Tradeoff Between Fuel Consumption and Emissions for PHEVs

2010 DOE Hydrogen Program and Vehicle Technologies Annual Merit Review

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Project Overview

Timeline

- Start : September 2009
- End : September 2010
- Status: 60% complete

Barriers

- Cold start PHEV emissions.

Budget

- FY10 -$500K (ANL)
- FY10 - $400K (ORNL)

Partners

- Oak Ridge National Laboratory.
- Engine and Emissions Research Program at ANL.

Research Objective

Evaluate various energy management strategies to mitigate PHEV cold start emissions and improve fuel efficiency

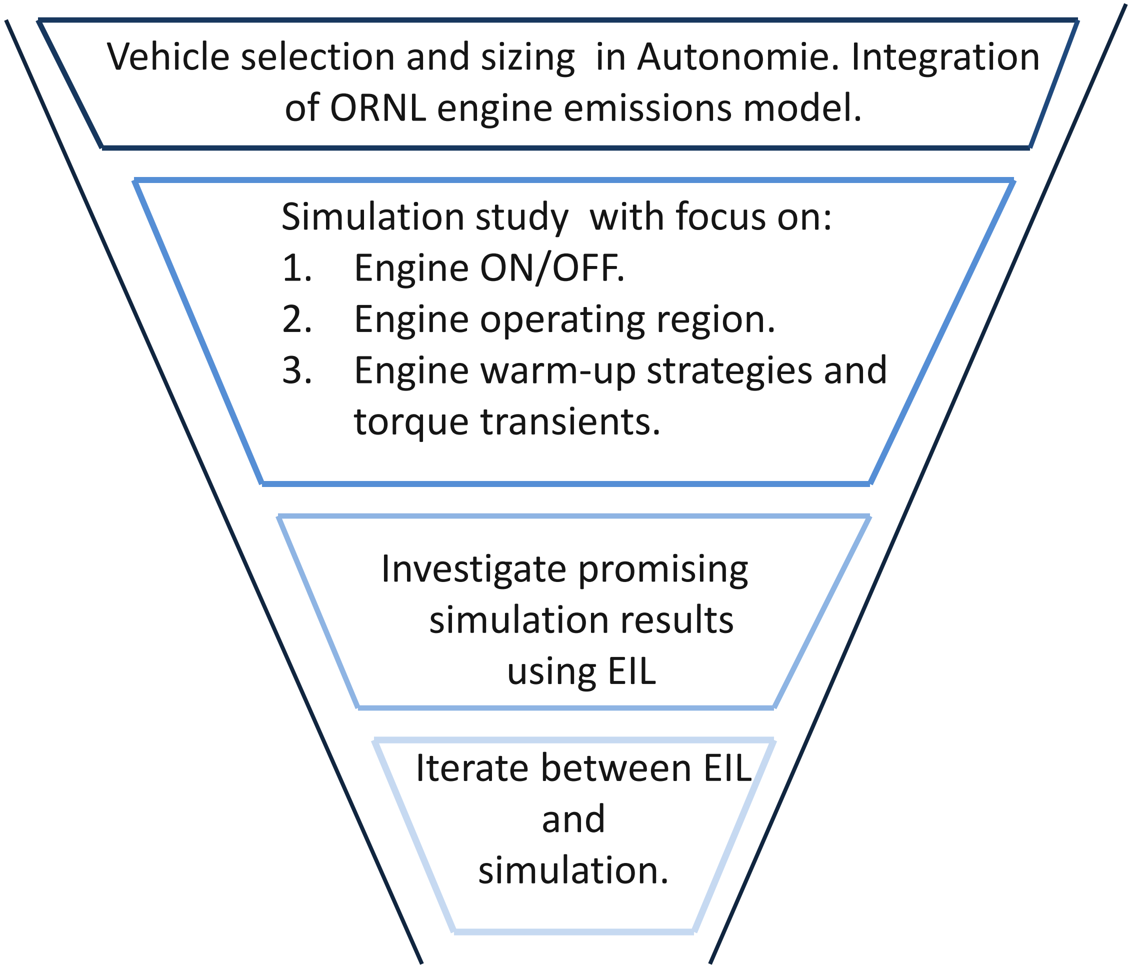
The research is geared towards the following vehicle systems simulation and testing strategic goals –

- Demonstrate market-readiness of grid connected vehicle technologies by 2015.
- Complete the successful deployment of AUTONOMIE as an industry standard advanced component and vehicle modeling and simulation tool, as well as the integration of a detailed vehicle cost model into AUTONOMIE.
- Validate, in a systems context, performance targets for deliverables from the Power Electronics and Energy Storage Technology R&D activities.
- Outcome will impact all vehicle level control strategies used to evaluate PHEV fuel consumption potential for DOE.

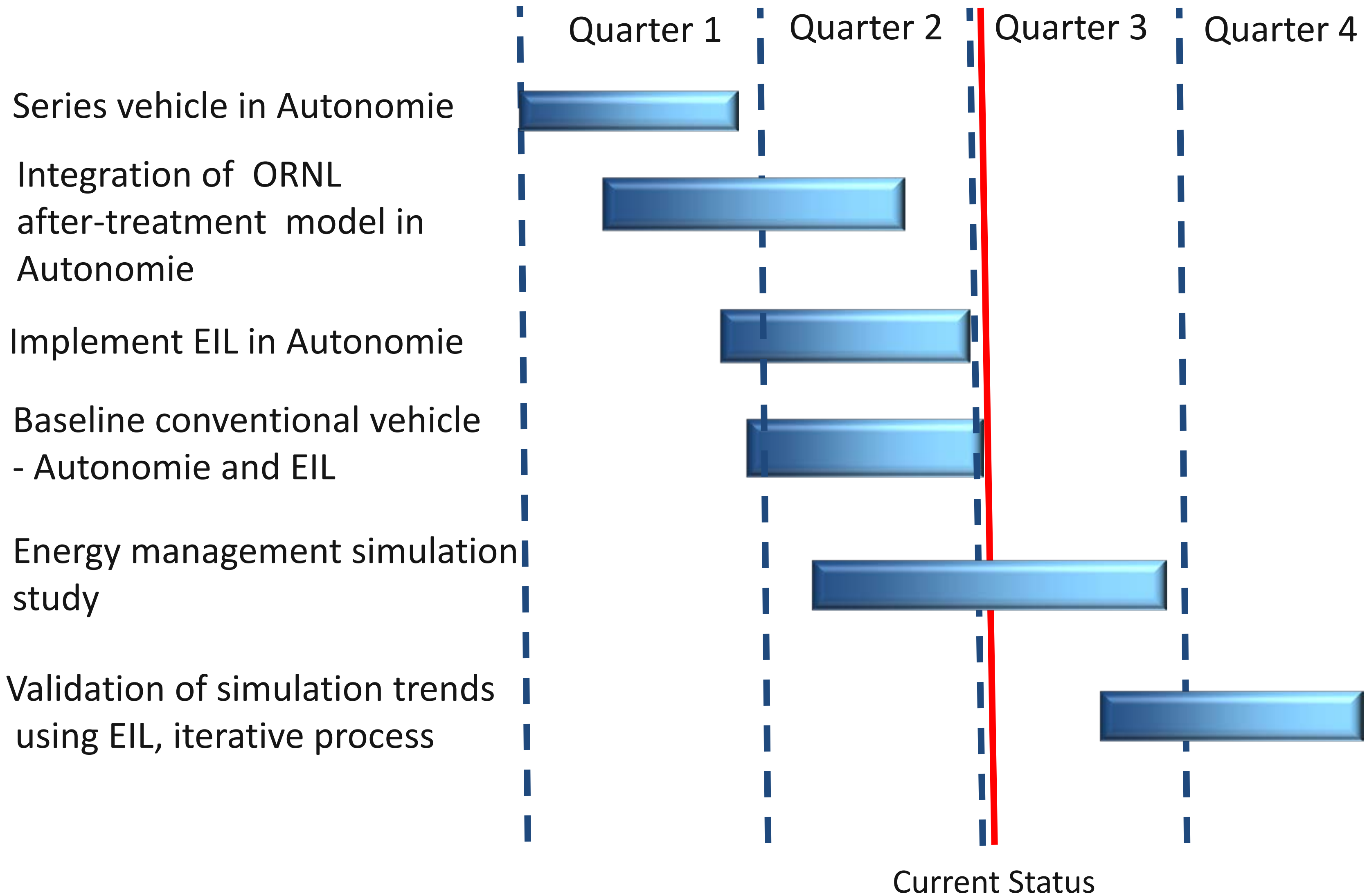
ornl
Oak Ridge National Laboratory

Approach

- Use Model Based Design (MBD) to evaluate energy management strategies.
- Validate trends / results with Engine-in-the-loop (EIL).



Milestones


Quarter 1
Quarter 2
Quarter 3
Quarter 4
Series vehicle in Autonomie
Integration of ORNL after-treatment model in Autonomie
Implement EIL in Autonomie
Baseline conventional vehicle - Autonomie and EIL
Energy management simulation study
Validation of simulation trends using EIL, iterative process
Current Status

Technical Accomplishments
Series Vehicle Defined in Autonomie

Performance Requirements

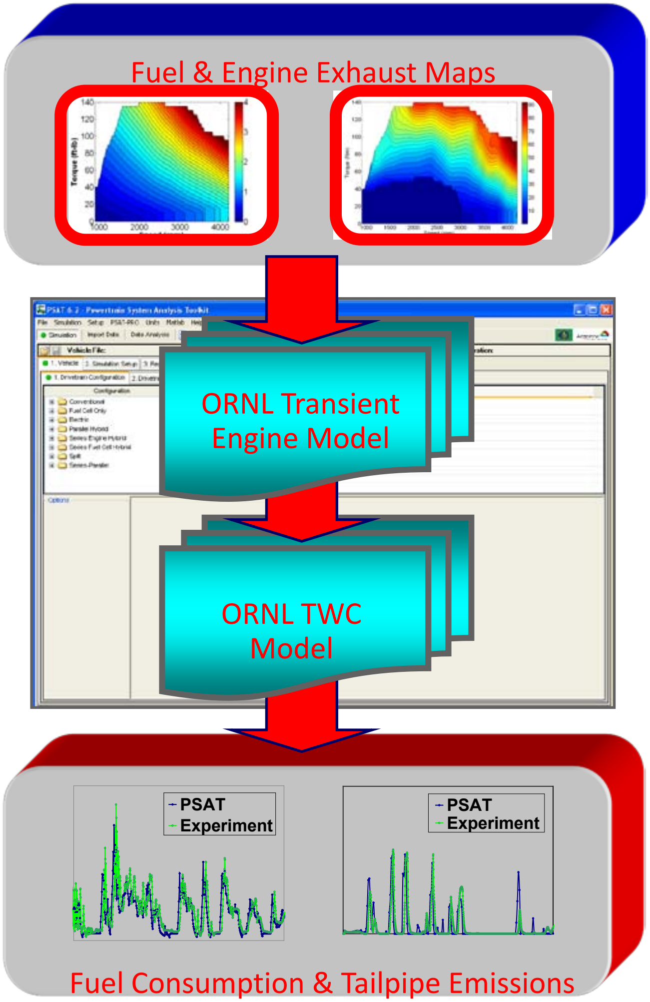
1. 0-60 = ~9sec
2. Vmax > 100 mph
3. 6% grade at 55 mph at GVW.
4. ~ 20 miles equivalent electric range on UDDS.
5. Use existing engine for hardware validation

Parameter	Value
Curb weight	1800 kg
GVW	2440 kg
Engine	110 kW , 2.2 L SIDI engine
Electric Machine Power	130 kW / 13000 rpm
Generator Power	110 kW / 6000 rpm
Battery	41 Ah, 10 kWh Li-ion
Cd	0.37
FA	2.54 m2
Tire	P225_75_R15 (0.359)
Fixed ratio	1.6
Final drive ratio	4

Technical Accomplishments

ORNL After-treatment Model and Integration in Autonomie

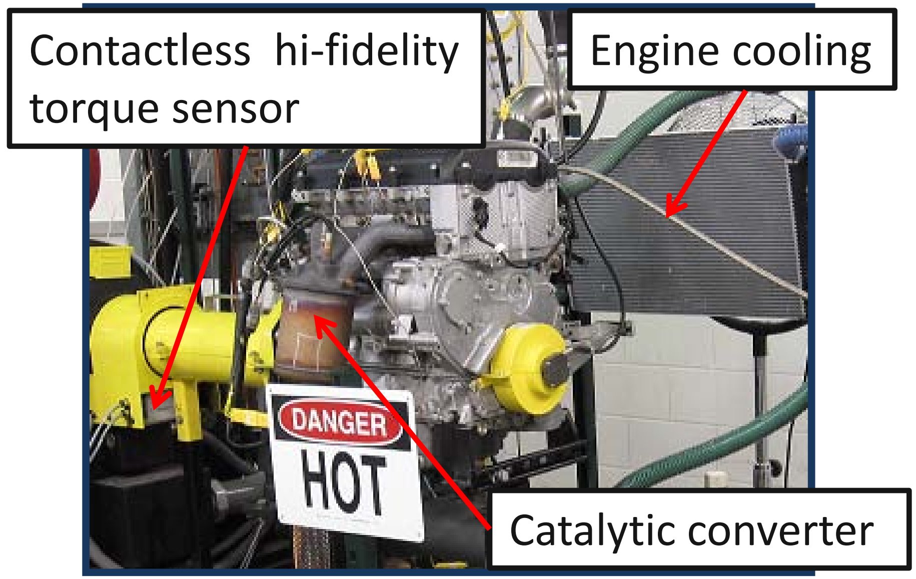
- **Transient engine model estimates transient engine exhaust properties and fuel economy based on corrections to steady-state maps**
  - Assumption: engine transient exhaust properties and fuel consumption depend not only on the instantaneous speed and torque, but also on the recent past history
  - Methodology: the differences between the transient and steady-state results is approximated by the first-order lags and an engine warm-up index
  - Advantage: A good prediction for engine-out emissions, exhaust temperature, and fuel economy associated with cold and warm starting conditions
- **TWC model is based on a simplified, transient, one-dimensional representation of exhaust flow through a catalytic monolith**
  - Assumption: exhaust flow is a plug-in laminar flow and uniform across the cross section of the monolith
  - Methodology: (a) a non-linear set of coupled PDEs are used to account for mass and energy conservation; (b) a global reaction mechanism accounts for oxidation reactions, water-gas shift reactions, NO reduction, and oxygen storage occurring with in the washcoat; (c) the tracked gas species include NO, CO_2, CO, H_2, O_2, H_2O, C_3H_6 and C_3H_8;
  - Advantages: low CPU cost and a general tool for analyzing emissions reduction associated with stoichiometric combustion



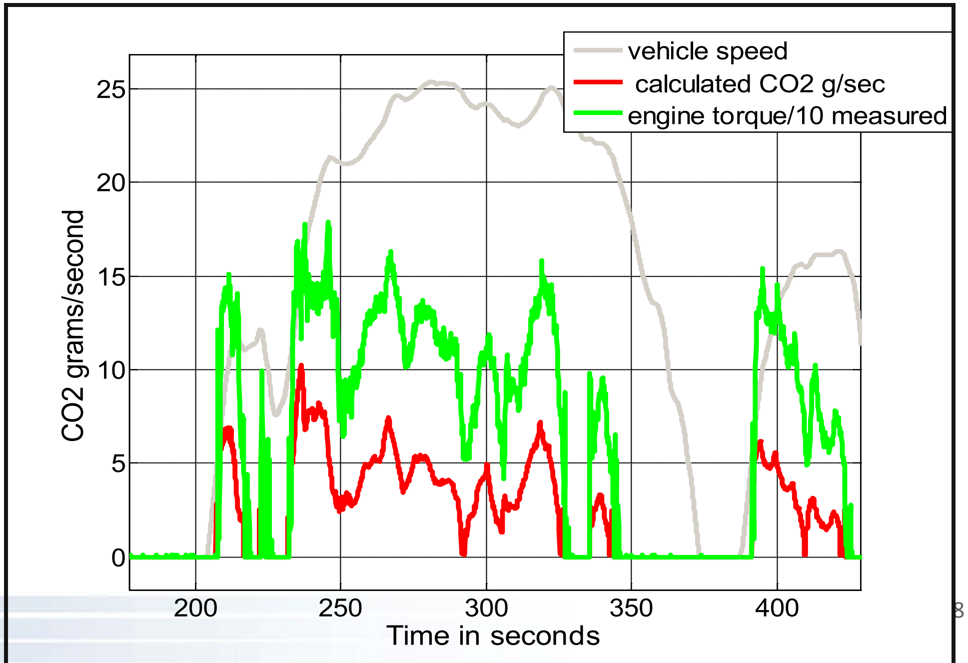
Technical Accomplishments

Development to Support Transient Engine Testing

- Several hardware changes made to existing engine (initial setup was only for steady-state).



- Developed post processing for emissions analysis – calculation of specific emissions from volumetric fractions (raw emissions bench).



Technical accomplishment

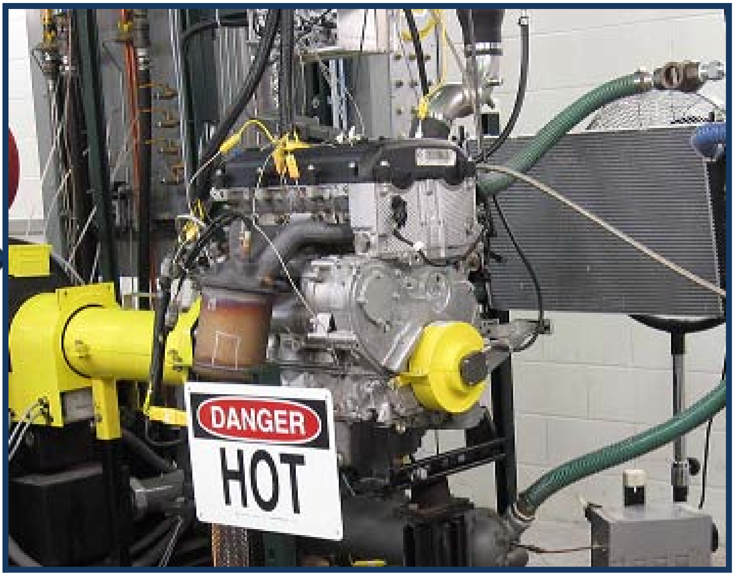
Engine-In-the-Loop (EIL) Operational in Autonomie

Vehicle is modeled in Autonomie

Torque command to engine

Torque feedback propels the vehicle

Engine hardware behaves as if in a vehicle



1. Modular dSPACE system for real time emulation of vehicle.
2. Creation of generic configurations in Autonomie for systematic implementation of engine in the Loop.

Technical Accomplishments

Autonomie Engine Model Validated with Hardware using EIL

Vehicle type and cycle	Autonomie Model	Engine in the Loop
Conventional vehicle		
Urban Cycle (hot start)	29.4 mpg	28.35 mpg
NEDC (hot start)	32 mpg	32.15 mpg
Hybrid (power split)		
Urban Cycle (hot start)	44.9 mpg	46.7 mpg

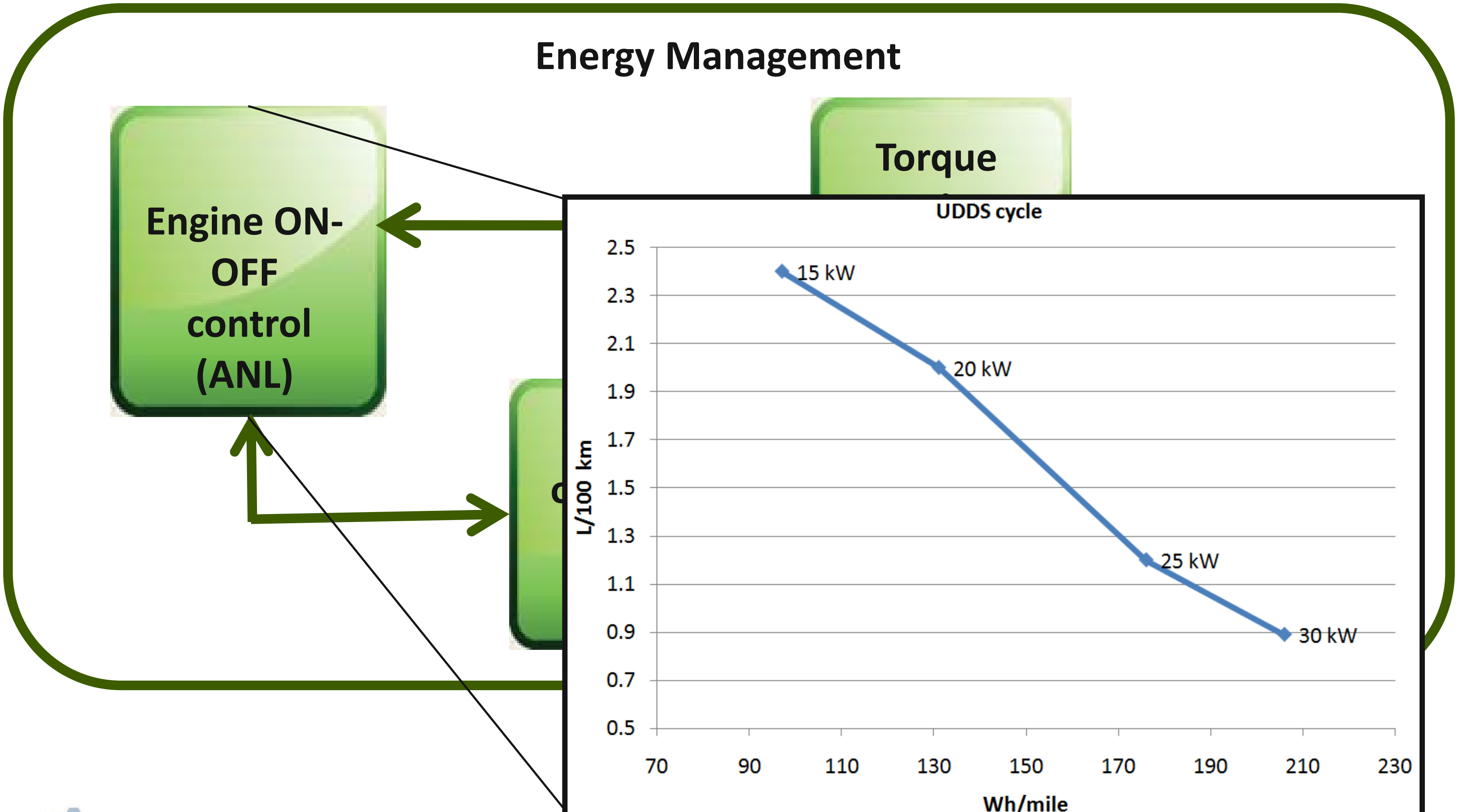
Preliminary Cold Start EIL Fuel Consumption Close to Label FC

Conventional vehicle – Opel Vectra	Engine in the Loop	Label Fuel economy (mpg)
NEDC urban segment	21.1 mpg	19.9 mpg
NEDC combined	30 mpg	27.6 mpg

Lower powertrain efficiency at cold start
not modeled.
Therefore,
EIL mpg> label mpg

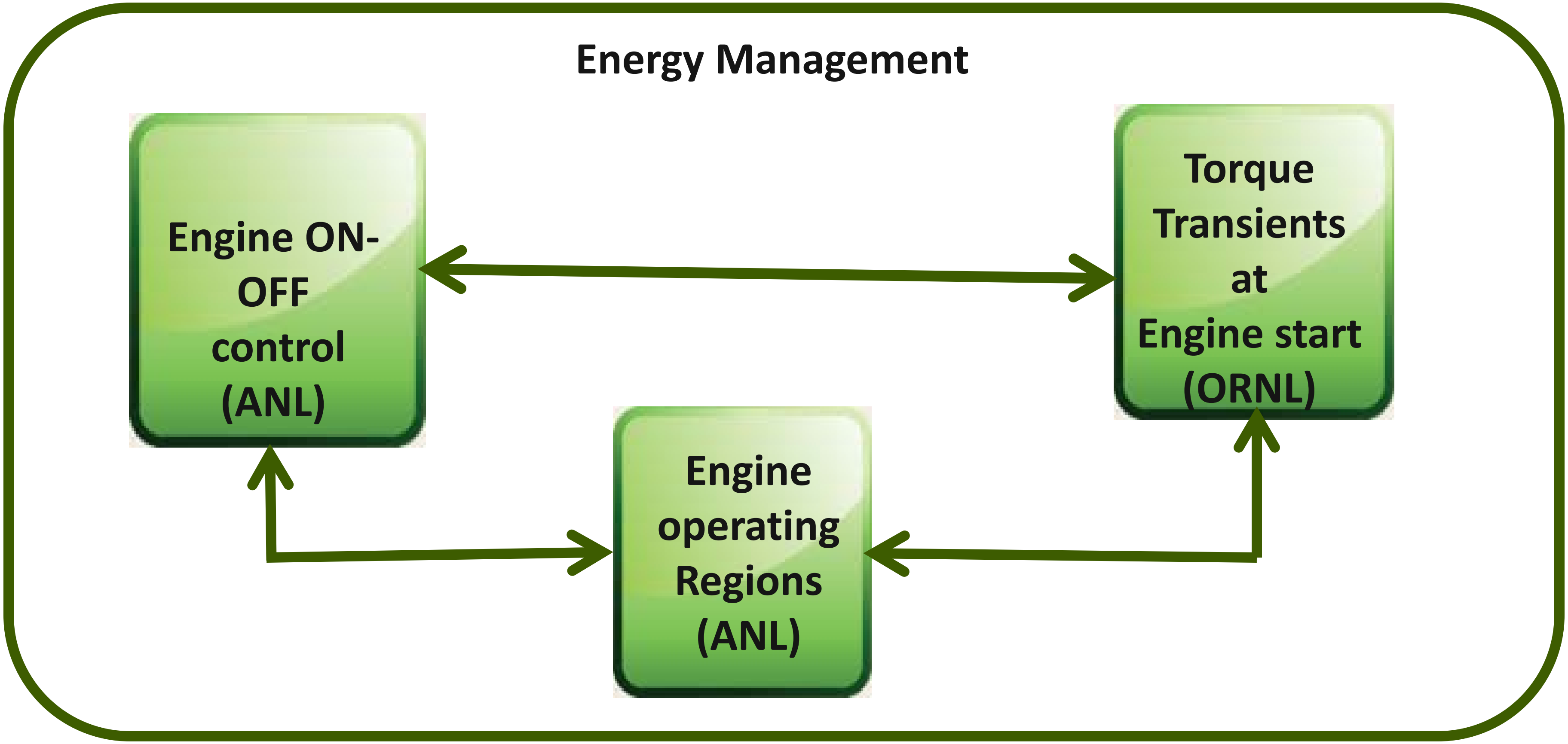
Technical Accomplishments

Simulation Study Underway – Impact of Engine ON Power Thresholds on Fuel Consumption and Emissions. (ANL)



Technical Accomplishments

Simulation Study Underway – Engine Warm-up Strategies and Torque Transients. (ORNL)



Future Work

- FY 10: Project continues as per road-map
  - Complete simulation study
  - Validate and optimize results with Engine in the Loop.

- FY 11:
  - Model Based Design will be used to evaluate other PHEV powertrain configurations (parallel, power split) for fuel consumption and emissions trade-off.
  - Validate vehicle level control strategies with ANL's vehicle test facility data.

Collaboration with Other Institutions

- Dr. David Smith, Oak Ridge National Laboratory
  - Development of after-treatment device and emissions model.
  - Energy management during engine cold start for emissions control.
  - Co-PI on the project.

- Dr. Thomas Wallner, Engine and Emissions research, Argonne National Laboratory.
  - PI for bio-fuel research on the 2.2 L SIDI Engine.
  - Support on implementation of the ‘Engine in the Loop’ concept on the SIDI engine.
  - Collaboration on other bio-fuel transient evaluation (EIL) projects.

Summary

- Model Based Design approach is being used to evaluate trade-off between fuel consumption and emissions for a PHEV.
- Simulation study is being performed on a series PHEV vehicle model with a detailed engine and after-treatment subsystem model.
- Engine in the Loop capability developed at Argonne National Laboratory will be used for validation/ refinement of the simulation study.
- Project outcome (energy management philosophies) will be used for the Battery Mule project.
- Observations from the project will be used in all future studies related to energy management for PHEVs.