U.S. Department of Energy Multi-laboratory Heavy Vehicle Emissions Reduction Program (Managed by Gurpreet Singh)

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Battelle

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automotive

Importance of Diesel Power

- All U.S. heavy trucks (class 7 and 8) are diesel powered
- 80% of medium trucks are diesel powered
- 10% of large (>8500 lbs gvw) pickuptrucks are diesel powered
- Every commodity except for information, natural gas, and electricity is transported by diesel trucks – no alternatives existing or under development

Importance of Diesel Power (contd)

- 50% of new personal vehicles are pickups, vans, and SUV's
  – half of these are pickups, most rapidly growing segment
  – 1 pickup for every 5 licensed drivers in the U. S.
- Increased vehicle cost increases importance of service life and value retention – diesel engines 3x gasoline engines.
- All highway fuel use increase since 1973 due to trucks, fuel used by all trucks exceeds use by cars since 1996.
- In 1999, on-highway diesel use nearly 35,000 million gallons, additional 10,000 million gallons off-highway.
- U. S. EPA – nonroad diesel emissions 38% of all mobile sources of NOx and 60% of mobile sources of PM by 2010.

Importance of Diesel Power (contd)

- Diesels power 25,000 of the 40,000+ new school buses each year
- Diesels power all freight trains, all agricultural equipment over 20 hp, all heavy construction, logging, mining, and commercial marine equipment
- All diesel applications depend on technology developed for heavy duty trucks for improvements in fuel consumption and emissions

The Role of OTT and OHVT

- OTT addresses the future energy, economic, and environmental challenges of highway transportation.
- Within OTT, the OHVT addresses heavy duty vehicles.
- OTT represents the single largest concentration of diesel technology development in the U. S. Government.
- OHVT focuses on heavy and light trucks, but, with co-funding from other parts of OTT, provides the core of essential diesel technology for the entire diesel community.

The 21st Century Truck Program

- The DOE, represented by the OTT, leads a new partnership between government and the U. S. on-highway transportation industry, including truck, bus, diesel engine, and component suppliers.
- Government partners are the DOE, the DOD, the DOT, the EPA, the OMB, and the OSTP.
- Goals are . improve fuel efficiency
  . reduce emissions
  . enhance safety
  . reduce total owning and operating cost
  . maintain or enhance performance
- Reduction in emissions is perhaps the most important goal, and is the enabling challenge.

NRC Review of the DOE/OHVT Program

- NRC was requested to conduct an independent review of the OHVT program by Dr. James Eberhardt, director of OHVT.
- Recommendation 2….”The diesel engine is the most efficient, economical power plant available today for trucks…..The fuel economy benefit of the diesel engine will not be realized unless emissions standards can be met….The diesel engine will require exhaust gas aftertreatment to meet the projected emissions standards for 2007-2010. Therefore, OHVT programs must be sharply focused on meeting future emissions standards.”

Multi-laboratory Heavy Vehicle Emissions Reduction Program Goal

- The goal of the Multi-Laboratory Heavy Vehicle Emissions Reduction Program is to develop technologies and supporting fundamental science that will enable heavy duty diesel engines to meet future EPA emissions standards, and to produce exhaust whose character is not detrimental to public health.
- In order for fuel consumption and greenhouse gas emissions reductions to be realized, diesel emissions of NOx, PM, and HC must simultaneously be reduced.
- The program will use the unique expertise and capabilities of the National Laboratories and will focus on aftertreatment, combustion, and the science to deliver integrated systems.

Program Objectives

- The baseline is a direct injected, turbocharged diesel engine with detailed electronic control of fuel injection, with cooled exhaust gas recirculation, and with emissions of approximately 2 g/bhphr NOx and 0.1 g/bhphr PM.
- The objectives of the program are to
  1) reduce NOx by 95% over representative heavy and light duty cycles
  2) reduce PM by 95% (mass and numbers) over the same cycles
  3) effectively eliminate HC (no adverse health effects and no perceived odor)
  4) develop mechanisms and models to predict and design for emissions reduction and service life.

Strategy

- The OHVT's historical strategy has been to team with industry, who has cost shared programs 50+%.
- As new emissions standards are becoming more technically challenging, OHVT will also engage the DOE national laboratories in a coordinated program, linking the best capabilities of each lab.
- Seven of the labs have a broad history in diesel and spark ignited combustion and/or aftertreatment over several years. They are ANL, LLNL, LANL, NREL, ORNL, PNNL, and SNL (both Albuquerque and Livermore). These seven labs have been brought together and make up the multi-lab emissions reduction group.

Strategy (contd)

- The Multi-Lab Emissions Reduction Group is being assisted by a group of key industry technical leaders (advisors) to assure that the most important questions are addressed first and that research results are delivered in the most useful form for immediate implementation. Early participants are caterpillar, Cummins, Detroit diesel, and john Deere.
- World leading skills and facilities that could contribute to major advances in diesel emissions reduction have been identified at each lab.

Strategy (contd)

- The group has identified the highest priority research for these assets.
- The group has developed descriptions of key work to be done in each research topic.
- These work descriptions will for the basis for DOE staff to establish specific projects in the national laboratory community.

Roles and Responsibilities

- National Labs will focus on emissions science, mechanisms, parametric design tools, and experimental validation of these tools. This work has a high pre-competitive fundamental science content, does not directly support current products, and may be very speculative.
- Industry will focus on component and system development and will guide the National Labs to assure relevance.
- Industry and the National Labs will collaborate on system and component testing and evaluation.
- As funding increases, the group will be expanded.

Regulatory Drivers

- Scheduled NOx and PM regulations
- Growing health concern concerning HC and ultra-fine PM
- Growing concern about global warming and CO2 (fuel economy)
- Sulfur in fuels and lubricants – impact on PM and on aftertreatment devices

Non-regulatory Drivers

- Public concerns for health and odor
- Economic issues
  - . fuel consumption
  - . durability, reliability
  - . cost (first cost, service, warranty, liability)
  - . packaging, weight, heat rejection, environmental exposure/robustness

Key Technology Issues

- In-Cylinder
  - . In-cylinder combustion and fluid dynamics
  - . Injection timing and rate-shape
  - . Multiple injection events
  - . Cooled EGR
  - . Other diluents (water?)
  - . Air-fuel mixing (pressure, hole diameter)
  - . Air-fuel mixture uniformity
  - . Local temperature (the NOx driver)
  - . Time at temperature with adequate O2 (PM driver)

Key Technology Issues (contd)

- Nox Aftertreatment
  - . Sulfur management
  - . NOx adsorber catalyst and system development
  - . Reductant introduction technology (H2, CO, HC)
  - . SCR catalyst and system development
  - . Plasma catalyst system development
  - . Heat addition
  - . Controls and sensors
  - . Urea distribution and filling technology
  - . On Board Diagnostics (OBD)

Key Technology Issues (contd)

- PM Aftertreatment
  - Regeneration on all duty cycles
  - Low temperature plugging – bypass?
  - Heat addition
  - On Board Diagnostics (OBD)
  - Ash contamination
  - Cost of substrate and coatings
  - Sulfur contamination

National Laboratory Capabilities

- Argonne National Lab (ANL)
  . Gas phase separation/chemistry management
  . Fuel spray characterization, dense sprays
  . Hybrid vehicle system modeling and control
  . Control system algorithm development for engineering/aftertreatment systems
- Lawrence Livermore National Lab (LLNL)
  . Chemical kinetics
  . Plasma physics/chemistry
  . HCCI (team with Sandia)

National Laboratory Capabilities (contd)

- Los Alamos National Lab (LANL)
  - . Auxiliary heat – microwave
  - . Reductants
  - . Computational fluid dynamics/heat transfer
  - . Catalyst testing/screening/characterization
  - . HC sensors
- The National Renewable Energy Lab (NREL)
  - . Vehicle field testing
  - . On-vehicle emissions testing and analysis
  - . Engine/fuels impact on air quality
  - . Renewable/alternate fuels analysis
  - . Vehicle cab thermal management

National Laboratory Capabilities (contd)

- Oak Ridge National Lab (ORNL)
  . New materials synthesis
  . Emissions control systems integration and characterization
  . Analytical emissions instrumentation development
  . Engine testing in dynomometer test cells and in-cell emissions characterization
  . Materials characterization - microstructure

National Laboratory Capabilities (contd)

- Pacific Northwest National Lab (PNNL)
  - . Surface chemistry, catalyst mechanisms, models
  - . Materials synthesis
  - . Plasma engineering
  - . Health effects mechanism analysis
  - . Aerosols
- Sandia National Labs (SNL)
  - . In-cylinder analysis
  - . Modified kinetics
  - . Catalyst materials processing, gas phase
  - . Laser diagnostics
  - . Sensors
  - . Spray-injector-PM analysis

Research Prioritization

- Work selected as most important for the first year of funding – (**) topics were require more emphasis than (*) topics
  - In-cylinder
    - ** Expansion of in-cylinder models
    - * Alternative combustion processes
  - PM and HC
    - ** Active regeneration
    - * Aging, ash plugging, cleanup models
  - NOx
    - ** Sulfur management, NOx adsorber, SCR
    - ** Active regeneration
    - * NOx adsorber catalyst and system
    - * Reductant
    - * More rapid catalyst innovation
  - Emissions Control Systems (NOX + PM)
    - *System emissions reduction analysis

Resources (millions of dollars)

FY 2002	FY 2003	FY2004	FY2005	FY2006	FY2007
4.176	7.0	12.0	19.0	13.0	10.0