

# THE DAAAC PROTOCOL FOR ACCELERATED AGING OF DIESEL AFTERTREATMENT SYSTEMS

Diesel Aftertreatment Accelerated Aging Cycles  
(DAAAC)



# Presentation Outline

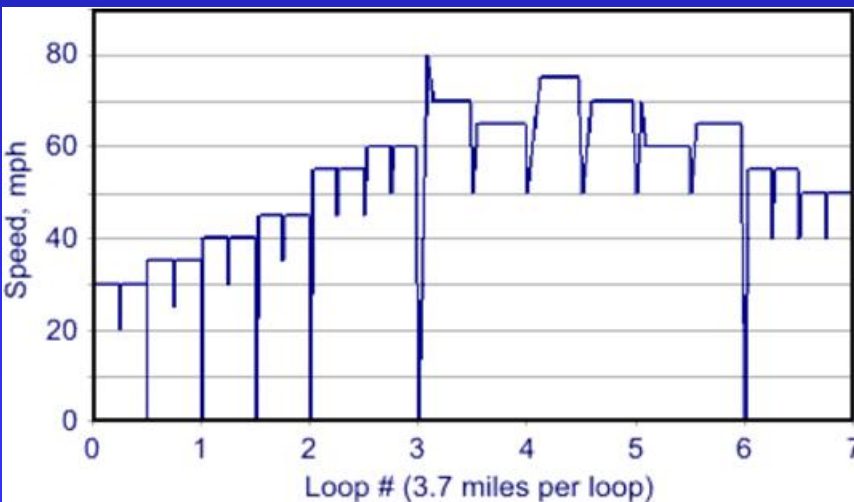
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- Background
- DAAAC-HD Challenges
- DAAAC-HD Objectives
- Approach
- Test Plan
- DAAAC Consortium
- Future Plan

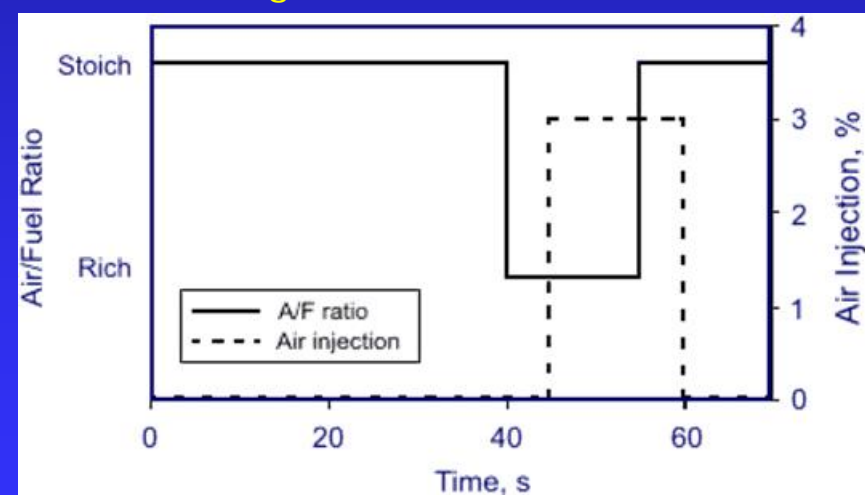


# Background - Deterioration Factor (DF) Determination

- US Light-Duty Vehicle Regulated Useful Life (RUL) = 192,000 to 240,000 km (120,000 to 150,000 miles)
- EPA "Final Rulemaking for Emissions Durability Test Procedures", December 29, 2005
  - EPA Standard Road Cycle (SRC) = 1943 Hours (75% of 192,000km (90,000 miles))
  - EPA Standard Bench Cycle (SBC) = 100-300 Hours (Application Dependent)
- SBC cannot be used for diesel-engine applications – the genesis of DAAAC



Standard Road Cycle (SRC)



Standard Bench Cycle



# Background - Deterioration Factor (DF) Determination

- On-Road Heavy-Duty Engine RUL = 696,000 km (435,000 miles)
  - 35 - 50% of RUL Based on Actual In-Use Operation (Including Transient Operation) >4,250 Hours
  - No Accepted Accelerated Bench Aging Cycles
- DAAAC-HD Consortium Created to Develop Aging Cycles for Heavy-Duty Diesel Emission Systems



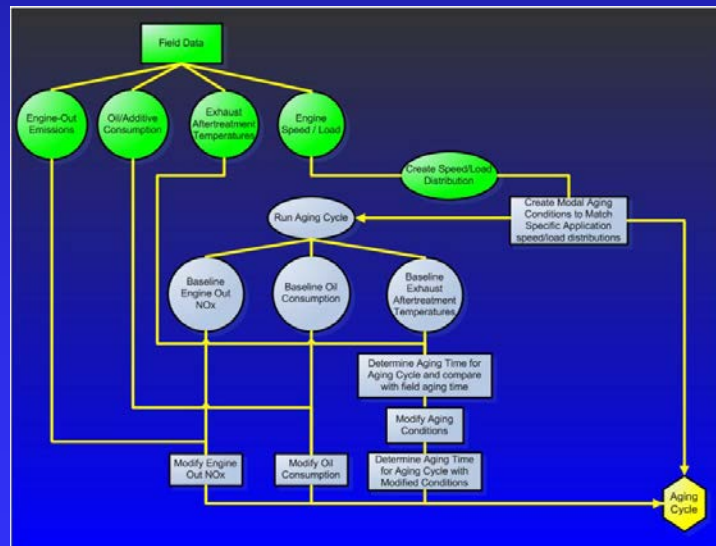
# DAAAC-HD Challenges

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- Wide Range of Emissions Standards and Durability Requirements
- Wider Range of Equipment Options/Choices for Diesel Over Gasoline
- Gasoline Aftertreatment Systems }
  - Three-Way Catalyst (TWC) & HC Absorber } one aging cycle (SBC)
  - Oxygen Sensor – HEGO/UEGO }
- Diesel Aftertreatment Systems }
  - Diesel Oxidation Catalyst (DOC) }
  - Diesel Particulate Filter (DPF) }
  - In-Cylinder Post Injection or “7<sup>th</sup>” Injector } one aging cycle NOT likely
  - Selective Catalytic Reduction (SCR) }
  - DEF Injection System / NO<sub>x</sub> Sensor(s) }
  - All “Other” Emission Related Systems }
  - Variable Geometry Turbocharger }
  - EGR System (Valve, Cooler, Etc.) }
  - Aftercooler, Injectors }
- Challenge – How to Develop ‘Generic’ Accelerated Aging Procedure

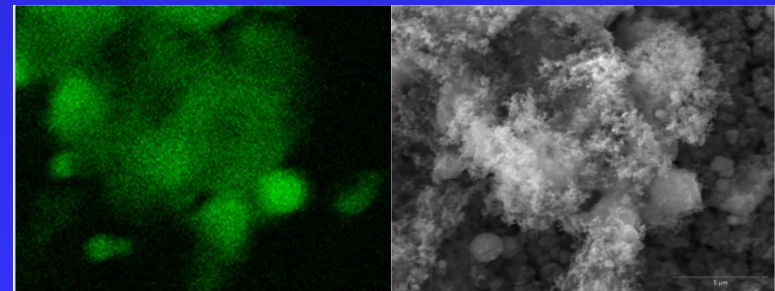
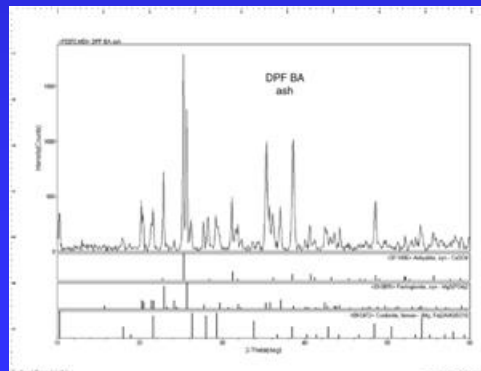
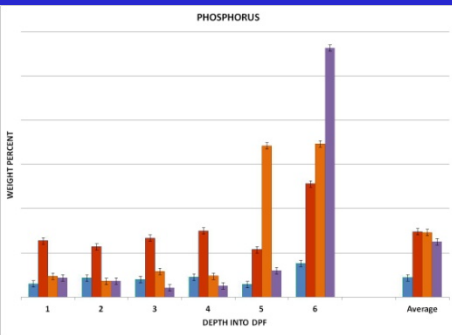
# DAAAC-HD Objective

- Develop an Accelerated Aging *Protocol* for Diesel Aftertreatment Systems
    - *The purpose of the DAAAC Protocol is to result in catalytic system deterioration similar to that observed in field-aged units*
- by
- *Using scientifically supported procedures, based on extensive physical and chemical analyses of field-aged system components*



# DAAAC-HD Approach (1)

- Employ Sound Algorithms With Prior History
  - Arrhenius equation for aging time and temperature correlation
    - example: EPA LD Vehicle SRC-SBC algorithm – EPA FRM 12/29/2005
- Employ Sound Physical Analyses for Correlation
  - Surface Area - BET
  - Deposit Elemental Analysis – PIXE
  - Crystalline Compounds Identification – (XRD)
  - Optical Microscopy – (OM)
  - Scanning Electron Microscopy (SEM)



# DAAAC-HD Approach (2)

- Thermal Component
- The Arrhenius equation relates the rate of a reaction to temperature

$$k = Ae^{-\frac{E_a}{RT}}$$

$k$  Rate constant

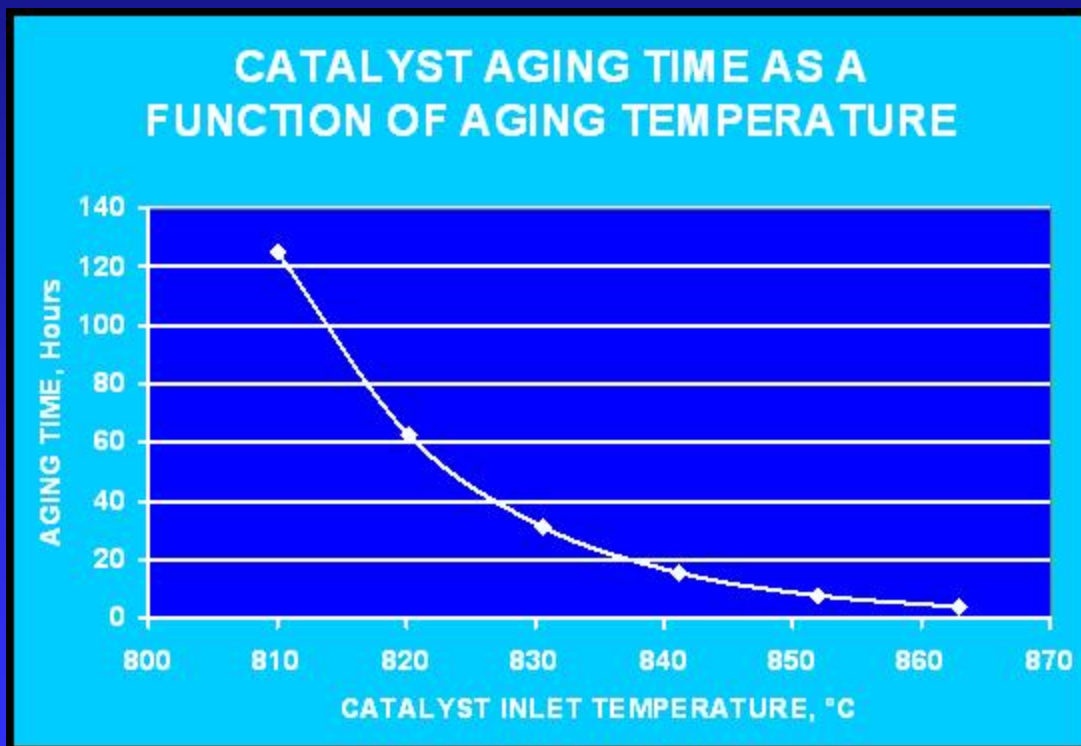
$A$  frequency factor or pre-exponential factor

$e$  Mathematical quantity, e

$E_a$  activation energy

$R$  gas constant

$T$  temperature (Kelvin)



$E_a = 96.5$  kJ/mol for CO oxidation on Pt 111 face (gasoline)





# Ed from DAAAC Data

- Early DAAAC Work Assumed  $E_d$  for SCR as 150 kJ/mol
- Later Work used 98 kJ/mol, Based on SwRI IR&D
- Data From City Bus Aging and Testing Determined  $E_d$  for City Bus V-SCR Catalyst

$E_d$  for City Bus V-SCR Formulation  
=  $113 \pm 5.6$  kJ/mol

| Inputs     | $\eta_{ref}$ | 100 %                            |       |              |            |          |          |  |  |
|------------|--------------|----------------------------------|-------|--------------|------------|----------|----------|--|--|
|            | $E_a$        | 150 kJ/mol                       |       |              |            |          |          |  |  |
|            | A            |                                  |       |              |            |          |          |  |  |
|            | R            | 0.008314 kJ·mol <sup>-1</sup> ·K | 250°C |              |            |          |          |  |  |
|            |              |                                  |       |              | ANR = 1.00 |          |          |  |  |
|            | Temp.        | Temp.                            | Time  | $\eta_{NOx}$ | k          | ln(k)    | 1/T      |  |  |
|            | °C           | K                                | hrs   |              |            |          |          |  |  |
| Field Aged | 335          | 608.15                           | 322   | 28.8         | 0.002211   | -6.11423 | 0.001644 |  |  |
| Bench A    | 325          | 598.15                           | 532   | 32           | 0.001278   | -6.66231 | 0.001672 |  |  |
| Bench B    | 318          | 591.15                           | 674   | 27.3         | 0.001079   | -6.83206 | 0.001692 |  |  |
| Bench C    | 356          | 629.15                           | 188   | 20.9         | 0.004207   | -5.4709  | 0.001589 |  |  |
| slope      | -13755       |                                  |       |              |            |          |          |  |  |
| $E_a$      | 114.3591     |                                  |       |              |            |          |          |  |  |
| Oven aging |              |                                  |       |              |            |          |          |  |  |
| Temp., °C  | 356          |                                  |       |              |            |          |          |  |  |
| Time, hr   |              | 188                              |       |              |            |          |          |  |  |

### Arrhenius correlation

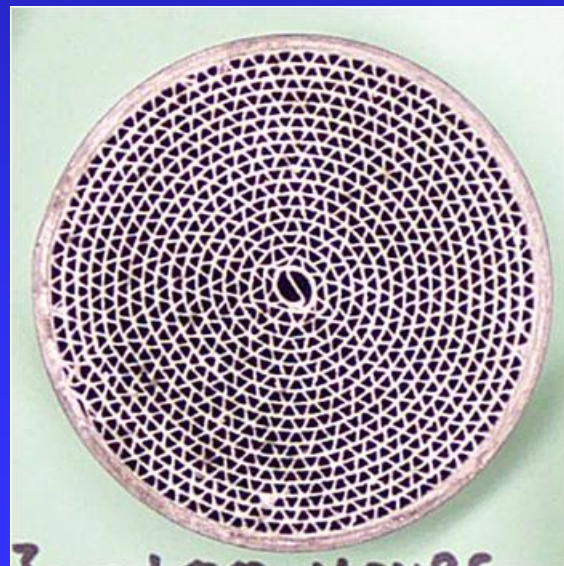
$y = -13755x + 16.416$   
 $R^2 = 0.9864$

|                             | 250°C | ANR   |       |       |       | 480°C | ANR   |       |  |
|-----------------------------|-------|-------|-------|-------|-------|-------|-------|-------|--|
|                             | 0.5   | 0.75  | 1     | 1.25  | 0.5   | 0.75  | 1     | 1.25  |  |
| $E_a$                       | 112.6 | 104.3 | 114.4 | 113.7 | 107.3 | 112.5 | 116.3 | 123.0 |  |
| Average $E_a$ =             | 113.0 |       |       |       |       |       |       |       |  |
| Std. Dev. $\sigma_n^{-1}$ = | 5.6   |       |       |       |       |       |       |       |  |

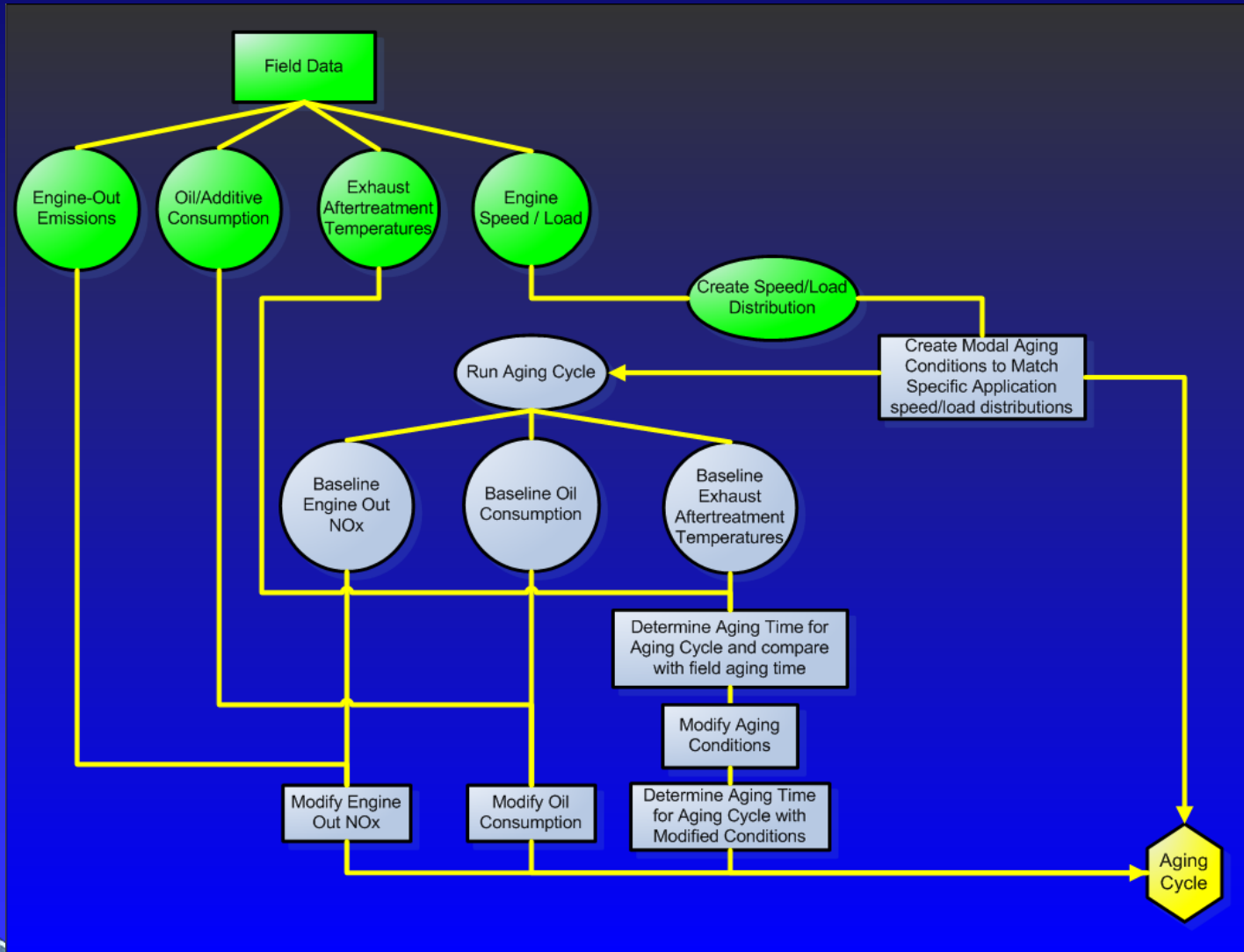
# DAAAC-HD Approach (3)

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- Chemical Component
- Heavy-Duty Diesel Engines May Consume Oil at a Higher Rate than Light-Duty Gasoline Engines
- Heavy-Duty Diesel Engines Have Higher Hour/Mile Requirements
  - Oil Effects on Catalysts and Filters Likely to be More Significant
- Include Oil Aging in DAAAC Procedures



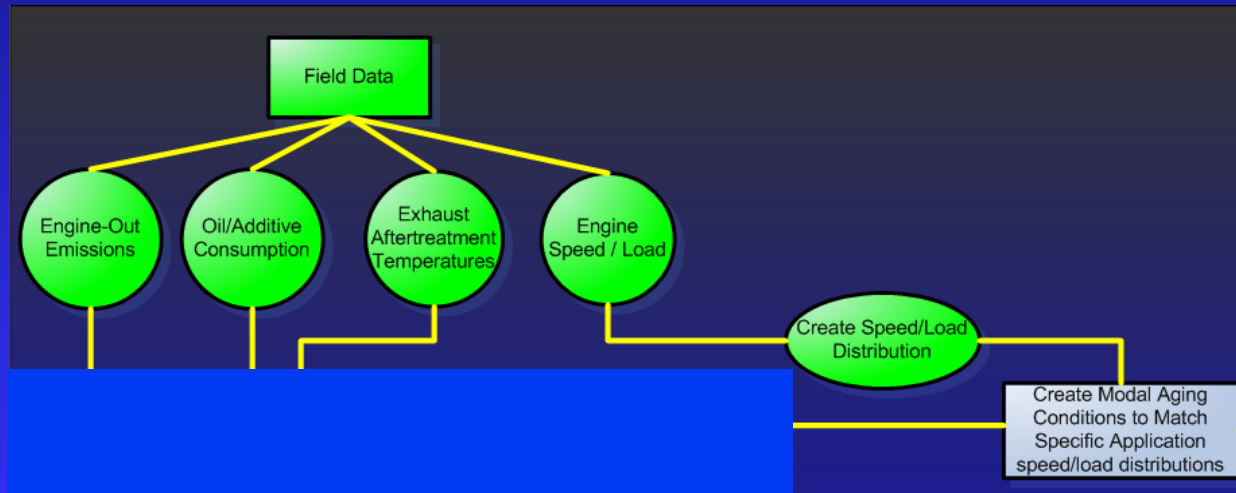
# DAAAC-HD Protocol Flow Diagram



# DAAAC-HD Test Plan (1)

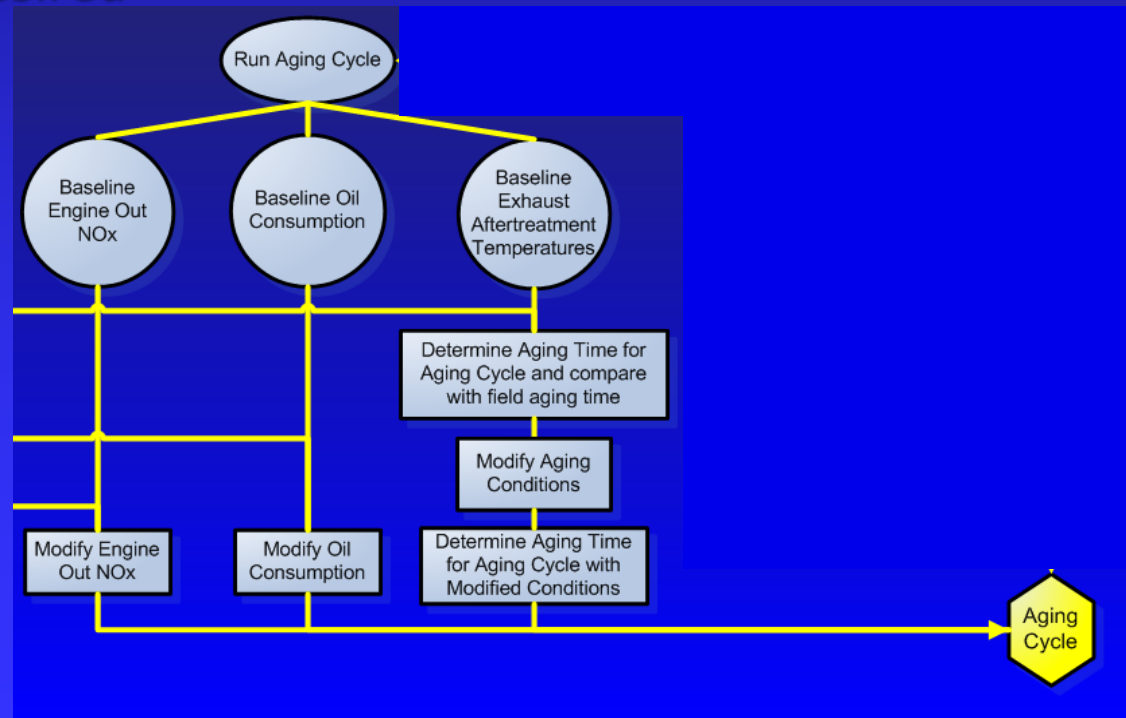
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- Acquire Field-Aged Components (DOC, DPF, SCR) and Field-Aging Data
- Sort Field Data by Time at Cycle Conditions
- Determine Base Accelerated Aging Cycle



# DAAAC-HD Test Plan (2)

- Run Bench Engine Aging Cycle
- Measure Temperatures and Oil Consumption Rates
- Process Field and Bench Temperature and Oil Data Determine Accelerated Aging Duration Equivalent to Field
- Adjust Aging Cycle Temperatures / Oil Consumption to Modify Bench Aging Duration as Desired

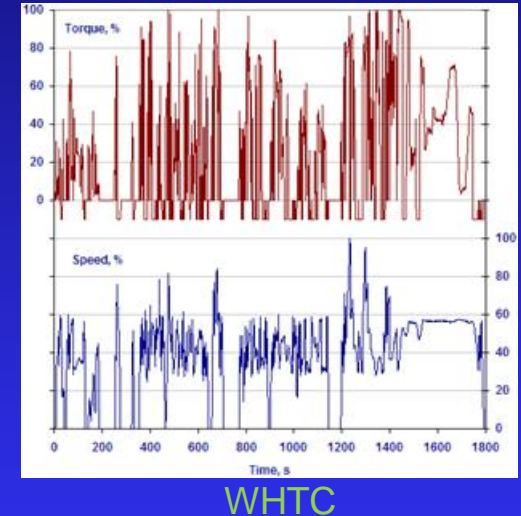
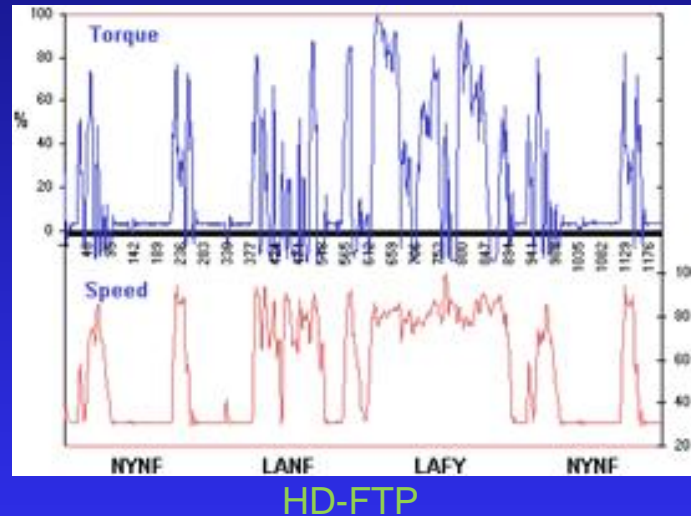


# DAAAC-HD Test Plan (3)

- Emissions Testing Comparison – Field versus Bench
- Several Standard Cycles Available as Appropriate

■ Transient  
■ Steady-State

- NRTC
- RMC
- ETC
- ESC
- FTP
- SET
- WHTC
- WHSC



- Synthetic Gas Reactor Testing of Core Samples Also Employed
  - SwRI's Universal Synthetic Gas Reactor<sup>®</sup> (USGR)<sup>®</sup>

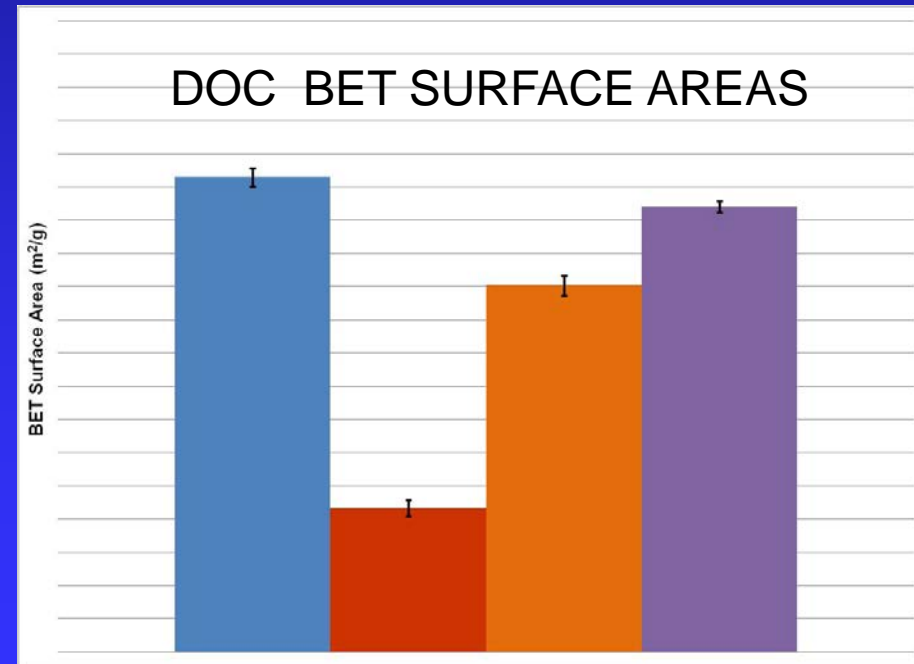


# DAAAC-HD Test Plan (4)

- Catalyst Physical Analyses Comparison – Field versus Bench
  - surface area - BET
  - deposit loadings and profiles - PIXE
  - identify crystalline deposit compounds - XRD
  - image deposits – OM & SEM
  - other analysis as appropriate – e.g. porosity



DPF OIL ASH



# DAAAC-HD Test Plan (5)

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- Systems Evaluated To Date
  - City Bus V-SCR, 110,000 km
  - Long-Haul Truck V-SCR, 600,000 km
  - Long-Haul Truck DOC+cDPF, 60,000 miles
- Multiple Bench Aging Iterations Performed





# DAAAC-HD Consortium (1)

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- Cooperative Research Program
- Initial Two-Year Term Began December 2008
- Expanded into Third Year April 2011
- Currently discussing DAAAC-II (1 - 3 years)



# DAAAC-HD Consortium (2)

January 2006  
DAAAC conceived

Based on EPA SRC/SBC Rulemaking  
December 2005

February 22, 2008  
Symposium held in San Antonio

HD – LD split  
LD 'indefinitely postponed'

November 15, 2008  
DAAAC-HD Consortium Initiated  
V-SCR & DOC+cDPF

April 18, 2011  
DAAAC-Y3 Initiated

Consolidation

2012 – 20xx  
DAAAC-II ?

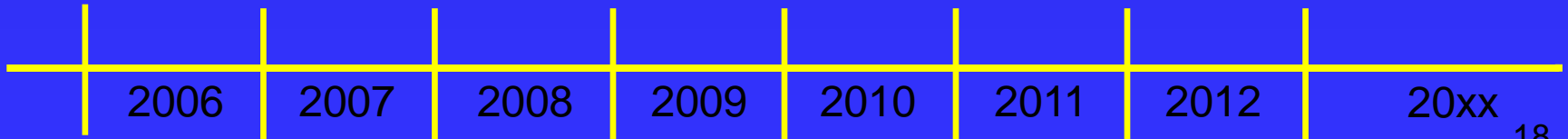
DOC+cDPF+SCR

X, 20xx  
DAAAC-xx ?

Target  
Regulations ?

Global  
Financial Crisis

Regulator Meetings



# DAAAC-HD Consortium (3)

- Caterpillar



- Doosan



- Isuzu



- Lubrizol



- MTU



- Scania



- Umicore



- GE Transportation



- Engine Manufacturers
- Lube Oil Formulator
- Catalyst Industry

- Sweden
- Japan
- Korea
- Germany
- USA



# DAAAC-HD Consortium (4)

- Communications - Website

DAAAC-HD Active Website  
[www.daaac.swri.org](http://www.daaac.swri.org)

Monthly Progress Reports

PAC Review Meetings

E-mails

Telephone

**DAAAC**  
Diesel  
Aftertreatment  
Accelerated  
Aging Cycles  
(DAAAC)

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### DAAAC-HD Project Underway - New Members Welcome

**Southwest Research Institute**  
6220 Culebra Road  
San Antonio, TX 78238  
USA

The genesis of the DAAAC program was the EPA Final Rule for Emissions Durability Test Procedures, published in December of 2005 [ [LINK](#) ].

It applies to the certification procedures required to sell vehicles in the U.S. The rule provides a Standard Bench Cycle (SBC) for accelerated aging of emissions system components. The SBC can be used in place of the Standard Road Cycle (SRC) that requires vehicles to be driven for 120,000 miles, with periodic emissions measurements. Using the SBC offers significant savings in both time and expense to achieve the certification requirements. However, it cannot be used for diesel-fueled vehicles. Hence, all such vehicles must currently perform the full 120,000 mile SRC procedure. Based on input from industry, there was a strong desire to have a similar Diesel Aftertreatment Accelerated Aging Cycle (DAAAC) for diesel emissions components.

On February 22, 2008, SwRI hosted the DAAAC symposium in San Antonio, TX. Fifty-nine people from thirty-four companies and organizations attended the Symposium ([Attendees List](#)). The Symposium reviewed some of the existing understanding of diesel aftertreatment system aging mechanisms and aging methods. The shared information and discussions provided insight to begin the challenge of developing a standard bench cycle for diesel aftertreatment systems.

At the Symposium, Southwest Research Institute offered the first proposal for an industry consortium to develop DAAAC aging procedures. As a result of the feedback on the initial proposal, SwRI prepared a single revised proposal designed to address the needs of both light-duty and heavy-duty.

Given the continued levels of interest in the DAAAC concept, SwRI was encouraged to continue with the initiative. The decision was made to concentrate on heavy-duty diesel aftertreatment systems. A proposal addressing heavy-duty diesel applications was sent out on July 11, 2008. Following an initial meeting on October 17, 2008, the DAAAC-HD project officially began on December 15, 2008. The project currently has seven members representing US, Japanese, European, and Korean OEMs and suppliers. It is designed for a two-year term ending December 15, 2010.

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**Related Terminology**

Diesel Aftertreatment Accelerated Aging Cycles  
DAAAC

**Related Information**

Department of Engine and Vehicle R&D  
Engine, Emissions & Vehicle Research Division



# DAAAC-HD Consortium (5)

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- Communications - Meetings
  - Nine PAC meetings to date
  - Four coincided with SAE World Congress
  - Three coincided with DEER Conference
  - Two held in San Antonio at SwRI



# DAAAC-HD Consortium (6)

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- Regulators

- EPA and EU Commission have been involved from program start
- Offer DAAAC Protocol as acceptable procedure for emissions certification
- Explore possibility of DAAAC Protocol written into emissions regulations



# DAAAC Future Plan

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## DAAAC-II

- New MultiYear Program Plan Under Discussion
  - Includes US 2010 emissions system DOC+cDPF+SCR+AMOX
  - Incorporates mileage accumulation with data acquisition to 150,000+ miles
    - Up to five long haul trucks anticipated
  - Includes off-road SCR-only system
  - Multiple iterations of bench engine aging
- Meetings/Discussions Continuing



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