Cummins Westport
The Natural Choice

CWI Heavy Duty Engine Development Update: Natural Gas Vehicle Technology Forum 2017

February 21, 2018

Stephen Ptucha

Product Management & Planning
Cummins Westport Inc.

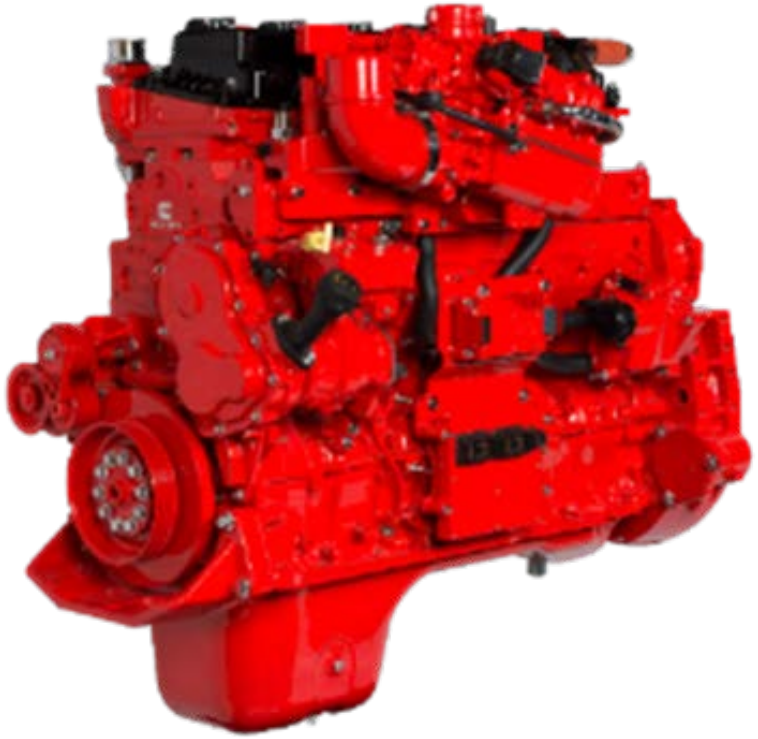
Ultra-Low Emissions Heavy-Heavy Duty 12 Liter

CALIFORNIA ENERGY COMMISSION

South Coast AQMD

SoCalGas
A Sempra Energy utility

Clean Energy



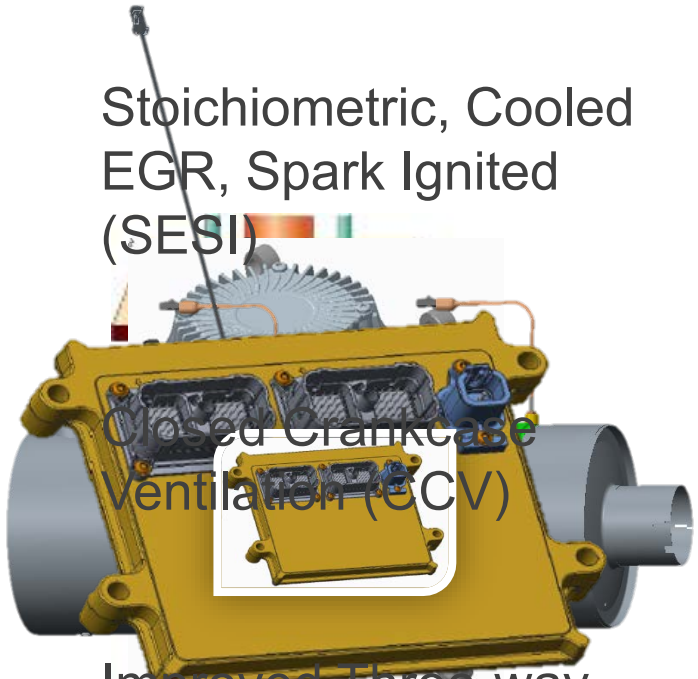
<0.02g NOx

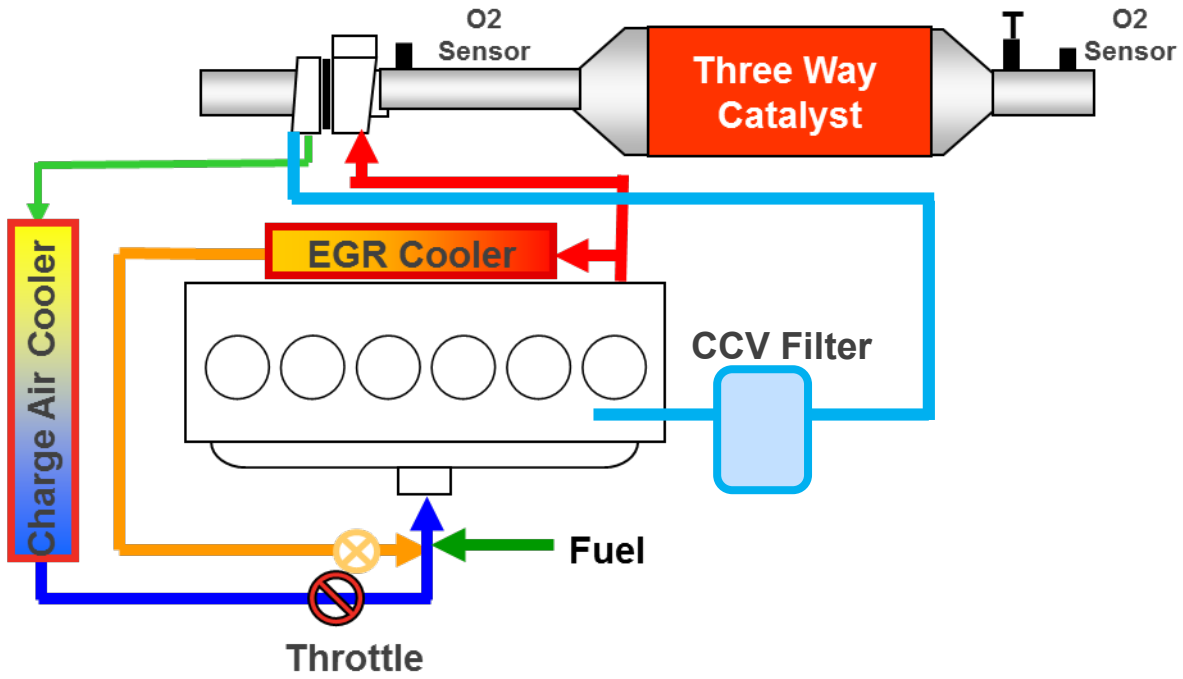
CALIFORNIA AIR RESOURCES BOARD

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

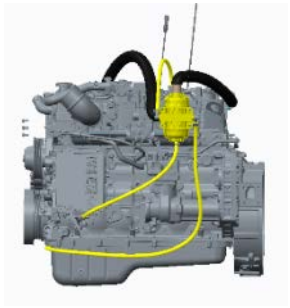
CWI Near Zero Architecture

- Stoichiometric, Cooled EGR, Spark Ignited (SESI)
- Closed Crankcase Ventilation (CCV)
- Improved Three-way Catalyst
- Spark Ignited
- Optimized controls





Project Timeline



Technology Development

Alpha Prototype

Beta Prototype

Limited Production

Production

2013 to 2016

Jan 2016

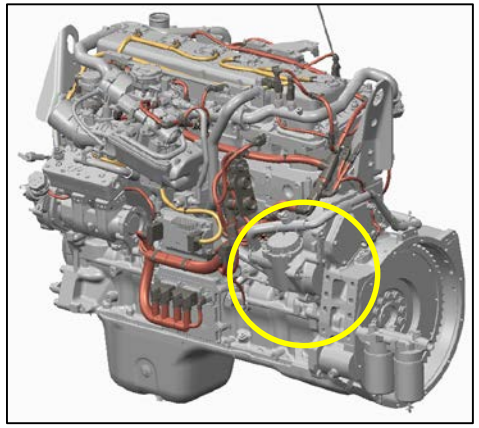
3Q16

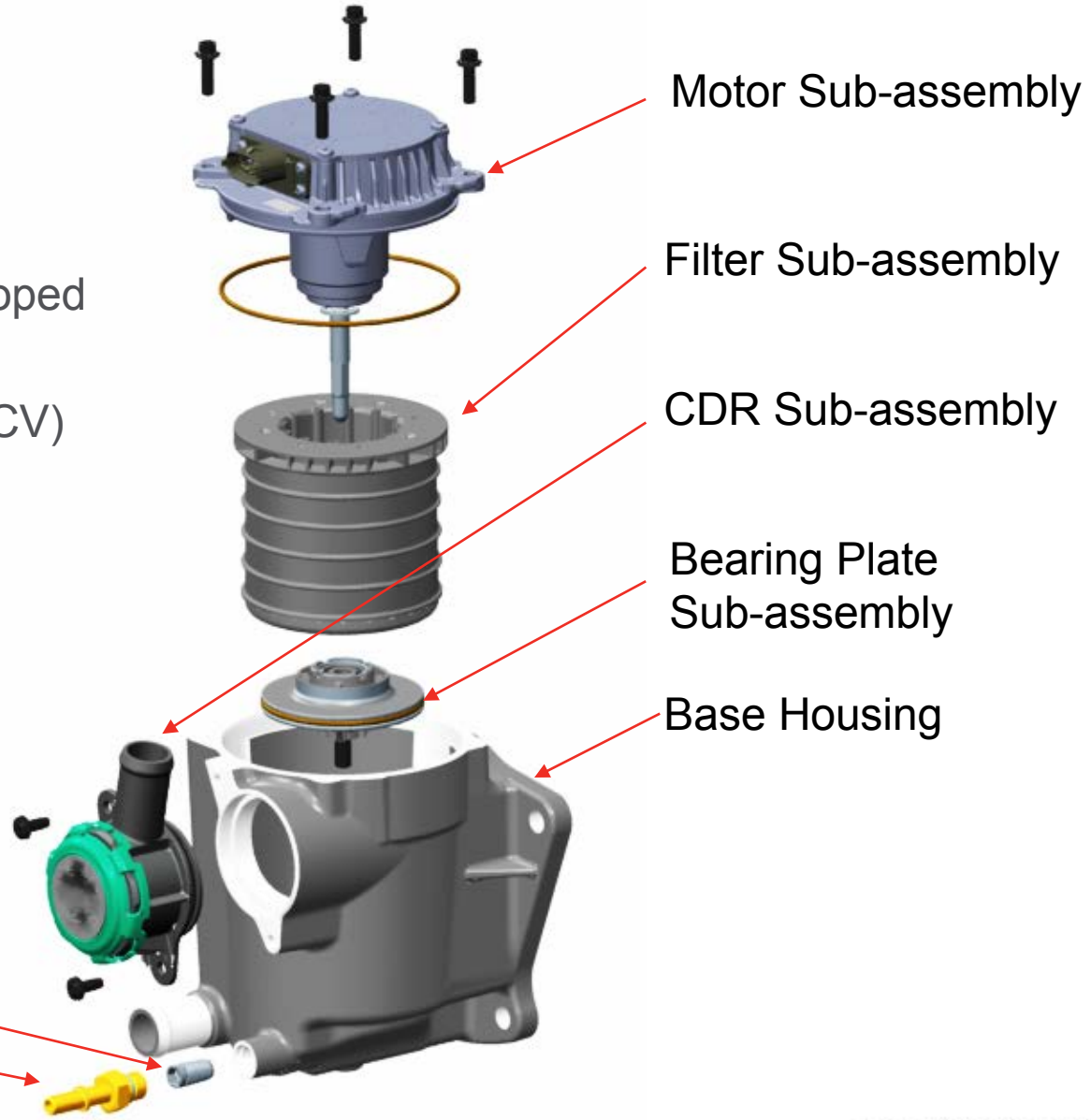
2Q17

1Q18

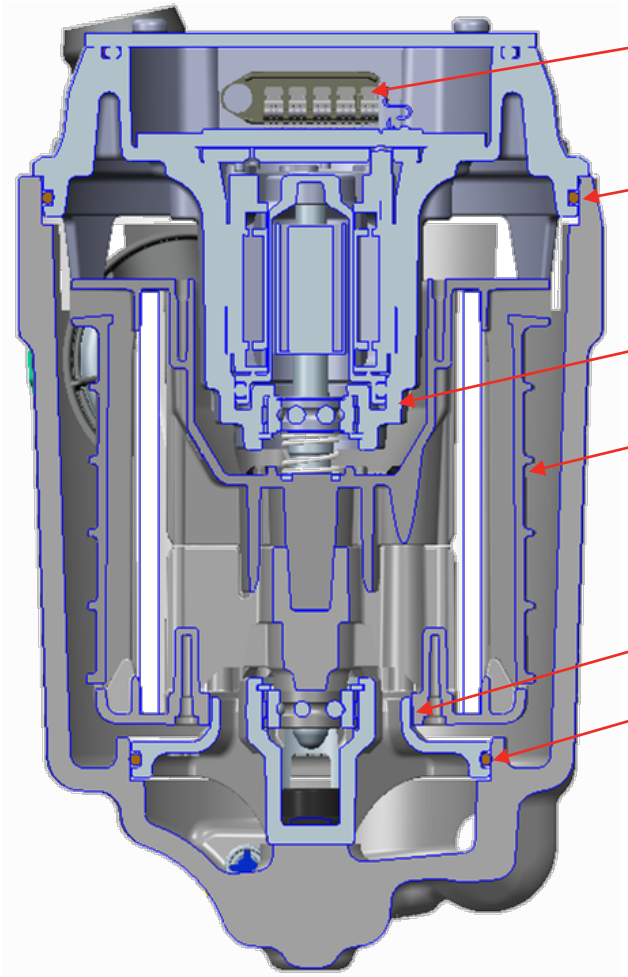
Closed Crankcase System

- L9N uses a static crankcase coalescent filter
- ISX12N performance / packaging constraints accomplished with active coalescent filter – developed by Cummins Filtration
- Electric Drive Rotating Crankcase Ventilation (eRCV)
  - Compact size
  - High performance aerosol droplet separation
  - High cleaning efficiency
  - Low restriction
  - Extended Maintenance Interval





Electric Drive Rotating CV (eRCV)



Motor controller

Electric connector

Electric Motor Seal

Gas Outlet

Electric Motor

Filter Element

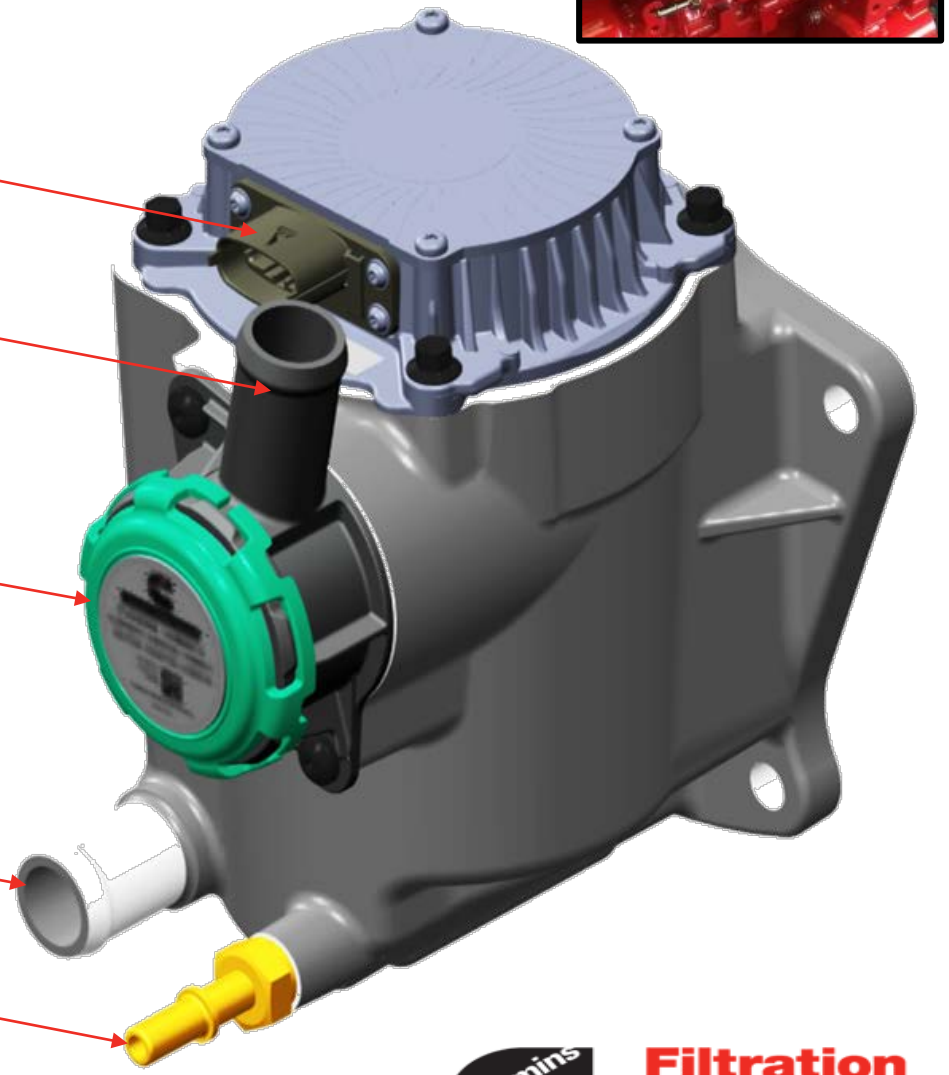
CDR Valve

Bearing plate

Bearing plate seal

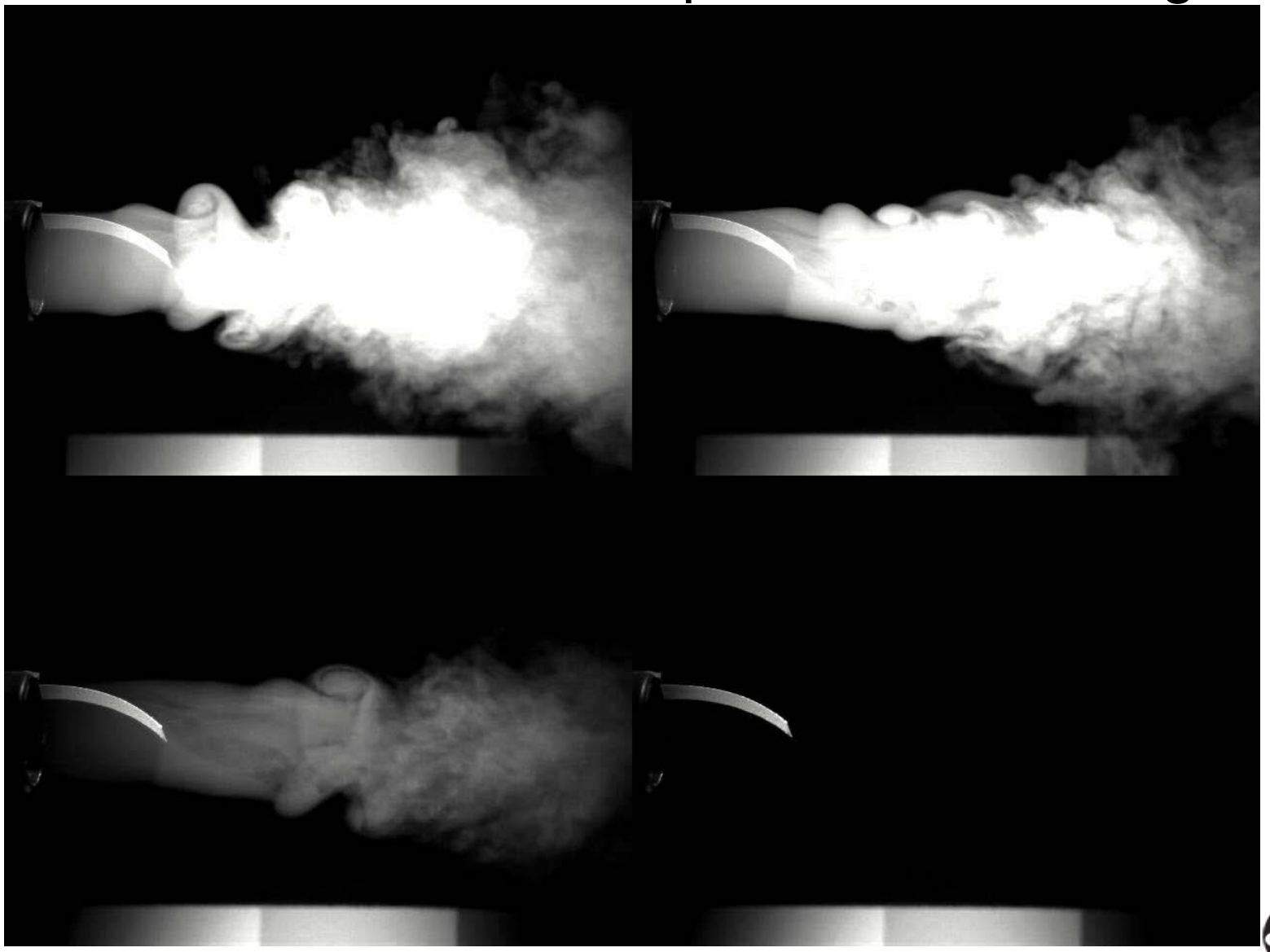
Gas inlet

Drain



Cummins Filtration

High Speed Visual Comparison Raw Blow-by and Various Cummins Filtration Aerosol Separation Technologies

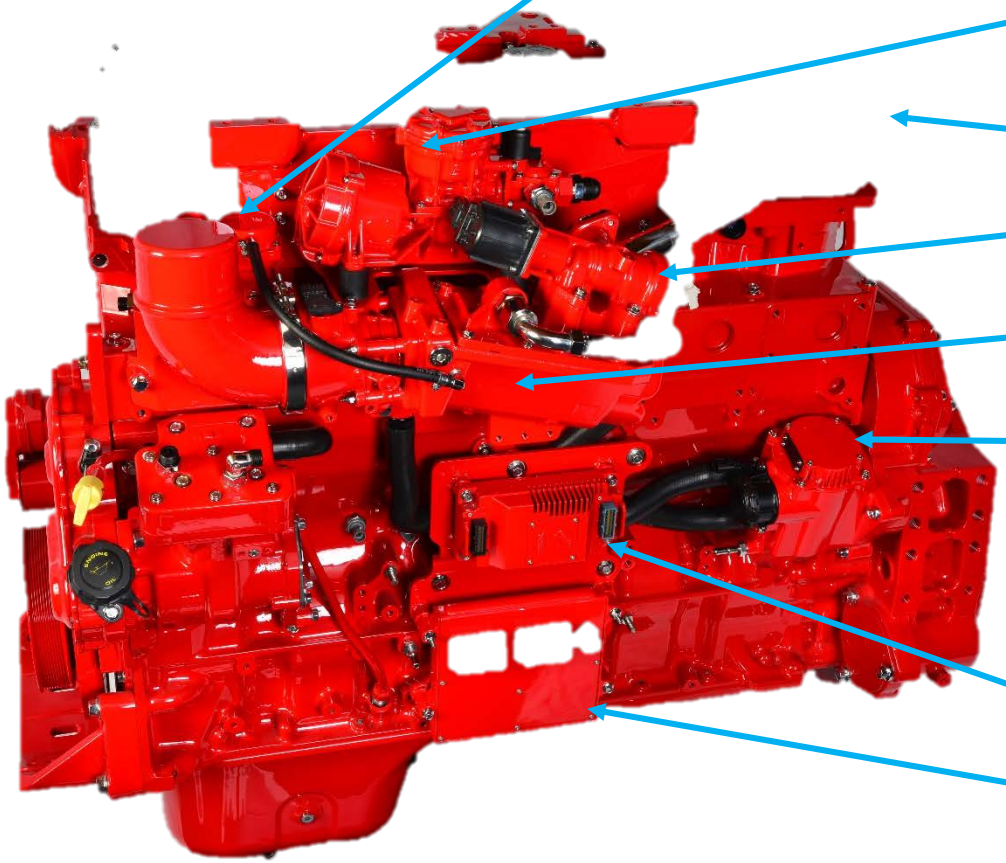


Cummins Filtration

Improved Fuel System

- Faster response
- Increased fuel delivery accuracy
- Improved reliability

- Proportional flow valve replaces previous valve and gas mass flow sensor
- New engine control unit with added I/O's and memory
- Redesigned EGR system for improved control



- Compressor Recirculation Valve (CRV)
- Fuel Control Valve
- EGR Cross Over Tube
- EGR Valve
- Fuel / EGR Manifold
- eCRV (Closed Crankcase Breather)
- Ignition Control Module
- Engine Control Module

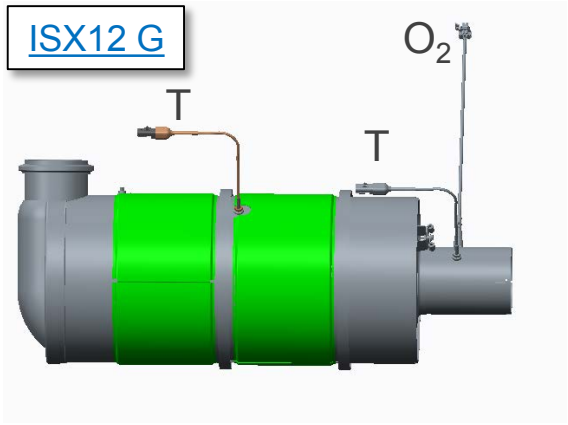
Three-way Catalyst Aftertreatment

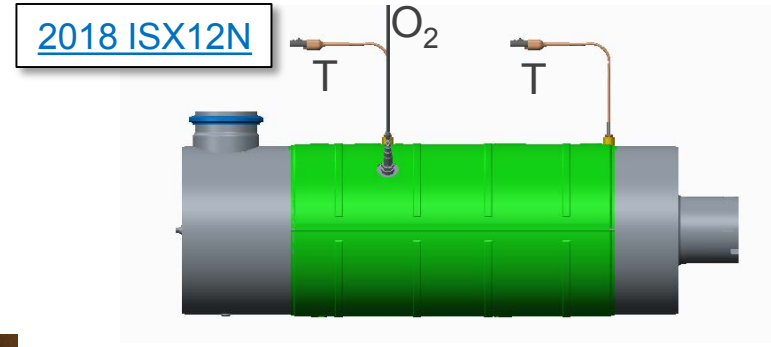
NOx Reduction to 0.02g

- Improved washcoat and precious metal formulation
- Increased volume:
  - Increase length ~80 to 200mm
  - Same diameter
- Sensor reposition
  - Temperature from outlet to body
  - O_2 moved from outlet to mid-bed

HD-OBD compliant

- Unibody design





Typical end-in, end-out configuration

HD-OBD

- EPA / CARB requirement in 2018 for alternative fueled engines
- Infrastructure development
  - Data logging, reporting and communication protocol completed to SAE J1939/84 standard
  - new ECM with increase memory, throughput and I/Os
  - Enhanced or added sensors
- Diagnostic algorithm / software creation (Monitors)
  - Added & enhanced diagnostic algorithms to meet CCR 1971.1
- Calibration
  - Tuning of system for accurate and repeatable detection
- OBD demonstration
  - demonstrated monitors function as expected with failed or partially failed parts

Example Sensors
Exhaust manifold pressure (A)
EGR delta P (E)
Intake manifold pressure and temperature (E)
CCV pressure (2nd A)
Exhaust gas oxygen (E)

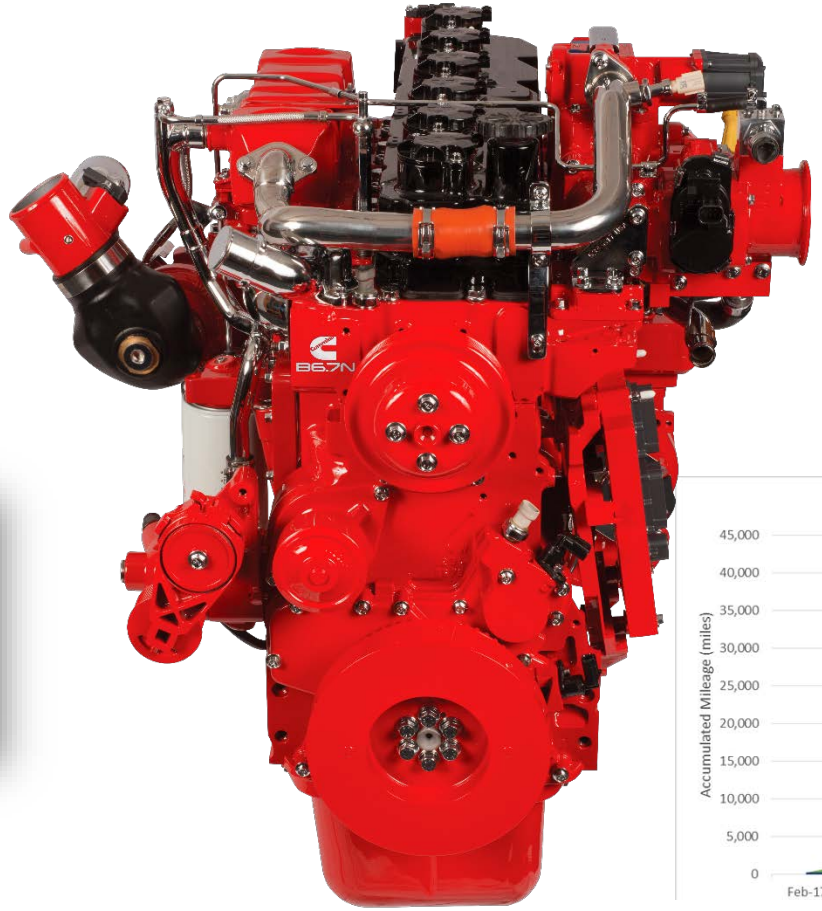
(A) = added / (E) = enhance

Example Monitors
Fuel system
Misfire
EGR system
Boost pressure control
Catalyst

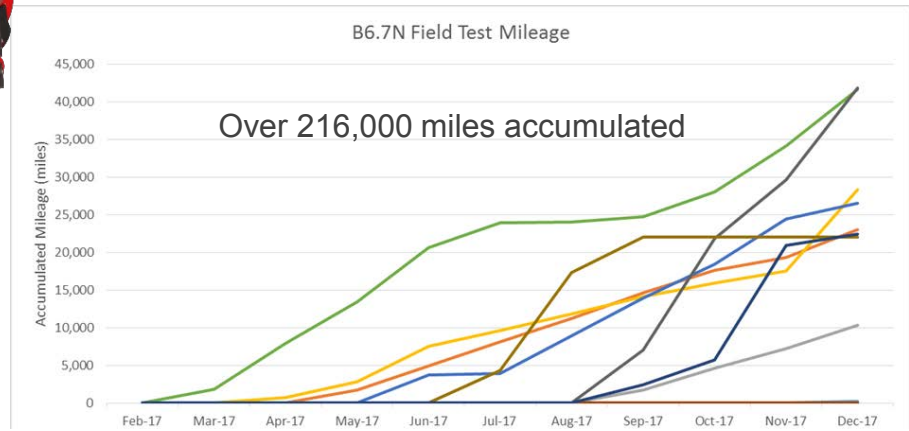
Advanced 6.7 Liter NG HD-OBD Engine Development

CALIFORNIA ENERGY COMMISSION

gti GAS TECHNOLOGY INSTITUTE



CHECK



Move to Zero … new for 2018

ISX12N™	L9N™	B6.7N™
		
0.02 g/bhp-hr NOx	0.02 g/bhp-hr NOx	0.1 g/bhp-hr NOx
11.9 liters	8.9 liters	6.7 liters
320 – 400 hp 1150 – 1450 lb·ft	250 – 320 hp 660 - 1000 lb·ft	200 – 240 hp 520 – 560 lb·ft

Westport

Near Zero Product Plan

(Certified to ARB Near Zero NOx standard - 0.02 g/bhp·hr)

Engine	2016	2017	2018	2019
ISB6.7G	Available	Available	Not Available	Not Available
B6.7N*	Not Available	Not Available	Available	Available
ISL G	Available	Available	Not Available	Not Available
ISL G NEAR ZERO	Available	Available	Not Available	Not Available
L9N	Not Available	Not Available	Available	Available
ISX12 G	Available	Available	Not Available	Not Available
ISX12N	Not Available	Not Available	Available	Available

Legend

Available

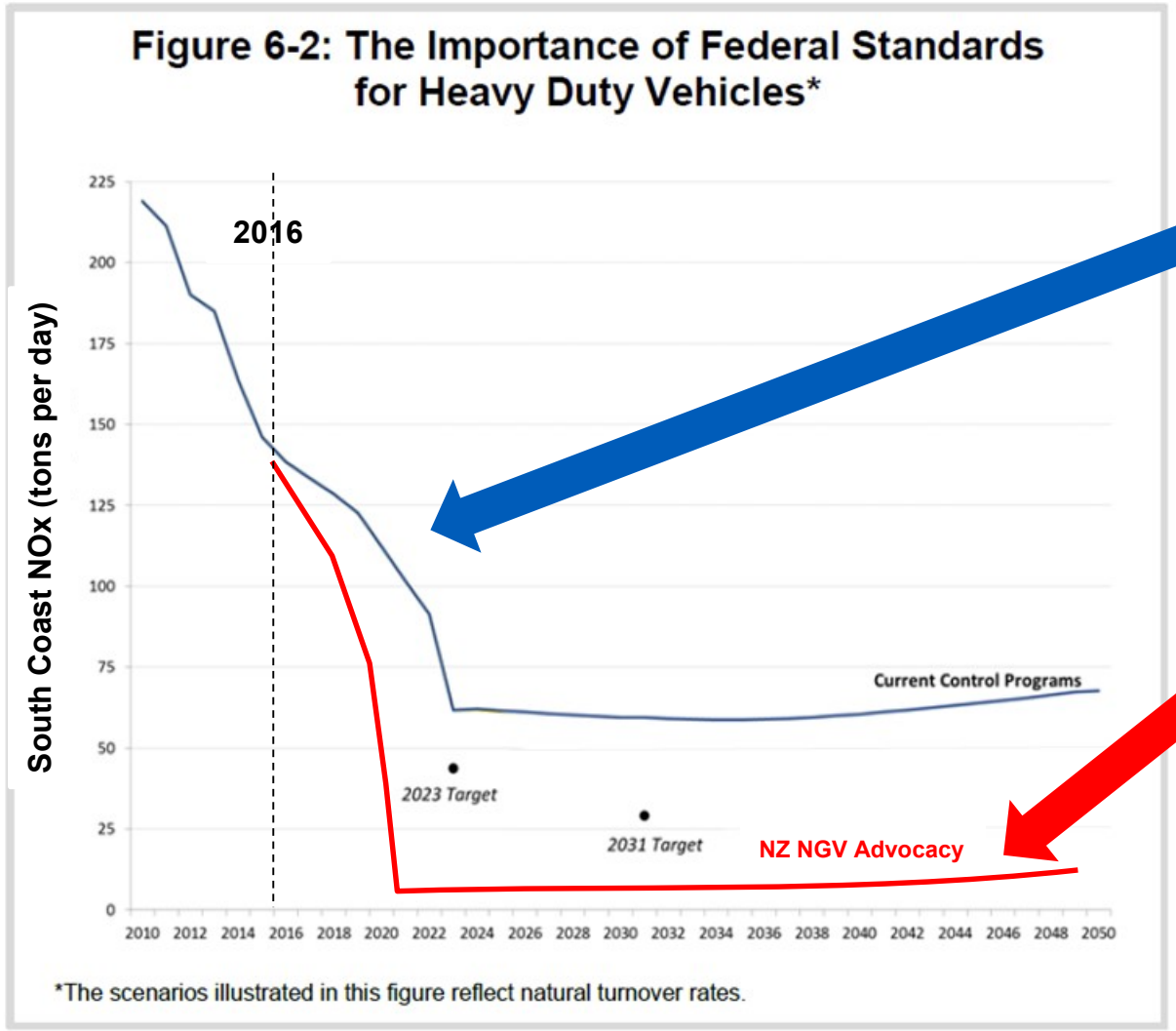
Not Available

L9N & ISX12N certified at launch to California ARB (Near Zero) Optional Low NOx (0.02g/bhp·hr)

*** ISB6.7 G & B6.7N certified at launch to California ARB Optional Low NOx (0.1 g/bhp·hr)**

ISL G, ISL G NZ and ISX12 G engines are not available post 2017 (not OBD compliant)

Potential of Near Zero Implementation



Current control programs drive all HD vehicles to 2010 0.2 NOx standard by 2023… rapid progress but still not enough to hit Clean Air targets

A NZ NGV advocacy program overlay could reduce NOx 90% below current controls (around 60 extra tons per day)

Market Adoption

- Engine / Vehicle Availability
- TCO
  - Maintenance
  - Fuel Savings
  - Infrastructure
  - Capital Cost
- Technology Life /
  Newer “perfect” technology
- Incentivize the goal
  - Cost effective solutions
- Educate fleets to pull product
  demand

Questions

Stephen Ptucha

Product Management & Planning
Cummins Westport Inc.