Thank you for the opportunity to share insights with you today.

About us: The Diesel Technology Forum is supported by leaders in advanced diesel engines, vehicles, equipment, components and fuels.

- AGCO
- Bosch
- Caterpillar Inc.
- CNH Industrial
- Cummins Inc.
- Daimler
- Deere & Company
- FCA
- General Motors
- Isuzu Motors
- Johnson Matthey
- Mazda North American Operations
- MTU America
- Neste
- Renewable Energy Group
- Umicore
- Tenneco
- Volvo Group
- Yanmar

Allied Members
- National Biodiesel Board
- Western States Petroleum Association
Overview of Diesel Technology

Current Commercial Vehicle Fleet Characterization

Off-Road Equipment Considerations

Biofuels use in Diesel Engines
Oregon’s Trucks and Buses Are Mostly Diesel

Technology Types for All Commercial Vehicles in Oregon (2019)
- Diesel: 71%
- Gasoline: 25%
- CNG: 3%
- Electric: 0%
- Not Defined: 1%

Technology Types for Class 8 Trucks in Oregon (2019)
- Diesel: 97%
- CNG: 3%

Technology Types for School Buses in Oregon (2019)
- Diesel: 83%
- CNG: 3%
- Gasoline: 3%
- Not Defined: 11%
Diesel is a Technology of Continuous Improvement

60:1

It takes 60 of today’s diesel trucks to generate the same emissions as a single older diesel truck.

Source: U.S. EPA Office of Transportation and Air Quality (OTAQ)
What is a “new technology diesel” truck?

2010 and later model year

• Incorporates the most advanced emissions control systems – Selective Catalytic Reduction (SCR) and particulate matter (PM) filters.
• Achieves near zero emissions.
• 2007 first year for PM filters

CLEAN DIESEL PROGRESS
Heavy-Duty On-Highway

Diesel Emissions Control System

Exhaust gases leave engine

Reduced volume of emissions leaves tailpipe, PM and NOx near zero levels.

Engine

Particulate (PM) trapped in diesel particulate filter

DEF injected into exhaust

NOx reduction in SCR Catalyst

This schematic shows how Selective Catalytic Reduction (SCR) with a Diesel Particulate Filter (DPF) System works. Untreated exhaust gas passes from the engine into a DPF that removes over 95 percent of particulate matter and soot. The exhaust moves into a mixing chamber where the exhaust gas is dosed with a precise spray of diesel exhaust fluid (DEF) reacts with oxides of nitrogen (NOx) on a special catalyst and converts these gases into nitrogen dioxide and water vapor. The system reduces PM and NOx and other emissions to near zero levels.

DieselForum.org/SCR

Source: U.S. EPA Office of Transportation and Air Quality (OTAQ)
Share of Near Zero Emissions Diesel Trucks and Buses in Oregon

55% of Oregon’s diesel commercial fleet is MY 2007 & newer.....near-zero PM emissions.

National average = 55%

Source: IHS Markit; July 2019
Health Effects Institute Advanced Collaborative Emissions 2015 Study (ACES) finds PM filters perform well; validates NOx mitigation and found no adverse health outcomes from exposure

Health Effects Institute ACES Study of New Technology Diesel Engines Finds Major declines in PM Mass and Numbers Emissions 2015
Newest generation Diesel Trucks Are already delivering measurable clean air and climate benefits to the region

What are the NOx, PM and C02 reduction benefits provided through new technology diesel trucks to Washington State and Oregon to date between 2010 and 2018?

- NOx = 600,000 tons
- PM = 42,000 tons
- C02 = 3.7 million tons
- Fuel savings = 358 million gallons

What are the anticipated benefits to Oregon and Washington State from the adoption of cleaner and more efficient trucks between 2010 and 2030 owing to the Phase 1 & 2 fuel economy standards?

- NOx = 2.3 million tons
- PM = 157,000 tons
- C02 = 41 million tons
- Fuel Savings = 4 billion gallons

According to U.S. EPA's Greenhouse Gas Equivalencies calculator, the CO2 and fuel savings benefits are equivalent to taking 8.7 million passenger cars off the road, or converting them to EVs, and the same amount of electricity used by over 7 million homes.
Factors that influence investment $ in new trucks

- Overall Economic conditions of the business sector – present, future – real or imagined.
- Incentives to purchase: dealer promotions/discounting/trade value; government incentives, pre-regulatory milestone vehicles
- Cost vs. Benefit:
  - Warranty remaining, breakdown frequency and cost,
  - Anticipated fuel & maintenance cost savings of new,
  - Approaching major maintenance intervals-engine rebuilding (miles depends on unit/utilization),
  - Other business factors - driver recruitment/retention, safety equipment, insurance rates
  - Optimize buy new and trade/sell existing based on all factors above
But What Does it Cost? $$$

Composite price of a new Class 8 diesel OTR truck = $110,000.
The composite price of a four-year-old Class 8 tractor is about 50 percent that of a new tractor ($55,000).

Source: California Air Resources Board, Truck and Bus 2010 Rulemaking Initial Statement of Reasons, Appendix I: Costs and Cost Methodology

Very Difficult to generalize cost -- not All Class 8s are the Same
Is it a day cab? Is it a sleeper? What is it hauling...what are the transmission needs? Is it an automated manual with predictive cruise control? What are the horsepower needs of the engine? Is it a tandem or single axle?

$113,000 ....$125,000
Further Improvements Ahead

- **Clean Truck Initiative – making diesel even nearer-to-zero**
  - Truck and Engine Makers discussing with USEPA and CARB next round of standards for further NOx emissions reductions from HDTs.
  - Will address issues like low-load cycle emissions, emissions durability, real world testing.
  - Timeframe for implementation TBD but 2025-2027, with industry discussing voluntary pull-ahead.

- **GHG rules – Phase II implementation underway;**
  - Manufacturers delivering Phase 2 products today

- **Alternative Fuels**
  - Truck and Engine manufacturers exploring additional alternative fuels for class 3-8 trucks (hydrogen, electrification);
  - Smaller, lighter vehicles with shorter delivery ranges initial targets.
  - None commercially available today in heavier vehicle classes beyond limited demonstration fleets/vehicles.
  - Commercial scale for zero emission technologies likely to be measured in decades from now. (*Mckinsey, et al.*).
“How Long until Diesel is Replaced by eTrucks?”
McKinsey’s Perspective the Race of ePowertrains

Exhibit 2: Race of ePowertrains

- Timing of average cost parity between battery electric versus diesel trucks
- Weight classes: LDT, MDT, HDT
- Gradients behind eTrucks indicate range with early beneficial use-cases

Source: McKinsey Energy Insights, McKinsey Center for Future Mobility
“Will EV Trucks Replace Diesel?”

McKinsey’s global view on adoption of eTrucks

Exhibit 3: Adoption curves of eTrucks across regions and weight classes

- **Exhibit 3**
  - Adoption curves of eTrucks across regions and weight classes
  - Share of new sales

- **US %**
  - HDT
  - MDT
  - LDT

- **Europe %**
  - HDT
  - MDT
  - LDT

- **China %**
  - HDT
  - MDT
  - LDT

Legend:
- Fossil fuels (predominantly diesel)
- eTruck (early adoption scenario)
- eTruck (late adoption scenario)

Weight class definitions:
- **US** HDT: Class 8 (>15t), MDT: Class 4-7 (6.4-15t), LDT: Class 2-3 (3.5-6.4t)
- **Europe** HDT: 16t, MDT: 7.5-18t, LDT: 3.5-7.5t
- **China** HDT: >14t, MDT: 6-14t, LDT: 3.5-6t

Source: McKinsey Energy Insights, McKinsey Center for Future Mobility
But Wait, There’s More. Advance Biofuels Add Significant Benefits at Low Cost

California Case Study

Of all the fuel types and technologies, biodiesel and renewable diesel are contributing the greatest CO2 reductions in California....and it takes a diesel engine to realize the benefits

If WA joins CA, OR and BC...West Coast will be the largest Renewable Diesel Fuel Market in the World
Use of biodiesel fuels offers additional means of reducing emissions

**Emissions Reductions in Diesel Engines Without Aftertreatment:**

<table>
<thead>
<tr>
<th>Emissions Reduced</th>
<th>B100</th>
<th>B20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Unburned Hydrocarbons</td>
<td>-67%</td>
<td>-20%</td>
</tr>
<tr>
<td>Carbon Monoxide</td>
<td>-48%</td>
<td>-12%</td>
</tr>
<tr>
<td>Particulate Matter</td>
<td>-47%</td>
<td>-12%</td>
</tr>
<tr>
<td>Polycyclic Aromatic Hydrocarbons</td>
<td>-80%</td>
<td>-13%</td>
</tr>
<tr>
<td>Ozone Potential</td>
<td>-50%</td>
<td>-10%</td>
</tr>
</tbody>
</table>

A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions
http://www.epa.gov/otag/models/analysis/biodsl/p02001.pdf
OEMS supporting B20

as listed per [www.biodiesel.org](http://www.biodiesel.org) website

*Models equipped with Cummins engines are B20 approved. See NBB website for details.*
A word on off-road

• Medium-duty trucks powered by a model year 2009 or older diesel engine;

• Heavy-duty trucks powered by a model year 2006 or older diesel engine; and,

• Non-road diesel engines model year 2009 or older commonly used in public contracts
Off road equipment has different emissions standards and timeframes

- Non-road diesel engines model year 2009 or older commonly used in public contracts
Retrofit of Non-road diesel engines model year 2009 or older “commonly used in public contracts”:

- Public contracts – road projects vs. infrastructure vs site preparation or other? Most construction sites have a range of equipment – less than 50- hp up to over 500 hp depending on the project and tasks.

- “Smaller” types of equipment <75hp (e.g. Skid Steer Loaders, compact excavators) units tend to be newer, because they are utilized more, are cheaper to buy and replace, so they are typically newer generation units, and have lower emissions than larger machines; Also equipment rental options readily available; rent instead of own cheaper for some contractors.

- Medium size equipment (75-750 hp) can include excavators, pavers, trenchers, telehandlers, wheel loaders, bulldozers,- replacement variable based on use,

- Larger costlier machines >750 hp (Excavators, motor graders, bulldozers, articulated trucks) can tend to be replaced less frequently

- Generally fewer Retrofit options available for off-road machines and equipment than HD trucks; greater variability; costly application engineering; unique considerations – add on filters in exhaust/muffler are can cause operator visibility and safety issues.

CATERPILLAR EMISSIONS RETROFIT SOLUTIONS
Caterpillar has taken the lead in meeting and surpassing EPA emissions guidelines, while helping Cat equipment users do their part to maintain air quality. Retrofits from Caterpillar Emissions Solutions provide cost-effective compliance options for existing Cat-Powered equipment. Cat Emissions Retrofits are also available for a range of competitively powered equipment.

Four methods of Cat Emissions Retrofit Solutions for off-road machines include Engine Repowers, Engine Upgrade Groups, Oxidation Catalysts, and Diesel Particulate Filters.
Summing it All Up

New generation of diesel technologies with PM controls and NOX reduction (SCR) are proven, widely available and offer significant customer, climate and environmental benefits over previous generations.

Retrofit opportunities for all vehicles and equipment must be evaluated on a case by case basis for both technical and economic reasons.

Advanced high-quality biofuels like renewable diesel and biodiesel should be considered as readily available means to reduce emissions in existing vehicles.

THANK YOU

Allen Schaeffer
Executive Director
Aschaeffer@dieselforum.org
(301) 668-7230