Advanced Diesel Engines and the Exhaust Emission Controls

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Houghton, MI
October 8, 2009
Mining Diesel Emissions Council (MDEC) Conference
Toronto, Canada

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Outline of Presentation

1. On-Highway and Off-Highway Emission Standards
2. Two National Academies Studies on Fuel Economy Technologies
3. Review of the 21st Century Truck Partnership and Representative Peters – U.S. House Science and Technology Committee Bill on Vehicle Technology R & D
4. MTU Research Results for CPF and DOC Systems – Passive and Active Regeneration
5. Future Light-Duty Emission Control Systems
6. Future Heavy-Duty On-Highway and Off-Highway Emission Control Systems
7. Advanced Diesels – How to Reduce Fuel Consumption
8. Questions and Comments?

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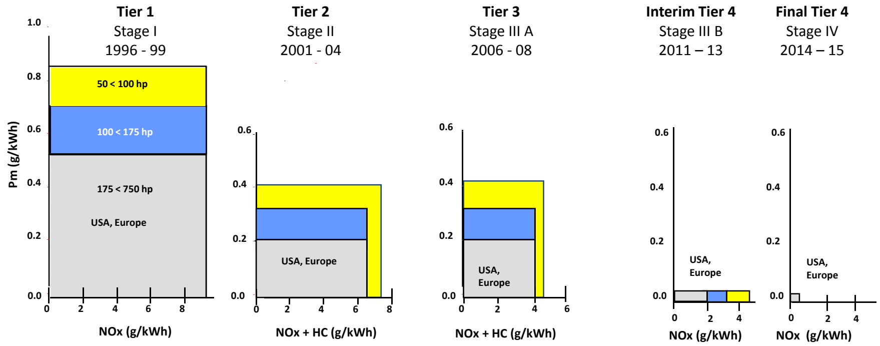
1. On-Highway and Off-Highway Emission Standards

On-Highway HD Vehicle EPA Standards

- 2007 PM 0.01 grams/bhp-hr
- 2010 NO_x 0.2 grams/bhp-hr

Non-Road Emission Standards: 50-750 hp



1996	1998	2000	2002	2004	2006	2008	2010	2012	2014	2016

NONROAD FUEL (US) 3500 ppm sulfur → 500 ppm | 15 ppm

NONROAD FUEL (EU) 10 – 2000 ppm sulfur → 10 - 1000 ppm | 10 ppm ?

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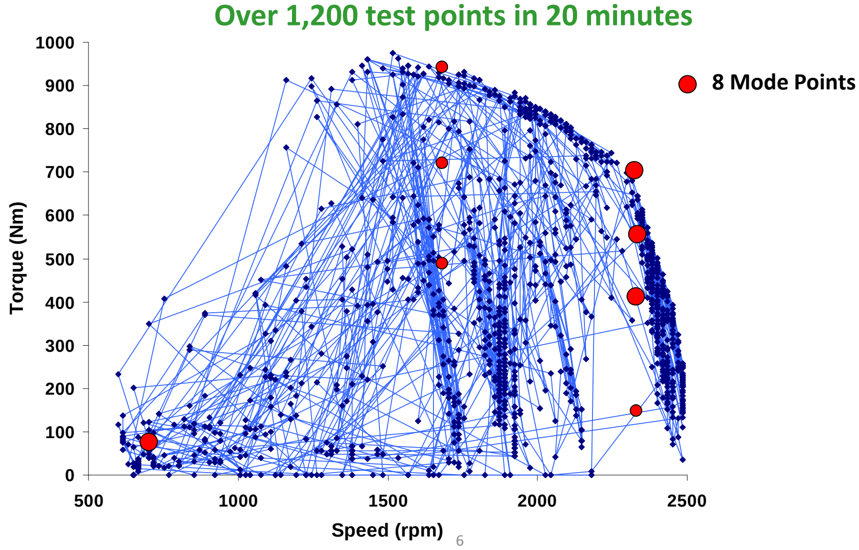
TIER 4 EPA NONROAD TRANSIENT CYCLE

Over 1,200 test points in 20 minutes



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2. Two National Academies Studies on Fuel Economy Technologies

National Research Council Fuel Economy of Light Duty Vehicles

Chair: Dr. Trevor Jones, Chairman and CEO
ElectroSonics Medical Inc.

Dr. Thomas Asmus, Senior Research Executive (retired)
DaimlerChrysler Corp

Dr. Rodica Baranescu, Manager, Engineering Technologies
NAVISTAR

Dr. Jay Baron, President
Center Automotive Research

Dr. David Friedman, Clean Vehicles Program
Union of Concerned Scientists

Dr. David Green, Corporate Fellow
National Transportation Research Center

Dr. Linos Jacovides, Director, (retired)
Delphi Research Labs

Dr. John Johnson, Presidential Prof. Emeritus, Mechanical Engineering, Engines and Air Pollution
Michigan Technological University.

Dr. John Kassakian, Prof. Electrical Engineering and Director, Lab. for Electromagnetic & Electronic Systems
Massachusetts Institute of Technology

Dr. Roger Krieger, (retired)
Research & Development
General Motors Corp.

Dr. John Moskwa, Prof. and Director, Powertrain Control Laboratory
University of Wisconsin

Mr. Gary Rogers, President, CEO and Sole Director
FEV Engine Technology, Inc.

Dr. Robert Sawyer, Professor of Energy Emeritus
Dept. of Mechanical Engineering
University of California, Berkeley

NRC Committee on Fuel Economy of Light-Duty Vehicles Statement of Task

The committee formed to carry out this study will provide updated estimates of the cost and potential efficiency improvements of technologies that might be employed over the next 15 years to increase the fuel economy of various light-duty vehicle classes. Specifically, the committee shall:

1) Reassess the technologies analyzed in Chapter 3 of the NRC report, *Impact and Effectiveness of Corporate Average Fuel Economy (CAFE) Standards* (2002) for efficacy, cost, and applicability to the classes of vehicles considered in that report. In addition, technologies that were noted but not analyzed in depth in that report, including direct injection engines, diesel engines, and hybrid electric vehicles, shall be assessed for efficacy, cost and applicability. Weight and power reductions also shall be included.

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NRC Committee on Fuel Economy of Light-Duty Vehicles Statement of Task

2) Estimate the efficacy, cost, and applicability of emerging fuel economy technologies that might be employed over the next 15 years. Promising engine, transmission and vehicle technologies shall be selected in light of factors that may motivate their market adoption such as economic impacts, oil imports, greenhouse gas emissions, increased market share for "light trucks" including sport utility vehicles (SUVs) and minivans, and the possible emergence of fuel cell, biofuel, and electric vehicles.

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NRC Committee on Fuel Economy of Light-Duty Vehicles Statement of Task

3) Identify and assess leading computer models for projecting vehicle fuel economy as a function of additional technology. These models would include both
   - lumped-parameter type models, where interactions among technologies are represented using energy partitioning and/or scalar adjustment factors, and
   - Full vehicle simulation, in which such interactions are analyzed using explicit drive cycle and engine cycle simulation, based on detailed vehicle engineering characteristics.

   Check the models against current, known fuel economy examples and select one of each type to perform the analyses of the effect of the technologies in 1 and 2 above.

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NRC Committee on Fuel Economy of Light-Duty Vehicles Statement of Task

4) Develop a set of cost/potential efficiency improvement curves, as in Chapter 3 of the 2002 NRC report, that is guided by the following question:

   “What is the estimated cost and potential fuel economy benefit of technologies that could be applied to improve the fuel economy of future passenger vehicles, given the constraints imposed by vehicle performance, functionality, safety and emission regulations?

   The ten vehicle classes considered in the 2002 report shall be analyzed, including important variants such as different engine sizes (e.g. 6 and 8 cylinders). Most analyses shall be with the engineering judgment model, but sufficient cases to ensure overall accuracy shall be checked with the engine mapping model.

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NRC Committee on Fuel Economy of Light-Duty Vehicles Statement of Task

5) Define and document the methodology(ies) and inputs used to estimate the incremental costs and benefits of the fuel economy technologies chosen by the committee. Although methodologies vary, the committee's report should specify its calculation methodology(ies) to levels of specificity, clarity and completeness sufficient for implementation and integration into models that project the fuel economy capability of vehicles, fleets and manufacturers. The report should also provide and document estimates of all parameters and input data required for implementation of these methodologies.

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NRC Committee on Fuel Economy of Light-Duty Vehicles Statement of Task

6) Assess how ongoing changes to manufacturer's refresh and redesign cycles for vehicle models affect the incorporation of new fuel-economy technologies.

The committee's analysis and methodologies will be documented in two NRC-approved reports.

- An interim report will discuss the technologies to be analyzed, the classes of vehicles which may employ them, the estimated improvement in fuel economy that may result, and the models that will be used for analysis.
- The final report will include detailed specifications for the methodologies used and the results of the modeling using the input from the interim report and any new information that is available.

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National Research Council
Fuel Economy of Medium- and Heavy-Duty Vehicles

National Academies Board on Energy and Environmental Systems (BEES)

First Meeting
Dec 4 – 5, 2008
Washington, D.C.

Second Meeting
February 4 – 5, 2009
Washington, D.C.

Third Meeting
April 7 – 8, 2009
Dearborn, MI

Forth Meeting
June 18 – 19, 2009
Ann Arbor, MI

Fifth Meeting
August 6 – 7, 2009
San Antonio, TX

Sixth Meeting
September 23 – 24, 2009
Washington, D.C

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EISA 2007
SEC. 108. NATIONAL ACADEMY OF SCIENCES STUDY OF MEDIUM-DUTY AND HEAVY-DUTY TRUCK FUEL ECONOMY.

(a) In General- As soon as practicable after the date of enactment of this Act, the Secretary of Transportation shall execute an agreement with the National Academy of Sciences to develop a report evaluating medium-duty and heavy-duty truck fuel economy standards, including—

(1) an assessment of technologies and costs to evaluate fuel economy for medium-duty and heavy-duty trucks;
(2) an analysis of existing and potential technologies that may be used practically to improve medium-duty and heavy-duty truck fuel economy;
(3) an analysis of how such technologies may be practically integrated into the medium-duty and heavy-duty truck manufacturing process;
(4) an assessment of how such technologies may be used to meet fuel economy standards to be prescribed under section 32902(l) of title 49, United States Code, as amended by this subtitle; and
(5) associated costs and other impacts on the operation of medium-duty and heavy-duty trucks, including congestion.

(b) Report- The Academy shall submit the report to the Secretary, the Committee on Commerce, Science, and Transportation of the Senate, and the Committee on Energy and Commerce of the House of Representatives, with its findings and recommendations not later than 1 year after the date on which the Secretary executes the agreement with the Academy.

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Assessment of Fuel Economy Technologies for Medium and Heavy Duty Vehicles

Abbreviated Statement of Task.

The committee will conduct an assessment of fuel economy technologies for medium and heavy-duty vehicles. According to the Energy Independence and Security Act of 2007, Section 108, the study is to develop a report evaluating medium-duty and heavy-duty truck fuel economy standards.

The committee will:
1) consider appropriate approaches to measuring fuel economy for medium- and heavy duty vehicles that would be required for setting standards;
2) assess current and potential technologies and estimate improvements in fuel economy for medium-duty and heavy-duty trucks that might be achieved;
3) address how the technologies identified in Task 2 above may be used practically to improve medium-duty and heavy-duty truck fuel economy;
4) address how such technologies may be practically integrated into the medium-duty and heavy-duty truck manufacturing process;
5) assess how such technologies may be used to meet fuel economy standards to be prescribed under section 32902(k) of title 49, United States Code, as amended by Section 108;
6) discuss the pros and cons of approaches to improving the fuel efficiency of moving goods in the trucking sector against setting vehicle fuel economy standards; and
7) identify the potential costs and other impacts on the operation of medium-duty and heavy-duty trucks.

The study committee will not recommend a standard but the results of its analysis will give guidance to the National Highway Traffic Safety Administration as it moves forward with how to address fuel economy standards for medium and heavy-duty trucks.

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Committee Members

Dr. Andrew Brown, Jr.,
Exec. Director & Chief Technologist
Delphi Corporation

Dr. Dennis Assanis,
Prof. & Director, Auto Research Center
University of Michigan

Dr. Nigel Clark,
Prof. & Director Center for Alternative Fuels, Engines & Emissions
West Virginia University

Duke Drinkard,
VP, Maintenance (retired)
Southeastern Freight Lines

Dr. Roger Fruechte,
Director, Electrical & Controls Integration Lab
General Motors R&D

Dr. Roger Bezdek,
President
Management Information Svcs.

Thomas Corsi,
Director, Supply Chain Mgmt., Logistics, Business & Public Policies
University of Maryland

Dr. David Foster,
Prof. & Director, Engine Research Center
University of Wisconsin

Dr. Ron Graves,
Director, Fuels, Engines & Emissions Research Center
DOE/ORNL

Dr. John Johnson,
Presidential Prof. Emeritus, Dept Mechanical Engineering
Michigan Technological University

Drew Kodjak,
Executive Director
International Council on Clean Transportation

David Merrion,
Executive Vice President (retired)
Detroit Diesel

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Committee Members

Tom Reinhart,
Program Manager, Engine Design & Development
Southwest Research Institute

Dr. Charles Salter,
Exec. Director, Engine Development (retired)
Mack Trucks / Volvo Powertrain

Dr. James Winebrake,
Chair, Dept Science, Technology & Public Policy
Rochester Institute of Technology

John Woodrooffe,
Head, Transportation Safety Analysis
University of Michigan Transportation Institute

Dr. Martin Zimmerman,
Chief Economist & Group VP
Ford Motor Company

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3. Review of the 21st Century Truck Partnership and Representative Peters – U.S. House Science and Technology Committee Bill on Vehicle Technology R & D

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National Research Council
Review of the 21st Century Truck Partnership

John H. Johnson, Chair

NRC Committee to Review the 21st Century Partnership

Board on Energy and Environmental Systems
500 Fifth St., NW
Room Keck 943
Washington, D.C. 20001
202-334-3222

June 25, 2008

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Advisers to the Nation on Science, Engineering, and Medicine

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21st Century Truck Partnership

Facts About 21CTP

Federal agencies:
- **DOE**
- **DOT**
- **DOD**
- **EPA**
- **National Laboratories:**
  - **Pacific Northwest National Laboratory, Richland, Wash.**
  - **National Renewable Energy Laboratory, Golden, Colo.**
  - **Sandia National Laboratories, Livermore, Calif.**
  - **Argonne National Laboratory, Argonne, Ill.**
  - **Oak Ridge National Laboratory, Knoxville, Tenn.**

History

Launched in 2000 by Vice President Al Gore

Initially under DOD (U.S. Army) Lead; now DOE (FreedomCAR and Vehicle Technology)

Funding declining lately

Industrial partners:
- **Allison Transmission**
- **BAE Systems**
- **Caterpillar**
- **Cummins**
- **Detroit Diesel**
- **Eaton Corporation**
- **Freightliner**
- **Mack Trucks**
- **NAVISTAR**
- **NovaBUS**
- **Oshkosh Truck**
- **PACCAR**
- **Volvo Trucks North America**

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21st Century Truck Partnership Testimony to House

- "Testimony on the R & D Needs for the 21st Century Truck Partnership Program based on the Review of the Program by the National Academies U.S. House Subcommittee on Energy & Environment of the Committee on Science & Technology," March 24, 2009, Dr. John Johnson.
  - "In light of the potential fuel economy regulations by NHTSA as required by Section 102 of EISA, it is important that the Federal government fund the DOE program at levels such as $200 million/year with $90 million/year for engine, emission control systems, and biodiesel fuels research. The program should be funded for 5-10 years at this level so that the industry will have the technology in the 2015-2020 timeframe to meet potential fuel economy regulations. Safety is an important part of the program with support in the past from DOE and DOT, with DOT providing the majority of the budget. As crash protection measures have not substantially reduced highway fatalities during the past decade, the main objective going forward will be to prevent crashes using crash avoidance technologies and in-vehicle communications systems. There is need for $25 million per year for safety related research which should be designated for DOT by line item for the 21st Century Truck Partnership."

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21st Century Truck Partnership Testimony to House cont'd

— "I am very supportive of a bill that commits the United States Government to a research program that results in the development of fuel efficient and safe heavy-duty trucks. The U.S. has always been a world leader in developing advanced trucks – the heavy-duty diesel engine has always been cutting edge technology in durability, reliability, low fuel consumption, and now in 2010 low in emissions. This product development and manufacturing base in the U.S. must be maintained if we as a country are to be strong in the global economy. This industrial base is also important to the military, particularly to the Army and Marines since diesel powered vehicles and diesel fuels are critical elements of our ground forces. We must maintain this base which will happen with an aggressive R & D program in the commercial sector that includes maintaining National Laboratories and Universities as strong components in the program."

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July 2009 DRAFT

H. R. ____

To provide for a program of research, development, demonstration and commercial application in vehicle technologies at the Department of Energy

Mr. PETERS introduced the following bill; which was referred to the Committee on___

SEC. 1. SHORT TITLE

This Act may be cited as the "Advanced Vehicle Technology Act of 2009"

SEC. 2. FINDINGS.

Congress finds that –

1. According to the U.S. Energy Information Administration the
2. transportation sector accounts for approximately 28 percent of the U.S. primary energy demand and greenhouse gas emissions, and 24 percent of global oil demand;
3. The domestic automotive and commercial vehicle manufacturing sectors have increasingly limited resources for research and development of advanced technologies;
4. Suppliers are playing a more important role in vehicle technology development, and should be better integrated into federal research efforts;
5. Priorities for the Department's vehicle technologies research have shifted drastically in recent years between diesel hybrids, hydrogen fuel cell, and plug-in electric hybrids, with little scant continuity between them;
6. The federal government should balance its role in researching longer-term exploratory concepts and developing nearer term transformational technologies for vehicles;

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SEC. 3. OBJECTIVES.

The objectives of this Act are to develop technologies and practices that –

1. Improve the fuel efficiency and emissions of all vehicles produced in the United States;
2. Reduce transportation sector reliance on petroleum-based fuels;
3. Support domestic manufacturing of advanced vehicles;
4. Move larger volumes of freight and more passengers with less energy and emissions;
5. Allow for greater consumer choice of vehicle technologies and fuels;
6. Shorten technology development and integration cycles in the vehicle industry;
7. Ensure a proper balance and diversity of federal investment in vehicle technologies;

TITLE I – VEHICLE RESEARCH AND DEVELOPMENT

SEC. 101. PROGRAM.

(a) ACTIVITIES - The Secretary shall conduct a program of basic and applied research, development, demonstration and commercial application activities on materials, technologies, and processes with the potential to substantially reduce or eliminate petroleum use and related emissions of the nation's automotive and commercial vehicle sectors, including activities in the areas of –

1. hybridization or full electrification of vehicle systems;
2. batteries and other novel energy storage devices;
3. power electronics;
4. vehicle manufacturing technologies and processes;
5. engine combustion optimization;
6. waste heat recovery;
7. transmission;
8. hydrogen fuel cells and related technologies;
9. aerodynamics, rolling resistance, and accessory power loads of vehicles and associated equipment;
10. vehicle weight and size reduction;
11. friction and wear reduction;
12. engine and component durability;
13. innovative propulsion systems;
14. engine compatibility with alternative fuels;
15. modeling and simulation of vehicle and transportation systems;
16. fueling and charging infrastructure;
17. sensing and communications technologies for vehicle, electrical grid, and infrastructure;
18. reduction of rare earth magnetic materials, precious metals, and other high-cost or rare materials in advanced vehicles; and
19. other research areas as determined by the Secretary.

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(b) TRANSFORMATIONAL TECHNOLOGY R&D –The Secretary shall ensure that the department continues to support activities and maintains competency in mid-to-long-term transformational vehicle technologies with potential to achieve deep reductions in petroleum use and emissions, including activities in the areas of --

1. hydrogen fuel cell, storage, and infrastructure research and development, technology validation, safety codes, and standards;
2. multiple battery chemistries and novel energy storage devices;
3. other innovative technologies research and development

(c) INDUSTRY PARTICIPATION – to the maximum extent practicable activities under this act shall be carried out in partnership with automotive manufacturers, heavy commercial and transit vehicle manufacturers, equipment suppliers, fuel suppliers, electric utilities, universities, and independent research laboratories. In carrying out this act the Secretary shall --

1. determine whether a wide range of domestic manufacturers and suppliers are represented in ongoing public-private partnership activities and, where possible, seek to partner with firms that have not traditionally participated in federally-sponsored research and development activities;
2. leverage the capabilities and resources of, and formalize partnerships with, industry-led stakeholder organizations and trade associations with expertise in the research and development of advanced automotive and commercial vehicle technologies;
3. streamline processes for transferring technologies and research findings to industry.

(d) INTERAGENCY AND INTRAAGENCY COORDINATION - To the maximum extent practicable, the Secretary shall coordinate research, development, demonstration, and commercial application activities between --

(1) relevant programs within the Department including the offices of --

(A) Energy Efficiency and Renewable Energy
(B) Science
(C) Electricity Delivery and Energy Reliability
(D) Fossil Energy
(E) The Advanced Research Projects Agency - Energy
(F) Other offices as determined by the Secretary

[[(2) relevant technology research and development programs within other federal agencies including --

(A) Department of Transportation
(B) Department of Defense
(C) Environmental Protection Agency
(D) Other agencies as determined by the Secretary or an officer of the Executive Office of the President]]

TITLE II - MEDIUM AND HEAVY DUTY COMMERCIAL VEHICLES

SEC. 211. PROGRAM

(a) IN GENERAL - The Secretary, in partnership with [[relevant research offices and programs of the Department of Defense, Department of Transportation, and the Environmental Protection Agency, and]] a diversity of industrial stakeholders, shall carry out a program of cooperative research, development, demonstration and commercial application activities on advanced technologies for medium-to-heavy duty commercial and transit vehicles, including activities in the areas of:

(1)engine and combustion research
(2)waste heat recovery and conversion
(3)improved aerodynamics and tire rolling resistance
(4)energy and space-efficient emissions control systems
(5)heavy hybrid and energy storage technologies
(6)drivetrain optimization
(7)friction and wear reduction
(8)engine idle and parasitic energy loss reduction
(9)electrification of accessory loads
(10)on-board sensing and communications technologies
(11)integration of these and other advanced systems onto a single truck and trailer platform

(b) LEADERSHIP – The Secretary shall appoint a full-time Director to coordinate research, development, demonstration and commercial application activities in medium-to-heavy duty commercial and transit vehicle technologies. Responsibilities of the Director include–

SEC. 212. CLASS 8 TRUCK DEMONSTRATION.

The Secretary shall conduct a competitive grant program to demonstrate the integration of multiple advanced technologies on a single long-haul Class 8 truck and trailer combination platforms, including technologies that provide substantial improvements in engine efficiency, aerodynamics, reduction of combined vehicle and trailer weight, hybridization of powertrain and auxiliary systems, and reduction of parasitic loads. Applicant teams may be comprised of truck and trailer manufacturers, equipment suppliers, fleet customers, university researchers, and other applicants as appropriate for the development and demonstration of an integrated Class 8 truck and trailer platform.

SEC. 214. NON-ROAD APPLICATION PILOT PROGRAM

The Secretary is authorized to undertake a pilot program of research, development, demonstration and commercial applications of fuel and emissions reduction technologies for heavy duty non-road equipment [[such as those used in construction, agriculture, heavy industry, mining, forestry and lawn and turf,]] and shall seek opportunities to transfer relevant research findings and technologies between the non-road and on-highway equipment and vehicle sectors.

SEC. 215. NATIONAL ACADEMIES REPORT.

Not later than 6 months after enactment the Secretary shall enter into an arrangement with the National Academies of Sciences to conduct a detailed study of the potential for fuel economy and emissions improvements for a range of heavy vehicle technologies. Not later than 18 months after enactment the Secretary shall transmit to Congress a report of the study along with a report on the Secretary's response to the findings and recommendations of the study, including how the study was used to inform the process for setting research priorities of the interagency partnership.

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4. MTU Research Results for CPF and DOC Systems – Passive and Active Regeneration

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DPF Modeling and Experimental Data to Support Model Development: Past Research and Future Directions

John H. Johnson
Presidential Professor
Michigan Technological University
April 29, 2009
12th CLEERS Workshop
University of Michigan – Dearborn, MI

http://www.cleers.org/workshops/workshop12/index.php

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I Acknowledge the Support of:
Cummins
GM/DOE
John Deere/DOE
Navistar
Dow Automotive
DDC/DOE
that have supported our (MTU) DPF Research the past 10 years.

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– Observations by JHJ
  - Experimental and modeling results are complimentary
  - Quality experimental data are needed to support modeling development
  - Both modeling and experimental data have inaccuracies
  - Models can calculate quantities that can not be determined experimentally

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MTU Early Work on Passive Regeneration and the Effect of Wall PM Mass on Pressure Drop Including a Cake Filtration Model

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An Advanced 1D 2-Layer Catalyzed Diesel Particulate Filter Model to Simulate: Filtration by the Wall and Particulate Cake, Oxidation in the Wall and Particulate Cake by NO2 and O2, and Regeneration by Heat Addition

Hasan Mohammed – Cummins/Michigan Technological University
Antonio Triana – John Deere/Michigan Technological University
S.L. (Jason) Yang – Michigan Technological University
John H Johnson – Michigan Technological University

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Wall oxidation model

- Modeling accurate PM oxidation in the wall is difficult, because the physical structure is not well defined.
  - Simplifying assumptions have to be made.
  - Should be computationally feasible
  - Numerical solution with small PM mass in wall should not allow numerical errors to propagate.
  - Regeneration framework should be compatible with that of the PM cake layer.

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2006-01-0467

Wall Oxidation Model

- For each axial discretized location, sum all the PM present in each of the 'slabs' of the filter wall and form a 'virtual' wall layer.
- Determine reaction rates in the wall such that if a similar amount of PM were present on the wall under the same conditions, they would both deplete by the same rates.
- Determine the O_2 and NO_2 exiting layer I and entering the filter wall.
- Regeneration equations similar to those in layers I and II, can be applied.

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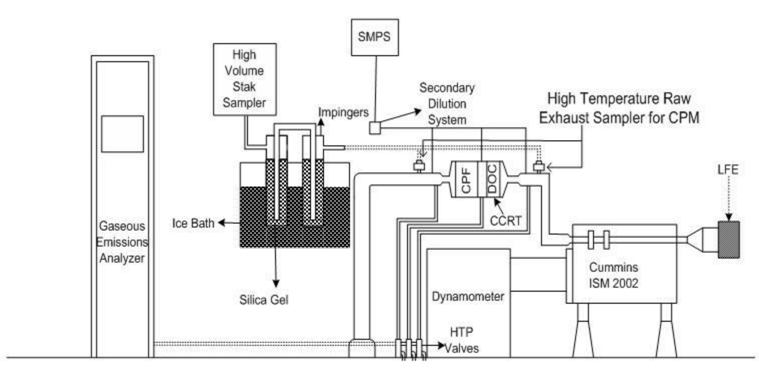
2006-01-0467

Experimental Test Setup



CCRT: Catalyzed Continuously Regenerating Trap
CPF: Catalyzed Particulate Filter
HTP: High Temperature Pneumatic
CPM: Carbonaceous Particulate Matter

LFE: Laminar Flow Element
DOC: Diesel Oxidation Catalyst
SMPS: Scanning Mobility Particle Sizer

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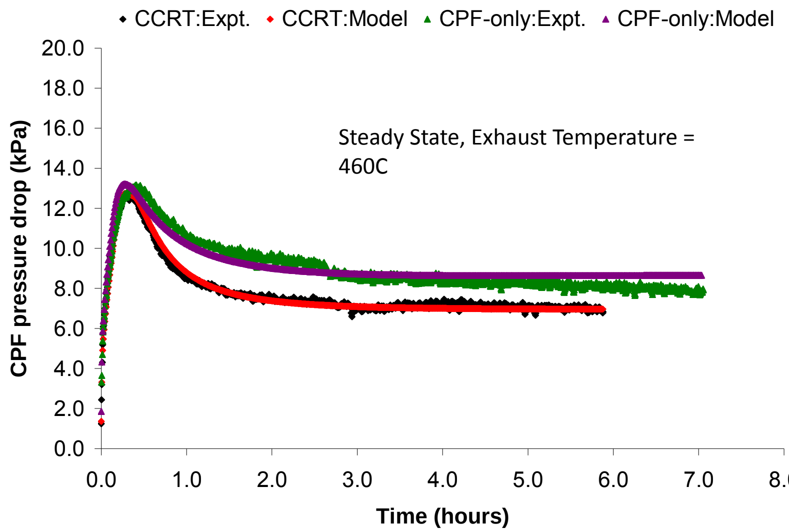
2006-01-0466

75% load: CCRT® and CPF-only



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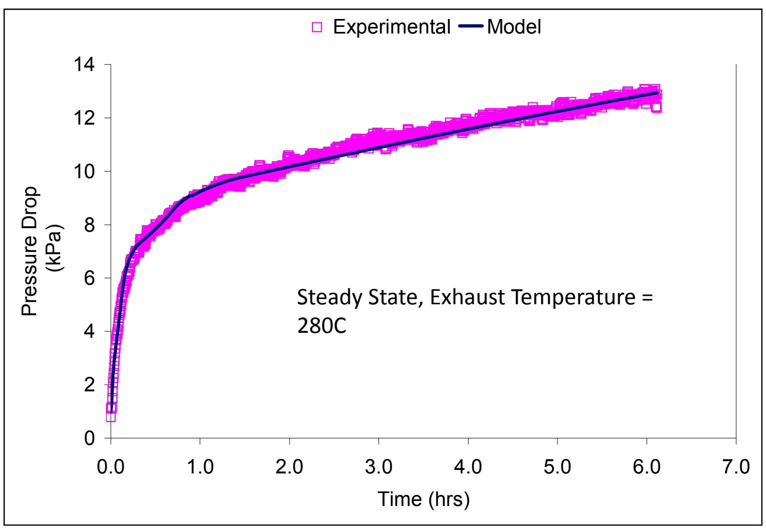
2006-01-0466

20% load: Pressure drop in CCRT® configuration



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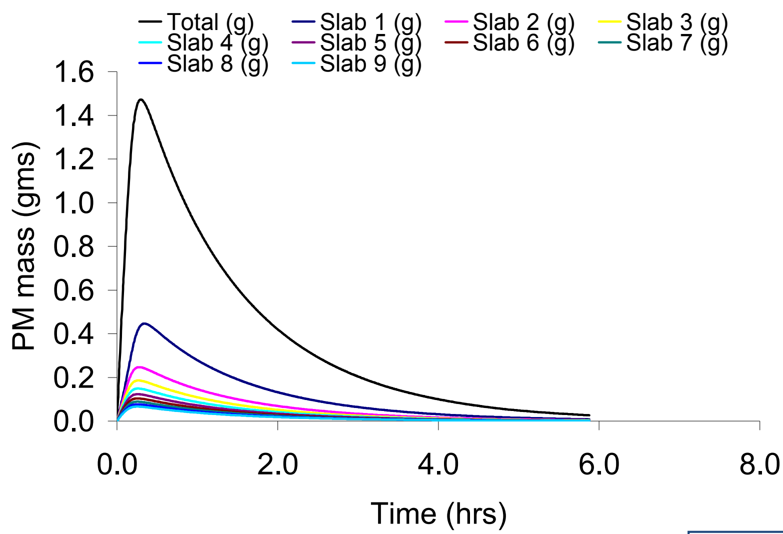
2006-01-0466

Oxidation in the wall at 75% CCRT®



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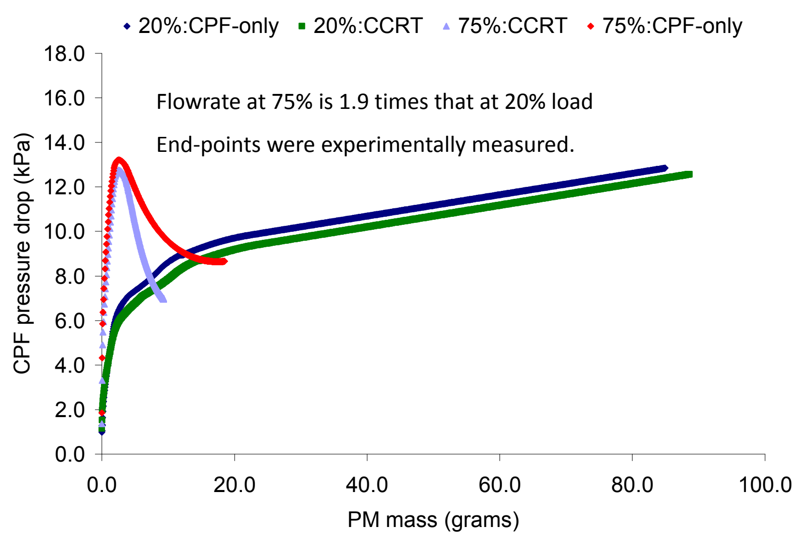
2006-01-0466

CPF Pressure drop with PM Load



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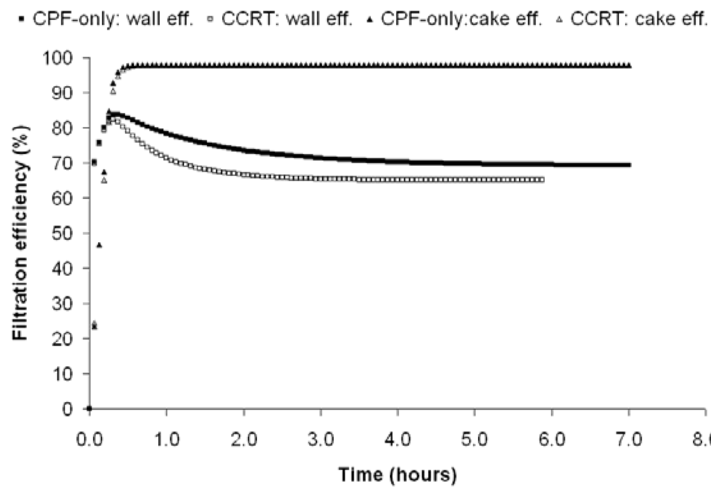
2006-01-0466

75% load CCRT®: Filtration Efficiency



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2006-01-0467

Study of the Filtration and Oxidation Characteristics of a Diesel Oxidation Catalyst and a Catalyzed Particulate Filter

Kiran C Premchand, John H Johnson and Song-Lin Yang

Michigan Technological University

Antonio P Triana and Kirby J Baumgard

John Deere Product Engineering Center

MichiganTech

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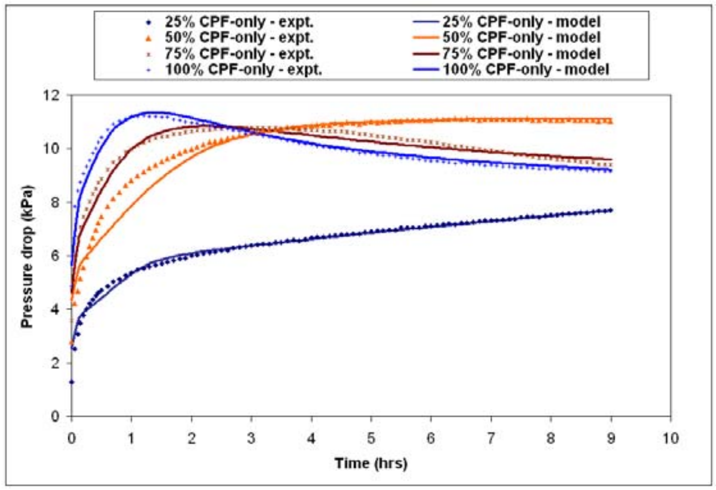
CPF model calibration results – Model vs. Experimental pressure drop profiles in CPF-only configuration



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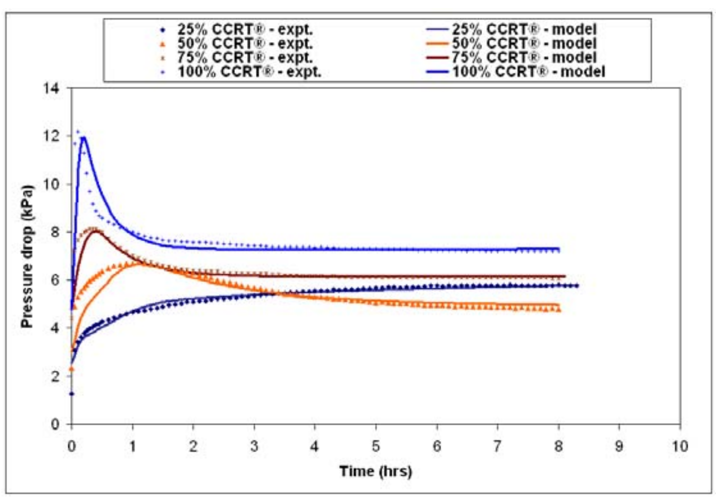
2007-01-1123

CPF model calibration results – Model vs. Experimental pressure drop profiles in CCRT® configuration



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2007-01-1123

Comparison of experimental and model-predicted PM mass deposited and oxidized

			Experimental				Model				
Configuration	Load	CPF Inlet temperature	Total inlet PM	PM deposited	PM oxidized	% PM Oxidized	PM deposited	PM oxidized	% PM Oxidized	% difference (oxidized)	% difference (deposited)
	(%)	(°C)	(g)	(g)	(g)	(%)	(g)	(g)	(%)	(%)	(%)
CPF - Only	25	250	25.3	19	6.1	25.0	19.3	5.6	22.1	1.7	-2.9
	50	343	23.0	16	6.8	30.3	15.8	6.7	29.3	-1.1	-1.0
	75	379	19.7	12	7.5	38.9	12.2	7.2	36.3	1.9	-2.6
	100	405	21.4	5	16.2	76.6	5.4	15.7	73.1	8.0	-3.5
CCRT®	25	267	16.0	12	3.9	25.2	10.3	5.5	34.1	-14.1	8.9
	50	364	14.0	6	7.8	57.1	5.9	8.0	56.9	1.7	-0.2
	75	408	15.4	3	12.2	80.5	3.0	12.1	78.7	1.6	-1.8
	100	428	21.6	2	19.4	90.7	2.2	19.1	88.6	12.0	-2.1

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K.C.Premchand. "An Experimental and Modeling Study of the Filtration and Oxidation Characteristics of a Diesel Oxidation Catalyst and a Catalyzed Particulate Filter". Master's Thesis, Michigan Technological University. 2006.

A Methodology to Estimate the Mass of Particulate Matter Retained in a Catalyzed Particulate Filter as Applied to Active Regeneration and Onboard Diagnostics to Detect Filter Failures

Rayomand H. Dabhoiwala, Dr. John H. Johnson,

Dr. Jeffrey D. Naber and Dr. Susan T. Bagley

Michigan Technological University

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Motivation Behind Development of this Method

- Accurate estimation of the PM mass retained in the CPF is important in order to determine the time to carry out the active regeneration in an operating vehicle or other stationary diesel engine installation.
- But out of the total PM mass in the CPF, 98% of the mass is in the cake and rest 2% in the wall. However the wall contributes more than 50% to the total pressure drop even with 2% of the total PM mass in it (except at low loads).
- Hasan et. al (2006-01-0466) and Kiran et al. (2007-01-1123) have shown that the mass in the wall oxidizes as a function of time, exhaust gas temperature and NO_2 concentration. This results in change in the wall permeability and in turn the wall pressure drop.
- Thus estimation of the mass retained in the CPF based on the calculated cake and wall pressure drop (accounting for the variable wall permeability) and the measured total pressure drop would give accurate results compared to estimations based on the total pressure drop and empirical relations.

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2008-01-0764

Equation Developed to Estimate Cake Mass (4 of 4)

- Simplifying equation (7) we get

$$m_{cake} = [\frac{\Delta P_{total}}{\mu Q} - \frac{C_2}{k_t} - C_3] * \frac{k_p}{C_1} \quad \text{... (8)}$$

where

$$C_1 = \frac{1}{\rho_p} \frac{1}{16 n^2 a^2 L^2} \quad \text{... (8a)}$$

$$C_2 = \frac{w_s}{4naL} \quad \text{... (8b)}$$

$$C_3 = \frac{2}{3} \frac{LF}{na^4} \quad \text{... (8c)}$$

K_t = Permeability of wall

K_p = Permeability of cake

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2008-01-0764

MTU Present Work on Active Regeneration

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An Experimental Study of Particulate Thermal Oxidation in a Catalyzed Filter during Active Regeneration

Krishna Pradeep Chilumukuru

Dr. John H. Johnson

Dr. Jeffrey D. Naber

Michigan Technological University

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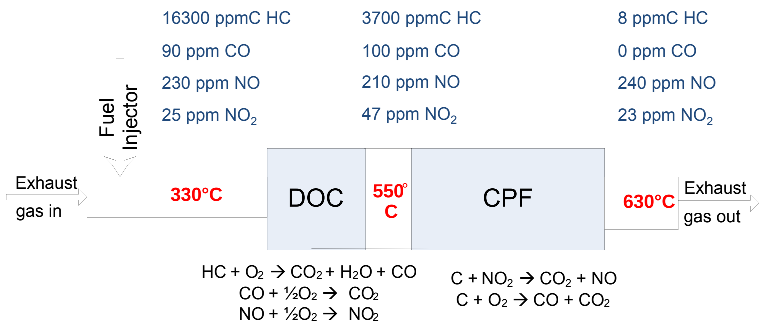
Michigan Tech Create the Future

Aftertreatment Setup

Cummins 2007 RPF system



RPF: Regenerative Particulate Filter

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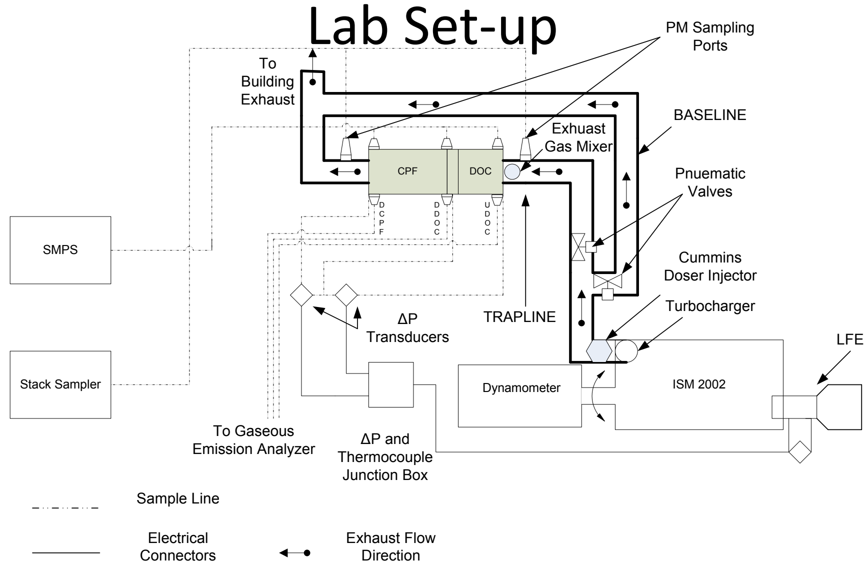
2009-01-1474

Lab Set-up



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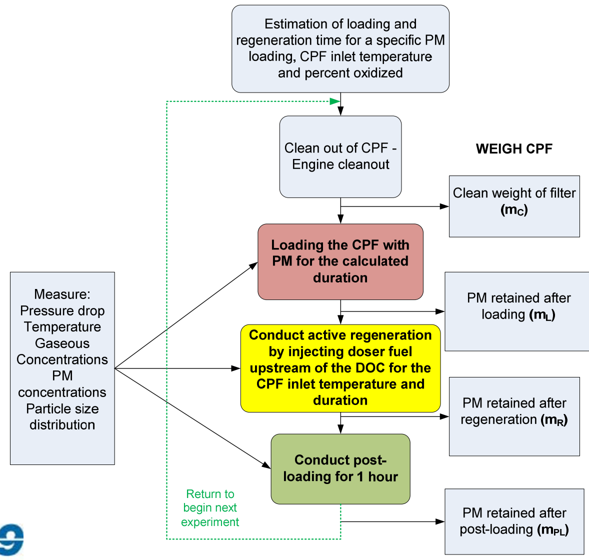
2009-01-1474

Test Procedure



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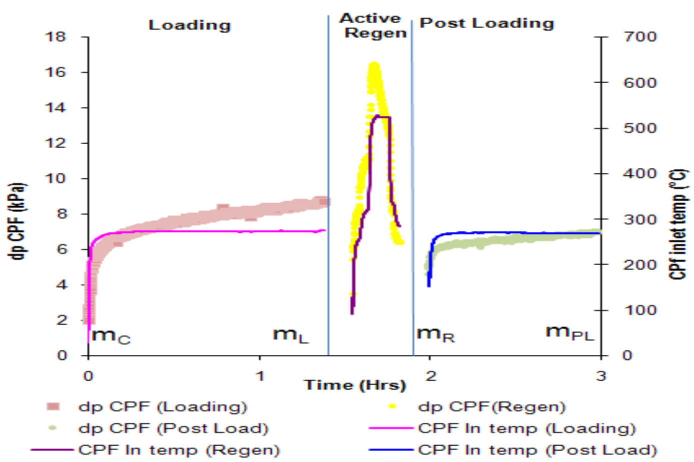
2009-01-1474

Test Procedure - Schematic



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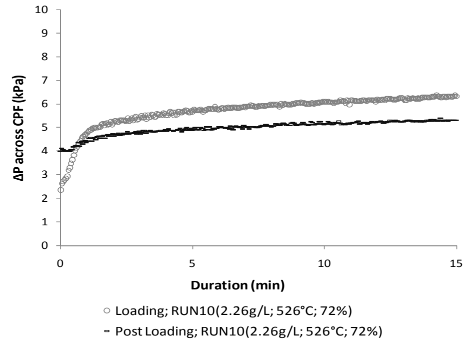
2009-01-1474

Experimental Results (Contd.)

- Post-Loadin



- It was observed that during post-loading the ΔP across the CPF was consistently lower as compared to loading from a clean filter
- Deep bed filtration regime is not present resulting in a lower overall ΔP since wall of the CPF is nearly clean and the cake layer is intact after partial-regeneration, thus no PM mass enters the wall [3].

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2009-01-1474

Modeling the Filtration, Oxidation and Pressure Drop Characteristics of a Catalyzed Particulate Filter during Active Regeneration

Rohith Arasappa, Kiran Premchand, Krishna Chilumukuru, Dr. John H. Johnson, Dr. Jeffrey D. Naber, Dr. Song-Lin Yang

Michigan Technological University

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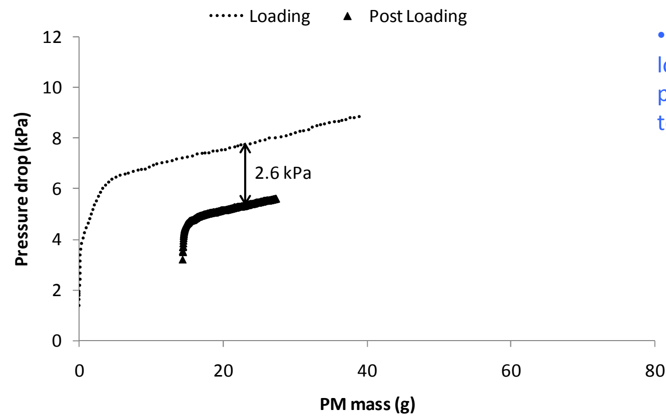
Michigan Tech
Michigan Technological University

Comparison between Loading and Post Loading Pressure Drop



- Total pressure drop for loading and post loading plotted as a function of total PM mass in the filter

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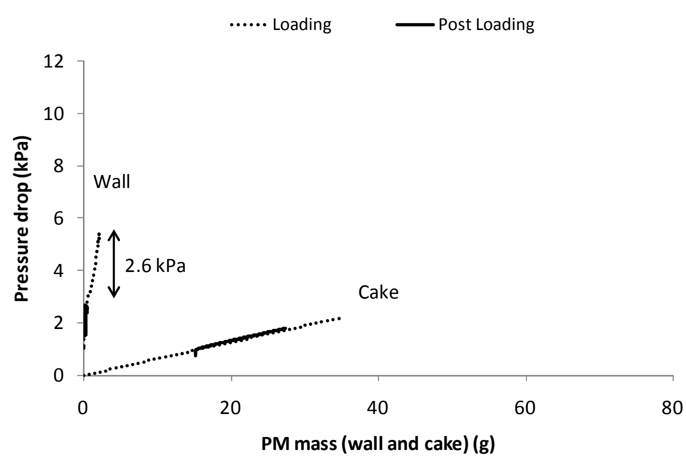
2009-01-1274

Run 10 (525 C, 2.2 g/L, 60%)



- Wall pressure drop as a function of wall mass and cake pressure drop as a function of cake mass
- Cake pressure drop is comparable
- Wall pressure drop has a 2.6 kPa difference

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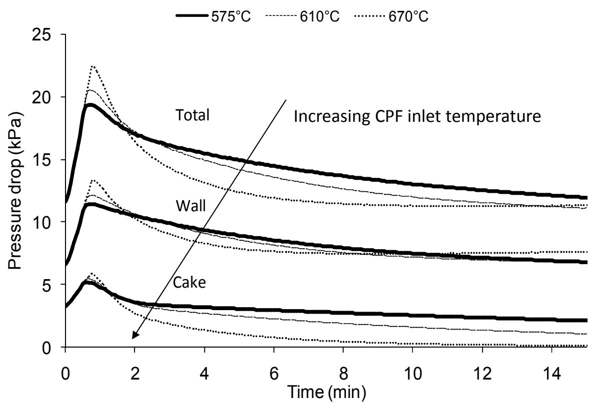
2009-01-1274

Ramp-Up at 8°C/sec – Pressure Drop Results



- 575, 610 and 670°C represent the temperature inside the filter for 2.2 g/l PM loading and CPF inlet temperature of 525, 550 and 600°C
- Higher peak pressure drop for higher CPF inlet temperature at constant ramp-up to target temperature

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2009-01-1274

NGK Membrane Filter Data

Yasuyuki Furuta,
Takashi Mizutani,
Yukio Miyairi,
Kazuya Yuki
and Hiroshi Kurachi
NGK Insulators, Ltd.

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Illustrated PM Loading Observations.

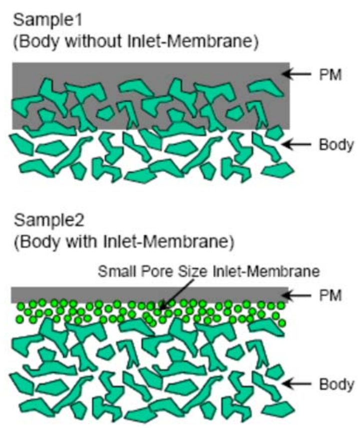

Fig. 6: Illustrated PM Loading Observations.

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2009-01-0292

PM Amount vs. Pressure Drop (Honeycomb Structure).

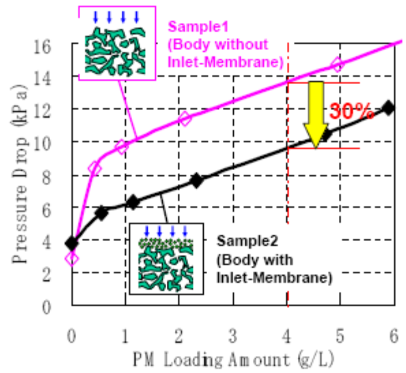

Fig. 9: PM Amount vs. Pressure Drop (Honeycomb Structure).

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2009-01-0292

PM Amount vs. Filtration Efficiency (Honeycomb Structure).

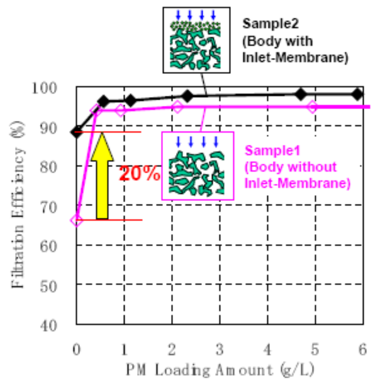

Fig. 10: PM Amount vs. Filtration Efficiency (Honeycomb Structure).

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2009-01-0292

5. Future Light-Duty Emission Control Systems

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BMW Group
Wolfgang Stütz
NRC Sept 2007
Page 1

BMW Diesel.

National Research Council
Committee on Fuel Economy of Light-Duty Vehicles

Fuel Economy of BMW Diesel Vehicles

September 10th 2007, Washington DC

Wolfgang Stütz
BMW Group

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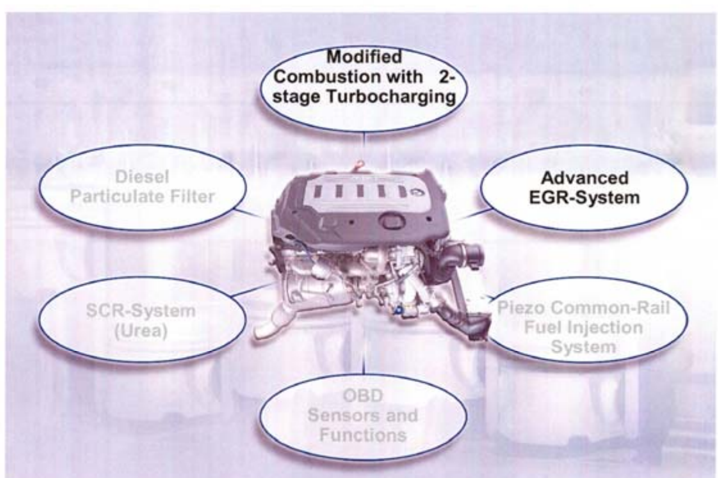
BMW Group
Wolfgang Stütz
NRC Sept 2007
Page 17

BMW Diesel.

TIER2 BIN5 Concept.



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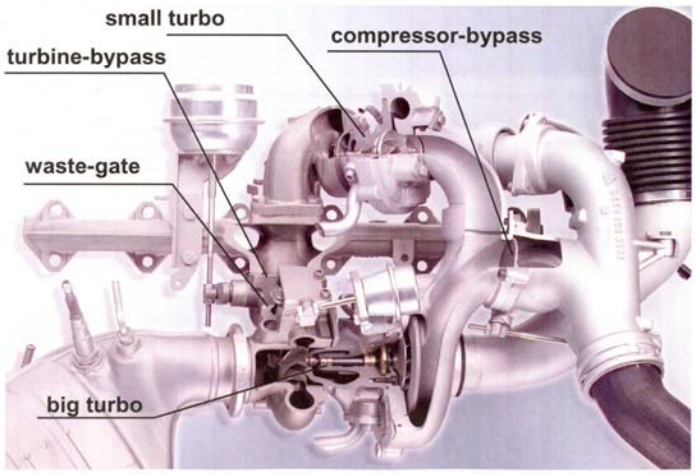
BMW Group
Wolfgang Stütz
NRC Sept 2007
Page 18

BMW Diesel.

Variable Twin Turbo – compact design.

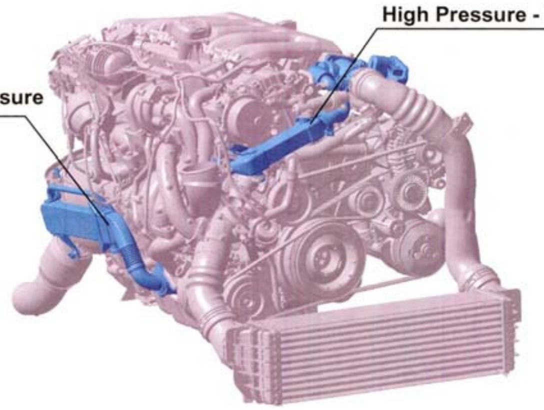


69

BMW Group
Wolfgang Stütz
NRC Sept 2007
Page 19

BMW Diesel.

EGR-System.



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VOLKSWAGEN

AKTIENGESELLSCHAFT

Volkswagen of America, Inc.

Presentation to NAS Vehicle Fuel Economy Committee

November 27, 2007

David Geanacopoulos

Director of Industry-Government Relations

EPA Meeting

Volkswagen Group Powertrain, November 16, 2007

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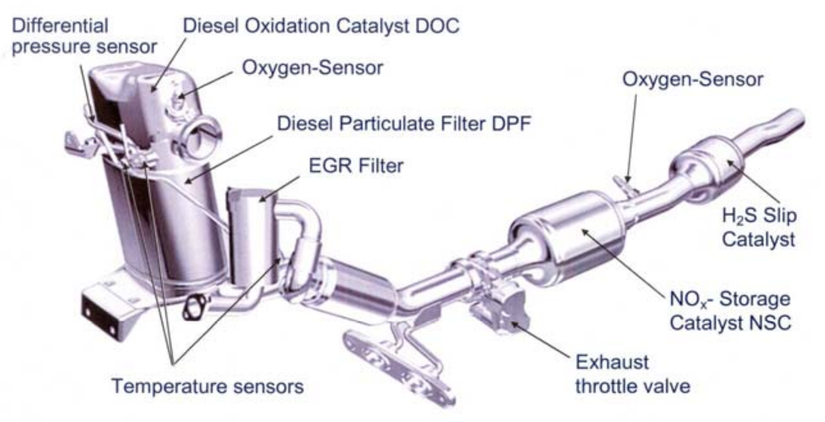
After-Treatment Components



EPA Meeting

Volkswagen Group Powertrain, November 16, 2007 17

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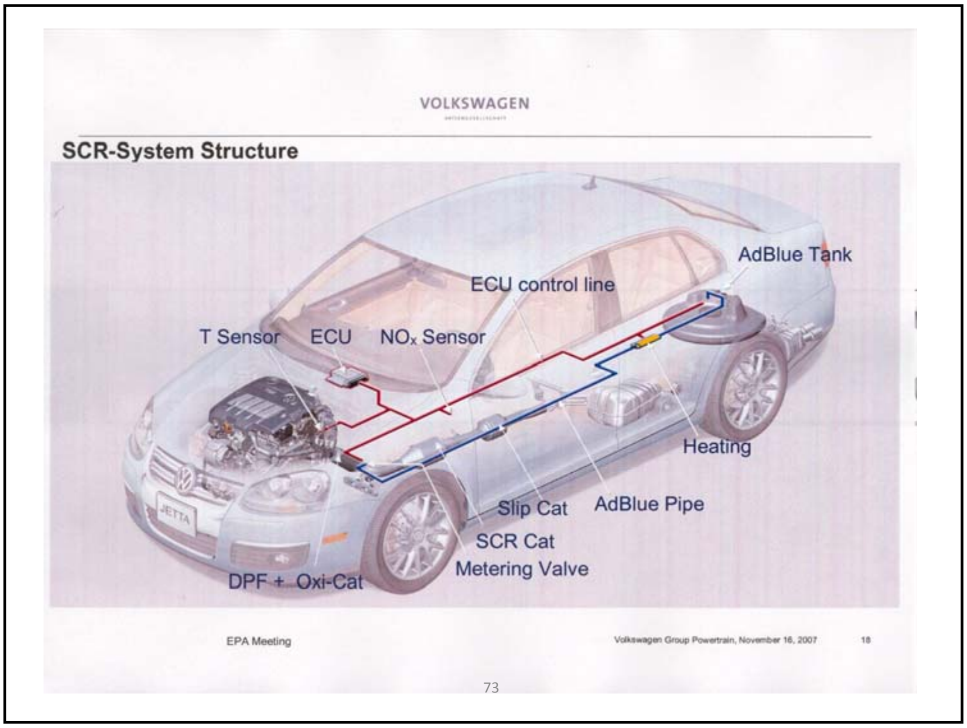
VOLKSWAGEN
SCR-System Structure
AdBlue Tank
ECU control line
T Sensor
ECU
NOx Sensor
Heating
Slip Cat
AdBlue Pipe
SCR Cat
Metering Valve
DPF + Oxi-Cat
EPA Meeting
Volkswagen Group Powertrain, November 16, 2007
18
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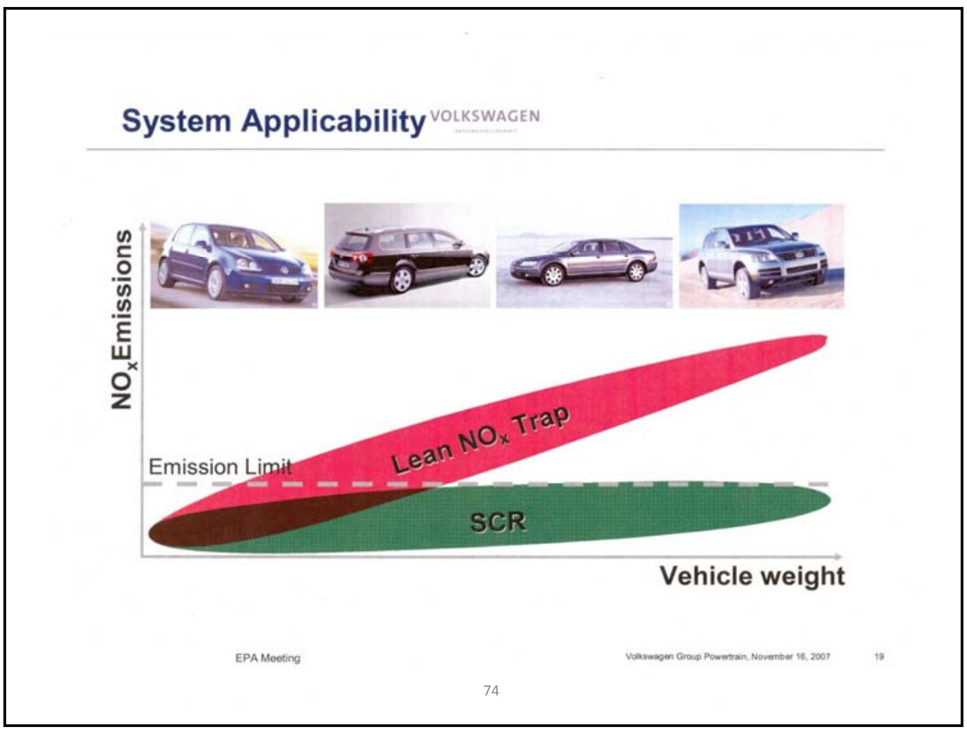
System Applicability
VOLKSWAGEN
NOx Emissions
Lean NOx Trap
Emission Limit
SCR
Vehicle weight
EPA Meeting
Volkswagen Group Powertrain, November 16, 2007
19
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6. Future Heavy-Duty On-Highway and Off-Highway Emission Control Systems

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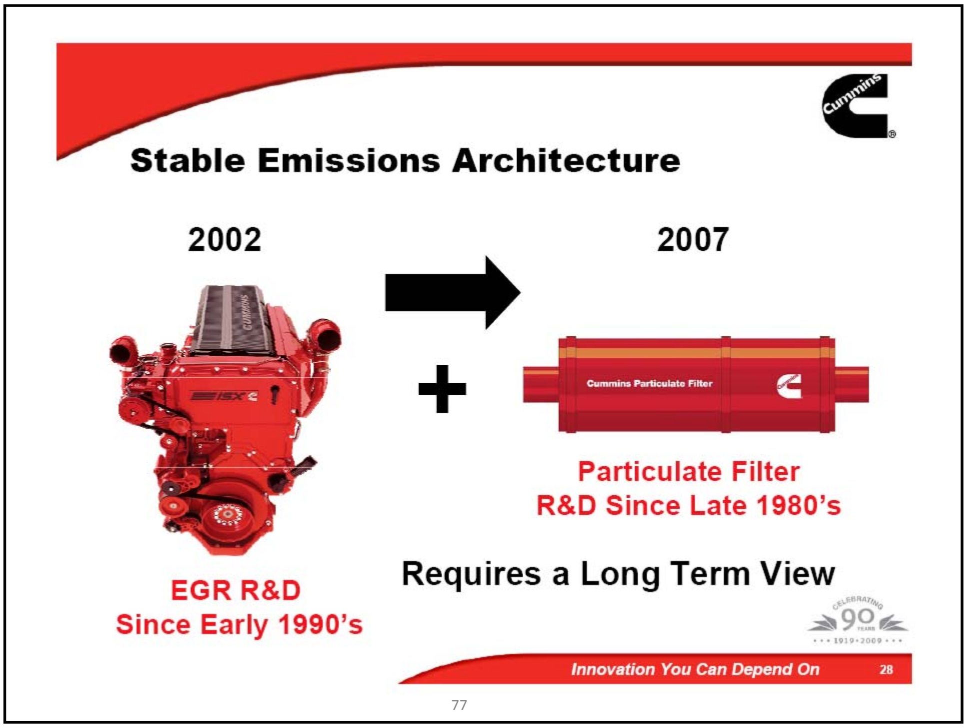
Stable Emissions Architecture
2002
2007
Cummins Particulate Filter
Particulate Filter
R&D Since Late 1980's
EGR R&D
Since Early 1990's
Requires a Long Term View
CELEBRATING 90 YEARS
1919-2009
Innovation You Can Depend On
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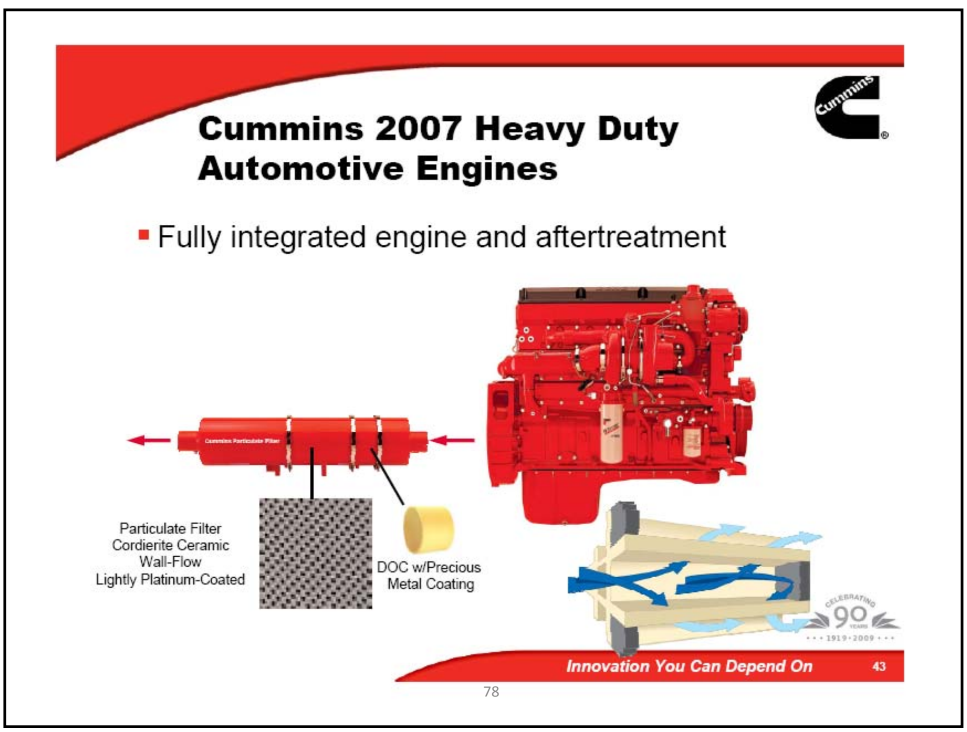
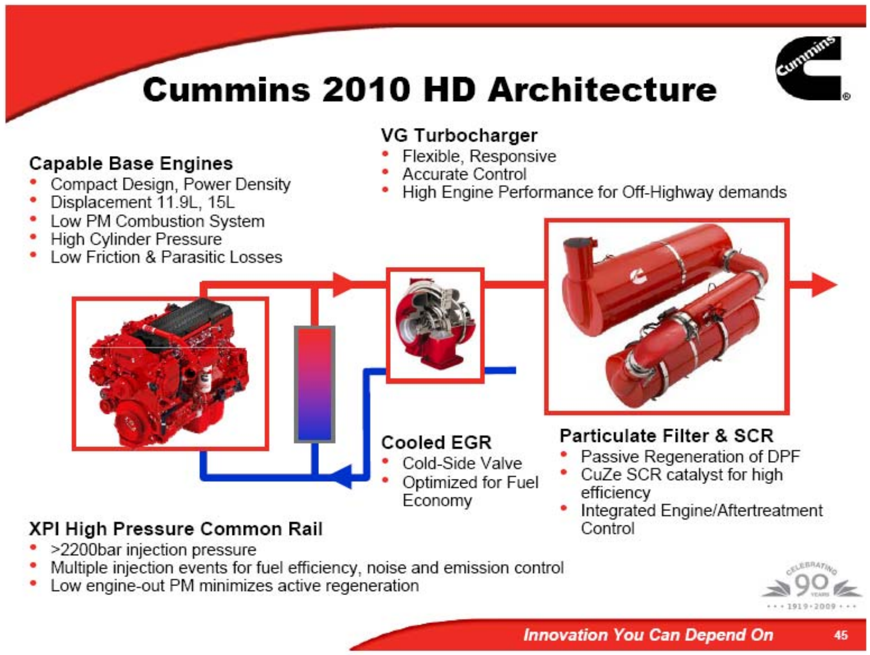

Cummins 2007 Heavy Duty
Automotive Engines
Fully integrated engine and aftertreatment
Particulate Filter
Cordierite Ceramic
Wall-Flow
Lightly Platinum-Coated
DOC w/Precious
Metal Coating
CELEBRATING 90 YEARS
1919-2009
Innovation You Can Depend On
43
78


Cummins 2010 HD Architecture
VG Turbocharger
Flexible, Responsive
Accurate Control
High Engine Performance for Off-Highway demands
Capable Base Engines
Compact Design, Power Density
Displacement 11.9L, 15L
Low PM Combustion System
High Cylinder Pressure
Low Friction & Parasitic Losses
Cooled EGR
Cold-Side Valve
Optimized for Fuel Economy
Particulate Filter & SCR
Passive Regeneration of DPF
CuZe SCR catalyst for high efficiency
Integrated Engine/Aftertreatment Control
XPI High Pressure Common Rail
>2200bar injection pressure
Multiple injection events for fuel efficiency, noise and emission control
Low engine-out PM minimizes active regeneration
Innovation You Can Depend On
45

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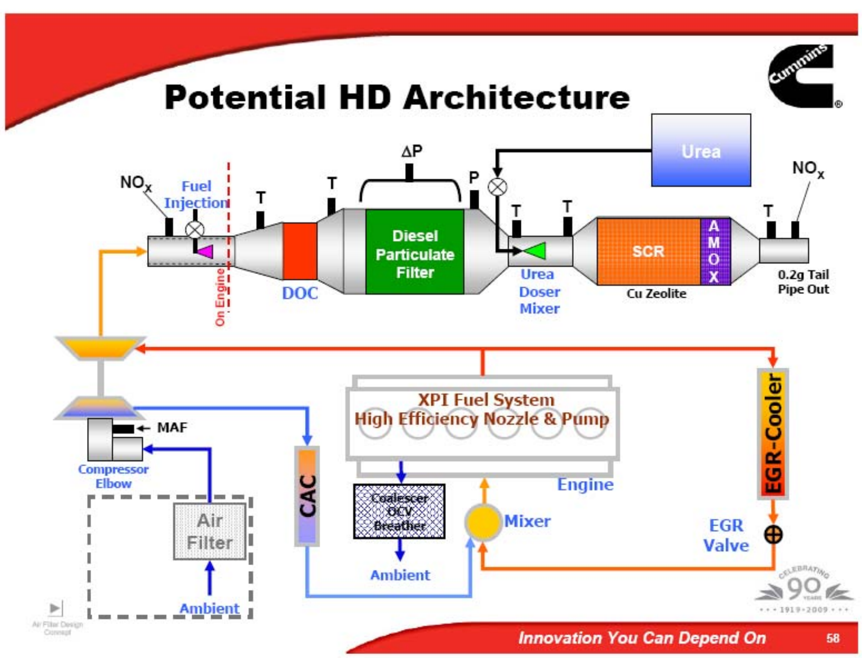
Potential HD Architecture
Urea
ΔP
NOx
Fuel Injection
T
P
On Engine
DOC
Diesel Particulate Filter
Urea Doser Mixer
SCR
AMOX
Cu Zeolite
0.2g Tail Pipe Out
MAF
Compressor Elbow
Air Filter
Ambient
CAC
XPI Fuel System
High Efficiency Nozzle & Pump
Engine
Coalescer OCV Breather
Mixer
EGR-Cooler
EGR Valve
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Model Based Control of SCR Dosing and OBD Strategies with Feedback from NH3 Sensors

Andrew Herman, Ming-Cheng Wu, David Cabush and Mark Shost
Delphi Powertrain Systems

SAE 2009 World Congress

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2009-01-0911

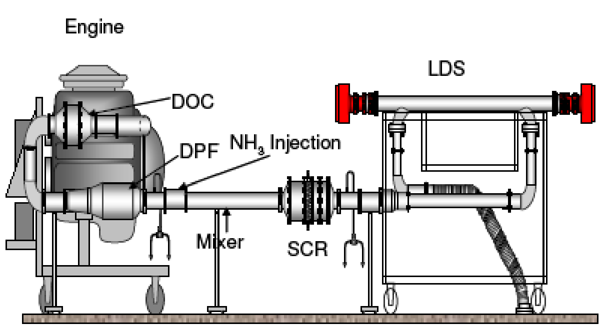

Figure 2. Exhaust system configuration consisting of DOC, DPF and SCR catalysts.

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2009-01-0911

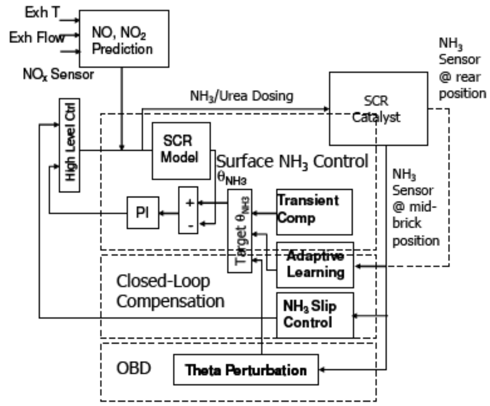

Figure 4. SCR control scheme schematic

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2009-01-0911

Experimental Studies
for DPF and SCR Model, Control System, and OBD Development
for Engines Using Diesel and Biodiesel Fuels.

Technical Proposal Project Narrative

In response to
U.S. Department of Energy
National Energy Technology Laboratory
University Research in Advanced Combustion and Emissions Control
DE-PS26-09NT0001227

Submitted to
U.S. Department of Energy
Golden Field Office
1617 Cole Blvd.
Golden, CO 80401-3393

Submitted by
Dr. John H. Johnson
Michigan Technological University
Dept of Mechanical Engineering
1400 Townsend Drive
Houghton, MI 49931

Dr Gordon Parker
Dr Jeff Naber
Dr S.L.Yang
Dr Jason Keith

January 16, 2009

Michigan Tech
Michigan Technological University

JOHN DEERE

NAVISTAR
POWERING INGENUITY

WATLOW

Cummins

JM
Johnson Matthey

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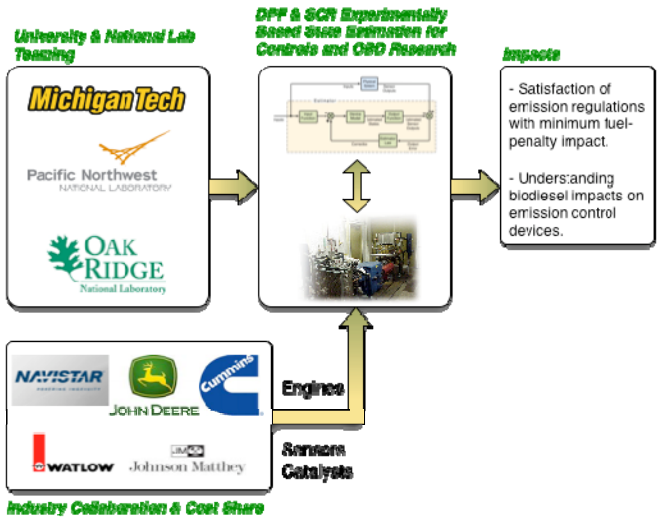

Figure 1. Project participants, collaboration flow, and expected results. Merit Review Criterion Discussion

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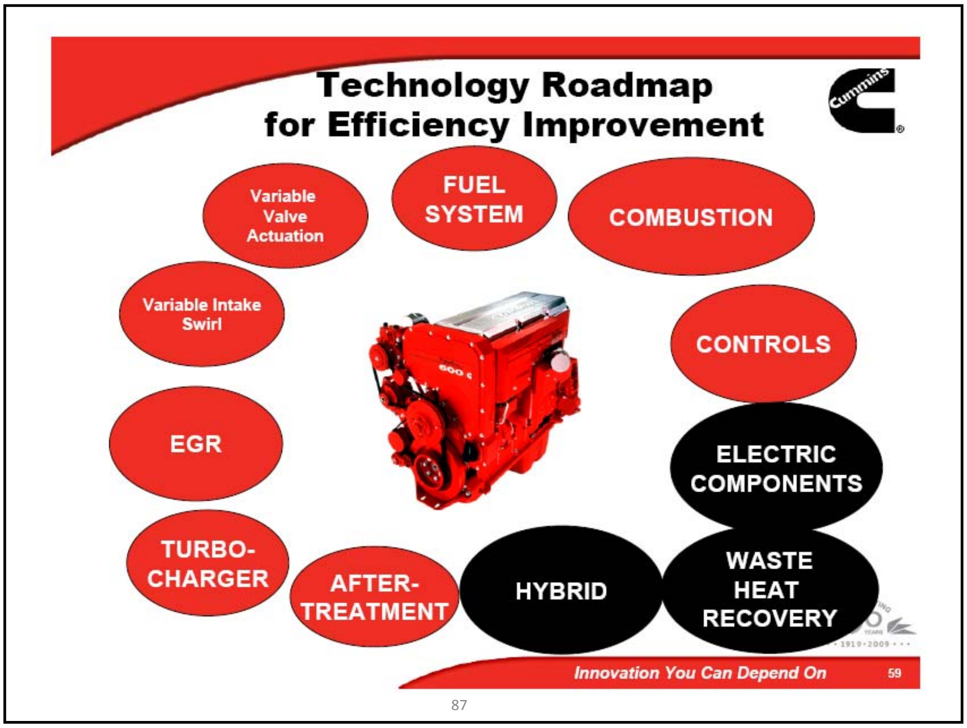
7. Advanced Diesels – How to Reduce Fuel Consumption

86


Technology Roadmap
for Efficiency Improvement
Cummins
Variable Valve Actuation
FUEL SYSTEM
COMBUSTION
Variable Intake Swirl
CONTROLS
EGR
ELECTRIC COMPONENTS
TURBO-CHARGER
AFTER-TREATMENT
HYBRID
WASTE HEAT RECOVERY
Innovation You Can Depend On
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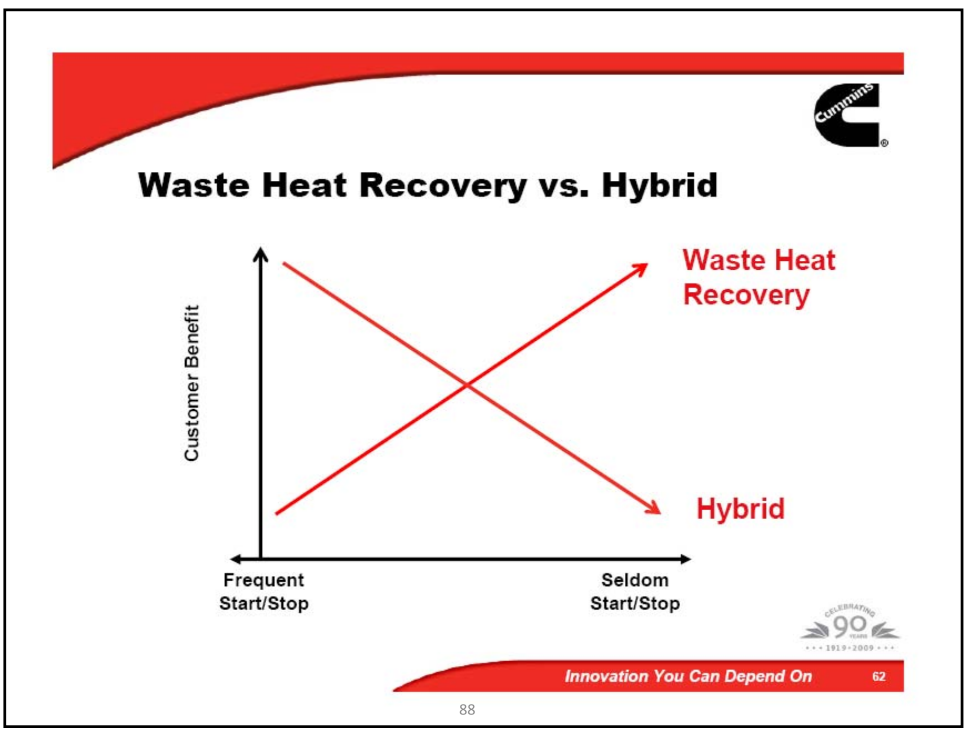
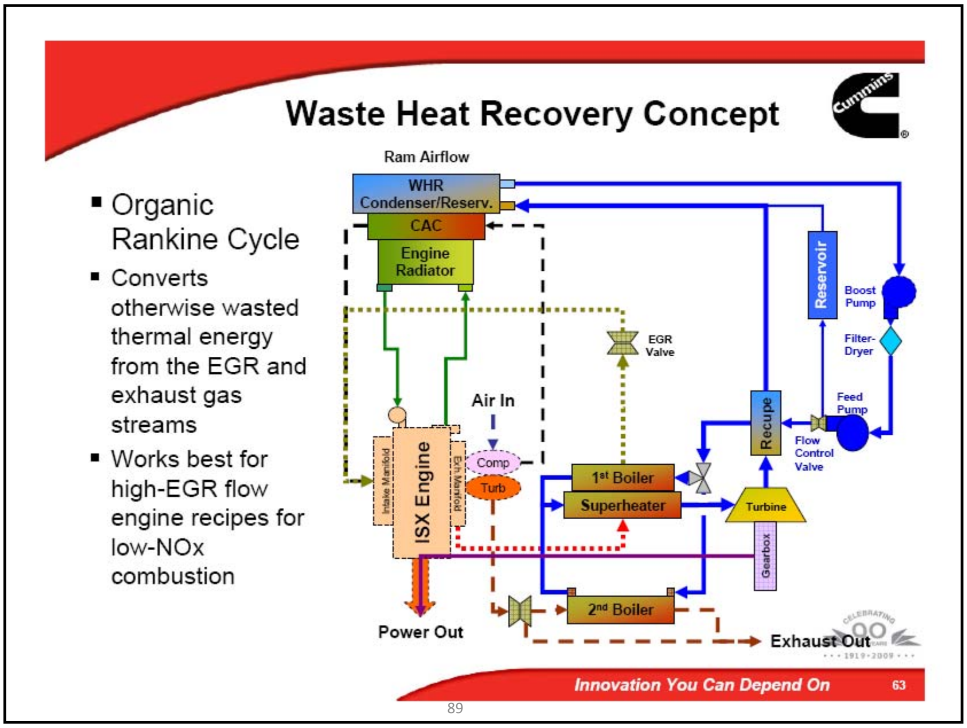
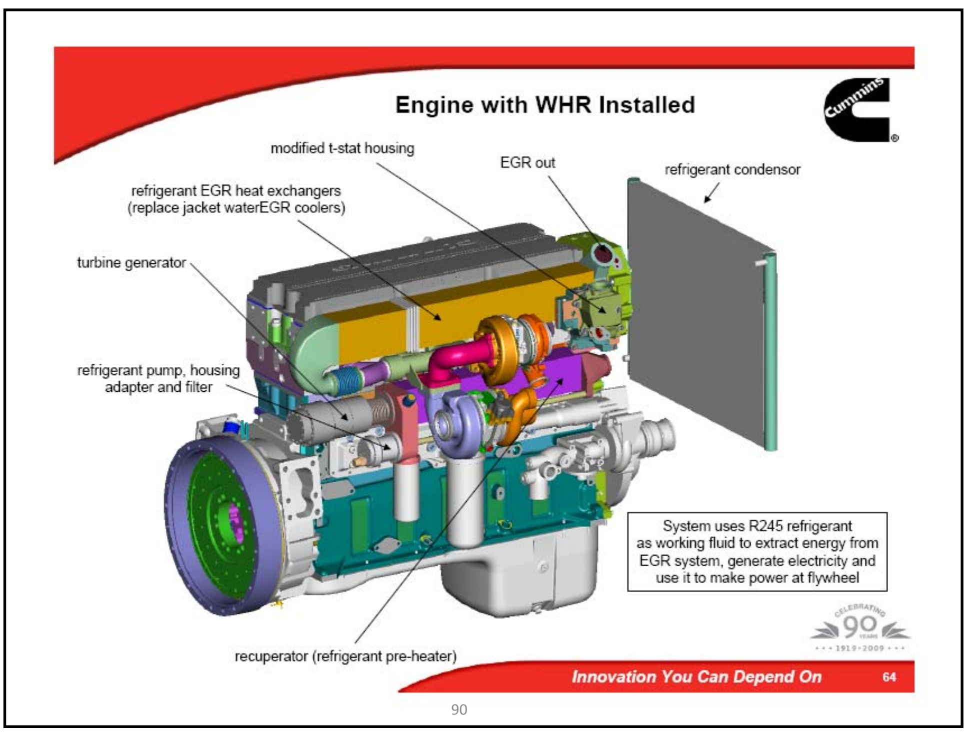
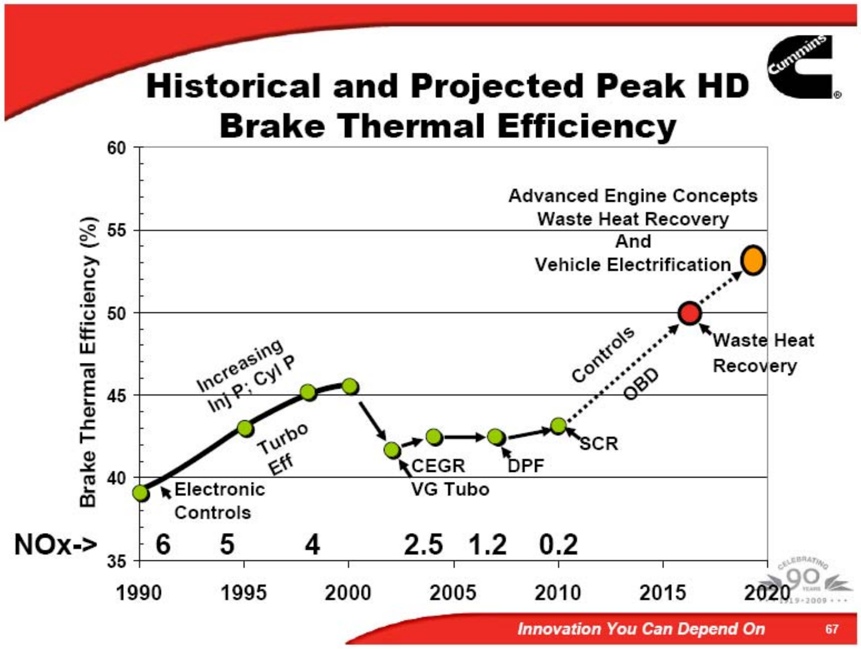

Cummins
Waste Heat Recovery vs. Hybrid
Customer Benefit
Waste Heat Recovery
Hybrid
Frequent Start/Stop
Seldom Start/Stop
CELEBRATING 90 YEARS
1919 • 2009
Innovation You Can Depend On
62

88


Waste Heat Recovery Concept
Cummins
▪ Organic Rankine Cycle
▪ Converts otherwise wasted thermal energy from the EGR and exhaust gas streams
▪ Works best for high-EGR flow engine recipes for low-NOx combustion
Ram Airflow
WHR Condenser/Reserv.
CAC
Engine Radiator
Reservoir
Boost Pump
Filter-Dryer
EGR Valve
Air In
Feed Pump
Recupe
Flow Control Valve
Intake Manifold
ISX Engine
Exh Manifold
Comp
Turb
1st Boiler
Superheater
Turbine
Gearbox
2nd Boiler
Power Out
Exhaust Out
CELEBRATING 90 YEARS 1919-2009
Innovation You Can Depend On
63
89


Engine with WHR Installed
Cummins
modified t-stat housing
EGR out
refrigerant condensor
refrigerant EGR heat exchangers (replace jacket waterEGR coolers)
turbine generator
refrigerant pump, housing adapter and filter
System uses R245 refrigerant as working fluid to extract energy from EGR system, generate electricity and use it to make power at flywheel
recuperator (refrigerant pre-heater)
CELEBRATING 90 YEARS 1919-2009
Innovation You Can Depend On
64
90



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8. Questions and Comments?

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