load was analyzed
- Estimated %mpg improvement in US06 and other EPA drive cycles.
- Pointed out the need for changes in fuel economy test procedure to properly evaluate TEGs benefits



Remarks:

Presented at the 3rd TEG Workshop

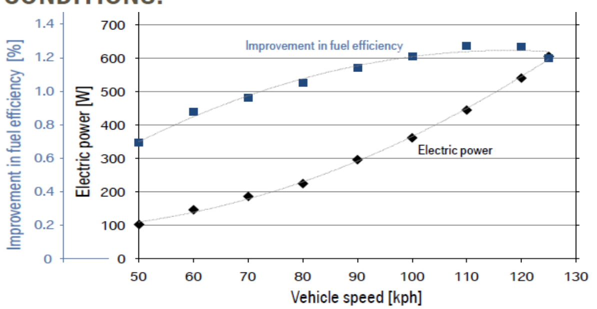
Results confirmed by prototype tests done by OEM.

GM : Reviewed and agreed with Argonne estimates.

BMW : Similar mpg gains for their X6 prototype.

Ford : EPA & EU off-cycle credits / EcoInnovation credits

BMW X6 TEG PROTOTYPE VEHICLE.
SYSTEM PERFORMANCE FOR STEADY STATE CONDITIONS.



Milestones

Define baseline vehicle
Develop & test scripts to automate simulations, result compilation

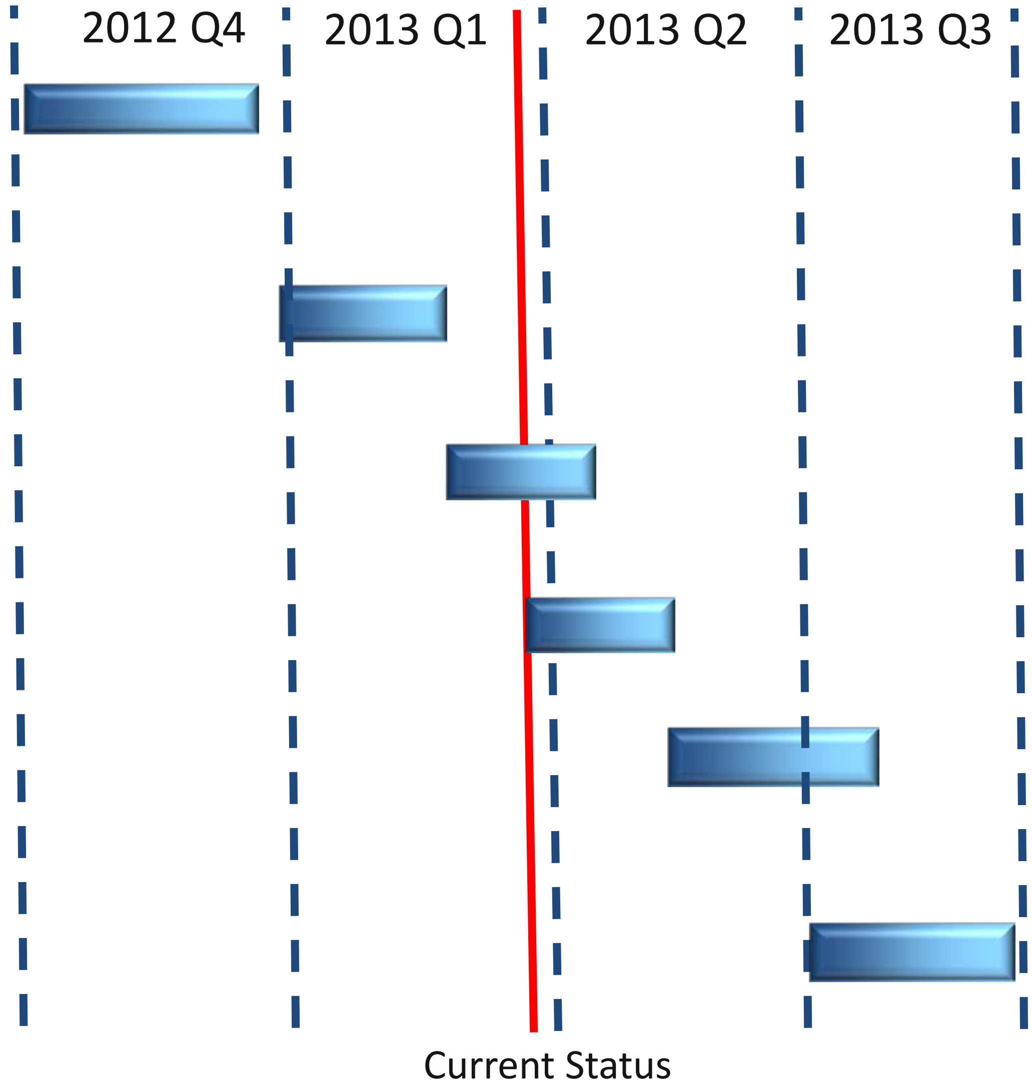
Evaluate the fuel saving potential of auxiliary electrical energy sources on baseline vehicle

Updating control logics of Belt Integrated Starter Generator (BISG)

Integrating the TEG model from GM

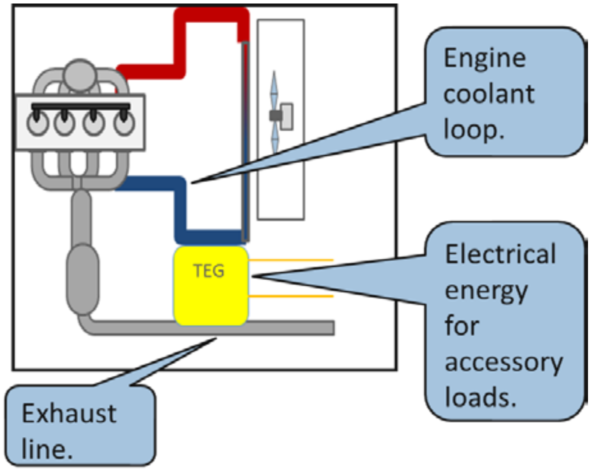
Evaluating the potential of the TEG on BISG

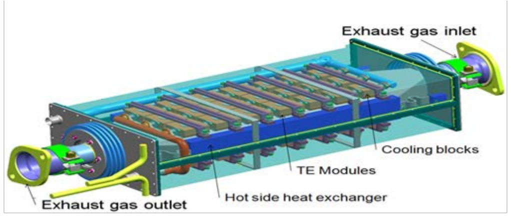
Evaluate the benefits in other hybrid powertrain architectures



Approach

- Baseline vehicle
  - Belt Integrated Starter Generator (BISG)
- TEG module
  - TEG model is from FY-11 study
  - Add new Skutterudite module data
  - System design factors
    - # of modules and layout
    - Power rating
- What if
  - Conversion efficiency improves
  - More waste heat is recovered
  - Thermal cycling can be reduced





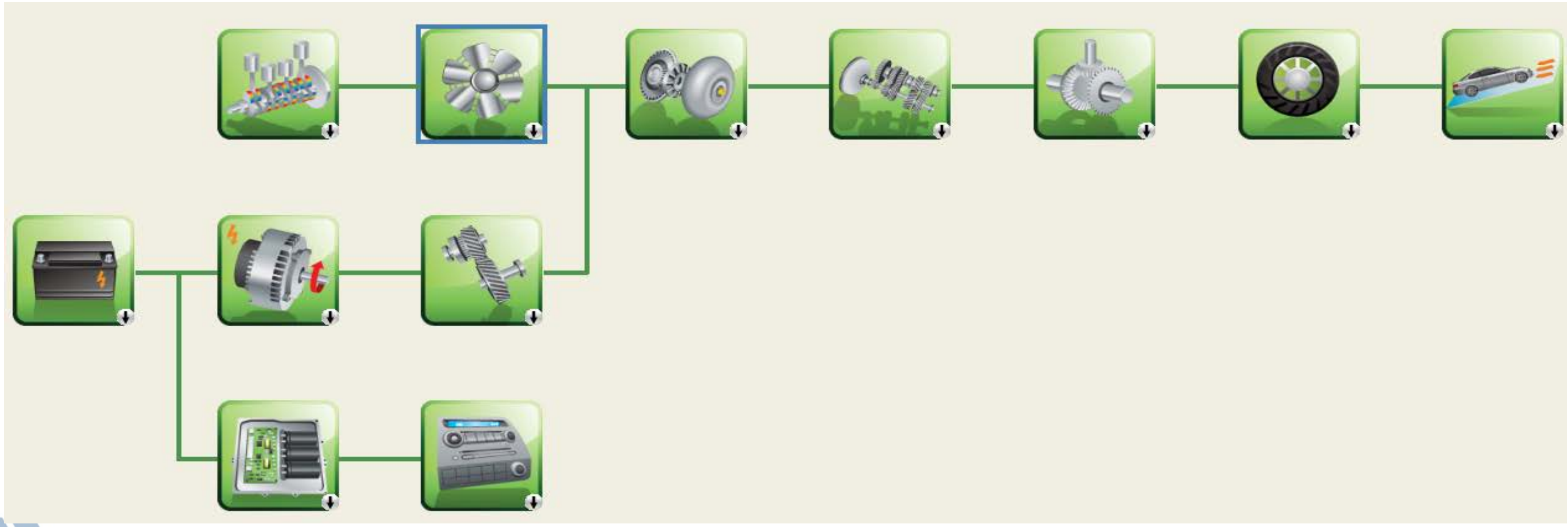
From John W Fairbanks, 'Automotive Thermoelectric generators and HVAC', presented at the DOE internal meeting, Washington DC, Nov 2011

Approach

- Determine the impact of an auxiliary electric power source like TEG on baseline vehicle
  - Fuel Displacement
  - Net Present Value (NPV) of the $ savings
  - Determining the $/W that will make such devices commercially viable
  - Will control logic changes or larger motor size improve the benefits?
    - E-Assist vs. Reducing engine usage
  - Is a larger battery or ultra capacitor necessary for capturing transient power from TEG?
- Integrate the latest TEG model from GM
- Evaluate the impact of the TEG on BISG
  - Effect of Skutterudite materials over BiTe.
  - Effect of conversion efficiency
  - Effect of varying temperature limits on TEG
- Add other powertrain architectures

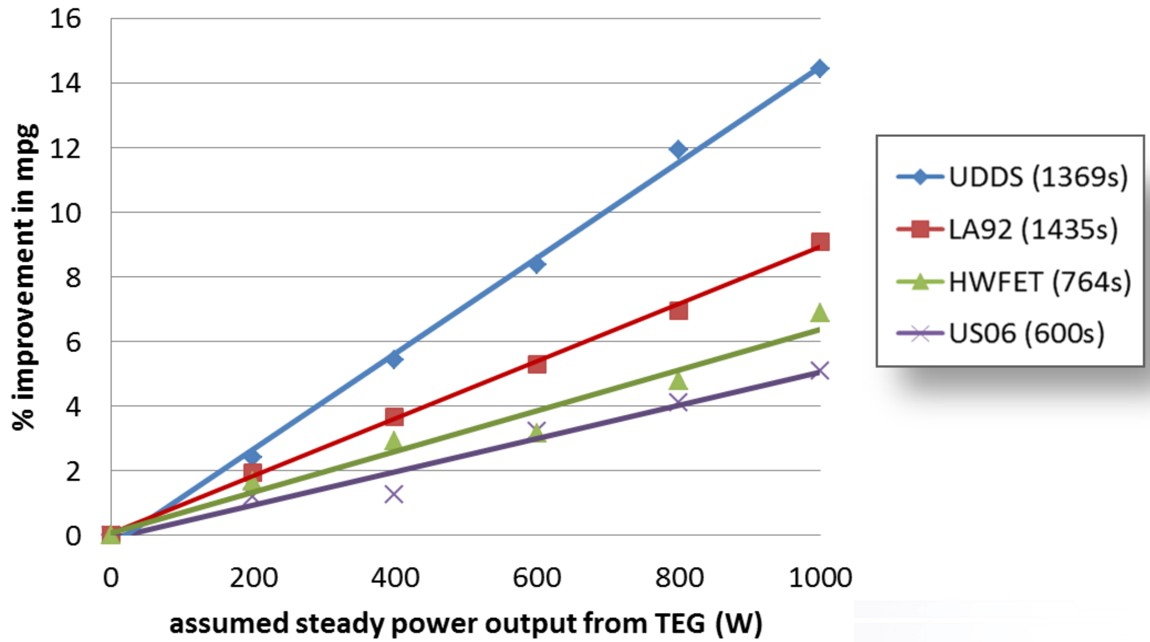
Technical Accomplishments
Baseline Vehicle Defined

- Midsize 2wd vehicle
  - Belted Integrated Starter Generator
  - Engine 115 kW
  - Motor 10kW
  - Battery 1.4kWh usable
  - Auxiliary power source (up to 1kW; could be any technology such as TEG)



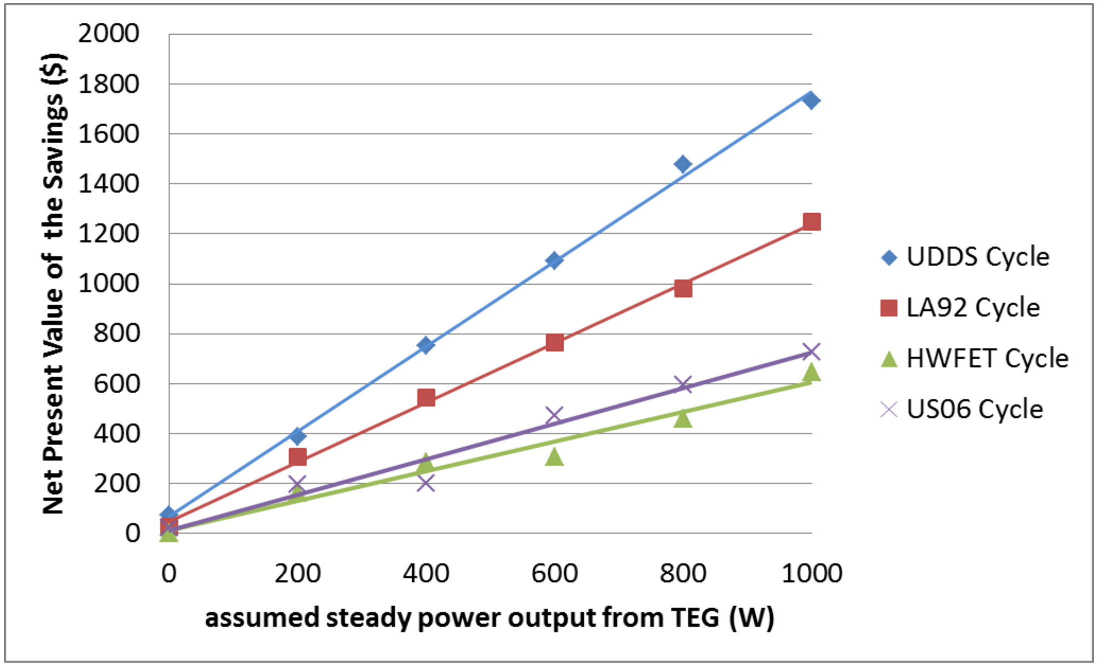
Technical Accomplishments
TEG Fuel Saving Potential Quantified

- Assumptions
  - Steady power source, available over the entire drive cycle
  - Motor can assist engine at any speeds. Limited only by SOC thresholds
  - Benefit estimation use BISG with no auxiliary power as the baseline
- Charge Sustaining operation
- Less aggressive & longer cycles show more benefits



Technical Accomplishments
Net Present Values (NPV) Estimated

- Assumptions
  - NPV of gasoline savings over the lifetime of vehicle
  - 150k miles & 15 years of vehicle usage
  - Reduced vehicle usage after the initial 6 years (based on NHTSA surveys)
  - 7% discount rate
  - Gasoline cost →$4/gallon



Proposed Future Work: FY13 – Ongoing work
Evaluate Effect of New TEG Model from GM

- Integrate the latest high fidelity TEG model from GM
- New TEG design is still not published
  - Skutterudite material properties are known
  - Estimate number of modules & layout for TEG
  - Estimate fuel economy benefits

- Earlier studies indicated the under utilization of modules in the earlier prototype designs

Proposed Future Work: FY14 Potential Activities

Explore New Ideas, Establish Requirements, Benchmarks & Design Targets For TEGs to be Cost Effective

- New ideas related to the use of TEG
  - What if we can store all the exhaust heat from the engine?
  - How much exhaust heat do we need for it to be cost effective?
  - Can a thermal reservoir enable the use of other TEG materials
  - With thermal reservoirs, can thermal cycling of TEGs be reduced?
    - Can this facilitate use of cheaper materials ?
  - What if we raise the conversion efficiency with current TEG system designs
- GM will provide feedback for critical and practical sense checking
- Simulate cases that look promising

Summary

- How much promise do TEGs hold for E-assist vehicles ?
  - For an auxiliary power source of 1kW steady electric power
  - Simulations show 5% - 14% mpg increase, depending on cycle
- How much can the customer pay for an auxiliary energy source/recovery device in an E-assist vehicle?
  - $0.5 to $2 per W (assuming steady power over entire drive)

- Next Steps
  - Evaluate the potential of the new TEG from GM
    - # of Skutterudite modules
    - Configuration
  - Evaluate new ideas for TEG