

Cummins
Mobile
Off-Highway
Emission Technology
Development



August 2009



Agenda

- Cummins at a Glance
- Product Range
- Emission Regulations
- Technology
 - Cooled Exhaust Gas Recirculation (EGR)
 - Selective Catalytic Reduction (SCR)
 - Diesel Particulate Filters (DPF)
 - Quantum In Cylinder Technology
- B20 Biodiesel





Cummins at a Glance

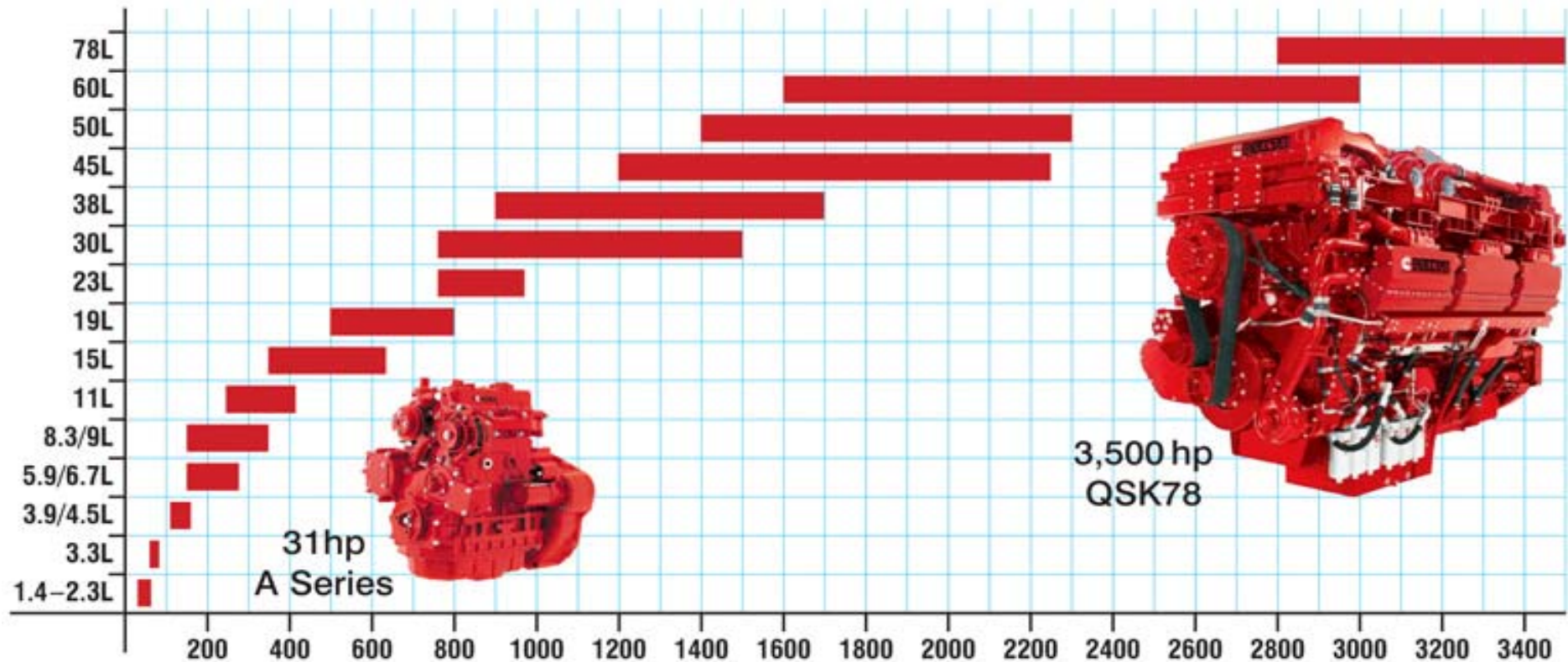
- *Clessie Cummins started operations in 1919 in Columbus Indiana.*
- *Now a Global manufacturer with **factory owned world wide distribution.***
- *\$15.3 Billion annual turn over (2008).*
- *Industry Leader in Diesel engine technology and **emissions solutions.***
- *Industry Leader in **Fuel efficiency initiatives.***
- *Market segments: Mining, Automotive, Marine, Power Generation, Agriculture, Rail, Oil and Gas.*
- *Global commitment to **Customer Support Excellence.***





Broad Product Range

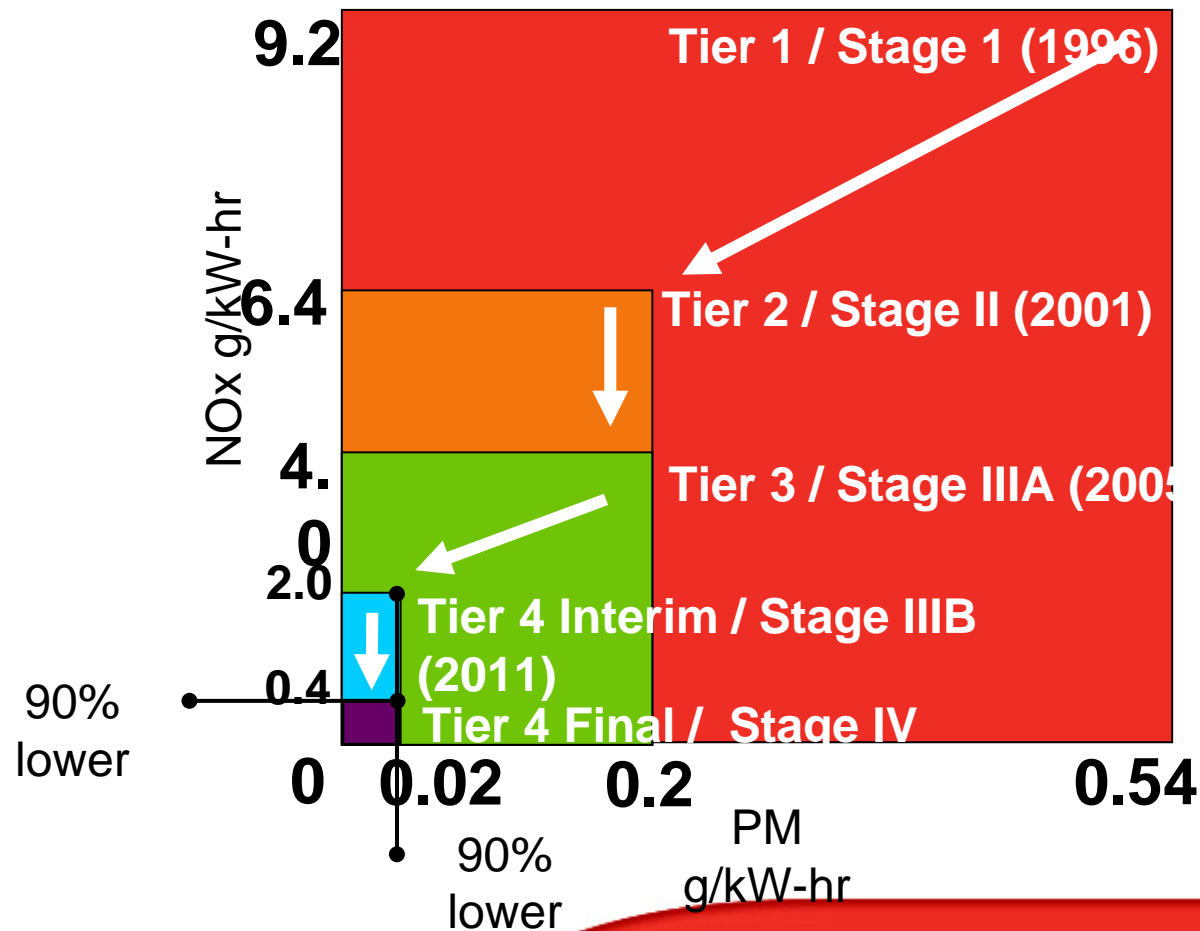
- A major expansion of the range since the late 1990s with twice the number of engine platforms





Near Zero Emissions

Tier 4 brings a 90% reduction in emissions compared to Tier 3
Achieving near zero emissions by 2014 Final



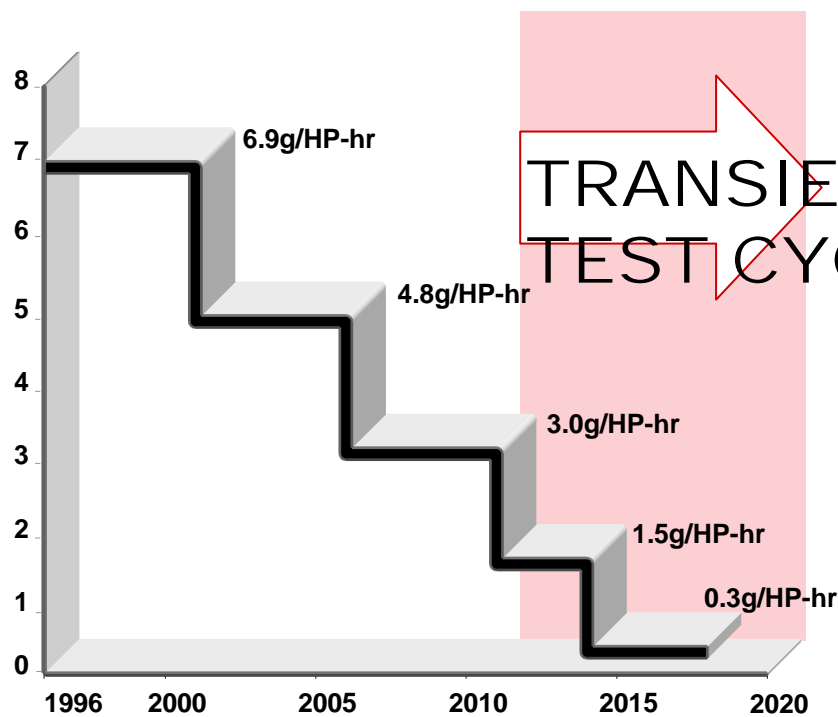
Representative of most stringent emission levels
174-751 hp (130-560 kW)



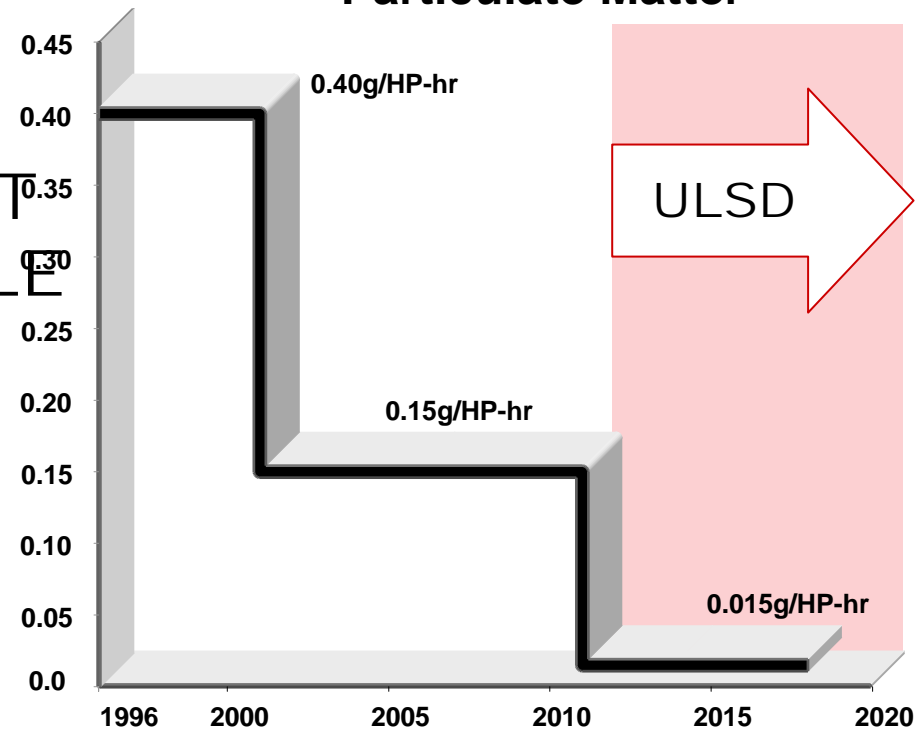


Towards Tier 4 Final 2014

NO_x / NO_x+HC



Particulate Matter



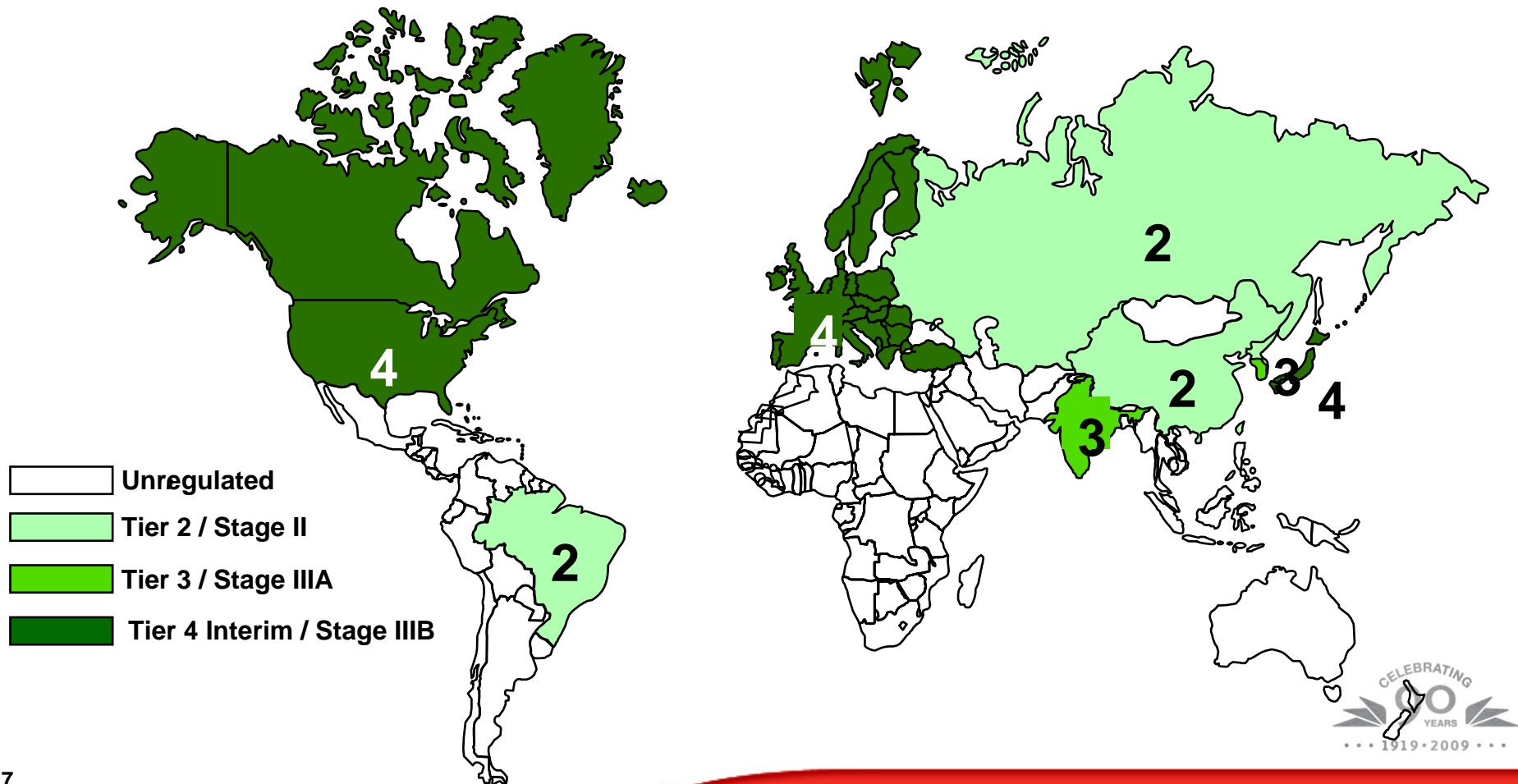
Near-Zero Emissions





Non-Road Emissions 2011

Tier 4 commences N. America, EU & Japan for >174 hp
Very limited availability of ULSD expected in other areas



Improving Air Quality: Tier 3 MOH Below 751 hp (560 kW)



US EPA Mobile Off Highway	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
302 - 602 HP	Tier 1	Tier 2				Tier 3				Tier 4			
603 - 751 HP	Tier 1	Tier 2			Tier 3				Tier 4				
> 751 HP	Tier 1					Tier 2					Tier 4		
European Union	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
302 - 602 HP	Stage I	Stage II				Stage II A				Stage III B			
603 - 751 HP	Stage I	Stage II				Stage II A				Stage III B			
> 751HP	No Regulations in Effect												

Tier 2

NOx + HC 6.4
CO 3.5
PM 0.20

Tier 3

NOx + HC 4.0
CO 3.5
PM 0.20

Reduction

38%
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8 *Regulated in grams per kW hour (g/kW-hr)*



Meeting Tier 2: >751 HP



- Certified to EPA Tier 2 MOH levels (1/1/06)
- Visible smoke virtually eliminated at rated power
- Reduced engine noise

US EPA Mobile Off Highway	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	
302 - 602 HP	Tier 1	Tier 2				Tier 3				Tier 4				
603 - 751 HP	Tier 1	Tier 2				Tier 3				Tier 4				
> 751 HP	Tier 1						Tier 2				Tier 4			

Emission levels
reduction (g/kW-hr)

NOx	9.2	NOx + HC	6.4	39%
HC	1.3		--	--
CO	11.4	CO	3.5	69%
PM	0.54	PM	0.20	63%



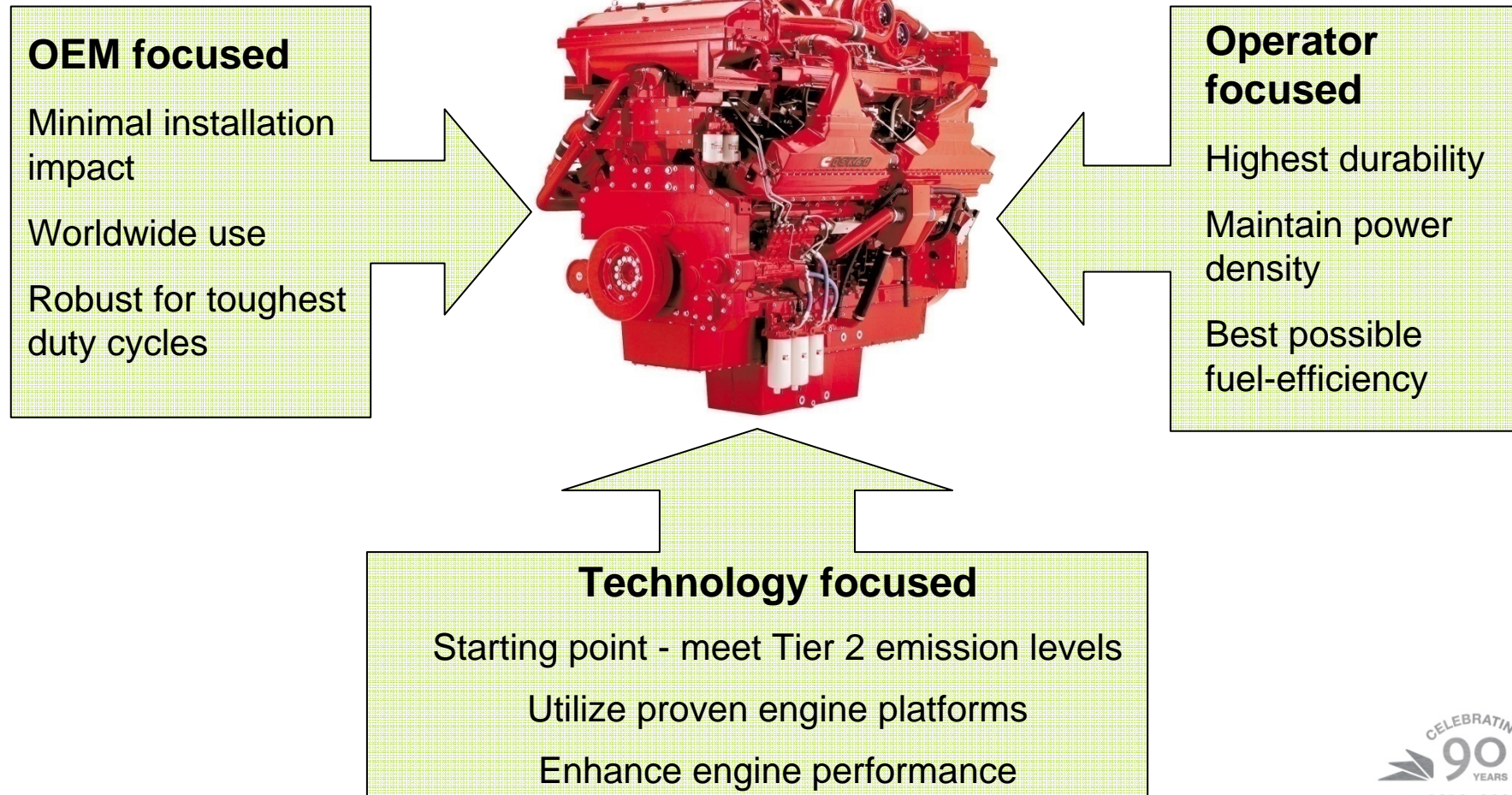


Technology Selection Criteria

- Engine manufacturers must consider the right technology for the customer needs
 - Reliability
 - Cost
 - Weight
 - Fuel consumption
 - Serviceability
- The best solution is common components across all applications and markets
- Requires a highly integrated technical supplier to match air handling, combustion, and emission control expertise leveraging on-highway heavy duty experience



Meeting Tier 2: The Design Challenge





Product Evolution <750 HP

Over 2 Million in Service
Reliable/Durable
Capable to Tier 2 emissions



B Mechanical

4 Valve Head with Centered Injection
Full Authority Electronic Fuel System
No Adjust Overhead



QSB

4 Valve Head with Centered Injection
High-Pressure Common-Rail Fuel System
Rear Gear Train
Advanced Combustion Technology
No Adjust Overhead



Tier 3/Stage 3
QSB



Technology Portfolio



- Cummins is able to leverage a broad range of technology solutions and experience
- The 'Right Technology' for each market

Application	Date	In-Cylinder Only	Cooled EGR/VGT	NOx Adsorber	SCR	PM Aftertreatment
Tier 3 / EU Stage IIIA	2005	●				
EPA Tier 2 > 751 hp	2006	●				
Euro 4 On-Highway	2006				●	
EPA 07 On-Highway	2007		●			●
EPA 07/10 Pickup Truck	2007		●	●		●
Euro 5 On-Highway	2009				●	
EPA 10 On-Highway	2010		●		●	●
Tier 4 Interim/ Stage IIIB	174-751 hp	2011	●			●
	75-173 hp	2012				



Cooled Exhaust Gas Recirculation

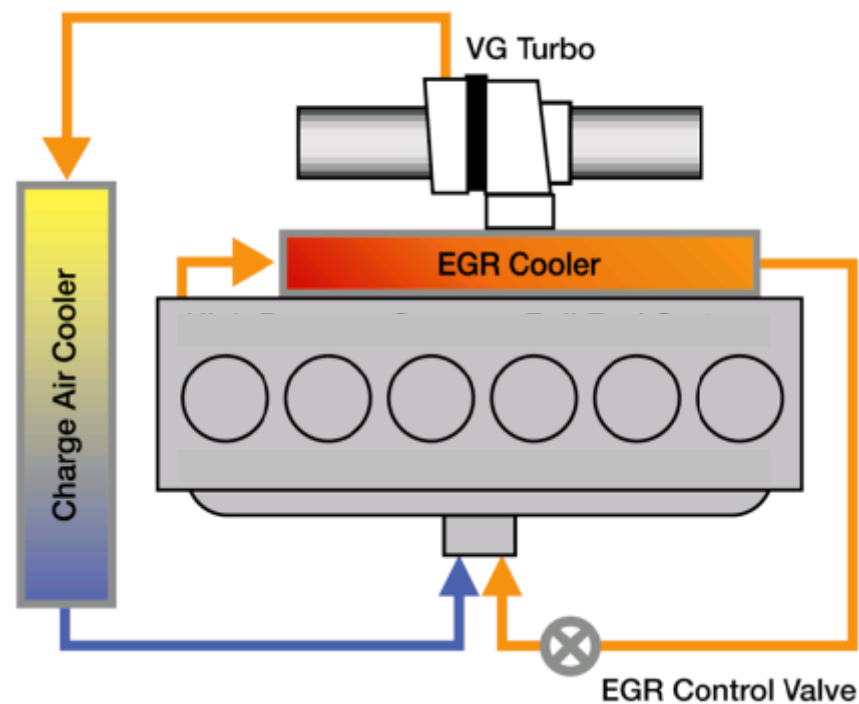
Cooled EGR or CEGR



Cooled EGR Process

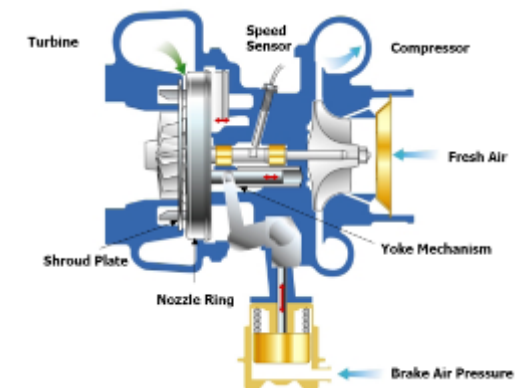
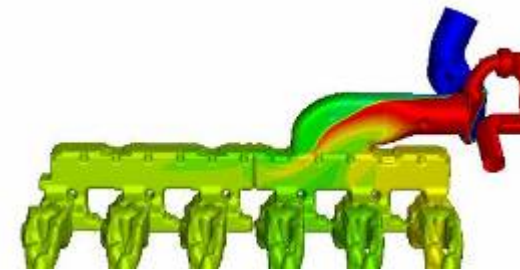
- Exhaust gas is taken from exhaust manifold and is cooled
- Exhaust gas is added to the intake manifold
 - ECM determines volume
 - EGR Valve controls
- Mixture of exhaust gas and fresh air is used in combustion cycle

Cooled-EGR Schematic



Key Components Needed for Cooled EGR

- **Exhaust Gas Cooler**
 - Shell and tube heat exchanger
 - Uses engine coolant to cool exhaust gas
- **Exhaust Gas Valve**
 - Electronically controlled by ECM
 - Hydraulically actuated using high pressure engine oil
- **Exhaust Gas Mixer**
 - Ensures homogeneous mixing of exhaust gas and fresh air
 - Mixing controlled by physical geometry
 - No moving parts or electronic control
- **Variable Geometry Turbocharger (VGT)**
 - Precision control of airflow at all engine speeds and loads
 - Provides necessary pressure differential to drive EGR
 - Electronically controlled by ECM
 - Hydraulically actuated using high pressure engine oil



Selective Catalytic Reduction





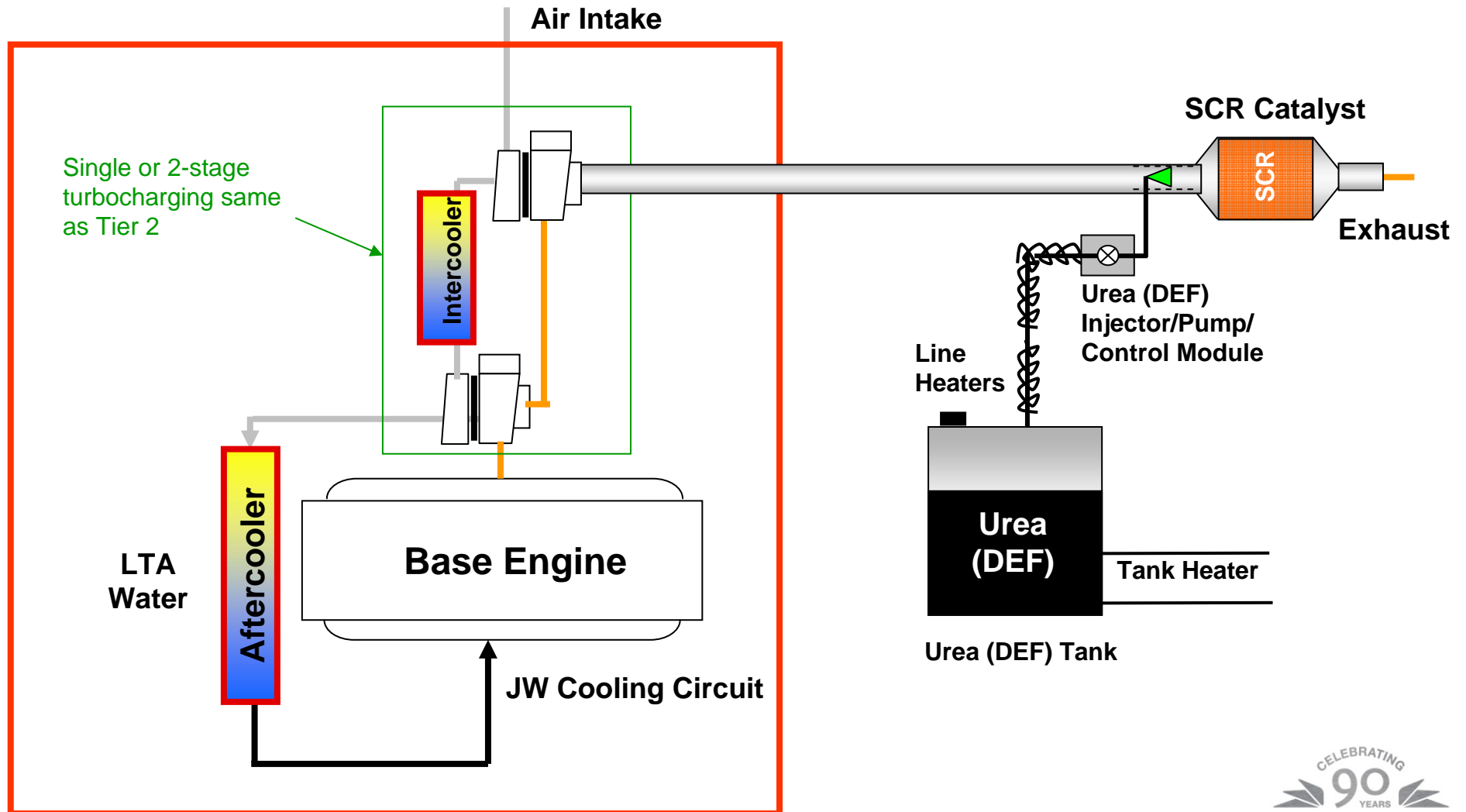
Selective Catalytic Reduction (SCR) Philosophy

- Ammonia and catalyst to transform NO_x in exhaust into nitrogen (N) and water (H_2O)
- A “reductant” is added to exhaust flow to create the reactions in a catalyst chamber
 - Liquefied Urea is best choice $(\text{NH}_2)_2\text{CO}$
 - Proven in on-highway European applications
 - Safe, clean, effective, and available worldwide





SCR Schematic for Tier 4 Interim





Key Components Needed for SCR

- Base engine very similar to current Tier 2
 - Air handling optimized for increase in back pressure
 - Low PM combustion recipe
- Urea handling and injection components
 - Urea tank
 - Urea pump
 - Dosing unit for injection
 - SCR catalyst chamber
 - Temperature and NOx sensors



Diesel Particulate Filter



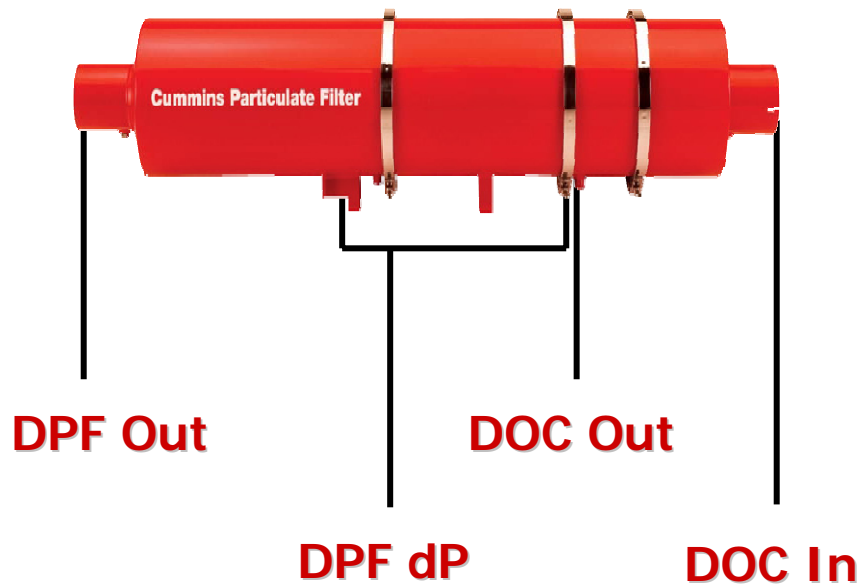


Diesel Particulate Filter (DPF)

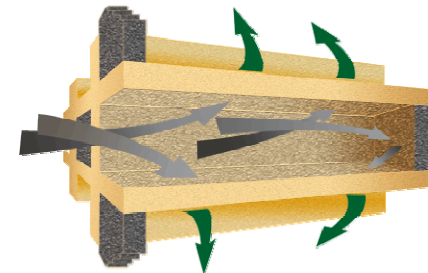
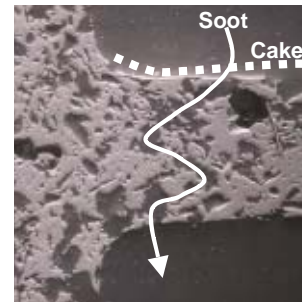
- The DPF filters and retains particulate in order to prevent the particulate from entering the atmosphere
- A Diesel Oxidation Catalyst (DOC) is used in sequence with the DPF (DOC – DPF)
- The DOC is used to drive up the exhaust stream temperature in the presence of exhaust-laden hydrocarbons
- The DPF is regenerated (PM burned off) by injecting hydrocarbons into the exhaust stream ahead of the DOC
- A DPF can be used in association with NOx-reducing technologies to meet Tier 4 Final emission limits



DPF Hardware

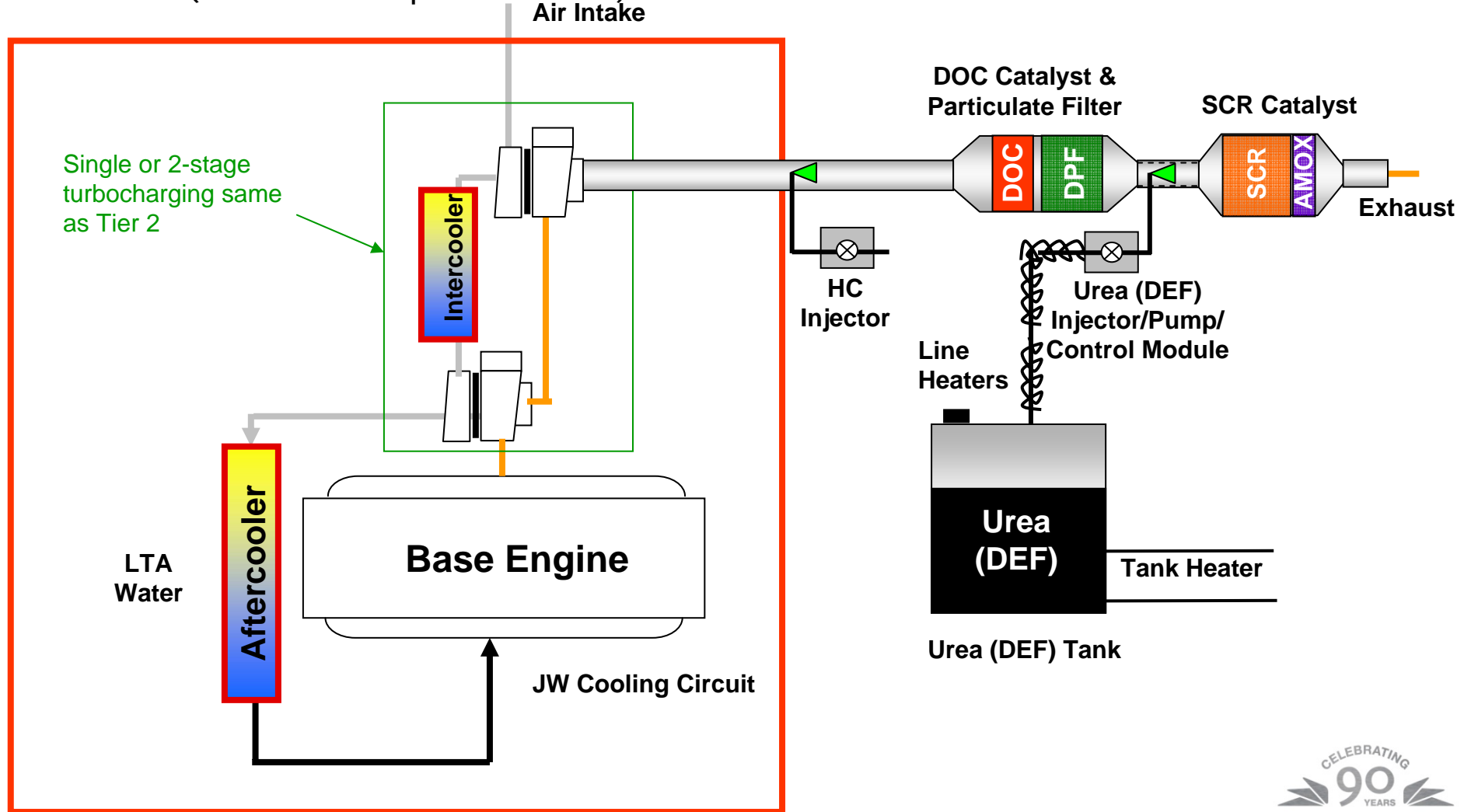


Wall-flow Filtration





DPF/DOC Schematic for Tier 4 Final (SCR example shown)



Quantum In Cylinder Technology



Meeting Tier 2: Proven Technology Enablers



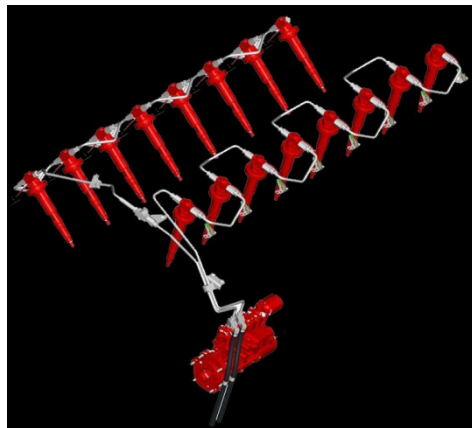
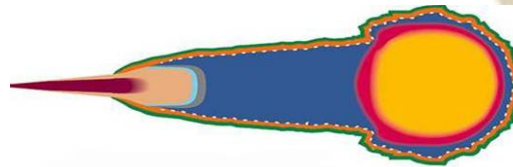
Combustion

Quantum advanced in-cylinder combustion proven on Tier 3 engines



Power cylinder

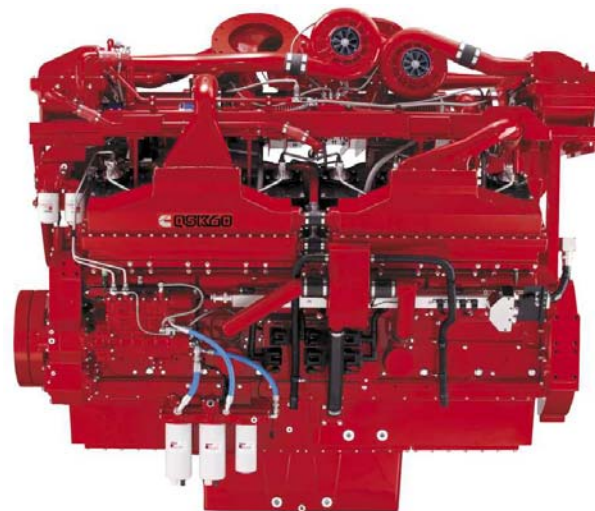
FCD piston provides over 10% durability increase



Fuel System

Modular Common Rail provides improved power delivery

Common rail proven on high volume engines



Controls

ECMs with over two times higher processing speed



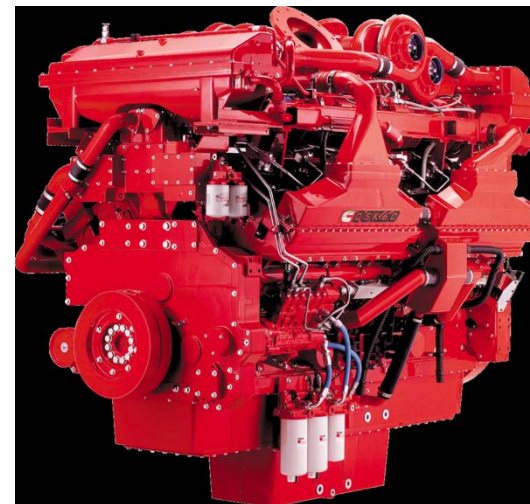
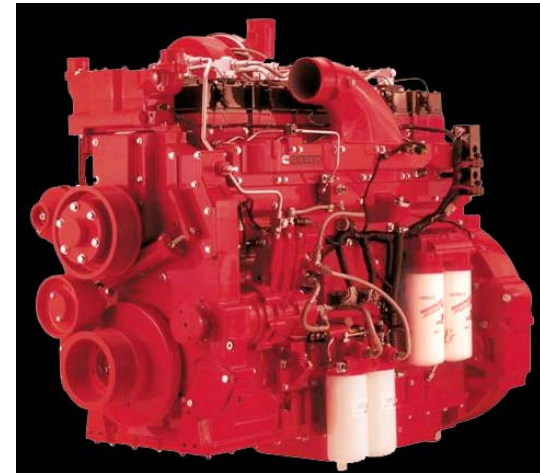
Meeting Tier 2 Integrated Quantum Technology



- Quantum technology provides a clear path beyond Tier 2 to EPA Tier 4 emissions:
 - Interim 2011
 - Final 2015
- Cummins unique in-house capability with vertically integrated core technologies:
 - Electronics
 - Fuel systems
 - Turbocharging
 - Filtration
 - Exhaust Aftertreatment



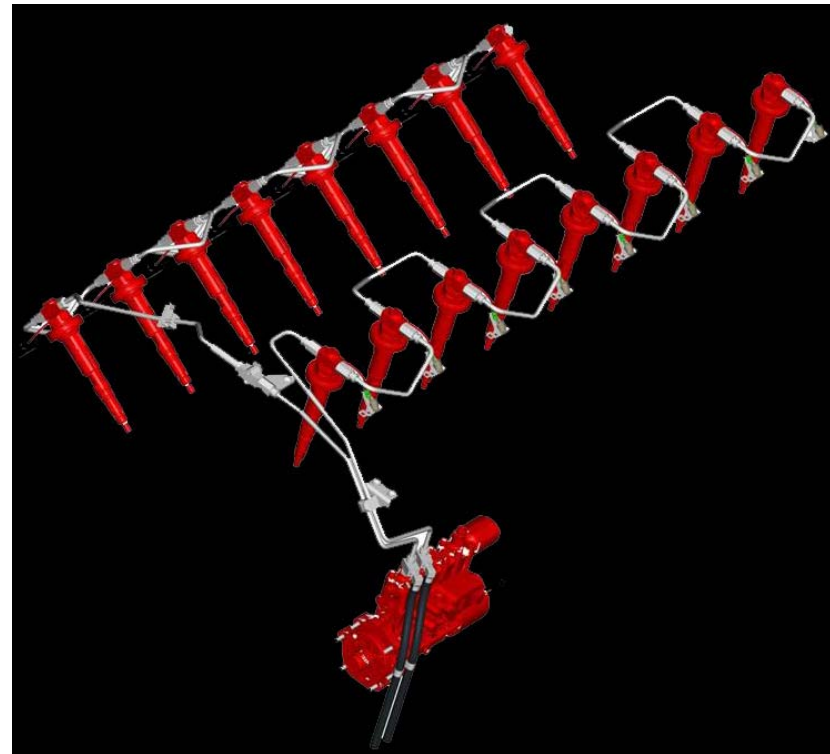
- Most effective emission solutions require fully integrated technology



Technology Enabler: Cummins MCRS



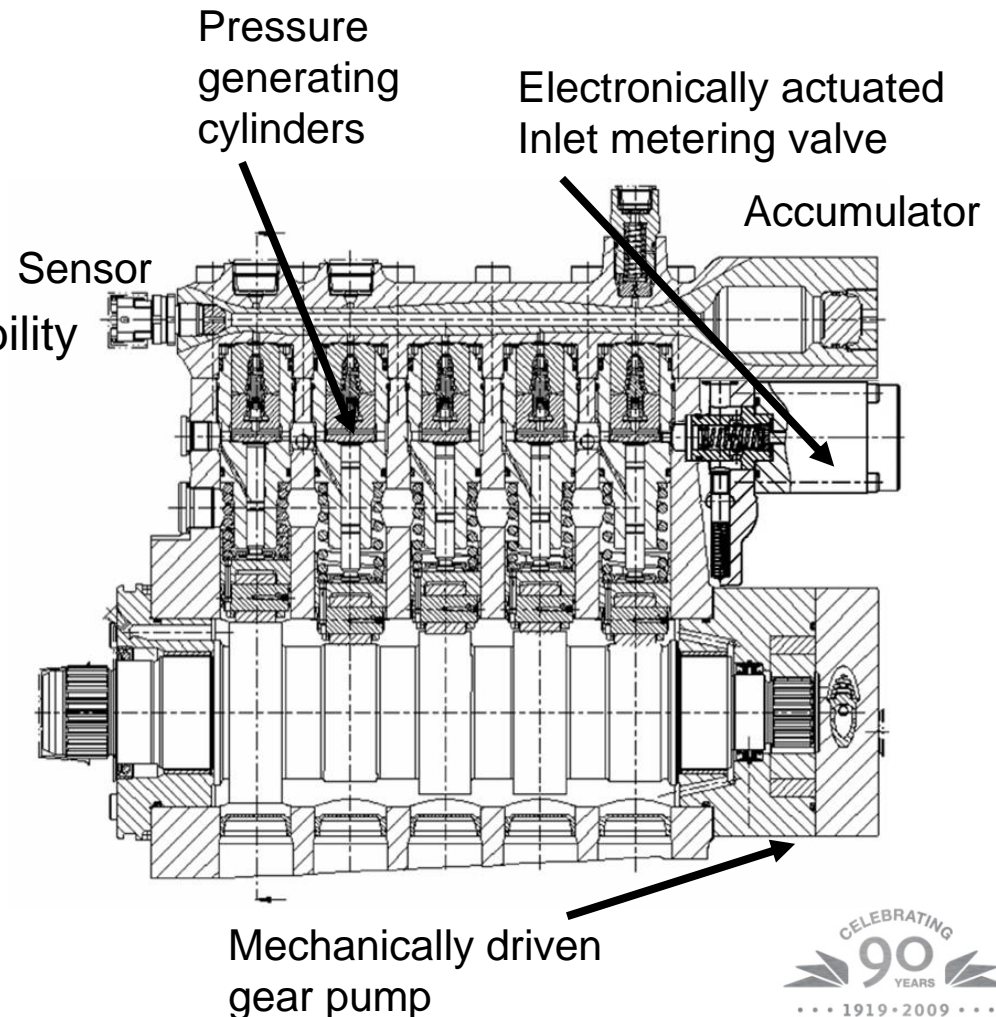
- Modular Common Rail System purpose-designed for high load factors / high hour with modular scalability across engine platforms
- Accumulator is integral to injector - enabling serial connection to pump without the need for a long fuel rail
- Double wall fuel lines
↓
- Simpler & more durable
- Enhanced power delivery:
 - idle stability improved by 50%
 - cold start improved by 50%
 - load acceptance 18% faster
- Every Tier 1 rating maintained



Technology Enabler: Cummins MCRS – High Pressure Pump



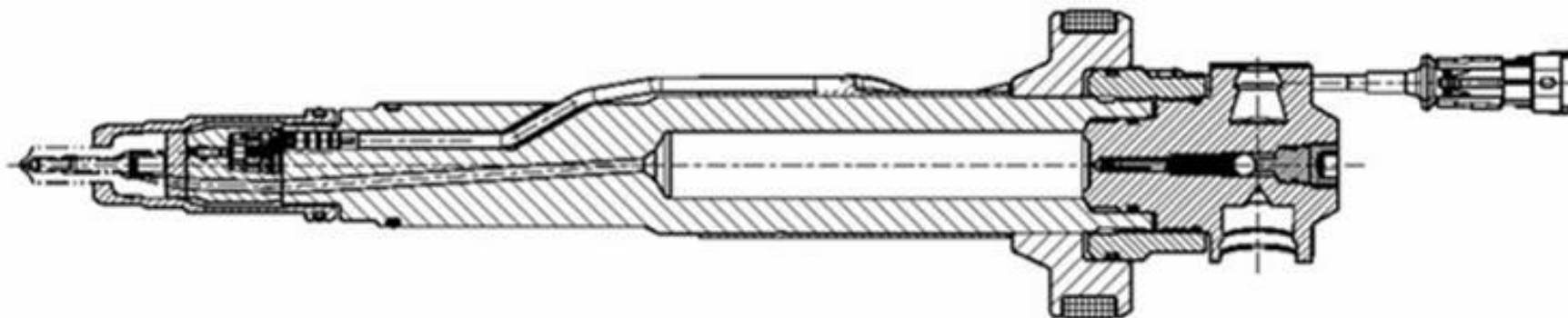
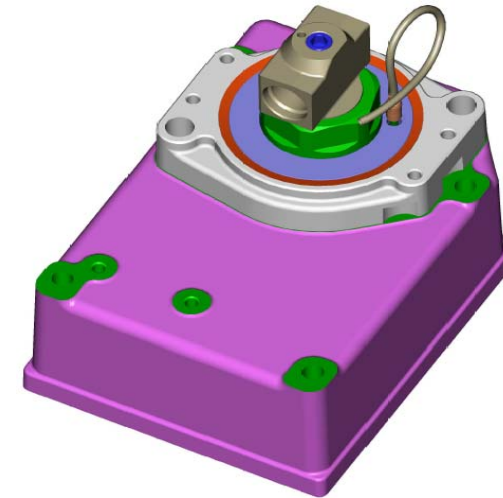
- High pressure fuel pump generates up to 1600 bar (23,000 psi) delivery
- Pressure sensor enables precision control by ECM
- Engine oil lubricated for higher durability
- Common 2/4/5 cylinder format



Technology Enabler: Cummins MCRS - Injection



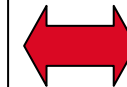
- Solenoid-controlled electronically actuated injectors
- Very fast response with multiple injections
- Highly accurate control of fuel metering & timing
- Integrated accumulator improves stability by helping to eliminate pressure pulsations between injectors
- Enables connection in series without the need for a long fuel rail
- New 4-bolt valve cover with high integrity sealing plate and LEM (Liquid Elastomer Molding) gasket



Technology Enabler: Electronic Architecture



CM850 ECM Upgraded Electronic Control Modules with over two times faster processing power
Continuously optimizes fuel-efficiency, engine response & emissions control
3 x CM850 common controllers



INSITE™
QUICKCHECK™
Electronic diagnostic & service tools
Real time engine monitoring



Modular Common Rail Fuel System

Drives 16 injectors, Fuel pump actuator & fuel lift pump

Engine Monitoring & Protection

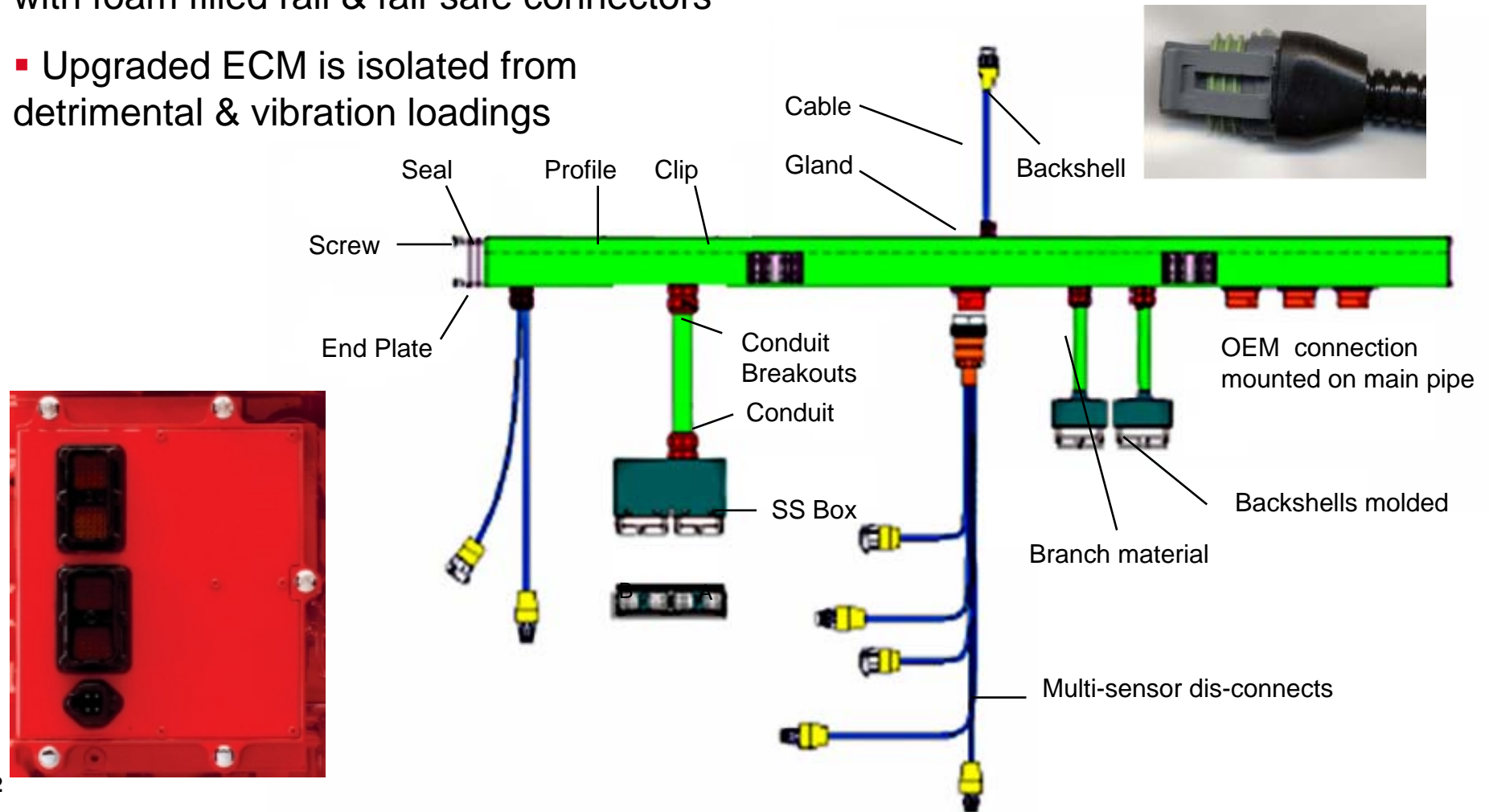
38 sensor package enhanced with **AEM** cylinder health



Technology Enabler: High Integrity Electronics



- Fully sealed wiring harness assembly with foam filled rail & fail-safe connectors
- Upgraded ECM is isolated from detrimental & vibration loadings





Tier 4 Program

Tier 4 research program started in July 2004:

- Building on previous off- and on-highway development
- Focus primarily on 174 – 751 HP to date

Initial phase focused on understanding customer requirements & analysis-based assessment of technology options

Engine testing was initiated in 2005 – 2006

Overall emissions & performance capability demonstrated on midrange & heavy-duty engines

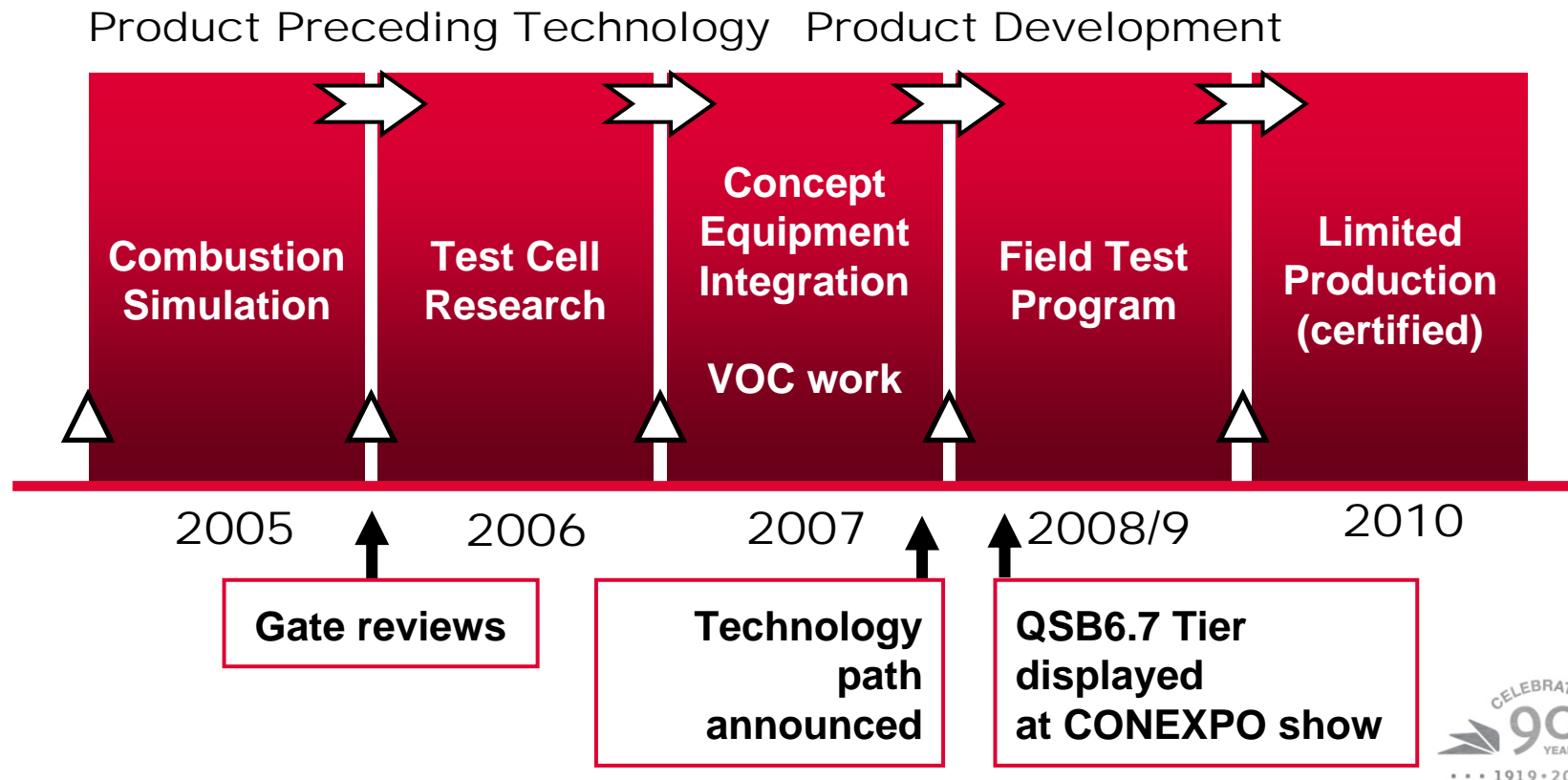
Concept installations in industrial applications completed – more in-process





Tier 4 Program

QSB6.7 & QSL certified engines are planned for limited a year ahead of emission regulations effect



B20 Biodiesel





**EVERY
TIME.**



Cummins Engine Business

FAQ: The use of B20 biodiesel blends in Cummins engines

Issued: January, 2009

What Cummins engines can be used with B20 biodiesel?

The current approved engine models are as follows:

On-Highway: ISX, ISM, ISL, ISC and ISB engines certified to EPA '02 and later emissions standards, ISL, ISC and ISB engines certified to Euro 3.

Off-Highway: QSX, QSM, QSL, QSC, QSB6.7, QSB4.5 and QSB3.3 engines certified to Tier 3/Stage IIIA, QSM Marine, QSM G-Drive.

High Horsepower Off-Highway built after January 1, 2008: QSK78, QSK60, QSK50, K2000E, K50, QSK45, QSK38, K1500E, K38, QST30, QSK23, QSK19 and K19. Also Marine QSK60, QSK50, K50 QSK45, QSK38, K38 QSK19, K19.

Cummins has approved B20 for the high horsepower engines listed above with the following fuel systems: Pressure Timed, High-Pressure Injection, Modular Common Rail Fuel Injection System and BOSCH Pump-Line-Nozzle.



Do I need to modify any service intervals when switching from petrodiesel to B20?

Due to the solvent nature of B20, and the potential for 'cleaning' of the vehicle fuel tank and lines, new fuel filters must be installed when switching to B20 on used engines. Fuel filters will need to be replaced at half the standard interval for the next two fuel filter changes. After this initial period, you may revert to the intervals specified in your O & M manual.

Are there any biodiesel fuel storage guidelines?

Use biodiesel fuel within six months of its manufacture date. Biodiesel has lower oxidation stability compared to petrodiesel. Avoid storing equipment with biodiesel blends in the fuel system for more than three months.

What materials are incompatible with biodiesel?

Natural rubber, butyl rubber and some types of nitrile rubber (depending on chemical composition, construction and application) may be particularly susceptible to degradation. Also, copper, bronze, brass, tin, lead and zinc can cause deposit formations. The use of these materials and coatings must be avoided for fuel tanks and fuel lines. Fuel fittings and connectors are acceptable due to the small surface area in contact with the fuel.

Note: Contact your vehicle manufacturer to determine if any of the OEM supplied components are at risk with biodiesel in order to prevent engine or vehicle damage.





EVERY™ SYSTEM.
INTEGRATED.

