

PHEV Engine Control and Energy Management Strategy

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Meeting**

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Overview

- **Timeline**

- **Project start date: Oct. 2009**
- **Project end date: Sept. 2012**
- **30% complete**

- **Budget**

- **FY10 (current) funding: \$400k**
- **FY11 (projected) funding: \$350k**
- **FY12 (projected) funding: \$350k**

- **Barriers**

- **Cold start PHEV emissions**

- **Partners**

- **Oak Ridge National Laboratory, project lead**
- **The University of Tennessee (UT), Knoxville, GATE center**
- **Argonne National Laboratory, Autonomie Series hybrid model and PHEV emissions study**
- **Robert Bosch LLC, production controller supply and support**

Objectives

- **Investigate novel engine control strategies targeted at rapid engine/catalyst warming for the purpose of mitigating tailpipe emissions from plug-in hybrid electric vehicles (PHEV) exposed to multiple engine cold start events.**
- **Optimize integration of engine control strategies with hybrid supervisory control strategies in order to reduce cold start emissions and fuel consumption of PHEVs.**
- **Ensure that development of new vehicle technologies complies with existing emission standards**

Relevance with regards to VT programs

- **Demonstrate market readiness of grid-connected vehicle technologies by 2015**
- **Develop advanced control strategies to optimize the performance and efficiency of advanced hybrid electric vehicle**
- **Complete the successful deployment of *Autonomie* as an industry recognized advanced component and vehicle modeling and simulation tool.**

Approach

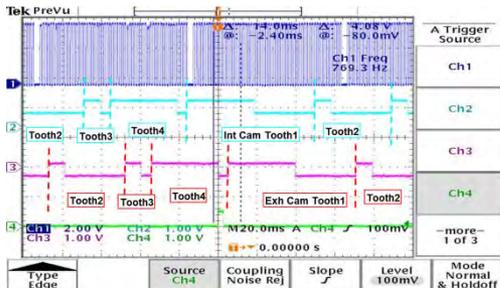
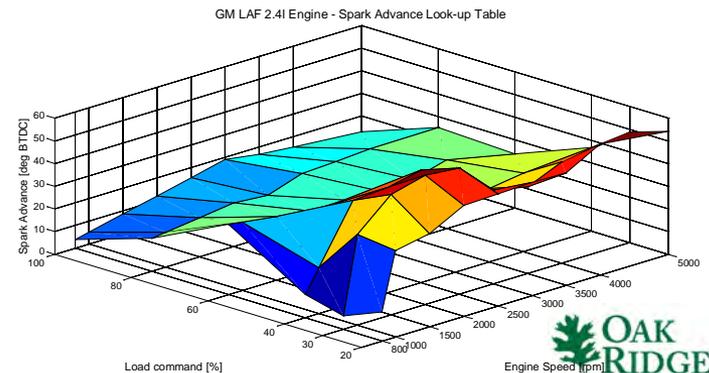
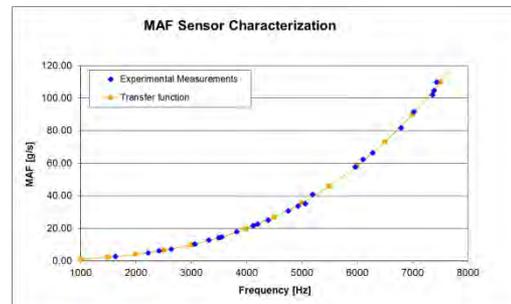
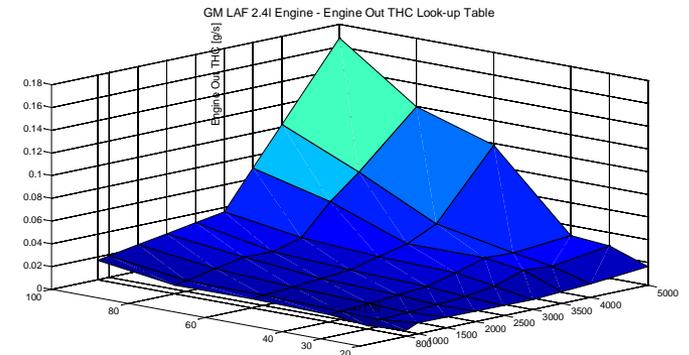
- **Gain full control over stand-alone engine operation in test cell**
 - Characterize engine performance, emissions and operation
 - Develop open source prototype engine controller
 - Commission controller on UT test cell
- **Optimize engine cold start strategies on stand-alone engine**
 - Implement best in class engine control strategies in open source controller
 - Improve/optimize strategies to reduce cold start emissions
- **Engine-In-the-Loop (EIL) system testing**
 - Leverage Autonomie PHEV model
 - Develop EIL platform suitable for PHEV emulation
 - Port Autonomie model into EIL platform
 - Commission and validate EIL system
- **Optimize hybrid supervisory strategies and engine control strategies as a system in order to reduce tailpipes emissions on the EIL test stand**
 - Integrate and improve hybrid supervisory control strategies from ANL-ORNL simulation study (“Trade-off between fuel economy and Emissions for PHEVs”)
 - Concurrently optimize both control strategies (engine and hybrid) as a system

Milestones

- **Milestone #1, September 30, 2010 :**
 - **Select and characterize OEM calibration for candidate engine**
- **Milestone #2, September 30, 2010 :**
 - **Develop and implement baseline engine control strategy for open source hardware**
- **Milestone #3, March 31, 2011 :**
 - **Set-up and parameterize an Engine-In-the-Loop (EIL) system to represent hybrid powertrain and vehicle .**
- **Milestone #4, June 30, 2011 :**
 - **Develop and implement new engine control strategies on open source hardware focusing on improving catalyst heating and cold engine emissions**
- **Milestone #5, September 31, 2011 :**
 - **Integrate supervisory hybrid control strategies with engine control strategies on engine dynamometer stand with HIL system and optimize cold emissions without consideration for fuel consumption**

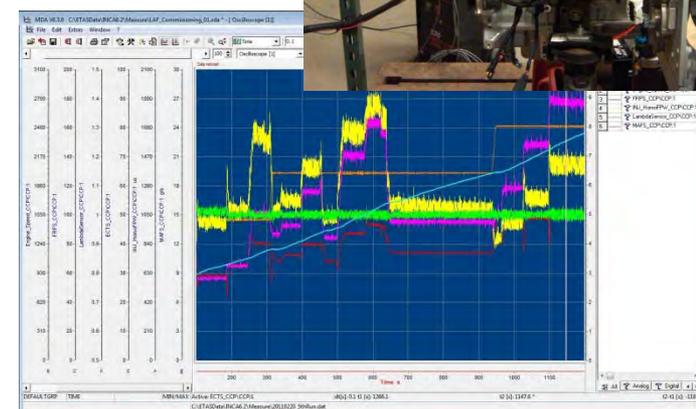
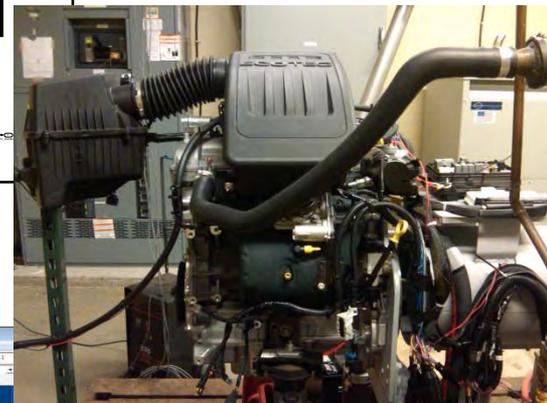
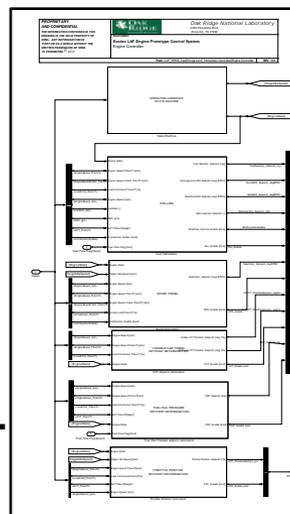
Accomplishments – Base Engine Characterization

- Procurement of 2011MY Equinox LT (vehicle equipped with 2.4I LAF Ecotec[®] engine previously selected for this project)
- Vehicle/engine instrumentation
- Engine characterization on ORNL chassis rolls facilities at NTRC
 - Engine out and tailpipe emissions
 - Performance and fuel economy
 - Engine base operations
 - Sensors and actuators transfer functions
- This completes Milestone #1.
- This data is critical to the development of our open source controller



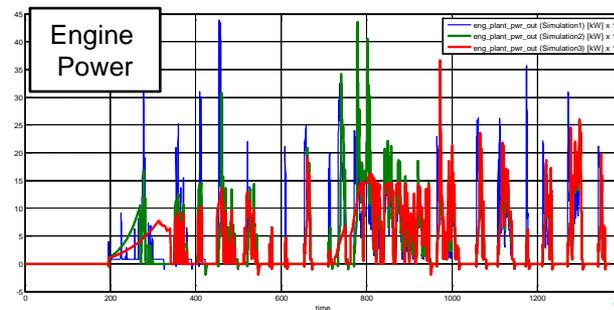
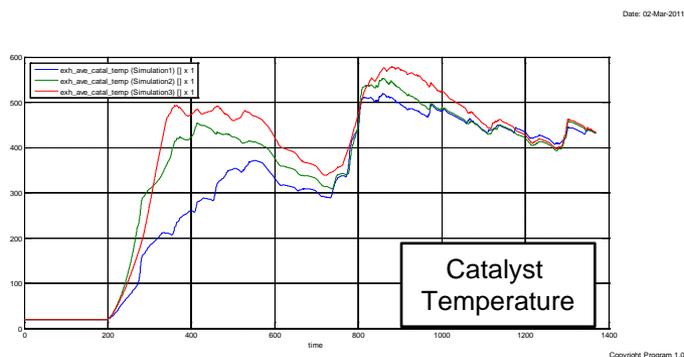
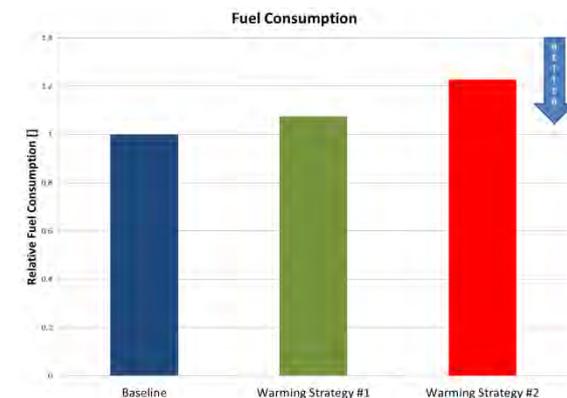
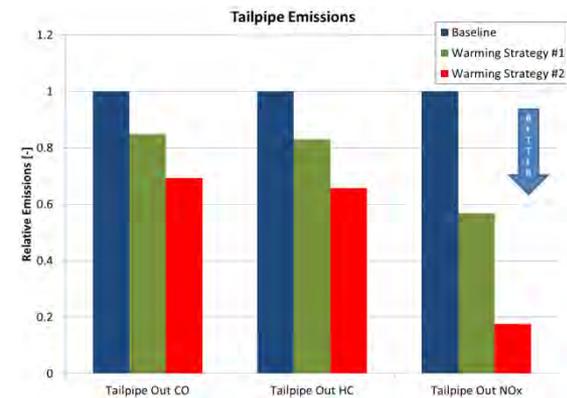
Accomplishments – Stand-alone engine operation in test cell with open source controller

- **Open source controller development**
 - Existing baseline strategies refinement
 - Customization with previously characterized engine operation data
 - Implementation into production-intent module
- **Test cell commissioning**
 - Test cell located at UTK's Advanced Powertrain Controls and System Integration (APCSI) facility.
 - First engine to be run at this new facility
 - Facilities enhancement were required
- **Engine commissioning**
 - Engine installation
 - Control system debugging and tuning
- **Engine mapping**
- **This completes Milestone #2.**
- **Unique controller provides full flexibility over engine operation including cold start behavior**



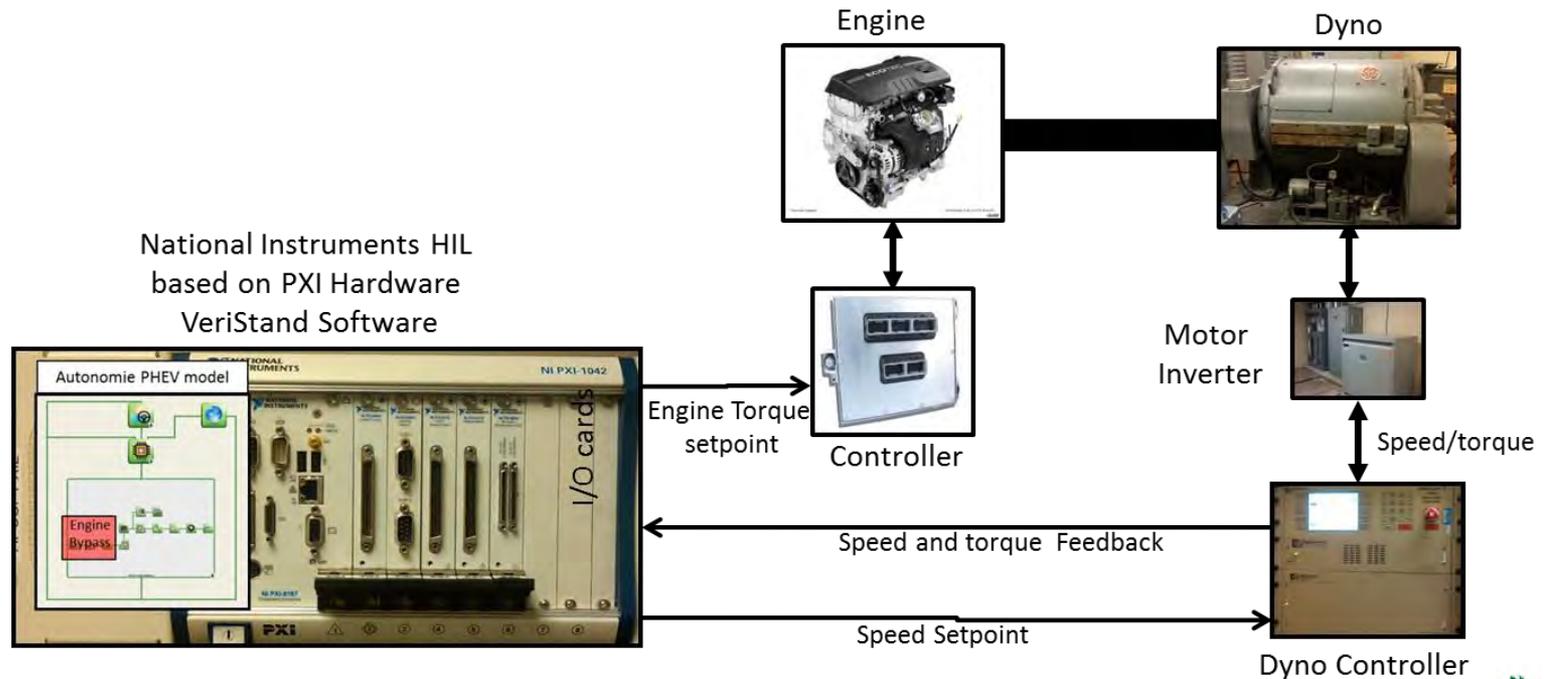
Accomplishments – Vehicle Simulation

- Leverage ANL/ORNL collaboration project (Tradeoff between Fuel Consumption and Emissions for PHEV's) whose focus is on Hybrid supervisory strategies optimization (Engine is a “black box” that can not be modified)
- Addition of a new team member :Andreas Malikopoulos, ORNL Weinberg fellow, to support simulation study and optimization phase
- Series hybrid powertrain simulation
- Reduced emissions through pre-warming and torque shaping come with a fuel economy penalty
- This simulation study provides vehicle and powertrain models for Hardware-In-the-Loop study



Accomplishments – Engine-In-the-Loop Setup

- **Hardware-In-the-Loop platform set-up**
- **Integration of Autonomie vehicle model onto real time platform**
- **This set-up enables the evaluation of an actual engine behavior for a specific vehicle configuration providing:**
 - **Real emissions measurements**
 - **Flexibility to change powertrain configurations and test conditions**

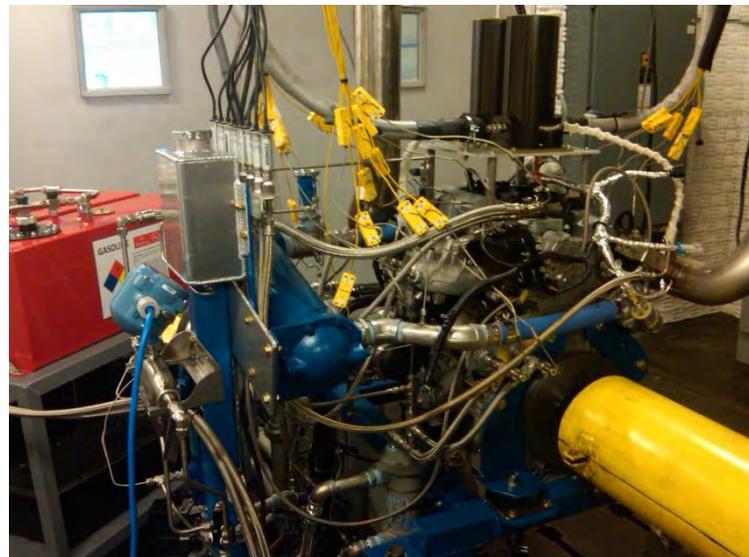


Accomplishments – Engine Cold Start Strategies

- **Literature search about gasoline direct-injected engine cold start and catalyst warm-up strategies.**
- **Strategies implemented into open source controller**
- **Strategies to combine:**
 - **Stratified cranking**
 - **Retarded ignition**
 - **Split Homogenous-Stratified injections**
 - **AFR optimization**
 - **High fuel pressure**
 - **Exhaust VVT retard**
- **Kukwon Cho from ORNL FEERC (Fuel Engine and Emissions Research Center) group will support that task and bring more engine experience to the project team**
- **Cold start strategies will be evaluated on open source controller and stand-alone engine in UT test cell**

Accomplishments – Industry Partnership

- **Advanced discussions with Robert Bosch LLC (Bosch) to collaborate on this project: NDA and CRADA initiated and progressing**
- **Bosch will supply:**
 - Engine controller for GM 2.0l GTDI LNF engine
 - Access to cold start calibration and bypass .
- **ORNL will supply facilities, engine and engineering resources**
- **Benefits:**
 - Use of production engine controller. No need to “re-invent the wheel” developing base control strategies. Effort can be focused on cold starts.
 - Access to production calibration (with GM’s approval).
 - Bypass features allow to keep all production strategies except for area of interest: cold starts
 - Guidance from Major Tier1 supplier
 - LAF engine and open source controller still available for testing and strategies validation on this project and subsequent projects



Collaboration and Coordination with Other Institutions

- **Oak Ridge National Laboratory**
 - Lead
 - Control systems development
 - Emissions and after-treatment expertise (FEERC)
- **The University of Tennessee Knoxville**
 - DOE Graduate Automotive Technology Education (GATE) center concentrated on hybrid powertrains and control systems.
 - Testing performed at UTK's Advanced Powertrain Controls and System Integration (APCSI) facility
 - Training graduate students in some of the unique aspects of advanced powertrain control development (two students working on this project)
- **Argonne National Laboratory**
 - Hybrid supervisory strategies optimization study (This project draws from a collaborative project between ANL and ORNL: Tradeoff between Fuel Consumption and Emissions for PHEV's).
- **Bosch**
 - Supply of development engine ECU and production calibration (with GM's approval)
 - Support to set up engine control system

Proposed Future Work

- **FY11**
 - **Engine-In-the-Loop commissioning at UT's APCI lab**
 - **Engine cold start strategies test and refinement on engine stand-alone setup**
 - **Supervisory control strategies implementation and development on EIL platform.**
 - **Commission LNF 2.0I GTDI engine and Bosch bypass control system in testcell**
 - **Implement new cold start strategies on Bosch bypass control system**

- **FY12**
 - **Iterative concurrent emissions optimization of engine control strategies and hybrid supervisory strategies**
 - **System optimization with fuel economy as an additional constraint**

- **FY13 (Tentative extension)**
 - **Bosch CRADA**
 - **HC trap investigation**

Summary

- **Established open source prototype engine controller running stand-alone engine operation in UT test cell**
- **Designed Engine-In-the-Loop platform**
- **Established PHEV Autonomie vehicle level model**
- **Implemented engine cold start strategies on open source controller**
- **Established relationship with Tier 1 supplier Bosch to supply production engine controller.**

Acknowledgements and Contacts

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- **Lee Slezak, *Program Manager Office of Vehicle Technologies***

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The University of Tennessee

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- **Dean Deter and Ben Newcomer, *Students***