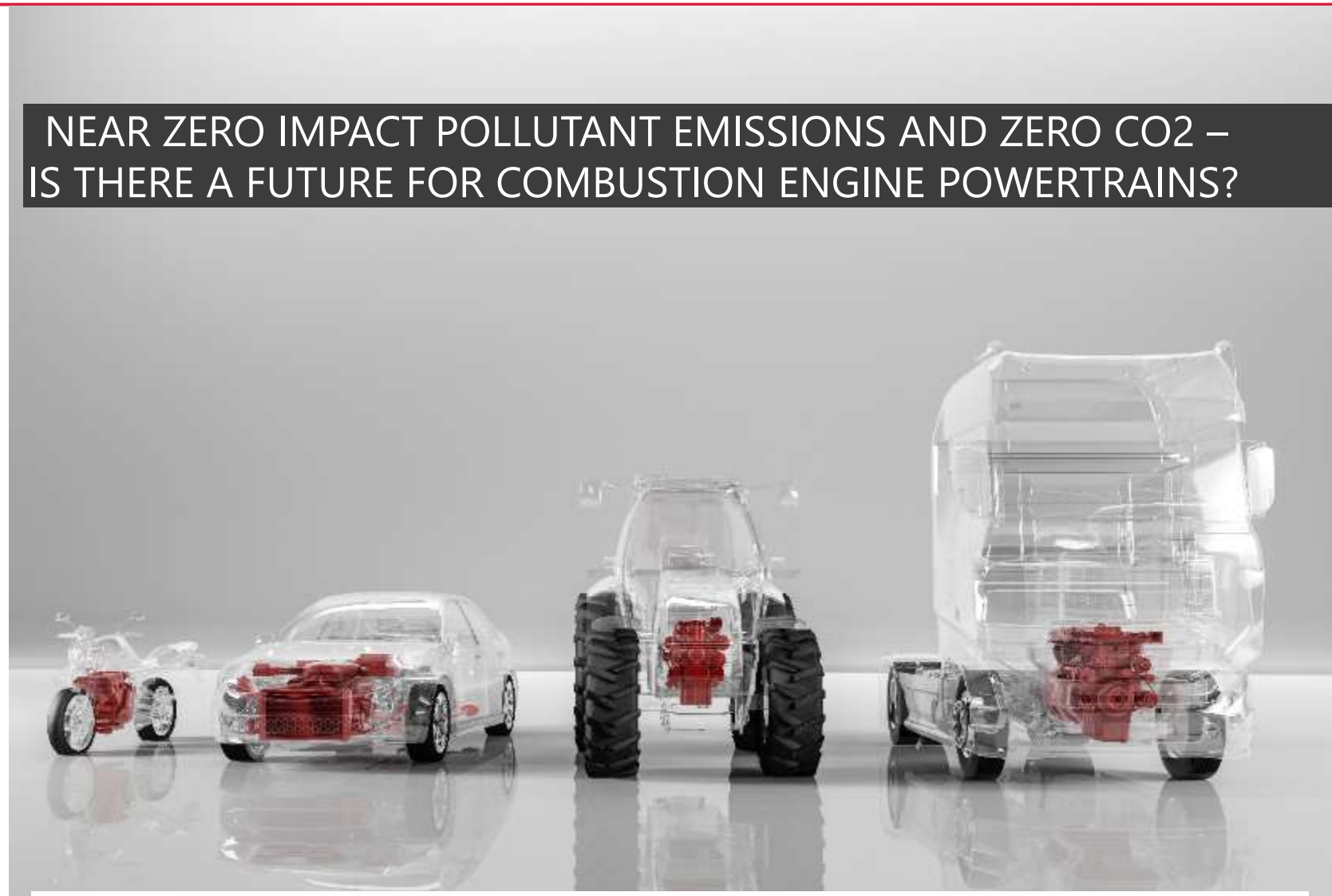
AACHEN, 2021-05-08

DR.-ING. CHRISTOPH MENNE

NEAR ZERO IMPACT POLLUTANT EMISSIONS AND ZERO CO2 – IS THERE A FUTURE FOR COMBUSTION ENGINE POWERTRAINS?



PREPARED FOR

SIAR

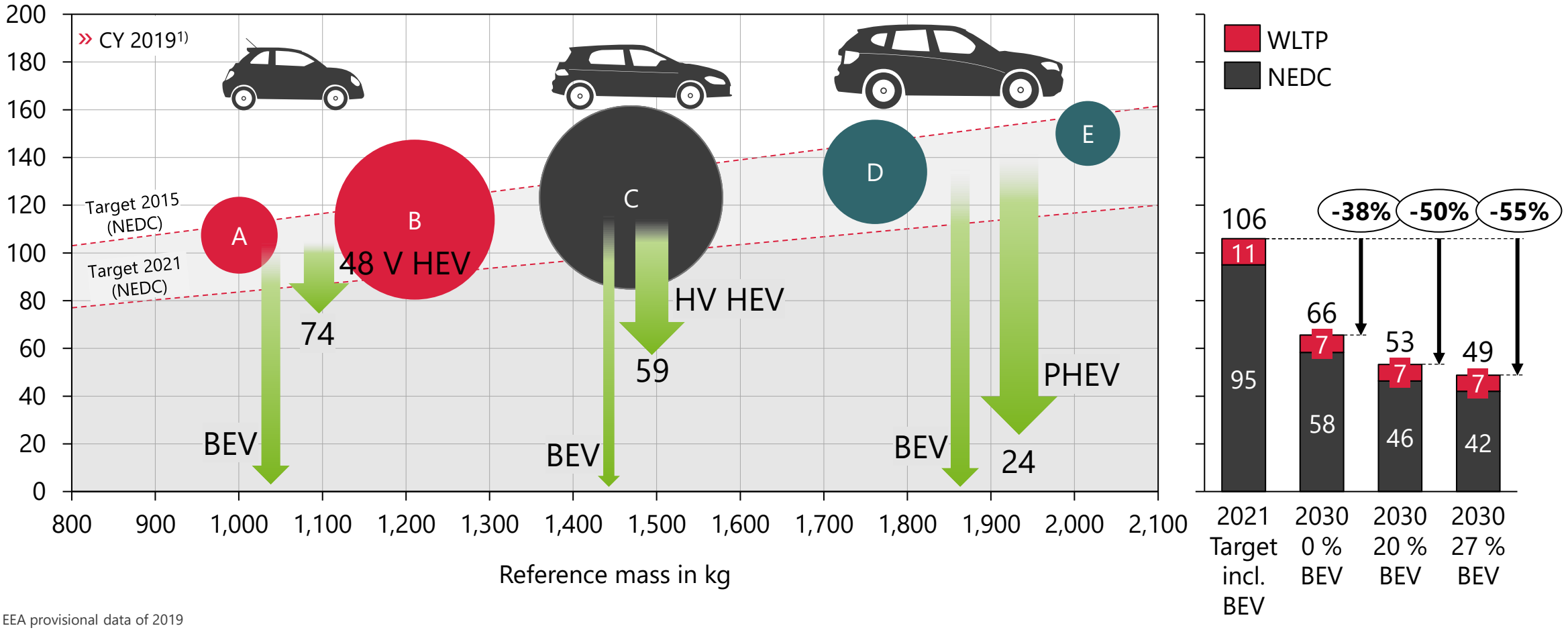
ROMANIA

SOCIETATEA INGINERILOR DE AUTOMOBILE DIN ROMANIA
SOCIETY OF AUTOMOTIVE ENGINEERS OF ROMANIA

FEV – SUPPORTING THE PRESENT
DEVELOPING THE FUTURE

2030 dedicated HEV, PHEV and BEV powertrain will contribute in the various vehicle segments to a significant reduction of CO2 emissions of new vehicles

CO_2 EMISSION IN NEDC FOR GASOLINE AND DIESEL BY VEHICLE SEGMENT IN EUROPE IN 2019



EEA provisional data of 2019
BEV distribution 2030: 20 % BEV = A/B 31 % + C 8 % D/E 25 % | 27 % BEV = A/B 39 % + C 15 % + D/E 29 %

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Agenda

- Introduction / Powertrain Market Share Forecast
- EURO 7 Emission Legislation
- Technologies Gasoline
- Technologies Diesel
- Future Outlook

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Your engineering and consulting partner – Strong, competent and reliable

GLOBAL REACH – ONE FACE TO THE CUSTOMER

735 M€
Revenue in 2019

~200
Patent applications per year

40+
Subsidiaries on four continents

6,700
Employees globally

300+
Test cells for engines, T/M, e-drives, fuel cells & batteries

>40
Years of experience

>70%
Academics

>50
Different nations

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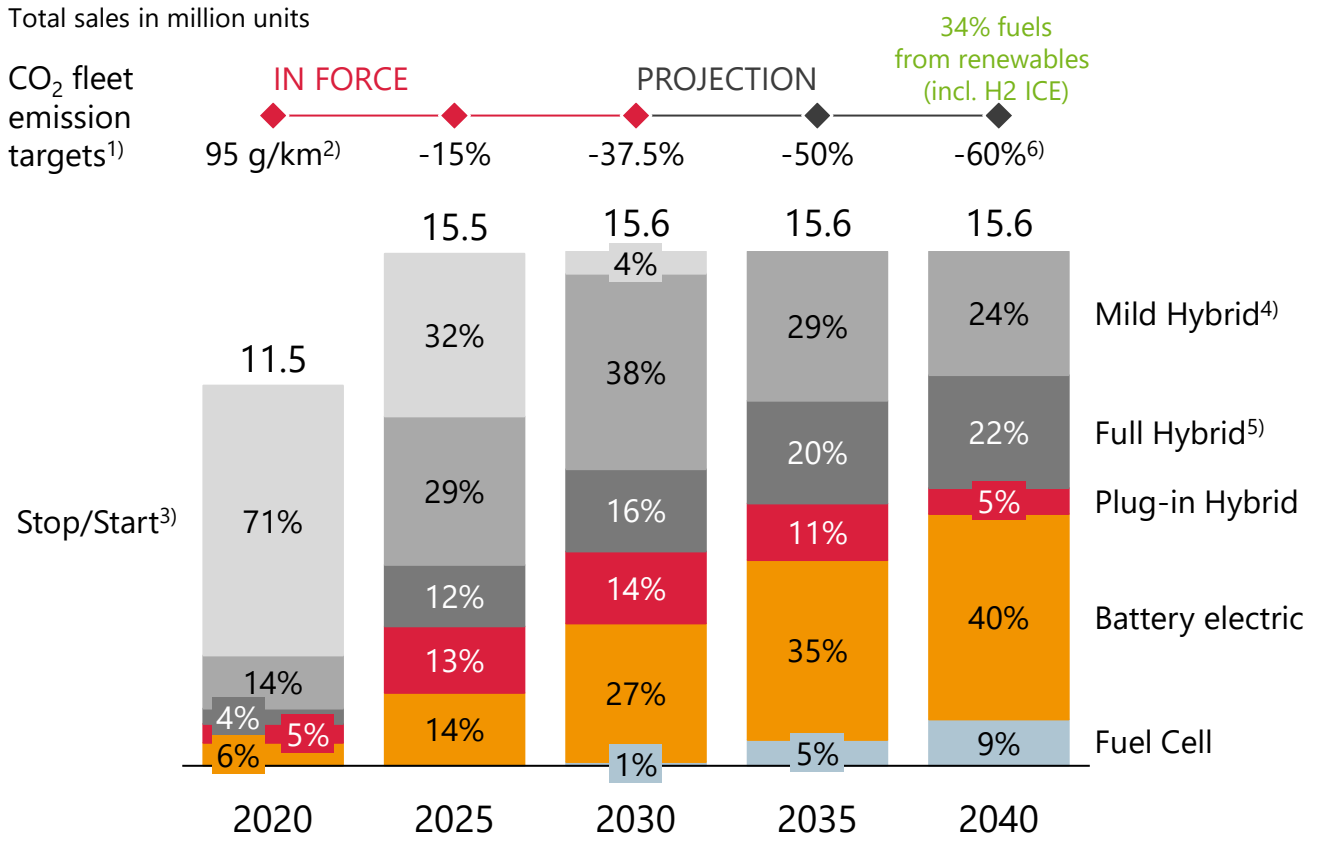
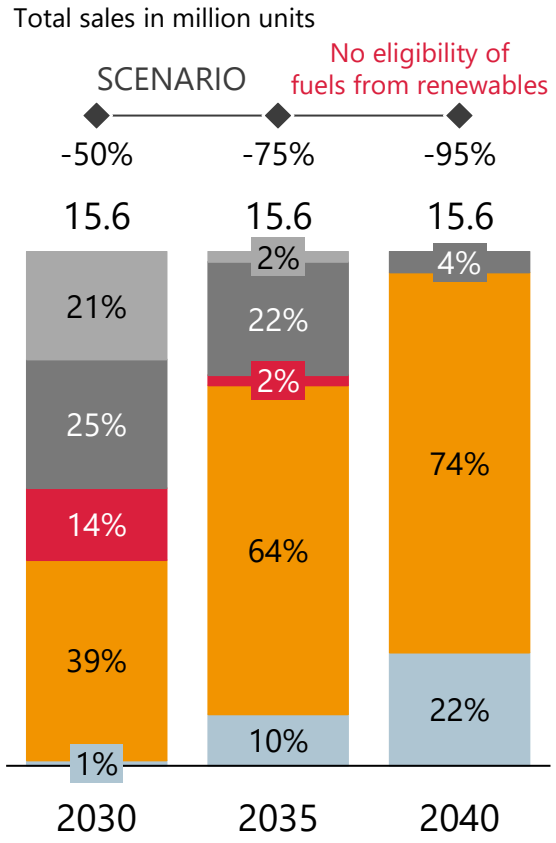
For European market region, a major shift to zero-emission vehicles is expected by 2030, increasing furthermore 2040

PASSENGER CAR ELECTRIFICATION SCENARIOS – VEHICLE SALES & POWERTRAIN TYPE SHARES

FEV BASE SCENARIO



"ACCELERATED"



1) 2021 target according NEDC, 2025 and 2030 targets and projection as OEM specific CO_2 emission reduction targets in reference to 2021 WLTP CO_2 emission
2) In 2020 target must be achieved by 95% least emitting vehicles within each automaker's fleet, 100% compliance for 2021
3) Stop/Start and 12 V energy management; 4) 12 V and 48 V mild hybrids; 5) Includes 48 V hybrids with full hybrid functionalities
6) This projection accomplishes 95% of CO_2 emission reduction within vehicle stock in 2050 by using 238 TWh of PtL (e-fuels) in 2040 and 602 TWh in 2050 respectively
Source: FEV

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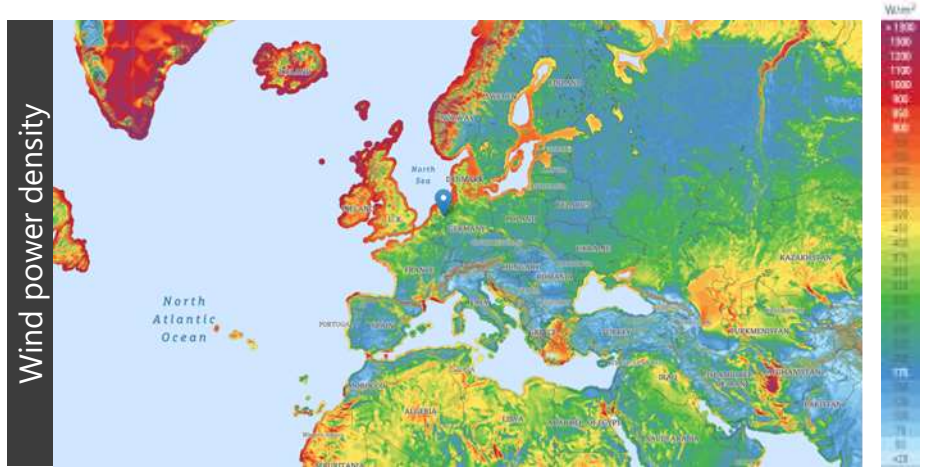
Renewable electrical energy is sufficiently available for hydrogen production
EU will stay being energy importing also in the renewable energy decades

ENOUGH SOLAR POWER AVAILABLE TO PROVIDE ELECTRICITY FOR THE WORLD, BUT WILL BE TRANSPORTED CHEMICALLY (H2)

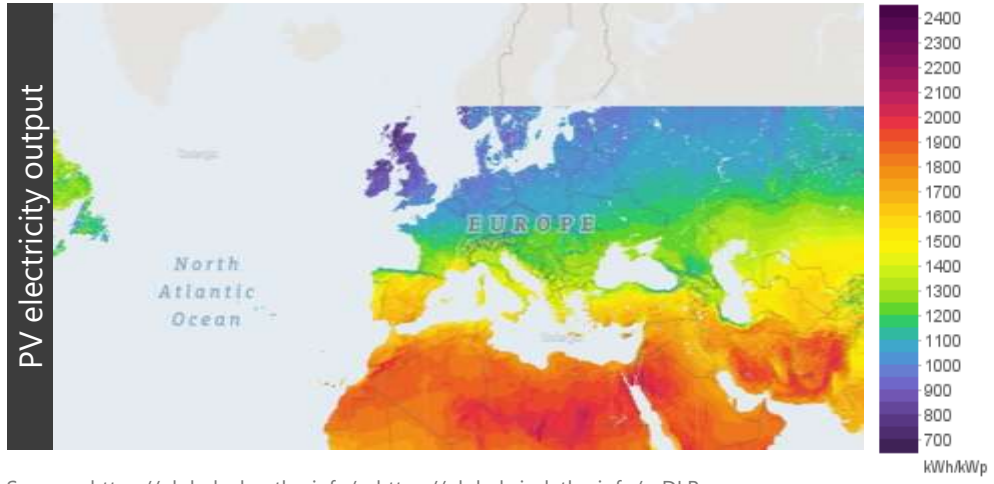


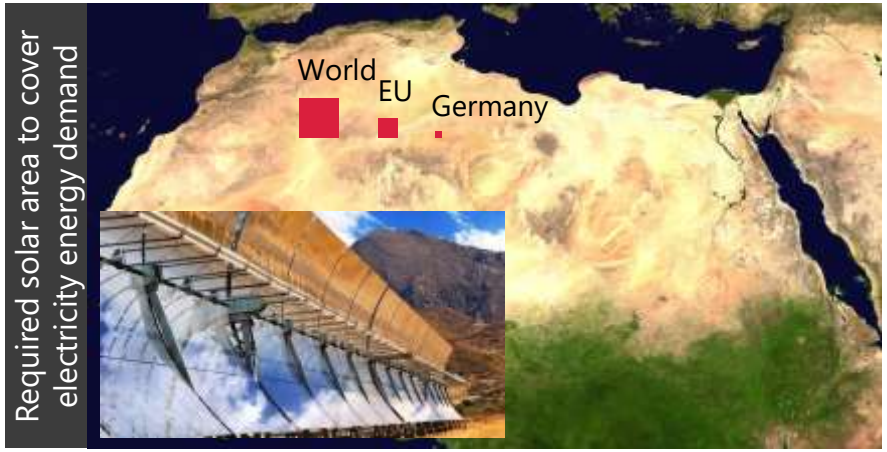
Domestic excess renewable energy (primarily wind)

- Storage and Re-electrification in times of calm darkness

Import of chemical carriers of renewable energy

- Germany's domestic renewable energy resources will not meet demand
- In Northern Africa an area of 300 km x 300 km is sufficient to cover the worlds electricity energy demand





Sources: https://globalsolaratlas.info/ https://globalwindatlas.info/ DLR

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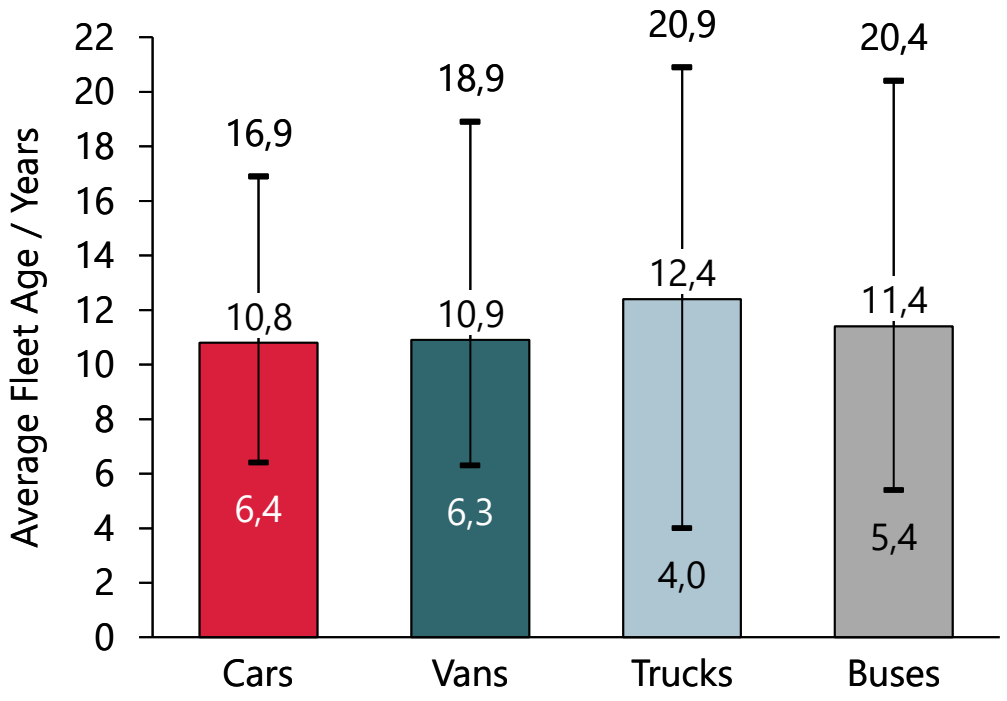
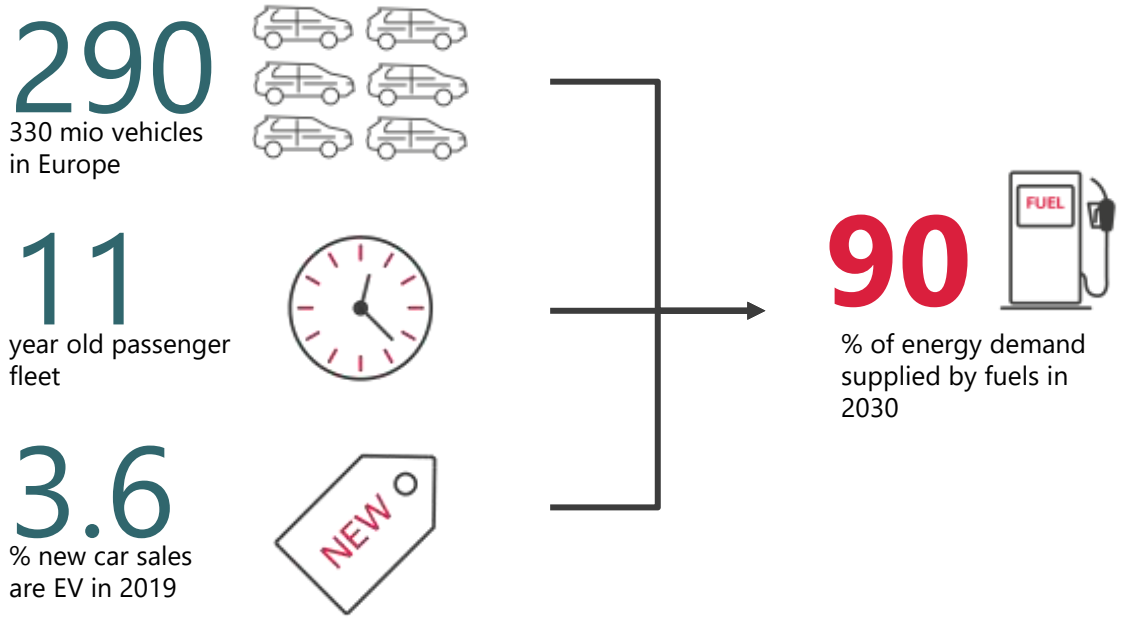
E-Fuels mandatory to achieve climate targets
Vehicle fleets renewal needs decades, 2030 energy mainly provided by fuels

FLEET RENEWAL



ENERGY SOURCE FOR MOBILITY IN 2030



*The extended tank-to-wheel balance considers the CO2 emissions created when conversing the energy carrier to kinetic energy and a subtract of carbon sinks that are realized during the production of the energy carrier; Legislation: based on GHG reduction targets for transport sector by European Commission; Source: FEV

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Objective is to improve local air quality and label IC engine as clean to avoid banning out of cities

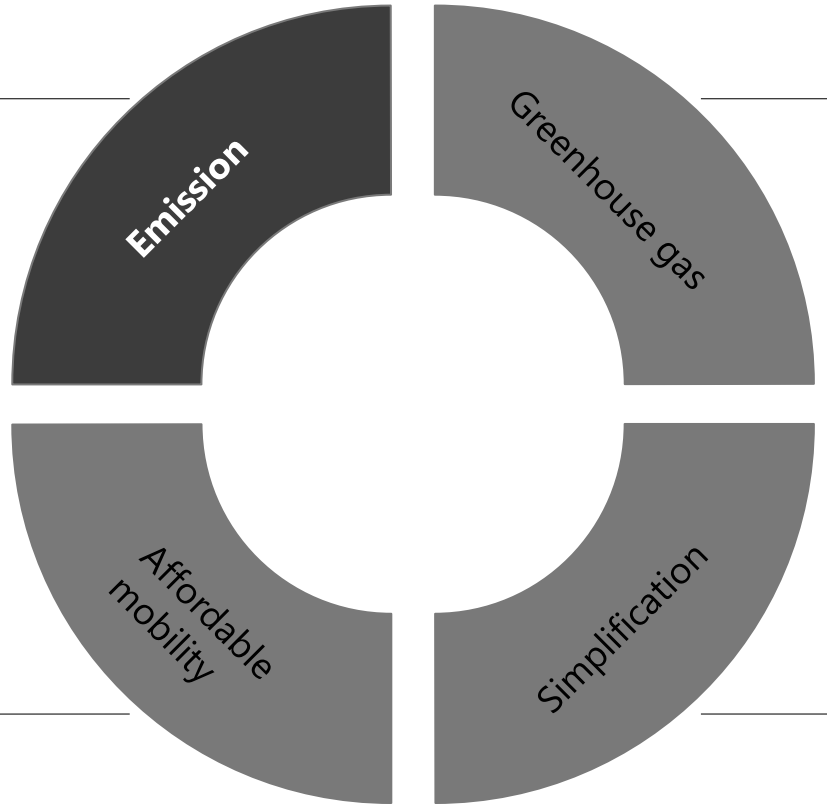
CLOVE CONSORTIUM OBJECTIVES

Reduction of emissions mainly in urban areas

→ improving of air quality

→ **Direction of zero emission vehicles**

→ **Making sure that IC vehicles can be considered as clean (no banning required**)



Greenhouse gas emissions need to be considered

Mobility should still be affordable

Simplification of legislation

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EU Motivation for EU7 legislation and resulting challenges

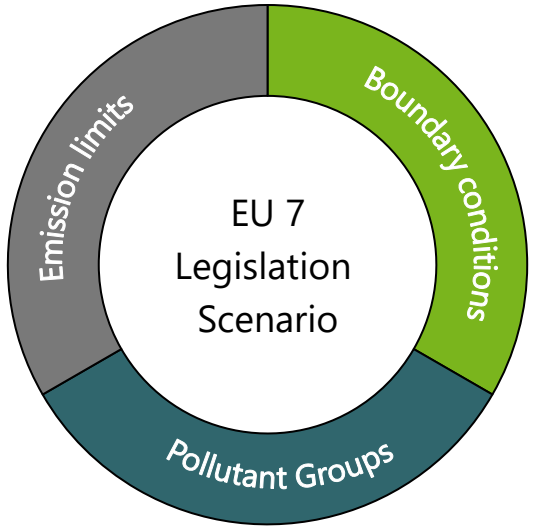
EURO 7 LEGISLATION SCENARIO

As much as possible reduced gaseous emission limits
Faster catalyst light-off necessary

Short urban driving distances will be regulated
Faster catalyst light-off necessary

Transfer RDE test to chassis dyno for new pollutants possible
Additional Tests for emission groups not measurable with PEMS

Fuel and powertrain neutral emission limits
Same pollutant groups and emission limits for all powertrains (Gasoline, Diesel, CNG, LPG …)



Extension of testing boundary conditions (RDE)
Largely unrestricted driving scenarios, no post-processing, allowance of all potential use-cases

Emission limits regulated on the road in RDE boundary conditions
Which lead to excessive add-on cost or CO_2 penalty

Monitoring of in-use emissions
To avoid degradation of EATS components,
To ensure durability in the useful life (240000 km, 15 years with CF=1)
Checked by OBM and In-Service Conformity tests

NH3, N20, CH4 limits for LDVs
Cold starts and enriched operations critical for Gasoline powertrains

Particulates measurement range from 23 nm to 10 nm
Higher filtration efficiency of particulate filter

CO_2 equivalents for GHG
CH_4 → 28 times higher Global Warming Potential (GWP) than CO2
N_2O → 265 times higher GWP than CO2

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CLOVE Proposal EU 7 - LDV 08.04.2021

Proposed testing conditions for Euro 7

Parameter	Current RDE boundaries	EURO 7 Normal Conditions of use	EURO 7 Extended Conditions of use
Emission Limit Form	Constant value in mg/km or #/km	A budget up to 16 km and a constant value in mg/km or #/km above 16 km	3 times the limit of normal conditions
Ambient temperature [°C]	Moderate: 0 – 30°C | Extended: -7 – 0°C & 30 – 35°C	-7 to 35°C	-10 to +45°C
Average speed [km/h]	Urban: 15-40 km/h, Limitations for trip distance and duration, and speed range coverage	As per normal use	As per normal use
Trip composition	33% urban, 33% rural, 33% highway	As per normal use	As per normal use
$v \times a_{pos}$ [95th] [W/kg]	Speed-based calculated maximum limits	**A restriction is applied to the maximum power developed for the first e.g. 1 to 2 km and 1 to 2 min (The exact approach and values are under investigation and testing)**	As per normal use
Relative positive acceleration RPA m/s^2	Speed-based calculated minimum limits		As per normal use
Drive-off	—		As per normal use
Positive elevation gain [m/100km]	Total: <1200 [m/100km] Urban: <1200 [m/100km]		As per normal use
Max. altitude [m]	Moderate: 0 – 700m | Extended: 700 – 1300m	1600 m	2200 m
Towing/aerodynamic modifications	Not included	Not included	Allowed
Age/Mileage of Vehicle [km]	ISC 100k | MaS 160k	Up to 240k km or 10 years (1)	Up to 240k km or 10 years (1)
Minimum mileage before testing	15000 km (ISC testing)	3000 km	As per normal use
Trip distance [km]	U/R/M >16 km each	Any	Any
Max. speed	145 [160] km/h	Any <160 km/h	All European conditions

(1) The durability of the emission control systems until the end of their lifetime will be dealt separately

Source: CONSORTIUM FOR ULTRA LOW VEHICLE EMISSIONS (CLOVE)

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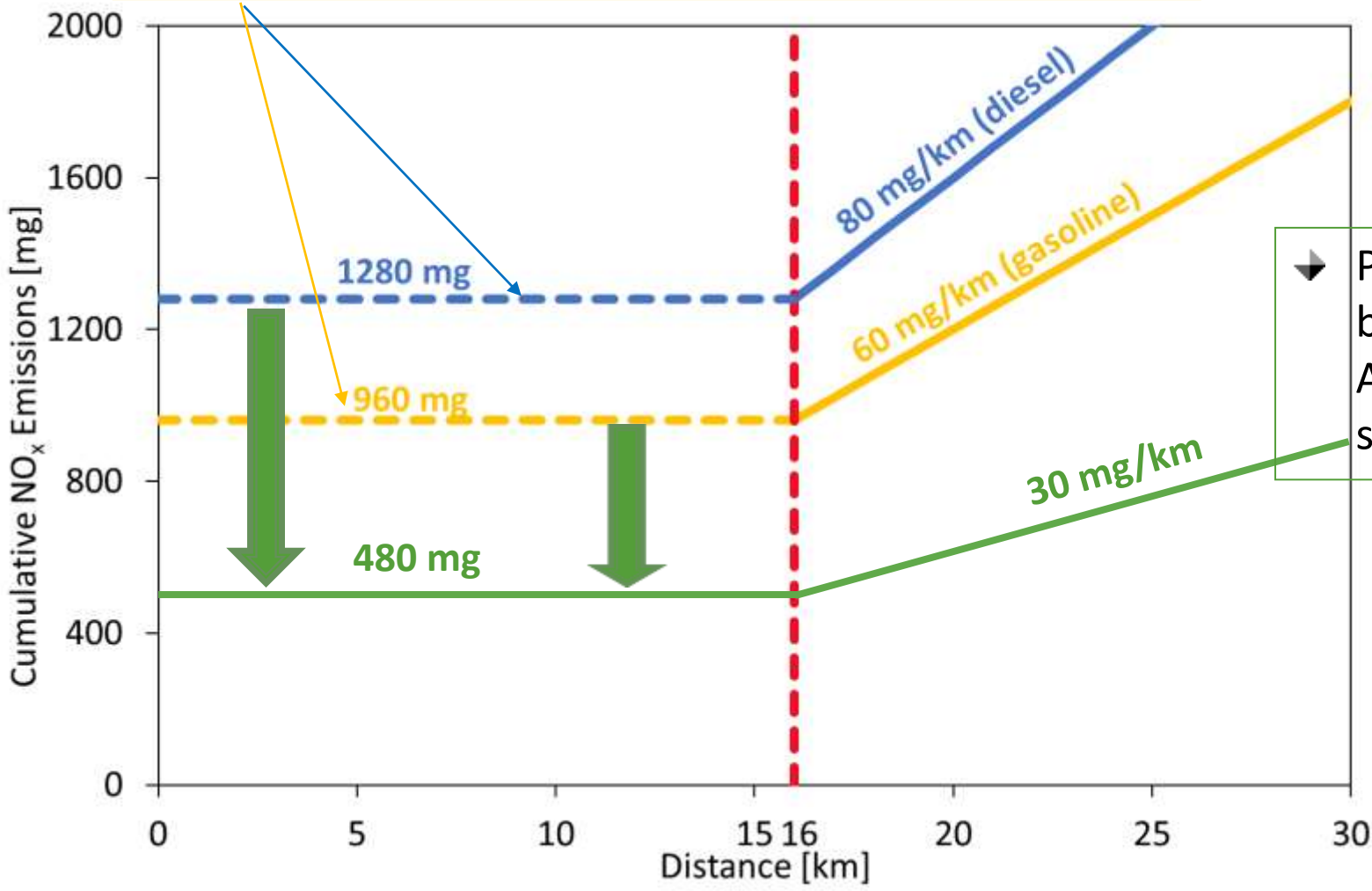
The proposed budget in comparison to Euro 6

- Current Euro 6 situation without conformity factor. Emission limit applies from 16 km and above



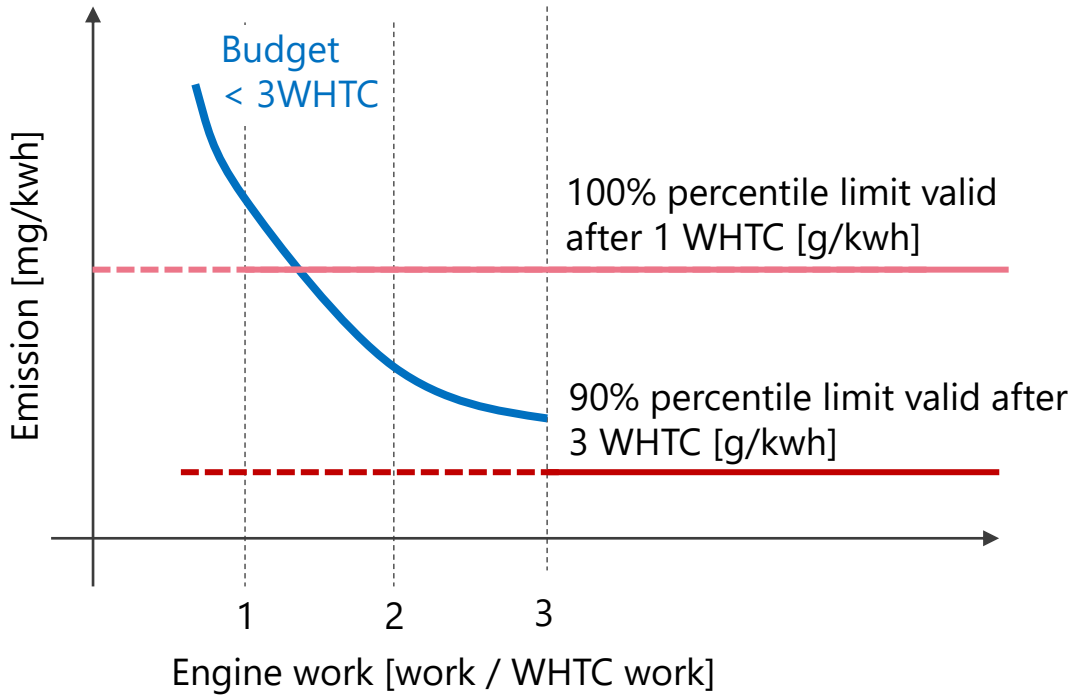
- Proposed Euro 7 budget (Scenario 1). Applicable from start

Emissions limits for cars/vans for normal conditions of use

Pollutant	CO	NMOG	NO_x	PM	PN_{10}	NH_3	CH_4 (*)	N_2O (*)	HCHO
Unit	mg/km	mg/km	mg/km	mg/km	#/km	mg/km	mg/km	mg/km	mg/km
Scenario 1									
Cars with and Vans	400	45	30	2	1×10^{11}	10	**20**	**20**	5
Vans with TPMLM>2500 kg & PWR<35 kW/t	600	45	45	2	1×10^{11}	10	**20**	**30**	**10**
Scenario 2									
Cars and Vans	400	25	20	2	1×10^{11}	10	10	10	5
	600	25	30	2	1×10^{11}	10	10	**15**	**10**

(*) Or a combined N2O + CH4 < sum of the proposed individual limits

HD EU-7 regulation approach basing on 3 limits. One for short trips / cold EATS and 2 for hot operation



- 3 Limit approach
  - Cum. Limit for all trips < 3WHTC. Work for spec. Limit is always 3WHTC
  - 100% percentile limit for 1WHTC window (need to be fulfilled after 1 WHTC)
  - 90% percentile limit percentile limit for 1WHTC window (need to be fulfilled after ~1 WHTC) for trips > 3WHTC
- Normal condition of use
  - < 1600m
  - -7 – 35°C ambient temperature
- Extended condition of use (emission factor 2)
  - -10 - -7°C & 35 – 45°C
  - 1600m – 2200m
- Low load operation
  - If average load goes below 10% rated power within one evaluation window 10% power is assumed for specific emission calculation

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HD EU-7 proposed limit values from Clove on 27.04.2021
Limit values are for 700tkm

Scenario	Limit	NOx [mg/kwh]	PN [1/kwh]	CO [mg/kwh]	NMOG [mg/kwh]	NH3 [mg/kwh]	N2O [mg/kwh]	CH4 [mg/kwh]
1	Budget @ 3 WHTC	150	2 E+11	1250	75	65	140	30
	100 % percentile	350	5 E+11	3500	200	65	160	100
	90% percentile	90	1 E+11	200	50	65	60	50

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Most challenging is the cold start operation
Hardware addons are required to address this topic

TECHNICAL SOLUTIONS TO ADDRESS THE CHALLENGES OF EU7 LEGISLATION

- Further reduction of emissions during cold EATS is required, fast EATS warm up
  - Short distance trip with high load
  - Unbeneficial catalyst condition and cold ambient at start

#1 eCat
Secondary Air

#2 Burner
HC Adsorber

...

#... Measures with
lower impact

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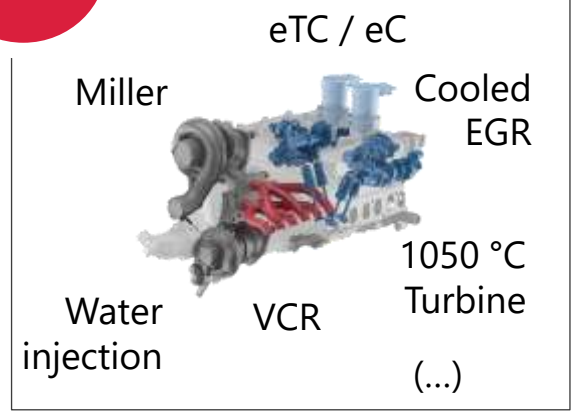
Resizing of the EATS + existing engine technologies to enable lambda = 1 required to handle the warm engine operation conditions

TECHNICAL SOLUTIONS TO ADDRESS THE CHALLENGES OF EU7 LEGISLATION

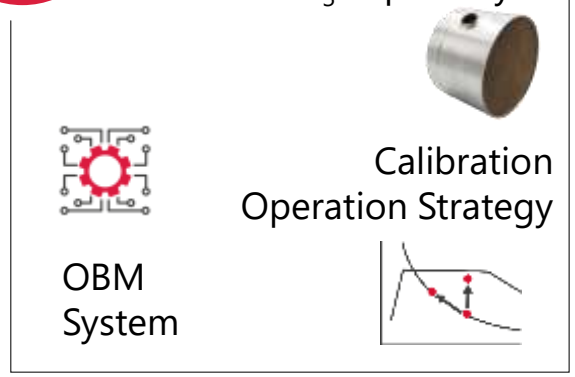
- Operation with warm EATS
  - Trailer up hill and high speed dynamic driving
  - Strong Accelerations without Enrichment
  - Keeping EATS warm (PHEV, HEV)
- NH3, CH4 an N2O emission
  - TWC coating, avoid rich operation, NH3 slip catalyst

#1 Lambda = 1 all operation points



#2 Upsizing of EATS system

#... Further measures



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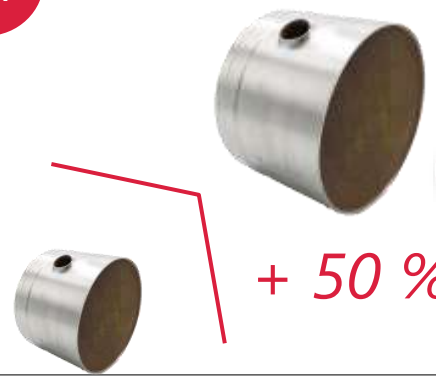
Mandatory Technology for Emissions Compliance EU7

GENERALLY VALID FOR MHEV AND PHEV IN COMBINATION WITH ALL ICE TYPES

#1 Advanced Catalyst
(increasing loading and volume)



&

#2 Newest GPF Technology
(soot monitoring, high efficiency)

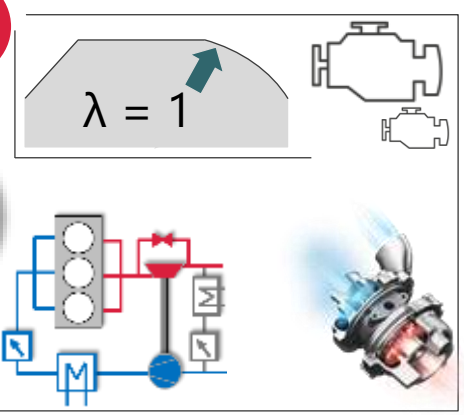
NH_3 Slip catalyst
(under investigation)

&

#3 Optimized combustion/controls
(350+ bar, charge motion, λ-split)

&

#4 Lambda = 1 in RDE boundaries
(rightsizing, Miller, cEGR, …)



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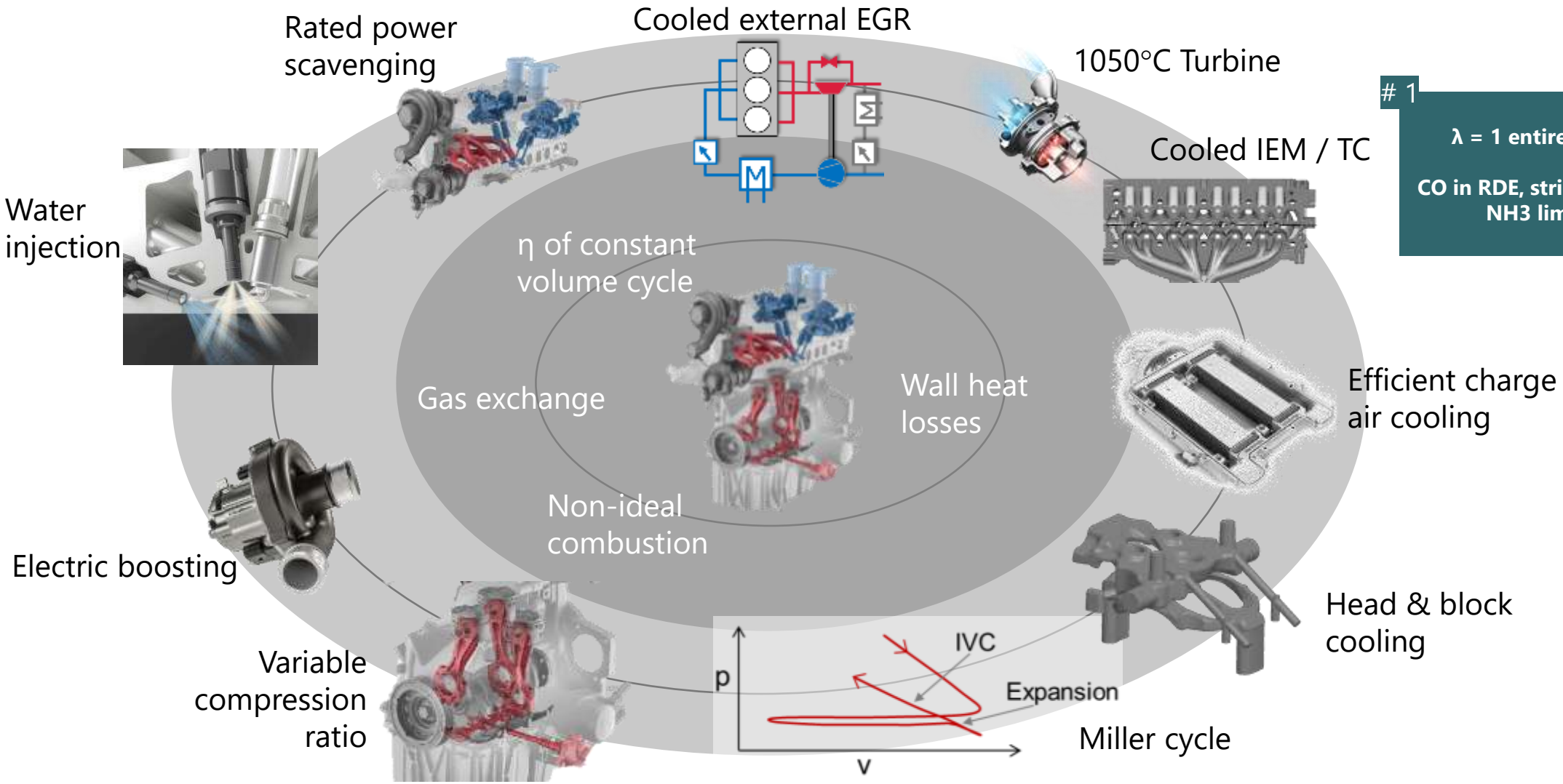
Technology overview how to achieve Lambda = 1 in entire map



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λ = 1 entire map

CO in RDE, stricter AES, NH3 limit

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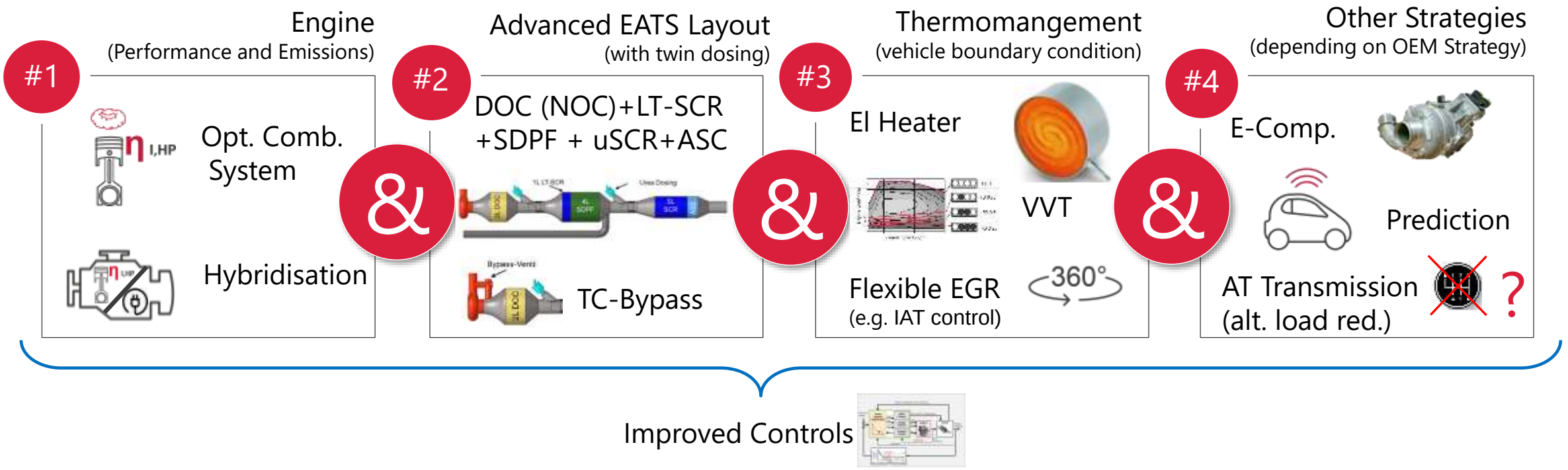
Full and Robust EU-7 Compliance demands System Approach and consists of four major Technology Packages to mitigate for TP Emissions appropriately

MAIN DECARBONIZATION APPROACHES

- Passenger car is most challenging for EU7 in contrast to LCV
- High performance engines needs an enlarged emission package
- EU7 low emission scenario requires an enlarged emission package (higher degree of electrification)



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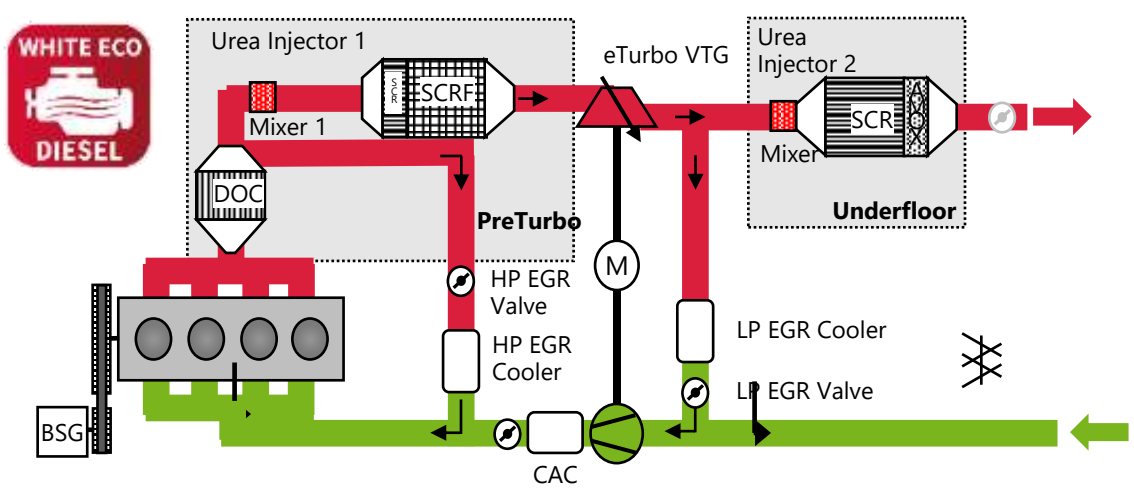
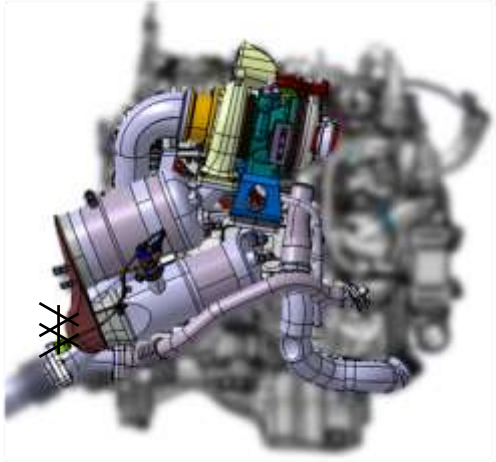
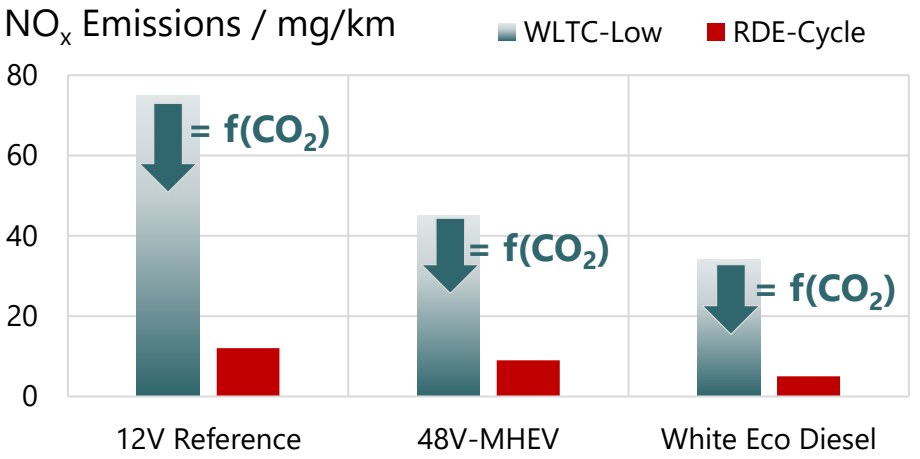
Reference project Diesel powertrain engineering - FEV invented and funded research and innovation project with industry partners

LD DIESEL NEAR-ZERO NO_x EMISSION CONCEPT

- NO_x-Emissions below 35 mg/km for 2x$WLTC_{Low}$ after cold start (6 km trip)
- NO_x-Emissions below 10 mg/km for RDE trips
- Minimized heating requirement → opt. fuel economy & lowest CO_2
- Reduced ki/DF impact
- Excellent performance
- 48V technology as a premise
- Succesful collaboration with five industrial project partners







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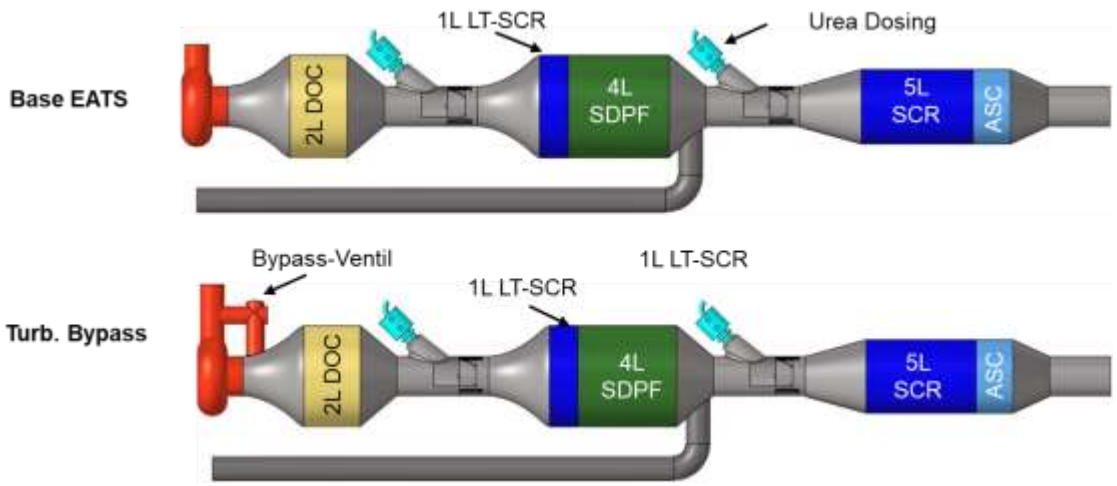
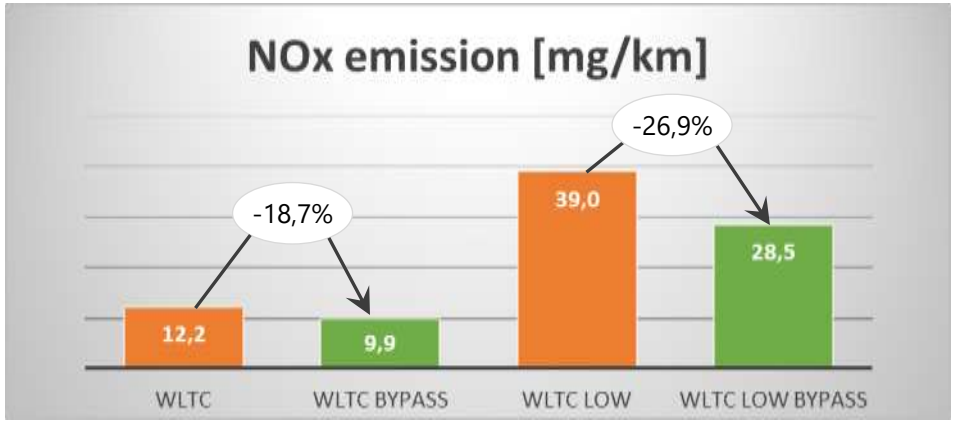
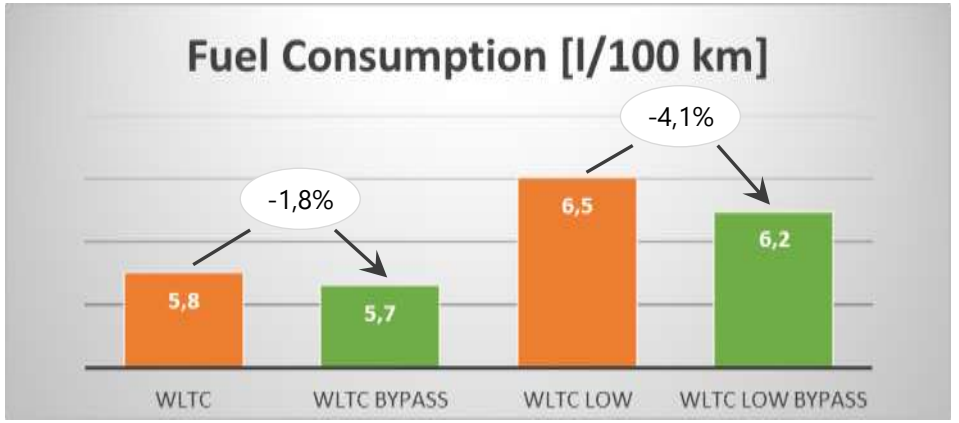
Implementation of learnings from pre-EATS demonstrator vehicle into conventional EATS concepts for near-zero emissions

ALTERNATIVE EATS LAYOUTS: TURBINE BYPASS







- Reduction of thermal inertia upstream first DeNox component minimizes heating requirement and fuel consumption resulting in Improved NO_x-FE tradeoff
- Potential deterioration of transient response can be compensated via e-boosting or torque assist via e-machine

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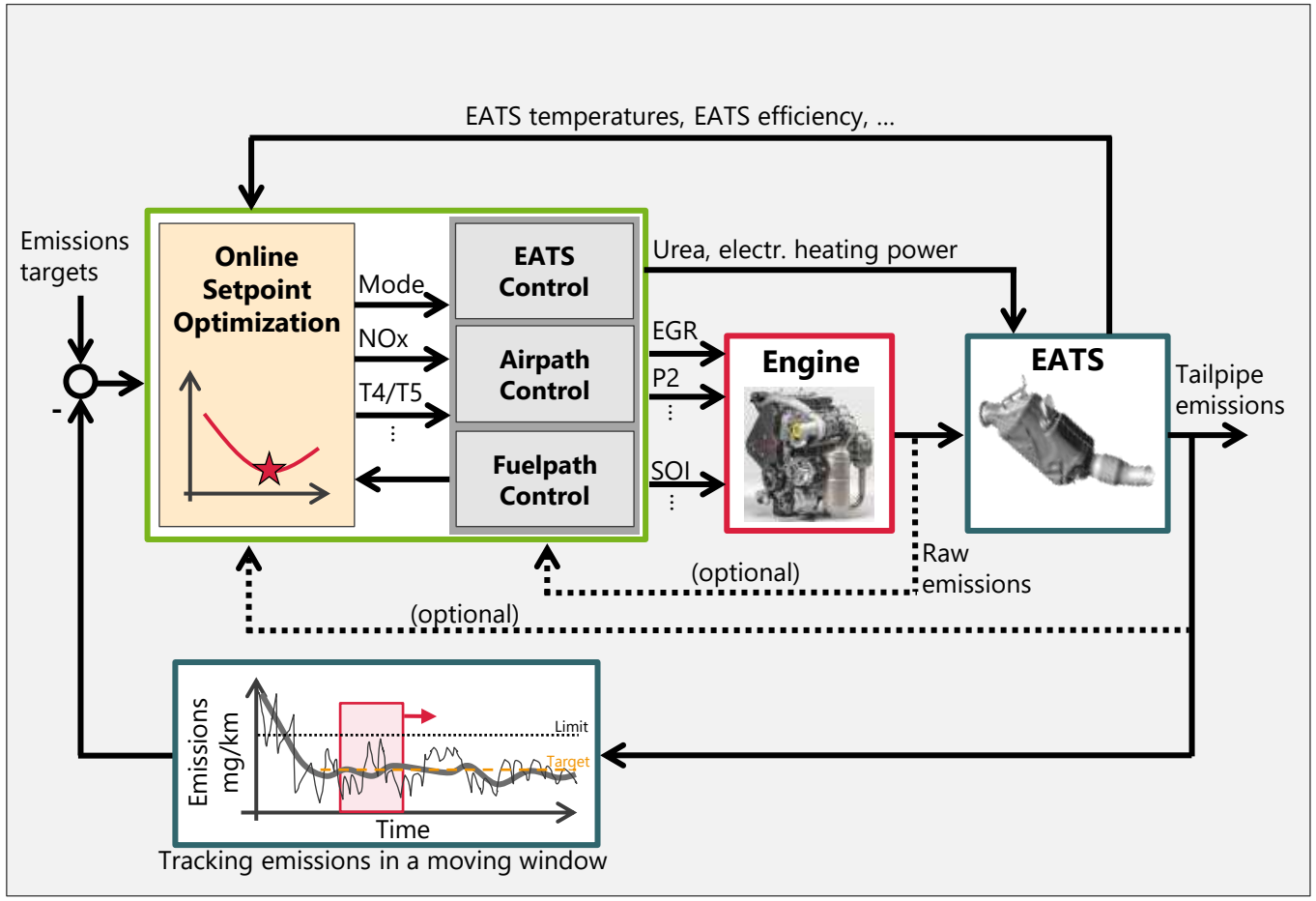
FEV System Coordinator for Energy and Emission Control Concepts for Advanced Emission Control

CONCEPT 2 – CLOSED-LOOP TP EMISSION CONTROL + ONLINE SET-POINT OPTIMIZATION



Summary

- Tracking emission history in a moving window
- **Online optimization** of engine operation while fulfilling emissions targets
  - Determination of optimal setpoints for NO_x, P2, SOI,…
  - Minimization of cost function considering CO_2, soot, AdBlue
- Correction of optimization based on emissions feedback
- OBM capable approach

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FEV's battery development center
Worlds largest independent battery development facility

EDLP IMPRESSIONS

DURABILITY

ENVIRONMENTAL

MECHANICAL

ABUSE

TEST CENTER SPECIFICATIONS

- 41.000 sqm site area, 12.000 sqm building area, 260 sqm add-on building for abuse tests
- 11.000 sqm production and storage
- VARIOUS TEST CASES SUCH AS:
  - Mechanical and functional tests, thermal investigation
  - Environmental, durability, abuse and homologation tests
- TESTING AREAS
  - 54 climate & temperature chambers;
  - 10 chambers for environmental testing
  - 4 Bunker & 1 fire hall for abuse testing

ADDED VALUE

- **Customized test program** (DVP&R) for all battery types & applications
- **Green label:** Roof with photovoltaic system (920 kWp) enables >>70% energy based on renewables

Source: FEV

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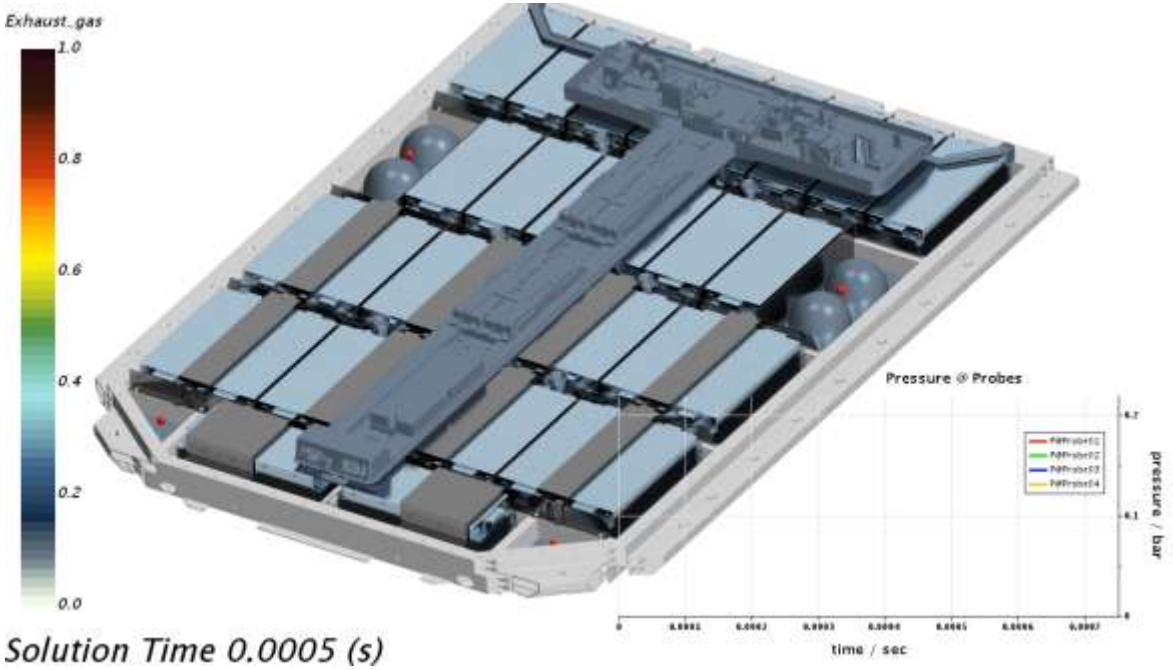
Thermal propagation (TP) development is key for automotive industrie
FEV´s offers unique competence & capability in TP development

FEV THERMAL PROPAGATION (TP) OPTIMIZATION PROCESS TO ACHIEVE STRINGENT CHINESE LEGISLATION (5 MIN)

SIMULATION



"Proof of layout and optimization of potential risks by thermal and CHT simulations"

TESTING

"Challenging thermal propagation test: More than 5 min. must be passed"

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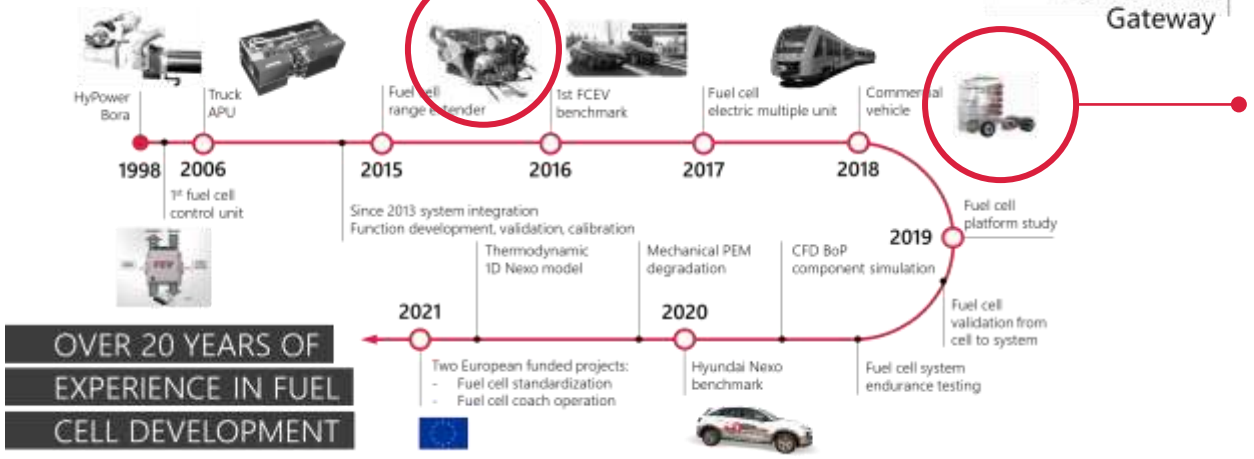
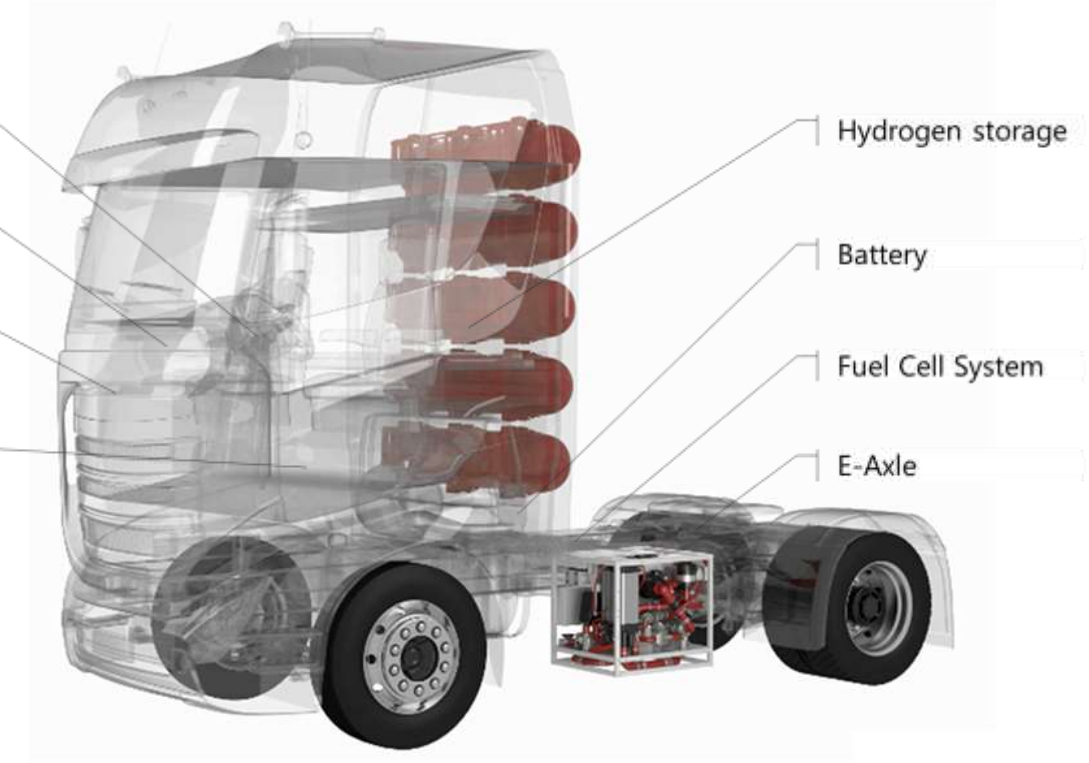
Market Trend Fuel Cell vehicles
FEV Fuel Cell Developments Projects since 20 years, accelerating 2015

FEV FC VEHICLES HAVE BEEN RUNNING ALREADY IN 2015





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FEV development of next generation dedicated hybrid engines w/ eFUELS
Several projects running with FEV´s patented VCR variable compression ratio

FURTHER ONGOING DEVELOPMENTS TARGETING ADDITIONAL 20% THERMAL EFFICIENCY (43%->50%)

DEDICATED HYBRID ENGINES WITH FEV TECHNOLOGY FOR 2030

TARGETS

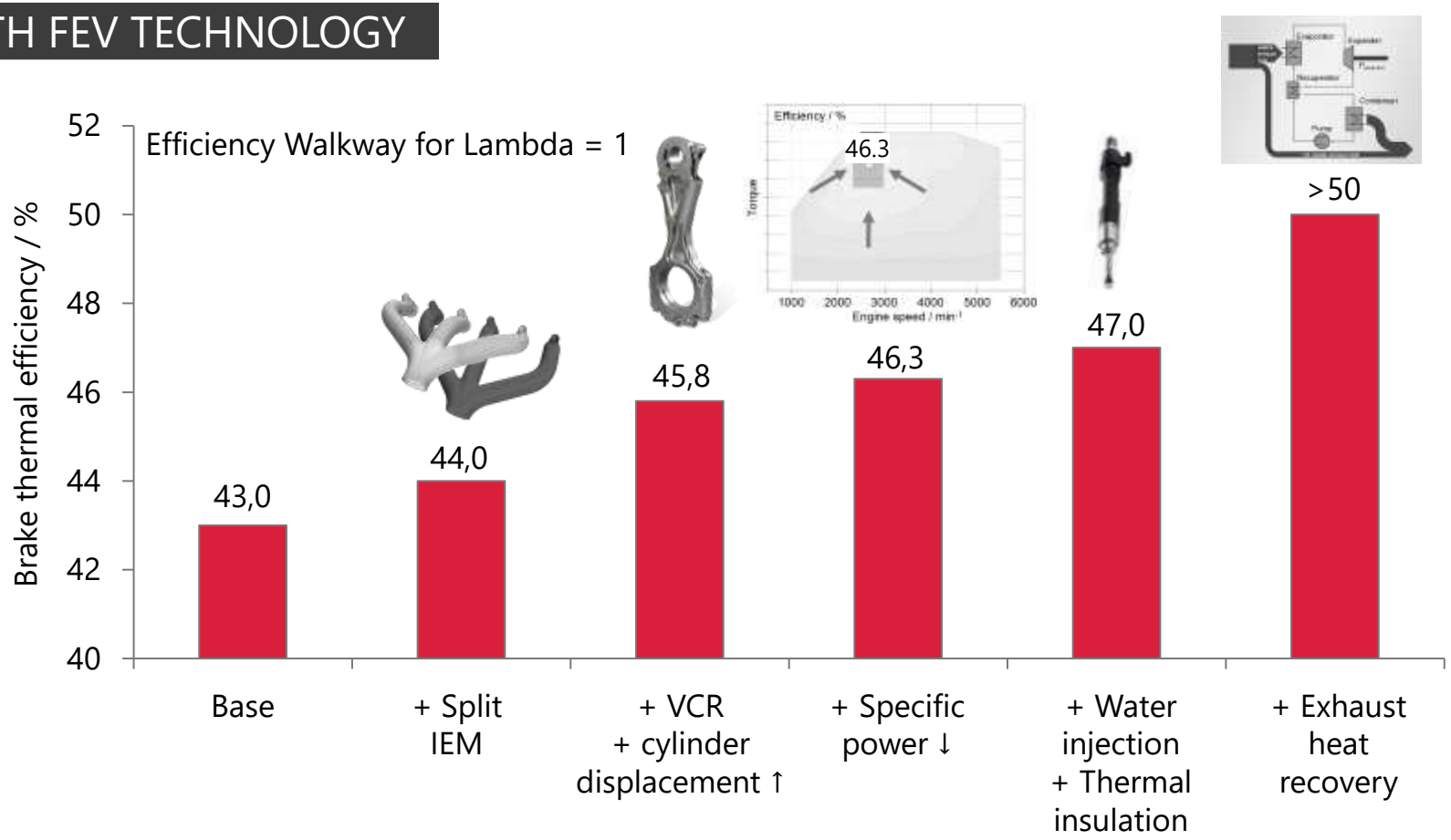
- 50+ % brake thermal efficiency

TECHNOLOGIES

- FEV VCR
- Pre-chamber
- Exhaust heat recovery
- Ultra-low specific power

FEV INVOLVEMENT

- Several projects with FEV VCR system
- Several pre-chamber projects
- One exhaust heat recovery project
- Several water injection projects



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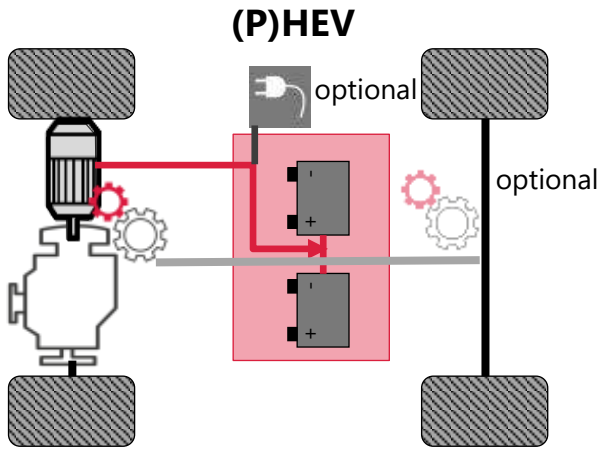
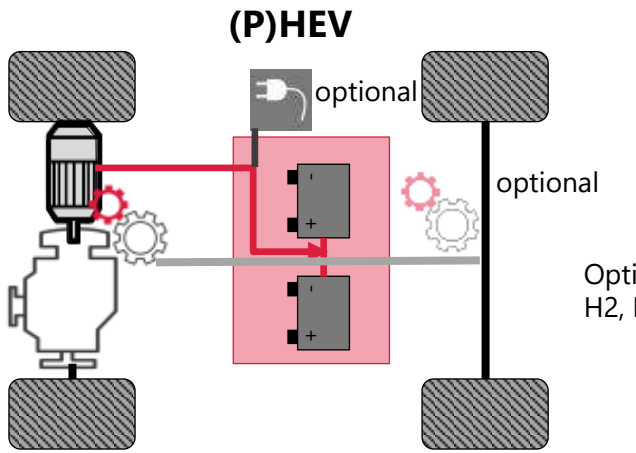
Electrification possible via three different platform approaches
Platform cost reduction to be considered for propulsion system strategy

NUMBER OF PLATFORMS

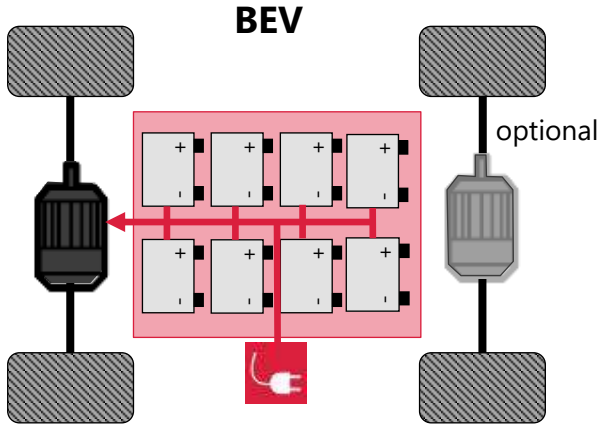
1 „NO BEV“



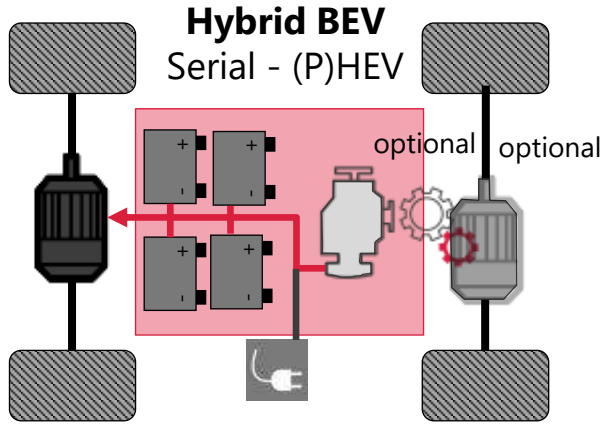
2 „HEV & BEV, 2 PLATFORMS“

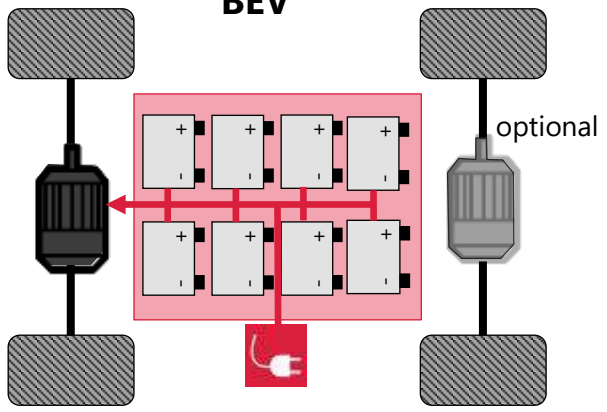


Optional
H2, E-Fuel



1 „HEV & BEV, 1 PLATFORM“





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Rolling chassis
Developed by FEV

MODULAR AND SCALABLE ELECTRIFIED ROLLING CHASSIS DELIVERS DEVELOPMENT BENEFITS

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KEY FINDINGS

Near Zero Impact Pollutant Emissions and Zero CO2 – Is there a future for combustion engine powertrains?

YES!

Pollutant emissions are negligible with EU7 scenarios

- **“zero impact”**

Combustion Engine powertrains are 100% clean and will achieve further efficiency improvements especially with electrification…

…. Nevertheless:

- **BEV will be mainstream in passenger car in 2030-2040 and also relevant for commercial powertrains**
  -> FEV offers unique development capabilities w/ eDLP and CAE
- **Hydrogen is main parallel path beside battery electric vehicles**
  -> FEV offers long term experience in FuelCell and H2-ICE developments
- **Hybrid vehicles w/ highly efficient combustion engines main focus in China and Japan. -> eFuels relevant for certain applications**

- **The FEV “Hybrid BEV” single platform approach for BEV & HEV allows to reduce vehicle platforms cost w/ FEV rolling chassis**

If no further information given gCO2/km relate to WLTP

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