The Past – Present – Future of Clean Diesel

Alexander Freitag
Director Engineering Systems Development
Robert Bosch LLC

Powertrain Strategies for the 21st Century: Facing the Challenge of Dramatic Fuel Economy Demands
Conventional powertrains – Game over?

The Oil Party is nearly over

Peak Oil

Beyond Oil

Crude Oil Extraction

Exa Joule/a

0 50 100 150 200 250 300

0 500 1000 1500 2000 2500

Year

TOM’S SHELL

Self Serve

Cash or Credit

Regular

Plus

Premium

ARM 9

LEG 9

First 9 Born

Medium Scenario

Campbell

Odell

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Conventional powertrains – Game over?

New powertrains: Estimated world market volumes

Internal Combustion Engines will remain the predominant power train for the near future.

Diesel Systems
The Past – Present – Future of Clean Diesel

Agenda

- The PAST of Clean Diesel
- The PRESENT of Clean Diesel
- The FUTURE of Clean Diesel
The Past – Present – Future of Clean Diesel

The PAST-PRESENT-FUTURE of Clean Diesel

- 1897: The first Diesel Engine, Paris World Exhibit
- 1912: The use of vegetable oils for engine fuels might seem insignificant today, but such oils may become as important as petroleum and coal tar products of the present.
- 1930: First Trip in the US by a diesel-powered car (Packard Sedan with Cummins Engine) Indianapolis to New York 800 miles for total cost of $1,38
- 1970: Oil Crisis 1970’s
- 1980: GM introduces as first North American OEM Diesel to the market accounting for 10% of GM’s overall vehicle sales
- 1990: By mid 1980’s more than 100 different diesel models were available from GM, Ford, and others, leading to the sales of diesel vehicles growing from 5% in 1980 to 20% in 2007.
- 2000: Bosch revolutionizes the diesel industry by introducing electronically controlled diesel systems and further reducing NOx and CO2. Bosch is the world leader in diesel systems with more than 40 million systems sold by January 2009.
- 2006: Mandated Ultra Low Sulfur Diesel in CA
- 2008: The New CLEAN Diesel gets introduced. DIESEL no longer a dirty word. 2 years in a row
- 2009/10: Green Car of the Year

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The PAST of Clean Diesel

The PRESENT of Clean Diesel

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Consumer Consideration Index

Would you purchase a clean diesel?

Steady Increase in Consumer Consideration of Clean Diesel Technology

Source: CNW Research
The Past – Present – Future of Clean Diesel

Clean Diesel Take-Rate PC/LD

Clean Diesel Technology achieved Take-Rate of > 30% in less than 2 years

Source: POLK

Registration Data
The Past – Present – Future of Clean Diesel

Alternative Powertrain Comparison

Clean Diesel Technology on par with other alternative Powertrains

Source: Polk / Edmunds

*Not incl. hybrid/electric only vehicles e.g. Toyota Prius, Chevy Volt, etc.
Total Cost of Ownership [TCO]

Clean Diesel offers TCO benefits (payback) in less than 18 months

Source: Carnegie Mellon University
### The Past – Present – Future of Clean Diesel

#### Clean Diesel Launch Calendar

<table>
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<th>Year</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
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Source: Bosch

**Clean Diesel Models will more than double within less than 3 years**
The Past – Present – Future of Clean Diesel

Agenda

The PAST of Clean Diesel

The PRESENT of Clean Diesel

The FUTURE of Clean Diesel
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Powertrain diversification for Today and the Future

- Gasoline
- Dual fuel
- EV / range extender
- EV / battery
- EV / fuel cell
- Alternative fuels
- Hybrid
- EV (battery / fuel cell)

Variety of Technical solutions needed to address energy reduction

1997  2010  2015  ?

Diesel Systems

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Available vehicles already significantly below Tier 2B5, measures for achieving Tier 2B2 defined.
Optimizing the Diesel System

Fuel Injection System
- New Generations
- Multiple Injections
- Reduced Tolerance
- Optimized Nozzle

Tolerance Reduction
- Zero Fuel Calibration
- Fuel Balancing Control
- Individual Cylinder Control

Combustion Process
- Reduction of compression ratio
- Partly homogenous combustion

Air Management
- Swirl-/Throttle Valve
- Turbo Charger/VGT*

Exhaust gas management
- Fast Catalyst Light-Off (reduce thermal losses)
- Diesel Particulate Filter
- NOx storage catalyst
- Catalysts temp control

*D= Variable Geometry Turbo
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System Approaches for FTP SULEV compliance

1. AdBlue Dosing
   - Improved series technology
   - Needs enhanced heat up, FE ↓, GHG ↑

2. AdBlue Dosing
   - Add HC and NOx buffer for low temperature
   - Complex control strategy required

3. HC Dosing
   - Promises good low temperature efficiency
   - Performance depends only on thermal critical NSC (LNT)

4. HC Dosing
   - Promises robustness and high efficiency
   - Complex and expensive

Different approaches are investigated to identify the best solution

NSC = NOx Storage Catalyst
cDPF = coated Diesel Particulate Filter
DOC = Diesel Oxidation Catalyst
SCR = Selective Catalyst Reduction
Close-coupled SCR yields to a significant improvement in NOx conversion due to higher SCR temperatures.
Strategies for T2B2/SULEV: Current Status

Results of Bosch SULEV Study (9.2010)

- SULEV target met w/ degreened (low mileage) components
- After (thermal) life time aging: failed
  → Thermal stress (high temperature due to DPF regeneration & desulphurization) causes aging of catalysts
  → Need better control of thermal events to prevent aging -> Model based temp monitoring

Improvements required:
More thermally stable catalyst and more precise temperature control
The Hybrid: Not only a Gasoline Alternative

**Fuel Consumption in g/kWh**

- Engine Speed [rpm]
- BMEP [bar]

- eHybrid Drive Advantage

**Emissions**

- NO\(_X\)
- CO
- HC
- Soot

- High
- Low

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Hybrid Technology Potential

**Split Test:**
Battery balance is also forced at the end of UDC

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**Cumulative CO₂ Emission**

- **Conventional Vehicle**
- **Hybrid - Full Test**
- **Hybrid - Split Test**

**CO₂ emission reduction** by combining urban with extra urban driving

* Basis: CO₂ Emission in g of Conventional Vehicle in NEDC
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Clean Diesel Greenhouse Gas Reduction Potential

Downsizing and -speeding - enabled by optimized CCS *

DeN Ox

CO₂ reduction

Evolution

9-11%

22%

29%

1-2%

24%

5%

Extreme Downsizing to 4-cyl.

St/St***

w/ ReCu

ThM**

Friction Reduct.

Down-sized displacement

2-4%

oCCS* – Package

De- NOx

Down-speed.

1-2%

oCCS plus DeNOx

DeNOx Package: engine (+ mgmt.) meas. for low NOₓ combustion

9-11%

22%

29%

Extreme Downsizing

2-3%

4-5%

1%

2-4%

St/St***

w/ ReCu

ThM**

Friction Reduct.

oCCS*

SUV w/ 4605 lbs, Basis: 200 kW DI-Diesel, 700 Nm

* CCS= Conventional Combustion System | ** ThM=Thermal management | *** St/St=Start/Stop System

COMMENTS

- %-value is reduction potential for stand-alone measures.
- “optimized CCS” - Package: engine (+ mgmt.) meas. for low NOₓ combustion
- DeNOx–Package: Active DeNOx-system (NSC NOx-trap or Sel. Catalytic Reduction).

Significant Potential in Greenhouse Gas reduction expected from Clean Diesel
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Clean Diesel Greenhouse Gas Reduction Potential

CO₂ emissions [g/mi]

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Significant Potential in Greenhouse Gas reduction expected from Clean Diesel

Source: EIA report based on GREET model

*estimated based on Bosch internal simulations
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Summary

- Clean Diesel well accepted by Consumers due to clear benefits
- Clean Diesel shows potential to meet future emission regulation
- Clean Diesel offers additional potential for GHG reduction
- Clean Diesel an Economical solution for Today and Tomorrow
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THANK YOU