Off-Highway Diesel Engine Emissions Overview

JOHN DEERE

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Emissions Overview

What is PM?

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❑PM:

- ➢**Also known as:**
  - Particulate Matter, Soot, Smoke
- ➢**What is it?**
  - Unburned Hydrocarbons (fuel)
- ➢**What causes it?**
  - Low combustion temperature
  - Low oxygen level during combustion
  - Low combustion pressure
- ➢**Why is it a regulated emission?**
  - Soot particles are very small and get trapped in the lungs
  - Associated as a cause of cancer

What is NOx?

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❑NOx:

- ➢**Also known as:**
  - Oxides of Nitrogen, Nitrogen Dioxide
- ➢**What is it?**
  - Molecule that is created in the combustion process
- ➢**What causes it?**
  - High combustion temperature
  - High oxygen level during combustion
  - High combustion pressure
- ➢**Why is it a regulated emission?**
  - NOx molecules attach to other elements in the atmosphere and produces smog

The PM & NOx Tradeoff:

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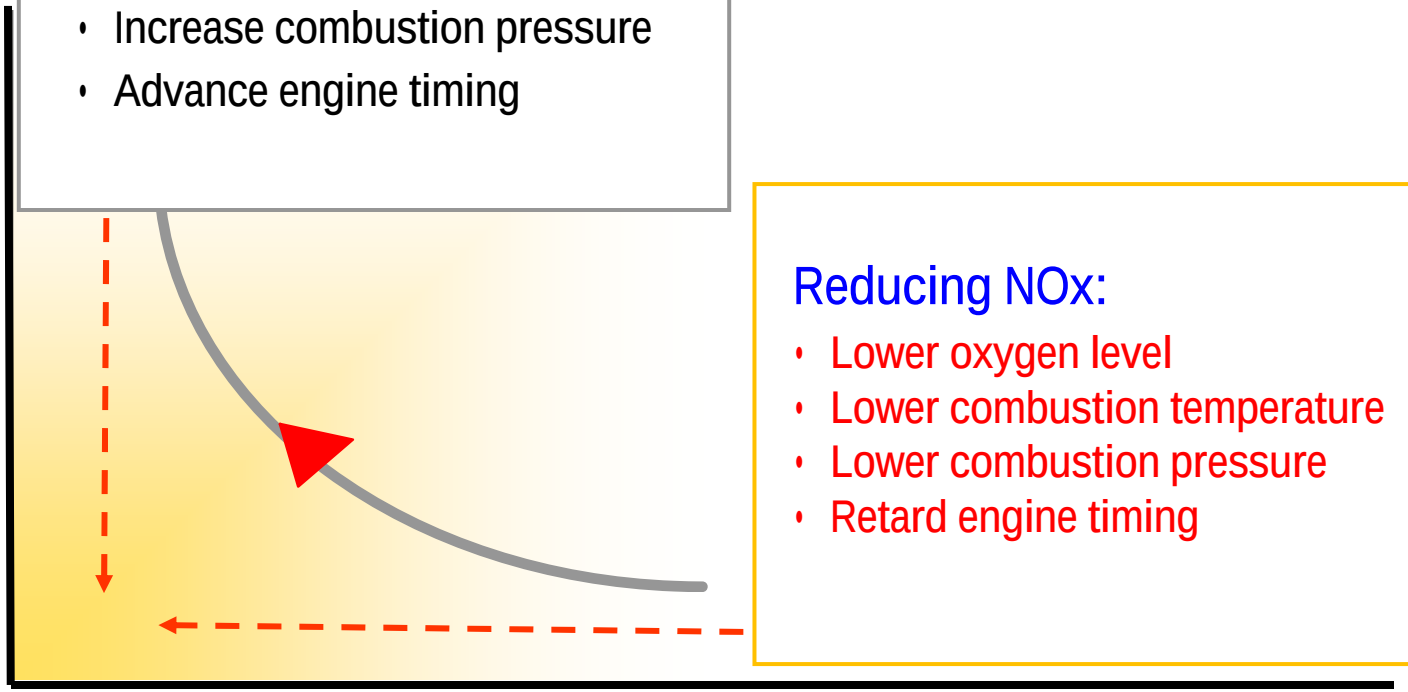
Reducing PM:

- Increase oxygen level
- High combustion temperature
- Increase combustion pressure
- Advance engine timing



Reducing NOx:

- Lower oxygen level
- Lower combustion temperature
- Lower combustion pressure
- Retard engine timing

Emission Regulation Dates

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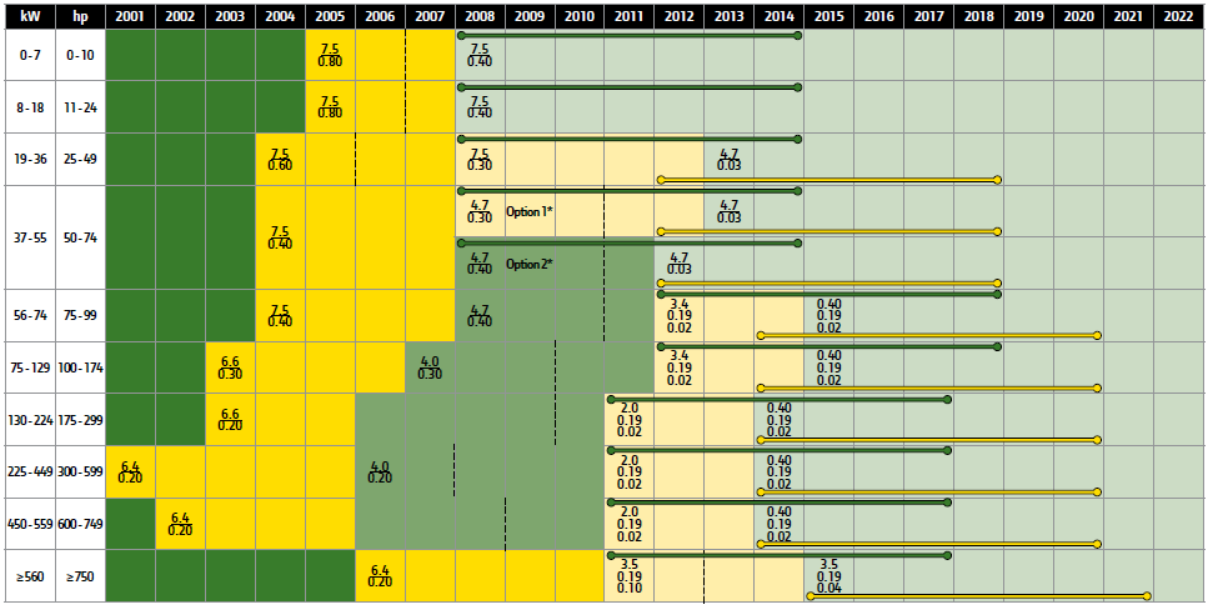
EPA nonroad emissions regulations



*In the 50 to 74 horsepower category there are two options. Option 1 requires a reduced PM level (.30 vs .40) but allows Final Tier 4 to be delayed one year (2013)

NOTE: The vertical dashed lines separating the years show when the seven-year life of the Tier 2/3 Equipment Flexibility Provision ends and engines can no longer be placed in vehicle production.

Legend

EPA	Tier 1	Tier 2	Tier 3	Interim Tier 4	Final Tier 4

New emissions regulations take effect January 1 of the year indicated by color change unless otherwise noted.

General Availability of Tier 4 Equipment Flexibility Provision	**Delayed** Availability of Tier 4 Equipment Flexibility Provision

Examples

NOx NMHC PM	2.0 0.19 0.025

2.0, the maximum amount of nitrogen oxides (NOx) allowed in g/kWh.
0.19, the maximum amount of nonmethane hydrocarbons (NMHC) allowed in g/kWh.
0.025, the maximum amount of particulate matter (PM) allowed in g/kWh.

NMHC + NOx PM	7.5 0.80

7.5, the maximum amount of NMHC + NOx allowed in g/kWh.
0.80, the maximum amount of PM allowed in g/kWh.

Deere Building block approach

What Emission Levels Changed for Tier 1?

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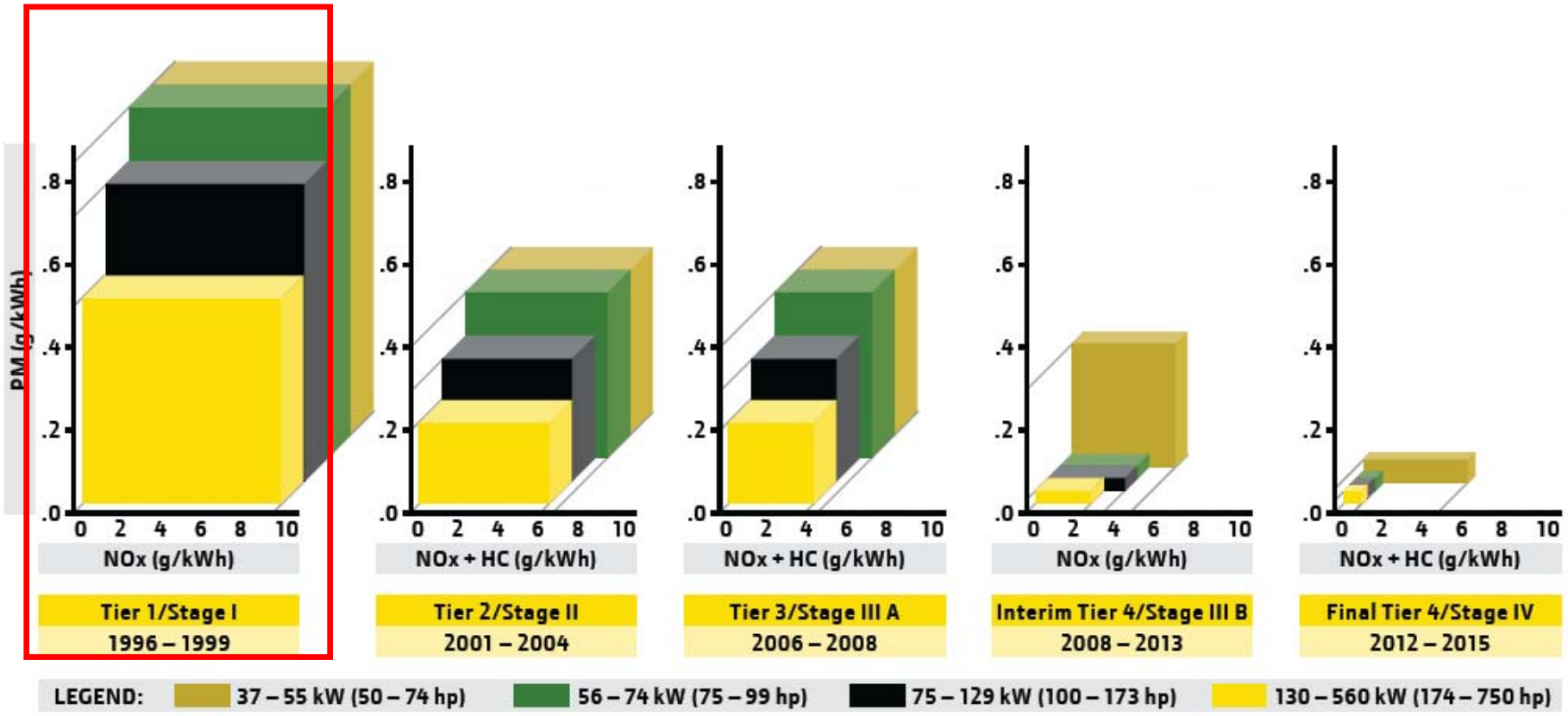
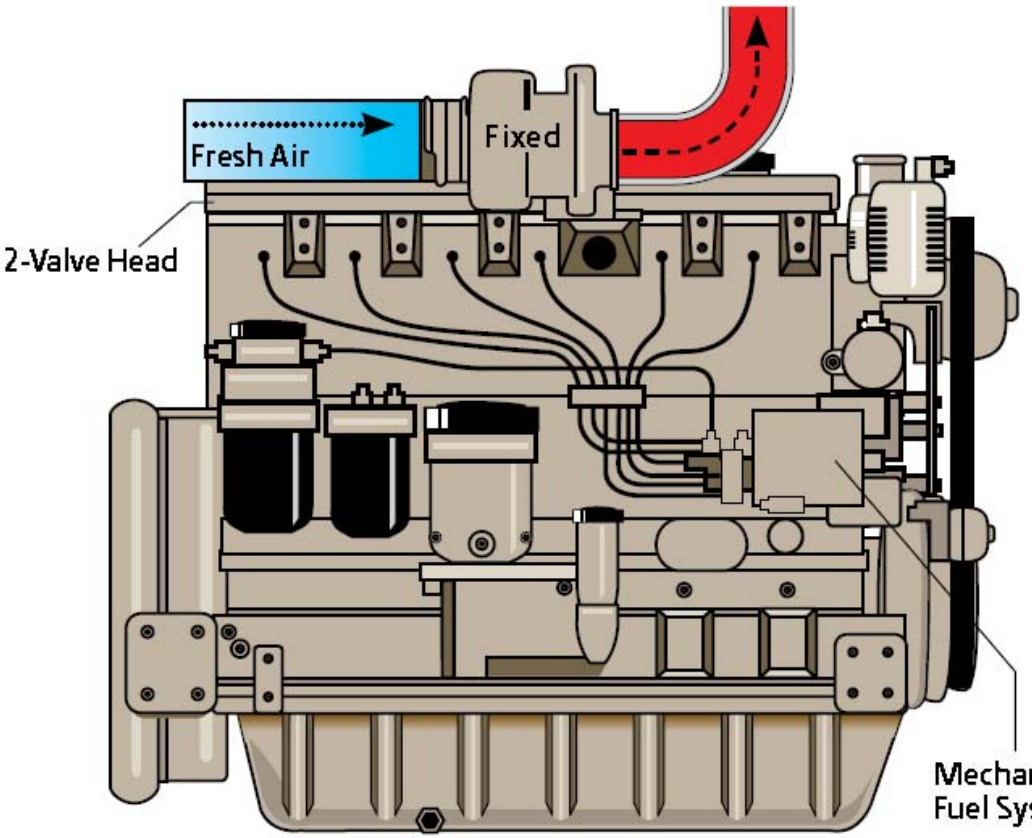
1996: Baseline Emissions Levels Established



Tier 1 Building Block



Key Features/Benefits:

- Improved Fuel Economy
- Increased Power Density
- Increased Power Range
- Improved Performance
  - Limited Power Bulge
  - Higher Peak Torque
- Minimal hardware and mounting location changes
- Emissions Compliance

What Emission Levels Changed for Tier 2?

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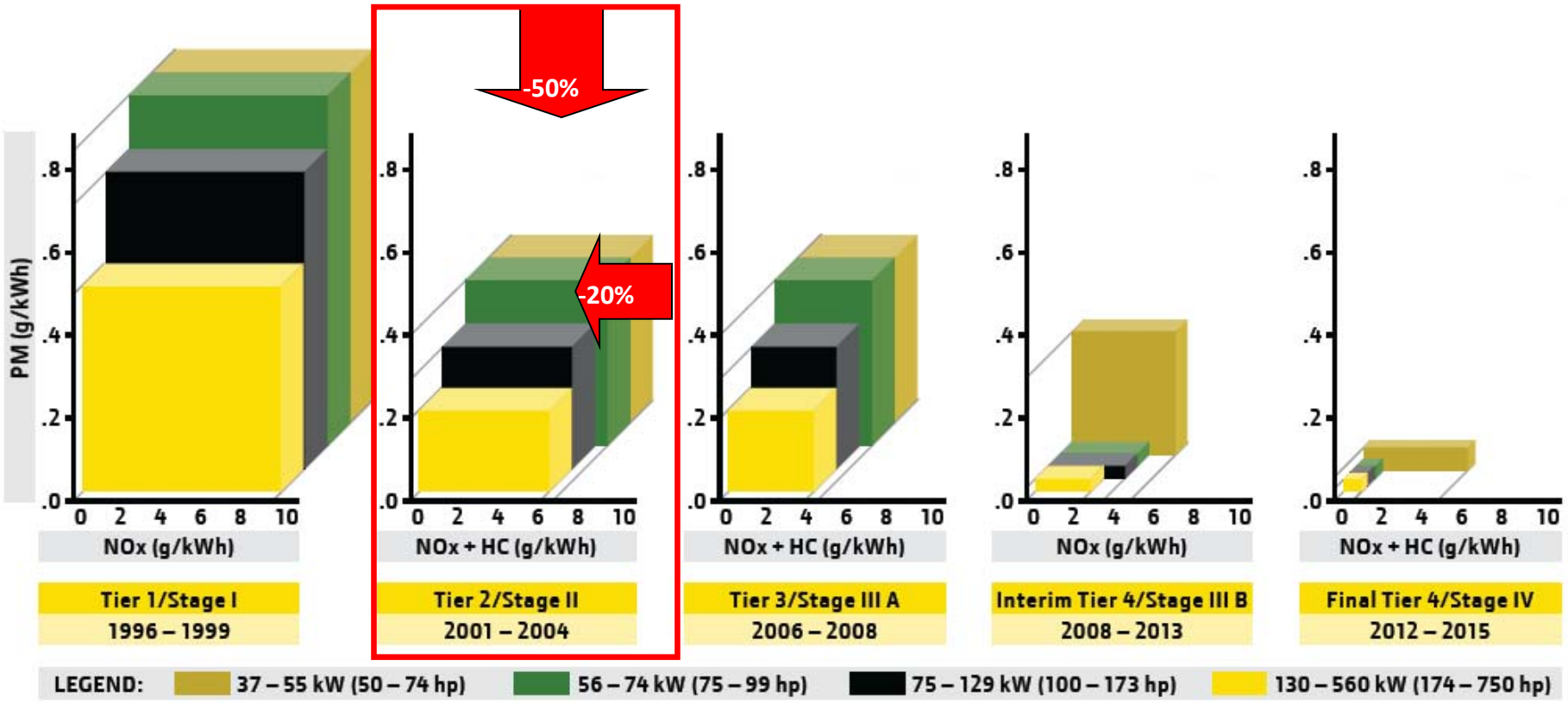
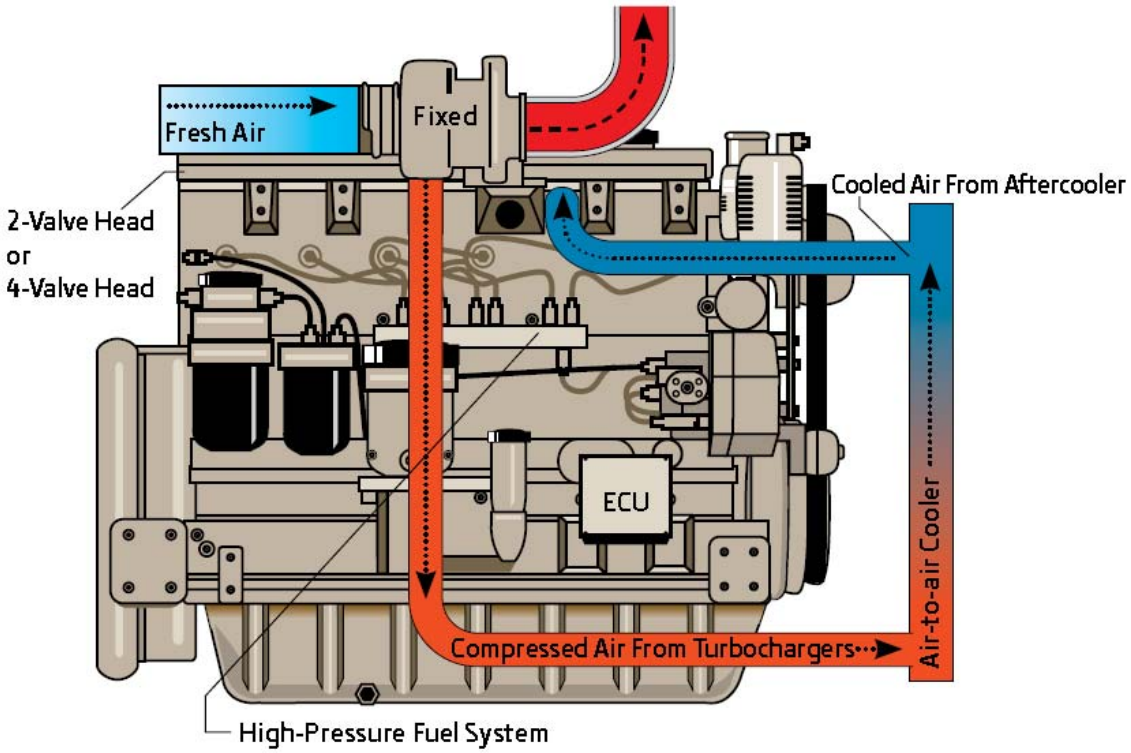
2001: 50% PM and 20% NOx reduction



Tier 2 Building Block



Key Features/Benefits:

- Improved Fuel Efficiency
- Increased Power Density
- Increased Power Range
- Improved Performance
  - More Power Bulge
  - Higher Peak Torque
  - Improved Low Speed Torque
- Lower Cost Options
- Minimal Hardware and Mounting Location Changes
- Emissions Compliance

What Emission Levels Changed for Tier 3?

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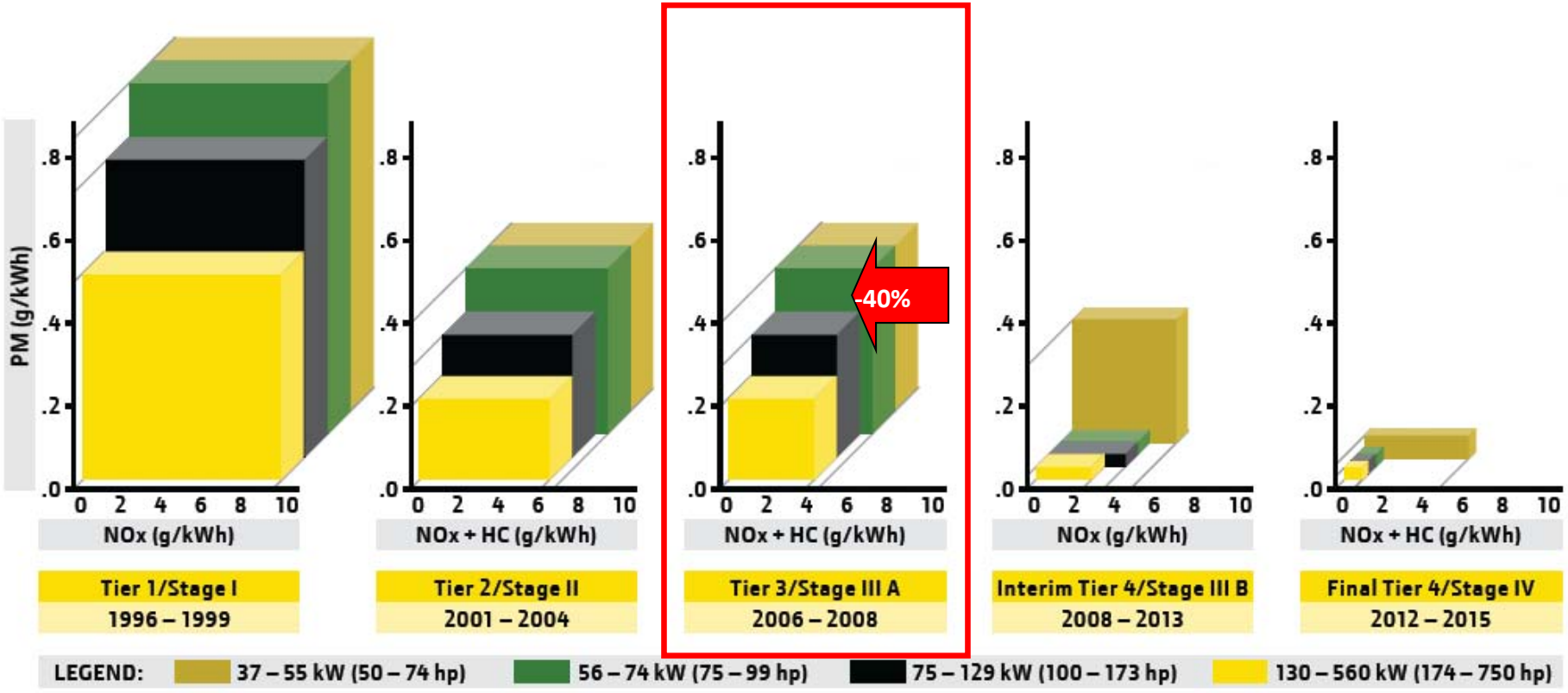
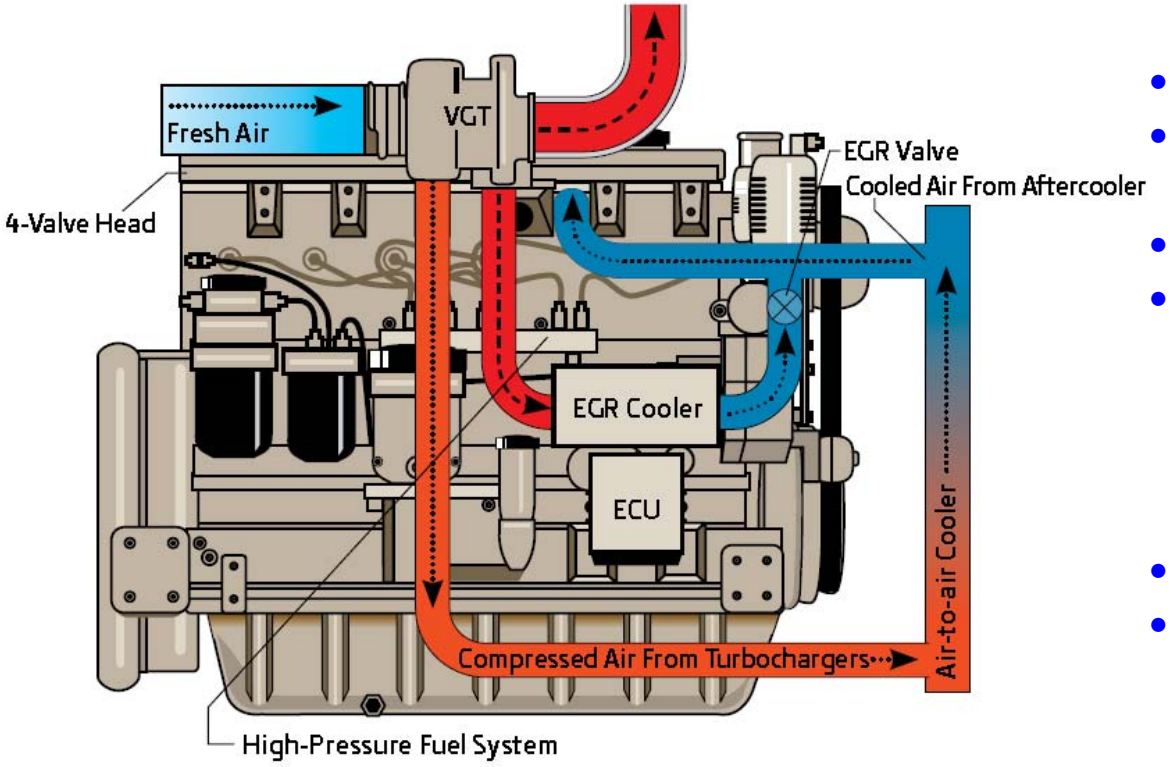
2006: 40% NOx Reduction



Tier 3 Building Block



Key Features/Benefits:

- Best In Class Fuel Efficiency
- Technology Platform Tailored to Meet Demands
- Increased Power Density
- Improved Performance
  - Power Bulge
  - Higher Peak Torque
  - Improved Low Speed Torque
  - Multiple Rated Speeds
- Lower Cost Options
- Emissions Compliance

What Emission Levels Changed for Interim Tier 4?

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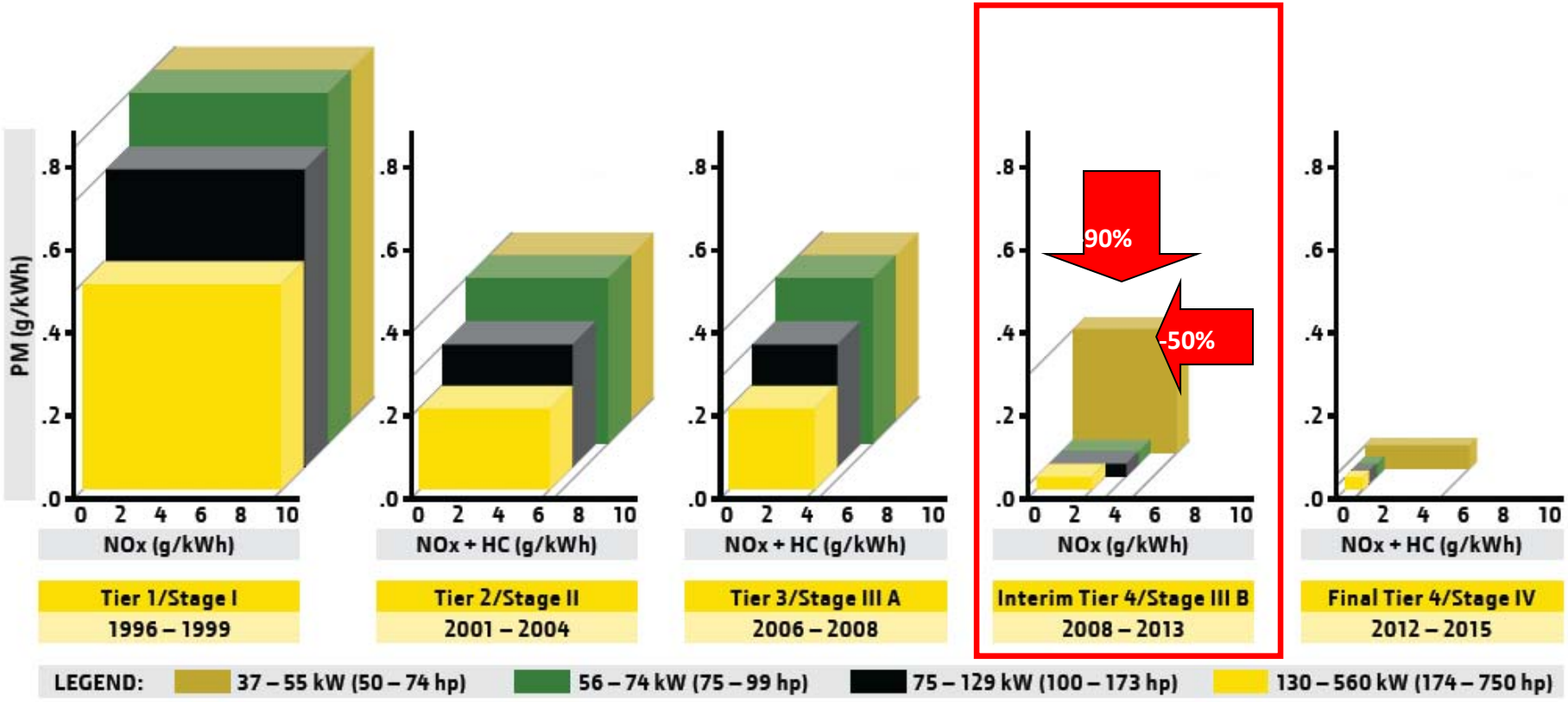
2011: 90% PM and 50% NOx Reduction



Interim Tier 4 Building Block

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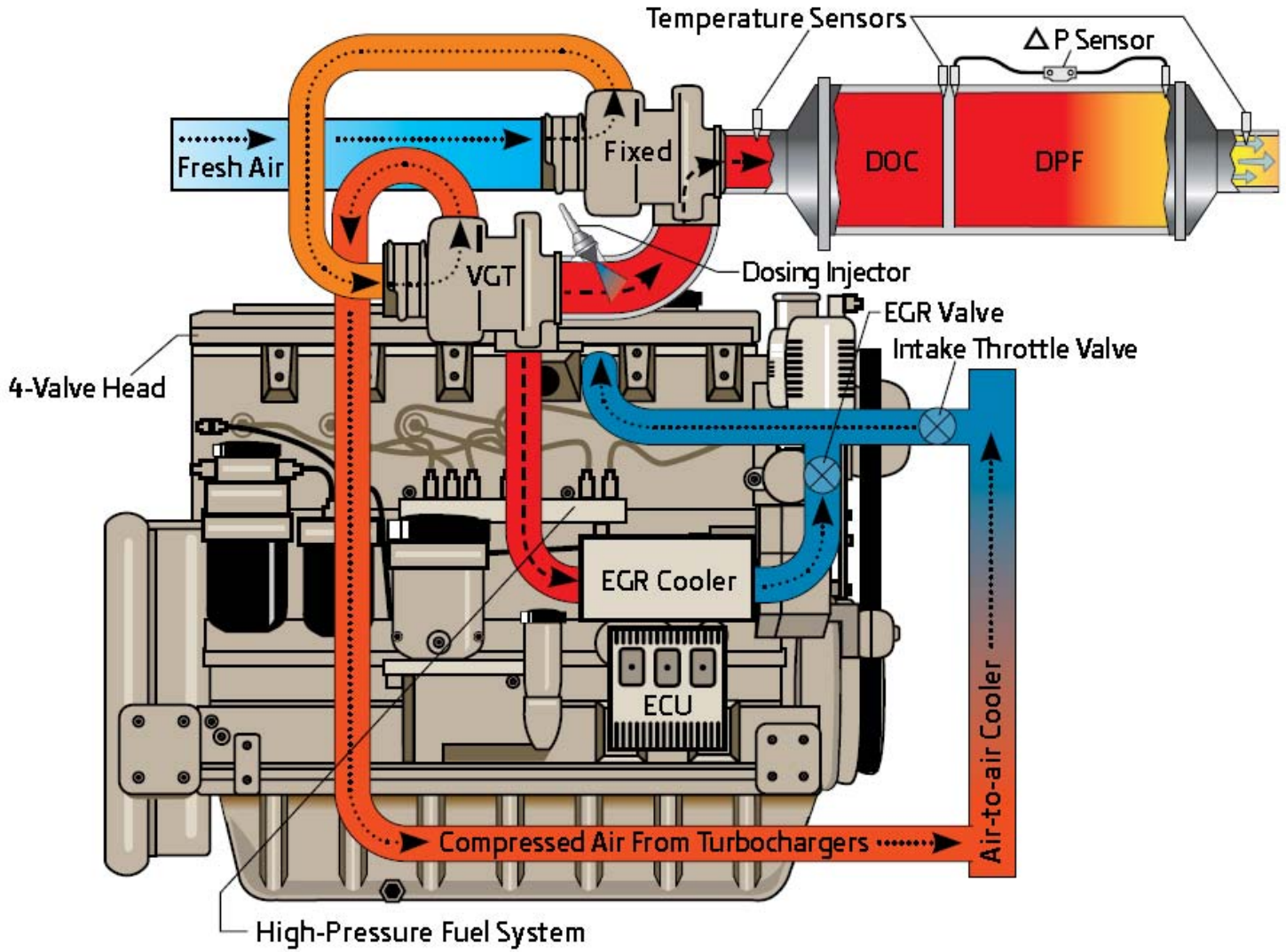

Interim Tier 4 Building Block

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Key Features/Benefits:

- Simple, Single Fluid Emissions Solution
- Best Available Technology for PM reduction with Smart Exhaust Filter
- Improved Fuel Efficiency
- Minimal Operator Involvement
- Increased Power Density
- Improved Performance
    - Power Bulge
    - Higher Peak Torque
    - Improved Low Speed Torque & High Altitude Performance (PSX Models)
    - Improved Transient Response
    - Multiple Rated Speeds
- Noise Reduction Improvements
- Emissions Compliance

What Emission Levels Change for Final Tier 4?

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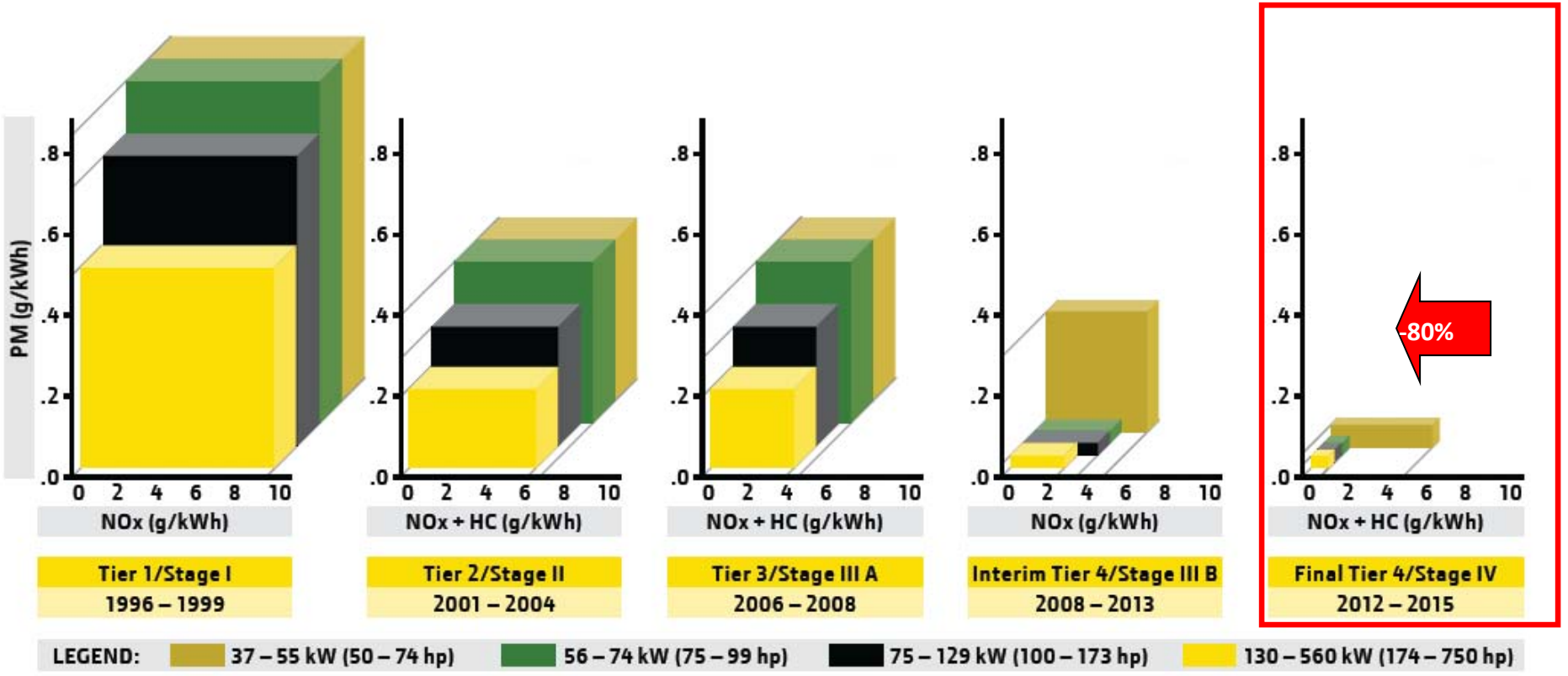
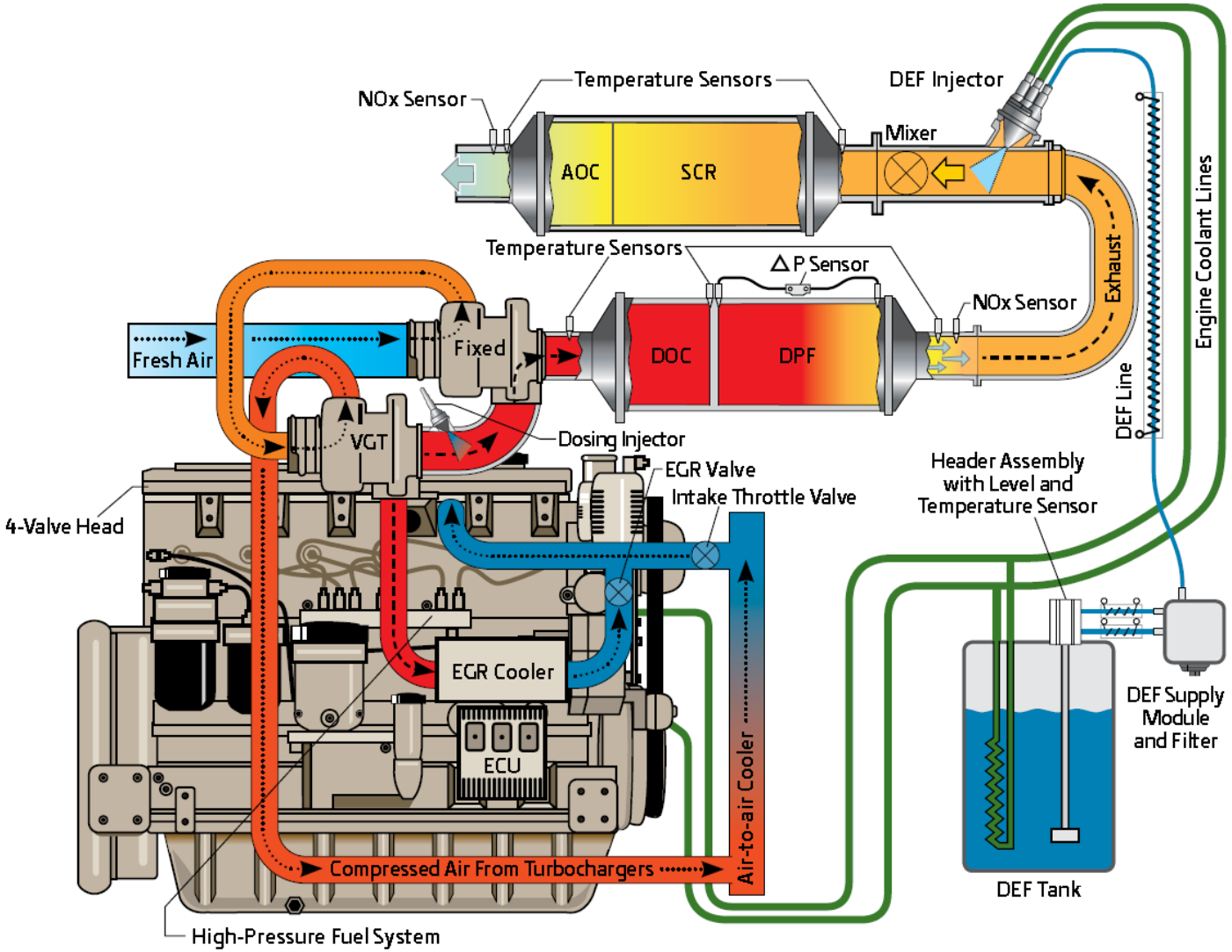
2014: 80% Reduction in NOx



Final Tier 4 Building Block



Final Tier 4 Building Block

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Key Features/Benefits:

- Minimal Operator Involvement
- Best Available Technology for PM & NOx Reduction with Integrated Emissions Control system
- World-Class Total Fluid Economy
  - Less Diesel Fuel Consumption Compared to iT4
  - Less Diesel Exhaust Fluid Consumption Compared to SCR-only Systems
  - Improved Fluid Efficiency Compared to iT4
- Longer Interval Between Active Filter Cleaning
- Extended Ash Service Interval
- Improved Performance
  - Power Bulge
  - Higher Peak Torque
  - Improved Low Speed Torque & High Altitude Performance
  - Improved Transient Response
  - Multiple Rated Speeds
- Emissions Compliance

Final Tier 4 Building Block

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Integrated Solution:

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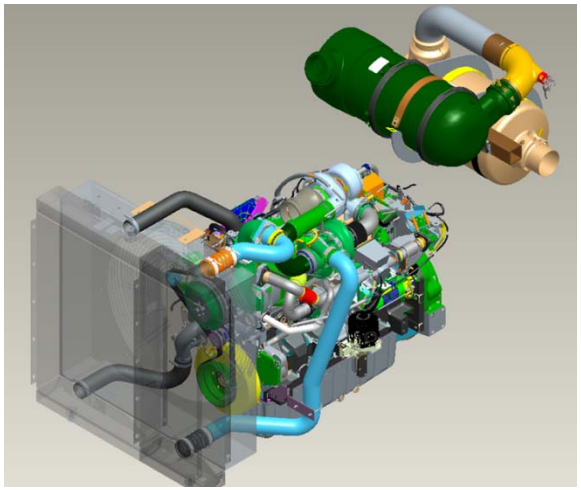
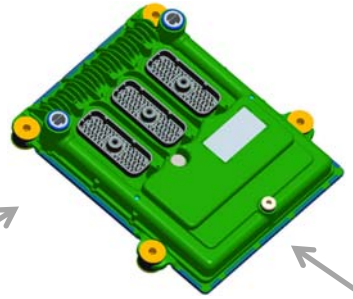
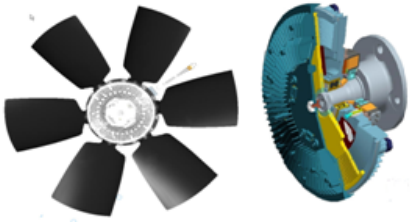
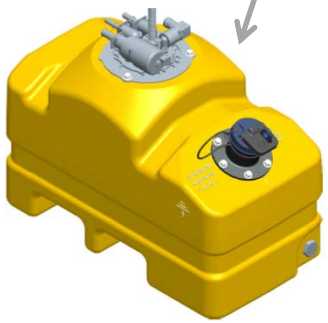
- Integrated Emissions Control System
  - Single ECU:
    - Controls All Engine Systems
    - Controls Exhaust System Aftertreatment
    - Controls Variable Speed Fan Drive
    - Provides Input/Output Capabilities for Applications





Variable Speed Fan





SCR: What is SCR?

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- **SCR: Selective Catalytic Reduction**
  - NOx Reduction In Exhaust Aftertreatment System
  - NOx molecules broken down with:
    - Diesel Exhaust Fluid (Urea/water solution)
    - Copper Zeolite Catalyst
    - Exhaust Temperature
  - Result is nitrogen gas (N_2) & water vapor (H_2O)

FT4 Engine and Aftertreatment Optimization

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- Adding Exhaust System SCR
  - Optimizes:
    - NO_x reduction in the Engine & the Aftertreatment
- High Pressure Fuel Systems
  - Reduce PM output of the engine
- Integrated Emissions Control System
  - Optimizes the overall system performance:
    - Improve/Maintain Transient Response
    - Improve Fuel Economy
    - Improve/Maintain Torque Rise

Final Tier 4 Value Proposition

Integrated Emissions Control system (IECS)

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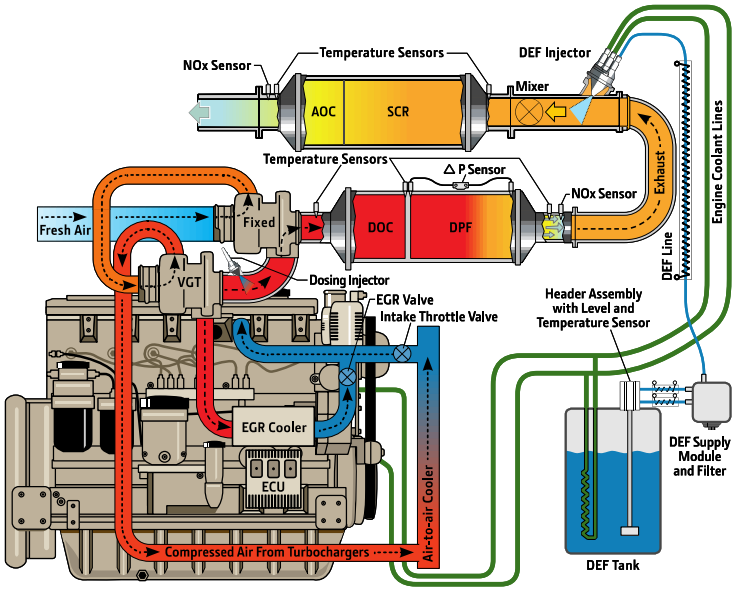
The optimization of four major emission building blocks

1. High Pressure Fuel Systems
2. Cooled External EGR
3. Exhaust Filter with DOC/DPF
4. Selective Catalytic Reduction (SCR)



High Pressure Fuel Systems

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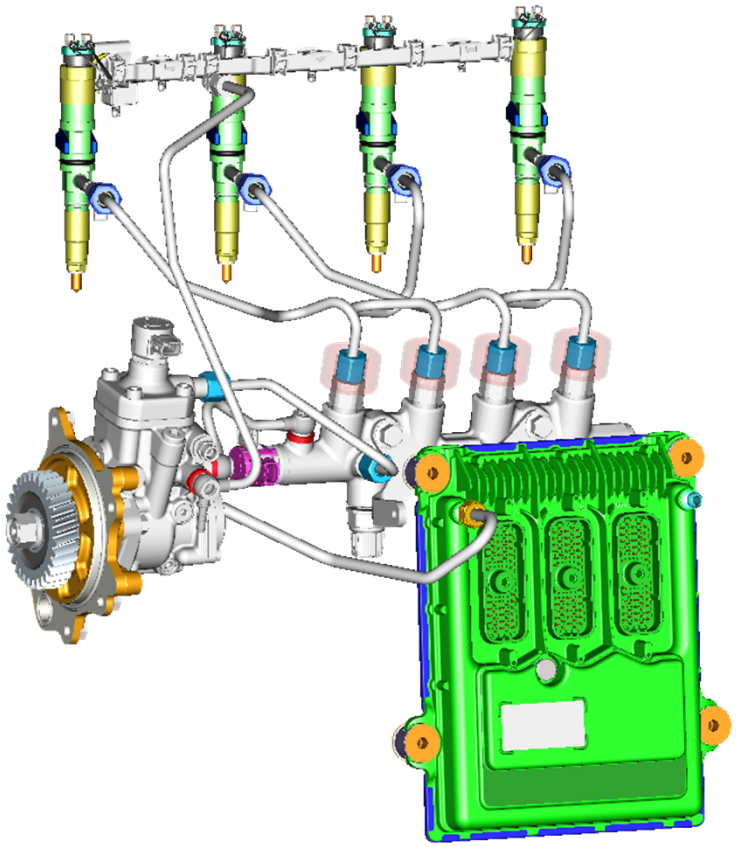
Increased operating pressures compared with IT4 (up to 36,000 PSI/2500 Bar)

Better fuel atomization, cleaner burn

- ✓fuel efficiency
- ✓less engine-out PM
- ✓less frequent DPF active regenerations



Cooled External EGR

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Lowers engine-out NO_x

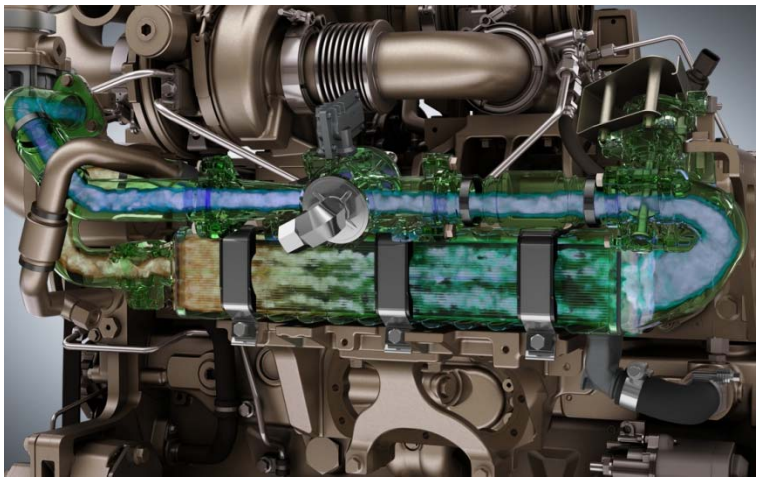
- ✓reduces need for SCR
- ✓minimizes DEF consumption

Allows for enhanced engine calibration and advanced fuel injection timing

- ✓maximizes diesel fuel efficiency
- ✓enhances transient response

When optimized with SCR

- ✓Lowers EGR flow rates in higher SCR efficiency operating zones = improved diesel fuel efficiency
- ✓ Increases EGR flow rates in lower SCR efficiency operating zones = improved DEF efficiency
- ✓ Optimized for total fluid efficiency



Diesel Oxidation Catalyst (DOC) & Exhaust Temperature Management (ETM)

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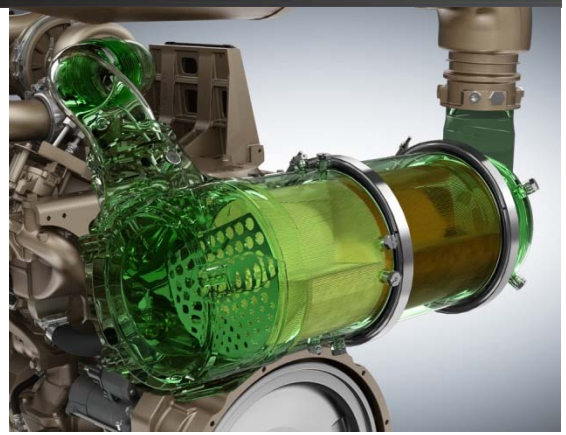


The DOC burns hydrocarbons (HC)

- ✓ produced by incomplete combustion
- ✓ injected in the exhaust stream during an active filter cleaning
- ✓ chemically produces the necessary heat to promote filter cleaning

ETM uses engine components (fuel system, air intake throttle, turbo) to raise exhaust temperature

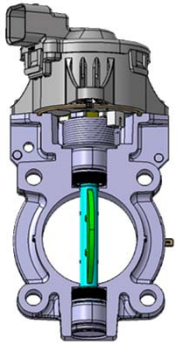
- ✓ supports the action of the DOC during filter cleaning

Both the DOC and ETM are an integral part of the engine and eliminate the need for a burner

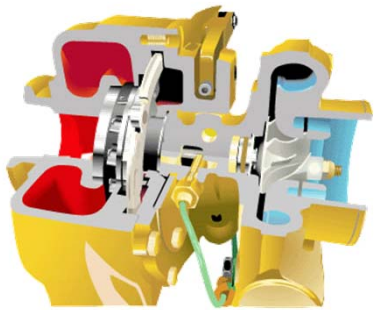
- ✓reduced cost & complexity
- ✓fuel efficiency

Injection system

Air intake throttle



Variable geometry turbo



Diesel Particulate Filter (DPF)

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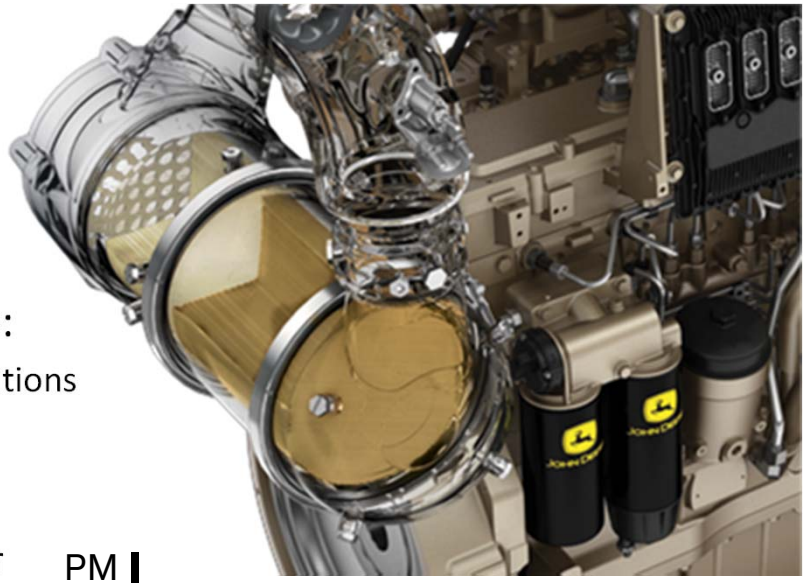
-Traps PM and allows engine exhaust heat to passively clean the filter during normal engine operation

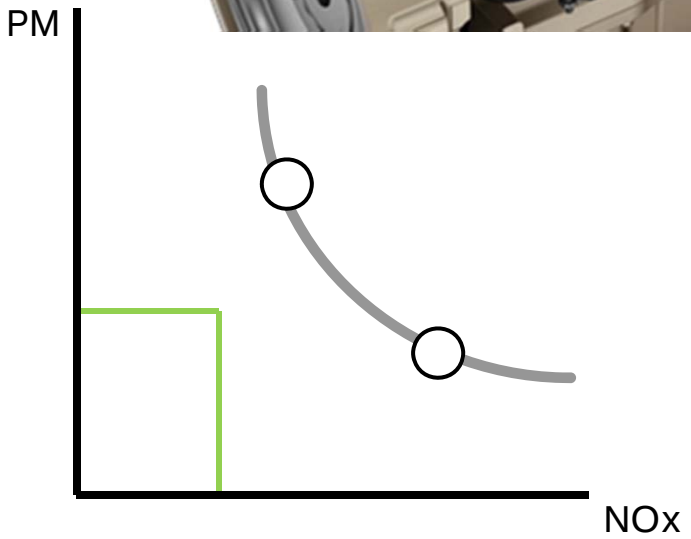
-Compared with no-DPF solutions, the Integrated Emissions Control system can be calibrated to produce:

- ✓ more PM…especially during engine transient response conditions
  - -better transient response = more productivity
- ✓ less NO_x
  - -less NO_x reduction downstream of the engine
  - -lower DEF consumption = smaller DEF tank size or longer interval between DEF refills

-No-DPF solution means PM level must be achieved in-cylinder

- ✗ PM control during transient conditions slows engine response and decreases productivity
- ✗ Engine must be calibrated to maintain PM levels which produces more NO_x, leading to higher levels of DEF consumption, larger DEF tanks and or shorter intervals between refills





Selective Catalytic Reduction (SCR)

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Cooled EGR reduces NO_x in-cylinder

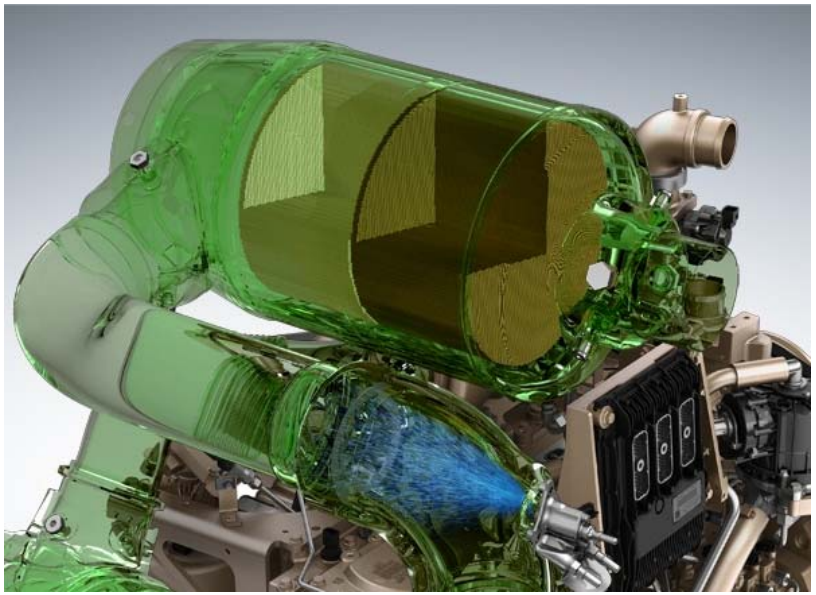
SCR reduces remaining NO_x released downstream of the engine using Diesel Exhaust Fluid (DEF)

Optimization of SCR and Cooled EGR allows for:

- ✓ Improved engine performance
  - -Better transient response
  - -Greater machine productivity
- ✓ Better diesel fuel efficiency
- ✓ Best total fluid consumption

Combination of SCR & Cooled EGR enables:

- ✓ Less DEF consumption
- ✓ Smaller DEF Tank
- ✓ Longer interval between refills



What is DEF?

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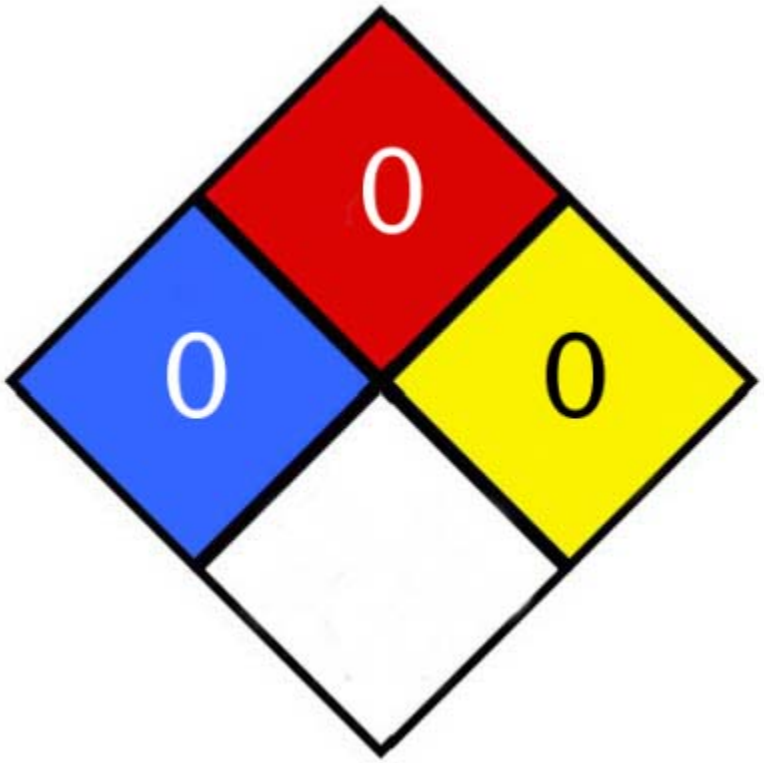
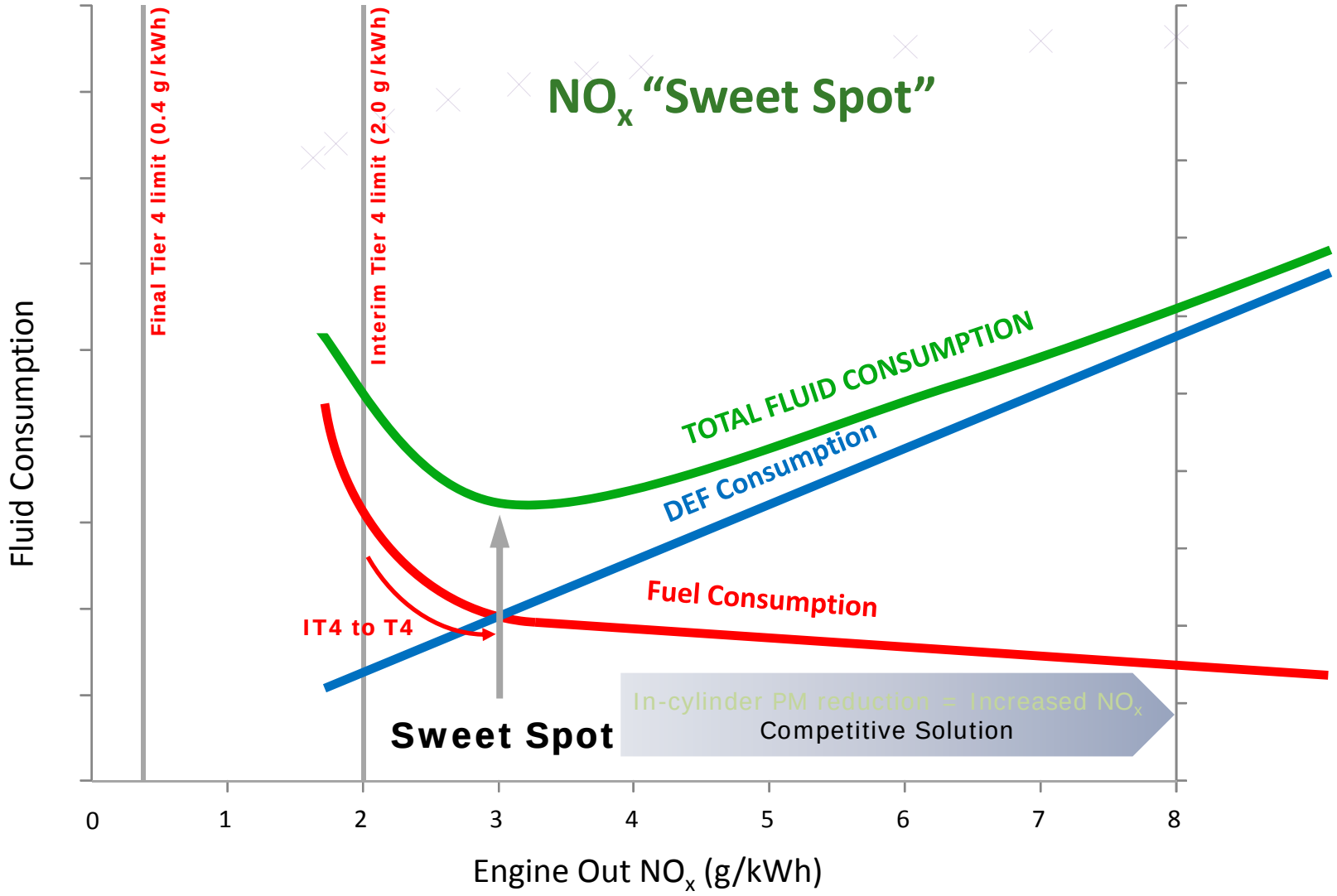
32.5% DEF grade urea & 67.5% demineralized water

- Non-Toxic
- Non-Flammable
- Non-Hazardous
- Not DOT Regulated



IECS Optimization - Best Total Fluid Efficiency



How Much DEF Do I Need?

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Approximately 4% of Fuel Consumption

Engine	gal/hr (l/hr)
6.8L	.1 (.4)
9.0L	.2 (.8)
13.5L	.3 (1.1)

* DEF usage rates shown are based on an average for typical engine duty cycles. DEF consumption is primarily a function of engine speed and load. Actual results may vary.

FT4 Value Proposition Summary

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Engine Performance:

Power Density:	equal to or better than IT4
Power Bulge:	equal to or better than IT4
Peak Torque:	equal to or better than IT4
Transient Response:	equal to or better than IT4 better than competitive No EGR, SCR & DOC only solutions testing of competitive IT4, 4.5L engine with DOC (Sept 2012)

Total Fluid Economy:

Equal to or better than Deere Interim Tier 4

Lower diesel fuel consumption (1% to 4%)

Lowest DEF consumption (1% to 3%)

Expect FT4 no-DPF/SCR solutions to increase DEF consumption above IT4 levels

Deere FT4 fluid economy advantage will grow over FT4 no-DPF/SCR only solutions

Deere will provide world class or best-in-class total fluid economy

FT4 Value Proposition Summary

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Maintenance Intervals

Oil & filter change: 250/500 hour oil pan options
Fuel filter: Annually, 500 hours or “as required”
Particulate filter ash service: up to 15,000 hours (application dependent)
DEF filter: interval to be determined

Operating Costs

Same or lower “total” (Diesel & DEF) fluid costs
Same maintenance costs (fuel filter, oil filter & engine oil)
Lower ash service costs (extended intervals)
Small increase (<$15) with “New” DEF filter

Reliability/Durability

More than 25,000 IT4 machines w/ 7 million customer hours
Over 700,000 test hours w/ FT4 engines at start of production
-Test hours split between test lab and prototype vehicles

“How does it impact me?”

Impact

- Increased knowledge needed
  - Need to know about regeneration and new operator interface icons
- Ultra Low Sulfur Diesel (ULSD) is required
  - High sulfur fuel will “poison” after treatment due to sulfuric acid
- All engines are electronic due to emissions controls
- Most engines will have a variable speed fan
  - Reduces noise. Also keeps engine temperatures in a window
- Spark Arrestor not necessary due to flow-through walls of DPF

Impact (Cont'd)

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- Engine package is larger
  - Need room for DOC/DPF and (many cases) SCR
- iT4/FT4 engine horsepower sizing more critical
  - Low duty cycle applications will require more DPF regenerations
  - Operation likely will not be affected with properly sized engine
- FT4 requires the use of a second fluid, DEF, for most engine models
  - Secondary tank sized relative to fuel tank

“How can I use a non-current emission Tier engine?”

Engine Flex

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- **New Source Performance Standards (NSPS) covers irrigation units. Regulation 40 CFR part 60.**
- **Must be a repower or mobile equipment!**
- **Repower**
  - **Can replace existing engine with one of same or later emission Tier.**
  - **Must be like-for-like fuel and horsepower. i.e. diesel vs. gas**
  - **Core engine required to be returned to equipment dealer/manufacturer.**

Engine Flex (cont'd)

- **Mobile Equipment**
- **Trailer mounted unit with wheels**
  - **Must be moved more than once in 12 month period.**

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Questions?