2006 DEER Conference Emission Controls for Heavy-Duty Trucks

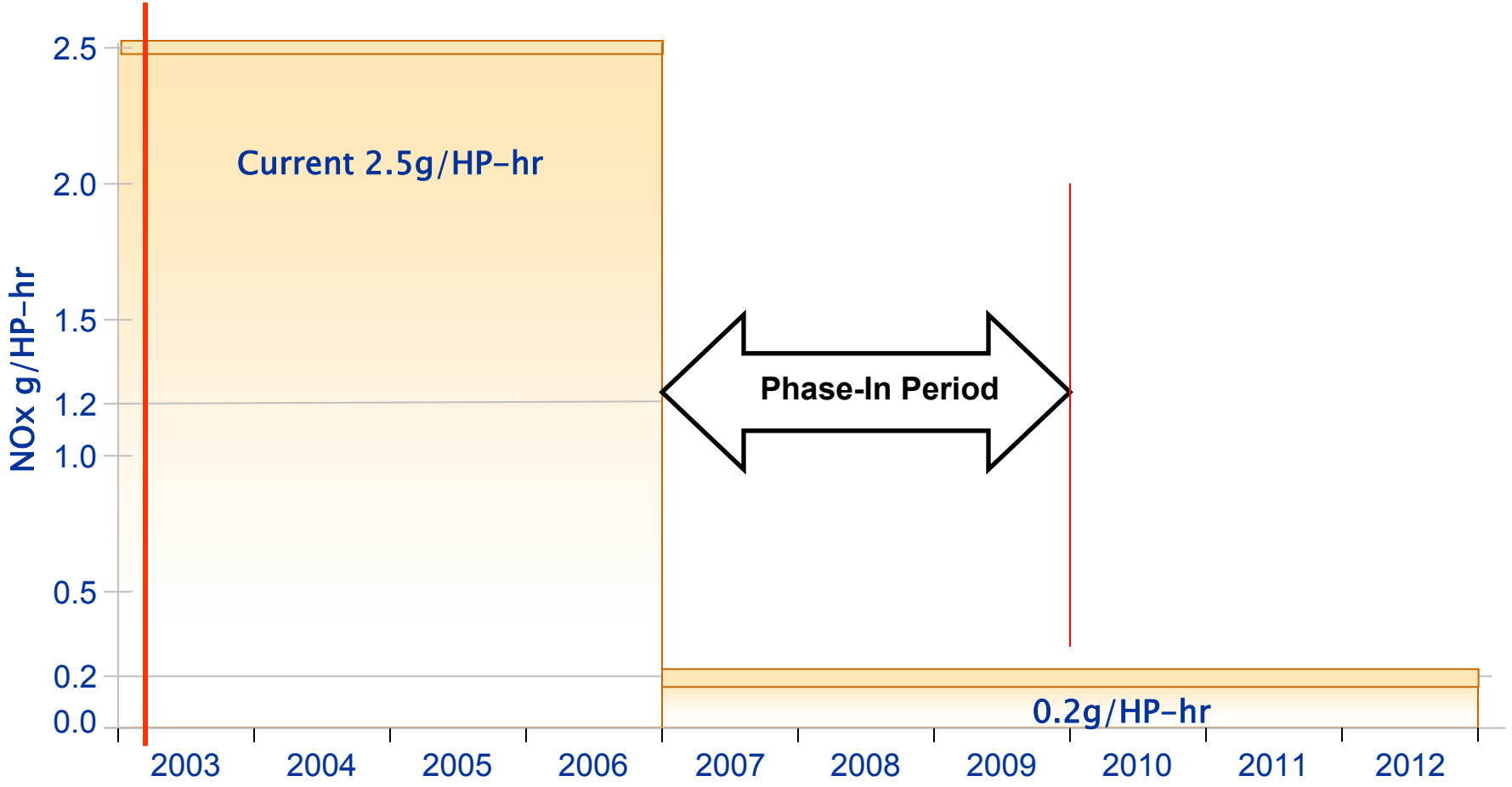
Emission Solutions

Overview

- Emission Standards – US and Worldwide
- Technology Options for Meeting Emissions
- System Integration
- Particulate Filter Technology
- SCR Technology
- Summary

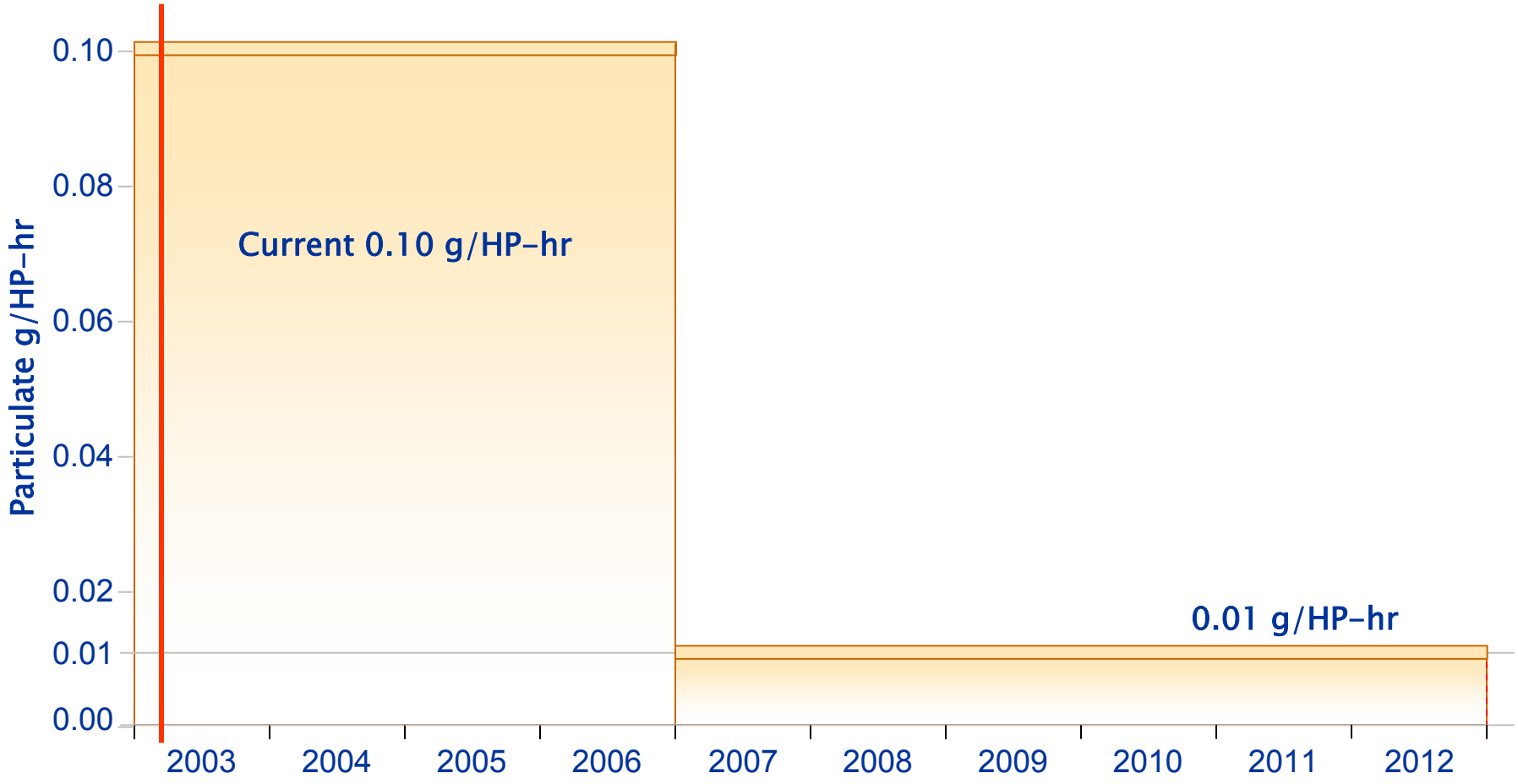
US07 Emission Regulation

NOx Emissions Time Line and Standards



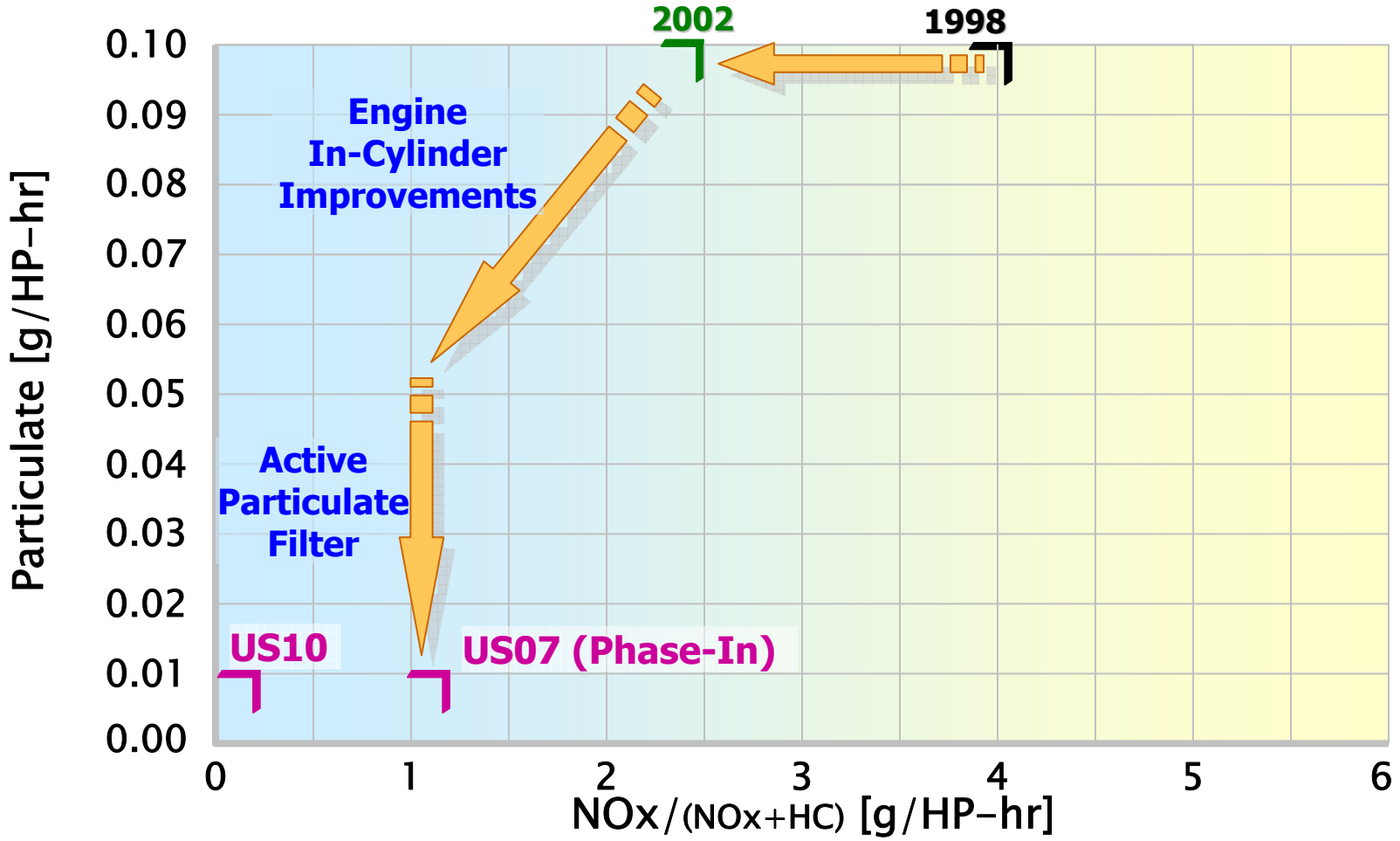
US07 Emission Regulation

Particulate Emissions Time Line and Standards



US07 Technology Selection was driven by Emissions Strategy

US2010 Requires Further NOx Reductions – Engine + Aftertreatment



Nonroad Emissions Standards - US

Emission Solutions

MOBILE OFF-HIGHWAY EMISSIONS REGULATIONS SCHEDULES

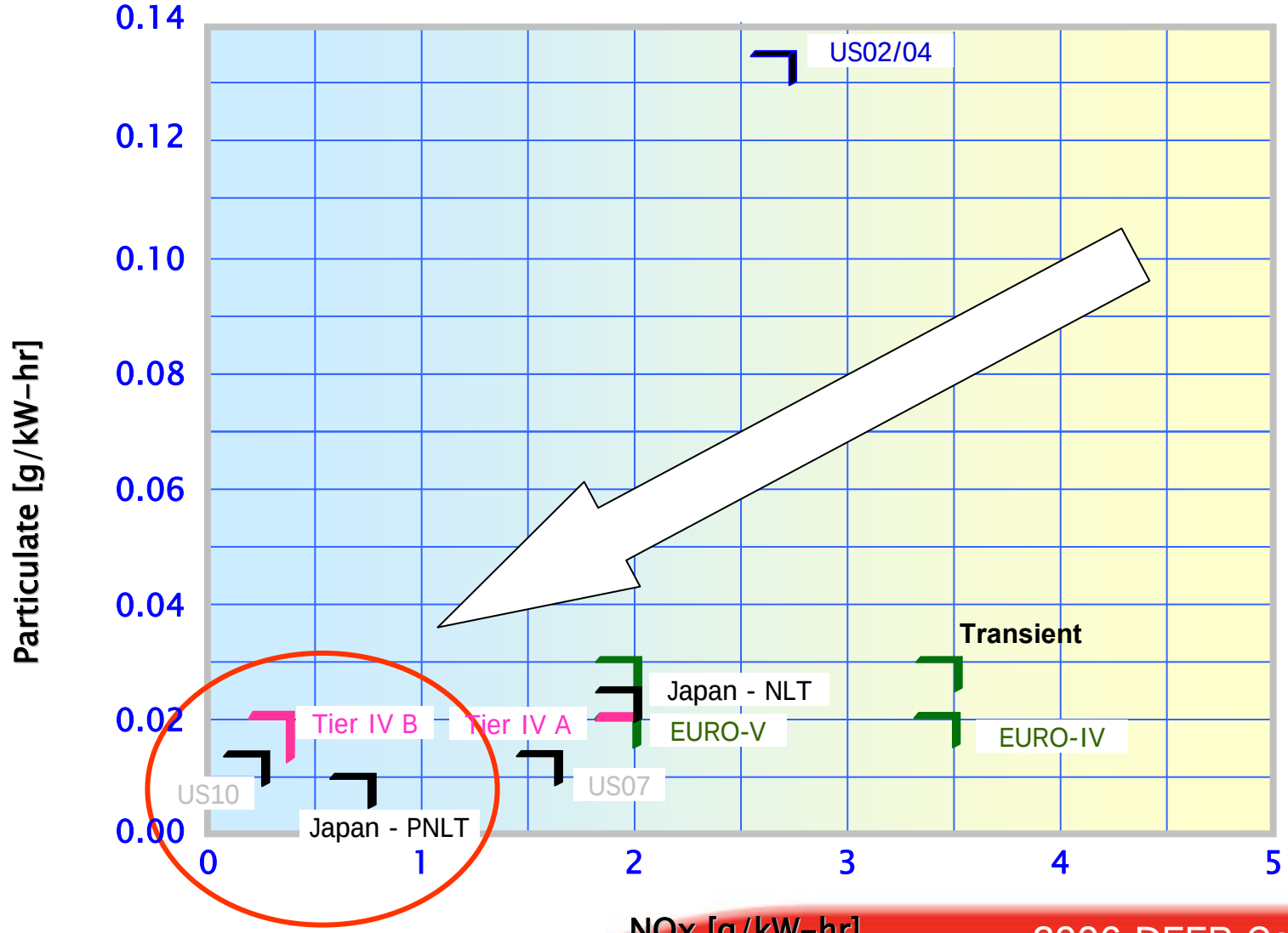
NOx / HC / CO / PM (g/kW-hr) [Conversion: (g/kW-hr) x 0.7457 = g/bhp-hr]
(NOx+HC) / CO / PM (g/kW-hr) [Conversion: (g/kW-hr) x 0.7457 = g/bhp-hr]

U.S. EPA

kW	(HP)	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
0 - 18	(0 - 24)		(7.5) / 8.0 / 0.80			(7.5) / 6.6 / 0.40									
19 - 36	(25 - 48)	(7.5) / 5.5 / 0.60				(7.5) / 5.5 / 0.30					(4.7) / 5.0 / 0.03				
37 - 55	(49 - 74)	(7.5) / 5.0 / 0.40				*(4.7) / 5.0 / 0.30* (4.7) / 5.0 / 0.40									
56 - 74	(75 - 99)									3.4 / 0.19 / 5.0 / 0.02			0.40 / 0.19 / 5.0 / 0.02		
75 - 129	(100 - 173)				(4.0) / 5.0 / 0.30										
130 - 560	(174 - 751)			(4.0) / 3.5 / 0.20					2.0 / 0.19 / 3.5 / 0.02			0.40 / 0.19 / 3.5 / 0.02			
>560*	(>751)*					(6.4) / 3.5 / 0.20			3.5 / 0.40 / 3.5 / 0.10 *0.67 / 0.40 / 3.5 / 0.10*[a]				3.5 / 0.19 / 3.5 / 0.04 *0.67/ 0.19 / 3.5 / 0.03*[b]		
		Tier 1		Tier 2		Tier 3			Tier 4A				Tier 4B		

a. Applies to portable power generation >1200hp.
b. Applies to portable power generation >751hp.

Heavy-Duty Emission Standards – Worldwide



Technology Options for Heavy-Duty Truck Emissions

- In-Cylinder Emissions Control Technology
  - more difficult with increasingly stringent standards
- Particulate Filter Technology
  - Demonstrated in retrofit systems (> 10,000 units) and light-duty
  - Active regeneration required to cover all duty cycles
  - Low sulfur fuel and Low ash oil enable this technology
- SCR Technology
  - Introduced in Europe to meet Euro 4 standards
  - Urea infrastructure required to enable this technology
- Lean NOx Trap (LNT) Technology
  - Technology is still under development - significant challenges
- Combined System Technologies

System Integration – On-Road Laboratory

MERLIN

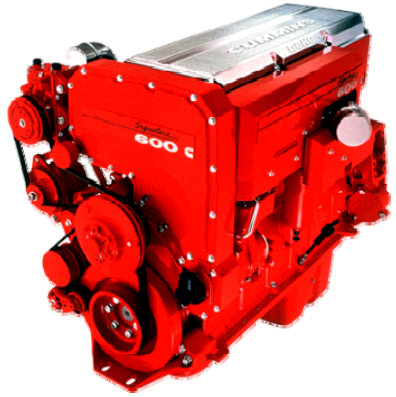
- Custom-Designed Straight Truck
- Extended Sleeper Cab for Computer W/Stations
- 6L 2002 Cooled EGR Engine
- NOx and SOx Adsorbers
- Particulate Filter
- Exhaust Fuel Injection Capability
- Comprehensive Data Acquisition
- Full System Simulation On-Board
- Controls Rapid-Prototyping
- Commissioned February 2002

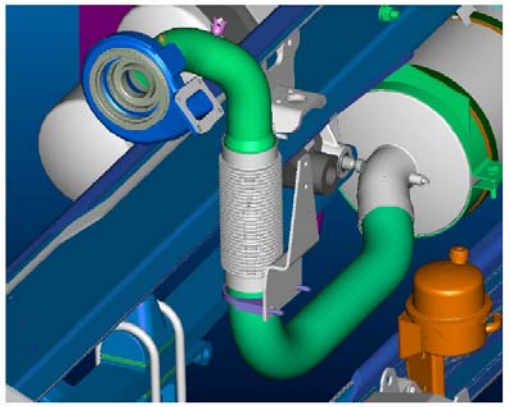
MERLIN - Mobile Emissions Research Laboratory

Cummins Emission Solutions

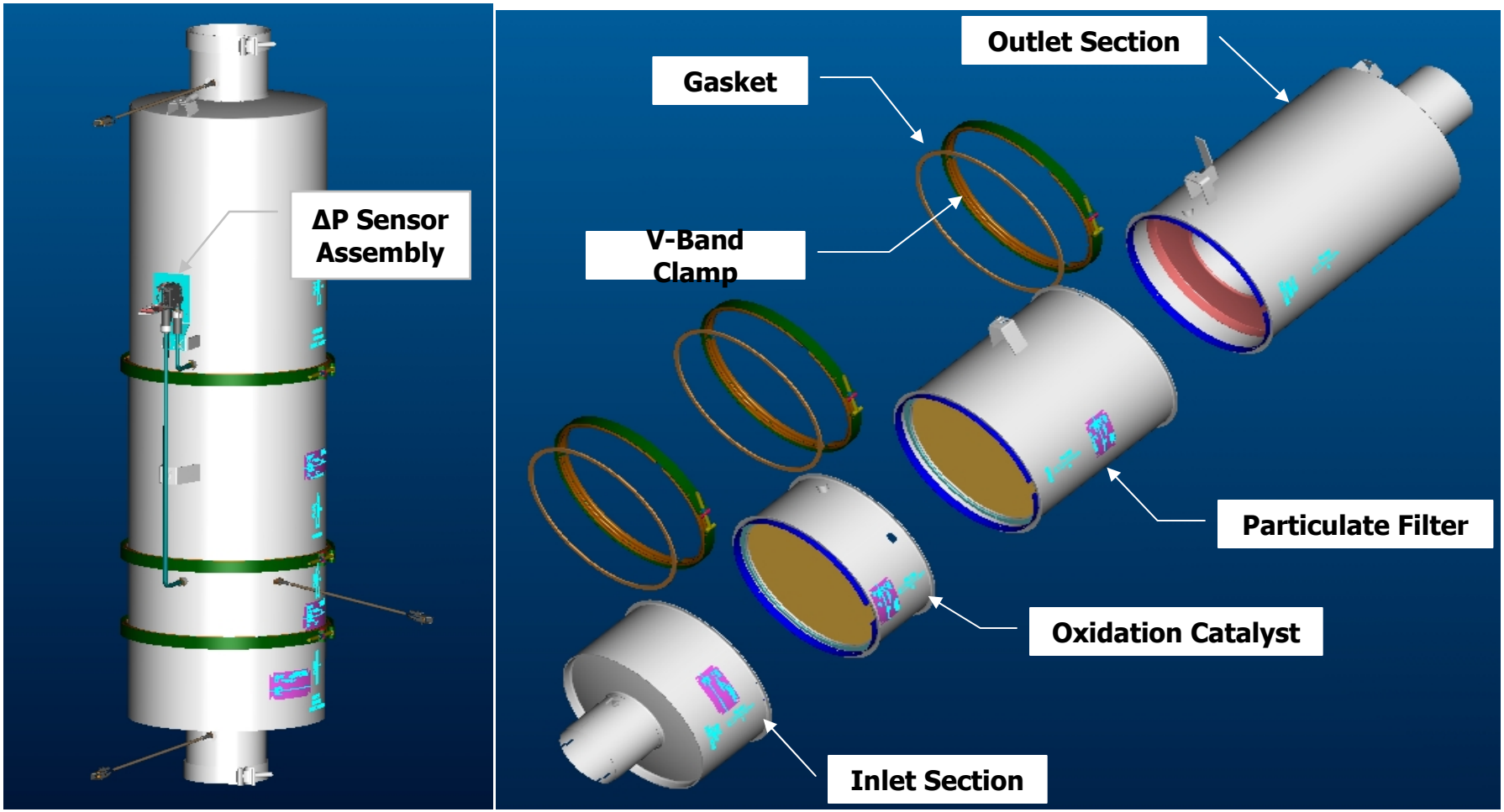
Heavy-Duty System Integration

Vehicle + Engine + Aftertreatment System Integration is Key





Particulate Filter Exhaust Assembly – Vehicle Mounted

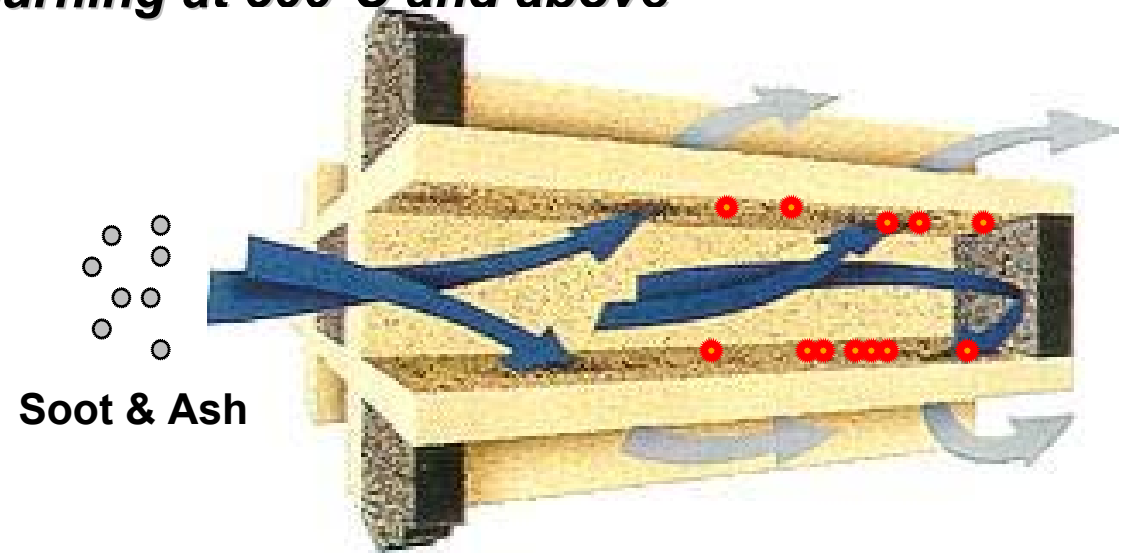


Particulate Filter Overview

Emission Solutions

- *Porous ceramic walls capture both soot and ash from exhaust*
  - *High filtration efficiency enables engines to meet US'07 std*
  - *Soot removed by periodic regeneration*
  - *Ash accumulates and requires removal and maintenance*

- *On a catalyzed filter, soot is consumed by:*
  - *NO_2 and "passive regeneration" between 220 - 450ºC*
  - *Catalytic reactions between 350 - 550ºC*
  - *O_2 burning at 500ºC and above*

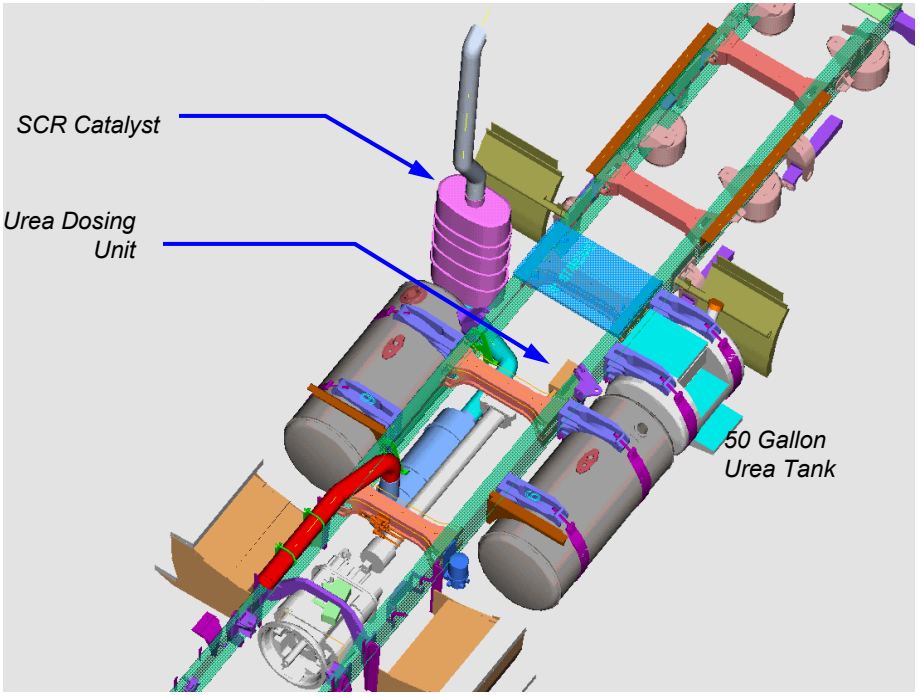


Selective Catalytic Reduction – SCR Europe On-Highway (Euro 4)

Cummins Emission Solutions

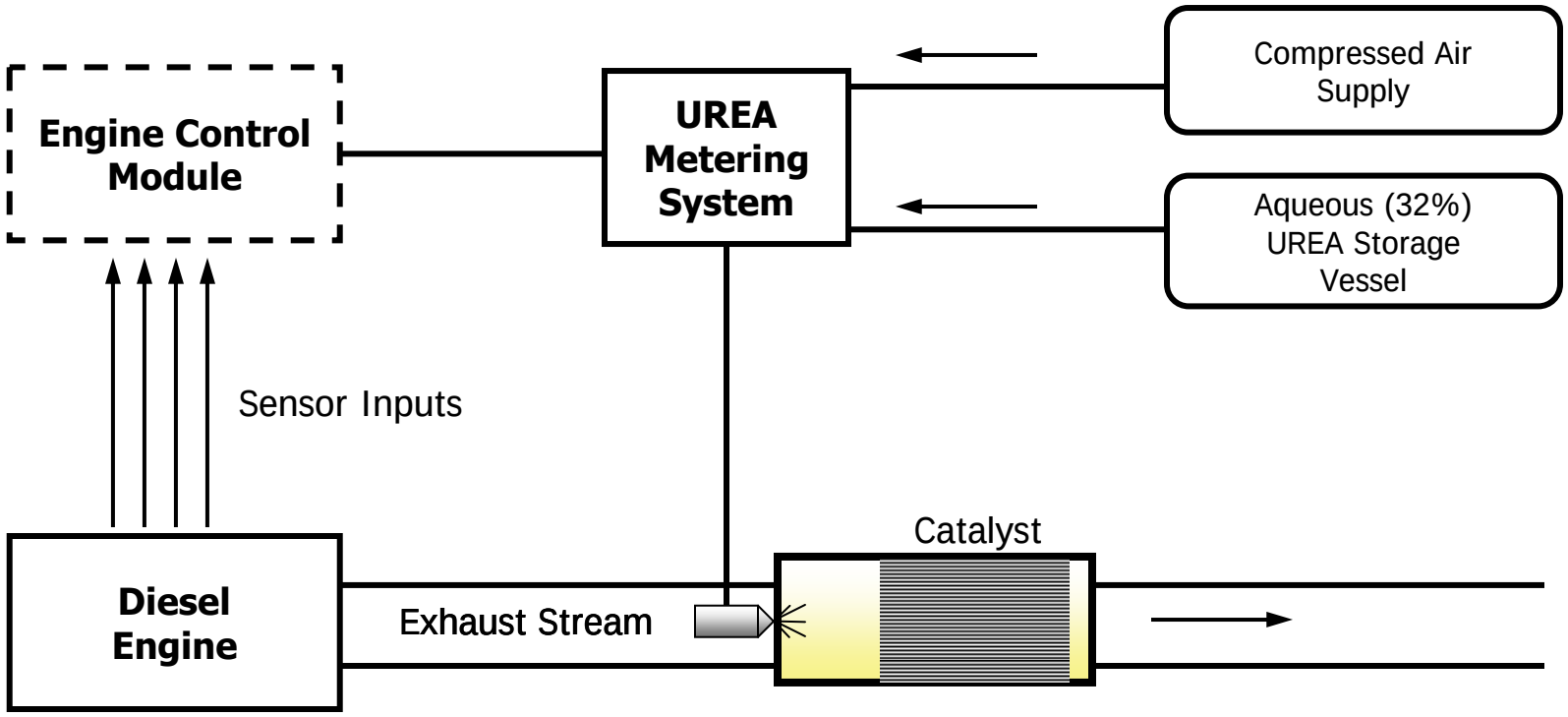
> U.S. Vehicle System Demonstration for Technology Integration
> In production in Europe

Kenworth T2000, 2001
ISX-450 1850 lb-ft @1200 RPM,
Eaton CST Autoshift 12 Speed



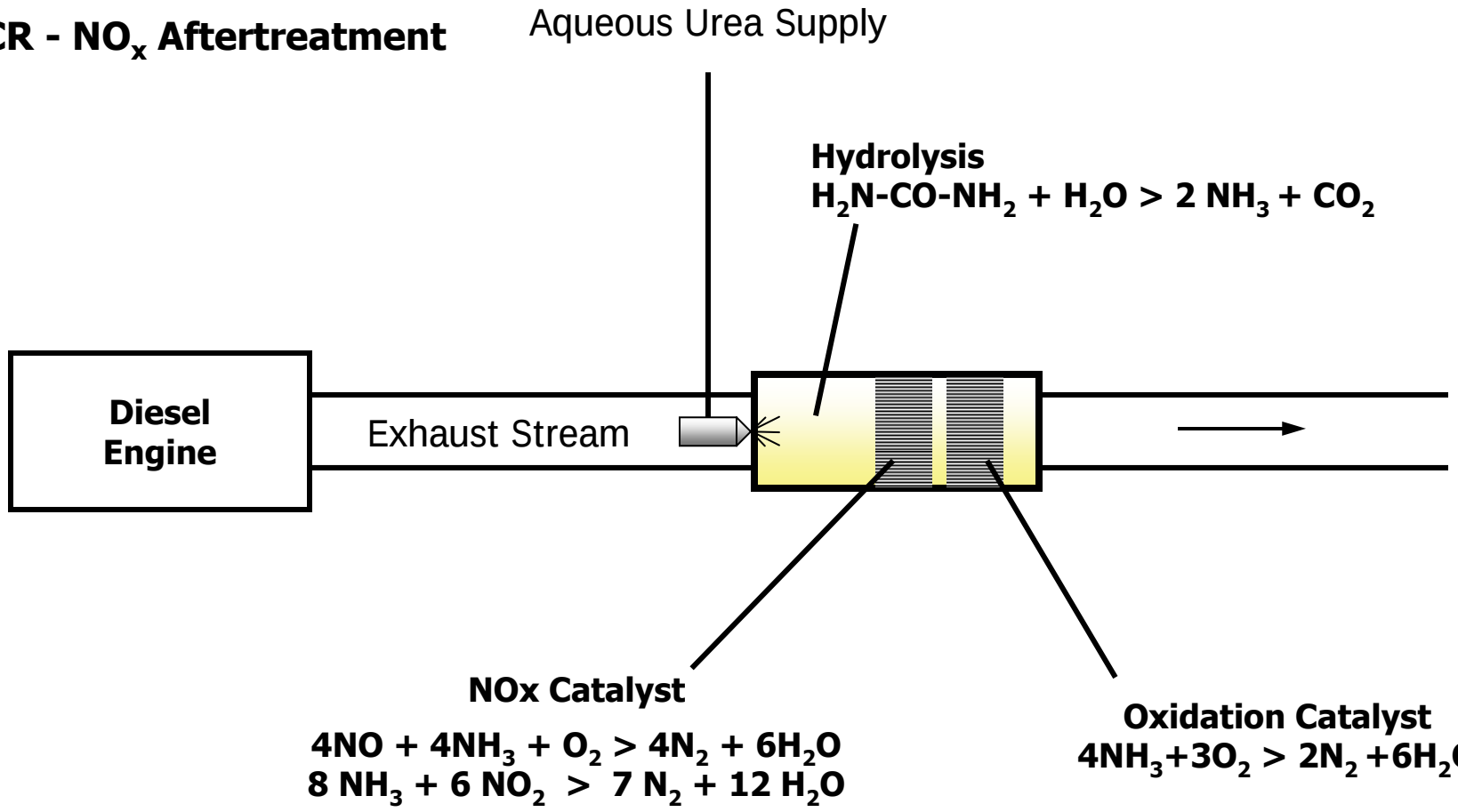
Selective Catalytic Reduction - SCR

SCR - NOx Aftertreatment



Selective Catalytic Reduction - SCR

SCR - NO_x Aftertreatment



Summary

System Integration to meet Customer Expectations and Emission Standards

- Integration with the Vehicle Design
- Integration between Engine and Aftertreatment – not a bolt-on device

Technology Development prior to Product Development

- Cross-functional team focused on Product Preceding Technology project

Disciplined Approach to Product Development

- New Product Introduction teams in place with defined VPI project milestones / gates
- Design for Six Sigma (DFSS) tools applied during design / development

Analysis Led Design

- Extensive use of modeling and analysis tools during the design phase
- Dynamic system modeling of vehicle / engine / aftertreatment / controls

Application of Platform Architecture across engine platforms

- Increased experience during development phase
- Allows for validation over broad range of applications and duty cycles