

# PHEV Engine Control and Energy Management Strategy

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U.S. Department of Energy**

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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

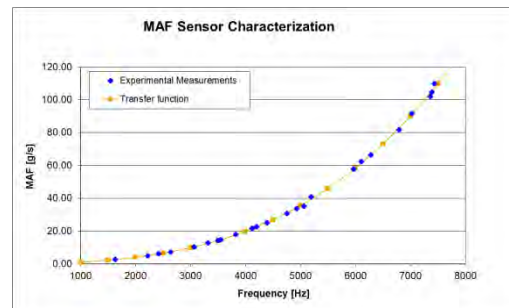
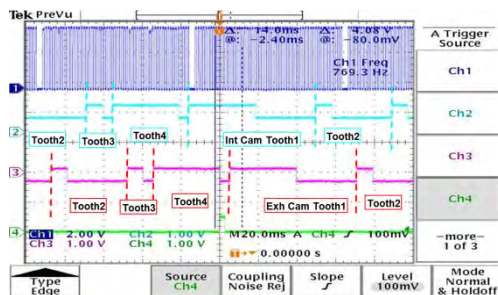
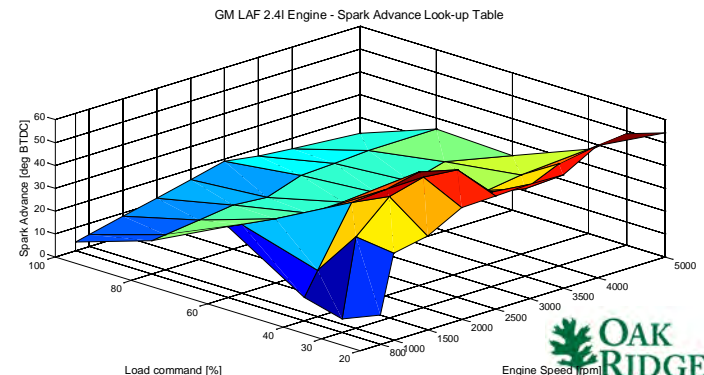
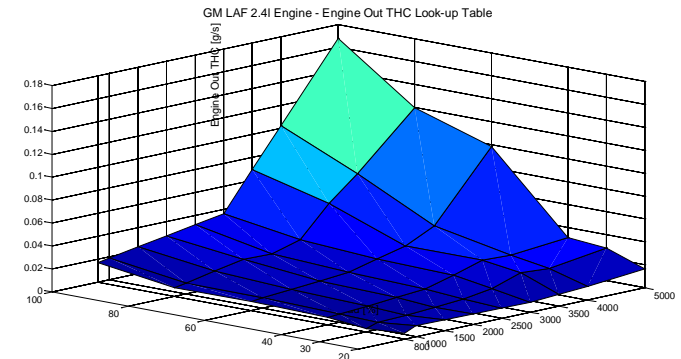
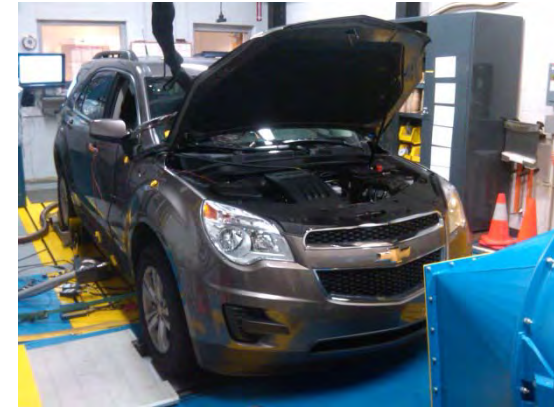
- **Gain full control over stand-alone engine operation in test cell**
  - Characterize engine performance, emissions and operation
  - Develop open source prototype engine controller
  - Commission controller on UT test cell
- **Optimize engine cold start strategies on stand-alone engine**
  - Implement 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

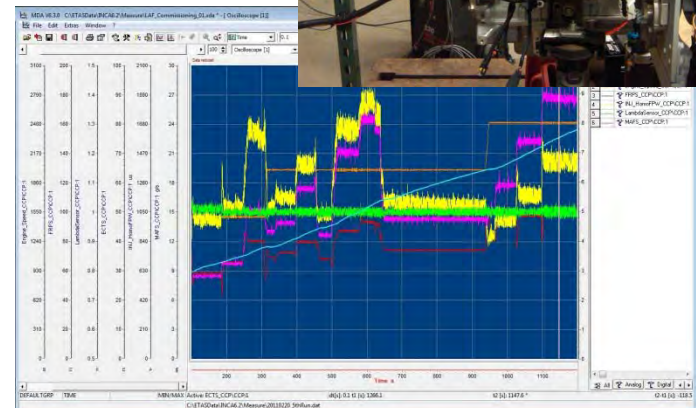
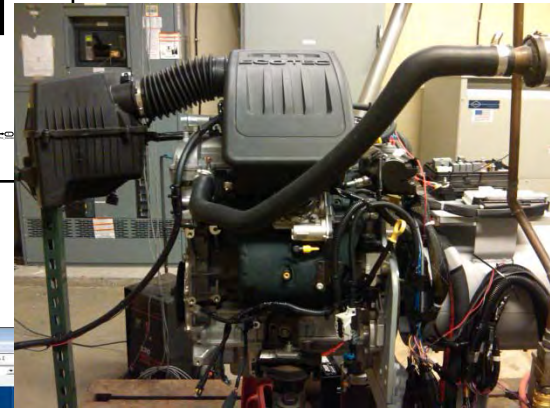
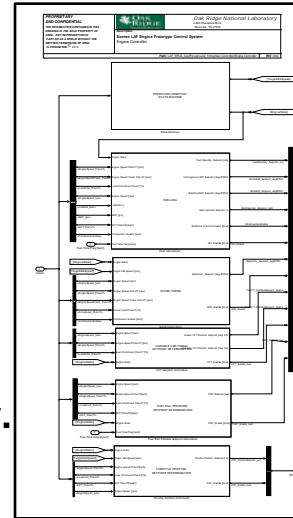
- Procurement of 2011MY Equinox LT (vehicle equipped with 2.4I LAF Ecotec<sup>®</sup> engine previously selected for this project)
- Vehicle/engine instrumentation
- Engine characterization on ORNL chassis rolls facilities at NTRC
  - Engine out and tailpipe emissions
  - Performance and fuel economy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





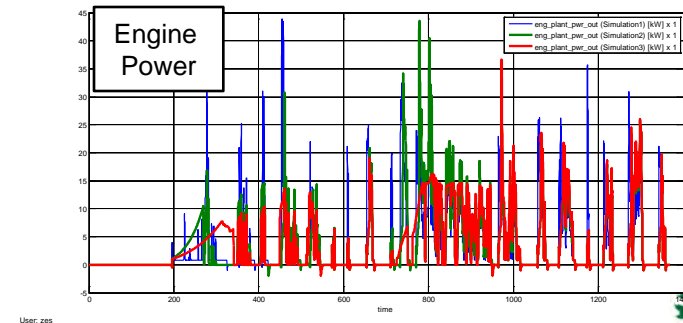
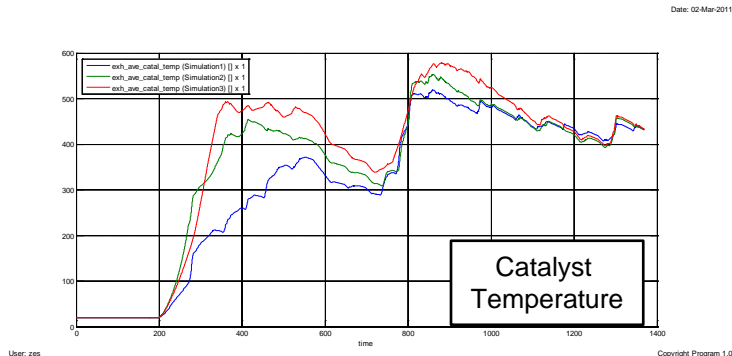
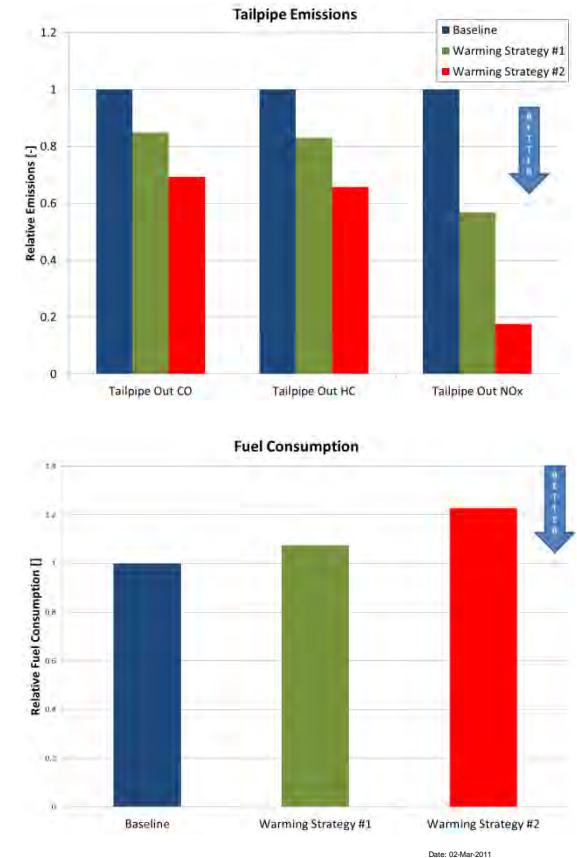
# Accomplishments – Stand-alone engine operation in test cell with open source controller

- **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

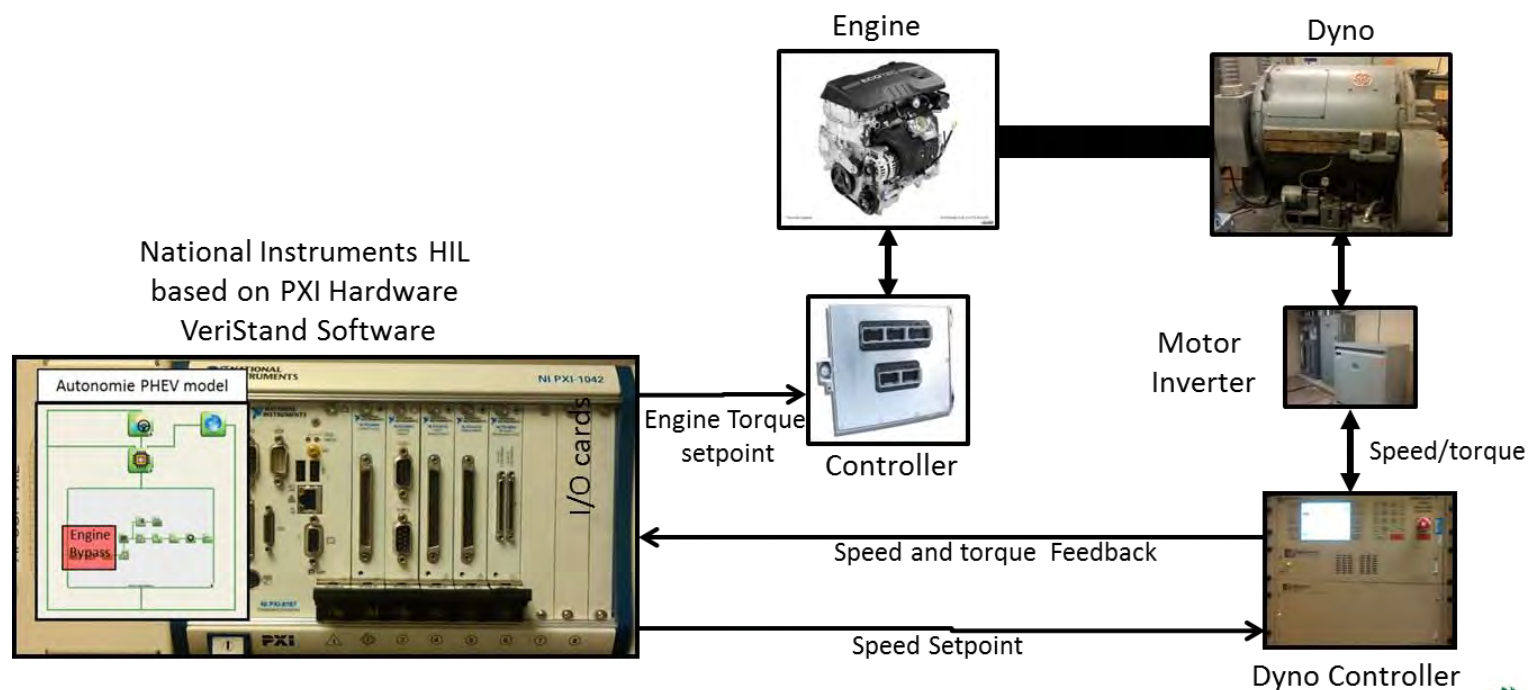
- Leverage ANL/ORNL collaboration project (Tradeoff between Fuel Consumption and Emissions for PHEV's ) whose focus is on Hybrid supervisory strategies optimization (Engine is a “black box” that can not be modified)
- Addition of a new team member :Andreas Malikopoulos, ORNL Weinberg fellow, to support 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**

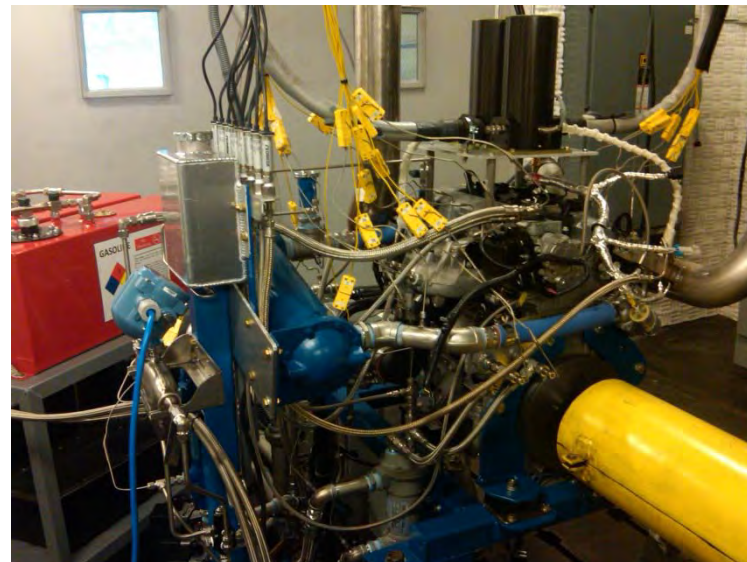


# Accomplishments – Engine Cold Start Strategies

- **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 2.0l 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

## ***DOE :***

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

## ***ORNL:***

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- **Paul Chambon, Andreas Malikopoulos and Kukwon Cho, *ORNL Investigators***

## **The University of Tennessee**

- **Dr David Irick, *Professor***
- **Dean Deter and Ben Newcomer, *Students***