The Past – Present – Future of Clean Diesel

Alexander Freitag
Director Engineering Systems Development
Robert Bosch LLC

CO_2 reduced by Bosch

The rise of today's clean diesel vehicles: performance, benefits and market growth

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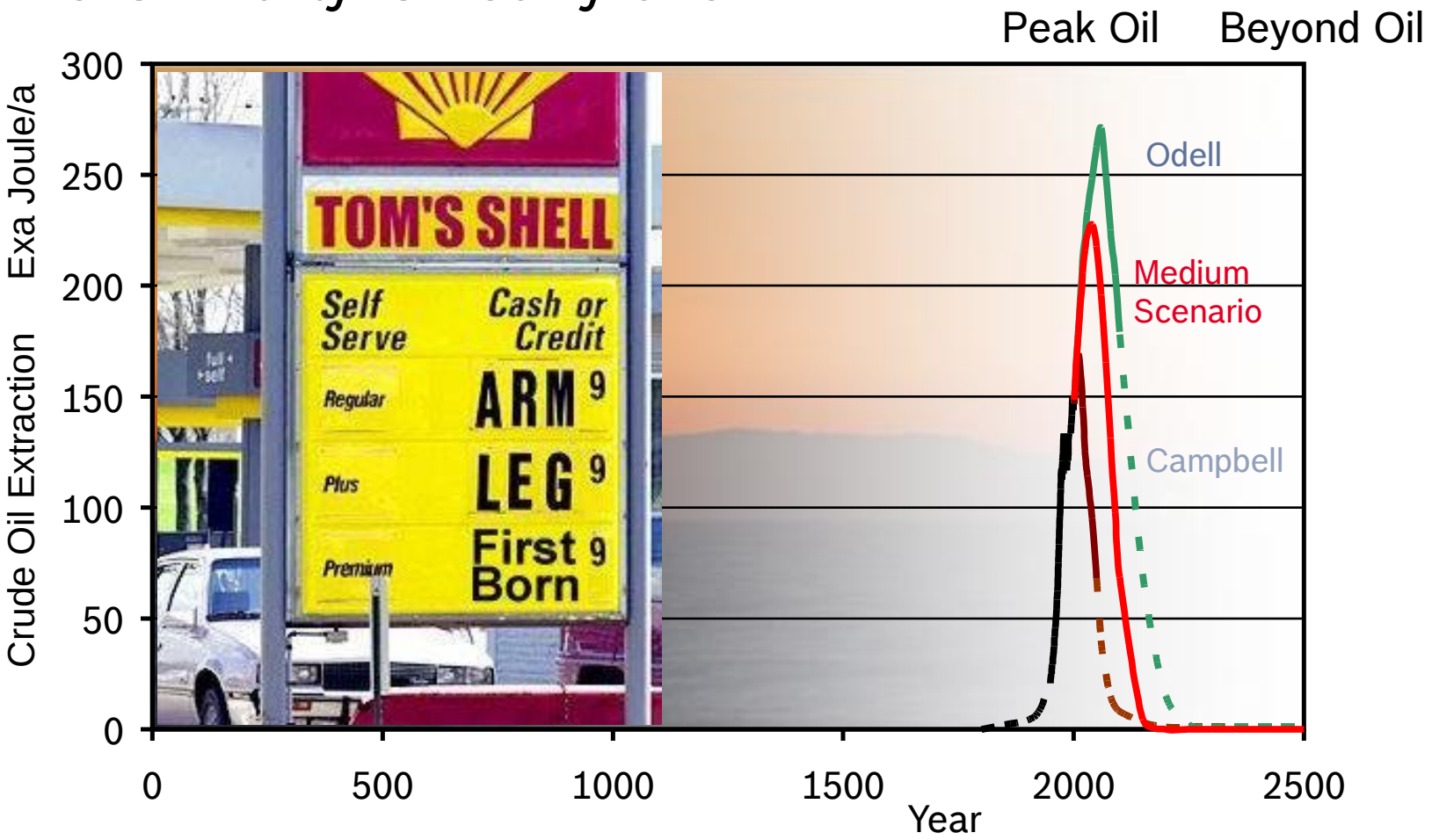
The Oil Party is nearly over



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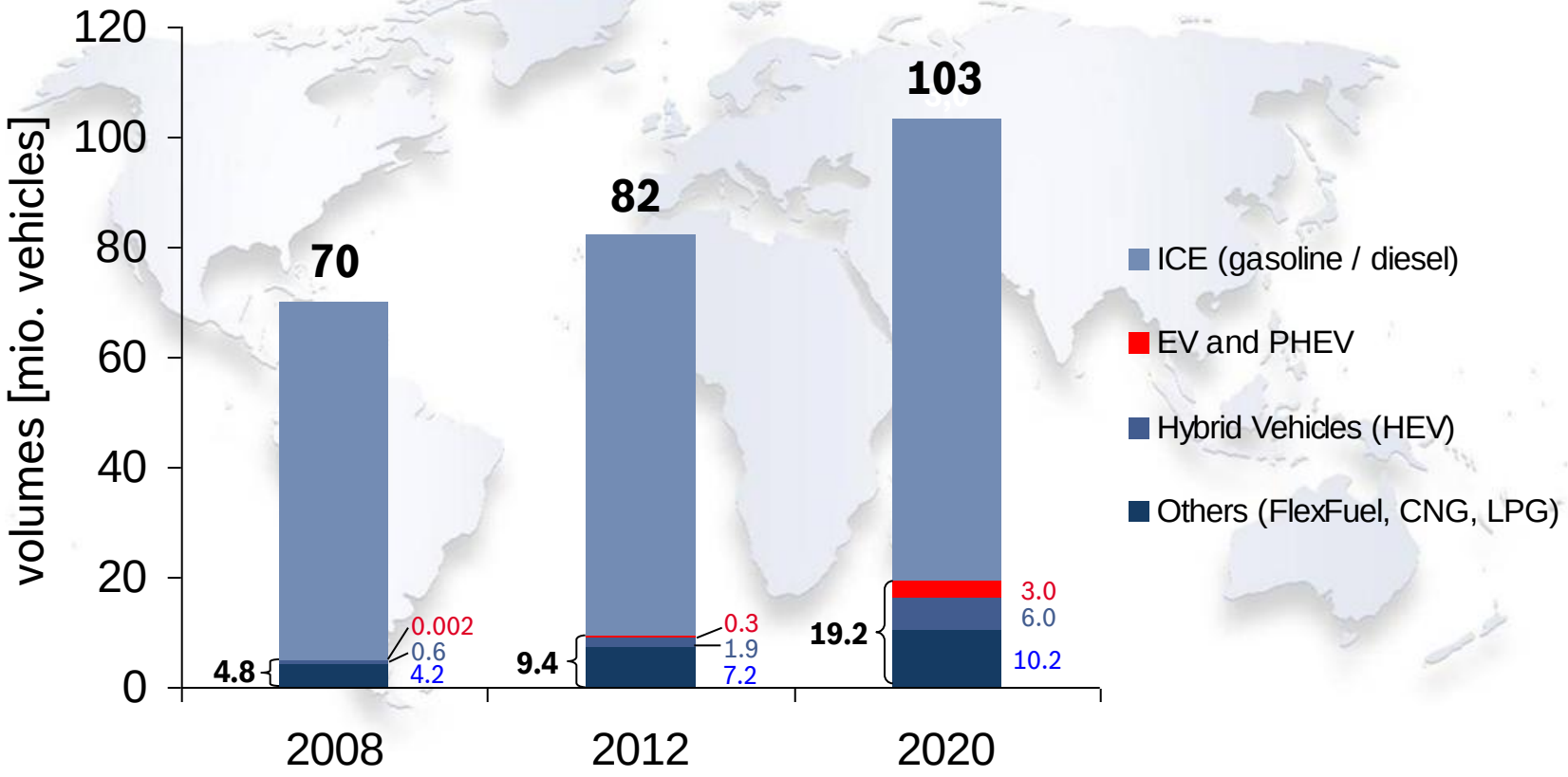
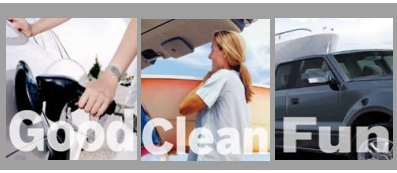
New powertrains: Estimated world market volumes



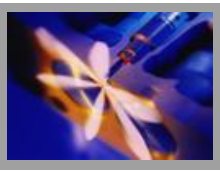
Internal Combustion Engines will remain the predominant power train for the near future

Agenda

The PRESENT of Clean Diesel

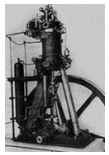


The FUTURE of Clean Diesel



The PAST-PRESENT-FUTURE of Clean Diesel

1897/1900 — The first Diesel Engine, Paris World Exhibit



1912 — Rudolf Diesel: "The use of vegetable oils for engine fuels might seem insignificant today. but such oils may become, in course of time, as important as the 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 tor total cost of $ 1.38

1970 — Oil Crisis 1970's

1980 — GM introduces as first North American OEM Diesel to the market accounting in 1981 for 10% of GM's overall vehicle sales

1990 — By mid 1980's more than 100 different diesel models to choose from. For OEM's like Mercedes and Peugeot the sales of diesels accounted for up to 85% and Bosch introduced electronics to the fuel system

2000 — Bosch revolutionizes the diesel Industry by introducing a Common Rail System. The market share in EUR for diesels accelerated from 1997 to 2007 from 20% to more than 50%, resulting in more than 50 million Systems sold by January 2009

2006 — Mandated Ultra Low Sulfur Diesel in CA and phase in on National Level in 2006

2008 — The New CLEAN Diesel get introduced - DIESEL no longer a dirty Word -

2009/10 — Green Car of the Year 2 years in a row

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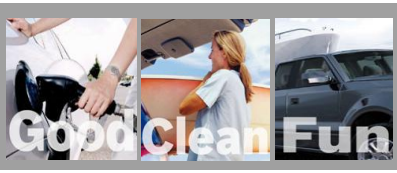
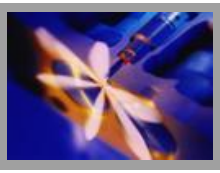
The PRESENT of Clean Diesel



The FUTURE of Clean Diesel



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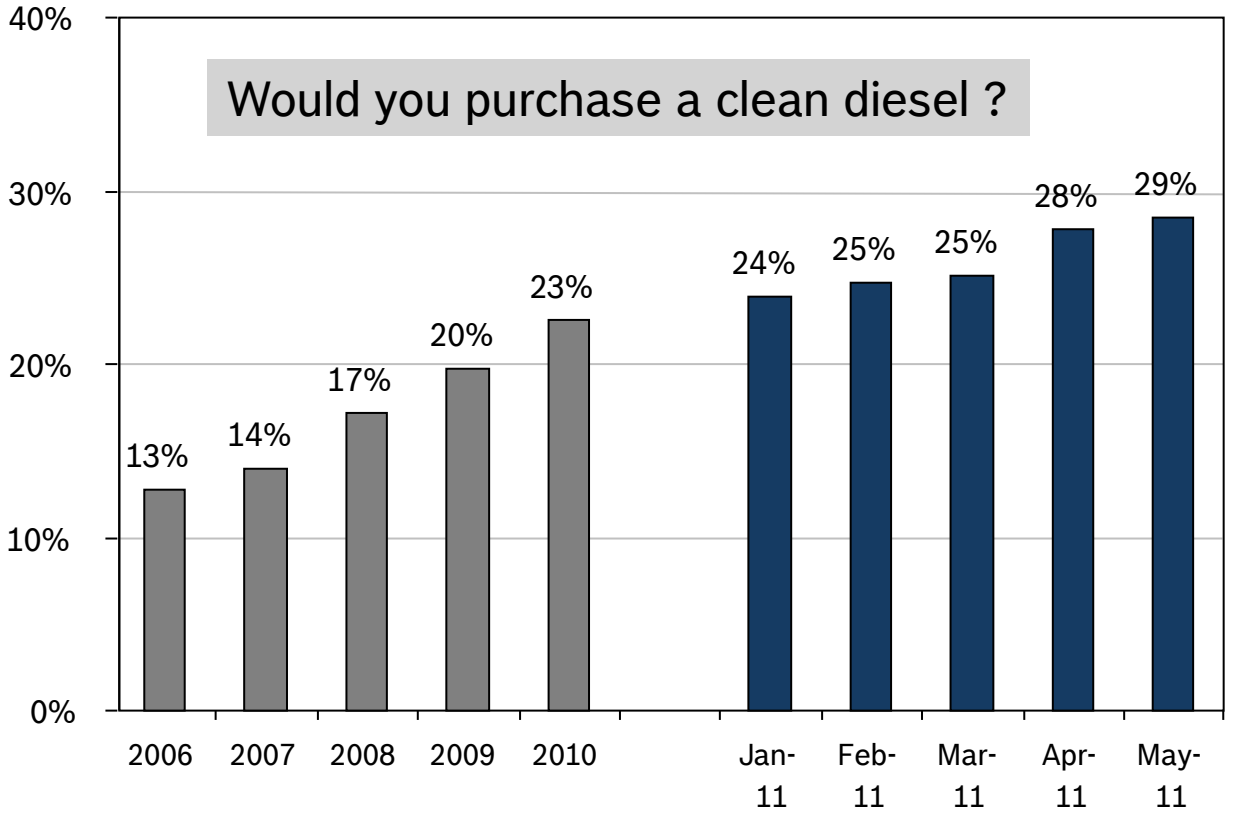
Consumer Consideration Index



Source: CNW Research

Steady increase in consumer consideration of Clean Diesel technology

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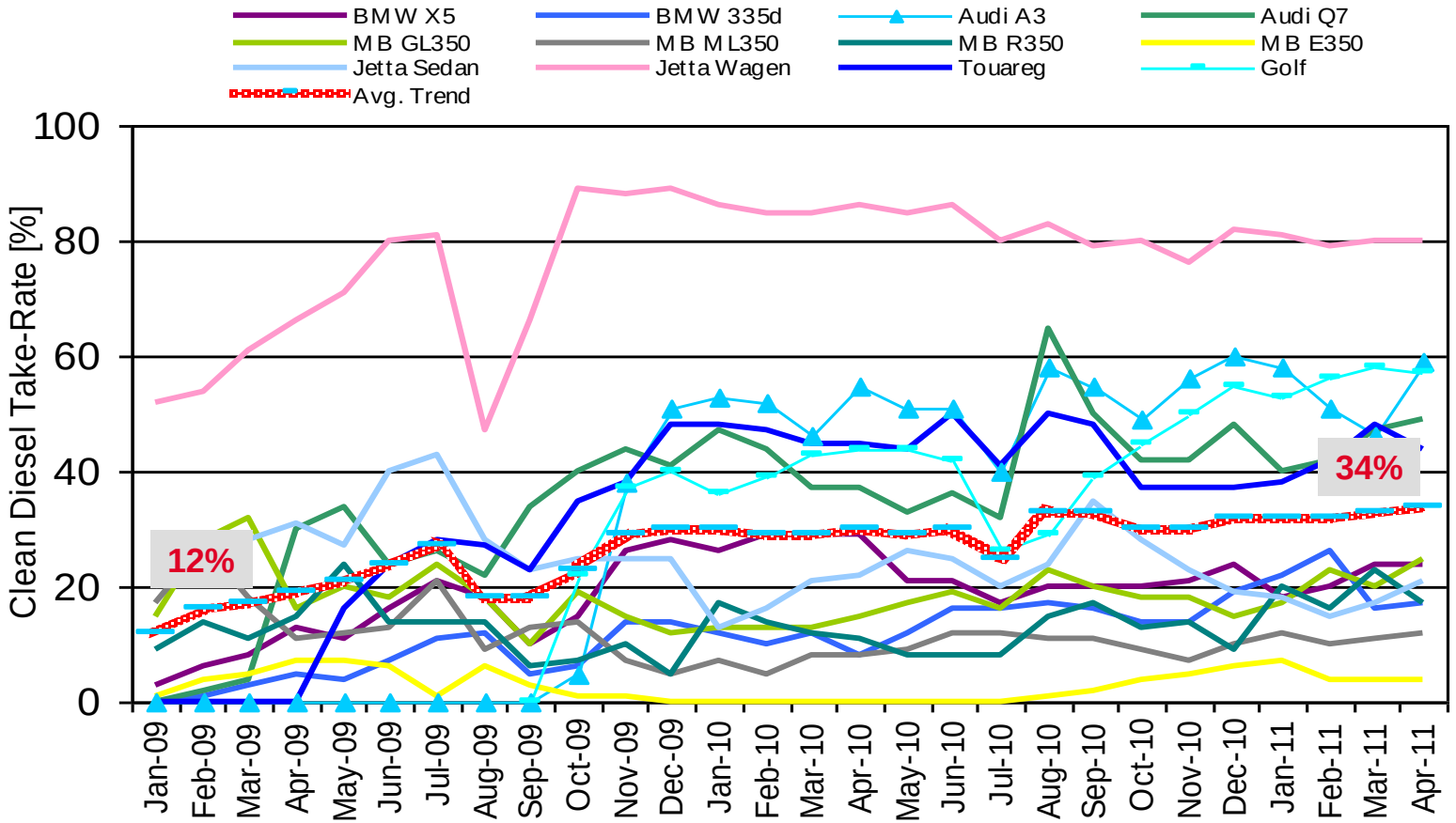
Clean Diesel Take-Rate PC/LD



Source: POLK Registration Data

Source: Polk

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

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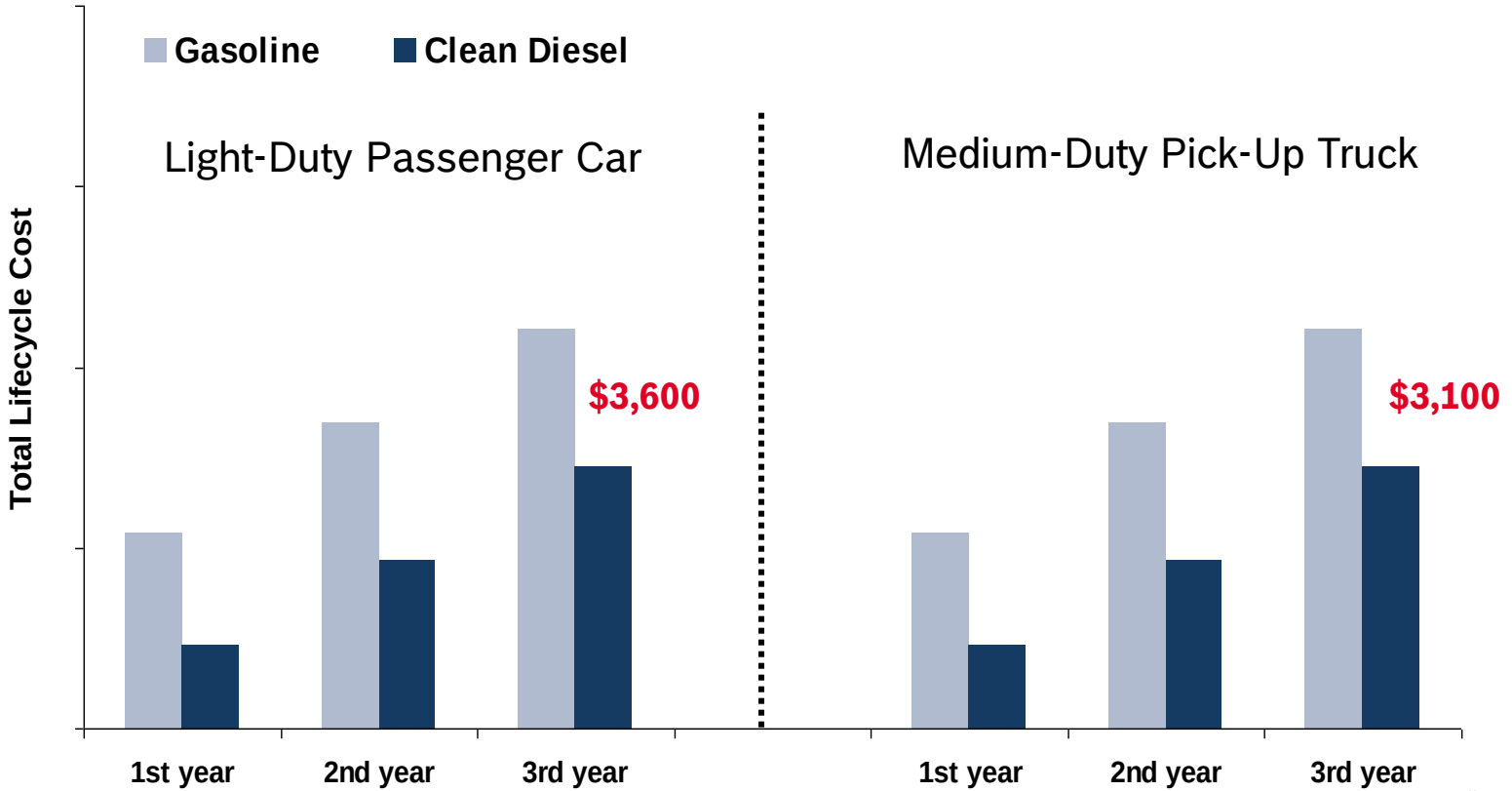
Total Cost of Ownership [TCO]



Source: Carnegie Mellon University

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

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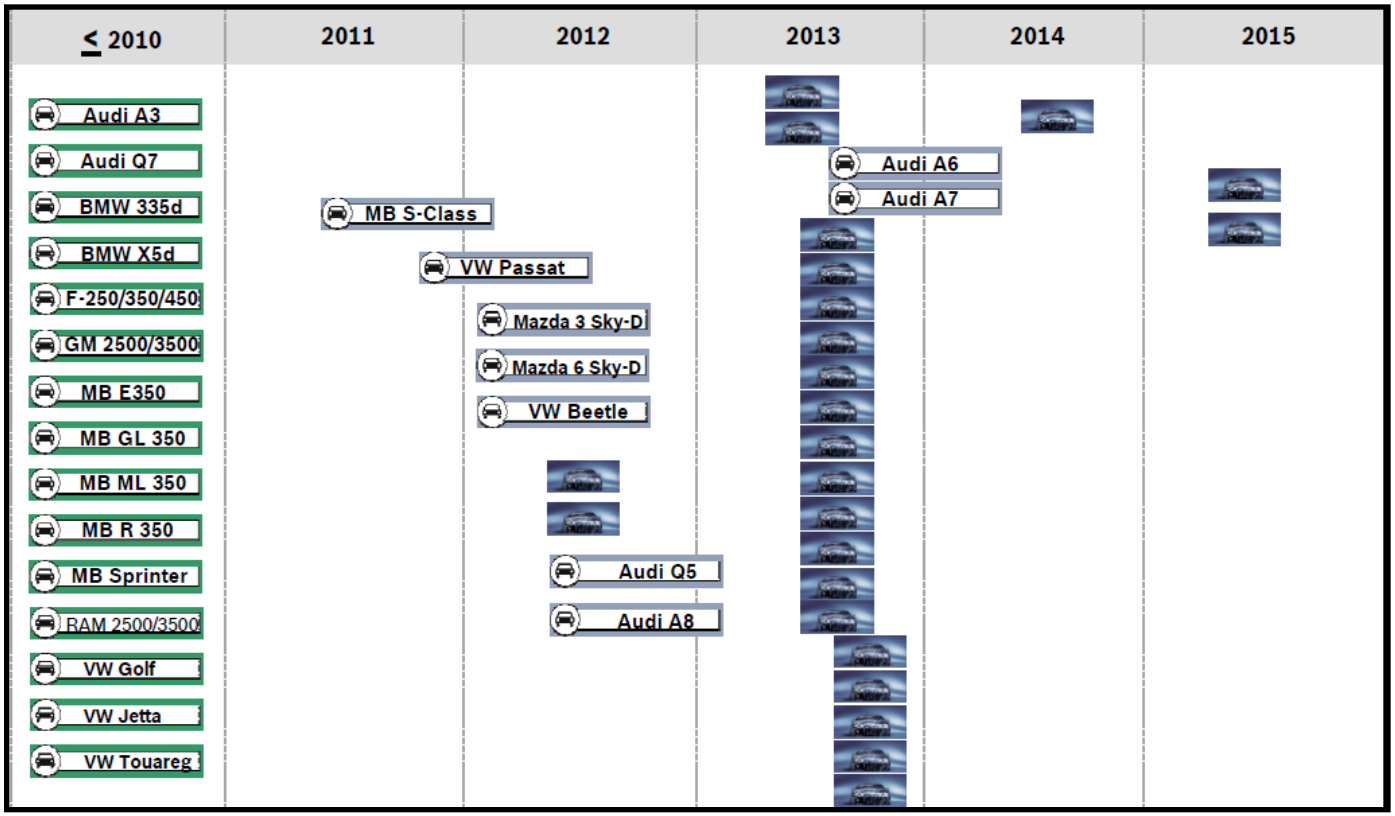
Clean Diesel Launch Calendar



Source: Bosch

Clean Diesel models will more than double in less than 3 years

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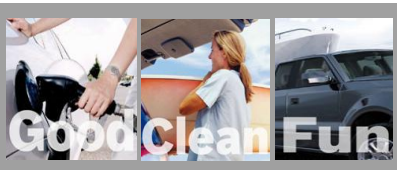
The PRESENT of Clean Diesel



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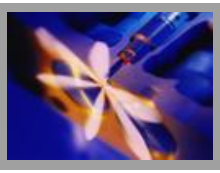
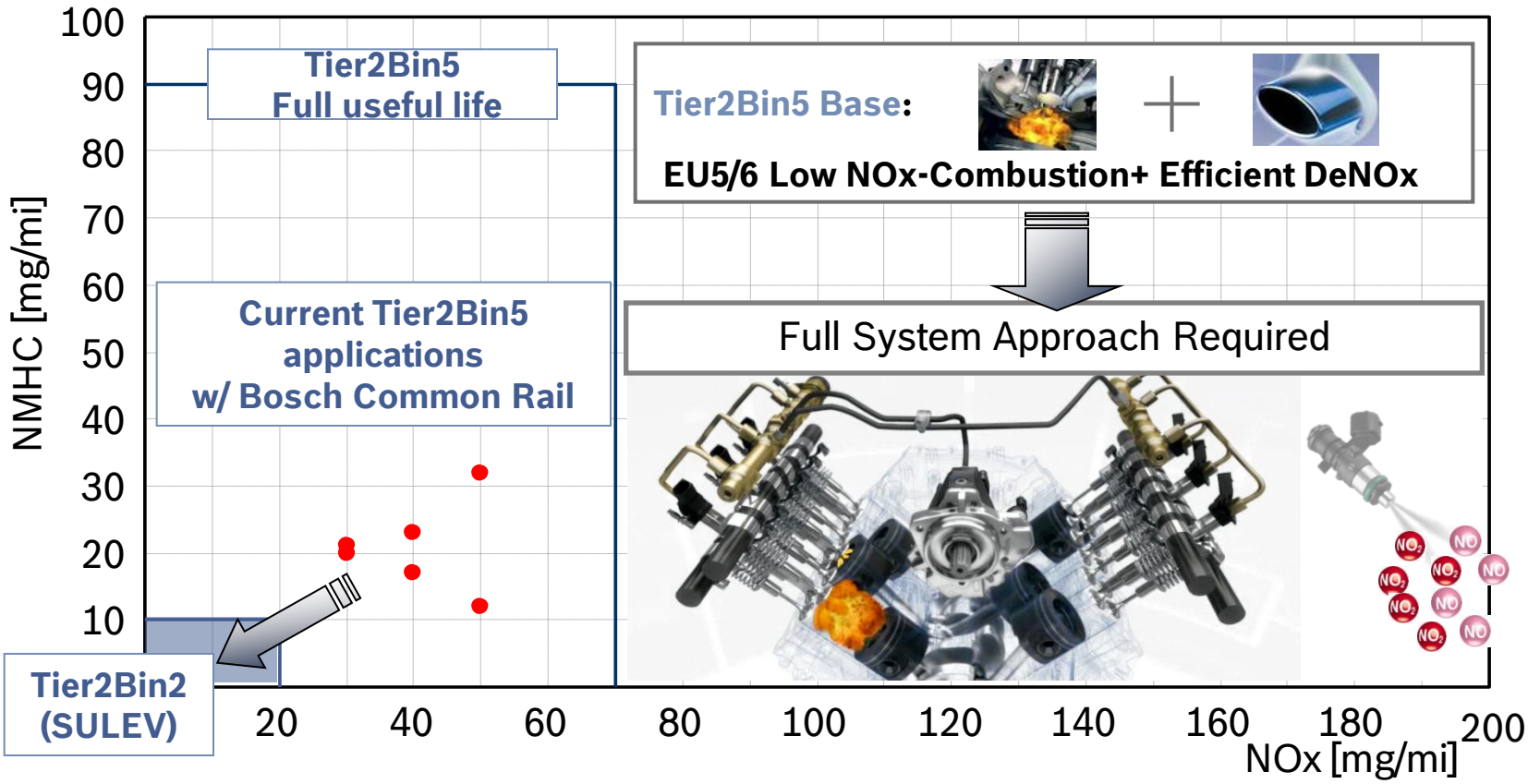


Strategies for T2B2/SULEV: Enhanced EGT



Available vehicles exceed T2B5. System approach needed to meet future requirements.

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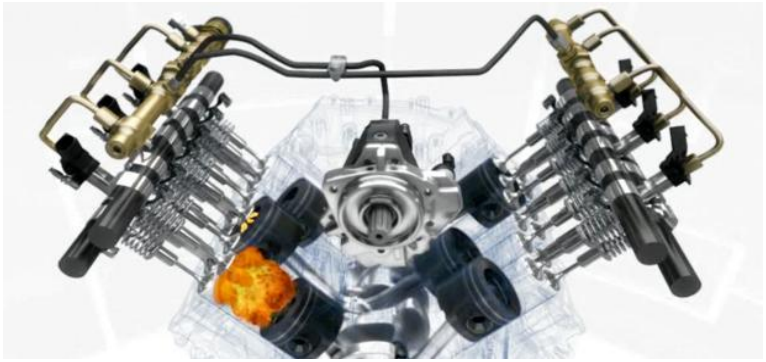
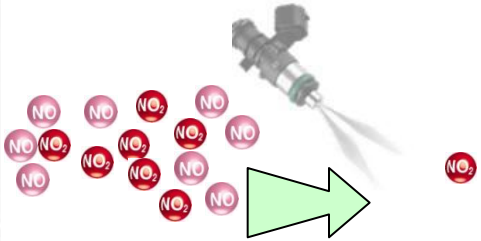
Optimizing the Diesel System





Combustion Process

- Reduction of compression ratio
- Partly homogenous combustion
- Nozzle optimization

Air Management

- Swirl-/Throttle Valve
- Turbo Charger/VTG

Exhaust gas management

- Flow and DEF distribution
- Fast Catalyst Light-Off (reduce thermal losses)
- Diesel Particulate Filter
- NOx storage catalyst
- Catalyst temp control

Fuel Injection System

- New Generations
- Multiple Injections
- Reduced Tolerance
- Optimized Nozzle

Tolerance Reduction

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

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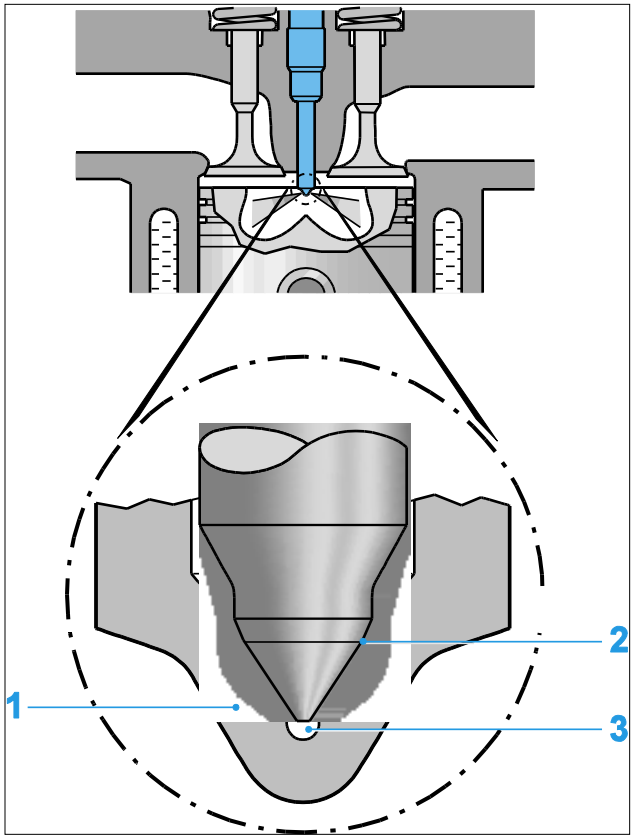
Combustion Process: Nozzle Optimization



-Interface between DFIE and engine

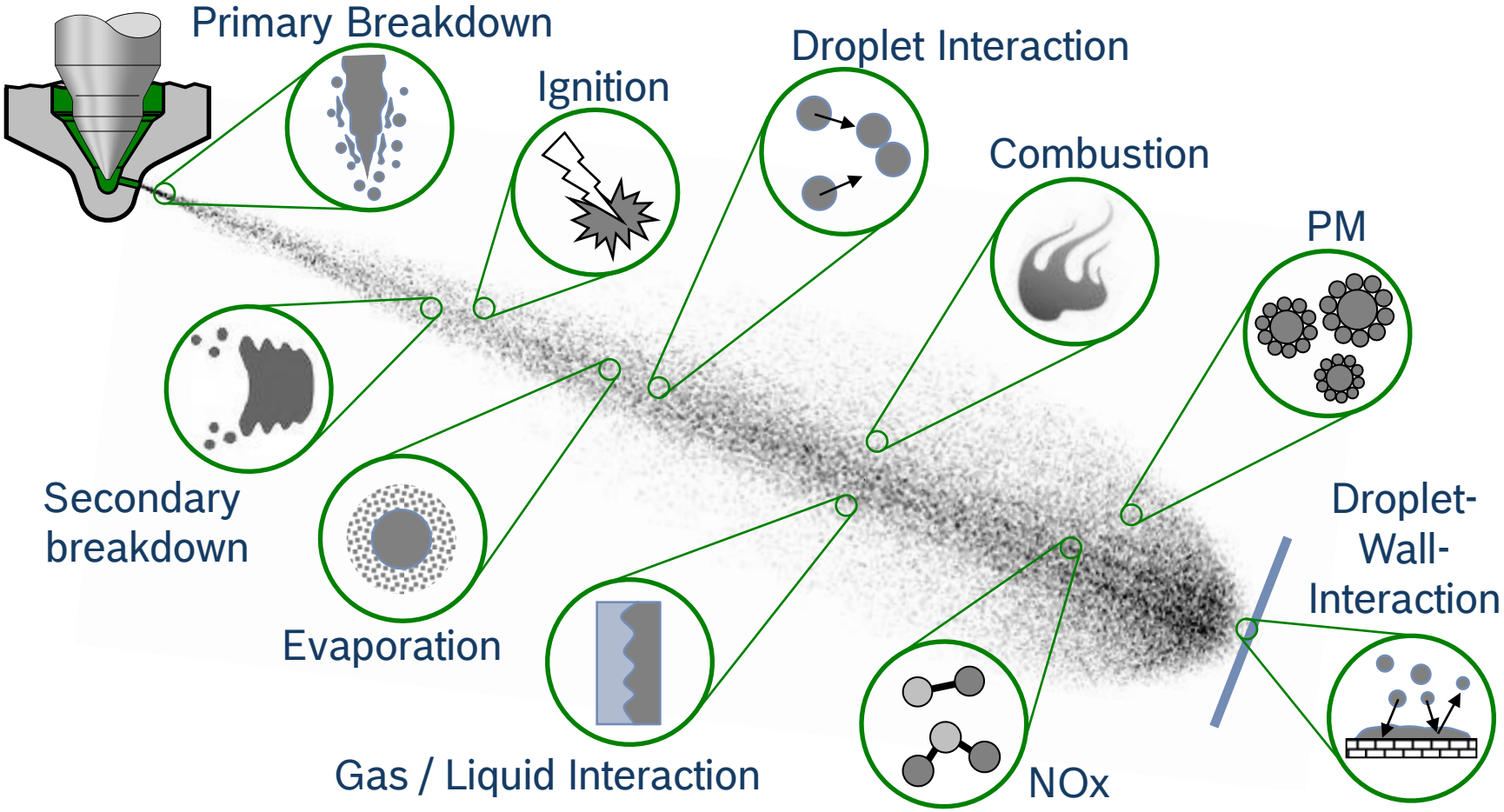
-Important parameters include

- Spray angle
- Number of Holes & Flow
- Injection-orifice geometry (1)
- Seat geometry (2)
- Sac-hole geometry (3)

Source: Bosch Diesel Engine Management, 4th edition

Nozzle optimization plays a large role in meeting emission requirements

Nozzle Spray Interaction



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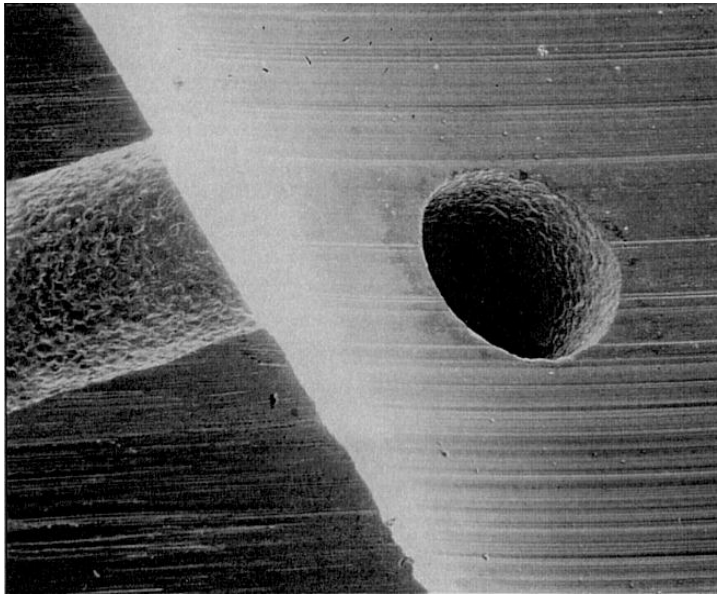
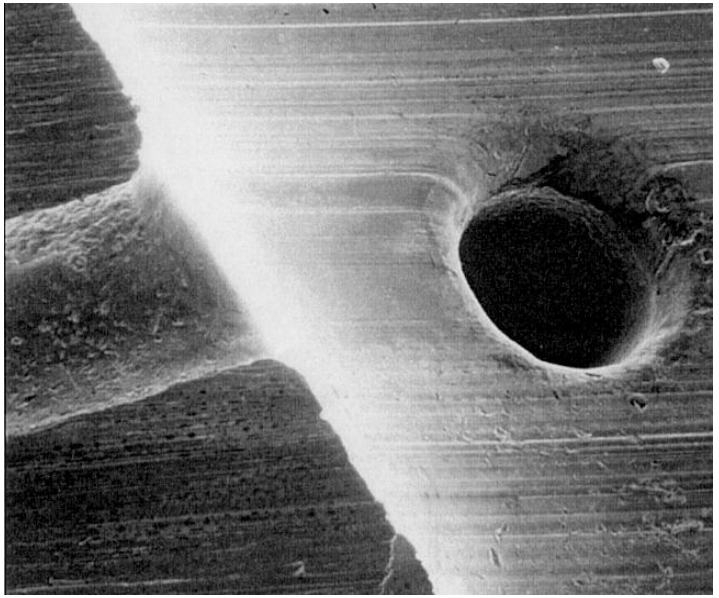
Nozzle Orifice
Hydro Erosive Grinding



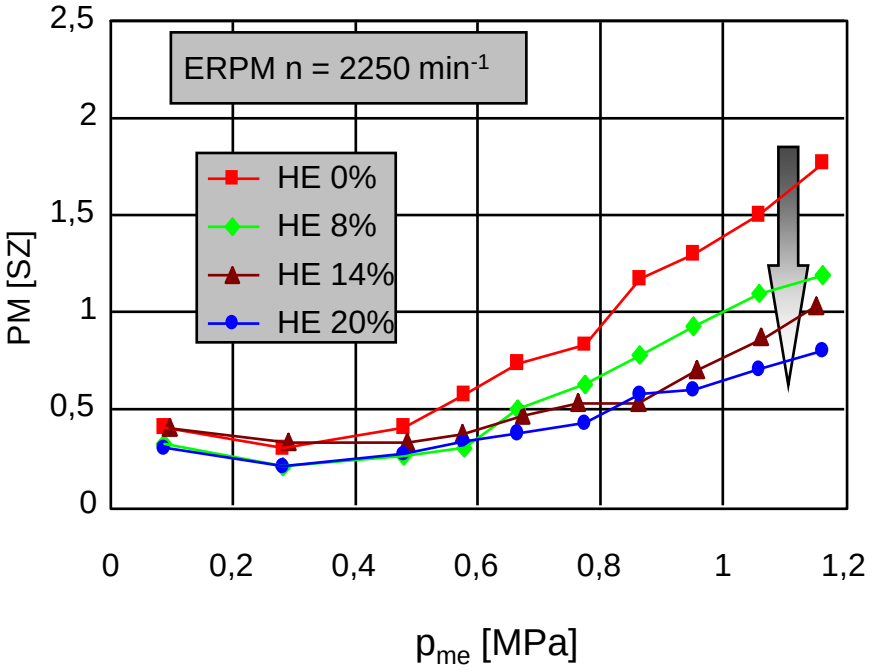
Sharp-edged
Hydraulic flow tolerance: ± 3,5%



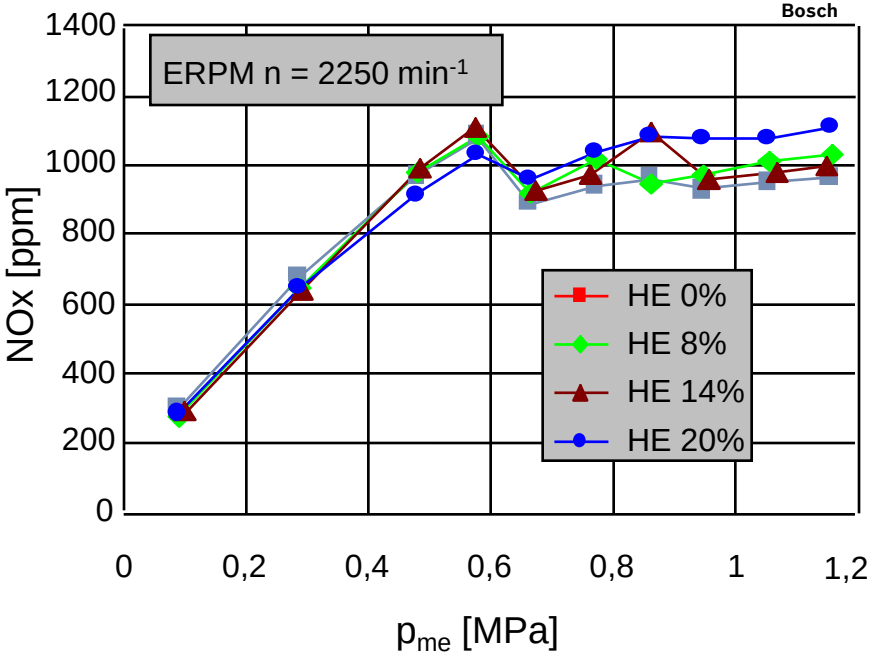
Hydroerosive rounded
Hydraulic flow tolerance: < ± 2 %

Source:
Bosch

Nozzle Orifice
Hydro Erosive Grinding: Emission influence



Source: Bosch



Hydrogrinding increases the discharge coefficient
Larger discharge coefficients can have a positive impact on emissions

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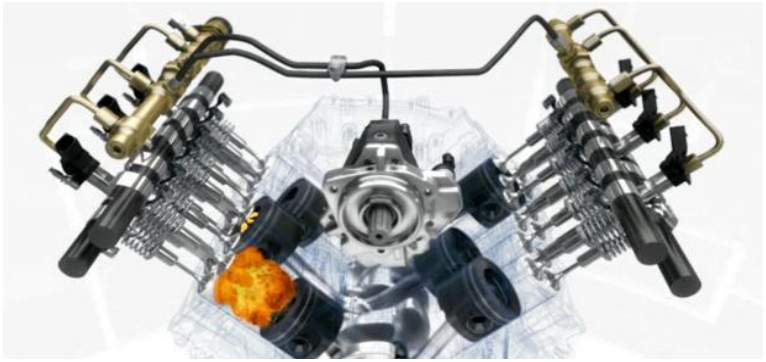
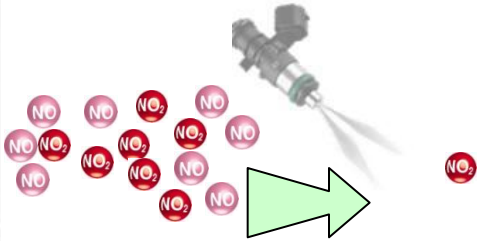
Optimizing the Diesel System





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Exhaust gas management

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- NOx storage catalyst
- Catalyst temp control

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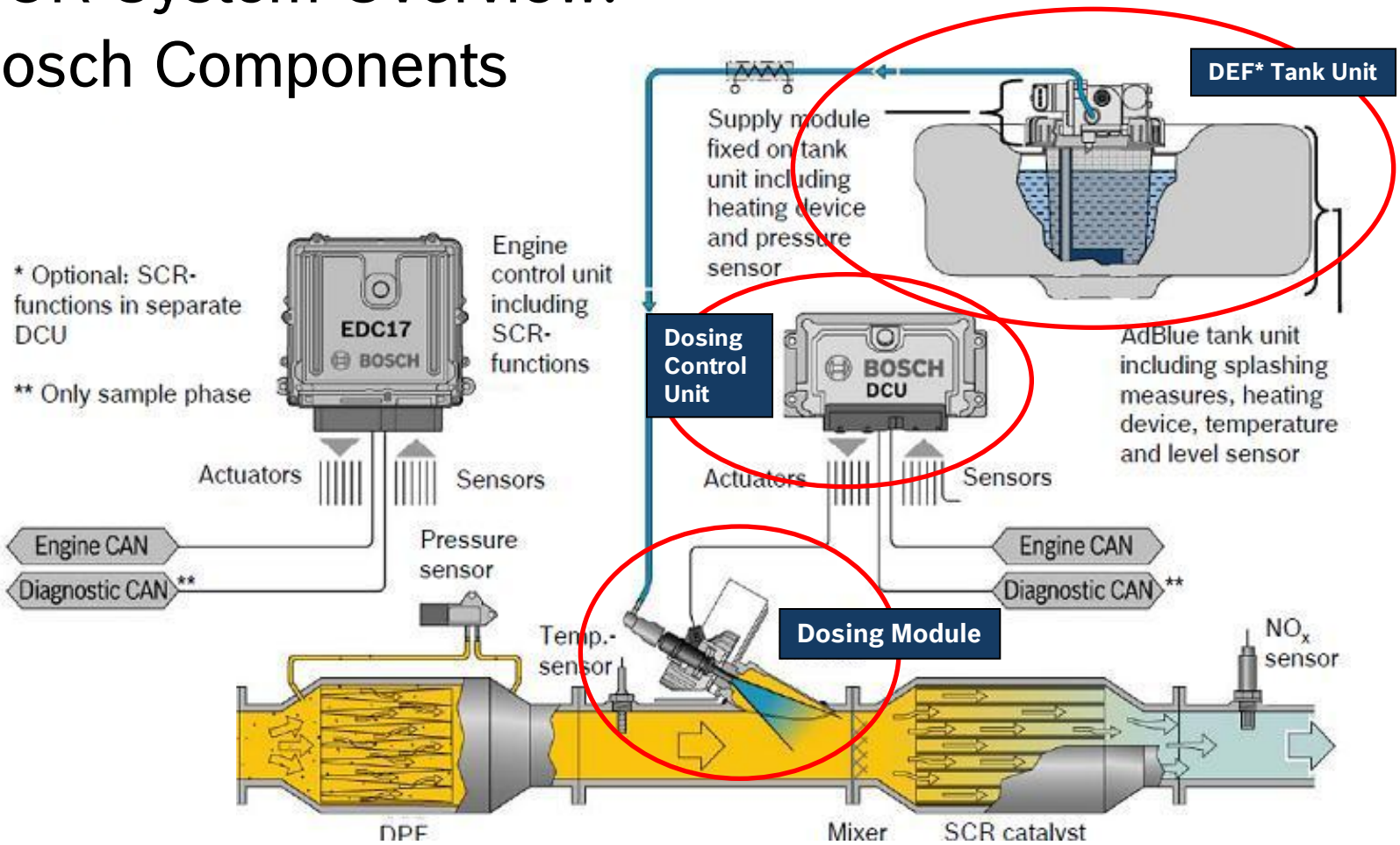
Catalyst with Denoxtronic – for low NOx emissions

- SCR (Selective Catalytic Reduction) reduces NO_x emissions with no increase in fuel consumption.
- A reduction agent is sprayed into the exhaust gas stream.
- With Bosch Denoxtronic, NO_x emissions are reduced by about 85%.

Reduction agent NH_3 and NO_x...

...are converted into water and nitrogen

SCR System Overview: Bosch Components



* DEF: Diesel Exhaust Fluid

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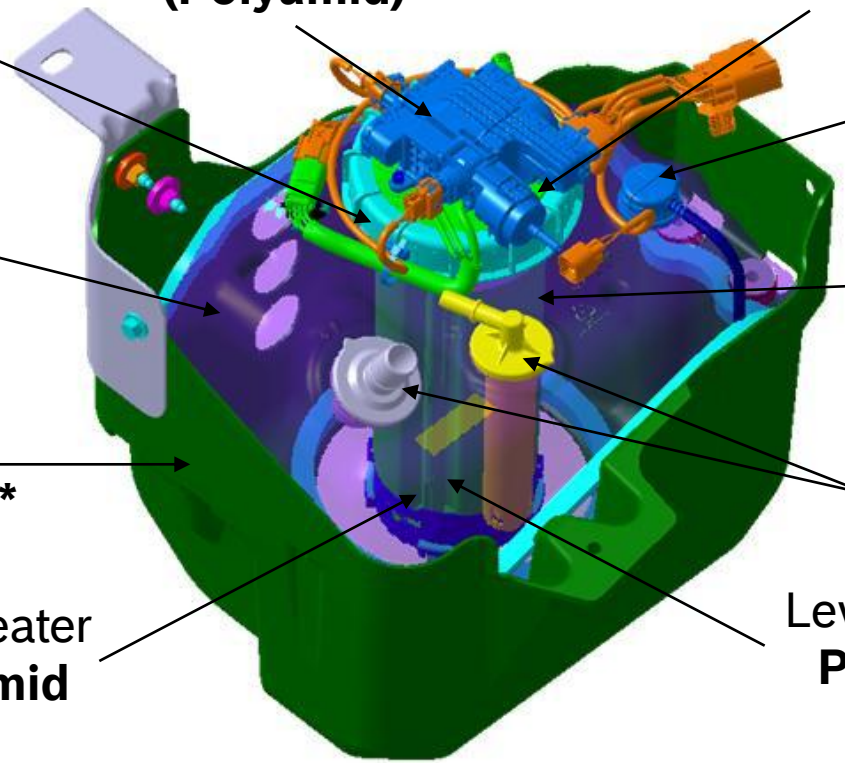
Plastic Materials of the Bosch SCR System



* High-density polyethylene
** Polytetrafluoroethylene (Teflon®)
*** Glass-fiber reinforced polyester

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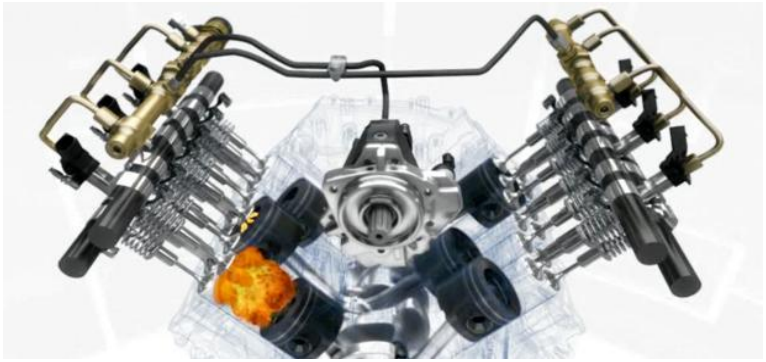

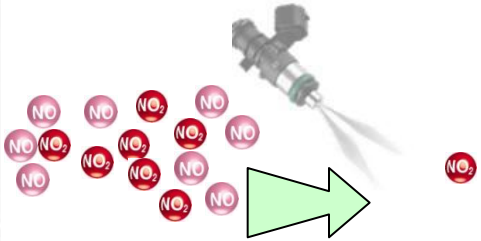

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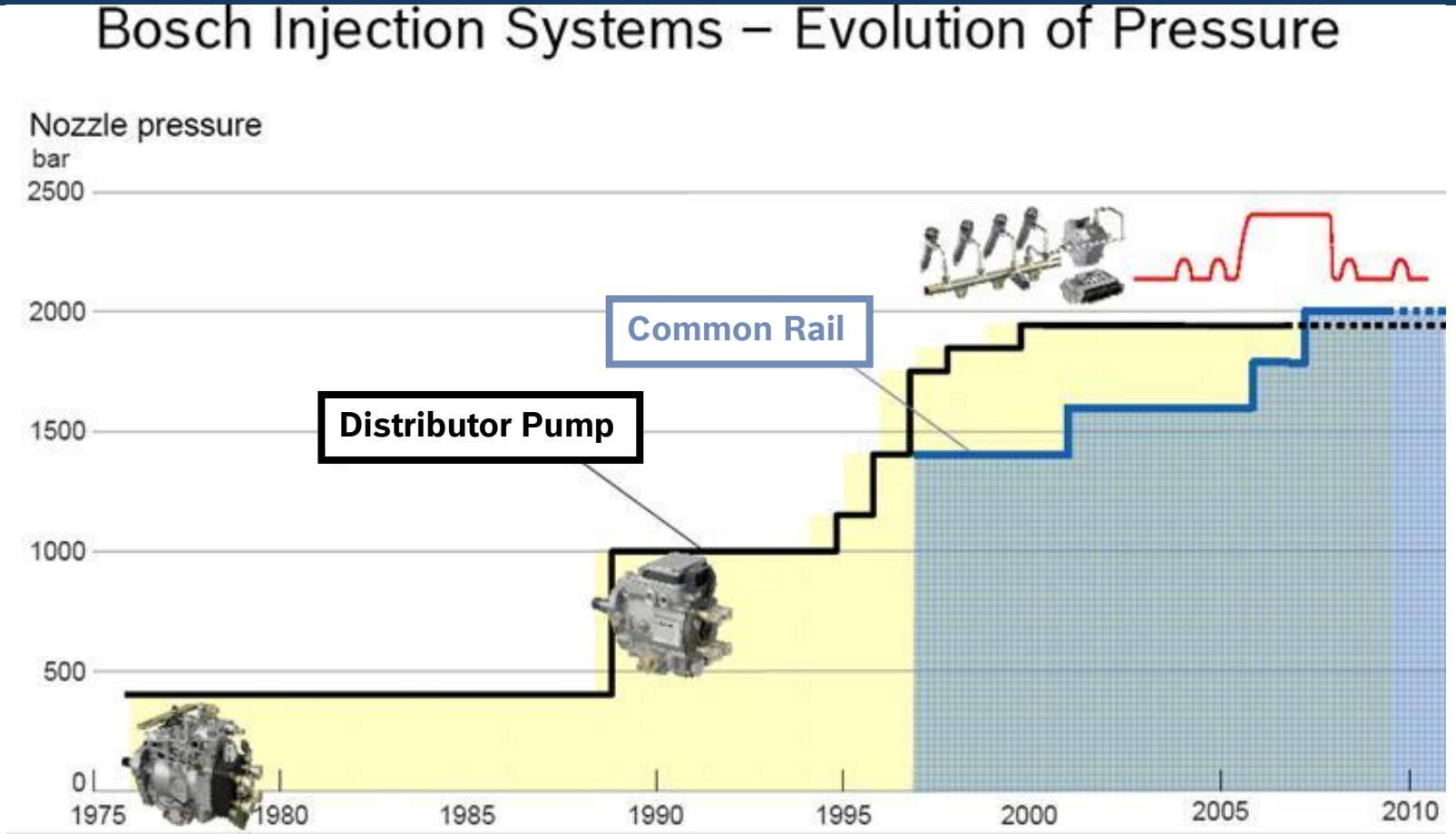

Injection Pressure will continue to increase in the future

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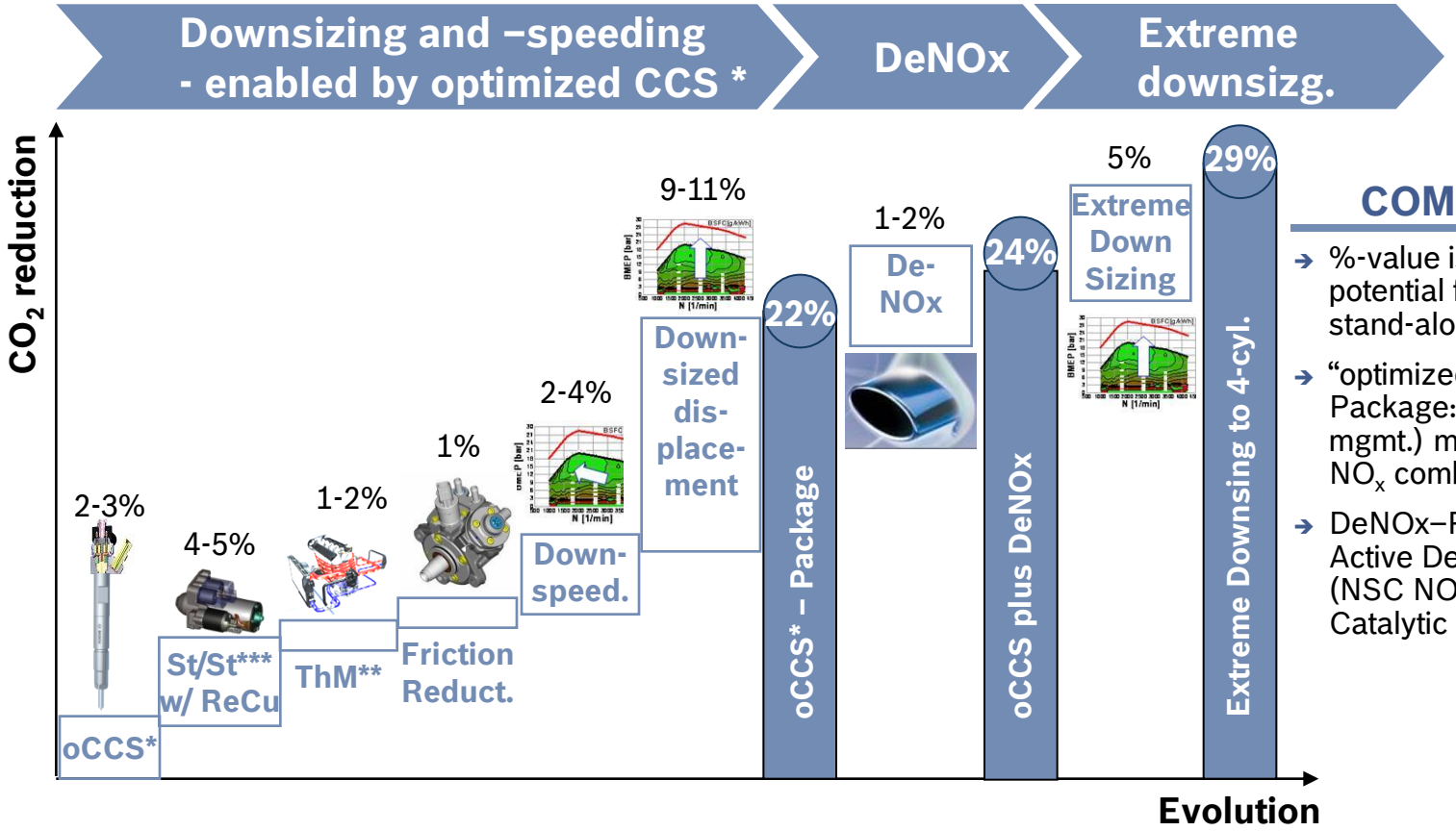
Clean Diesel Greenhouse Gas Reduction Potential



COMMENTS

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

Significant potential in greenhouse gas reduction expected from Clean Diesel

SUV w/ 4605 lbs, Basis: 200 kW DI-Diesel, 700 Nm
* CCS= Conventional Combustion System | ** ThM=Thermal management | *** St/St=Start/Stop System

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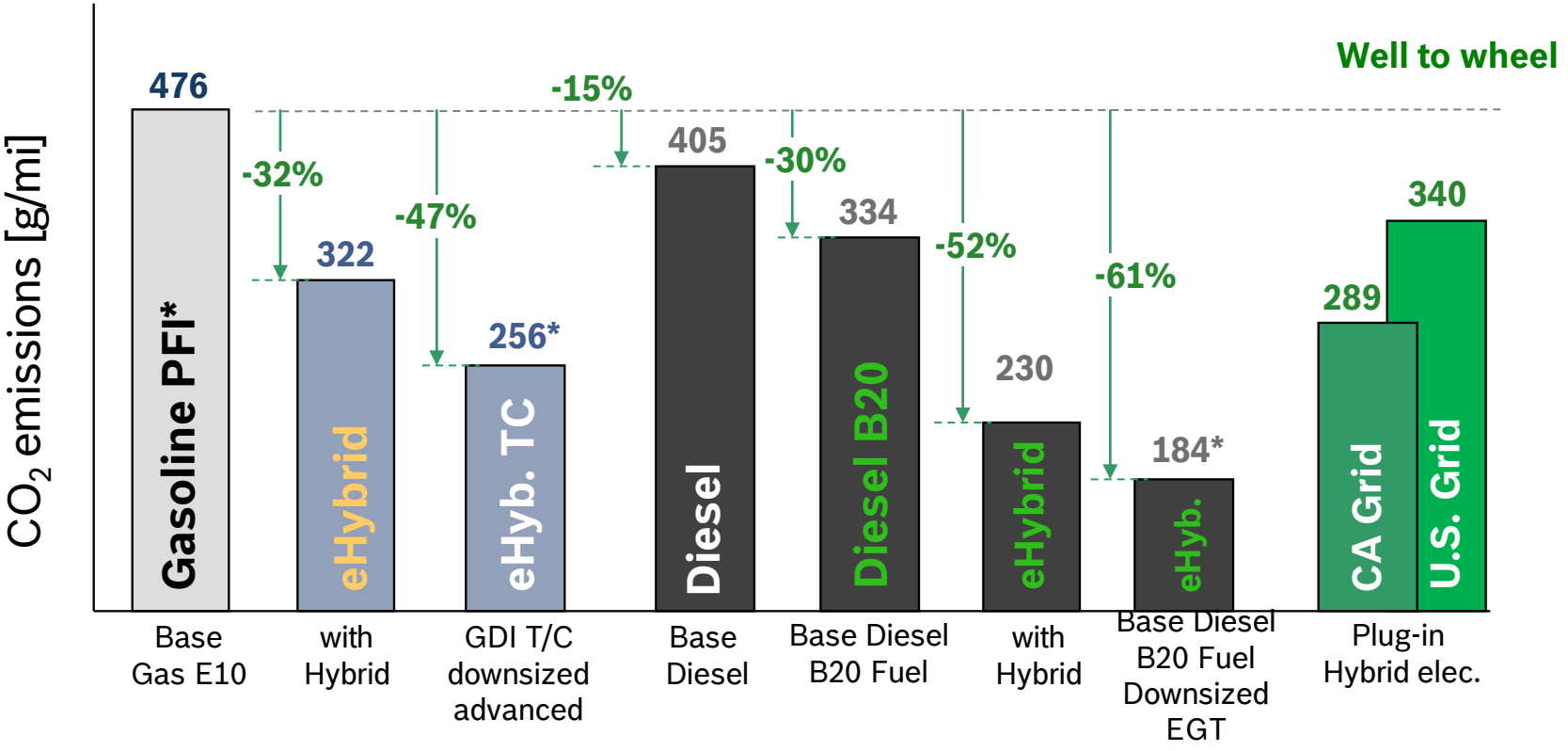
Clean Diesel Greenhouse Gas Reduction Potential



Source: EIA report based on GREET model

Significant potential in greenhouse gas reduction expected from Clean Diesel

*estimated based on Bosch internal simulations

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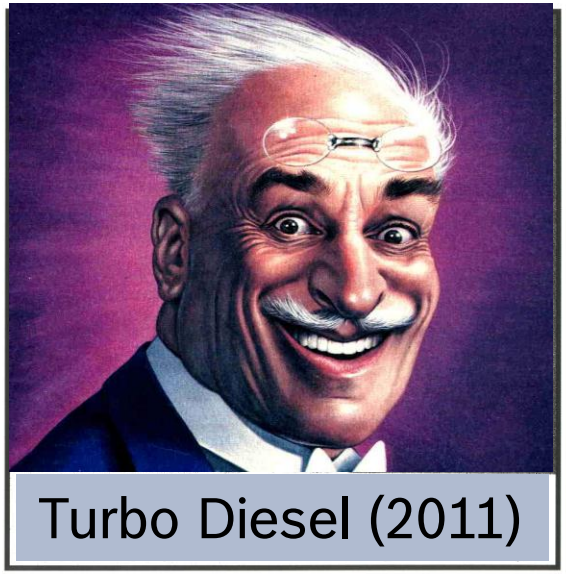
Summary

- Clean Diesel shows potential to meet future emission regulation
- Clean Diesel offers additional potential for GHG reduction
- Clean Diesel well accepted by consumers due to clear benefits
- Clean Diesel an economical solution for today and tomorrow

GOOD **CLEAN** **FUN-ctional**

Diesels are Fun to Drive



Turbo Diesel (2011)

Diesel cars have up to 50 % more torque than gasoline cars !

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