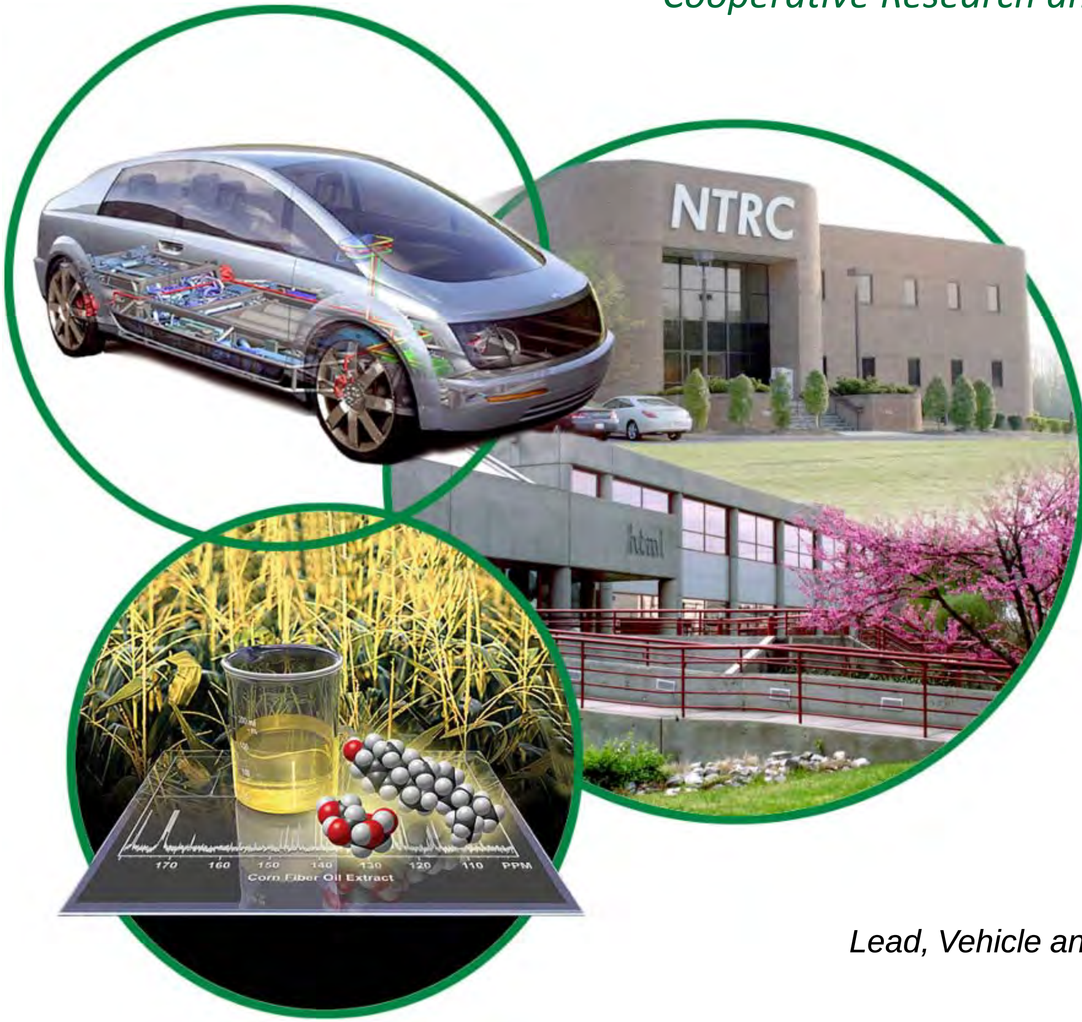
VSS062

The ArvinMeritor Dual Mode Hybrid Powertrain (DMHP): Opportunities and Potential for Systems Optimization

Cooperative Research and Development Agreement with ArvinMeritor



David E. Smith (PI)

Oak Ridge National Laboratory

2011 U.S. DOE Hydrogen Program and Vehicle Technologies Program Annual Merit Review and Peer Evaluation Meeting

May 9, 2011

Lee Slezak

Lead, Vehicle and Systems Simulation and Testing
Office of Vehicle Technologies
US Department of Energy

U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

OVERVIEW

Timeline

- Project start date: April 2011
- Project end date: Sept. 2013
- 0% complete

Barriers*

- Risk aversion
- Cost
- Constant advances in technology

**from 2011-2015 VTP MYPP*

Budget (DOE share)

- New project, no FY10 funding
- FY11 (current) funding: $350k
- FY12 (projected) funding: $500k
- FY13 (projected) funding: $500k

Partners

- ArvinMeritor
- Oak Ridge National Laboratory
  - Fuels, Engines, and Emissions Research Center (FEERC)
  - Power Electronics and Electric Machines Research Center (PEEMRC)
  - Center for Transportation Analysis (CTA)

<u>OBJECTIVE</u>: To reduce petroleum consumption for Class 8, heavy duty (HD) trucks through advanced powertrain hybridization

The "WHY"

- **Hybrid powertrains are of considerable interest because of potential reductions in fuel consumption, criteria pollutants and green house gas emissions.**
- **Parallel hybrids have been applied to light and medium duty trucks, where urban driving cycles are prevalent, while series hybrids have been successfully used for other applications like transit and school buses.**
- **Hybridization of the Class 8, HD powertrain is inherently challenging due to expected long-haul driving and limited opportunities for regenerative braking**

The "HOW"

- **Study systems optimization through model-based design and simulation of the ArvinMeritor Dual Mode Hybrid Powertrain (DMHP) specifically for Class 8 long haul trucks.**
- **Evaluate the merits of the DMHP using a combination of detailed modeling/simulation methods and laboratory hardware experimental testing.**
- **Use the results to estimate improvements in drive-cycle energy efficiency, fuel mileage and emissions.**

Essential for proper development, evaluation, and validation of emerging high risk, long term advanced transportation technologies.

RELEVANCE

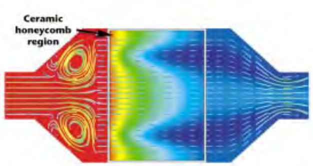
- **The ArvinMeritor DMHP CRADA directly supports the following VTP Multi-Year Program Plan Goal for VSST:**
  - Expand activities to develop and integrate technologies that address aerodynamic load reduction, hybridization, auxiliary load reduction, and idle reduction to greatly improve commercial vehicle efficiency.
- **The ArvinMeritor DMHP CRADA indirectly supports the following VTP Multi-Year Program Plan Goal for VSST:**
  - Demonstrate market readiness for grid-connected vehicle technologies by 2015.
  - Address codes and standards needed to enable wide-spread adoption of electric-drive transportation technologies
- **The ArvinMeritor DMHP CRADA addresses the following VSST Barriers:**
  - **Risk aversion**: Provides a mechanism to develop and verify the ArvinMeritor DMHP from a systems perspective through integration of both model-based design and hardware-in-the-loop principles.
  - **Cost**: Co-location of facilities and core technical expertise at the ORNL VSI laboratory creates an environment for controlled and timely evaluation of the ArvinMeritor DMHP.
  - **Constant advances in technology**: Unbiased verification of new advanced vehicle technologies, such as the ArvinMeritor DMHP, for reducing petroleum consumption in the heavy vehicle sector.

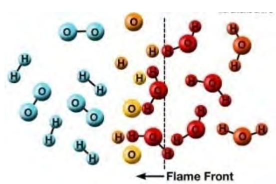
RELEVANCE

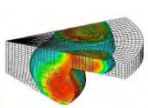
- **The ArvinMeritor DMHP CRADA addresses the following VSST Barriers:**
  - **Risk aversion**
    - Provides a mechanism to develop and verify the ArvinMeritor DMHP from a systems perspective through integration of both model-based design and hardware-in-the-loop principles. These enhancements reduce the technical and economic risk of the DMHP applications to commercial vehicles.
  - **Cost**
    - Cost of R&D: Co-location of facilities and core technical expertise at the ORNL VSI laboratory creates an environment for controlled and timely evaluation of the ArvinMeritor DMHP.
    - Cost of Technology Deployment: Results will improve the overall performance and total end-user cost via improved system integration and optimization.
  - **Constant advances in technology**
    - Successful deployment of the DMHP system for Class 8, HD commercial vehicles is a milestone advancement of the hybrid technology.

FY2011 MILESTONE

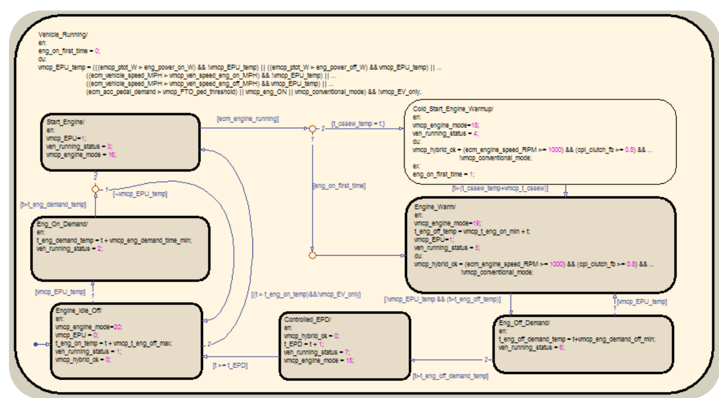
- **Complete detailed evaluation and optimization of the supervisory control strategy for the Generation 2 ArvinMeritor Dual Mode Hybrid Powertrain (September 30, 2011).**
  - The purpose of this CRADA is to develop and explore the potential of system optimization through model based design of the Dual Mode Hybrid Powertrain for Class 8 long haul trucks. HEV instantaneous equilibrium operating point methodologies will be applied to minimize fuel consumption over various cycles, and to establish a self learning algorithm such that vehicle can adapt to varying duty cycles and operating envelopes.
  - A high fidelity engine model will be integrated in order to better understand impacts to fuel consumption based on possible advanced combustion strategies and emissions constraints.





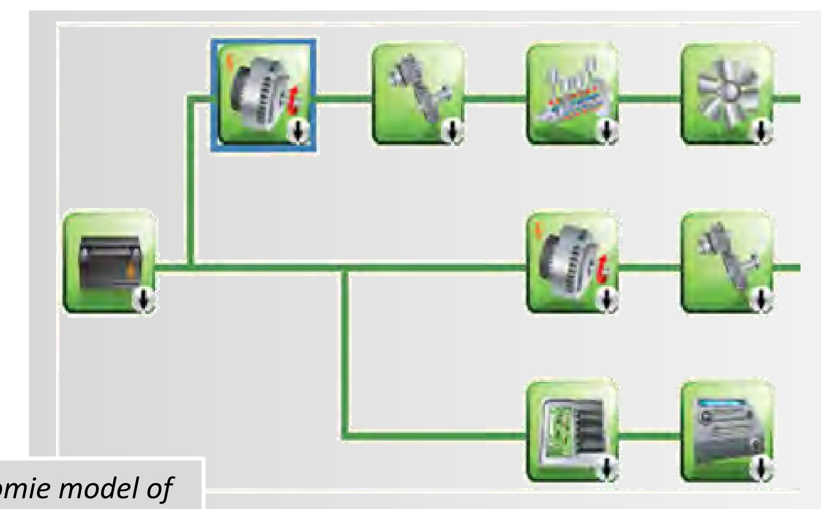


$$\left.\frac{dS}{dt}\right|_{CV} = \int \frac{\partial \dot{Q}}{T_w} + \ldots$$



APPROACH: Simulation and "Virtual Laboratory" Research

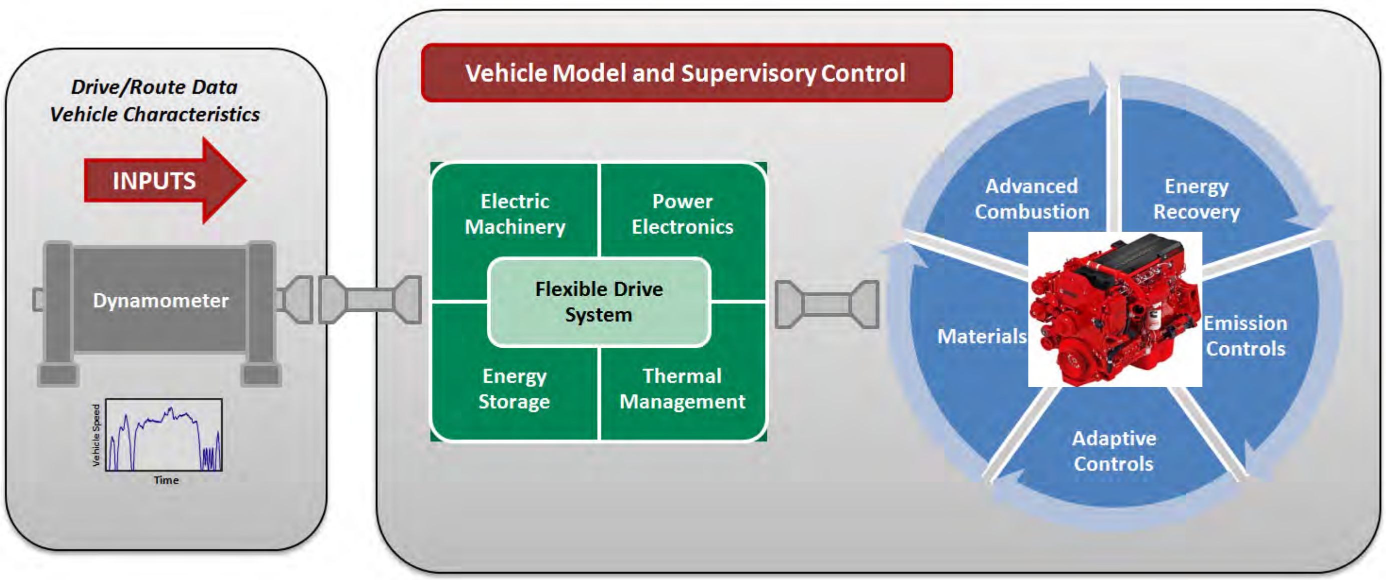
- **Simulation Model and Control Algorithm Development**
  - Develop and integrate a detailed engine model with the DMHP for understanding the engine interactions within the hybrid powertrain.
  - Update and further develop a robust DMHP vehicle simulation model for the study and discovery of potential operating scenarios of the total system, major components such as the engine and battery pack, and synergistic interactions under simulated load cycles.
- **DMHP Optimization Strategy Development**
  - Develop various optimization criteria based on fuel efficiency, freight efficiency, emissions or other relevant influential factors (including real world drive cycles).
  - Identify optimization parameters for the system, including supervisory control strategy and mechanical system considerations
- **DMHP System Optimization Studies**
- **Identify Further DMHP Improvement Potential**
- **Alternative Technology Evaluation**



Autonomie model of ArvinMeritor system

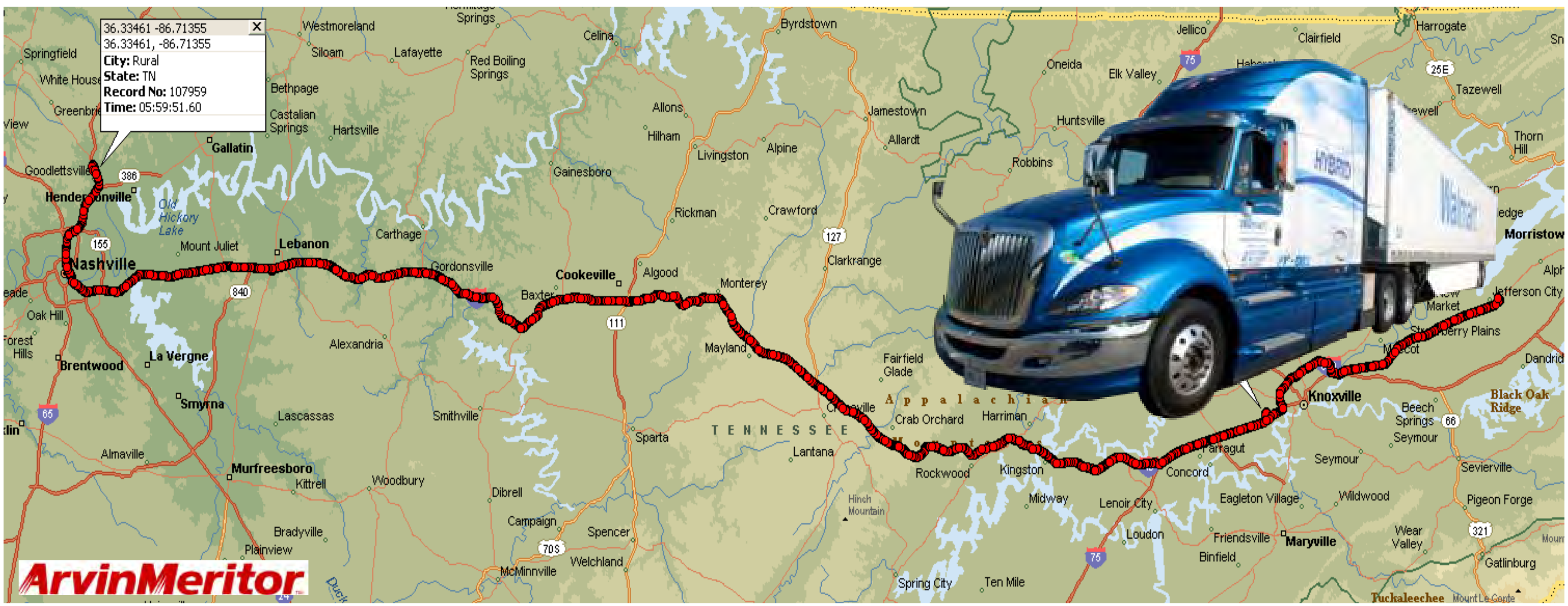
APPROACH: Hardware and Experimental Testing at ORNL Vehicle Systems Integration (VSI) Laboratory (ref. VSS-035)

- **Engine Acquisition, Installation, and Mapping**
  - Acquire a representative HD engine and dynamometer-compatible controller/wiring harness.
  - Benchmark engine to develop a performance/emissions map to support modeling efforts.
- **DMHP Simulated and Full System Dynamometer Testing**
  - Develop and test a simulated DMHP on the HD engine acquired in the previous task utilizing engine hardware-in-the-loop and advanced control methodologies.
  - Install and test a complete DMHP system (provided by ArvinMeritor) on powertrain integration dynamometer for full system hardware developmental testing.



APPROACH: On-Road Testing with Complete DMHP System

- **DMHP On-Road Testing in a HD Class 8 Truck**
  - Develop a test plan and install the necessary data acquisition and instrumentation on a prototype, Class 8 truck equipped with DMHP (vehicle provided by ArvinMeritor).
  - Place test vehicle into service to observe normal fleet operation over the road under real-life conditions. Information, such as vehicle loading, duty cycle, component physical conditions, etc. will be acquired and analyzed.
  - Findings will be transferred back to both the vehicle simulation model and the experimental full system test facility for an additional cycle of learning.



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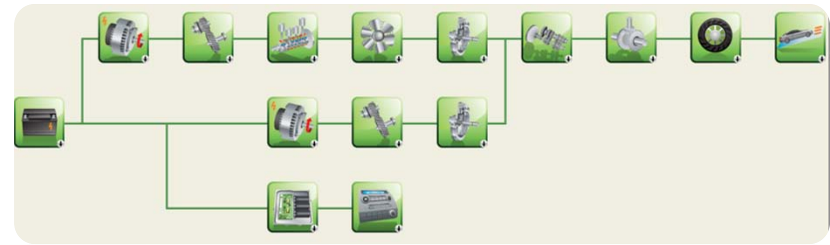
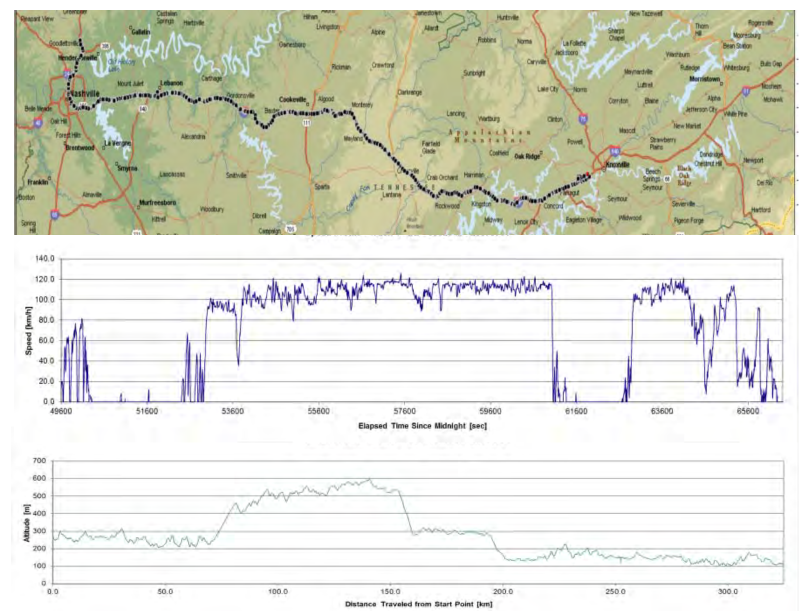
ACCOMPLISHMENT: Jump start to R&D through prior collaboration

- **CRADA being finalized , no work started currently, however ArvinMeritor has funded preliminary and exploratory studies:**
- **Established full vehicle model with DMHP powertrain in Autonomie modeling environment**
  - Proprietary engine data used for representative 2007 emissions compliant HD engine
  - Prototype electric machine (traction motor and generator) integrated into overall model
  - Well-structured supervisory control model architecture created and integrated into model
- **Vehicle model simulated over standard and “real world” drive cycles**
  - Standard heavy vehicle drive cycles were exercised to confirm expected operation of the DMHP, as well as baseline comparison for data found in the literature
  - “Real world” drive cycles were utilized based on the ORNL Heavy Truck Duty Cycle database.
- **Results suggested high degree of merit for DMHP → warrants much deeper research and development efforts**





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COLLABORATION AND COORDINATION

- **ArvinMeritor**
  - Development and delivery of Dual Mode Hybrid Powertrain, including prototype electric machines, integrated two-speed transmission, and respective control systems
  - Modification and delivery of full Class 8 test vehicle with prototype DMHP
- **Oak Ridge National Laboratory**
  - Fuels, Engines, and Emissions Research Center (FEERC)
    - Development of detailed engine model for use within Autonomie
    - Engine dynamometer commissioning and mapping of emissions and fuel economy
  - Power Electronics and Electric Machines Research Center (PEEMRC)
    - Power electronics and electric machine analysis and support
    - Assessment of interfacial relationships within high voltage traction drive system
  - Center for Transportation Analysis (CTA)
    - Provide access and use of ORNL Heavy Truck Duty Cycle (HTDC) database for developing “real world” drive cycles, **including grade**, to assess benefits of DMHP in simulation
    - Instrumentation of full vehicle to understand in-use operating patterns and opportunities for improvement to component sizing, control strategy, etc.

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PROPOSED FUTURE WORK

- **FY2012**
  - Engine selection and acquisition
    - Select appropriate engine for use during all phases of laboratory testing
    - Procure dynamometer specific engine control unit and wiring harnesses
  - Engine installation and dynamometer testing
    - Steady state and transient engine mapping for integration into component/vehicle models
    - Transient engine component-in-the-loop testing with DMHP and vehicle emulated in software
  - Preliminary DMHP system benchmarking
    - Receive complete DMHP system and install on test stand at ORNL VSI lab
    - Commission powertrain dynamometer system and complete baseline testing
  - Class 8 vehicle instrumentation and deployment
    - Install appropriate instrumentation and data acquisition equipment into prototype vehicle
    - Deploy vehicle into fleet service and initiate data monitoring
- **FY2013**
  - Detailed DMHP system testing at ORNL VSI
  - Complete data monitoring of in use vehicle data
  - Provide assessment for refined vehicle powertrain optimization and proposed future work

SUMMARY: The ArvinMeritor DMHP can enable measurable progress in applying hybrid powertrain technologies in the next generation of HD truck transportation systems

- **The successful implementation of DMHP requires a system level understanding of the complex interactions between various energy sources and energy consumption components, for various operating modes of HD, Class 8 on-highway trucks.**
- **Development of advanced DMHP for maximum efficiency and lowest possible emissions.**
  - Development and evaluation of optimized supervisory control and advanced propulsion strategies.
  - Exposure of full prototype system to transient and thermal conditions consistent with real world drive cycles.
  - Better understanding of component-to-component interactions.
  - Direct emissions measurements of full system necessary due to low-confidence level in predictive emissions modeling.
- **Component development, characterization, and commercialization.**
  - Pathway to rapid development and commercialization of high efficiency vehicle technologies for HD vehicles.
  - Model based design and HIL approach provide controlled yet efficient means for component and system discovery and refinements.

ACKOWLEDGEMENTS

Lee Slezak
Lead, Vehicle and Systems Simulation and Testing
Office of Vehicle Technologies
US Department of Energy

David Anderson
Vehicle and Systems Simulation and Testing
Office of Vehicle Technologies
US Department of Energy

Contacts

David Smith
Program Manager,
Advanced Vehicle Systems
(865) 946-1324
smithde@ornl.gov

Robert Wagner
Interim Director, Fuels
Engines and Emissions
Research Center (FEERC)
(865) 946-1239
wagnerrm@ornl.gov

Mitch Olszewski
Director, Power Electronics
and Electrical Power
Systems Research Center
(PEEPSRC)
(865) 946-1350
olszewskim@ornl.gov

Ron Graves
Director, Sustainable
Transportation Program
(865) 946-1226
gravesrl@ornl.gov

Johney Green
Director, Energy and
Transportation Sciences
Division
(865) 576-3711
greenjbjr@ornl.gov