An Off-Highway Perspective of Future Power Systems
Eric J. Hruby – Staff Engineer Aftertreatment Innovation
Contents

- Off-highway constraints to the engine system
- Combustion as a foundation
- Competing goals and objectives (NOx, PM, Heat Rejection, BSFC)
- Aftertreatment enabled solutions for the customer
2016 Test Results: 8400R Most Efficient Tractor

**Drawbar Power**
- **275kW**
- **NEW RECORD!**

**PowerMix-Field**
- **238g/kW**
- **NEW RECORD!**

**PowerMix-Transport**
- **428g/kW**
- **NEW RECORD!**

<table>
<thead>
<tr>
<th>Competitor</th>
<th>Stage</th>
<th>Drawbar Power</th>
<th>Drawbar Power</th>
<th>PowerMix-Field</th>
<th>PowerMix-Transport</th>
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</thead>
<tbody>
<tr>
<td>John Deere</td>
<td></td>
<td>238 + 9</td>
<td>275kW</td>
<td>238g/kWh</td>
<td>428g/kWh</td>
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<tr>
<td>Competitor A</td>
<td>IV/T4</td>
<td>242 + 10,7</td>
<td>238g/kWh</td>
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<tr>
<td>Competitor B</td>
<td>IIIb/IT4</td>
<td>249 + 20,4</td>
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<td>Competitor C</td>
<td>IV/T4</td>
<td>257 + 28,3</td>
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<td>Competitor D</td>
<td>IIIb/IT4</td>
<td>258 + 20,4</td>
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<td>Competitor E</td>
<td>IV/FT4</td>
<td>265 + 10,9</td>
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# Off-Highway Machines Operating Environment

<table>
<thead>
<tr>
<th>Condition</th>
<th>Working Speed</th>
<th>Cooling</th>
<th>Intake Air</th>
<th>Work Surface</th>
<th>Fluid Refill</th>
<th>Usage</th>
<th>Duty Cycles</th>
<th>Transient Demand</th>
<th>Off-Level</th>
<th>Vibration</th>
<th>Environment</th>
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</thead>
<tbody>
<tr>
<td>Wet</td>
<td>90 (Km/hr)</td>
<td>Ram Air</td>
<td>Clean</td>
<td>Pavement</td>
<td>At Station</td>
<td>Continuous</td>
<td>Few</td>
<td>Medium</td>
<td>Minor</td>
<td>Mild</td>
<td>Clean</td>
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<tr>
<td>Cold</td>
<td>8 (Km/hr)</td>
<td>Fan Power</td>
<td>Variable</td>
<td>Dirt</td>
<td>At Machine</td>
<td>Seasonal</td>
<td>Many</td>
<td>High</td>
<td>Substantial</td>
<td>Severe</td>
<td>Debris</td>
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<td>Slope</td>
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</tbody>
</table>
Off-Highway Engines Operation

Focus of Optimization

13.5L Tractor
13L Truck
Customer Demand for Productivity(Power) and Reliability
Systems Level Approach

- Operating Environment
- Customer Needs
- Additional Requirements...

Integrated Product

- Controls
- Air System
- Mechanical
- Aftertreatment

Requirements

Foundation For Success
Combustion System Optimization

Wide Range of Applications Needs

Combustion Development Process

- Port design
- Fuel Sprays
- Design
- Simulation
- Test
- Air motion CFD
- Swirl Testing
- Combustion CFD
- Combustion

Power (kW)

Volume

Construction & Forestry
Tractors etc.
Harvesters
Combustion Fundamentals: EGR or No-EGR

- Lower Piston/Head Surface Temperatures
- Lowest Total Fluid Economy
- Smaller Aftertreatment Components

![Diagram showing BSFC vs Engine Out NOx with EGR and No EGR curves, indicating lower BSFC and NOx emissions for No EGR.]

\[\text{DEF (g/kWh)} = 2.01 \times \text{ANR} \times \text{NOx (g/kWh)}\]

\[\text{ANR} = \frac{\text{Ammonia}}{\text{NOx}} \text{ molar ratio}\]
In Depth Benefits of EGR vs No EGR - Fuel Energy Distribution

EGR: Analogous to Waste Heat Recovery but for DEF

Heat Rejection (coolant + CAC) = 25%

No EGR: 10g/kWh NOx
- Coolant: 17%
- Power: 39%
- Exhaust: 36%
- CAC: 8%

Heat Rejection (coolant + CAC) = 35%

EGR: 3g/kWh NOx
- Coolant: 26%
- Power: 39%
- Exhaust: 26%
- CAC: 9%

Exhaust Heat 10% ↓

Heat Rejection 10% ↑

No EGR: 10g/kWh NOx
Exhaust: 36%
Power: 39%
Coolant: 17%
CAC: 8%

EGR: 3g/kWh NOx
Exhaust: 26%
Power: 39%
Coolant: 26%
CAC: 9%
Regulations Impossible Without Aftertreatment

8 Mode Composite
Future Advances in Combustion

- Biggest Impact in Combustion
- Enabled by Aftertreatment Advances
- Improved Customer Experience
2016 Test Results: 8400R Most Efficient Tractor

**Worthwhile Endeavor**

- **John Deere 8400R e23**
  - 238 + 9

- **Competitor A Stg IV/T4**
  - 242 + 10,7

- **Competitor B Stg IIIb/IT4**
  - 249 + 20,4

- **Competitor C Stg IV/T4**
  - 257 + 28,3

- **Competitor D Stg IIIb/IT4**
  - 258 + 20,4

- **Competitor E Stg IV/FT4**
  - 265 + 10,9

- **Drawbar Power** 275kW
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