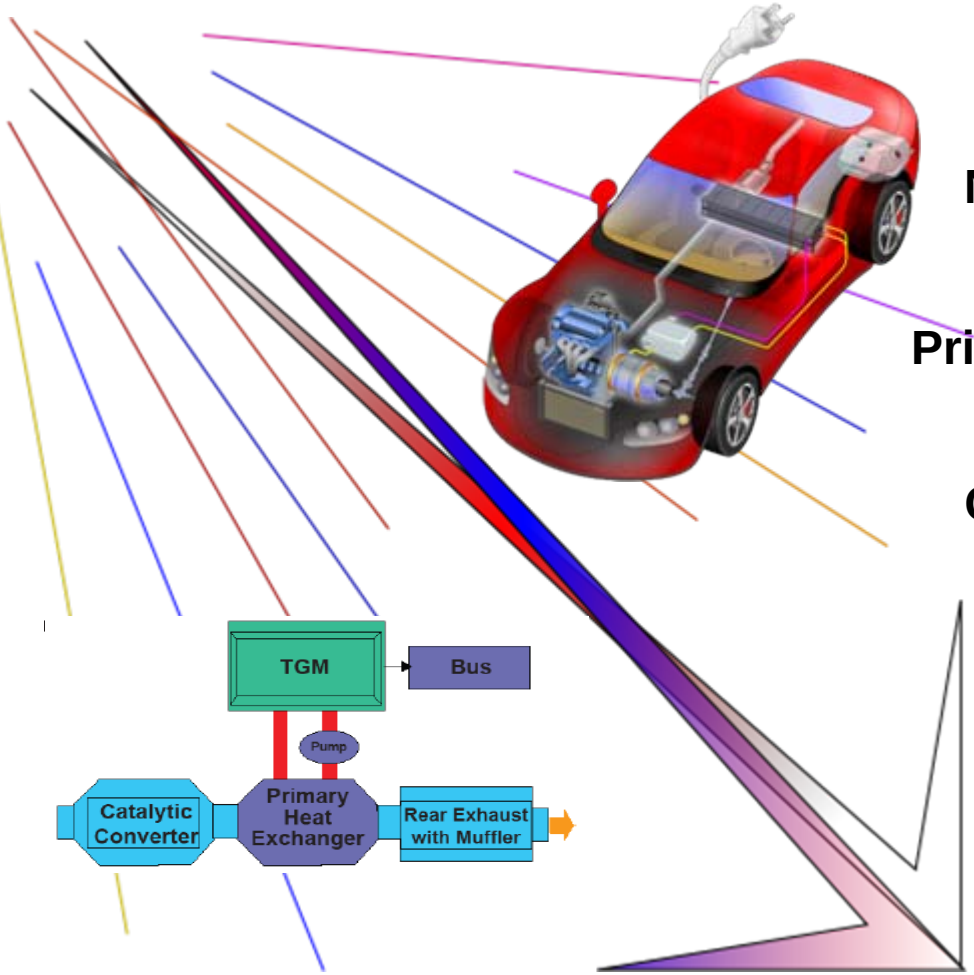
Vehicle Modeling and Simulation



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Principal Investigator: Matthew Thornton
Agreement: 17802

DOE Vehicle Technologies Program
Overview of DOE Vehicle Modeling and Simulation R&D

North Marriott Hotel and Conference Center
Bethesda, Maryland

February 28, 2008

This presentation does not contain any proprietary or confidential information

Objective:
Vehicle Modeling and Simulation

- **Provide technical analysis of future vehicle technologies and systems to support project planning decisions for both DOE and industry that will impact our dependence on imported petroleum**
- **Provide analytical support to DOE and USCAR technical teams addressing current technical R&D barriers and targets**
- **Perform analytical assessments of the potential long-term outcome of DOE programs in terms of national petroleum consumption**

Accomplishments FY07 and FY08: Vehicle Modeling and Simulation

- **PHEV Simulations and Analysis**
  - **Travel Profile Database**
  - **PHEV Impact on Components**
  - **Integration with Renewable Fuels**
  - **PHEV Economics**
  - **PHEV Test Procedures**
- **Route-Based Hybrid Vehicle Control**
- **Thermoelectric Generator Potential for Vehicle Waste Heat Recovery**
- **Integrated Vehicle Thermal Management Modeling**

FY 08 Work Plans: Vehicle Modeling and Simulation

- **Continue PHEV Simulations and Analysis**
  - **Medium-Duty Plug-in Hybrid Vehicle Analysis**
  - **Expand Travel Profile Database**
  - **Analysis of PHEV Impact on Components**
  - **Integration with Renewables and Bio-Fuels**
  - **PHEV Economics**
  - **PHEV Test procedures**
- **Route-Based Hybrid Vehicle Control**
- **Integrated Vehicle Thermal Management Modeling**
- **Exhaust System Thermal Analysis Test Bench**
- **Budget: $800K (~40% spent)**

PHEV Simulations and Analyses
PI: Tony Markel

Objective:

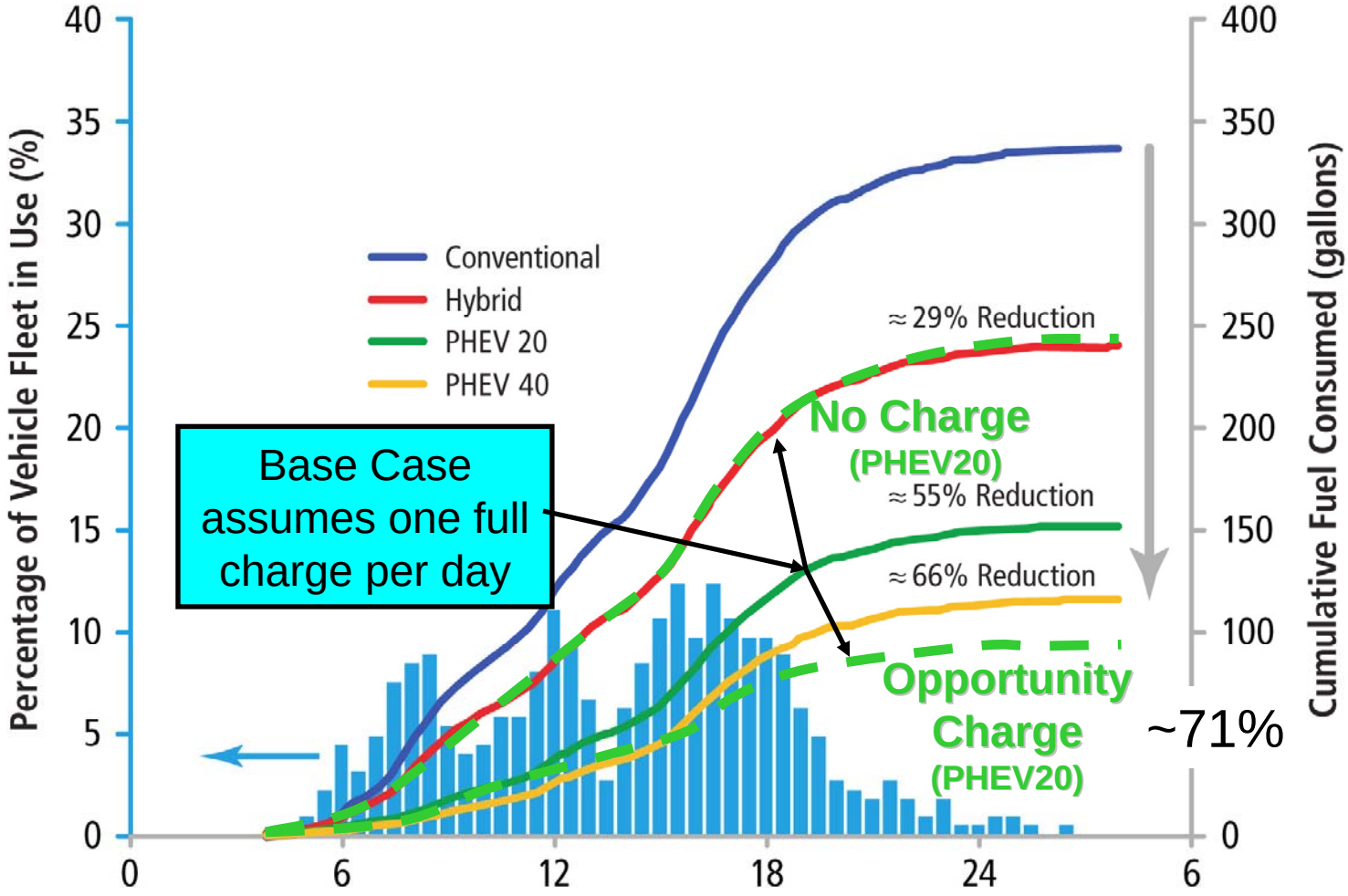
- **Provide assessment of the potential benefit of PHEVs and identify pathways for market integration by evaluating operation and performance under “real world” driving conditions, evaluating system component requirements, evaluating costs and benefit trade-offs, and assessing barriers to introduction into the fleet and eventual commercialization**

Accomplishments FY 07 & 08: PHEV Simulations and Analysis

- **Processed GPS travel profile data sets provide nearly 2000 real world driving profiles for simulation**
  - **Completed simulations for opportunity charge and no-charge scenarios (FY07)**
  - **Spectrum of duty cycles expanded with Los Angeles, Kansas City, and Tyler data (FY08)**
- **Assess PHEV Component Impacts**
  - **Energy storage, power electronics, emission control (FY07 & 08)**
- **PHEV/Biofuels Integration**
  - **Used GREET to review PHEV/fuel scenarios and their relative benefits (FY07)**
- **Economic Analysis and Marketability**
  - **Conducted an attribute-based market study suggesting cost effectiveness of PHEVs challenging (FY07)**
  - **Component cost goals important for reducing initial cost (FY07)**
  - **Reviewed potential impacts of incentives and other factors on cost equations (FY08)**
- **Test Procedures**
  - **Provided 4 recommended revisions to methods for reporting PHEV fuel consumption (FY 07, continuing in FY08)**

Recharge Scenario Impacts on PHEV Petroleum Consumption Benefits

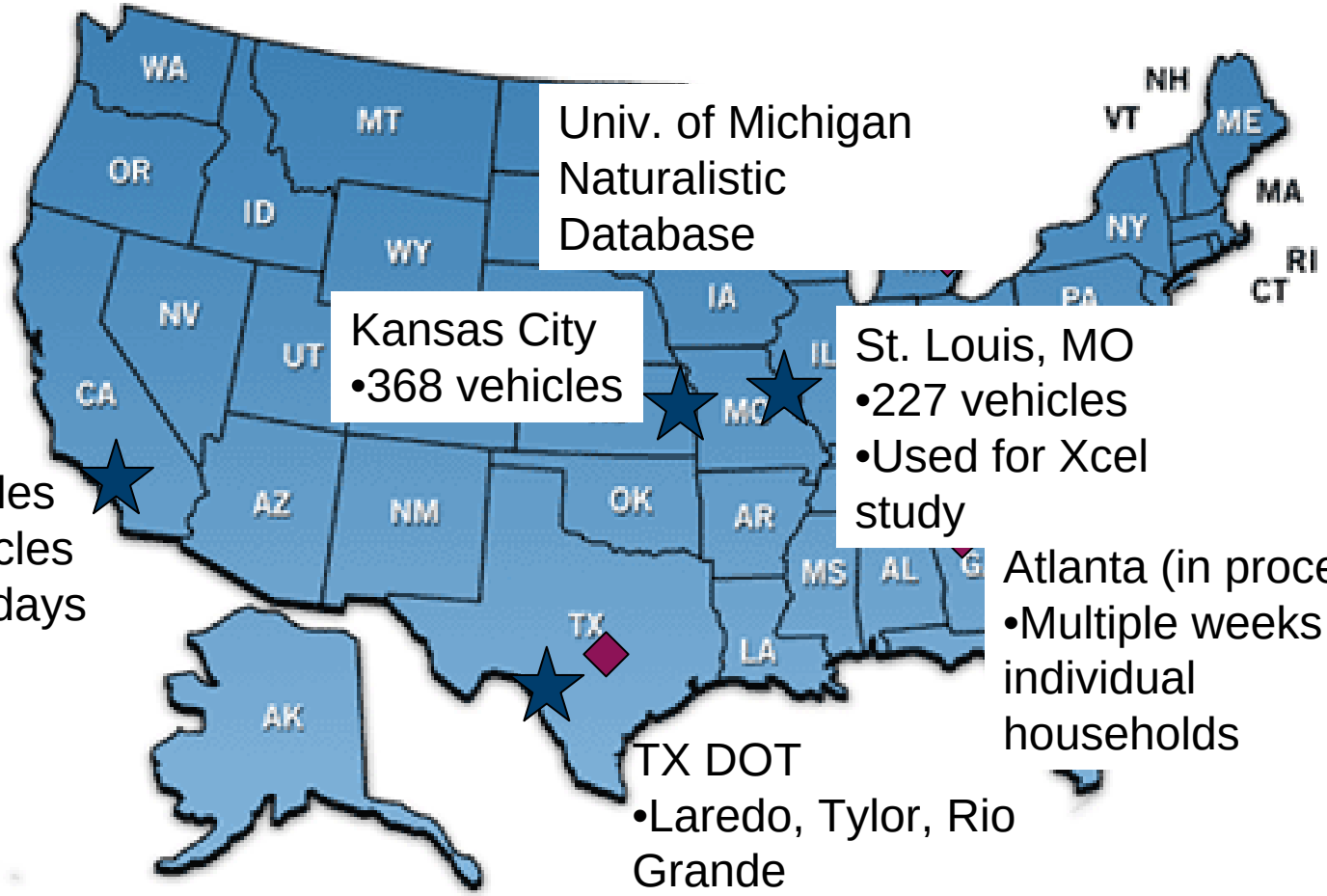
Opportunity charge: connect PHEV charger to grid any time that the vehicle is parked.



PHEV20 with Opportunity Charge provides greater benefits than PHEV40 with a single daily recharge.

Travel Profile Data Processing

Summary of Newly Processed Travel Data



Univ. of Michigan Naturalistic Database

Kansas City
•368 vehicles

St. Louis, MO
•227 vehicles
•Used for Xcel study

Los Angeles
•621 vehicles
•Multiple days

Atlanta (in process)
•Multiple weeks for individual households

TX DOT
•Laredo, Tylor, Rio Grande
•Austin (in process)

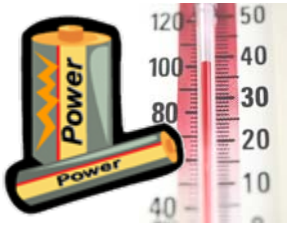
Each data set stored in a different format

Automated processing more challenging than expected

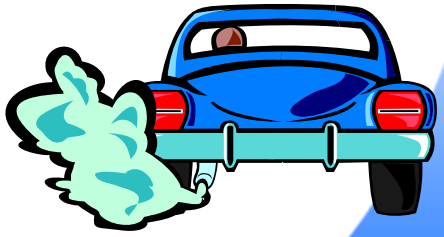
PHEV Component Impacts Summary

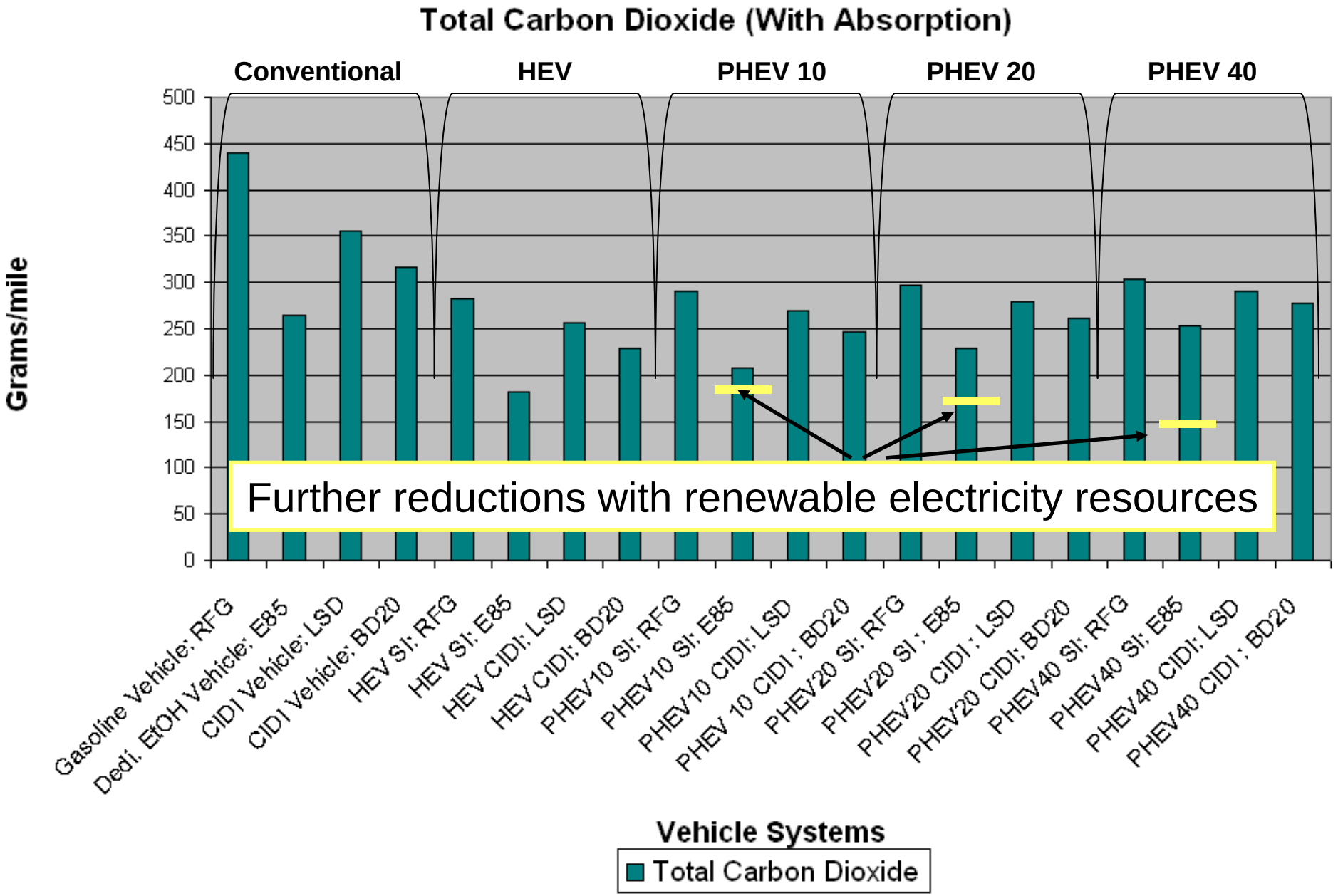
- **Energy Storage**
  - **PHEV introduces more long duration power pulses**
  - **Time at SOC depends on recharge behavior**
  - **Run simulations to set PHEV Battery requirements**

- **Power Electronics**
  - **PHEVs produce higher thermal loads on PEEMs and increase battery bus voltage fluctuation**



- **Engine/Emissions Control**
  - **Charge depleting electric PHEV simulations suggest potential reduction in emissions by reducing initial daily cold starts and total daily engine starts**





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** Assumes national average for electricity mix

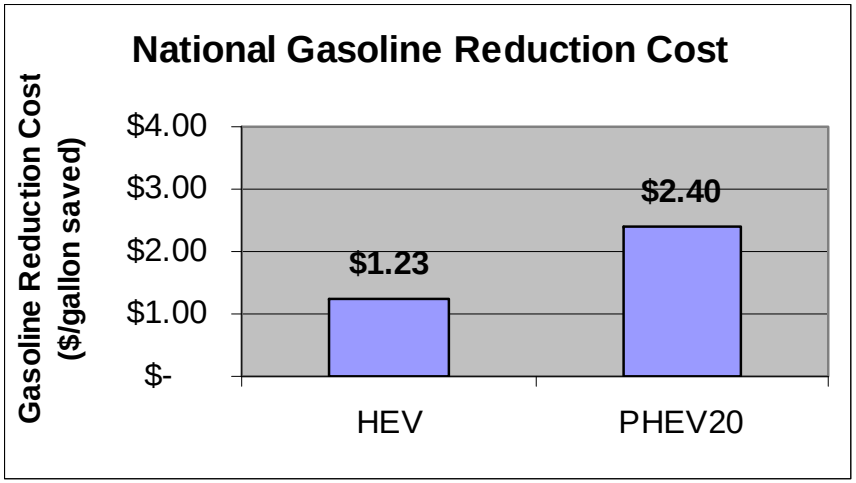
PHEV Economics Analysis: Incentives

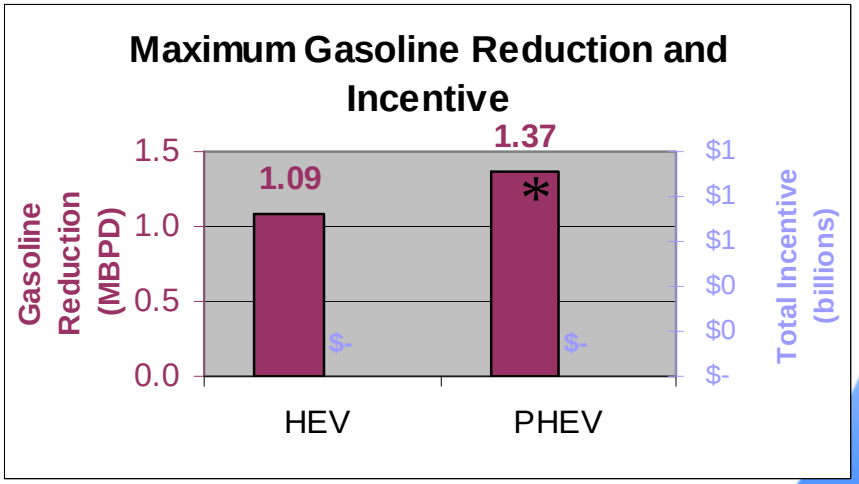
Accomplishment

- **Analyzed energy impacts from incentivizing PHEVs (cars)**
  - **Currently, a given level of incentives can directly incentivize far more HEVs and overall reduce oil use more than incentivizing PHEVs**
  - **Current level of federal HEV incentives, however, only replace ~0.1% of the fleet**
  - **If incentivizing PHEVs helps achieve DOE cost targets, PHEVs may over come the tipping point and have a larger impact than incentivizing HEVs**

Significance

- **Shows a pathway to reduce imported oil through PHEVs**





* PHEV20 based on number of cars only, not light trucks

FY 08 Work Plan:
PHEV Simulations and Analysis

- **Medium-Duty Plug-in Hybrid Vehicle Analysis**
- **Expand Travel Profile Database**
- **Analysis of PHEV Impact on Components**
- **Integration with Renewables and Bio-Fuels**
- **PHEV Economics**
- **PHEV Test procedures**
- **Budget: 350K (~45% spent)**

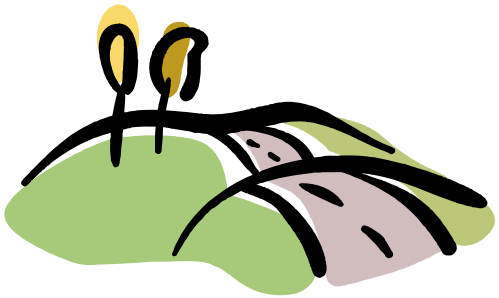
Justification and Future Plans: PHEV Simulations and Analysis

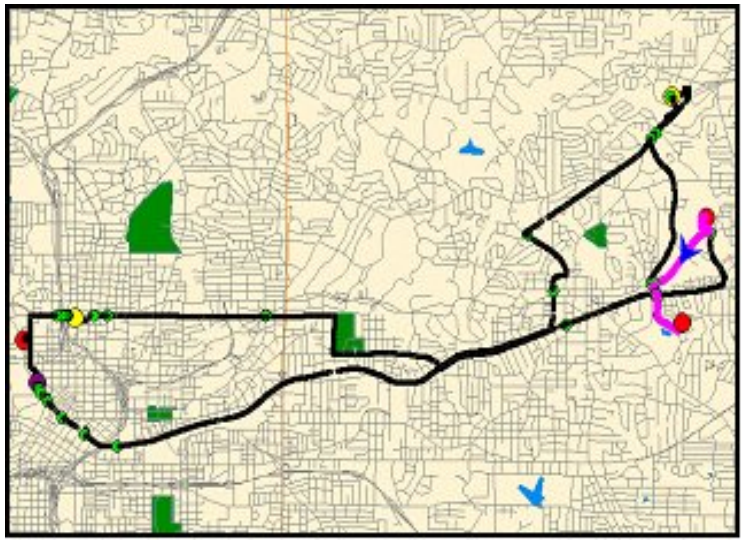
- **Supports grater DOE multi-lab PHEV and advanced vehicle technology evaluation efforts, including:**
  - **PHEV Demonstration**
  - **Vehicle component requirements (e.g. Energy storage and Power Electronics)**
  - **PHEV Benchmarking**
- **Perform simulation and modeling to help identify best pathways to fuel savings and fuel diversity with PHEVs**
- **Future Plans**
  - **On going project supporting PHEV R&D Plan**
  - **Use simulation tools to reduce battery coat and extend battery life**
  - **Explore V2G technologies and their ability to affect vehicle economics and renewables**

Route-Based Hybrid Vehicle Control
PI: Jeff Gonder

Objective:

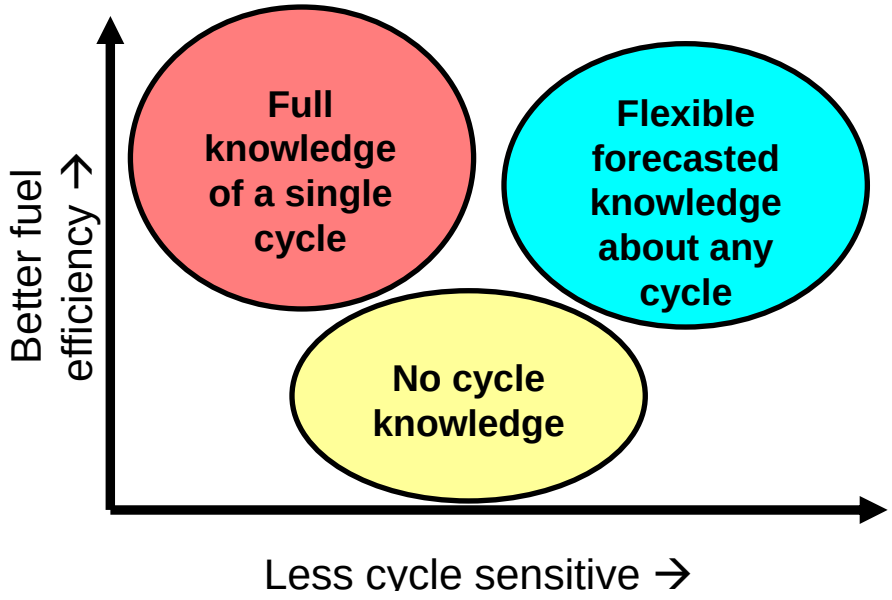
Maximizing HEV fuel efficiency over known or predictable drive cycles by optimizing the control strategy for that particular driving cycle.

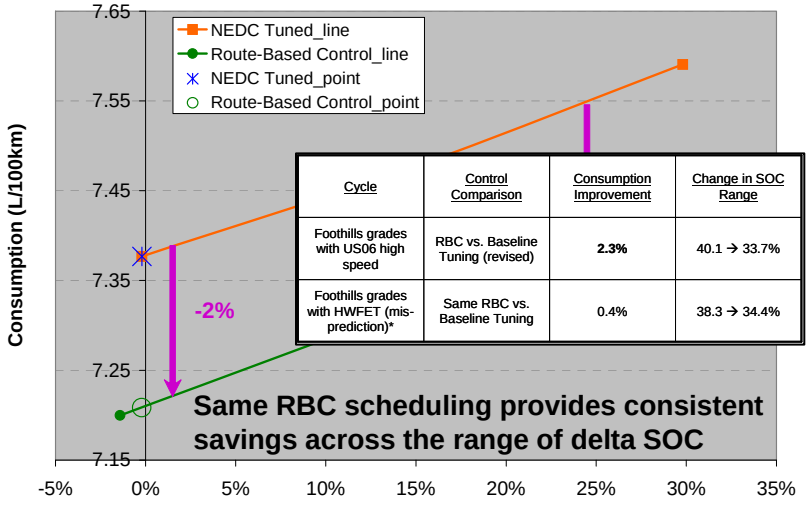




Accomplishments FY 07
Route-Based Hybrid Vehicle Control

- **Spectrum of possible RBC approaches; establishing a sound comparison baseline is critical for evaluating the benefit**
- **Example implementation demonstrates 2-4% fuel savings**
  - **Moderated by practical considerations (relative to effective baseline)**
  - **Considerable in aggregate (if applied across the fleet)**





Cycle	Control Comparison	Consumption Improvement	Change in SOC Range
Foothills grades with US06 high speed	RBC vs. Baseline Tuning (revised)	**2.3%**	40.1 → 33.7%
Foothills grades with HWFET (mis-prediction)*	Same RBC vs. Baseline Tuning	0.4%	38.3 → 34.4%

Work Plan FY08
Route-Based Hybrid Vehicle Control

- **Publish preliminary results**
- **Establish industry partner for hardware demonstration**
- **Budget: $75K (~35% spent)**

Accomplishments FY 08
Route-Based Hybrid Vehicle Control

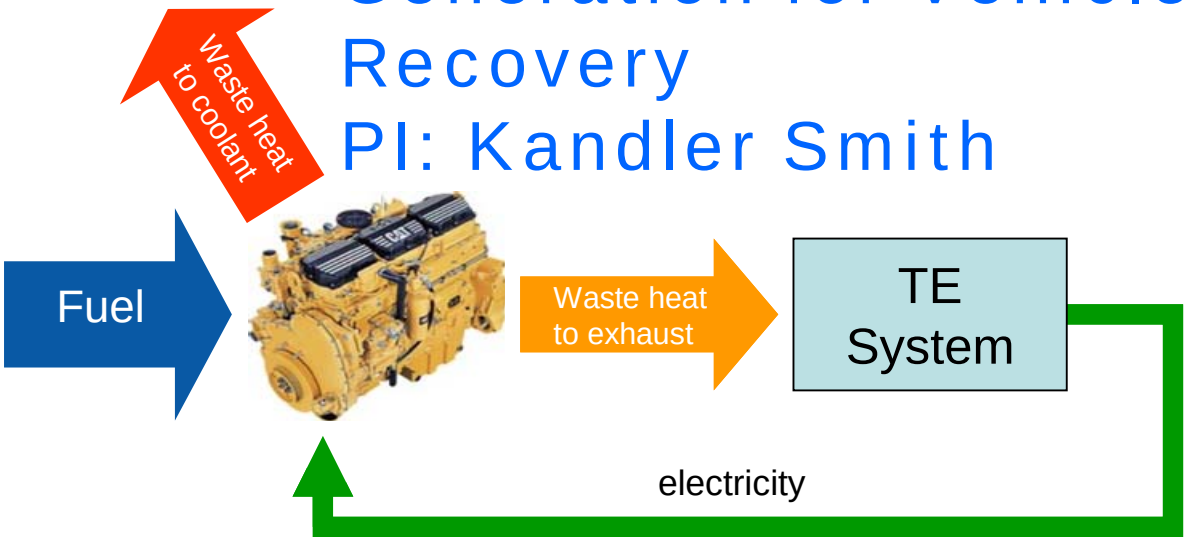
- **SAE paper to be published in April**
- **Working with industry partner on transit bus demonstration—in use application of adaptive HEV controls**

Justification and Future Plans:
Route-Based Hybrid Vehicle Control

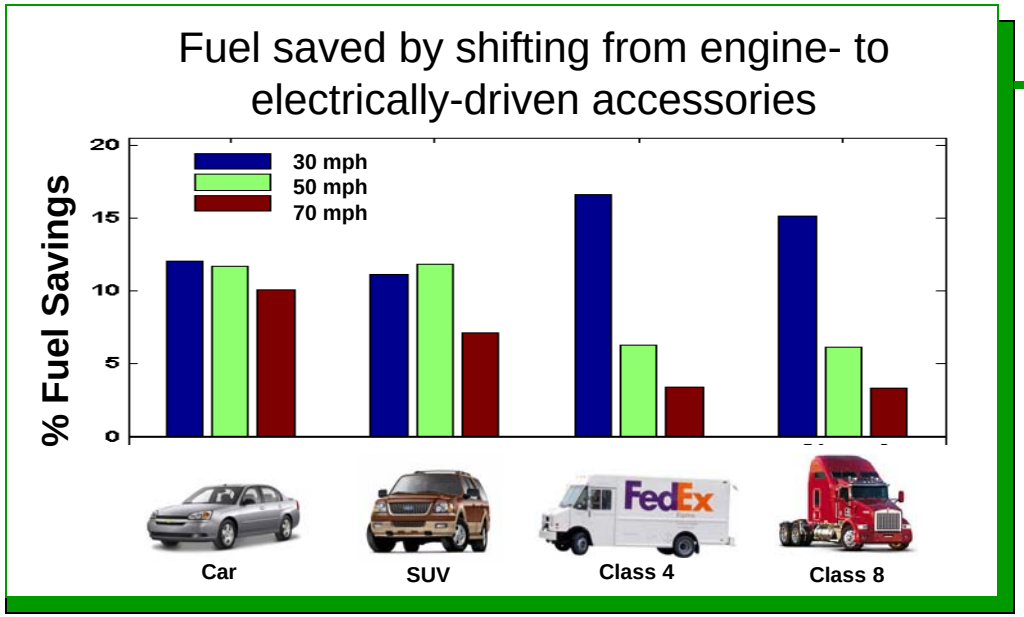
- **Supports DOE program goal of assessing advanced vehicle technologies and their impact on petroleum reduction**
  - **Low cost solution to implement**
  - **Can be transferred to other R&D areas to provide additional incremental benefits**
- **Possible next steps:**
  - **Collaborate with a partner for hardware demonstration (Light-Duty)**
  - **Apply approach to other R&D areas**
    - **PHEV application**
    - **Benefits to other areas (e.g. battery life, emissions…)**
  - **Explore translating GPS routes into representative driving cycle predictions**

Feasibility of Onboard Thermoelectric Generation for Vehicle Waste Heat Recovery

PI: Kandler Smith



Questions:
System topology?
Vehicle platform?
Fuel savings?
Driving cycle sensitivity?



- potential fuel savings
- cost/mass analysis
- waste heat availability

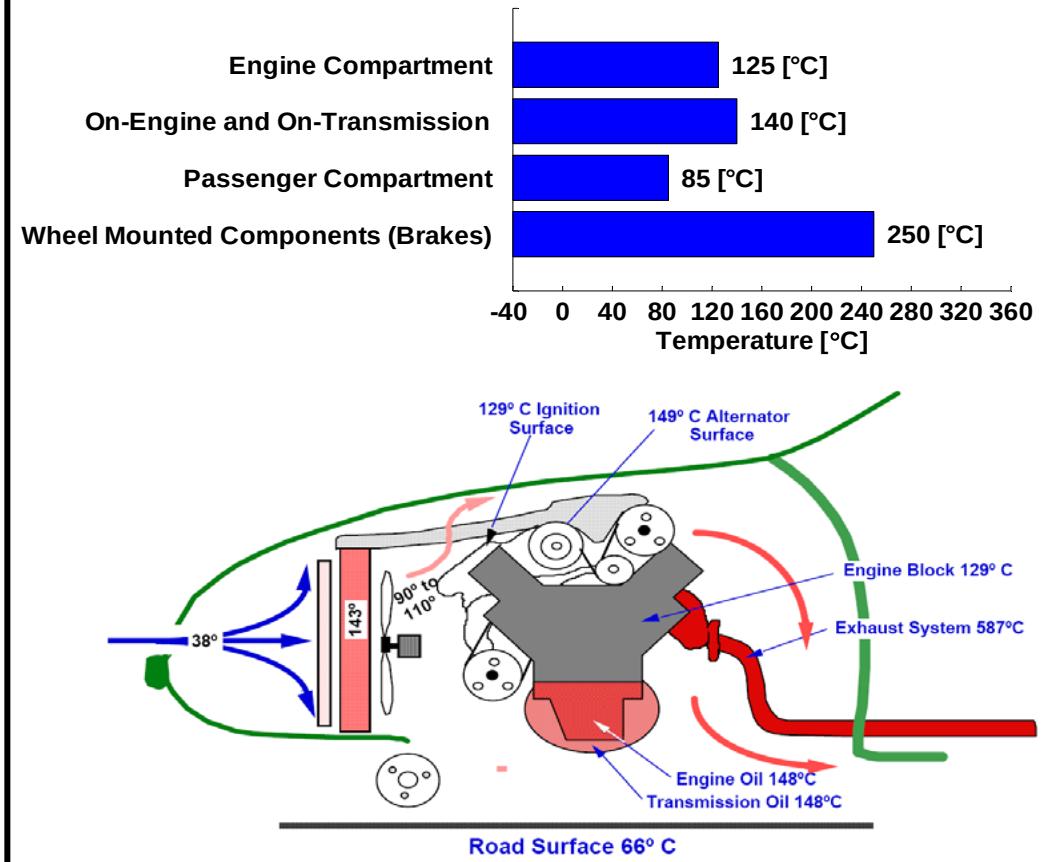
Accomplishments FY 07
Feasibility of Onboard Thermoelectric Generation for Vehicle Waste Heat Recovery

- **Eliminating alternator loads and shifting engine-driven accessories to electric-driven decreases fuel consumption (2-10% for light duty, 1-15% for heavy duty)**
- **Thermoelectric (TE) system cost/mass analysis shows Class 8 trucks (with high mass and VMT) would likely derive more benefit than Class 4 trucks or light duty vehicles**
- **Exhaust power analysis indicates that replacing alternator power with a TE system will be difficult (with the possible exception of class 8 trucks)**
- **Efficient, small-engine vehicles are least attractive vehicle platform (present highest TE system efficiency requirement; most sensitive to mass increase)**

Integrated Vehicle Thermal Management Modeling
PI: Kevin Bennion

Thermal Challenges/Impacts

- **Operating Temperatures.**
- **Reliability.**
- **Cost.**
- **Volume.**
- **Mass.**
- **Vehicle Efficiency.**
- **Safety.**
- **Occupant Comfort.**
- **Emissions.**



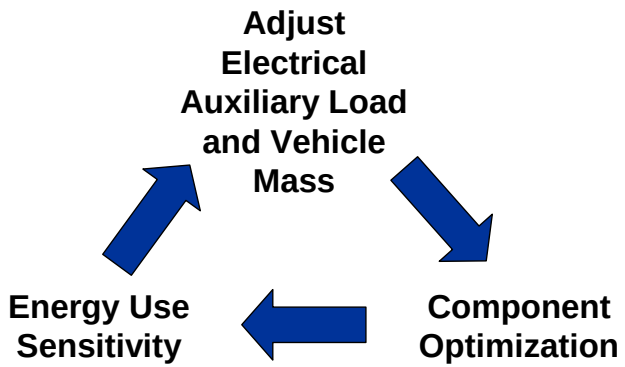
Source: International Electronics Manufacturing Initiative (iNEMI) Technology Roadmap – Automotive Chapter, January 2007.

Objective

- **Using a systems analysis approach, evaluate methods of optimizing the vehicle's thermal management systems.**

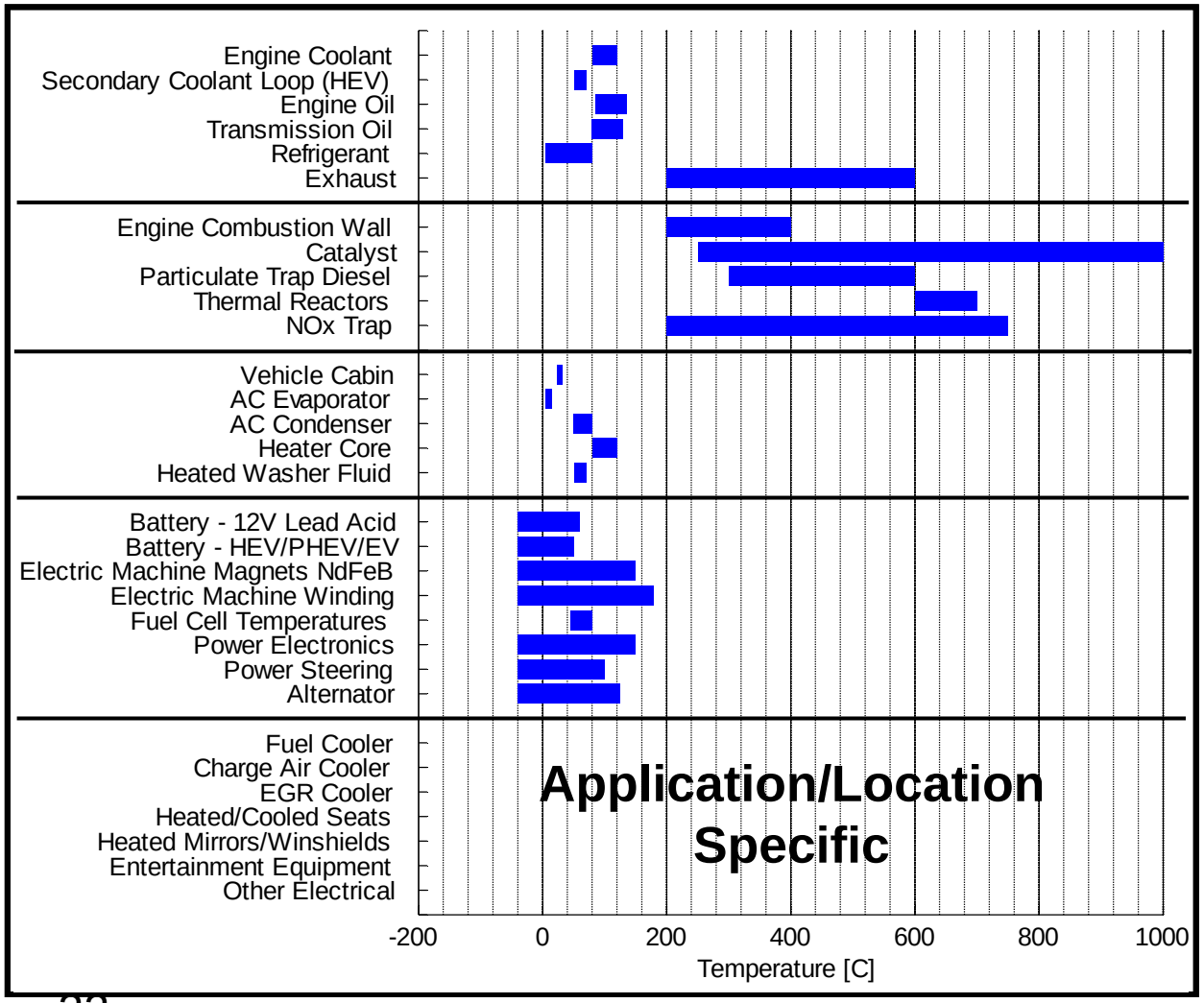
Work Plan FY08
Integrated Vehicle Thermal Management Modeling

- **Quantify impact of vehicle thermal management developments through simulation using:**
  - **Standard test cycles.**
  - **Real world drive cycles.**



- **Quantify energy use sensitivity to mass and electric auxiliary loads.**
- **Identify/develop lumped parameter transient thermal models for critical systems to integrate with existing vehicle simulation tools.**
- **Quantify through simulation potential thermal management opportunities.**
- **Budget: $150K (~35% spent)**

Accomplishments FY08
Integrated Vehicle Thermal Management Modeling



- **Identify component temperatures.**
- **Review current or proposed technologies for:**
  - **Waste heat utilization.**
  - **Combined or integrated cooling.**
  - **Ancillary load reduction.**
  - **Improved thermal management.**

Justification and Future Plans:
Integrated Vehicle Thermal Management Modeling

- **Provides systems approach to addressing waste heat utilization challenges--minimizing heating and cooling system complexity, and reducing mass.**
- **On going project transitioning from modeling and analysis of thermal management systems to testing and system integration in a vehicle**

Publications, Presentations

- **Markel and Pesaran, "Battery Requirements and Cost-Benefit Analysis for Plug-In Hybrid Vehicles" (Presentation) NREL report PR-540-42082, 2007**
- **Markel and Pesaran, "PHEV Energy Storage and Drive Cycle Impacts' (Presentation) NREL report PR-540-42026, 2007**
- **Gonder and Simpson "Measuring and Reporting Fuel Economy of Plug-In Hybrid Electric Vehicles" WEVA Journal, May 2007**
- **Markel "Platform Engineering Applied to Plug-In Hybrid Electric Vehicles" SAE Paper No. 2007-01-0292, 2007**
- **Markel and Gonder "Energy Management Strategies for Plug-In Hybrid Electric Vehicles" SAE Paper No. 2007-01-0290, 2007**
- **Thornton, Gonder, Markel, and Simpson "Using GPS Travel Data to Assess Real-World Energy Use of Plug-In Hybrid Vehicles" to be published in Transportation Research Record, Washington DC, 2007.**
- **Pesaran, A., Markel, T., Tataria, H. and Howell, D. "Battery Requirements for Plug-In Hybrid Electric Vehicles – Analysis and Rationale." Publication & Presentation at EVS-23, Anaheim, CA. December 2007**
- **Gonder, J. "Route-Based Control of Hybrid Vehicles, Project Description & Status Report." Presentation to the VSATT, October 4, 2006.**
- **Gonder, J. "FY07 Milestone 6.1: Route-Based HEV Control Strategy Report." DOE Milestone Report, July 2007.**
- **Gonder, J. "Route-Based HEV Control, Summary of FY07 Work." Presentation to the VSATT, September 5, 2007.**
- **Gonder, J. "Route-Based Control of Hybrid Electric Vehicles." Paper (2008-01-1315) & presentation to be delivered at the 2008 SAE World Congress, April 2008.**
- **Smith and Thornton "Feasibility of Onboard Thermoelectric Generation for Improved Vehicle Fuel Economy" Diesel Engine-Efficiency and Emissions Research Conference, Detroit, MI, August 2007.**
- **Smith and Thornton "Feasibility of Thermoelectrics for Waste Heat Recovery in Hybrid Vehicles" 23rd International Electric Vehicle Symposium, Anaheim, CA, December 2007.**

Questions