THE DAAAC PROTOCOL FOR ACCELERATED AGING OF DIESEL AFTERTREATMENT SYSTEMS

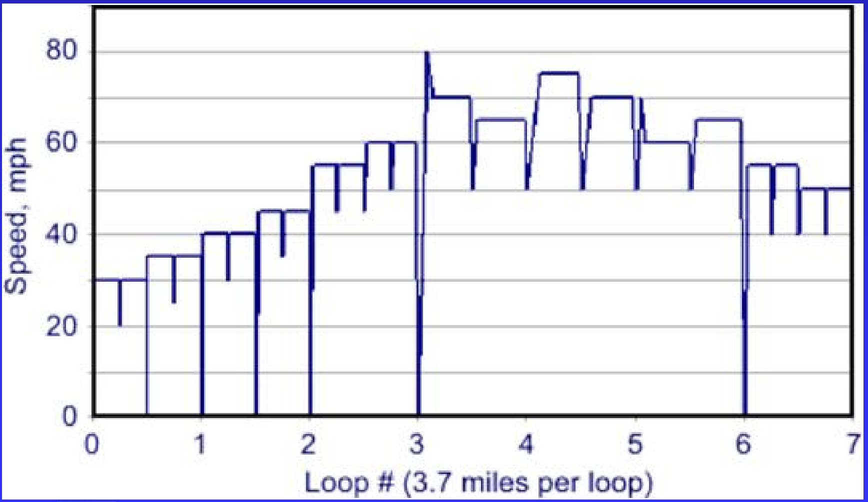
Diesel Aftertreatment Accelerated Aging Cycles (DAAAC)

Presentation Outline

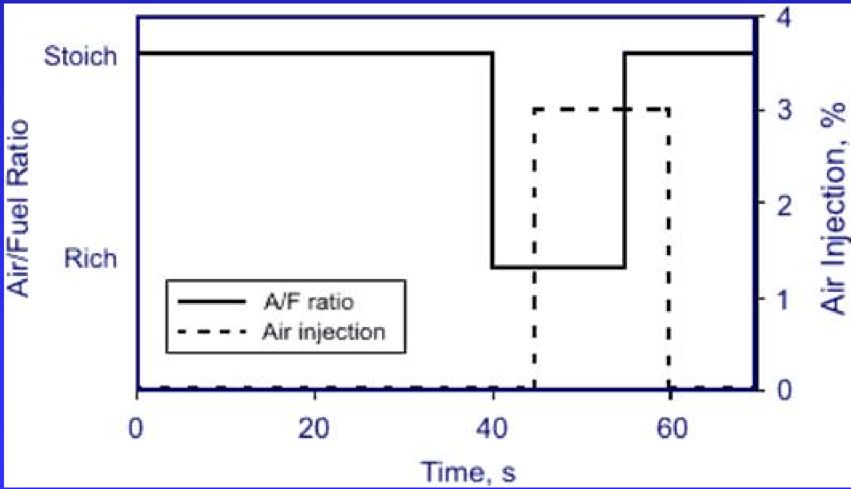
- Background
- DAAAC-HD Challenges
- DAAAC-HD Objectives
- Approach
- Test Plan
- DAAAC Consortium
- Future Plan

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

- 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 "7th" Injector } one aging cycle NOT likely
  - Selective Catalytic Reduction (SCR) }
    - DEF Injection System / NO_X 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

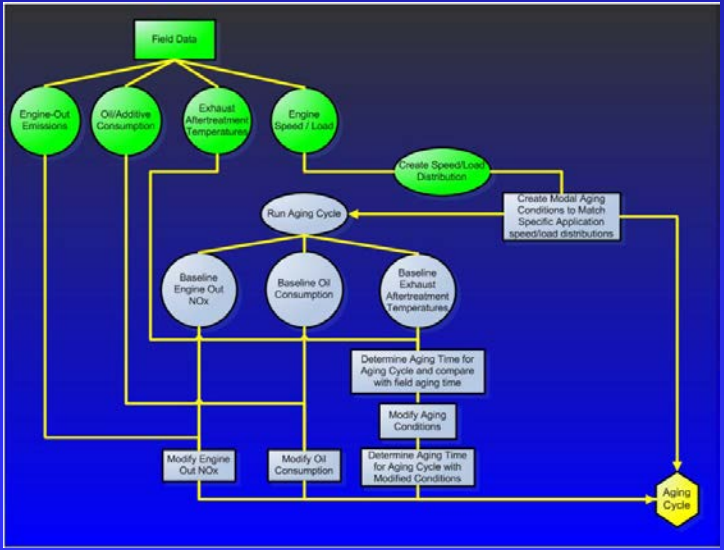
DAAAC-HD Objective

- 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*

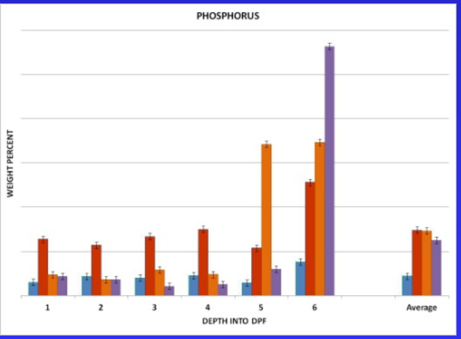
by

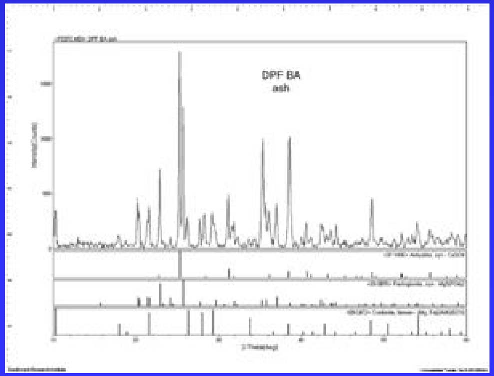
  - *Using scientifically supported procedures, based on extensive physical and chemical analyses of field-aged system components*

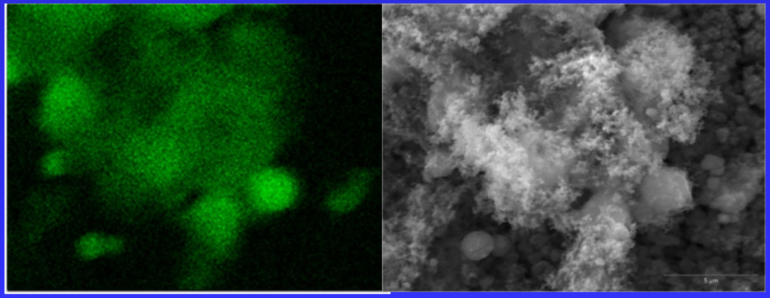


DAAAC-HD Approach (1)

- 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

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

k Rate constant

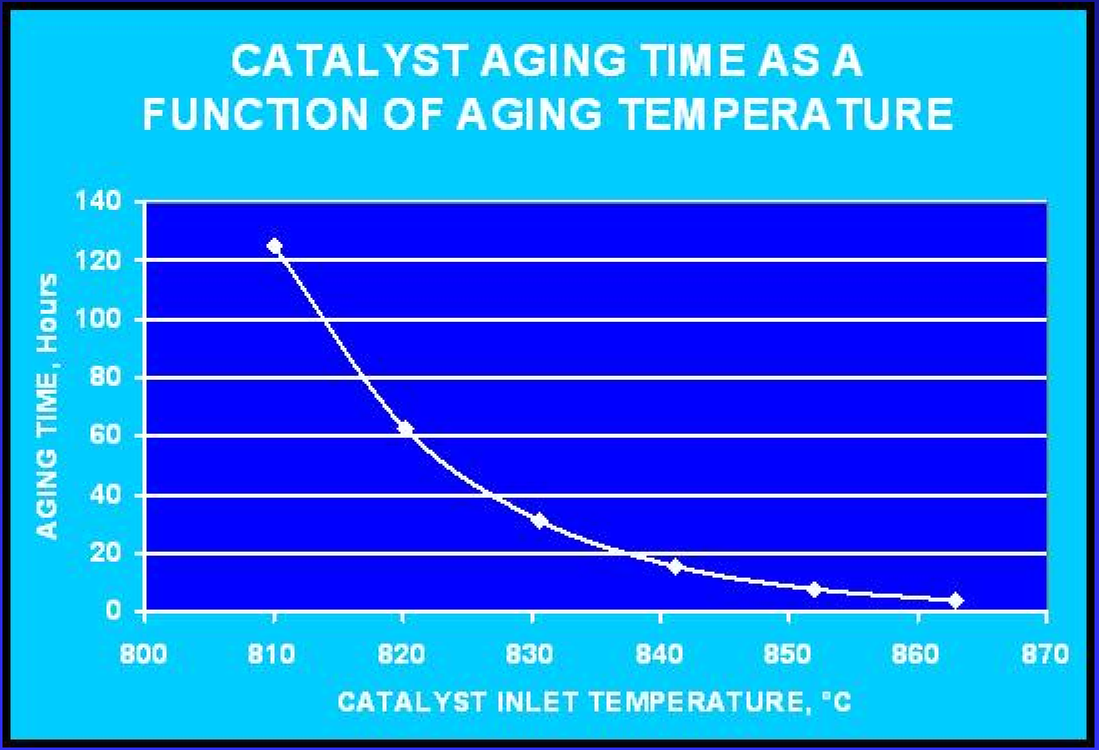
A frequency factor or pre-exponential factor

e Mathematical quantity, e

Ea 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 *Ed* 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 *Ed* for City Bus V-SCR Catalyst

Ed for City Bus V-SCR Formulation = 113 ± 5.6 kJ/mol

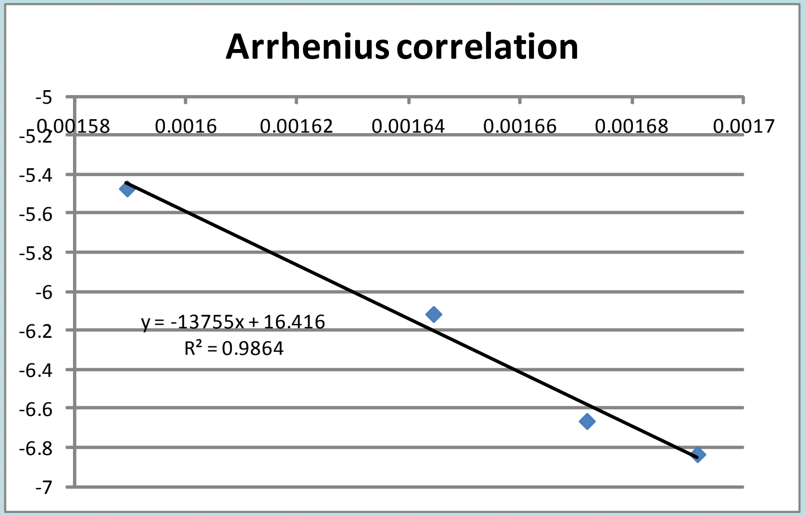
Inputs	η_{ref}	100 %	
	Ea	150 kJ/mol	
	A		
	R	0.008314 kJ·mol^{-1}·K	250°C
			ANR = 1.00

	Temp. °C	Temp. K	Time hrs	η_{NOx}	k	ln(k)	1/T
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
Ea	114.3591

Oven aging

Temp.,°C	Time, hr
356	188

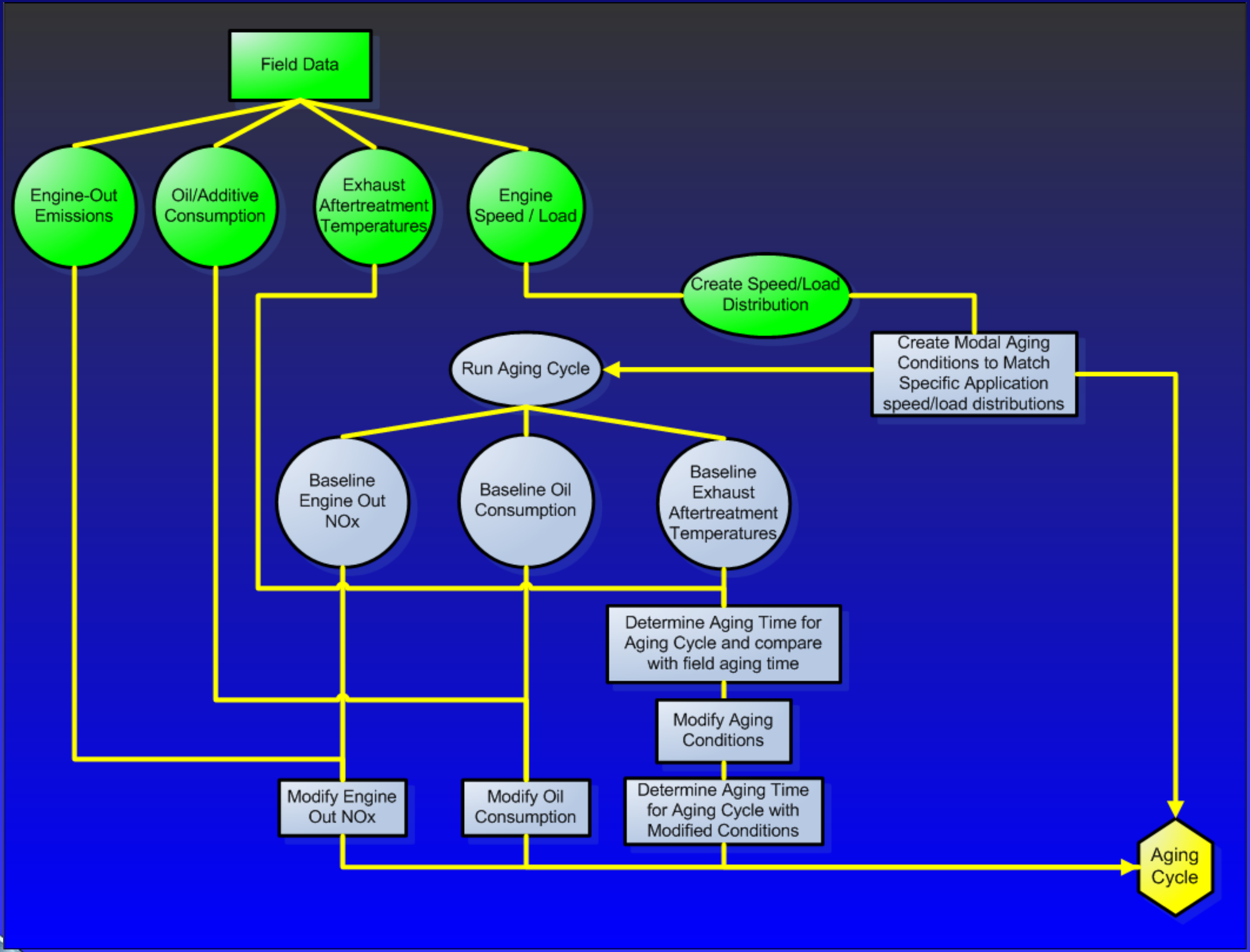


	250°C	ANR			480°C	ANR		
	0.5	0.75	1	1.25	0.5	0.75	1	1.25
Ea	112.6	104.3	114.4	113.7	107.3	112.5	116.3	123.0
Average Ea=	113.0							
Std. Dev. σn^{-1}=	5.6							

DAAAC-HD Approach (3)

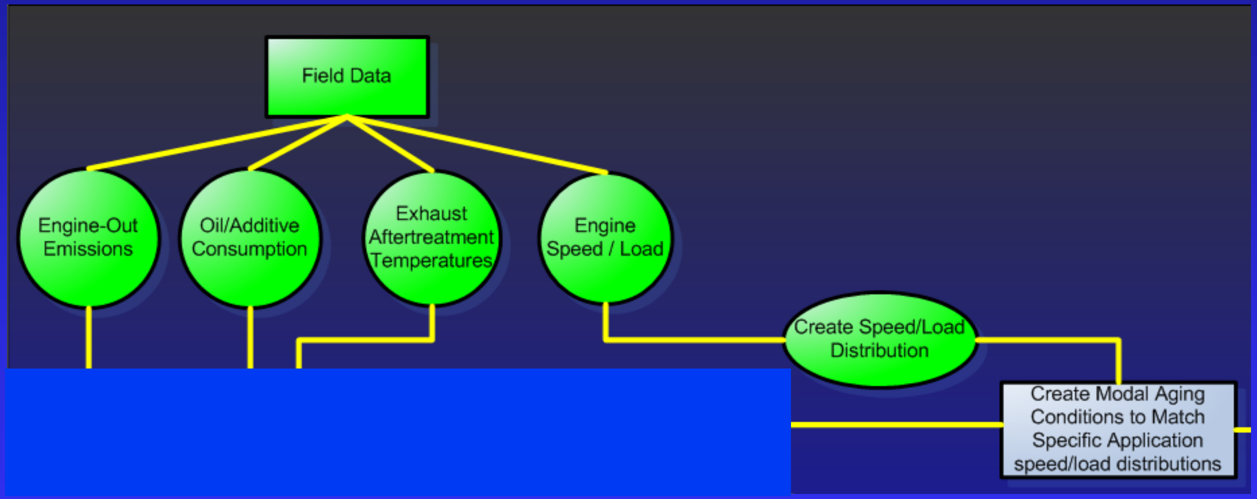
- Chemical Component
- Heavy-Duty Diesel Engines May Consume Oil at a Higher Rate than Light-Duty Gasoline Engines
- Heavy-Duty Diesel Engines Have Higher Hour/Mile Requirements
  - Oil Effects on Catalysts and Filters Likely to be More Significant
- Include Oil Aging in DAAAC Procedures

DAAAC-HD Protocol Flow Diagram



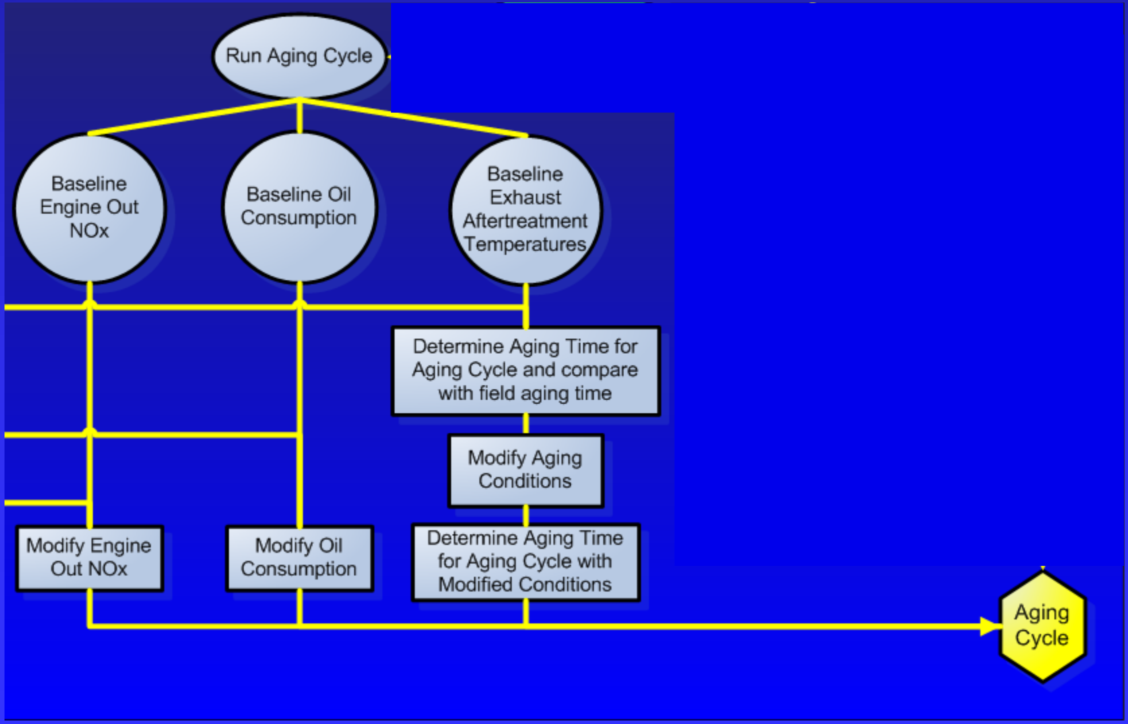
DAAAC-HD Test Plan (1)

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



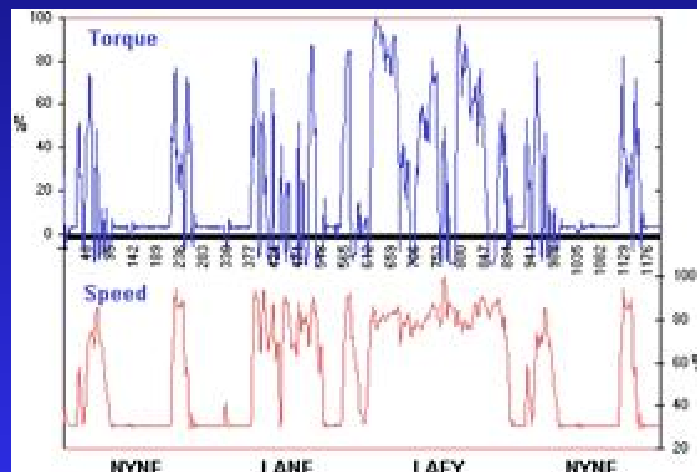
DAAAC-HD Test Plan (2)

- 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

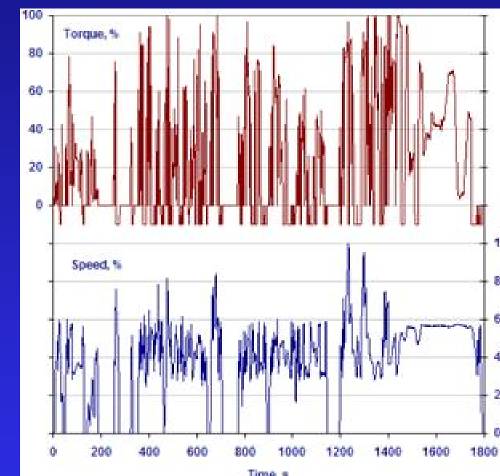


DAAAC-HD Test Plan (3)

- Emissions Testing Comparison – Field versus Bench
- Several Standard Cycles Available as Appropriate
  - Transient
  - Steady-State
    - NRTC
    - RMC
    - ETC
    - ESC
    - FTP
    - SET
    - WHTC
    - WHSC



HD-FTP



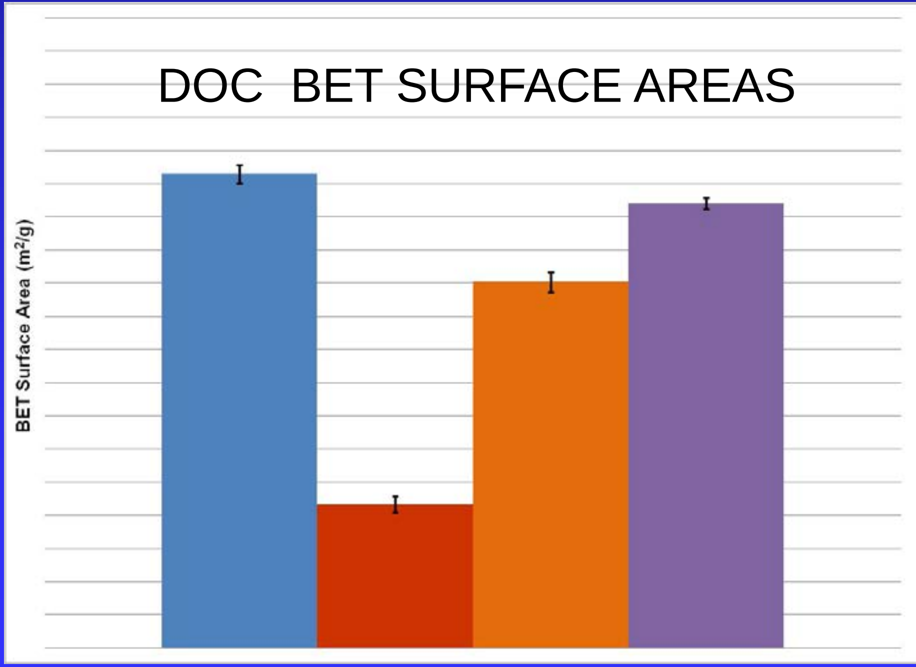
WHTC

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

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



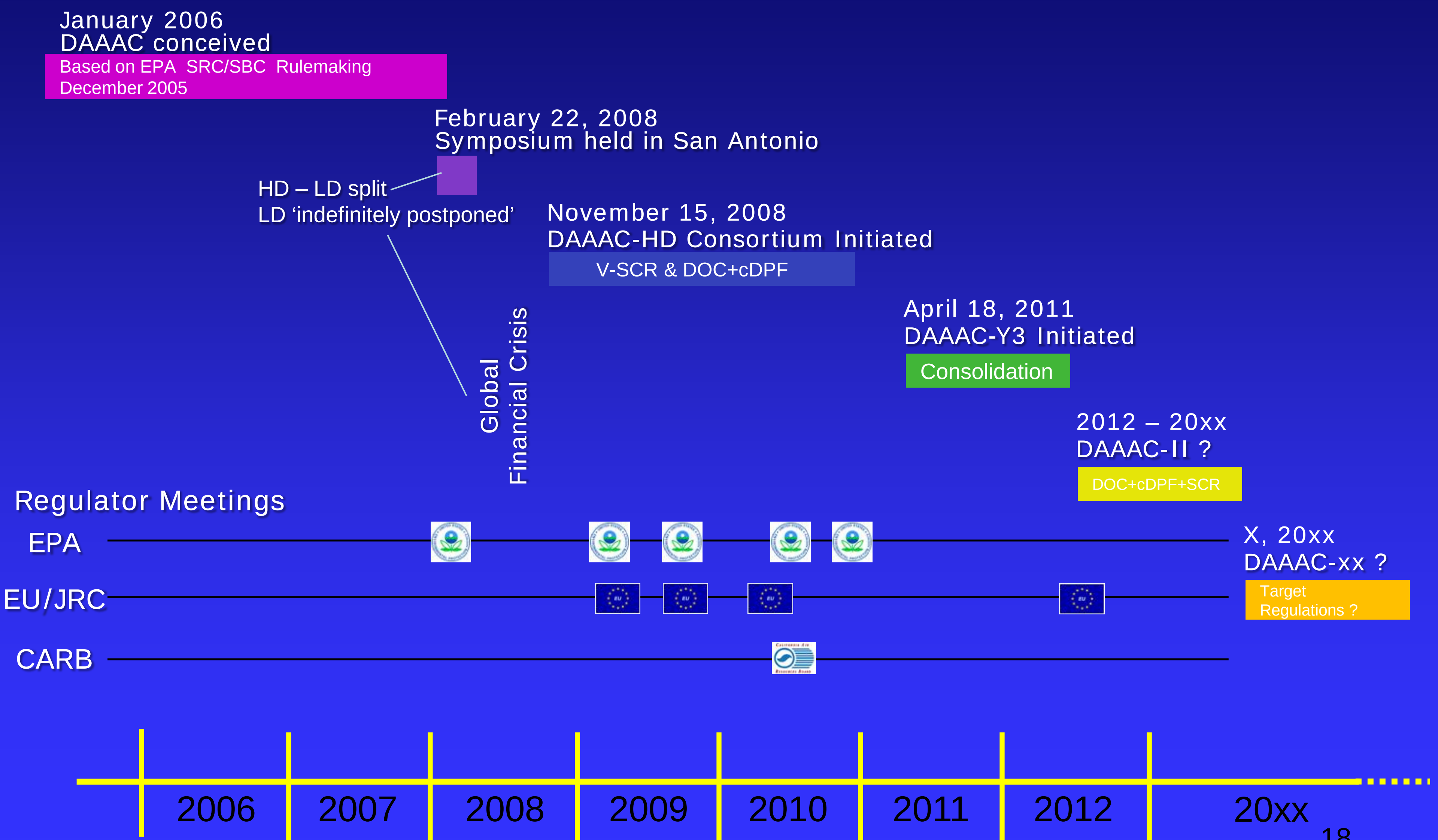
DAAAC-HD Test Plan (5)

- 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

DAACC-HD Consortium (1)

- 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)



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

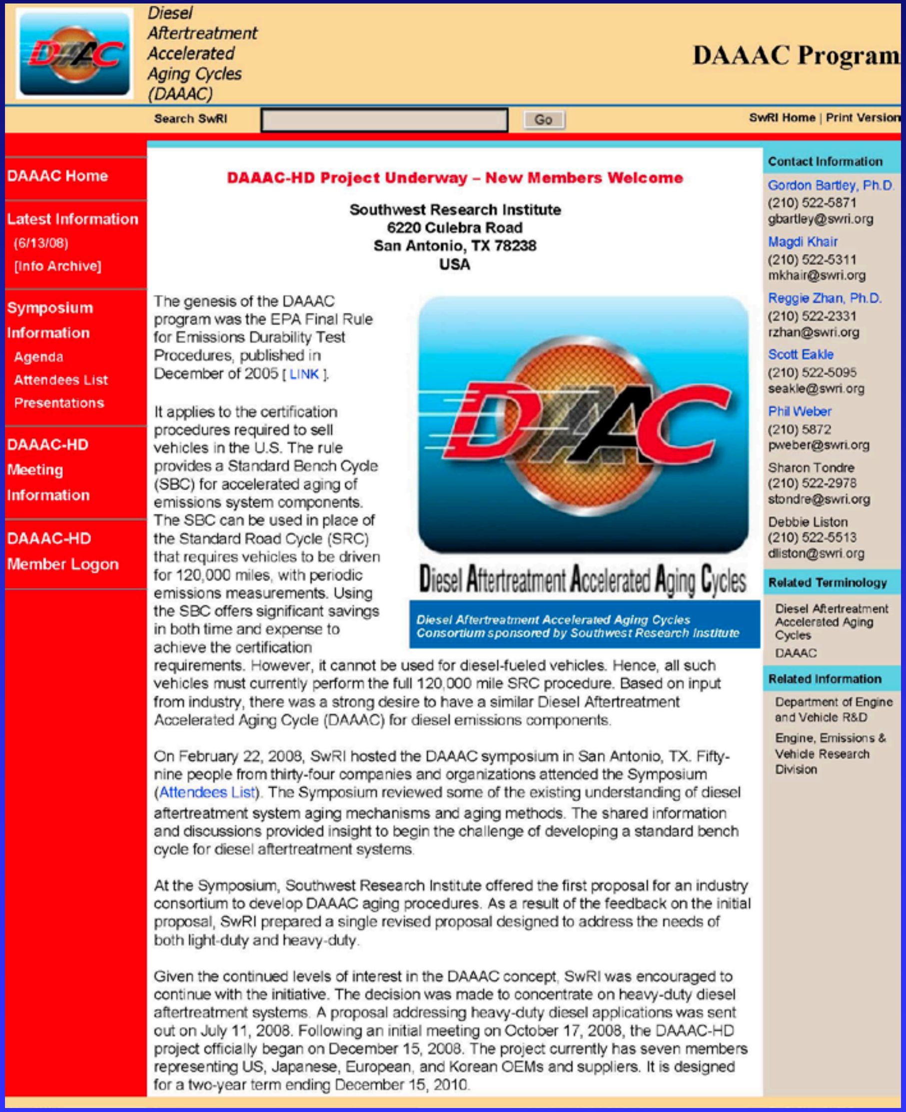
DAAAC-HD Active Website
www.daaac.swri.org

Monthly Progress Reports

PAC Review Meetings

E-mails

Telephone



DAAAC-HD Consortium (5)

- 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)

- 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

DAAC Future Plan

DAAC-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

Diesel Aftertreatment Accelerated Aging Cycles

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