Heavy Vehicle Propulsion Materials

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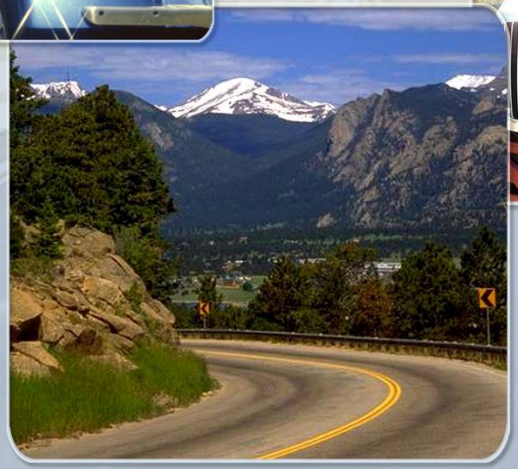
Key organizations: Cummins, Caterpillar, DDC, Ford, Corning, Dow, ORNL, ANL, PNNL, LLNL, U. Michigan, Notre Dame, Purdue



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Heavy Vehicle Propulsion Materials

HVPM Overview:

- The HVPM has a supporting role to the Engine Systems technical area.
- Methodology: Identify Major Barriers that result from material property limitations. Address material barriers with priorities aligned with Advanced Combustion Engines priorities and timelines.
- Requirements: Material solutions must meet application requirements and be near market readiness before the design of the advanced engine is completed (5 years before production). Material solutions must be cost competitive with existing technologies.
- Limitations: Limited resources require that material solutions be developed in partnership with industry as efficiently as possible. This allows resources to be made available to address the next material barrier on the Engine Systems priority list.

Heavy Vehicle Propulsion Materials

Materials R&D in support of engine efficiency. Several pathways to more efficient engines rely heavily on the development and application of advanced materials.

- **Valve-train Materials:** Light-weight high performance materials
  - Greater Efficiency and durability through lower reciprocating mass, greater wear resistance, and greater thermal tolerance.
- **Major Engine Components:** Cost-effective, high-performance cast materials
  - Materials with higher strength and fatigue resistance for engine blocks and cylinder heads: e.g., higher-quality cast iron or high-strength materials to reinforce highly stressed areas in conventional cast iron. Improve characteristics of materials in piston-ring-liner systems, bearings, bushings, and gear systems. Materials and coatings for thermal management for lower heat transfer to coolant and higher exhaust temperatures for after treatment or energy recovery.
- **Air Handling:** Materials for turbocharger and EGR system
  - Corrosion-resistant materials and coatings for EGR systems. High performance materials for turbocharger components, including lower mass rotating parts and housings with greater strength.
- **High Temperature Materials:** Exhaust System including valves and manifolds
  - Improved exhaust manifold materials and sealing methods to handle increased exhaust pressure, higher operating temperatures, and heavier turbochargers.
- **Materials for Waste Heat Recovery:** Mechanical and direct conversion materials
  - Improved materials for waste-heat recovery systems including thermoelectrics and turbocompounding.

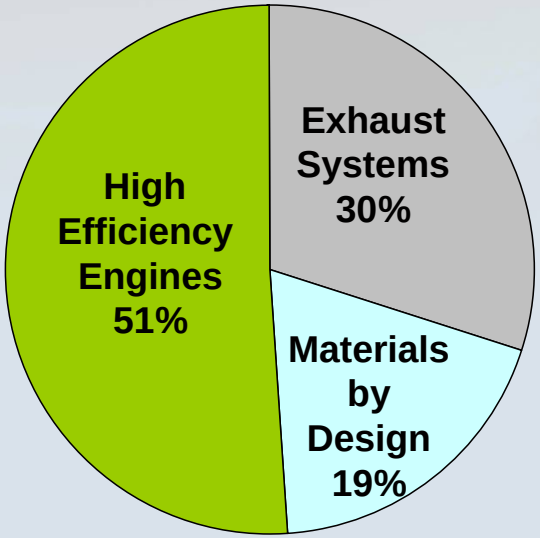
Heavy Vehicle Propulsion Materials

Materials R&D in support of emission reduction

- **Fuel Injection:** Materials and processing for precise injector spray control
  - Low mass, low wear, fast acting injector actuator and valve systems to coincide with in-cylinder emission control techniques. This includes new materials and processes for cams, roller or sliding followers, and axles (for rollers) to allow increased injection pressure and rate shaping, valve timing control, and compression braking optimization within packaging constraints.
- **Exhaust Aftertreatment:** Durable, high performance device substrates and coatings
  - Catalysts and DPFs with stable microstructures that can operate at high efficiency over a wide range of exhaust conditions with low back pressure and at least one million mile durability.
- **Sensors:** Materials and processes for sensor development (ex. NOx, SOx)
  - Robust sensor materials that survive the severity of the diesel engine environment. Direct sensing of the emission constituents of interest is challenging, yet valid technological objective. A minimum predictable life expectation of one million miles is an objective.
- **Lubricant control:** Materials for crankcase sealing, materials and lube interactions
  - New materials and surface treatments for valve stem–valve guide seals and at the ring-liner interface to control lubricant entry to the combustion chamber and thus control PM emissions.

Key HVPM Projects

- **Materials for High Efficiency Engines**
  - High Performance Fuel Injection
  - Lightweight High-Temperature Valves
  - Materials Compatibility
  - Material Surface Modifications
  - Component Evaluation



- **Materials for Exhaust Systems and Energy Recovery**
  - High Temperature Materials
  - Exhaust After-treatment
  - Advanced Sensors

- **Materials By Design**
  - Life Cycle Modeling
  - Materials Characterization
  - New Materials through Atomic Scale Modeling
    - Thermoelectric materials
    - Catalysts

Materials for High Efficiency Engines

Addresses the following Major Efficiency Barriers:

- **Cost of advanced materials and their processing**
- **Material limits (temperature capability and strength)**
- **Tribological limits of current materials and lubricants**
- **Limitations of current air-handling components and systems**
- **Relatively large thermodynamic losses in traditional combustion processes**

Addresses the following Major Emissions Barriers:

- **NOx/PM trade-off during combustion; maintaining efficiency and low NOx while keeping PM down:**
  - limitations of air-handling system
  - limitations of fuel-injection technology
  - incomplete optimization of cooled EGR and resolution of durability concerns

Materials for High Efficiency Engines

Light-Weight valves tested for 500 hr.

- Intermetallic, ceramic, and reference metallic valves tested in parallel
- Engine performance evaluated
- 1000-hr test planned for 2007

Materials for High Efficiency Engines: Accomplishments

- **Technology for Low-Cost Manufacturing $TiAl_6V_4$ components (Turbo Compressor Wheel)**
  - Modeling of Machining Processes
  - High-Speed Drilling > 180m/min
  - Thermal Oxidation Process to Greatly Reduce Wear
- **Metallic Thermal Barrier Coating Technology for HCCI Engine Designs**
- **High-Temperature Light-Weight Valve Technology**
  - Design to Meet Engine Customer Needs, Procure & Rig Test
  - Post Rig-Test (500 hr) Destructive Evaluation
  - Development of NDE technology & Pre-Engine Test Evaluation
  - 500-hr Engine Test & Performance Evaluation

Materials for Exhaust Systems and Energy Recovery

Addresses the following Major Efficiency Barriers:

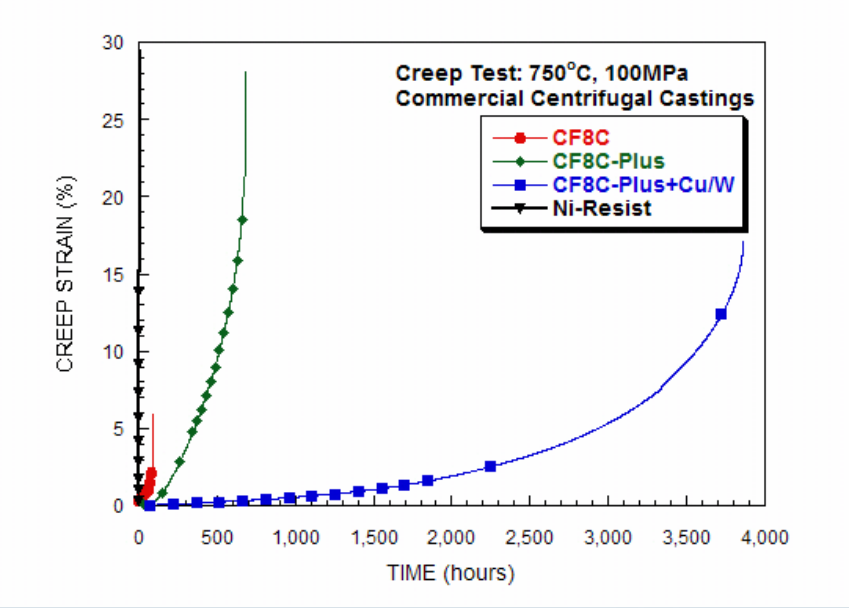
- **Poor cost-effectiveness of known exhaust-heat-utilization systems;**
- **Cost of advanced materials and their processing;**
- **Material limits (temperature capability and strength);**
- **Inadequate durable and accurate sensors;**
- **Relatively large thermodynamic losses in traditional combustion processes**

Addresses the following Major Emissions Barriers:

- **NOx/PM trade-off during combustion: maintaining efficiency and low NOx while keeping PM down:**
  - incomplete optimization of cooled EGR and resolution of durability concerns;
- **Aftertreatment system limitations for NOx and PM control**
  - degradation from sulfur in fuels and lubricants and long term durability;
  - inefficient management of engine exhaust temperatures for optimum catalyst efficiencies
  - incomplete understanding and optimization of catalysts;
  - regeneration of DPFs subjected to extended low-temperature operation;
  - inadequate sensors for process control or diagnostics;
  - impact of DPF regeneration temperature on down-stream NOx catalyst;
  - back pressure from aftertreatment and the negative impact on engine efficiency

Materials for Exhaust Systems and Energy Recovery – Example

Caterpillar Regeneration System (CRS) Housing



Creep data on CF8C-Plus Cu/W, 2 Turbocharger manufacturers are showing interest for thin-wall stainless steel turbo-charger casings (June-August, 2006)

Materials for Exhaust Systems and Energy Recovery

Accomplishments:

- **R&D 100 Award & Patent for Austenitic SS For Exhaust Manifold & Turbo Housing**
- **Durability, Design Data and Modeling for Diesel DPF Substrates**
  - Life Prediction Model and Material Testing Procedures
  - Material Screening for Back Pressure & Filtration Efficiency
  - Promising New Material Identified
- **Extensive Testing of Catalysts From Engine & Rig Tests in HTML Instruments**
- **Evaluation of Microstructural Changes in NOx Trap Materials via Ex-Situ Reactor & High-Resolution STEM**
  - Lean, Rich, and Lean-Rich Cycles
  - Accelerated Aging Conditions
  - With & Without SO_2
- **Characterization of Catalyst Microstructures & Deactivation Mechanisms**

Materials By Design

Address the following Major Efficiency Barriers:

- **Poor cost-effectiveness of known exhaust-heat-utilization systems;**
- **Cost of advanced materials and their processing;**
- **Material limits (temperature capability and strength);**

Address the following Major Emissions Barriers:

- **Aftertreatment system limitations for NOx and PM control**
  - degradation from sulfur in fuels and lubricants and long term durability;
  - effectiveness over a wide enough engine load range (i.e., temperature range) and during transients;
  - incomplete understanding and optimization of catalysts;
  - regeneration of DPFs subjected to extended low-temperature operation;
  - deficiencies in the fundamental understanding and modeling capabilities needed for designing effective catalysts through means other than trial-and-error;
- **Immature simulation and control systems integration, as well as static and dynamic optimization of multiple emission reduction systems.**
  - Limited simulation capability for these types of systems.

Materials By Design

New Materials through Atomic Scale Modeling

- Thermoelectric materials and Catalysts

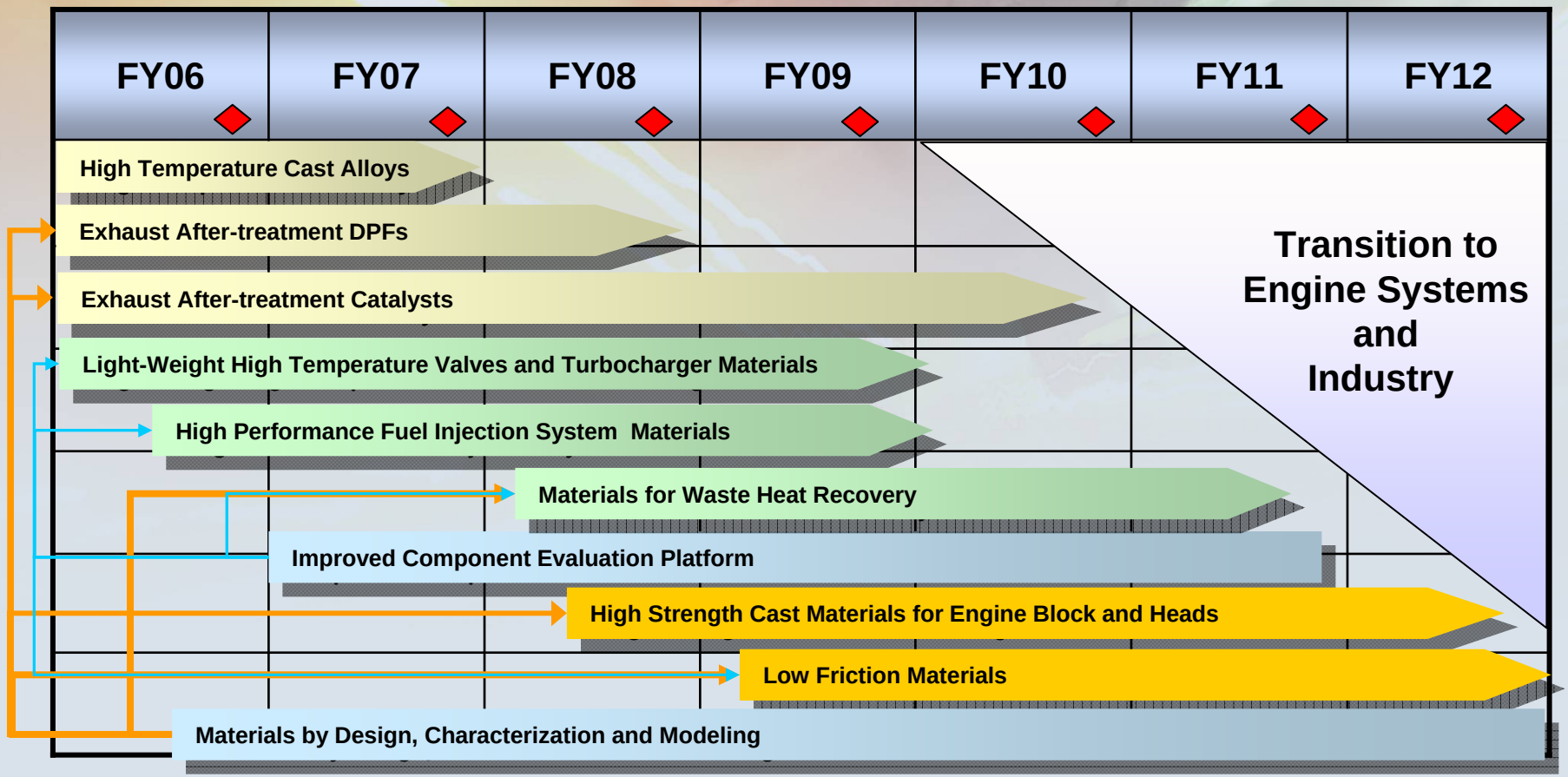
- **Goals:**
  - Develop new materials to improve device performance while reducing costs through computational modeling of materials composition, structures, and properties at the atomic and molecular (nano-) scale.
- **Accomplishments:**
  - Roadmap developed for Thermoelectric Materials with input from Industry, Academia, and other Government Agencies (24 organizations represented).
  - Characterization of DPF substrates for life-cycle durability model
  - Demo of "Science-Based Approach to Development of New/Improved Catalysts
    - 1st Principles Modeling, Synthesis of Catalyst Nanoclusters & Supports, Nano-scale Characterization of Catalysts
- **Relevance:**
  - Material limitations currently impact the performance, cost, and reliability of these technical areas which are essential to waste heat energy recovery and emission control devices for high efficiency internal combustion engines.
  - Thermal and mechanical cycling of ceramic DPF and catalyst substrates represents a significant challenge to meeting 1 million mile durability goal of emission control devices.

Future Direction

- Advanced Diesel Engine and Dyno for Materials and Components Test Bed
  - Will be installed at ORNL in FY 2007

- Materials Development to Support LTC Engine Designs
  - Materials durability and engine/component performance evaluated in Materials and Components Test Bed
  - FY 2008 – FY 2012 Focus on materials technology to support & enable advanced engine designs
    - Higher temperatures
    - Higher peak cylinder pressures
    - Increased use of waste energy recovery systems
    - Reduce mass and friction in rotating components
    - Next generation fuel injection systems
    - Sensor materials and processing

Propulsion Materials Timeline



◆ Status Review

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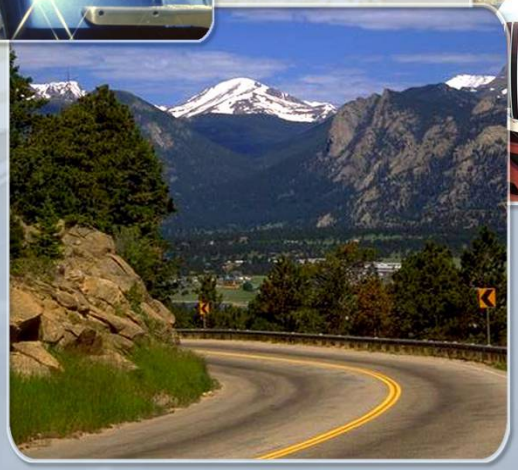

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