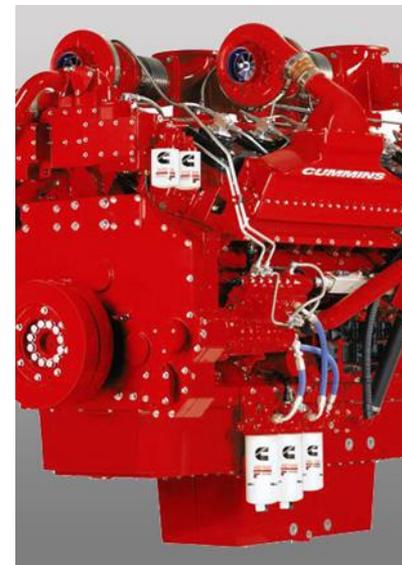




Cummins Tier 4 Technology Overview



Agenda

- Emissions legislation
- Cummins Tier 4 Technology
- Cummins Advantage

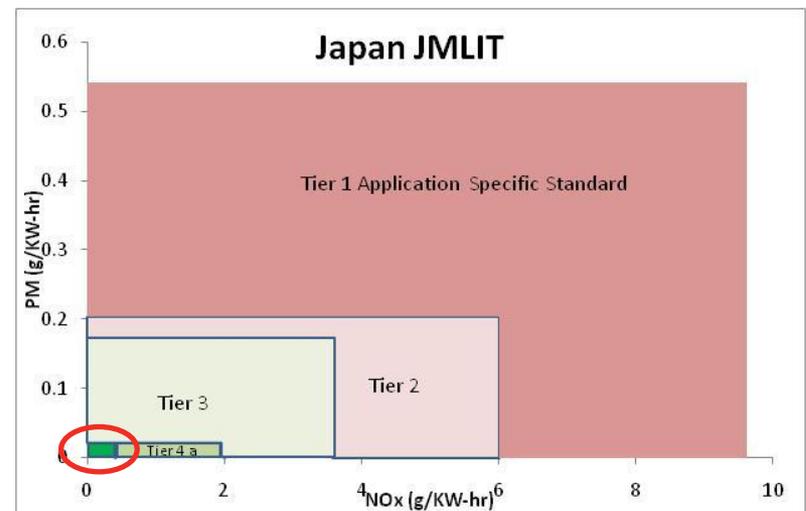
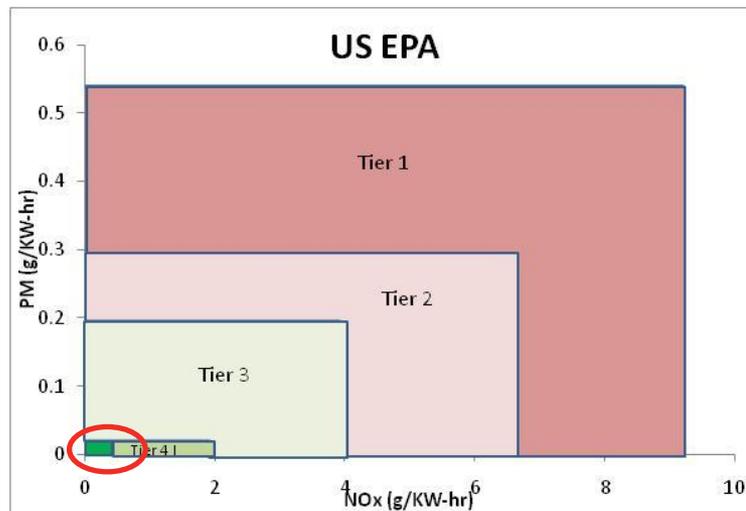
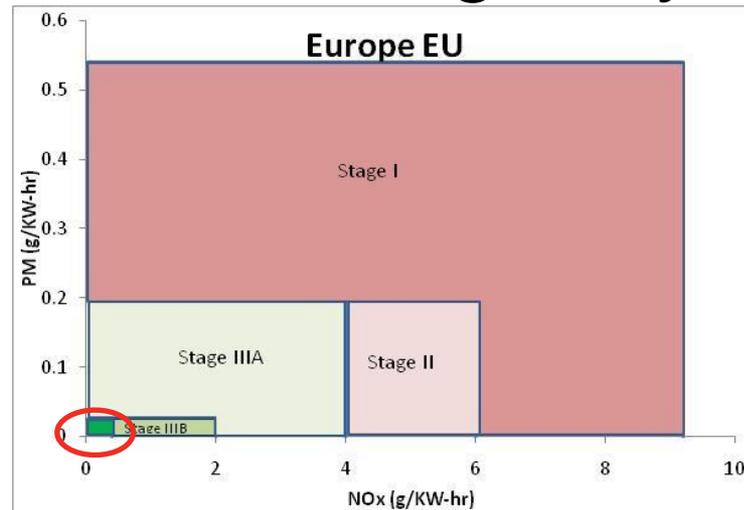


TIER 4

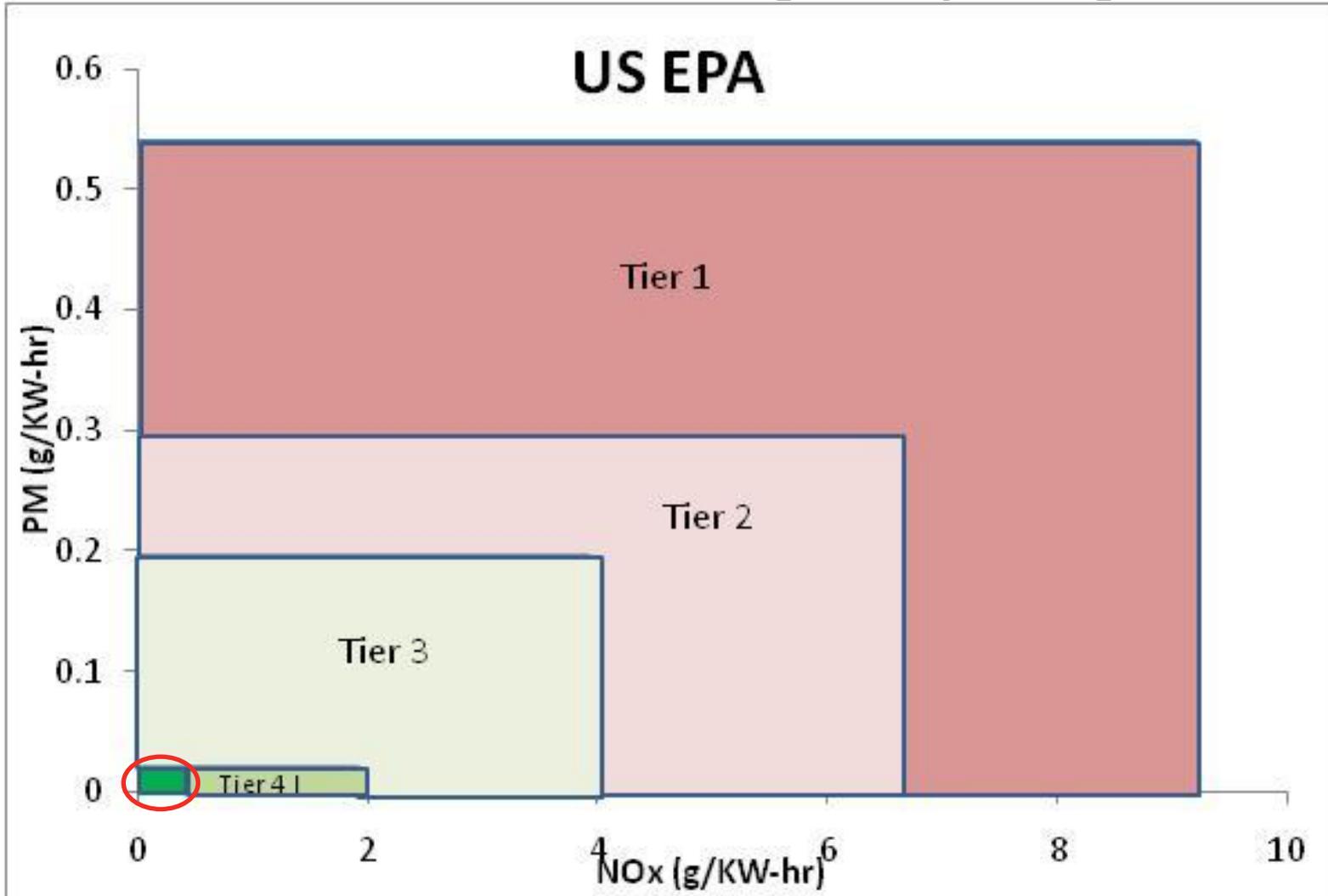
EMISSIONS LEGISLATION



Emission Box for Off-Highway Engines

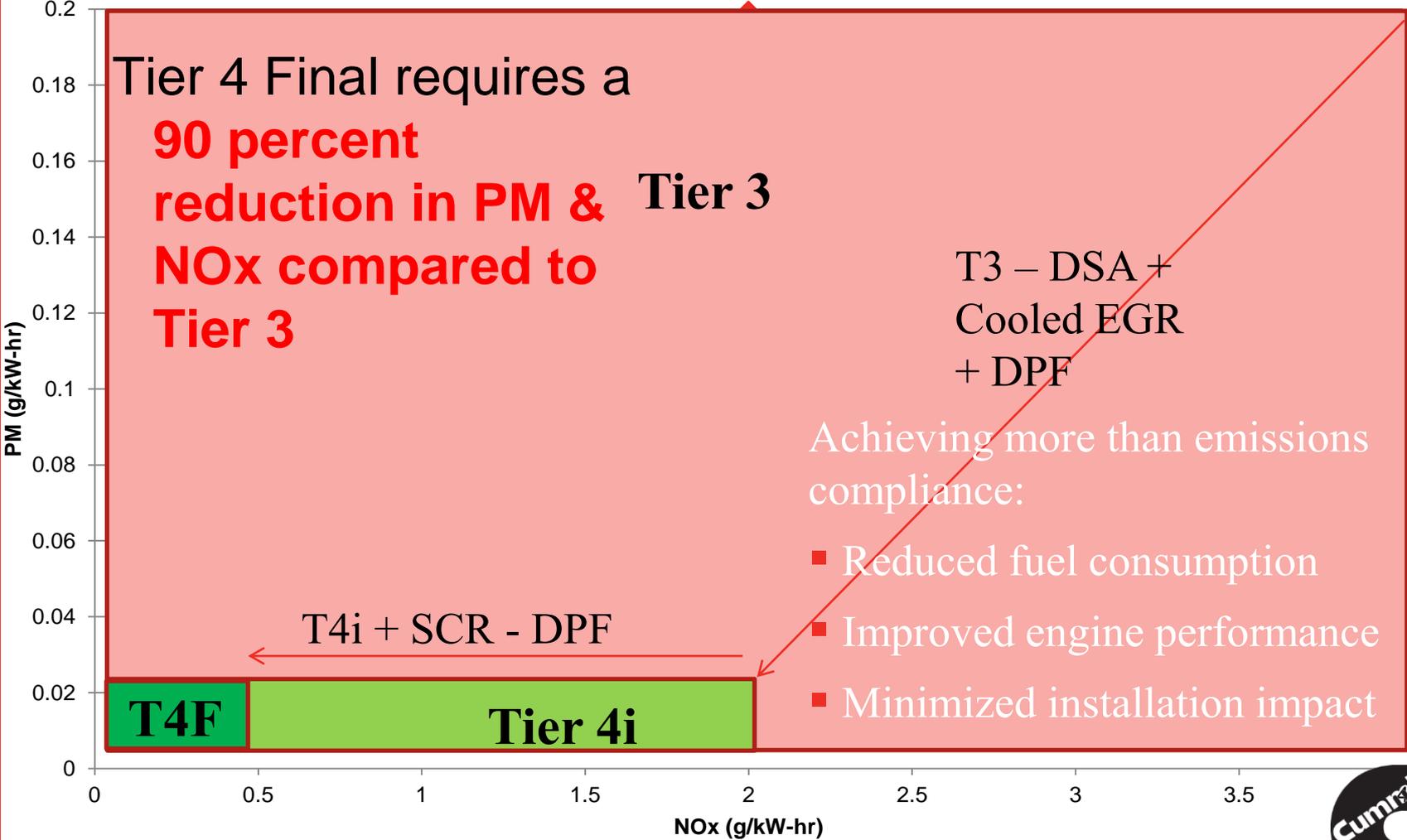


Emission Box for Off-Highway Engines



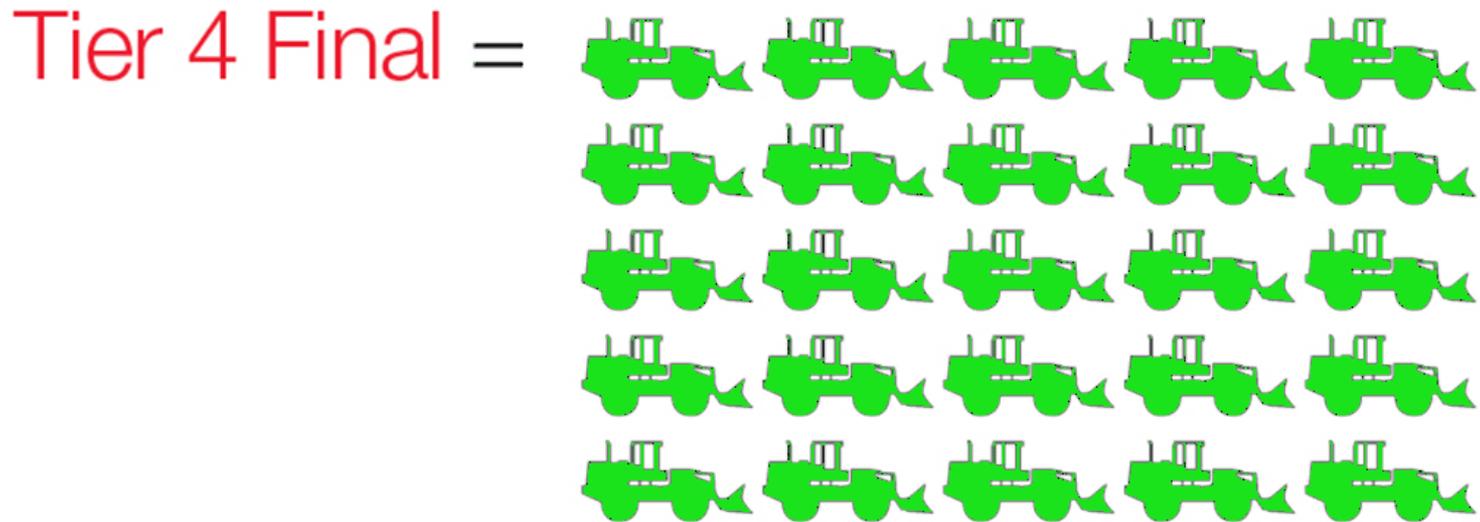
Emissions lineage

US Off-highway Emissions (<130kW)

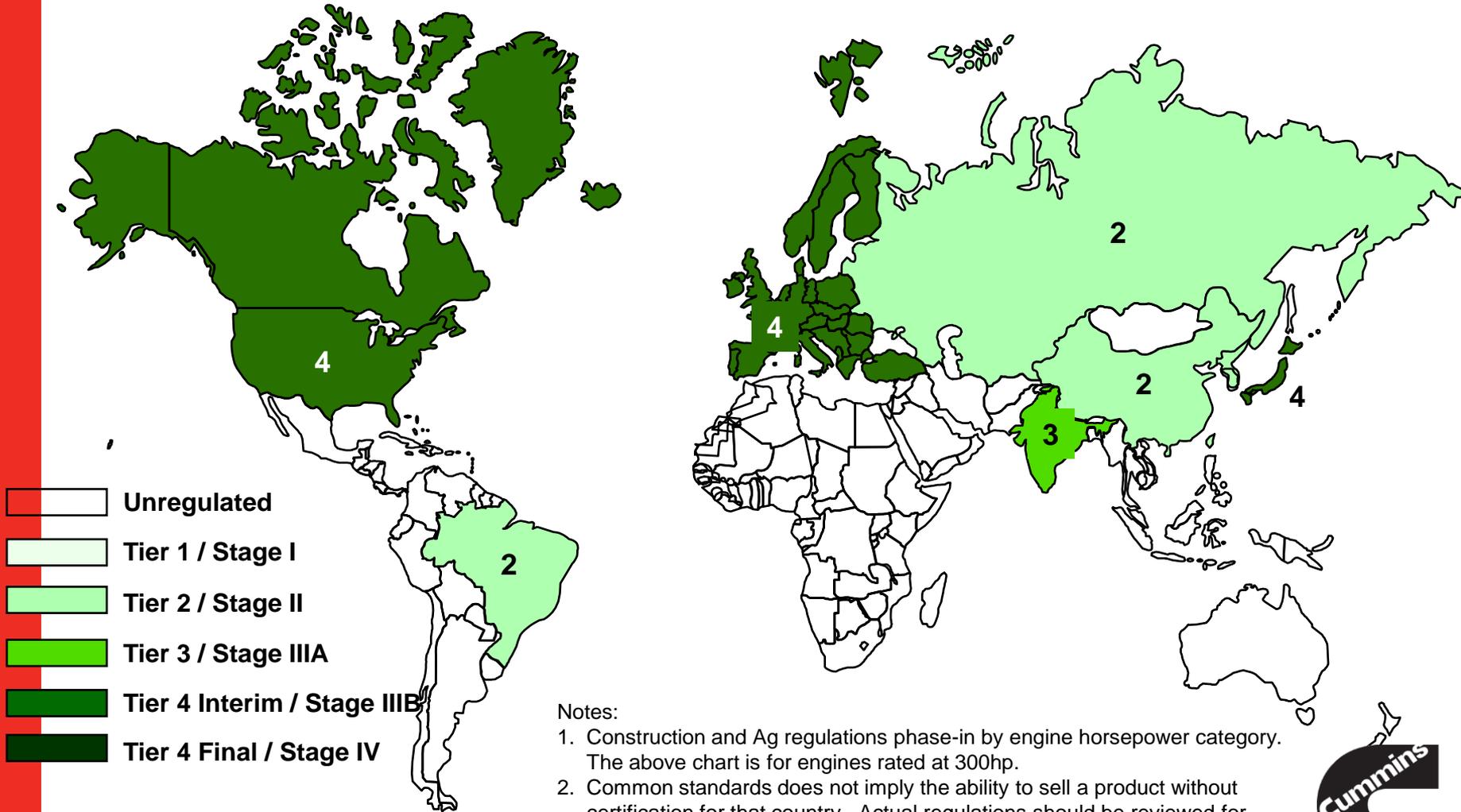


Achieving 'Near-Zero' Emissions

- Emissions from 25 x Tier 4 Final machines will be equivalent to just 1 x Tier 1 machine



Construction and Ag - 2011

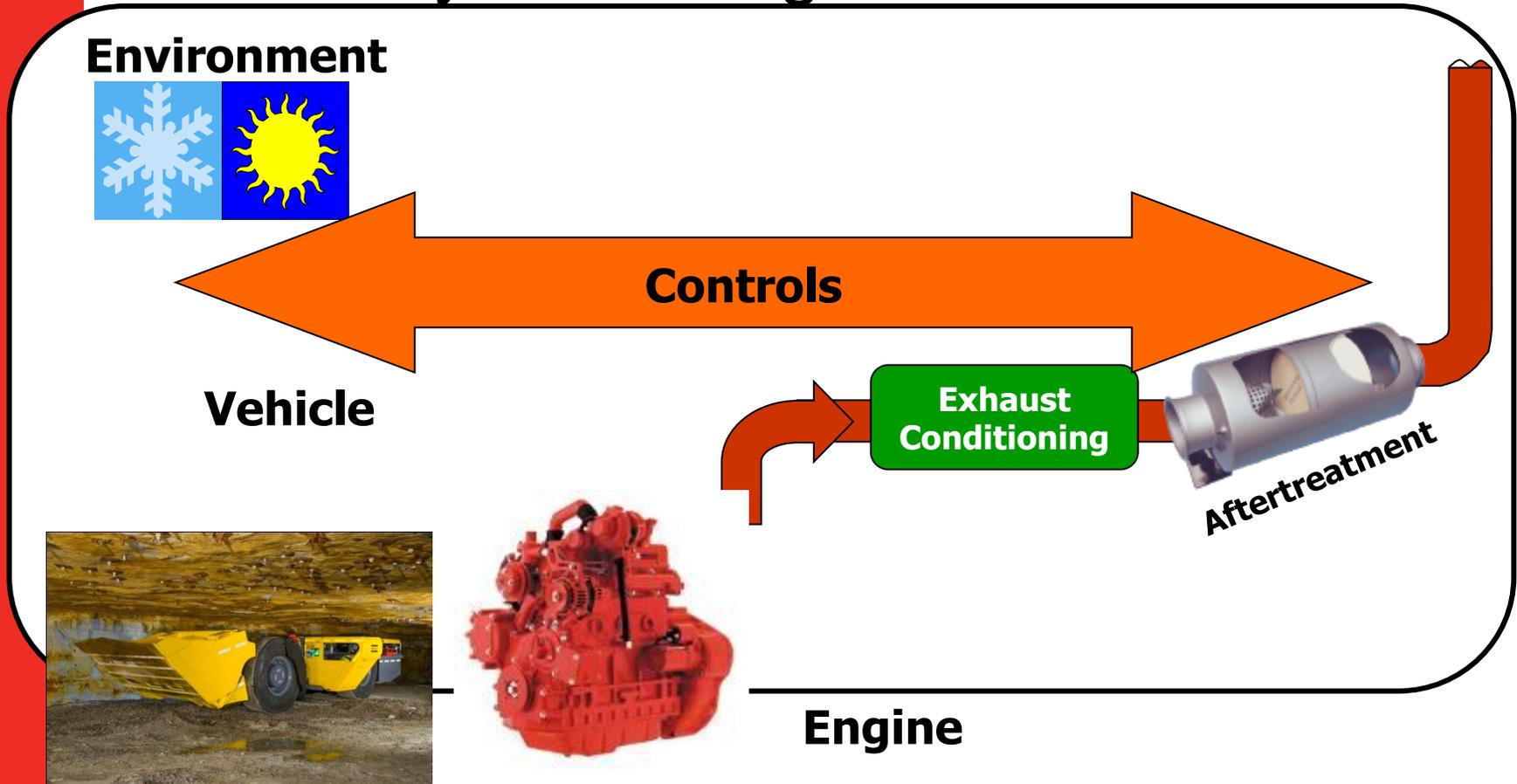


Tier 4

CUMMINS TECHNOLOGY REVIEW



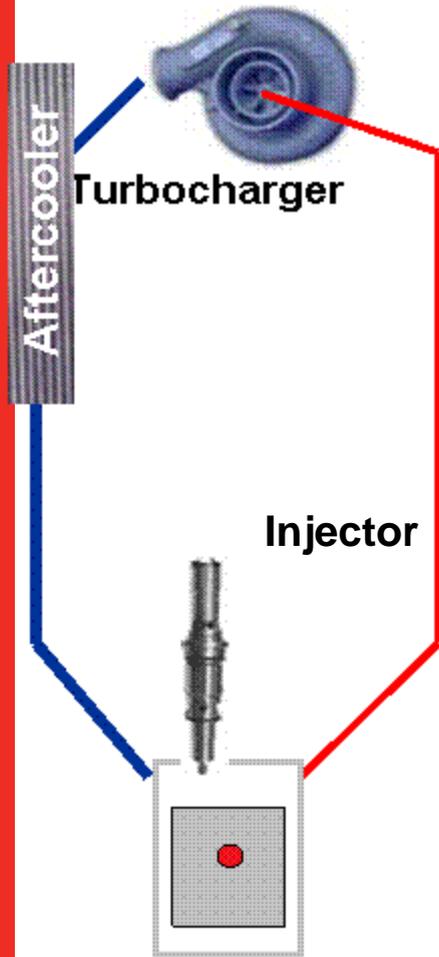
System Integration is Critical



The machine, engine and aftertreatment are part of a single system designed to optimize performance reliability, cost and emissions

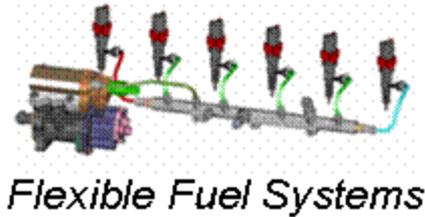


Building Blocks for Meeting Tier 4 Emissions

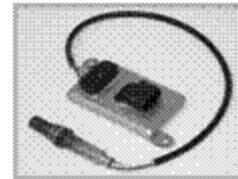


Cummins Tier 3 Engine

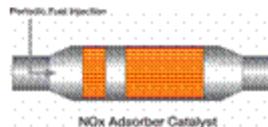
Possible Tier 4 Building Blocks



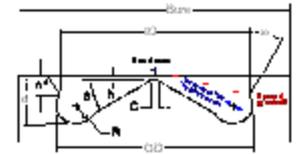
Air Handling



Advanced Controls



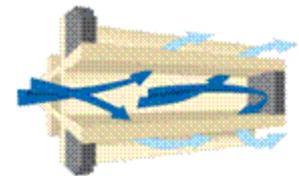
NOx Adsorber



Combustion Optimization



Cooled EGR



Particulate Filter



SCR

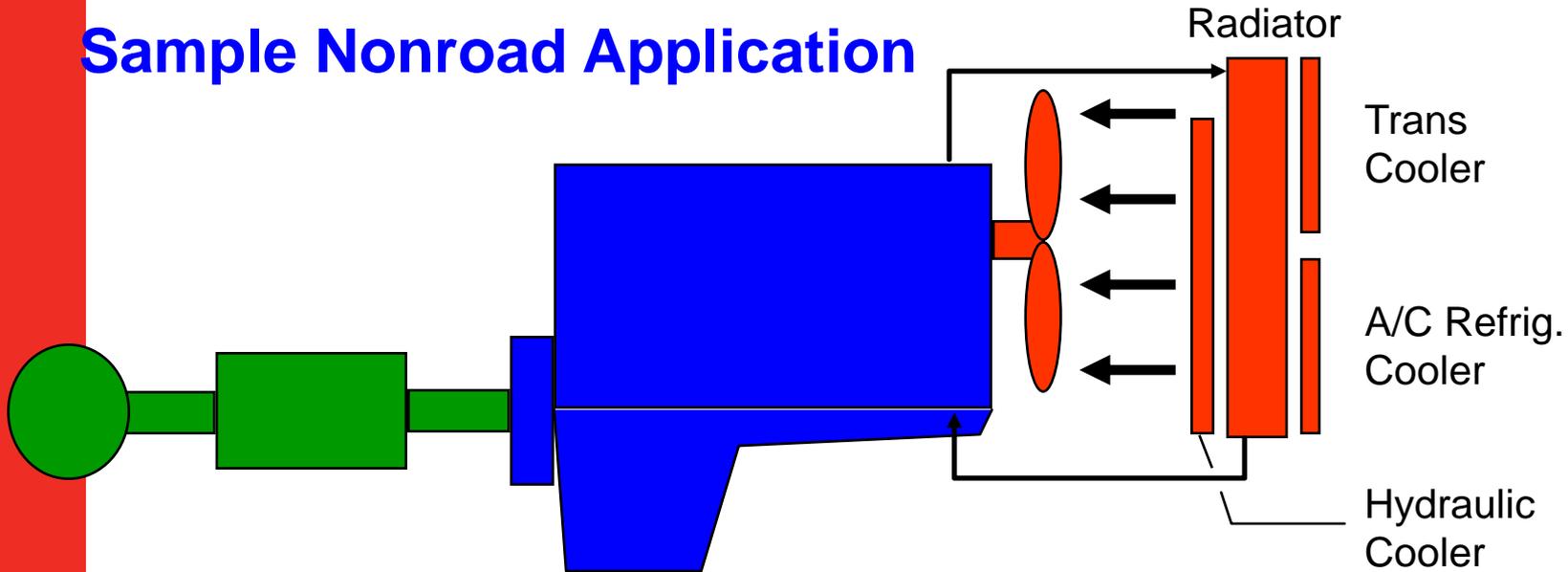


On-Highway ≠ Nonroad



On-Highway \neq Nonroad

Sample Nonroad Application



Drivetrain

Many Suppliers Of Low
Volume Components
Varied Drivetrain
Requirements

Engine

Many Ratings
Several Product Families
High Load Factors

Cooling System

Limited Available Space
No Ram Air; fan HP Increases
More Auxiliary Coolers
Dusty Environment
High Vibration & Impact Loads

Fuel sulfur content up to 5000 ppm, gone to 500 then 15 ppm in US by 2010.

Many OEM's, Global Business



Key Tier 4 Development Areas

■ Heat Rejection

- Minimization
- Optimization of cooling systems

■ Application Variation

- Robust to installation variation
- Cost impact for vehicle installation

■ Environmental Robustness

- Dust/Dirt
- Surface temperature requirements
- Vibration/Shock

■ Develop a solution with the lowest initial and life-cycle cost



“In-Cylinder” Development

- Exhaust Gas Recirculation (EGR)
- Advanced Combustion
- Variable Geometry Turbocharging (VGT)
- Fuel System



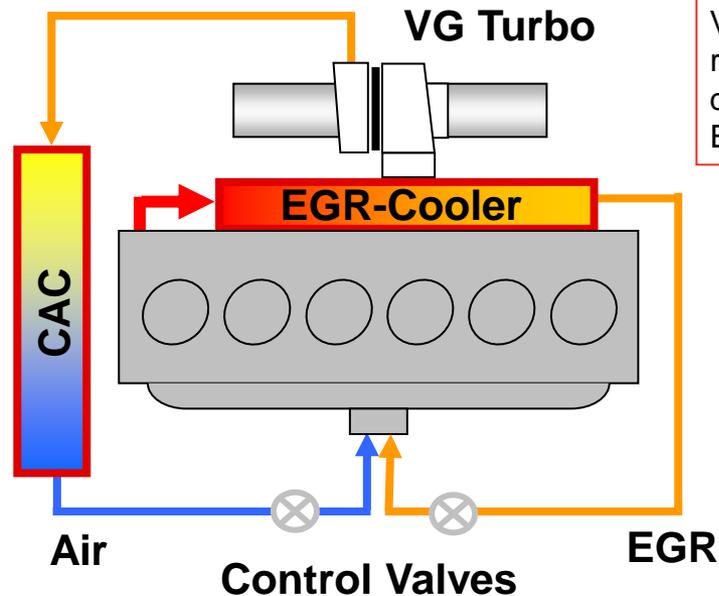
How EGR Works

- Cooled exhaust gas recirculation for NOx reduction for Cummins Tier 4/Stage IIIB

Recirculates the exhaust gas back into the cylinder reducing oxygen concentration. This lowers combustion temperature to reduce the formation of Oxides of Nitrogen (NOx)

Upgraded cooling package mitigates increased engine heat rejection

EGR system sensitivity to high sulfur fuel made it less viable for Tier 3 application, but offers potential for Tier 4 with ULSD

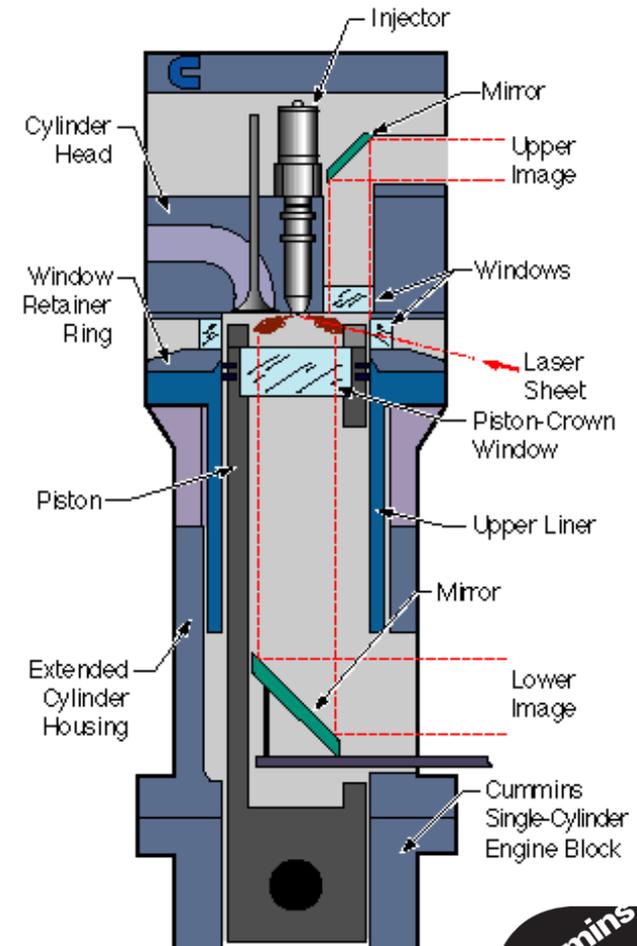
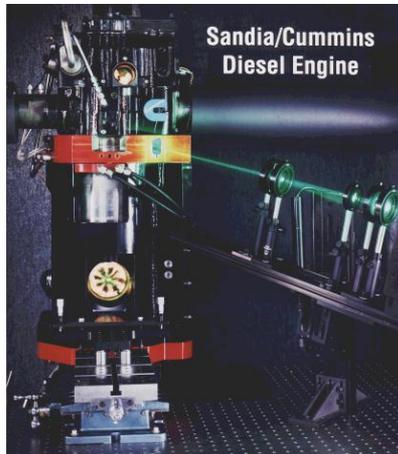


Variable geometry turbocharging is required to maintain correct pressure differential across the engine for ideal EGR flow

Control valve modulates the % EGR returned to cylinder

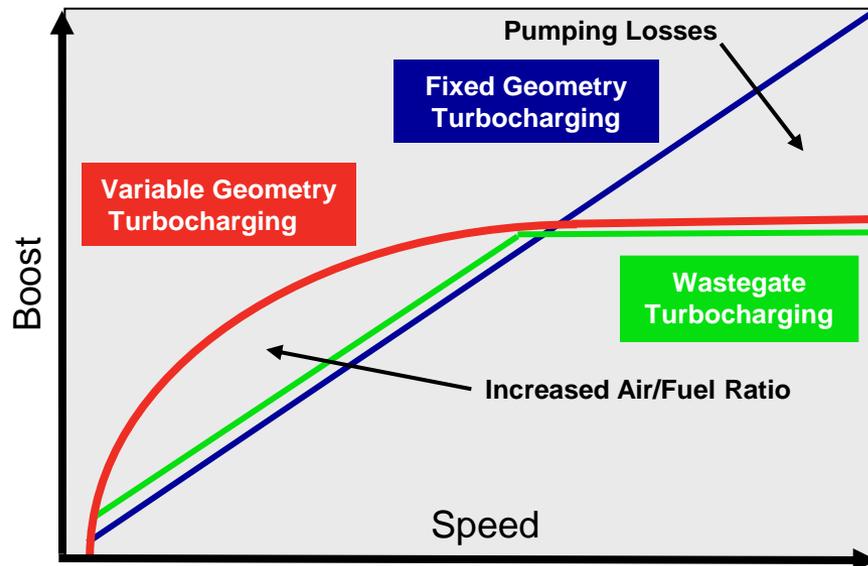
Advanced Combustion

- World class combustion research by Cummins & Sandia National Laboratories
- Laser-optical imaging of the combustion process gives precision modelling of injection spray & diffusion flame
- Enhances Cummins capability to meet emissions & optimize for fuel economy



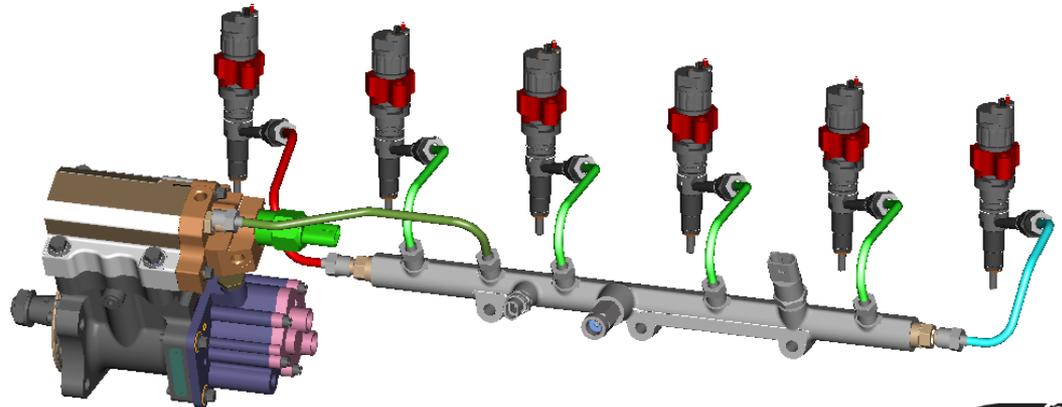
Cummins VGT

- Cummins variable geometry turbocharger with patented sliding nozzle design
- Improves boost efficiency across all engine speeds/loads
- Proven technology for Tier 4/Stage IIIB



Fuel Systems

- Cummins designs & manufactures high pressure common rail fuel systems
- Tier 4/Stage IIIB fuel systems requires:
 - higher fuel injection pressure
 - very fast response with multiple injection events
 - precise control of fuel metering timing
- Cummins next generation HPCR is recognized as industry leading technology



Aftertreatment Technology

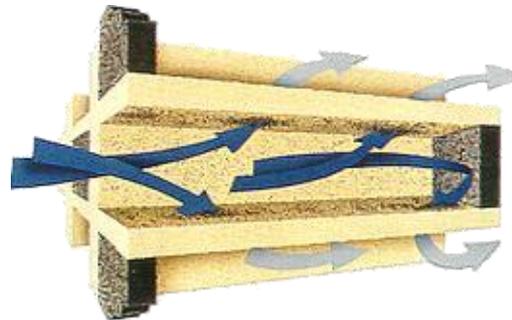
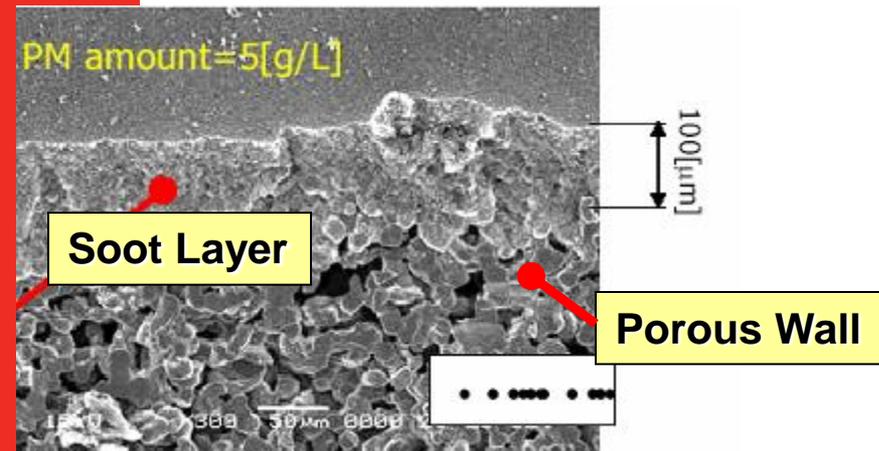
- Diesel Particulate Filters (DPF)
- Diesel Oxidation Filters (DOC)
- Selective Catalytic Reduction (SCR)



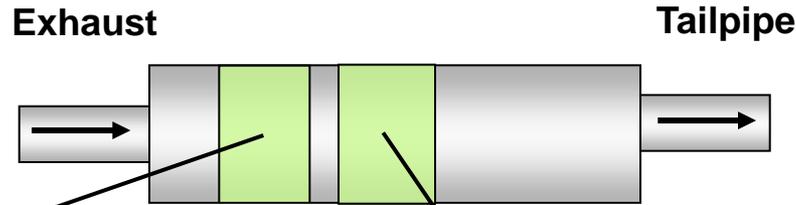
Wall Flow Particulate Filter



- A full filter consists of a porous ceramic honeycomb for collecting particles in the exhaust gas.
- The filter can be coated with precious metal for enhancing oxidation of hydrocarbons promoting low temperature oxidation of soot.
- On average, full filters reduce PM by about 90-95%.



How The DPF Works



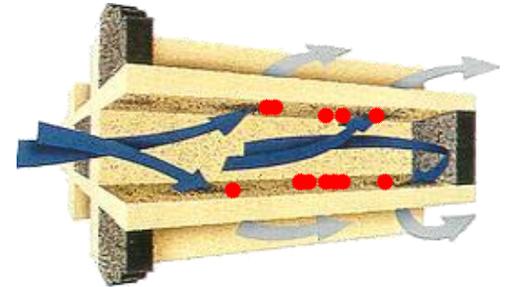
Diesel Oxidation Catalyst

DOC catalytic material reacts above 572°F (300°C) in passive regeneration mode to generate Nitrogen Dioxide (NO₂) which oxidizes the carbon soot



Diesel Particulate Filter

Ceramic wall flow filter captures up to 95% of the carbon soot (PM) carried by the NO₂. This collects on the filter to form Carbon Dioxide (CO₂) which leaves the tailpipe as clean gas



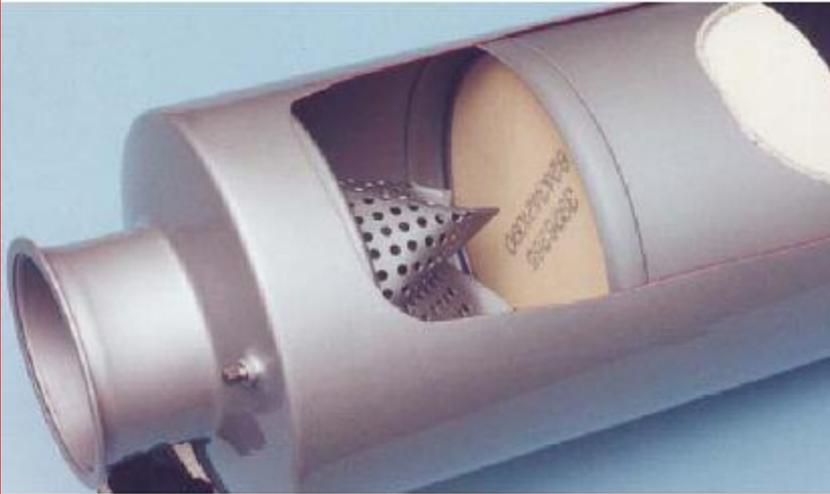
Active Regeneration

When soot accumulation in the DPF exceeds soot oxidation a periodic active regeneration mode is performed to prevent filter plugging. This is actuated by small quantities of fuel from a dosing injector or HPCR injection pulse during exhaust blow down. The heat released (no flame or burning) at 1022°F (550°C) ensures sufficient oxidation to remove soot

Filter Service

Build up of incombustible ash will eventually require filter service cleaning, though only required at very long intervals

Urea Based SCR: Overview



- A vanadia or zeolite based catalytic coating is applied to a honeycomb substrate
 - A urea-water solution (“AdBlue” or “DEF”) is used as a reagent for converting NO_x to N₂
-
- The urea is converted to ammonia in the exhaust above 200 deg C
 - NO_x conversion efficiency is high above 250 deg C.
 - Averages 70-85% NO_x reduction

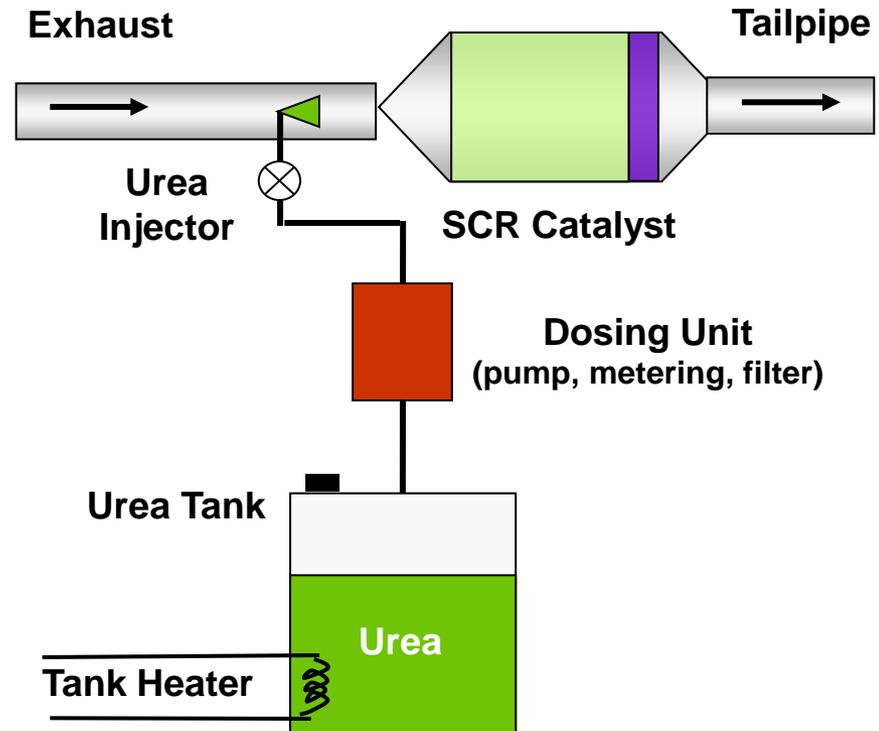
How SCR Works

Selective Catalytic Reduction

Urea solution is injected ahead of the catalyst. This converts to ammonia in the exhaust stream above 392°F (200°C)

The ammonia reacts with Oxides of Nitrogen (NO_x) over the SCR catalyst to form harmless nitrogen & water

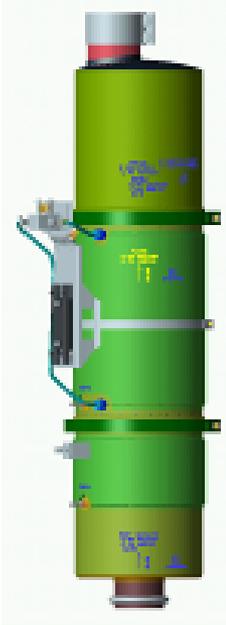
Urea is injected at a ratio of typically 5% to diesel fuel use, depending on duty cycle. Urea tank sizes vary, but must be refilled to ensure emissions compliance



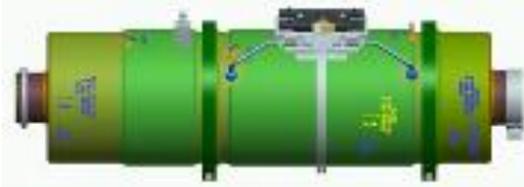
Urea Solution

The urea-water solution (AdBlue in Europe, DEF in USA) is a clear liquid, non-hazardous & non-flammable with a 12 month shelf life. Heaters are required to prevent urea freezing at 11°F (-11°F)

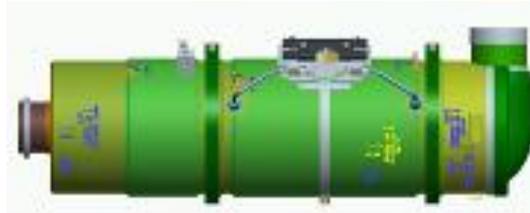
DPF & SCR Aftertreatment Configurations Examples



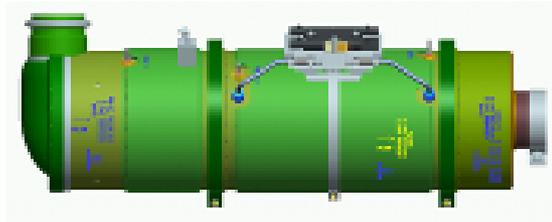
Vertical End-In End-Out



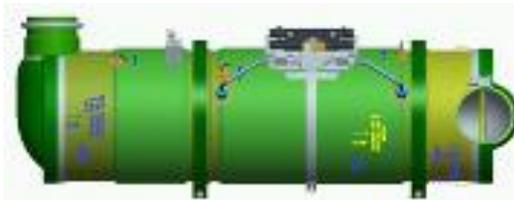
Horizontal End-In End-Out



Horizontal End-In Side-Out



Horizontal Side-In End-Out



Horizontal Side-In Side-Out



Vertical Side-In End-Out

Estimate of Application Impact of Cooled EGR & Aftertreatment for T4 QSB6.7

	Estimated Change from Tier 3
Heat Rejection to Coolant	40% increase
Heat Rejection to CAC	25% decrease
Engine Package	Addition of cooled EGR components
Aftertreatment Size	~ 12 inch diameter X 27 inch long canned with inlet & outlet sections
System Weight	Engine ~ 1180 (wet) Aftertreatment ~ 85 lb



TIER 4

CUMMINS ADVANTAGE



Experience Counts

- No engine manufacturer has this experience with Tier 4 technology:
 - 1,000,000 EGR Engines
 - 650,000 DPFs
 - 350,000 SCR systems produced
 - 100,000 XPI systems produced
 - 3 million VGTs produced
- The emissions requirement for later off-highway markets were part of the initial design profile of EGR, VGT & DPF
- We leverage our automotive platforms to develop products that are validated for the off-highway market



System Integration

- Unique in the industry – we design, build and integrate the complete system



Filtration



Diesel Exhaust Fluid



Direct Flow



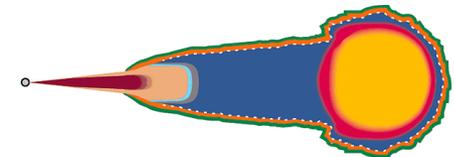
Electronic Controls



Aftertreatment System



Turbochargers



Combustion Technology



Fuel Systems

Clear Advantage: Fuel-Efficiency

Tier 4 Interim fuel saving over Tier 3	up to 5% typical
Tier 4 Final fuel saving Over Tier 4 Interim	Preliminary estimates: additional 2-3% (more than offsetting DEF cost)
Typical fuel saving at 5% (2500 hours / 6 gals hr)	750 gallons per year \$3000 saved
C02 savings (1 gal = 22.2 lbs)	8 tons less per year
Power Output / Transient Response	Retain Tier 4 Interim high output & improved response



Clear Advantage.
Every™ Time.

Tier 4 Final Architecture

QSB3.3

QSB4.5

QSB6.7

QSL9

QSX11.9

QSX15



CCC-SCR



CCC- SCR



CPF-SCR



Retain T4i Power Output

Retain CCC Installation Simplicity

Utilize CCC Simplicity

Retain or Lower Cost Of Operation

Increase Power Output / Density

Particulate Filter 'virtually' passive

Lower Cost Of Operation

Engines Pre-designed For Final

- Tier 4 Interim engines pre-designed for Final
- No significant change to engine installation envelope
- Ready to integrate with incremental SCR aftertreatment



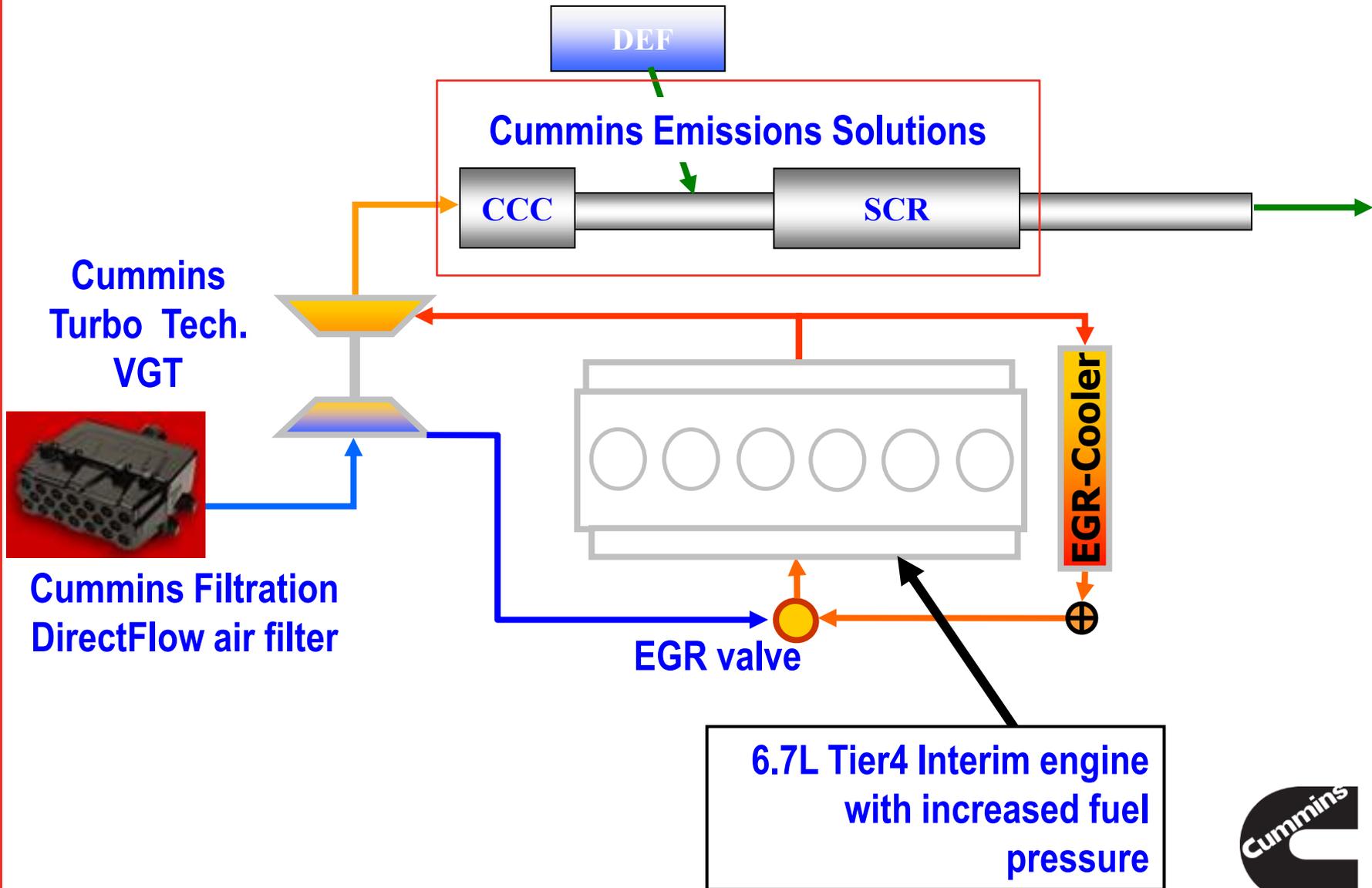
Tier 4 Interim and Tier 4 Final



QSB6.7



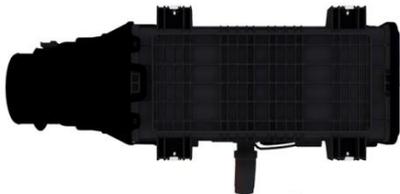
Tier4 Final QSB6.7 Architecture



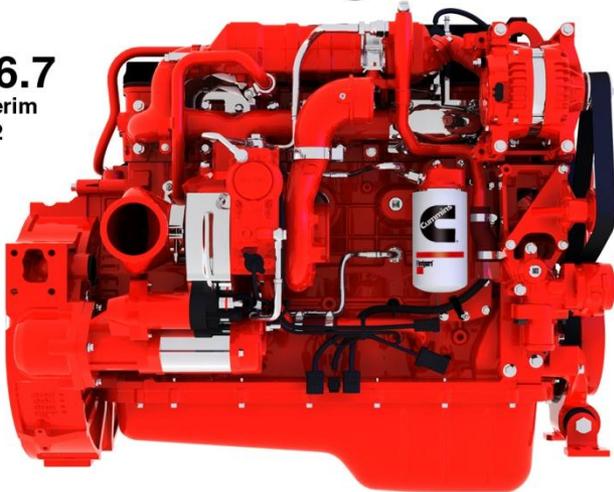
Interim to Final: QSB6.7

2011/12 146-300 hp 2014/15

Cummins
Direct Flow
Air Cleaner



QSB6.7
Tier 4 Interim
2011/2012



Cummins
Particulate Filter
(above 174 hp 2011)



Cummins
Compact Catalyst
(below 174 hp 2012)



**Ultra-Clean
Aftertreatment
CCC-SCR**
Cummins Compact Catalyst
Selective Catalytic Reduction

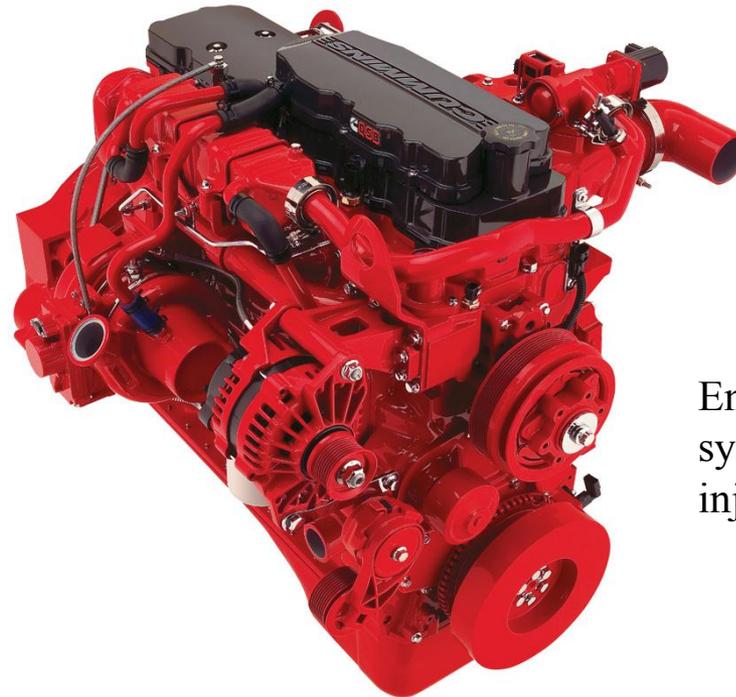


Interim to Final: QSB6.7

- Same power output and performance
- Fuel consumption further reduced
- No change to engine installation

Balanced EGR with SCR aftertreatment

ECM upgraded for faster processing
& SCR logic



Single VGT for
300 hp output

Enhanced HPCR
system with higher fuel
injection pressure

QSB6.7 engine lineage

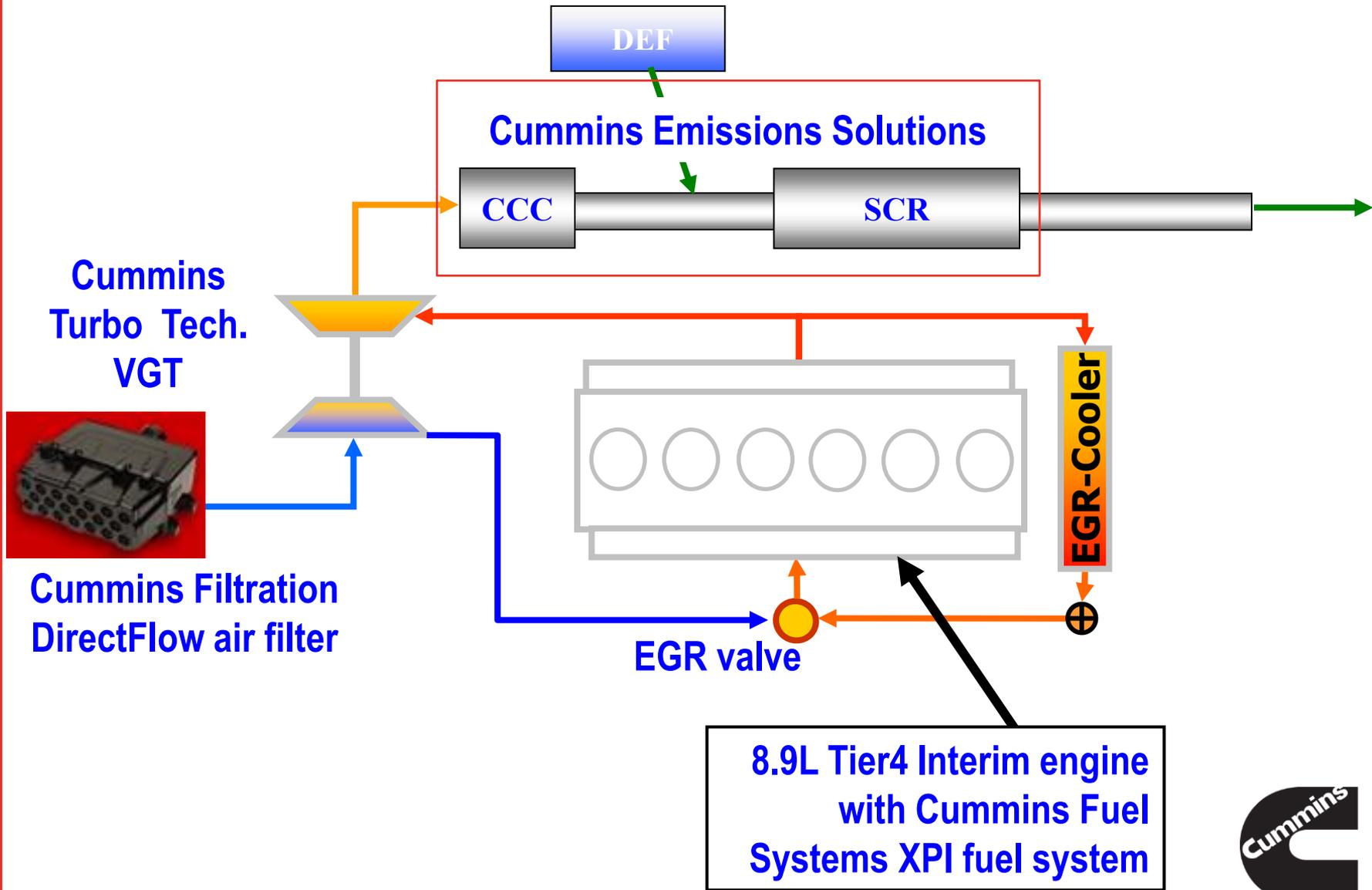
QSB6.7 GT174hp	T3	T4i	T4F
ECM	CM850	CM2250	CM2350
Fuel pressure	1600 bar	1800 bar	2200 bar
Turbocharger	WGT	VGT	VGT
NOx control	DSA	Cooled EGR	Cooled EGR + SCR
Crankcase ventilation	OCV, impactor only	OCV, coalescing filter	OCV, coalescing filter
Aftertreatment	None	DOC+DPF	DOC+SCR



QSL9



Tier4 Final QSL9 Architecture



Interim to Final: QSL9

2011

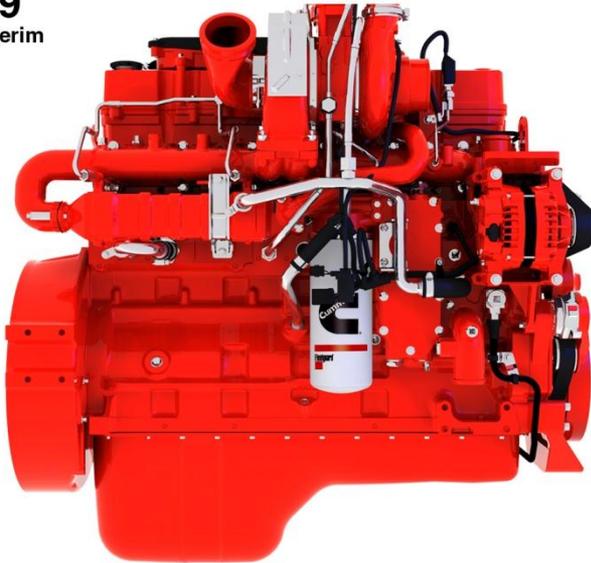
190-400 hp

2014

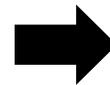
Cummins
Direct Flow
Air Cleaner



QSL9
Tier 4 Interim
2011



Cummins
Particulate
Filter



**Ultra-Clean
Aftertreatment
CCC-SCR**
Cummins Compact Catalyst
Selective Catalytic Reduction



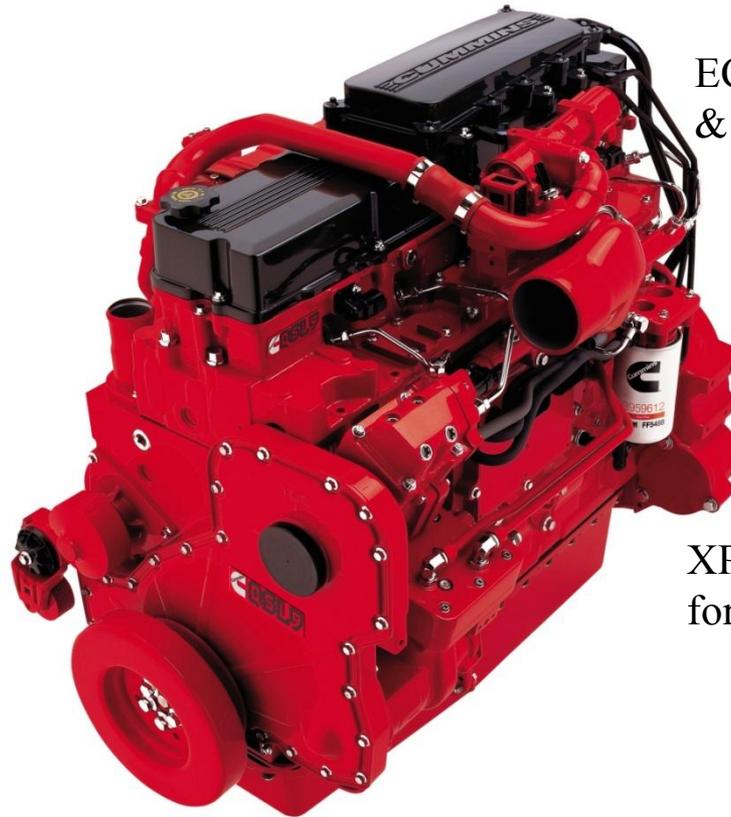
Interim to Final: QSL9

- Same power output and performance
- Fuel consumption further reduced
- No change to engine installation

Balanced EGR with SCR aftertreatment

ECM upgraded for faster processing
& SCR logic

Single VGT for
400 hp output



XPI fuel system capable
for Tier 4 Final

QSL9 engine lineage

QSL9	T3	T4i	T4F
ECM	CM850	CM2250	CM2350
Fuel pressure	1600 bar	2100 bar	2100 bar
Turbocharger	WGT	VGT	VGT
NOx Control	DSA	Cooled EGR	Cooled EGR + SCR
Crankcase ventilation	OCV, impactor only	OCV, coalescing filter	OCV, coalescing filter
Aftertreatment	None	DOC+DPF	DOC+SCR



Program Schedule

- Alpha build Q4 2011/Q1 2012
- Beta build Q4 2012/Q1 2013
- Limited Production Q4 2013
- Full Production - January 1, 2014



Field Test Activity

- Tier 4 VPI Service Team has compiled over 30,000 field test hours during Tier 4 Interim testing
- Tier 4 Final field test plan should achieve over 50,000 field test hours prior to launch
 - Several T4i field tests continuing on to T4F
- Field testing has incorporated 1) Cummins QSB6.7/QSL9 engines, 2) Cummins Emission Solutions Aftertreatment Systems, and 3) Cummins Filtration Direct Flow Air Filtration to understand how our Tier 4 solution performs as a package
- Field test engines are monitored daily for issues
- Ultimate goal release a reliable product



Summary

- Cummins Tier 4 work has been underway since 2004
- We are leveraging our on-highway experience with these potential technologies while using standard tools and processes to ensure we select the right technology for off-highway
- Cummins Inc. is uniquely positioned to deliver an integrated and optimized system for Tier 4



■ Questions?

