Materials Issues Associated with EGR Systems

Project ID: pmp_10_lance

DOE 2009 Vehicle Technologies Annual Merit Review and Peer Evaluation Meeting

May 21, 2009

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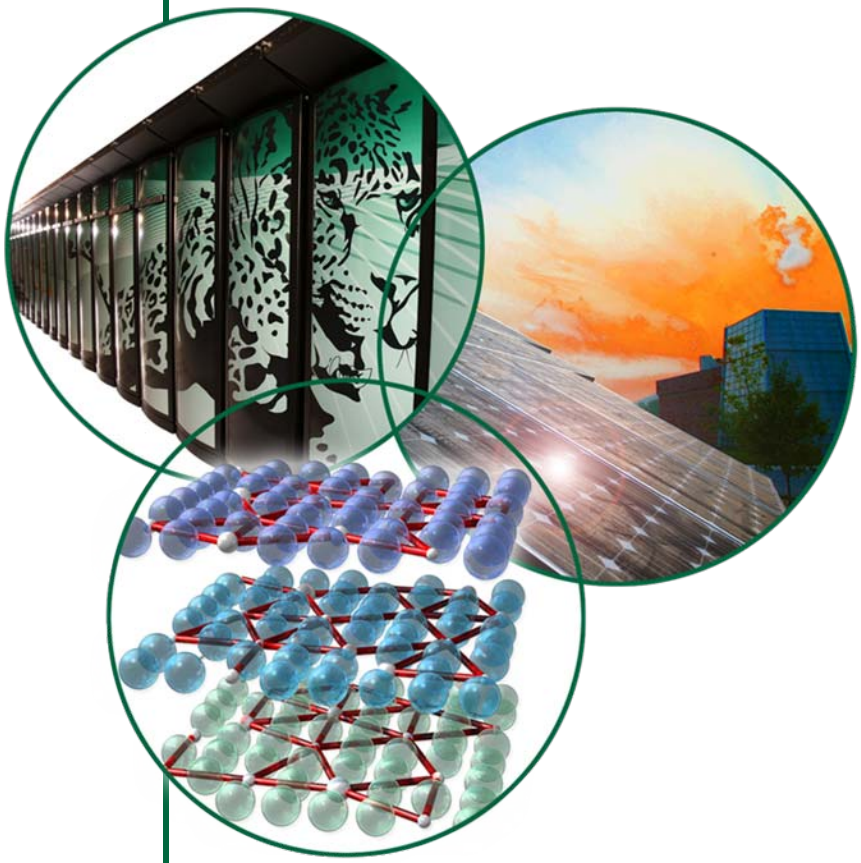

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U.S. Department of Energy, Assistant Secretary for Energy Efficiency and Renewable Energy, Office of Vehicle Technologies Program

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Overview

Timeline

- Start: February 2009
- End: September 2011
- 4% complete

Budget

- Total Project Funding
  - DOE-$1.6M
- Funding received:
  - FY08: $0
  - FY09: $174K

Barrier

- After-treatment systems have energy penalties that reduce the overall engine/after-treatment system efficiency.

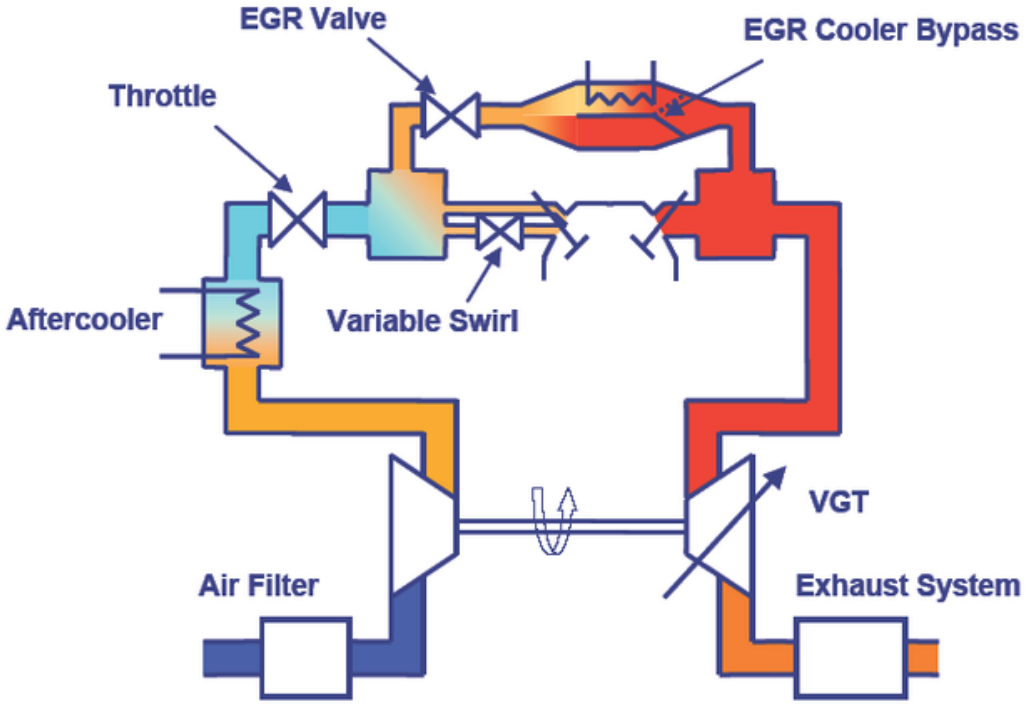
Targets

- Optimize cooled exhaust gas recirculation (EGR) for maximum NO_X reduction and minimum PM emission, mitigating durability concerns with EGR through materials engineering and operational controls.
- By 2012, develop the supporting materials technology required to enable prototypical heavy-duty engine efficiency of 55 percent while meeting prevailing EPA emissions standards.

Partners

- Caterpillar, Cummins, Detroit Diesel, Ford, GM, John Deere, Navistar, PACCAR and Volvo/Mack.

Background: High-Pressure Exhaust Gas Recirculation (HP-EGR)



- High-pressure EGR is the dominant NO_x-reduction technology.
- Exhaust gas laden with PM flows through the EGR cooler which causes deposits to form through thermophoresis and condensation.
- The deposit thermal conductivity is very low, which reduces the effectiveness of the EGR system.
- Increasing demands placed on the technology by more stringent NO_X emissions, advanced combustion, increasing use of non-petroleum-based fuels, and engine/aftertreatment system optimization requirements are leading to expansions of the technology into operational conditions that are relatively unknown or known to be problematic.

Background: High-Pressure Exhaust Gas Recirculation

- Information about deposit formation and removal is needed:
  - Thermo-physical and chemical properties of the deposit are needed for modeling.
  - Effectiveness of EGR systems often decline but then reach a plateau. Why?
  - The deposit changes with time due to temperature and HC/water condensation.
  - What is the adhesion mechanism and how can we stop it?
  - How does the deposit affect the EGR valve.
- Bio-based fuels produce different exhaust gas chemistry and PM.

Project Objective: Provide information to industry specialists about fouling deposit properties

Aim is to enable improved models and potential design improvements to reduce fouling and its impact on performance

- Characterize the thermo-physical properties of the deposit under different operating conditions on model EGR cooler tubes.
- Determine the long-term changes in deposit properties due to thermal cycling and water/HC condensation.
- Leverage existing project funded by the DOE Fuels program to allow more in-depth analyses on samples from biodiesel operation.
- Determine deposit adhesion mechanisms and methods to minimize them.

Milestones

- FY2009
  - Feb-09 Milestone: Assembled EGR Advisory Team from industrial experts at 9 diesel engine OEMs.
  - Feb-09 Go/No-Go Decision
    - Survey EGR Team Members as to what the greatest materials issues are relating to EGR systems. The survey results clearly indicated EGR cooler fouling as the primary concern.
  - Sep-09 Milestone: Task 1-Establish Experimental Setup
- FY2010
  - Dec-09 Milestone: Task 2-Complete Analysis of Industry provided EGR coolers.

EGR Materials Advisory Team

- An advisory team consisting of chief engineers responsible for EGR systems from nine diesel engine OEMs was assembled.
- EGR team companies included light-duty, heavy-duty and off-road diesel truck manufacturers:

Approach

- Task 1: Experimental Setup
  - We are pursuing a traditional engine-on-dynamometer to generate fouling deposits on model tubes.
- Task 2: Obtain and Evaluate Representative (Half-Useful-Life) EGR Coolers from Industry Members
  - This will provide a reference point that will guide our future research
  - It will also provide an opportunity to refine effective characterization tools:
    - Chemical Analysis: TGA/DTA, XRF, FTIR, XPS, Raman, GC-MS.
    - Thermal Analysis: Heat Capacity, Thermal Conductivity
    - Microstructural Analysis: SEM, TEM, Electron Microprobe, Optical Microscopy
    - Neutron Tomography

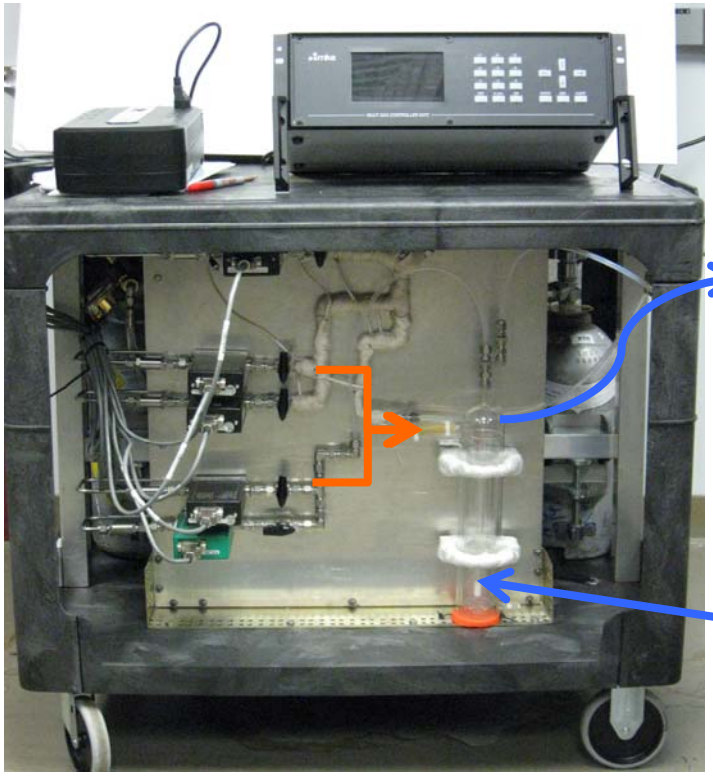
FY2009 Accomplishments

- Task 1: Experimental Setup
  - We have begun purchasing equipment.
- Task 2: Analysis of Industrial Samples
  - As of March 2009, five coolers have been received and are being cut open for analysis.

Future Work

- Extensive analysis of industry provided EGR coolers will be conducted. Coolers will be compared from multiple platforms (i.e. light-duty, heavy duty, off-road) to see if any common chemical/physical features of the deposits emerge.
- With these industrial reference points, we will design controlled experiments using the EGR cooler tube sampler.

Future work: In-situ studies with new portable gas manifold



- Testing to begin early summer 2009 after safety approvals.

Summary

- EGR will remain a key emissions technology for the foreseeable future as EPA regulations worsen degradation issues associated with PM.
- A team of industry advisors has been assembled that will help guide future research directions of this pre-competitive research.
- Team members were polled to determine the greatest material problem facing EGR systems. The vote was for EGR cooler fouling.
- Team members are providing EGR coolers for analysis.
- An engine and a sampler tube system for laying down controlled PM deposits is being designed and purchased. A portable gas manifold for controlled post-deposition aging is being built.