Off-Highway Diesel Engine Emissions Overview

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Emissions Overview
What is PM?

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?

**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:

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
### EPA nonroad emissions regulations

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**Legend**
- **EPA**
- **Tier 1**
- **Tier 2**
- **Tier 3**
- **Tier 4**
- General Availability of Tier 4 Equipment Efficacy Provision
- Delayed Availability of Tier 4 Equipment Efficacy Provision

**Notes:**
- New non-emissions regulations take effect January 1 of the year indicated by color change unless otherwise noted.
- The vertical dashed lines separating the years show when the seven-year life of the Tier 2/3 Equipment Efficacy Provision ends and engines cannot be placed in vehicle production.

**Examples**
- NOx: 2.0 g/kWh
- PM: 0.02 g/kWh
- HC: 0.15 g/kWh

**Important:**
- In the 50 to 74 horsepower category, there are two options: Option 1 requires a reduced PM level (0.02 g/kWh) but allows Tier 4 to be delayed one year (2013).
Deere Building block approach
What Emission Levels Changed for Tier 1?

1996: Baseline Emissions Levels Established

- Tier 1/Stage I: 1998 – 1999
- Tier 2/Stage II: 2001 – 2004
- Interim Tier 4/Stage III B: 2008 – 2013
- Final Tier 4/Stage IV: 2012 – 2015

Legend:
- 37 – 55 kW (50 – 74 hp)
- 56 – 74 kW (75 – 99 hp)
- 75 – 129 kW (100 – 173 hp)
- 130 – 560 kW (174 – 750 hp)
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?

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?

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?

2011: 90% PM and 50% NOx Reduction
Interim Tier 4 Building Block

- 4-Valve Head
- Fresh Air
- Fixed
- VGT
- Dosing Injector
- EGR Valve
- Intake Throttle Valve
- EGR Cooler
- Compressed Air From Turbochargers
- High-Pressure Fuel System
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?

2014: 80% Reduction in NOx
Final Tier 4 Building Block
Final Tier 4 Building Block

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
Integrated Solution:

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
SCR: What is SCR?

- **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 (N₂) & water vapor (H₂O)
FT4 Engine and Aftertreatment Optimization

- **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)

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

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

Lowers engine-out NO\textsubscript{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)

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
Diesel Particulate Filter (DPF)

- 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 NOx
    - less NOx 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 NOx, leading to higher levels of DEF consumption, larger DEF tanks and or shorter intervals between refills
Selective Catalytic Reduction (SCR)

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?

32.5% DEF grade urea & 67.5% demineralized water

- Non-Toxic
- Non-Flammable
- Non-Hazardous
- Not DOT Regulated
IECS Optimization - Best Total Fluid Efficiency

NO$_x$ “Sweet Spot”

- **Final Tier 4 limit (0.4 g/kWh)**
- **Interim Tier 4 limit (2.0 g/kWh)**

**TOTAL FLUID CONSUMPTION**
- DEF Consumption
- Fuel Consumption

**In-cylinder PM reduction = Increased NO$_x$**

Competitive Solution

**IT4 to T4**

Engine Out NO$_x$ (g/kWh)
# How Much DEF Do I Need?

## Approximately 4% of Fuel Consumption

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* 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

**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

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)

• 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

- 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.
• Mobile Equipment

• Trailer mounted unit with wheels
  • Must be moved more than once in 12 month period.
Questions?