UPCOMING CO2 LEGISLATION FOR COMMERCIAL VEHICLES IN EUROPE AND US

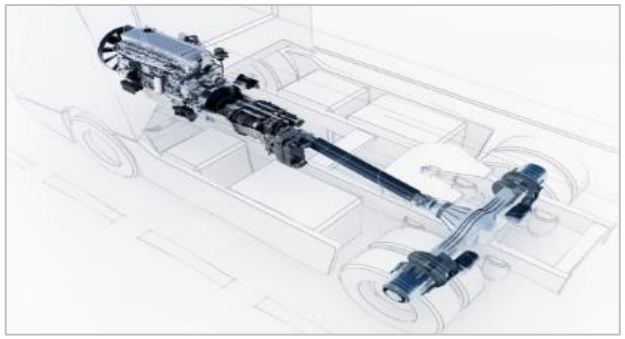
Lukas Walter, AVL

CHALLENGES FOR OUR CUSTOMERS

CO2 Legislation Competition in TCO

Advanced Emission in Emerging Markets

Automated Drivelines



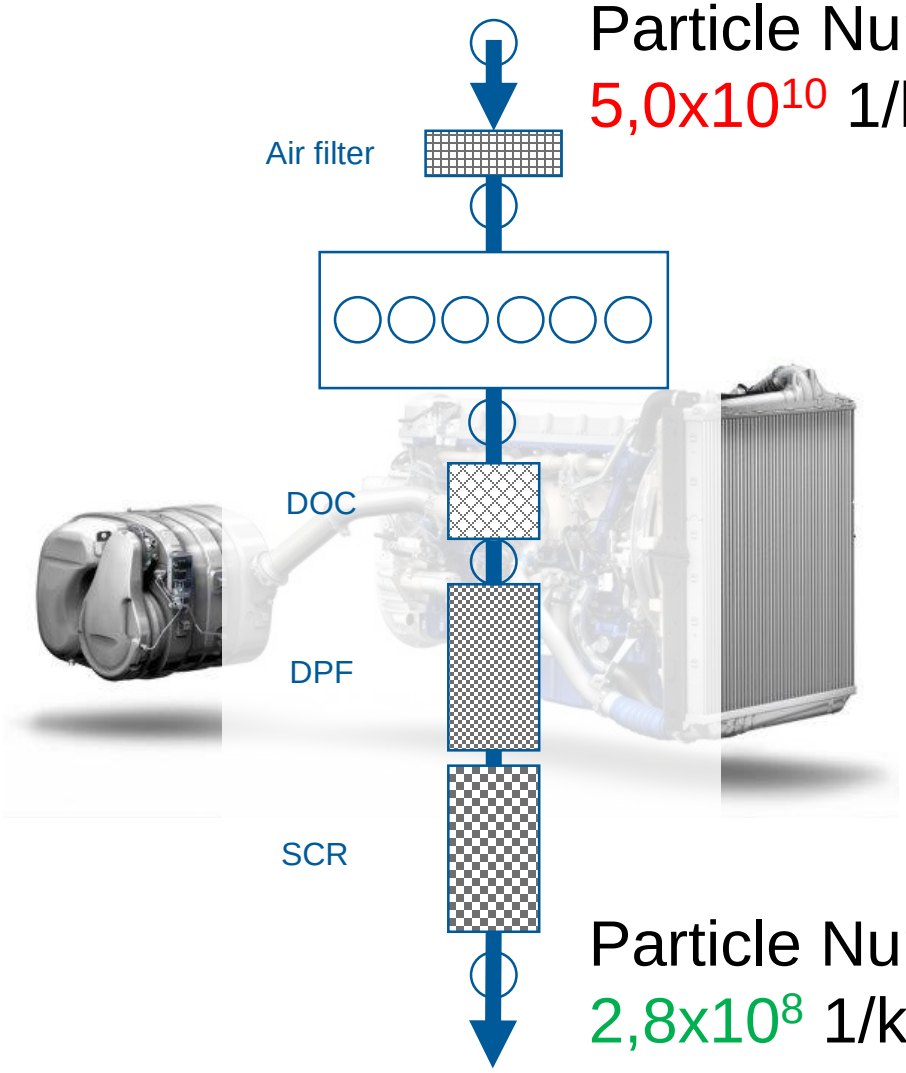
PT System Integration

Connected Driving ADAS

Electrification & Zero Emission CV´s

Shift to new areas and teams
Follow this shift fast

EMISSIONS CURRENT STATUS



Measured with AVL489 Particle Counter

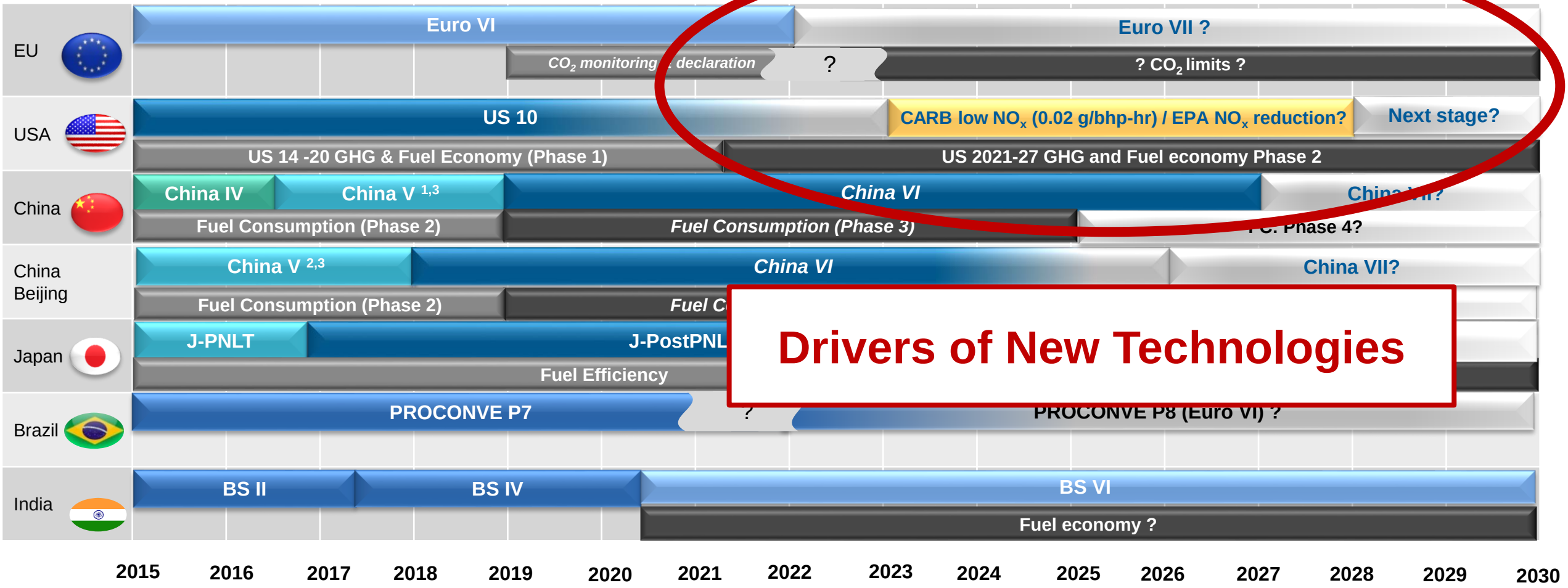
Euro VI close to zero emissions ?

NOx = 0.4 g/kWh
PM = 0.01 g/kWh

Significant further legislation steps upcoming

EMISSION LEGISLATION WORLDWIDE OVERVIEW – HDV – DIESEL

? assumption; *italic proposed/draft available* new type approval if applicable



Drivers of New Technologies

[1] 01/04/2016: municipal vehicles in east China (Beijing, Tianjin, Hebe, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Henan). Municipal vehicles nationwide: 01/01/2017. All HDV nationwide: July 1, 2017
[2] From 2016: new public HDV: DPF
[3] For urban areas: additional WHTC test required

Status: 05/2017

USA EPA CO2 AND FUEL CONSUMPTION PHASE 1 AND PHASE 2 – ENGINE STANDARDS

	MY		~BSFC Minimum g/kWh	BSFC in RMC g/kWh	Heavy Heavy Duty - Tractor
($g\ CO_2$/ hp-hr)	2014-		191	199	475
	2017-	-3%	185	193	460
	2021-	-5%	180	187	447
	2024-	-6%	176	183	436
	2027-		173	181	432

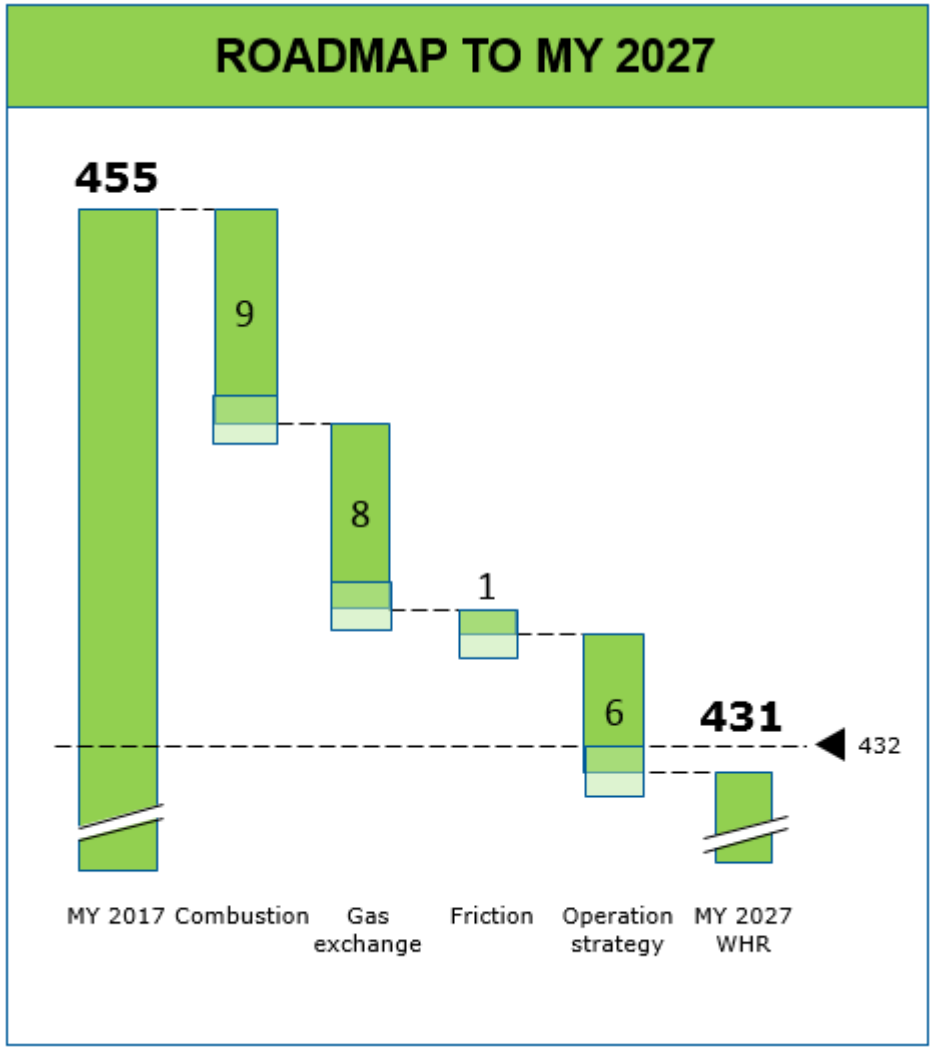
Test cycles: RMC (tractor engines), transient duty cycle (other engines); certification as tractor and vocational engine: both duty cycles.
Reweighting of RMC modes for Phase 2.
CH_4: 0.10 g/hp-hr (transient duty cycle)
N_2O: 0.10 g/hp-hr (transient duty cycle)
LHD: use in Class 2b-5 vehicle, MHD: Class 6-7, HHD: Class 8

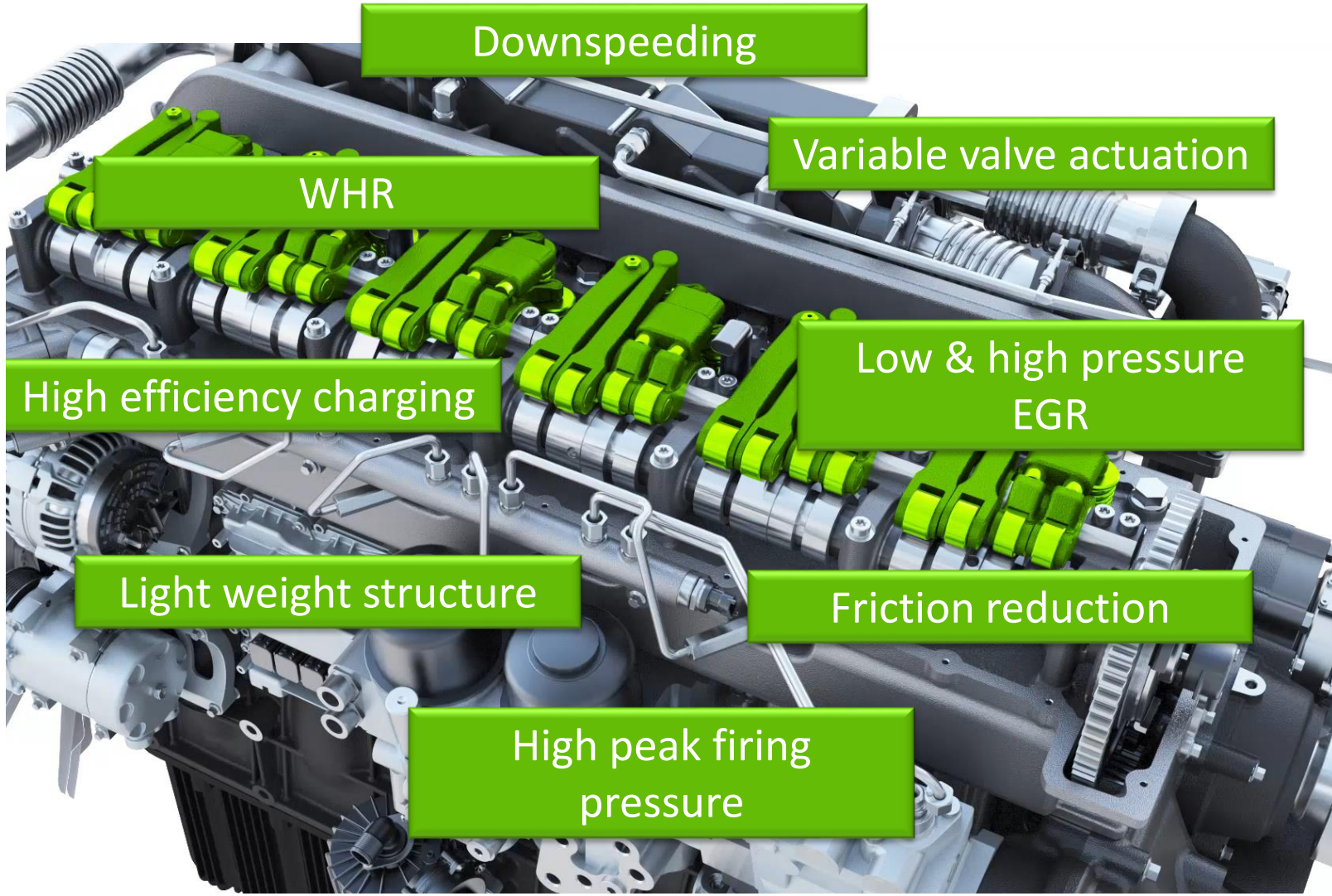
BTE ~ 49%

EMISSION CONCEPTS FOR ULTRA LOW NOX STANDARDS

	No EGR		EGR		
NOx_EO hot	**15 g/kWh**	**10 g/kWh**	**8 g/kWh**	**5 g/kWh**	**3 g/kWh**
	NOx_TP 0.2 g/kWh (incl. 30% margin)				
SCR eff. hot %	99.5	99.5	99.5	99.5	99.5
SCR eff. cold %	92	92	90	85	80
	NOx_TP 0.067 g/kWh (0.05 g/bhp-hr) (incl. 30% margin)				
SCR eff. hot %	99.7	99.7	99.7	99.7	99.7
SCR eff. cold %	98	96	94	89	87
	NOx_TP 0.027 g/kWh (0.02 g/bhp-hr) (incl. 30% margin)				
SCR eff. hot %	99.9	99.9	99.9	99.9	99.9
SCR eff. cold %	99	99	97	94	93

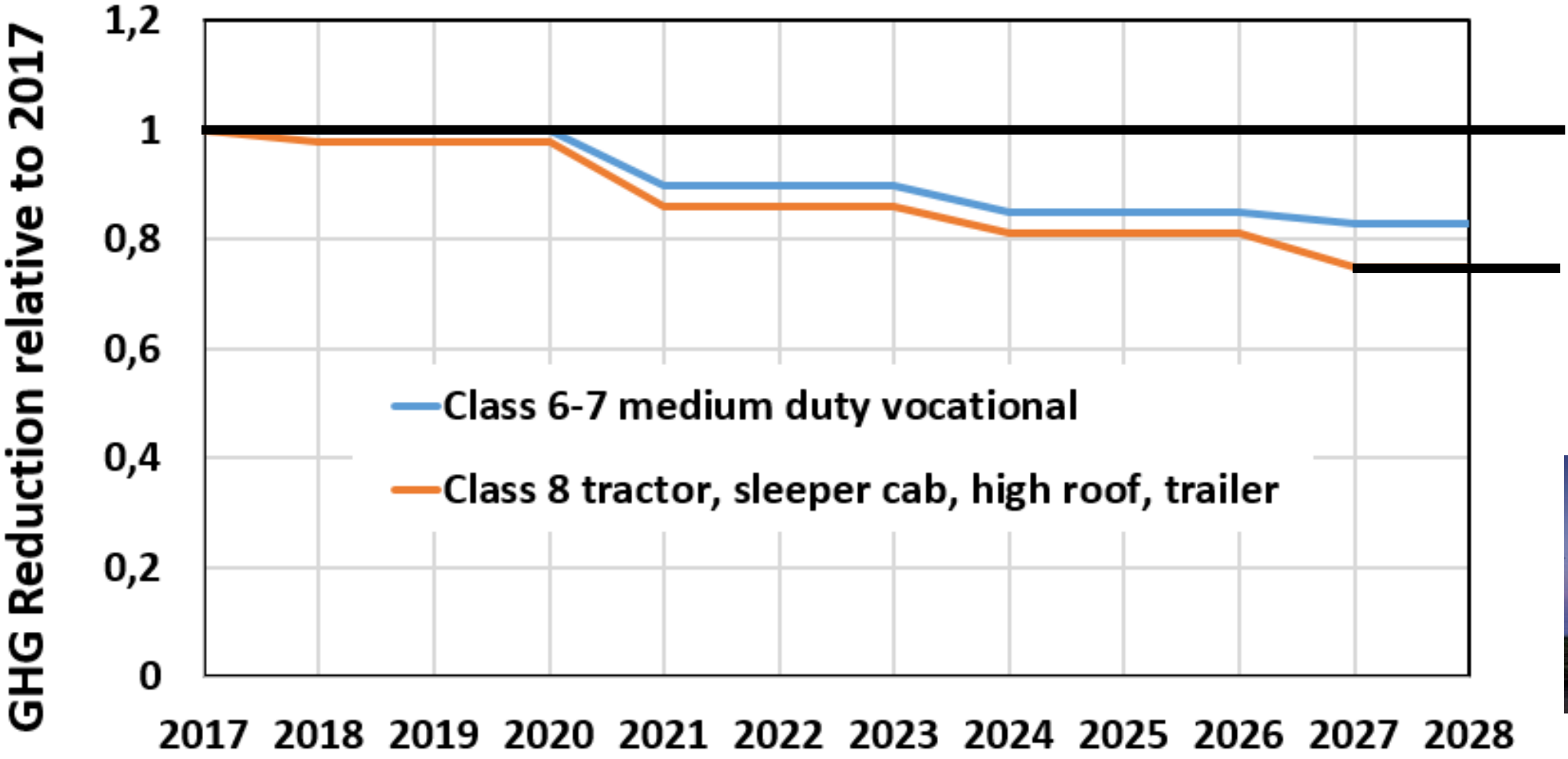
NEXT GENERATION DIESEL ENGINES FOR 2027





Publication: VDI engine congress 2017; Effects of CO2 & Ultra-Low NOx legislation on Commercial Base Engines

GHG REDUCTION REQUIREMENT FOR VEHICLE



-25%

Class 8 applications: -19 to -27%

Source: ICCT

VEHICLE FUEL CONSUMPTION REQUIREMENT

25% GHG

~8-10% **Vehicle aerodynamics**
Rolling resistance
Driveline losses
Mass reduction

~9-11% **Powertrain technologies**
Credits

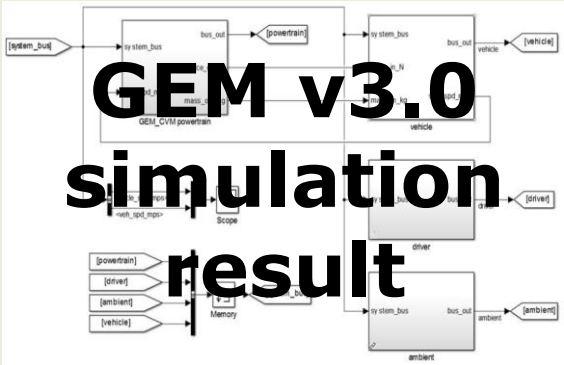
~6% **Engine FC**

US DoE SuperTruck Program

- Engine system demonstration of 50% or greater BTE
- Tractor-trailer vehicle demonstration of 50% or greater freight efficiency improvement

Source: Peterbilt, Volvo, Navistar, Freightliner

GHG PHASE 2 EVALUATION PROCESS



GEM v3.0 simulation result

−

Standard credits

−

Off-cycle credits

=

$$\frac{g}{tonmile}$$

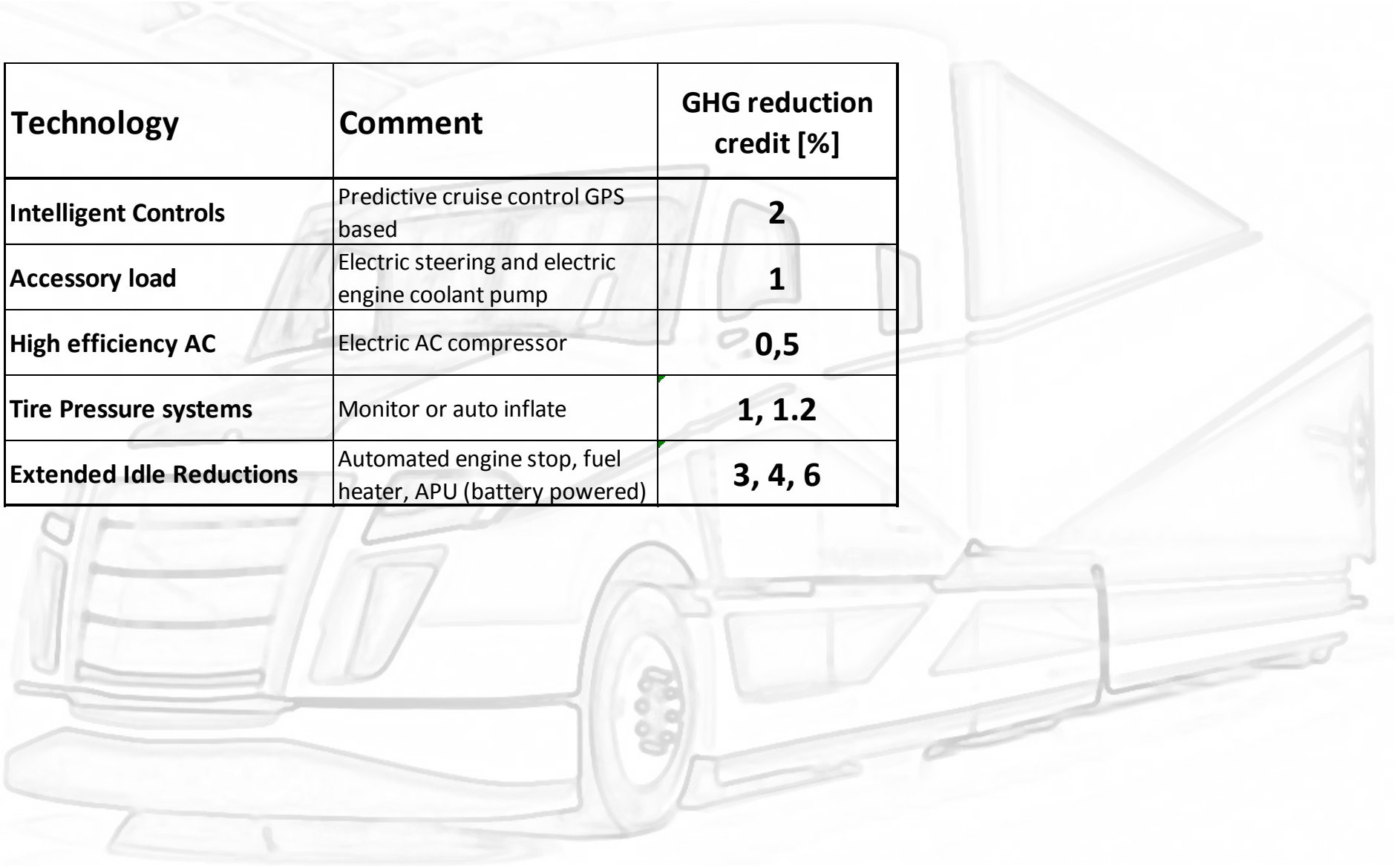
e.g.
- **Engine thermal efficiency**
- **Downspeeding**
- **Driveline efficiency**
- **Weight reduction**
- **Waste Heat Recovery**

e.g.
- **Engine displacement <14L**
- **Intelligent controls**
- **Accessory load**
- **High efficiency AC**
- **Tire pressure system**
- **Extended idle reduction**

e.g.
- **Extended aux. on demand**
- **Predictive thermal mgmt.**
- **Waste Heat Recovery**

GHG PHASE 2 TECHNOLOGY OPTIONS

Technology	Comment	GHG reduction credit [%]
Intelligent Controls	Predictive cruise control GPS based	**2**
Accessory load	Electric steering and electric engine coolant pump	**1**
High efficiency AC	Electric AC compressor	**0,5**
Tire Pressure systems	Monitor or auto inflate	**1, 1.2**
Extended Idle Reductions	Automated engine stop, fuel heater, APU (battery powered)	**3, 4, 6**



GHG PHASE 2 TECHNOLOGY OPTIONS

Technology	Comment	GHG reduction credit [%]	State of the art
Intelligent Controls	Predictive cruise control GPS based	**2**	**2**
Accessory load	Electric steering and electric engine coolant pump	**1**	
High efficiency AC	Electric AC compressor	**0,5**	
Tire Pressure systems	Monitor or auto inflate	**1, 1.2**	**1,2**
Extended Idle Reductions	Automated engine stop, fuel heater, APU (battery powered)	**3, 4, 6**	**3**
Engine displacement <14L	Weight reduction		**0,4**
6x2 configuration		**1.25, 2**	
WHR			
Engine downspeeding			
TOTAL GHG REDUCTION [%]			**6,6**

Need for more advanced technologies

GHG PHASE 2 TECHNOLOGY OPTIONS

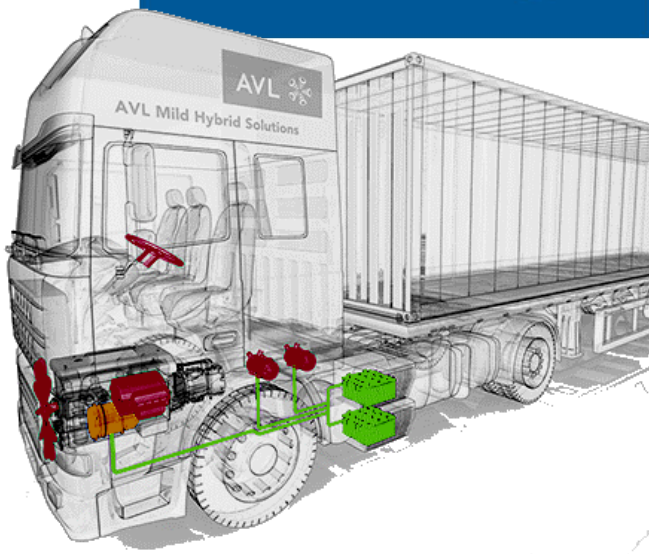
Technology	Comment	GHG reduction credit [%]	State of the art	Mild-Hybrid	WHR	Credit Builder
Intelligent Controls	Predictive cruise control GPS based	2	2	2	2	2
Accessory load	Electric steering and electric engine coolant pump	1		1		1
High efficiency AC	Electric AC compressor	0,5		0,5		0,5
Tire Pressure systems	Monitor or auto inflate	1, 1.2	1,2	1,2	1,2	1,2
Extended Idle Reductions	Automated engine stop, fuel heater, APU (battery powered)	3, 4, 6	3	6	3	6
Engine displacement <14L	Weight reduction		0,4	0,4	0,4	0,4
6x2 configuration		1.25, 2		1,25	1,25	2
WHR					3,5	4,5
Engine downspeeding				1,5	1	1,5
TOTAL GHG REDUCTION [%]			6,6	13,9	12,4	19,1

TECHNOLOGY MAIN ROUTES

25% GHG

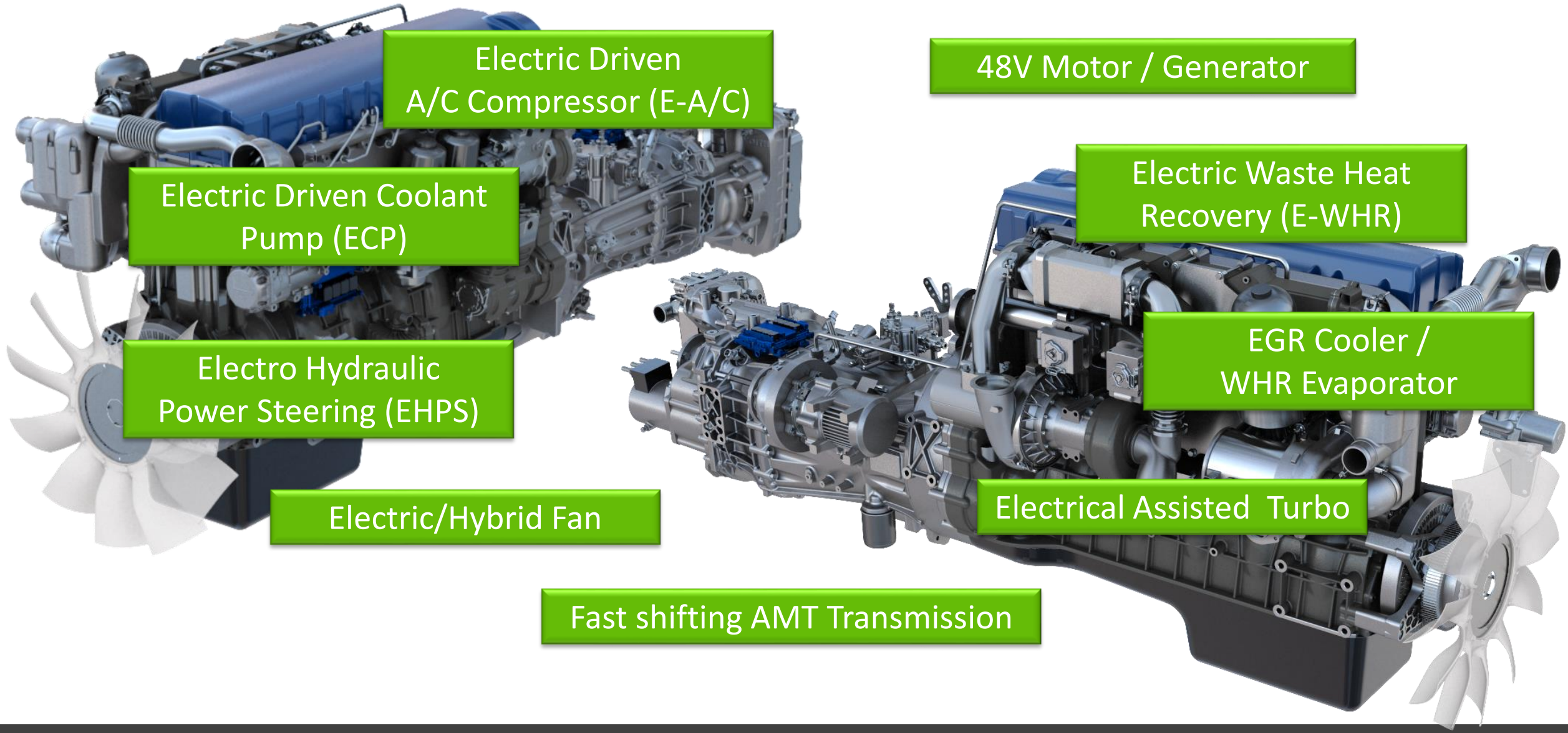
Target
9–11%

Mild-Hybrid
(benefit 13,9%)
Electric auxiliaries
E-boosting
Downspeeding
48V Battery APU

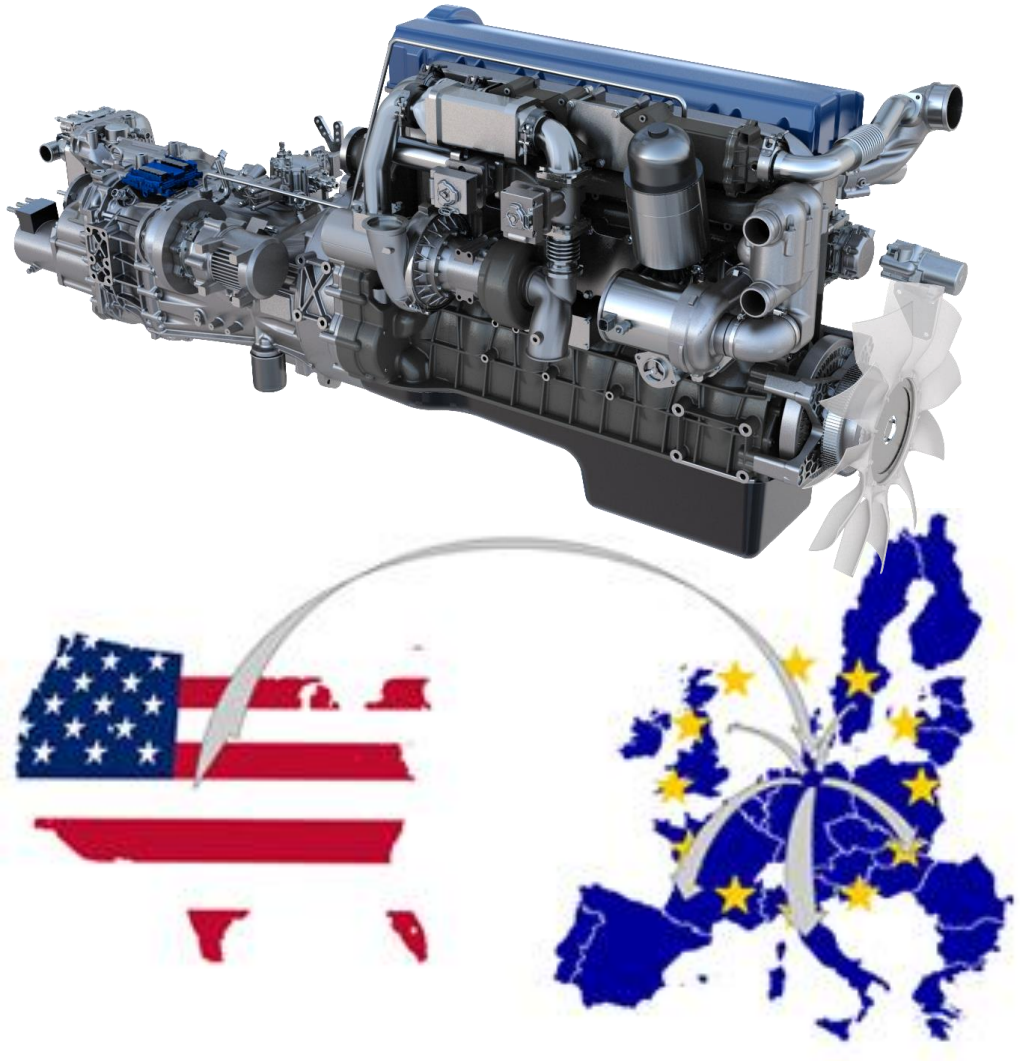


WHR
(benefit 12,4%)
Mechanical
Downspeeding

POWERTRAIN CONFIGURATION FOR FUTURE CO2 LEGISLATION



TRANSFER OF TECHNOLOGIES FROM THE US TO EUROPE



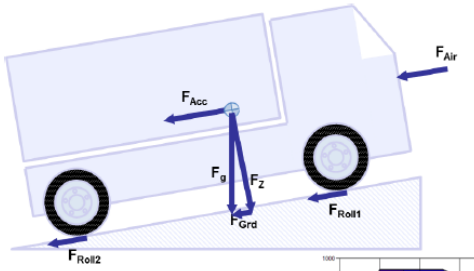
Europe: CO_2 test procedure for HDV

Component test procedures

Model Input

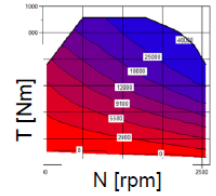
Vehicle	C_d x A, Mass,...
Tires	r_{dyn}, RRC
Gearbox / Axle	Loss maps i_{gears}, max. torque
Engine	Full load curve Fuel map WHTC-Corr. Factors
Air Compressor HVAC Alternator Cooling fan Steering pump	Auxiliaries *generic data for trucks *specific for buses
RESS / Motor	HDH System motor, battery

VECTO
Vehicle Energy Consumption Calculation Tool



$$P_e = P_{Air} + P_{Roll} + P_{Acc} + P_{Grd} + P_{Loss} + P_{Aux}$$

$$n = v \times 60 \times i_{axle} \times i_{gear} \times \frac{1}{D_{wheel} \times \pi}$$



Simulation of power demand, engine speed, fuel consumption, etc. in standardised target speed cycles.

VECTO TIMELINE

CO_2 test procedure for HDV

Already agreed actions for HDV are:

1) Establish a certification system for fuel consumption and CO_2 emissions of HDV.
2) Use results for monitoring and for customer information
3) Develop proposal for CO_2 limits

Comparable systems for trucks yet in US, Japan, China

Timeline EU:

1. Legislation and software for truck shall be finalised in 2017
2. Draft timetable for mandatory CO2 certification:
   - ? / 2018: Long-haul trucks (HDV classes 4, 5, 9, 10)
   - ? / 2019: Other truck classes
   - ? / ?: Coaches and city busses ≥1 year after trucks
3) Study on limit values ongoing.

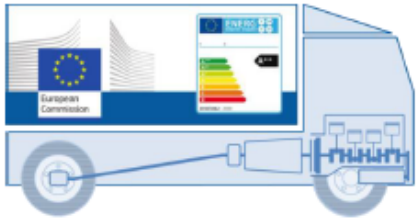
- **Timeline is agreed**
- **Implementation steps for different applications**

SIMULATION METHOD

IVT Institute of Internal Combustion Engines and Thermodynamics — TU Graz

Background of the Selected Method

First study "Lot 2" started with selection and elaboration of the best methodology (2010-2012)



Customer can select between various types of cabin, body or trailer, tires, transmission and engine.

→ Huge variety of component mix in each HDV model

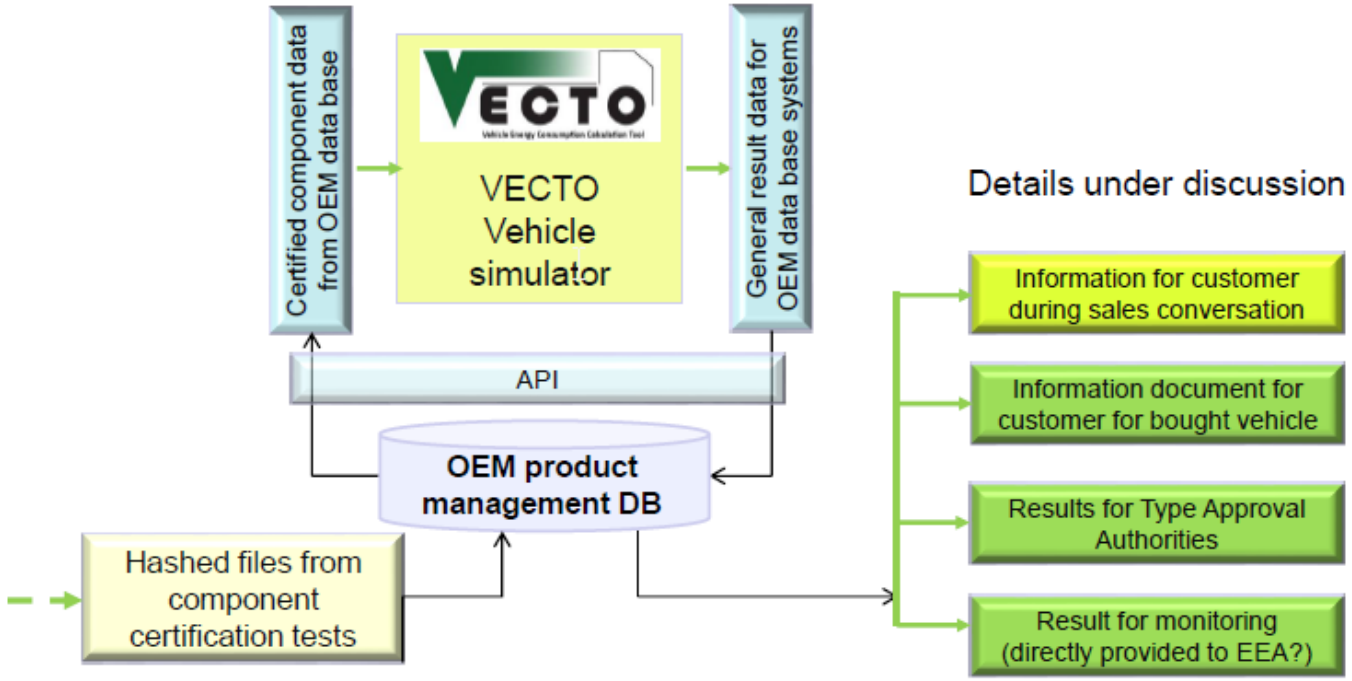
Option	Pro's	Con's
Chassis dyno	Reasonable reproducibility. Vehicle specific control systems for e.g. auxiliary engagement covered.	**Expensive** to test all HDV variants. Systems may be optimised for test conditions.
On-Road	Specific optimisations for test conditions (almost) not possible.	**Poor reproducibility**. Expensive to test all HDV variants.
Engine test	Already established. Good reproducibility.	Other **relevant components** of the HDV **not covered.**
Component test + simulation	**Cost efficient** Good reproducibility Covers most relevant components of the HDV	Vehicle specific control algorithms can hardly be considered. Regular update of methods + software necessary.

- **Selection of method to provide sufficient accuracy and reproducability**

VECTO INTEGRATION IN OEM SYSTEMS

Concept of Data Handling

For efficient data handling VECTO can be linked to OEM specific IT system by "API" that just translates data base values into VECTO input structures.



Hashes are passed through entire system to ensure traceability

- **First real back-to-back comparison between vehicles**
- **Future tool for truck sales organization**

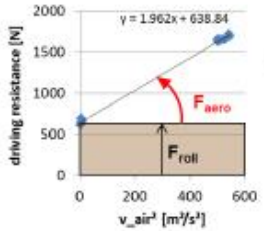
VECTO COMPONENT TESTING

IVT Institute of Internal Combustion Engines and Thermodynamics — TU Graz

Component testing

Norm body

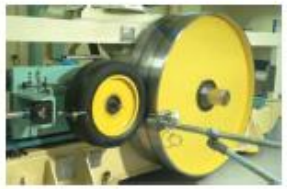
Constant speed test with „standard body“ and/or trailer. Measure torque at wheels and air speed.



Slope=ρ/2 x C_d x A

Tires

Drum test according to regulation EC1222/2009



Specific tire label value e.g. 4.51 kg/ton

Gearbox

Axle

Loss map options:
1) default values
2) measured idle losses
+ calc. torque dependency
3) Complete measurement

Map for losses for each gear

Engine

Engine test bed acc. R49: WHTC, full load curve, motoring curve and steady state fuel map

**Fuel map,
Full load, motoring curve
WHTC correction factors**

IVT-EM AVL TechTrends 23.03.2017

20

- **How to create reproducible component input**
- **Extensive component testing**

MODELLING PARAMETERS CONSIDERED IN VECTO

VECTO
Vehicle Energy Consumption Calculation Tool

TODAY:

- Vehicle class
- Axle and chassis configuration
- Maximum gross vehicle weight
- Engine maps including transient correction
- Transmission, torque converter
- Axle
- Air drag
- Tire
- Auxiliaries:
  - Engine cooling fan
  - Steering pump
  - Electric system
  - Pneumatic system
  - AC system
  - Transmission power take off (PTO)

FUTURE DISCUSSED:

Short term:

- Improved alternator
- Wide base singles
- Tire pressure monitoring
- Improved oil pumps
- Vehicle speed limiter

Mid term:

- PACC
- WHR
- Electric hybrids
- Electric TC
- A/C efficiency
- Active flow systems
- DCT
- Neutral idle

Long term:

- Cooling fan
- Air compressor
- Vehicle body redesign
- Adjustable fifth wheel
- CVT
- Hydraulic hybrids
- ECU/Engine software optimization

GEM v3.0

Mid-term plan considers the Mild-hybrid and WHR technologies

Credit Builder
2
1
0,5
1,2
6
0,4
2
4,5
1
18,6

COMPLEX SCENARIO FOR OEMS

Vehicle

Technology Balancing

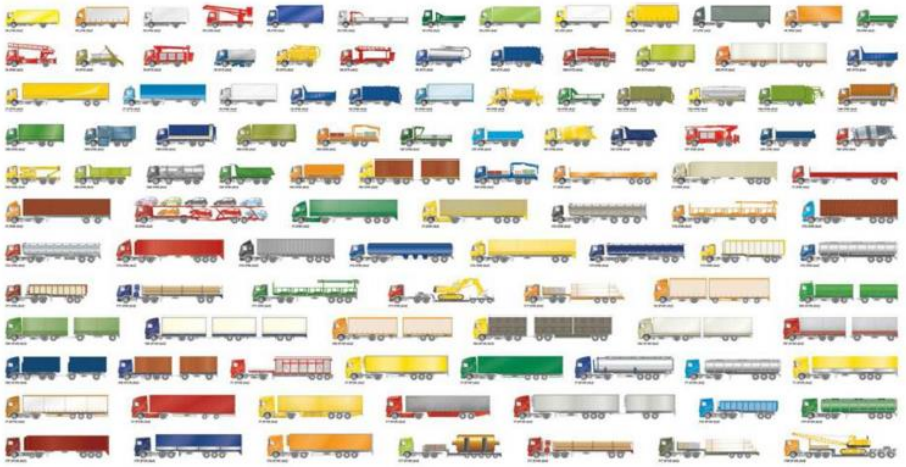
Powertrain

Technology Balancing

Engine

When ?

2021, 2024, 2027



ABT

Averaging, banking and trading

ACEA proposal Vehicle segmentation trucks ≥ 7.5 t

	Identification vehicle configuration			Class	Cycle allocation Vehicle configuration / weight / axle loads					Body/ trailer allocation	
	Axle configuration	Chassis configuration	weight***	Vehicle Class	Long haul	Regional delivery	Urban delivery	Municipal utility	Construction	Standard Bodies (B) / Standard Trailer (T) / Standard Semitrailer (ST)	Buses and coaches have separate table
2 axles	4x2	Rigid + (Tractor*)	7.5t - 10t							B1	
		Rigid + (Tractor*)	> 10t - 12t							B2 T1	
		Rigid + (Tractor*)	> 12t - 16t							B3	
		Rigid	> 16t							B4 T2	
		Tractor	> 16t							ST1	
	4x4	Rigid	7.5t - 16t								
		Rigid	> 16t								
		Tractor	> 16t								
3 axles	6x2/2-4	Rigid	all							B6 T2	
		Tractor	all							ST1	
	6x4	Rigid	all						R (7,15)**	B6** T2**	
		Tractor	all						+ ST (12,96)**	ST1**	
	6x6	Rigid	all								
		Tractor	all								
4 axles	8x2	Rigid	all	(15)	exclude 8x2 (very low sales volume < 1%)						
	8x4	Rigid	all	16					R (12,96)**	(generic CdxA)	
	8x6/8x8	Rigid	all	(17)	exclude all-wheel-drive vehicles (sales volume < 1%)						
EMS 2 axles	4x2	Tractor	all		T+ST+T (28t)	T+ST+T (18.7t)	ST1-v2 T2			T2 ST1-v2*	
EMS 3 axles	6x2/ 6x4	Rigid	all		R+D+ST (28t)	R+D+ST (18.7t)	B6 D+ST1-v2			B6 ST1-v2*	
		Tractor	all		T+ST+T (28t)	T+ST+T (18.7t)	ST1-v2 T2			T2 ST1-v2*	

R=Rigid+Body; Tr=Tractor; B=Body; T=Trailer; ST=Semitrailer; D=Dolly; (x, xt)=payload; (po)=payloadcurve over GVW; * ST1-v2=ST1 (use ST1 data)

* Tractors are treated as Rigids but with specific curb weight of tractor. Airdrag and weight/payload for semitrailer as for Rigid (simplification)

** construction vehicles with generic CdxA

*** Weight is maximum gross vehicle weight

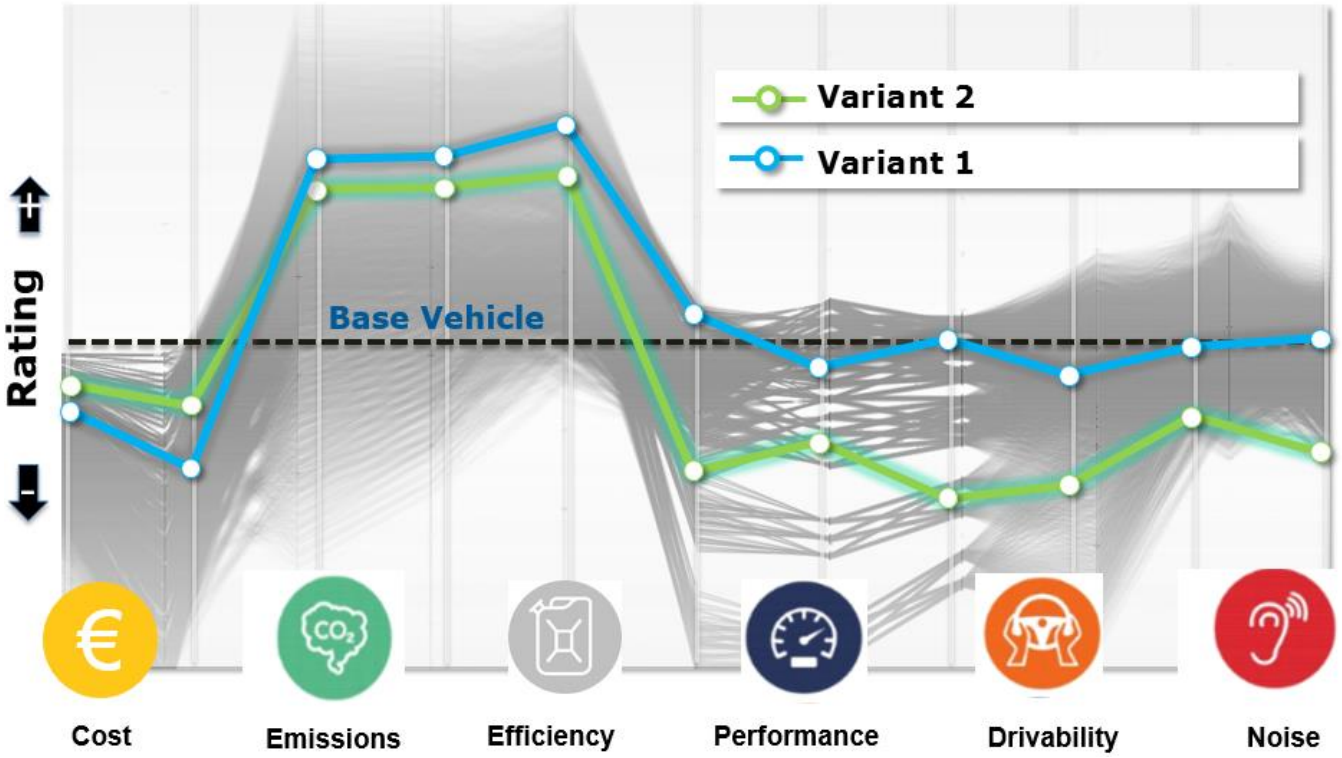
Introduction 2018

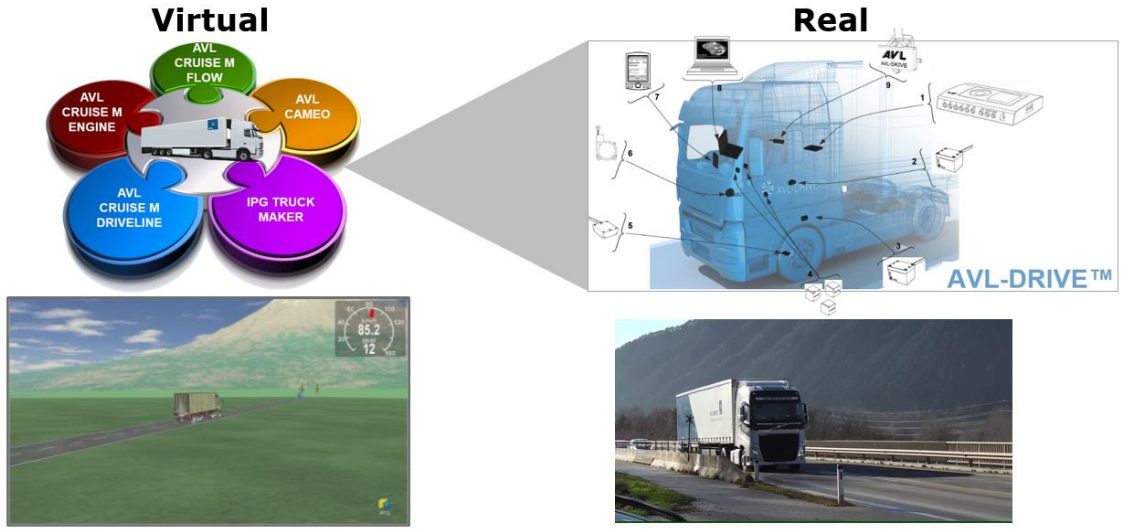
Source: ACEA white book

Weighting Factors for Duty Cycles

	Distance-weighted			Time-weighted [1]			Average Speed During Non-idle Cycles (mi/hr) [2]
	Transient	55 mi/hr Cruise	65 mi/hr Cruise	Drive Idle	Parked Idle	Non-idle	
Day Cabs	19 %	17 %	64 %	-	-	-	-
Sleeper Cabs	5 %	9 %	86 %	-	-	-	-
Heavy-haul tractors	19 %	17 %	64 %	-	-	-	-
Vocational—Regional	20 %					%	38.41
Vocational—Multi-Purpose (2b-7)	54 %					%	23.18
Vocational—Multi-Purpose (8)	54 %					%	23.27
Vocational—Urban (2b-7)	92 %					%	16.25
Vocational—Urban (8)	90 %					%	16.51
Vocational with conventional powertrain (Phase 1 only)	42 %	21 %	37 %	-	-	-	-
Vocational Hybrid Vehicles (Phase 1 only)	75 %	9 %	16 %	-	-	-	-

MODEL-BASED ATTRIBUTE BALANCING FOR END CUSTOMER VALUE



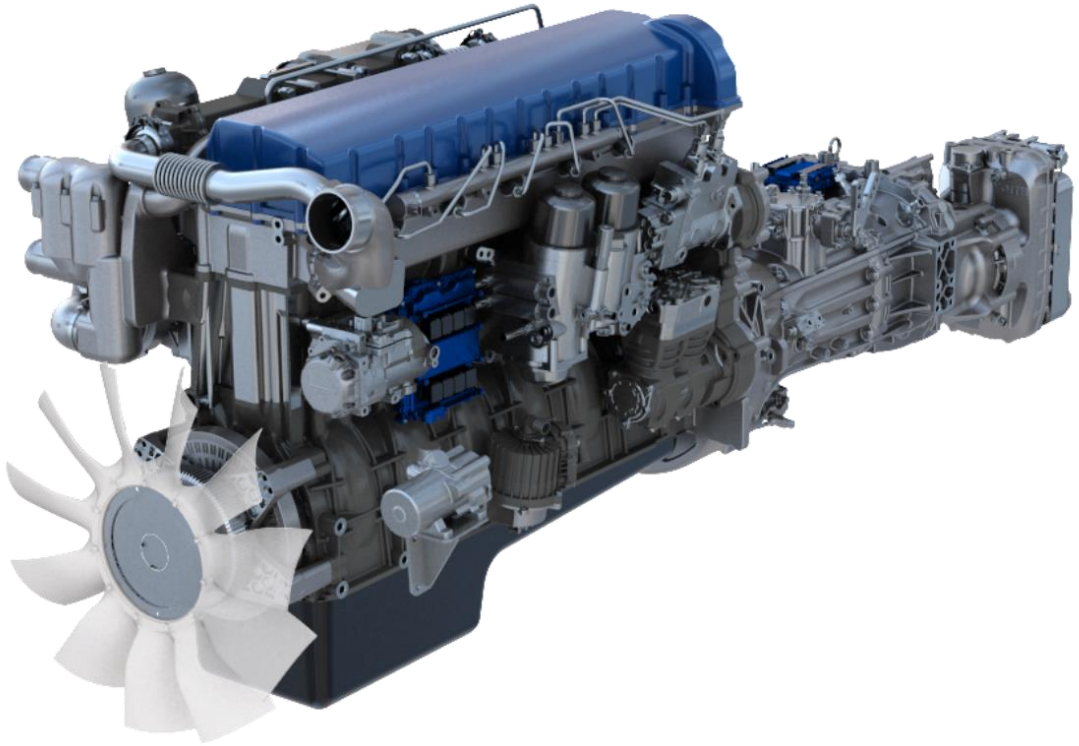


AVL Model-Based Development Platform

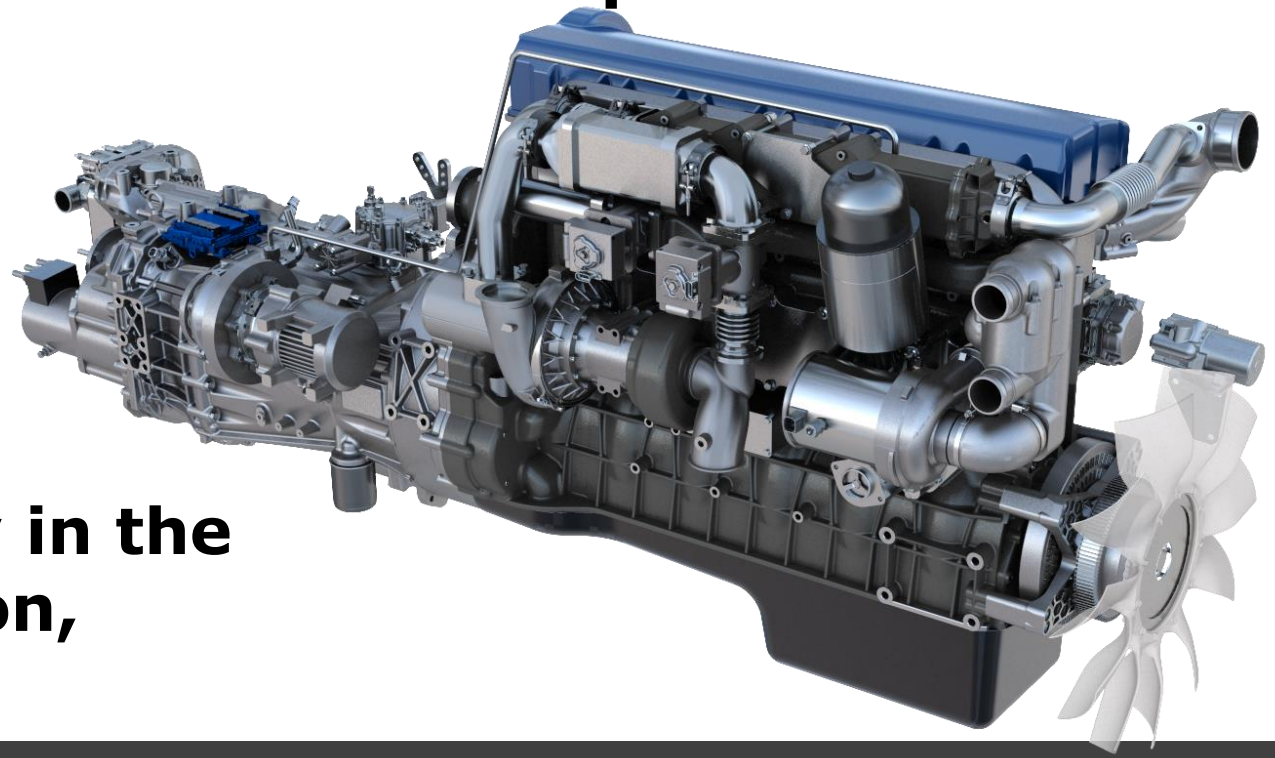
Published in 2015 at 8th AVL International Commercial Powertrain Conference

Attributes balanced in virtual environment

SUMMARY

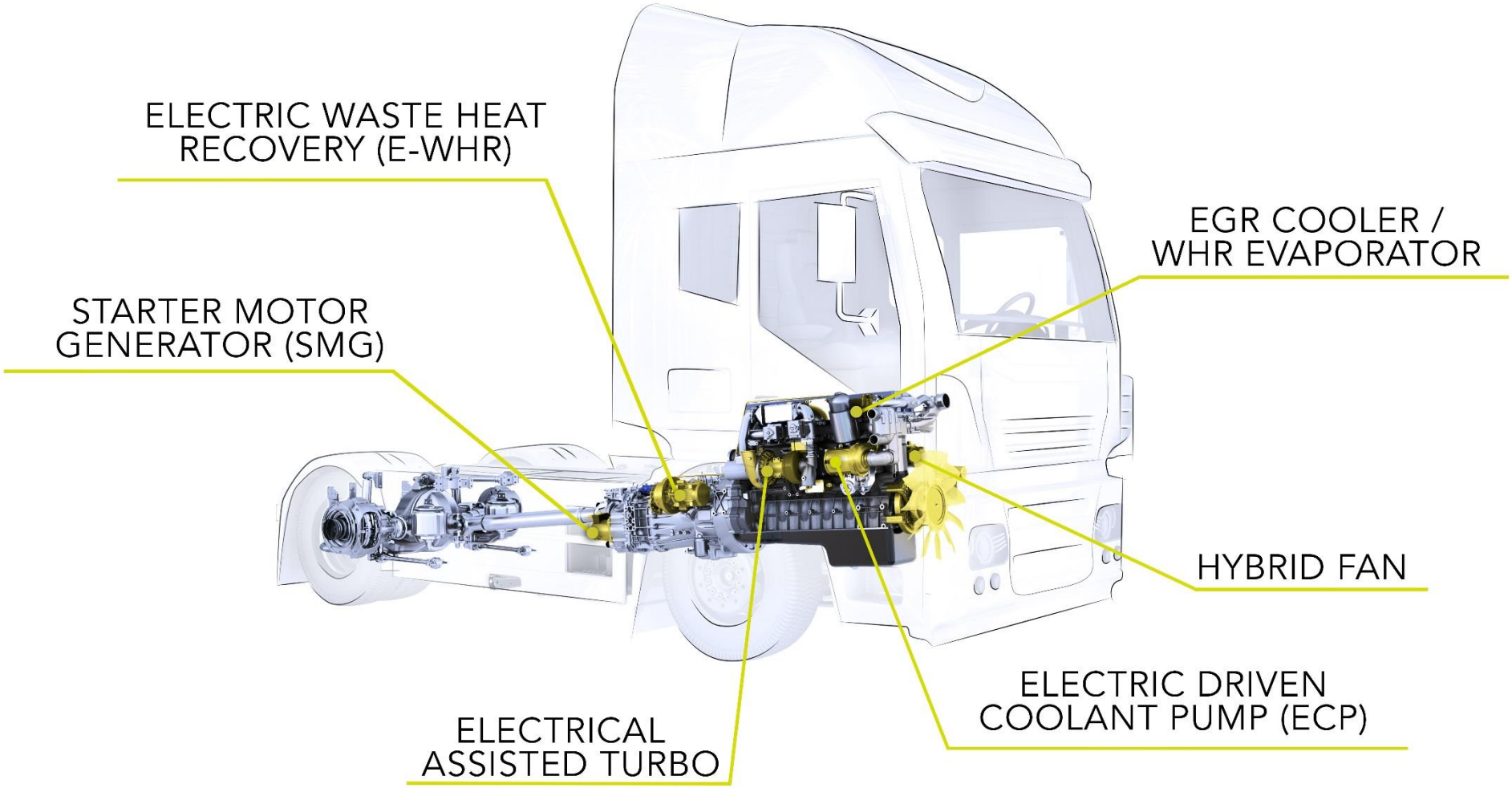


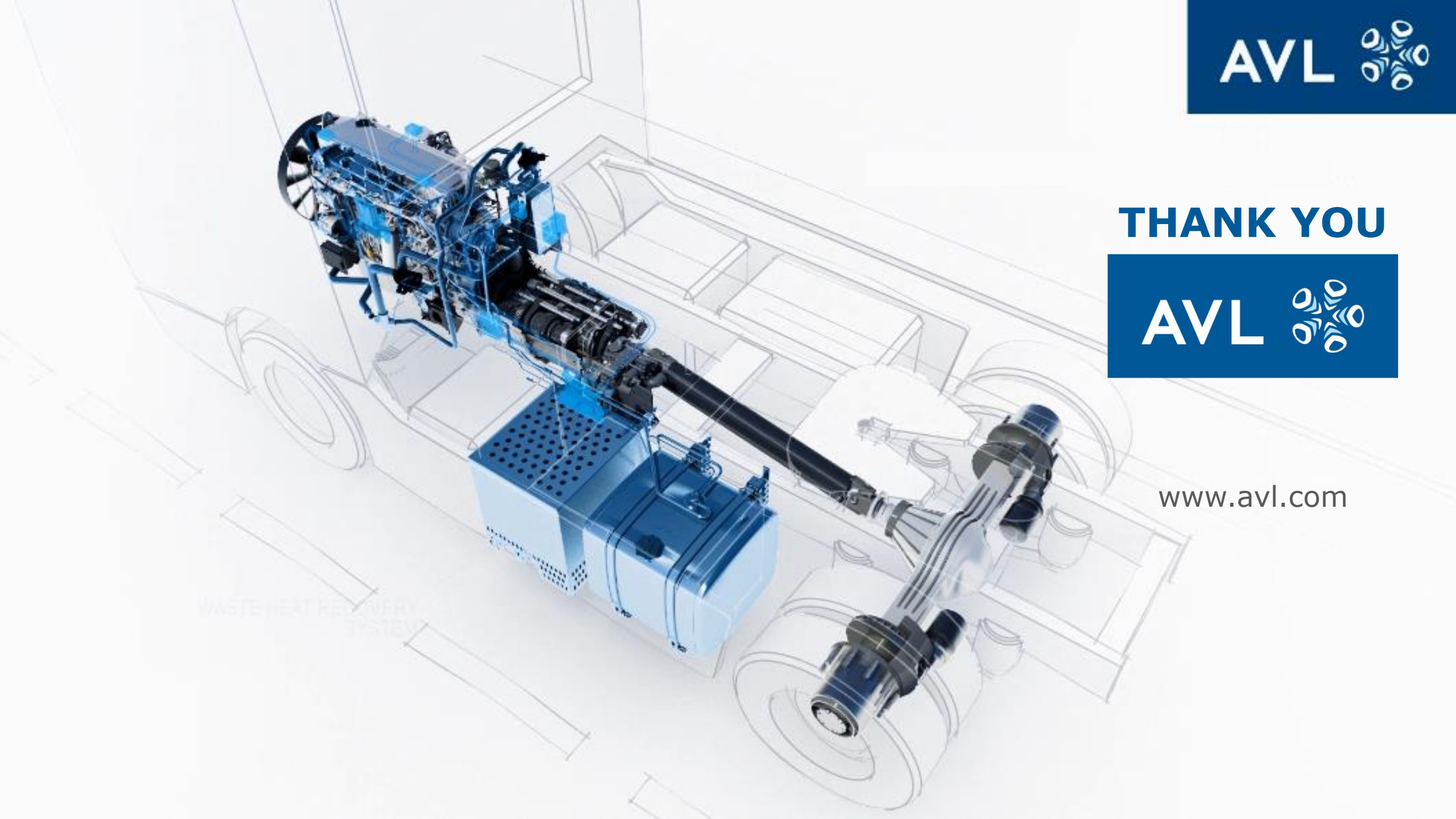
- **Two main routes are establishing, Mild-hybrid and WHR**
- **Technologies are available**
- **Legislation environment will be much more complex for OEMs**



AVL has invested significantly in the preparation for such legislation, technology and methodology!

PLEASE USE THE OPPORTUNITY TO LOOK AT THE INTEGRATION MODEL





THANK YOU

www.avl.com