Near Zero Emissions

The path forward for Internal Combustion Engine Technology

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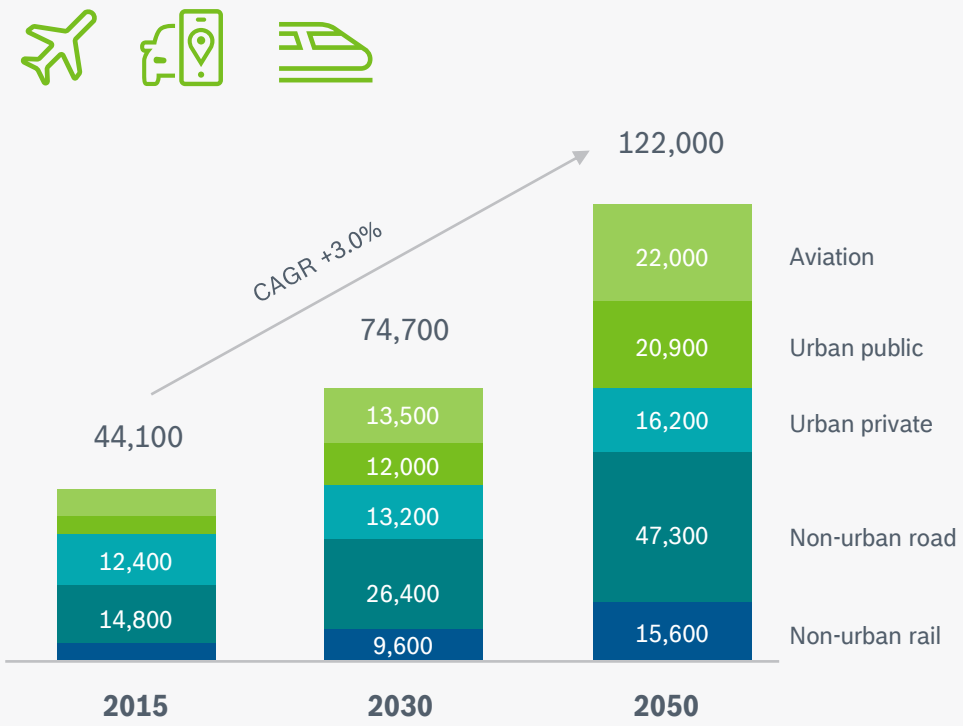
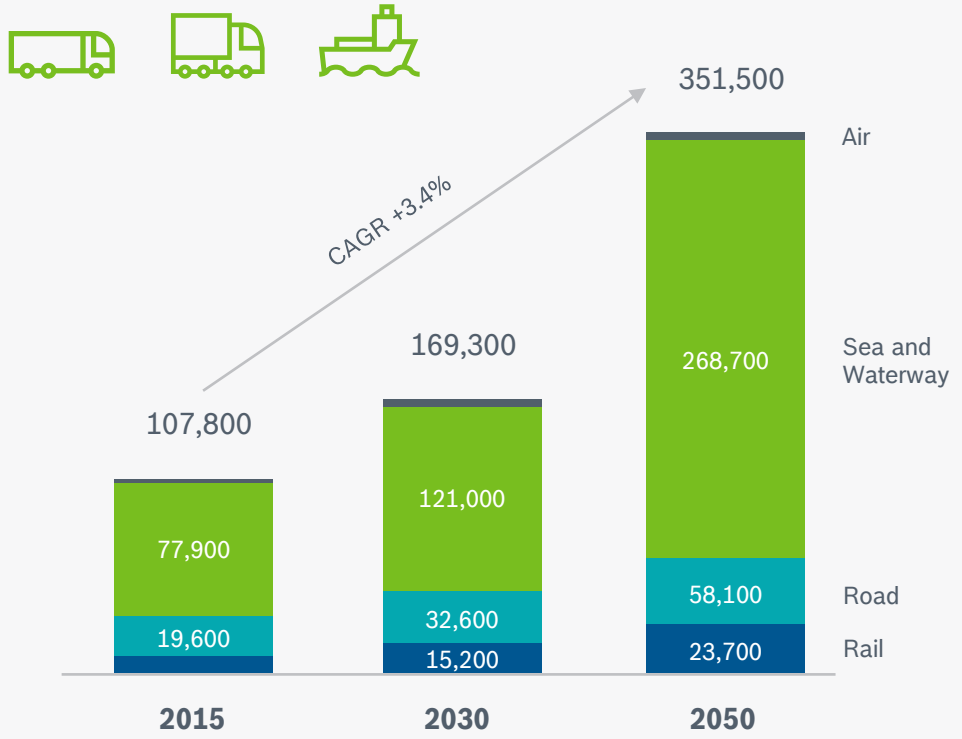
Demand for mobility is increasing

Global demand for passenger transport by mode
(bn passenger-km)



Freight transport demand by mode
(bn tons-km)



Source: ITF Transport Outlook 2019 CAGR: Compound Annual Growth Rate

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Mobility in India today: Challenges

Human health and climate change

20 %

of 40 large cities in India **exceed the limit**[1]

100 %

of 40 large cities exceed **particulates** in excess of **WHO guidelines**[1]

>200 mio t

of emissions produced by Transport sector in India in 2018. **India is 4th largest global emitter** [2]

Traffic accidents and urban mobility

11%

India is number #1 in global ranking of road fatalities (11% @ 3% global vehicle population) [3)]

46 min

In average people in India spend to commute to work**. 8th place in global Traffic Index ranking**[4]

Sources:

1 CPCB Annual Report 2015/2016 Air Quality for 40 cities >1 Mio inhabitants in 2015. 2 NITI Aayoog and Union of concerned scientists 3 Planning commission of India, 10th Five Year Plan. 150.000 road fatalities / a in 2016 and increasing ! – source MoRTH. India 3% of global car fleet but 11% of global road fatalities. 4 Numbeo Statistics 2019

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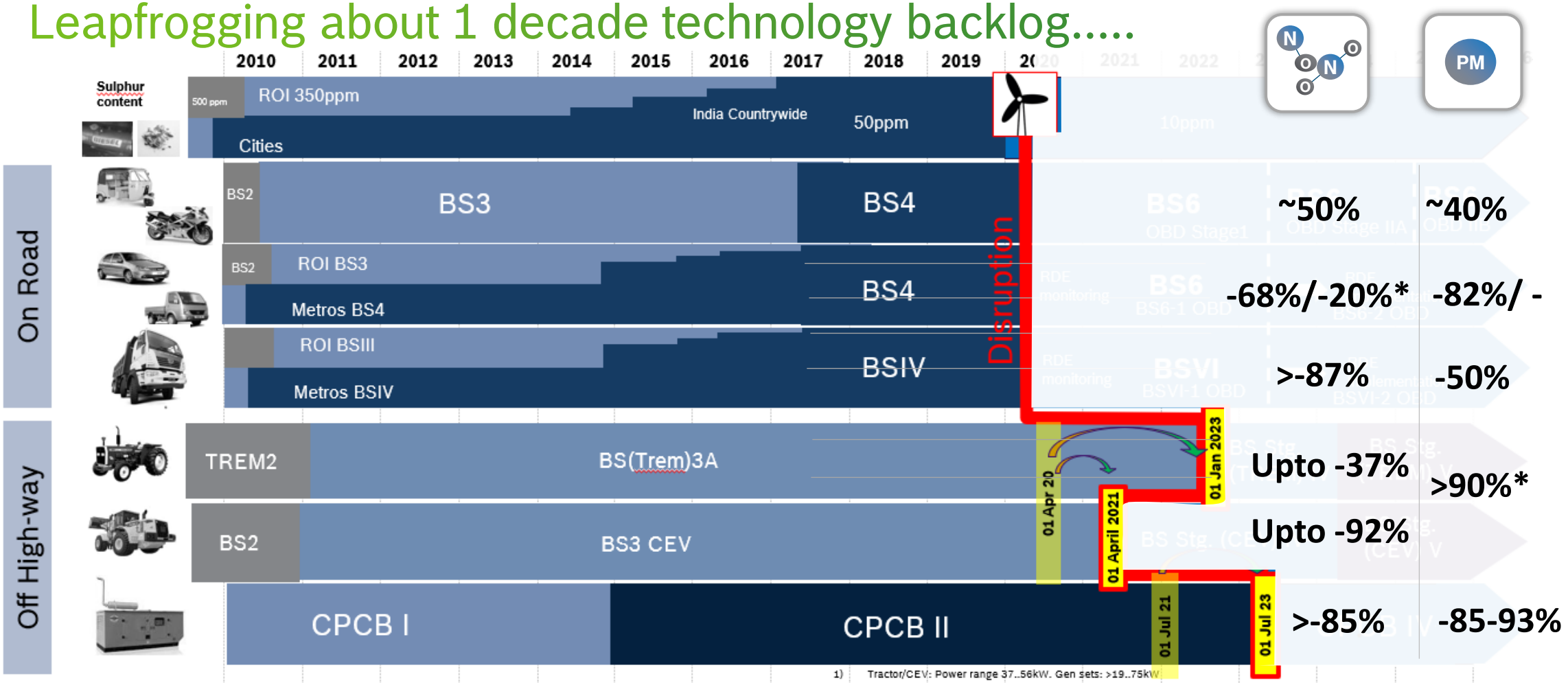
Leapfrogging about 1 decade technology backlog.....



Indian automotive industry is undergoing a disruptive technology change during the next years.
Key challenges are the fast technology change and high innovation degree.

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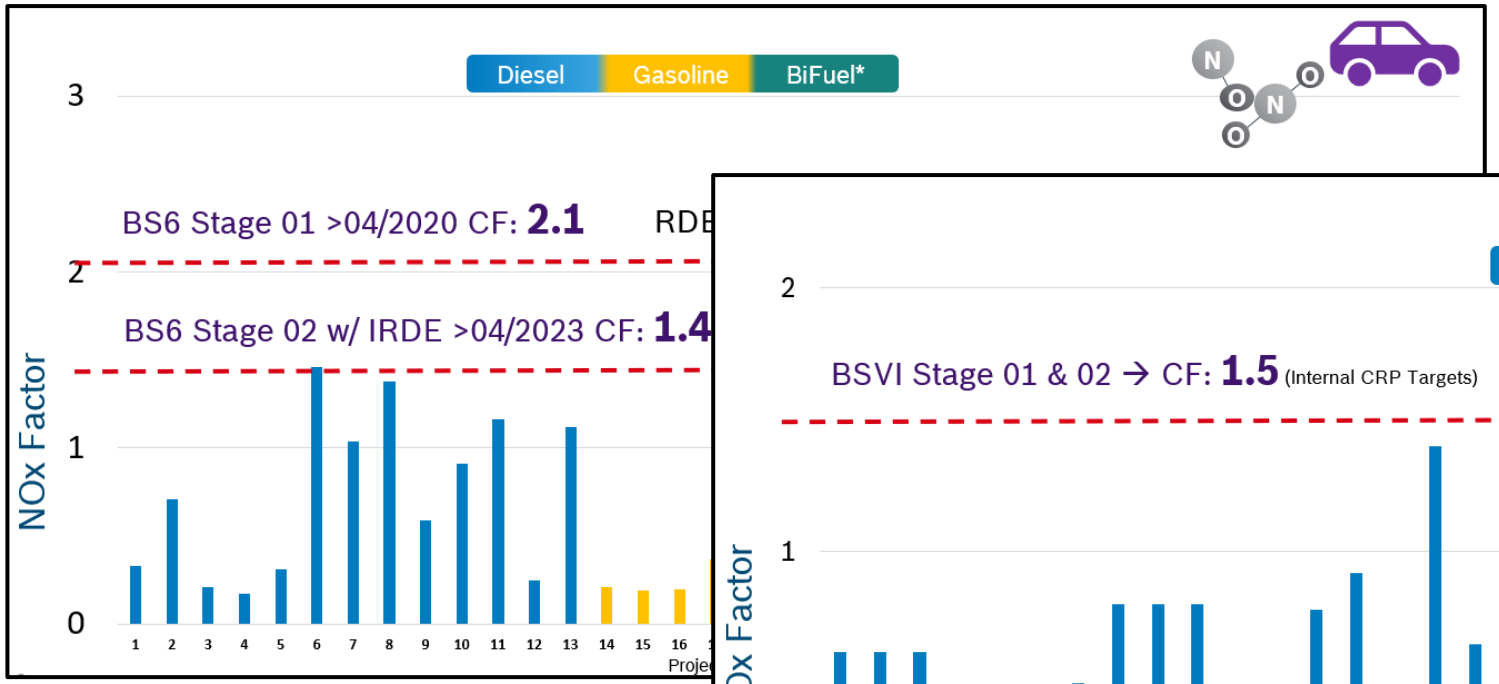
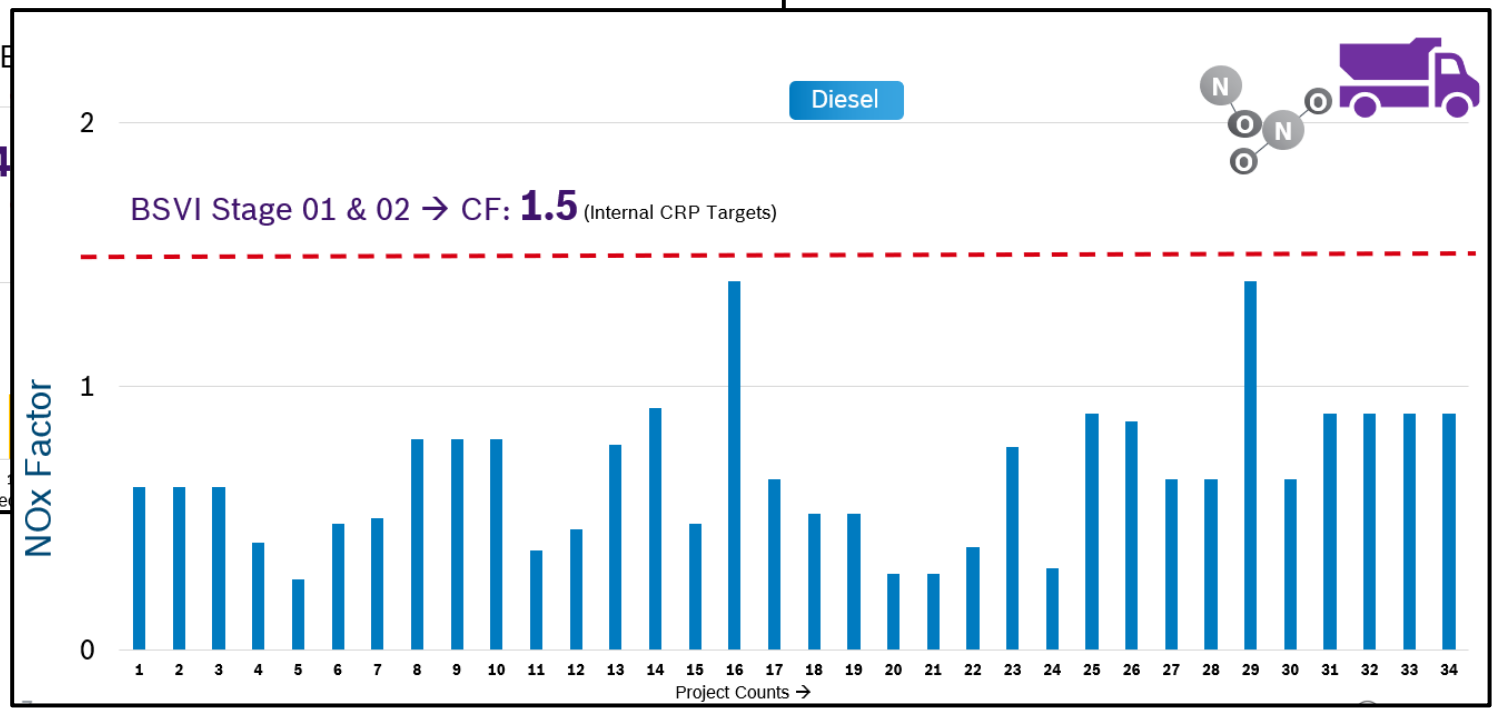
IRDE NOx emission results - We have come a long way





1) NOx-Factor: "conformity factor of NOx emission during IRDE as a ratio of measured NOx emission relative to the regulatory limit ". IRDE measured values with de-greened catalysts + 15% avg. aging factor assumed.
2) IRDE: Indian Real Driving Emissions
3) Measurements taken only for BS6 development programs handled by Bosch

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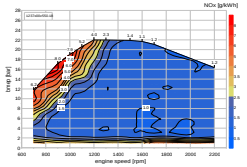
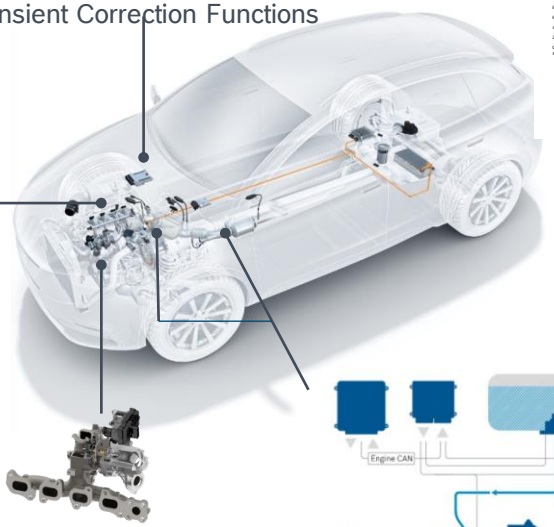
Modern Diesel concept: minimal impact on air quality

Efficient temperature management for engine control and exhaust-gas treatment
Transient Correction Functions

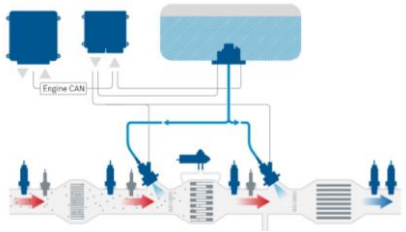


Optimized NOx Emissions
LP EGR
Predictive Emission Control (PEC)

Improved fuel injection
Upto 2500 bar with DRS

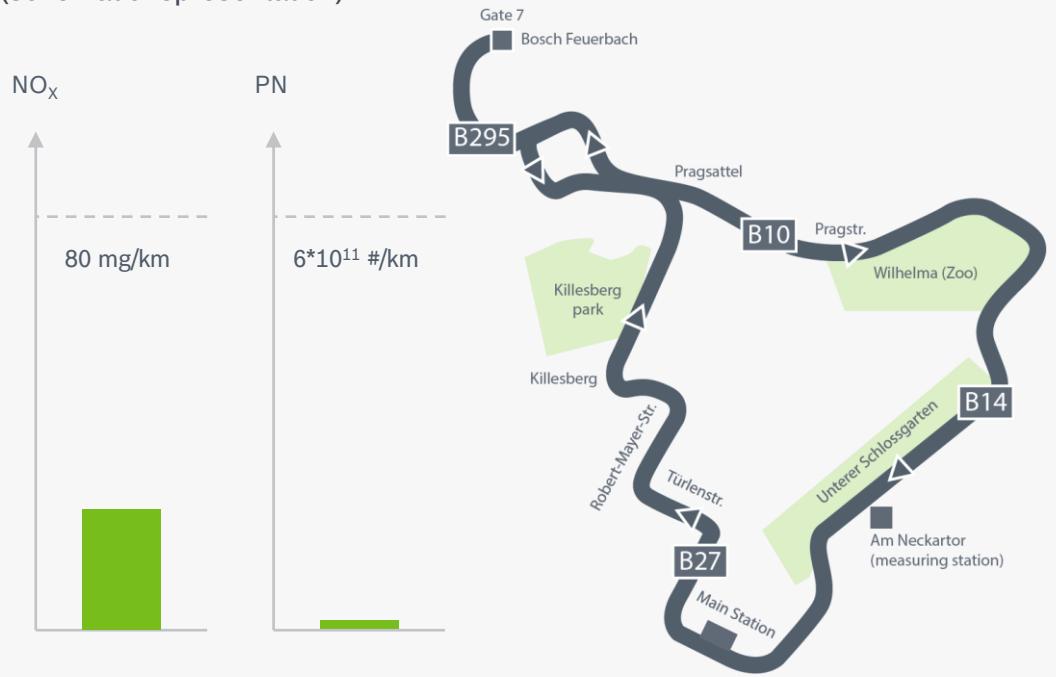


Highly dynamic turbocharging



Advanced Exhaust Gas Treatment
Double-injection SCR system

Emission levels during test drives in an urban environment (16 km) (schematic representation)



1) LP EGR – Low Pressure Exhaust Gas Recirculation
2) DRS – Digital Rate Shaping

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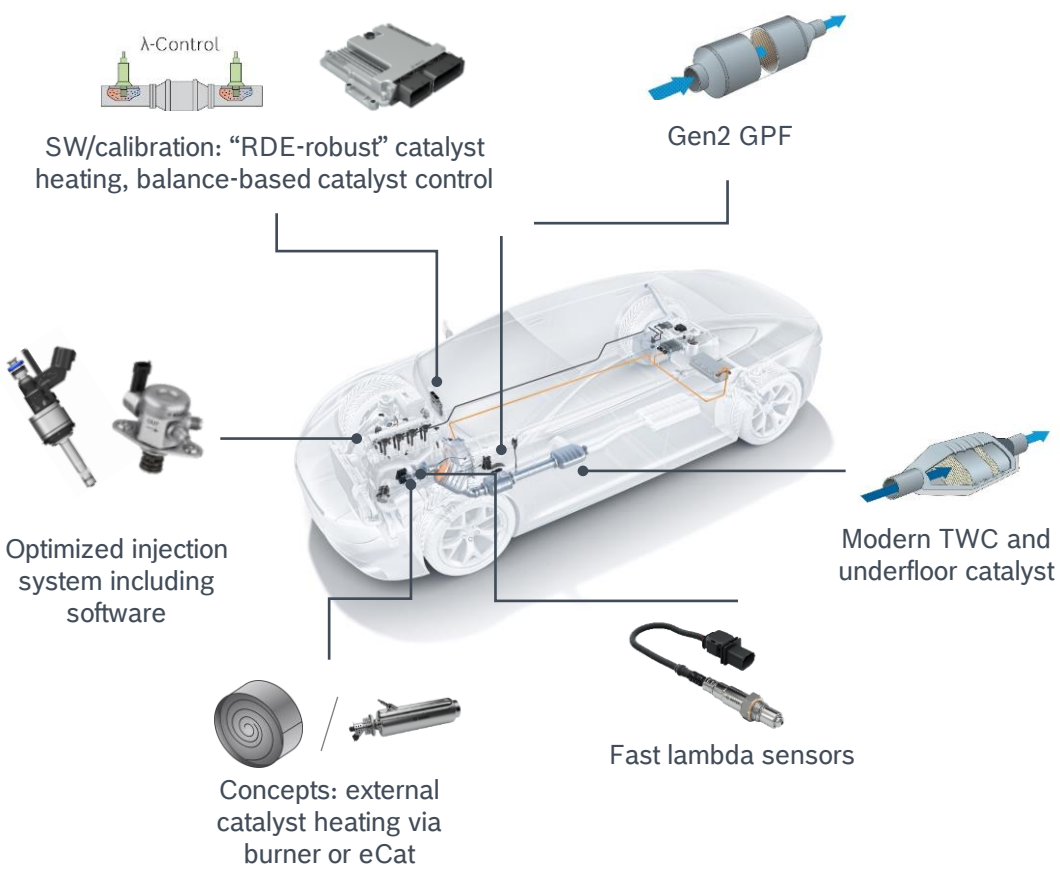
Modern Gasoline concept: minimal impact on air quality



Emission levels during test drives in an urban environment (16 km) (schematic representation)

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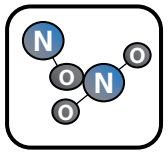
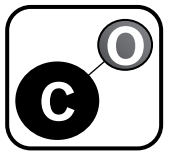
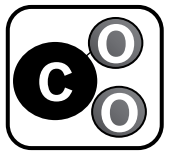
Bosch Cross India Mobility Tour – On-road emissions

3600km

Average Emissions:







Gasoline GDI BS6

3-Cyl. 1.0l
75kW 150Nm
3-Way Catalyst
Kerb Weight: 950kg + 200kg Payload

20 mg/km	**$3.9_{x10^{11}}$**	**84** mg/km	**154** gCO_2/km

-15%

Diesel BS6

4-Cyl. 1.7l
110kW 340Nm
LP-EGR+cEGR, NSC/cDPF+uf_pSCR [1)]
Kerb Weight: 1400kg + 400kg Payload

45 mg/km	Not measured Very low	**12** mg/km	**131** gCO_2/km

Low **P**ressure **E**xhaust **G**as **R**ecirculation, **N**O**x** **s**torage **C**atalyst, **c**oated **D**iesel **P**articulate **F**ilter, **u**nder**fl**oor **p**assive **S**elective **C**atalytic **r**eaction catalyst

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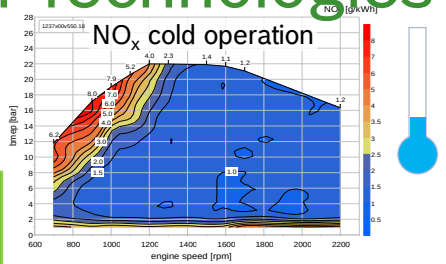
CV Segment – DI-SCR system setup example

CRSN Modular System
- Moderate nozzle flow
- Faster injector opening setting
- Up to 2500 bar

Improved fuel-injection

Flexible NOx raw emissions



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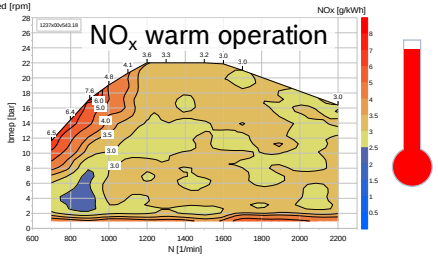
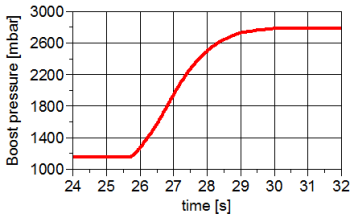
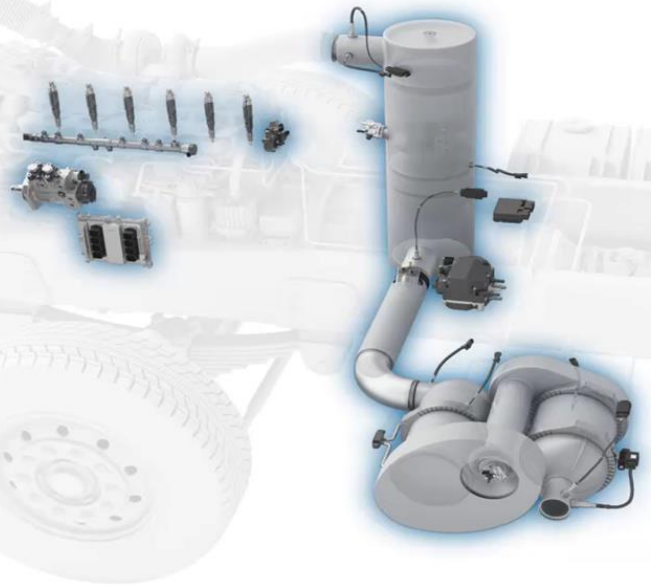
Efficient temperature management



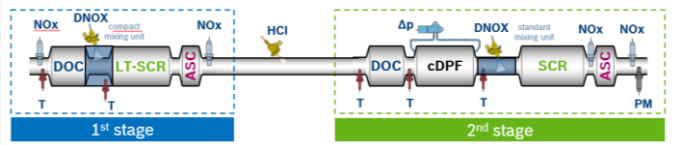
e.g. faster boost pressure build → more EGR in transient operation



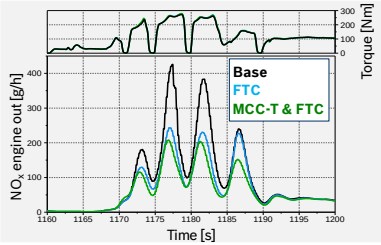
Improved turbocharging



Advanced exhaust-gas treatment



e.g. transient correction function air and fuel path



Extended software functions

Optimization in a system approach

1) DI-SCR : Double Injection Selective Catalytic Reduction

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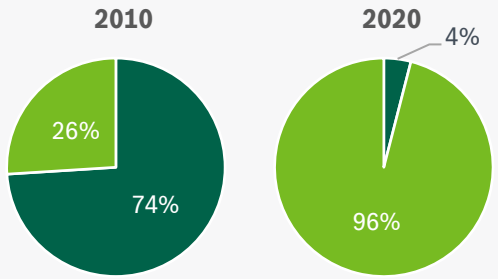
Affordable, low-emission mobility to improve local air quality

Situation in Germany: air quality has improved significantly, higher rate of compliance to NO_2 limits

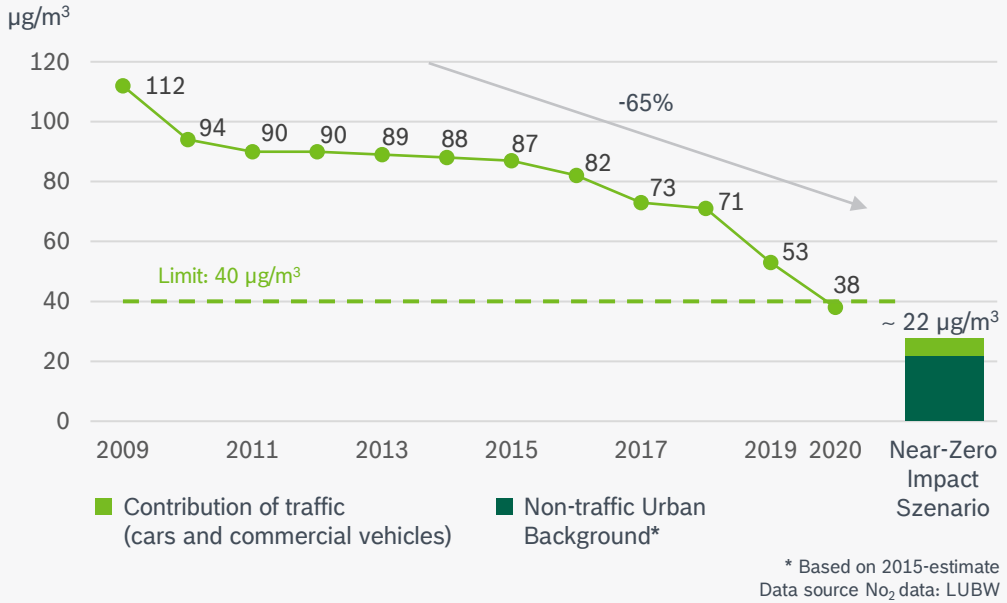


Measurement stations in Germany (city, traffic-oriented) with

- NO_2 annual mean ≤ 40 µg/m³
- NO_2 annual mean > 40 µg/m³

Data source:
German Environment Agency (UBA) 2020 projection

Stuttgart "Am Neckartor": significant NO_2 reduction



* Based on 2015-estimate
Data source No_2 data: LUBW

Outlook Near-Zero-Impact scenario: Close to zero contribution to local air quality from vehicle fleet with modern gasoline and diesel vehicles

Immission measurement box (IMB) and smart traffic management

NO_2

38 µg/m³

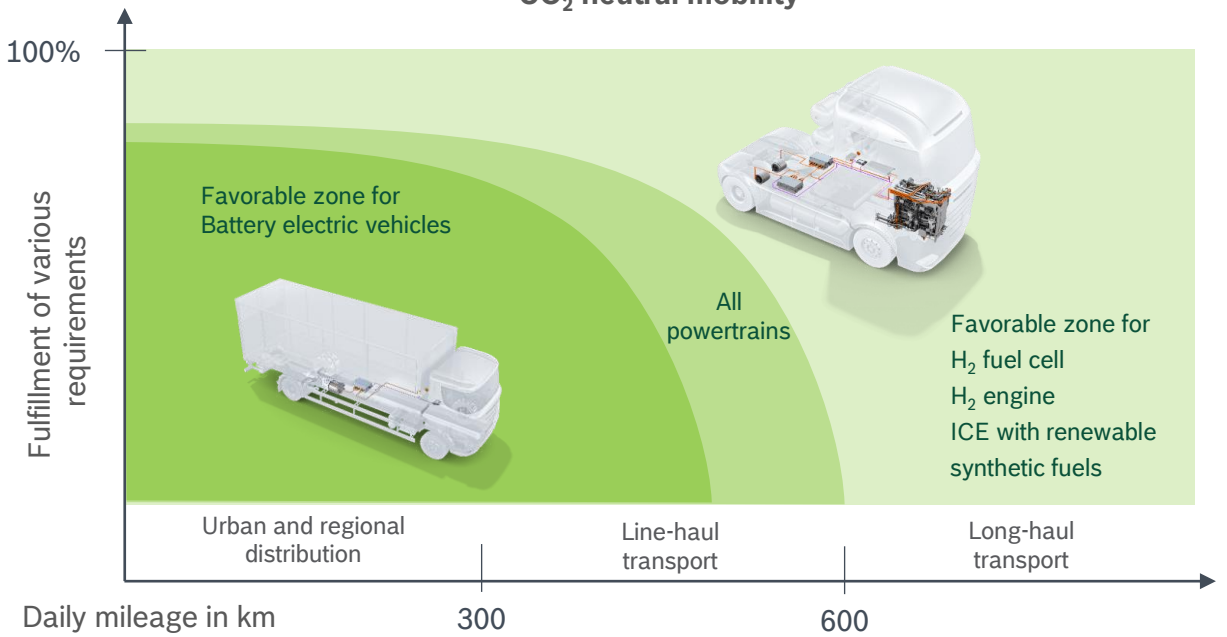
Through replacements in the vehicle fleet and other measures, the **NO_2 limit in Stuttgart "Am Neckartor" were complied with** in 2020

Different use cases need to be addressed by complementary technologies

Today
ICE as “all-rounder”

Example: Commercial Vehicles

CO_2 neutral mobility



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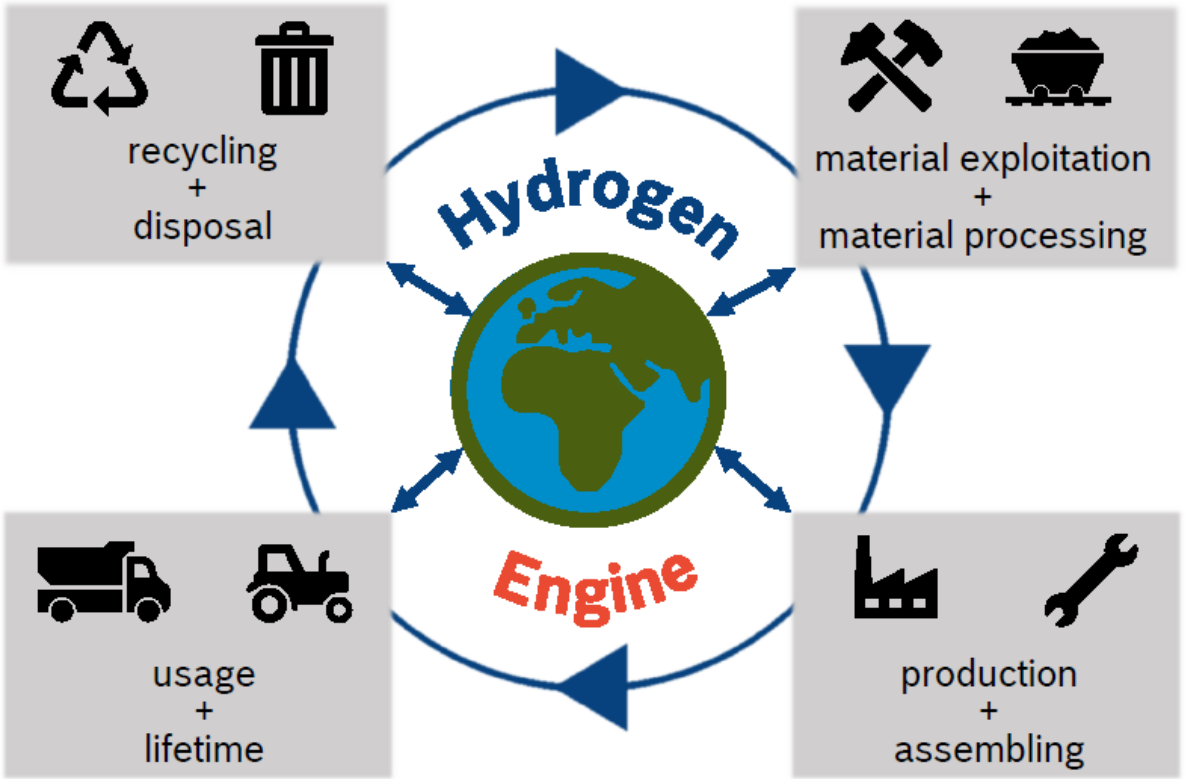
Motivation for Hydrogen engine

No relevant critical substances regarding recycling and disposal

Use of established recycling and disposal processes



Mainly steel and aluminum

Small amounts of precious metal for exhaust gas aftertreatment

Use and mining of rare earth materials not relevant

Robust use under all boundary conditions, efficiency like diesel

NO_x Emissions: No relevant influence on air quality

$PM_{2.5}$: Same order of magnitude as other CO_2 -neutral powertrains

Established development and production processes

Uses existing production facilities

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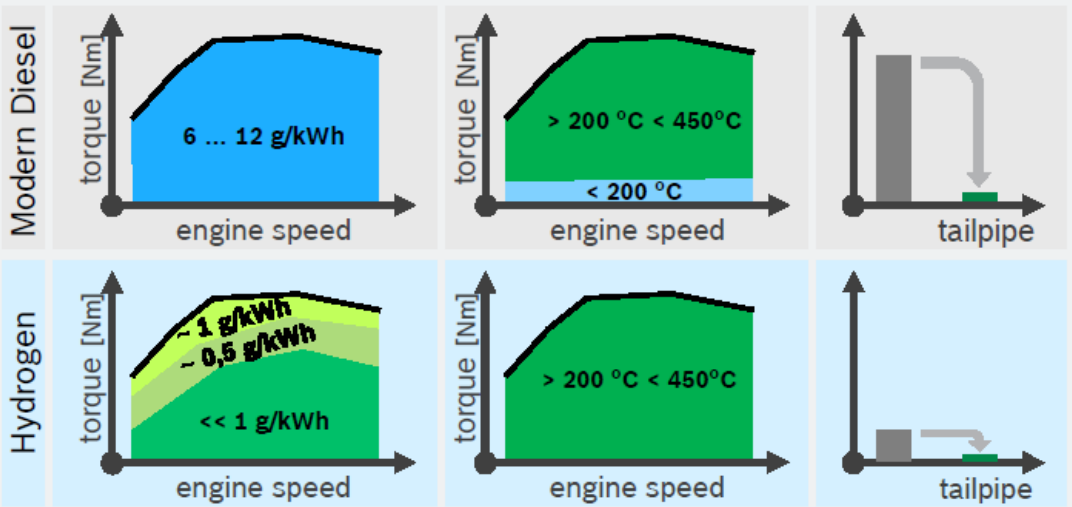
H_2 Engine Emissions – NOx, PM/PM, HC, CO

Nitrogen Oxides



- Clearly lower engine out level supportive
- Proven robust SCR-system as first choice

Particle Mass / Particle Number, Hydrocarbons, Carbon Monoxide

- Very low values due to C-free fuel
- Oxidation catalyst / particle filter
- For lifetime robustness mandatory EGT part

H2 Engine – All exhaust emissions are “close to zero”

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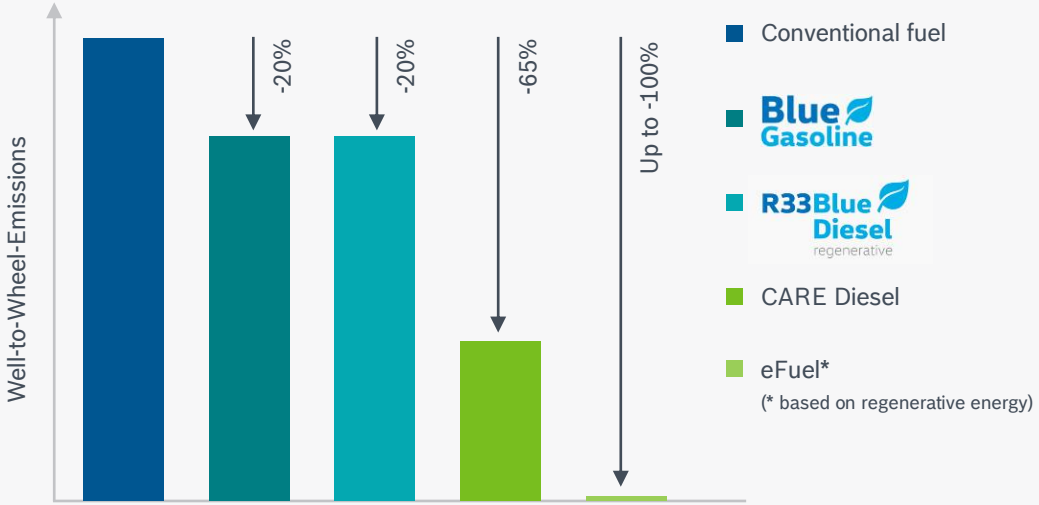
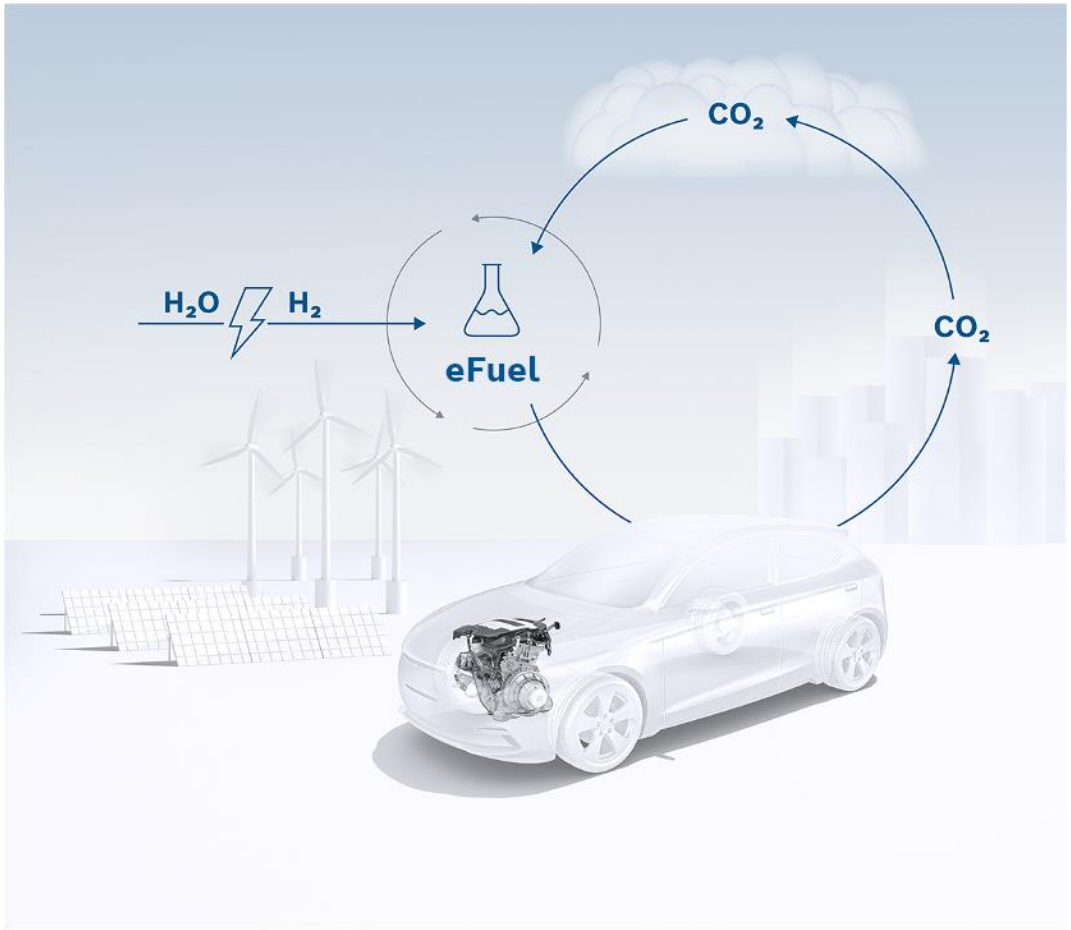
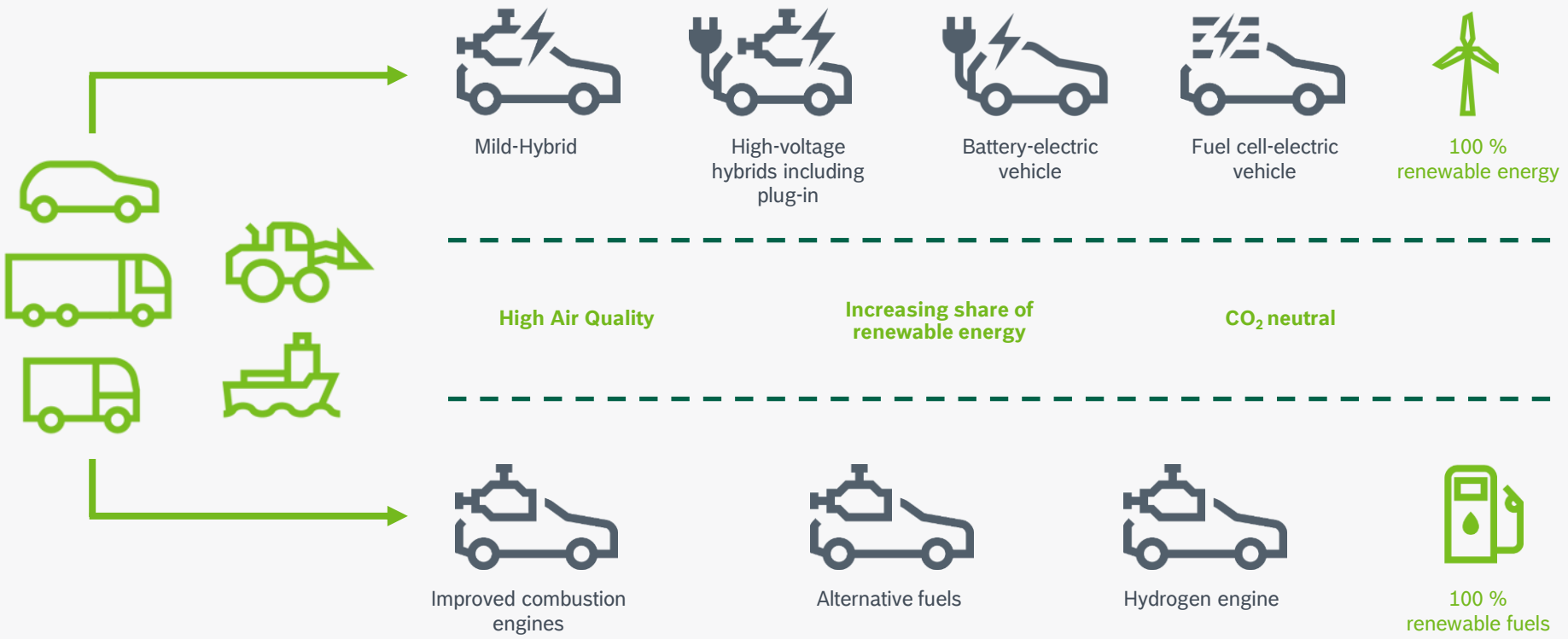
CO_2 reduction through renewable synthetic fuels





The entire spectrum of powertrain technologies and fuels are required to meet our climate goals

The crucial factor is that every vehicle is operated with energy from renewable sources.



Thank you for your attention!