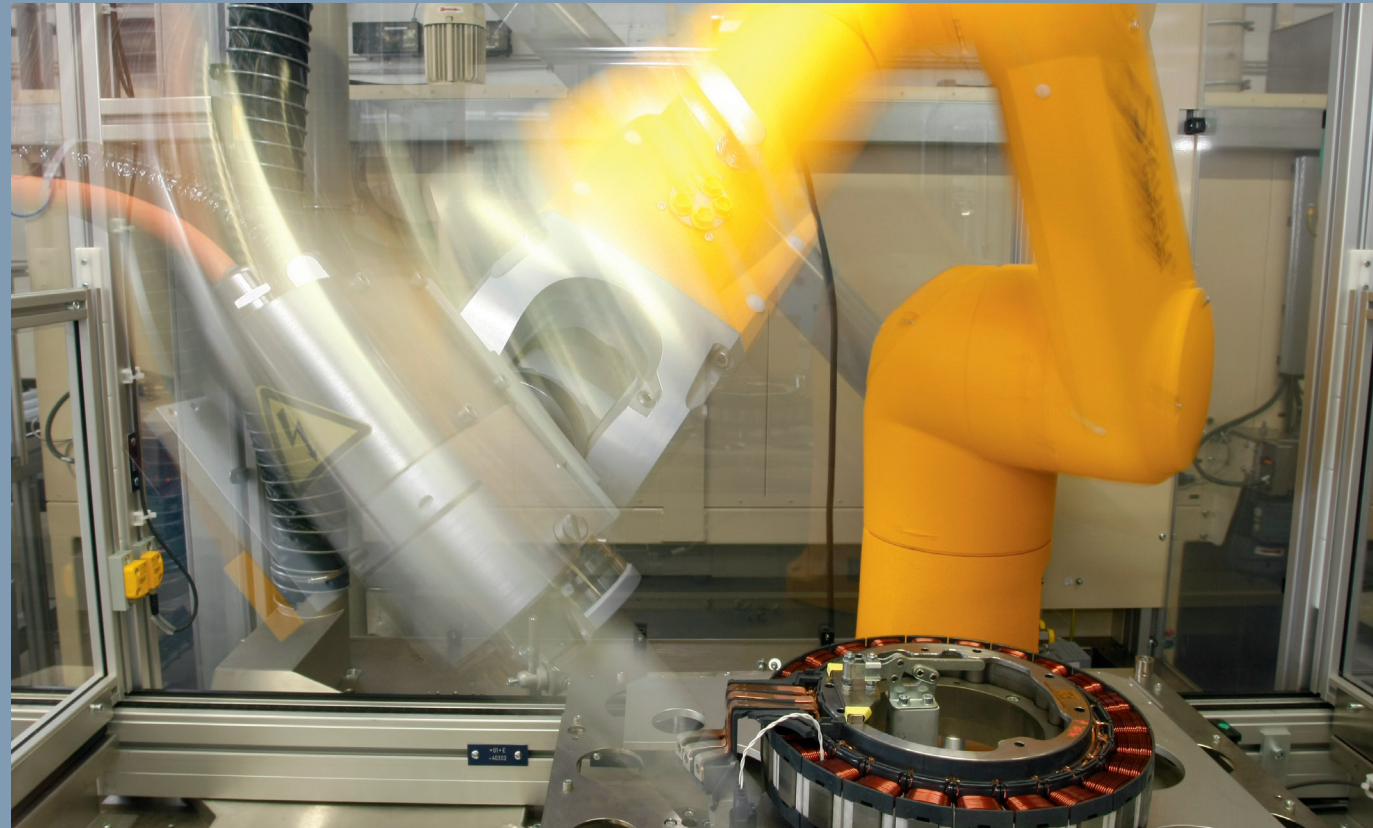


Antrieb im Wandel

Die Elektrifizierung des Antriebsstrangs von Fahrzeugen und ihre Auswirkung auf den Maschinen- und Anlagenbau und die Zulieferindustrie

Executive summary



Bildquelle: ZF Friedrichshafen

In Kooperation mit



Prepared for
VDMA – Forum Elektromobilität



ANTRIEB IM WANDEL – AUSWIRKUNGEN DER ELEKTRIFIZIERUNG DES ANTRIEBSSTRANGS AUF DEN MASCHINEN- UND ANLAGENBAU



Frankfurt am Main, March 1st 2018
FEV Consulting GmbH



- Conclusions and study approach
- Passenger car market
- Commercial vehicle market
- Non-road mobile machinery
- Follow-up services
- Contacts

This study analyzes value creation in three vehicle categories: Passenger cars, commercial vehicles and non-road mobile machinery

CONCLUSIONS FOR MACHINERY AND COMPONENT SUPPLIERS



- Additional value creation by electrified powertrains, advanced technology application and increasing vehicle sales can overcompensate reduction in conventional powertrain area (1.7% CAGR¹⁾ of manufacturing process²⁾ related value creation for passenger cars by 2030)
- The combined number of combustion engines³⁾ in Europe, USA and China is expected to decrease by approx. 10% between 2016 and 2030; in terms of total sales volume China is expected to remain largest market for conventional powertrains
 - There is still a substantial business potential for supplier of components and machines in the field of conventional powertrains
 - Business models and the allocation of internal resources must be adapted to a decreasing ICE market to ensure profitability
 - Suppliers of components and machines should consider to intensify business in the Chinese market by analyzing if sales and/or production activities need to be set-up or intensified in the Asian region
- For the majority of combustion engines an increase of complexity is expected due to application of advanced engine technologies
 - Opportunity for additional revenue streams requiring continuous improvement of existing competencies and capabilities in order to gain or remain in technology leadership position
- Market volume of components for electrified powertrains (both hybrid and pure electric powertrains) will significantly increase
 - Market players should identify their individual opportunities to participate in growing markets by utilizing existing core competencies and capabilities and dedicated build-up of new know-how
- In 2030 battery cell production accounts for 14 billion Euro²⁾ (approx. 10% of overall manufacturing process related value creation)
- The market development scenarios outlined in this study analyze expected vehicle sales. However, the impact on product development and manufacturing planning for suppliers of components and machines is expected to occur earlier in time
 - The business transformation process should already be ongoing or initiated immediately to foster leadership position and exploit the potential of additional business

1) CAGR = compound annual growth rate; 2) excl. material costs, overhead, profits; 3) sum of conventional and hybrid powertrains for pass. car, commercial vehicle, mobile machinery
Source: FEV

Increased powertrain complexity and market growth in China is expected to compensate decrease in value creation due to shift to electric powertrains

KEY TAKEAWAYS – PASSENGER CAR



Market	<ul style="list-style-type: none">■ In the base scenario key implications regarding powertrain electrification for the three analyzed markets, Europe, USA and China, are:<ul style="list-style-type: none">– A region average battery electric vehicle sales share of 22% is expected in year 2030, while in China a share of 29% is expected– In Europe and USA passenger car sales volume is assumed to remain almost constant on year 2016 level; in China increasing sales to 32 million units by 2030; Combined CAGR¹⁾ in the three markets of 1.5%
Machinery Industry	<ul style="list-style-type: none">■ In 2030, the manufacturing process effort (excl. battery cell production) for electric/electrified powertrains compared to a “standard” powertrain (combustion engine incl. 48 V mild hybrid system) is:<ul style="list-style-type: none">– Pure electric powertrain approx. 60% less manufacturing process effort– Plug-in hybrid powertrain approx. 25% more manufacturing process effort■ Combined EU, USA and China manufacturing process related value creation increases by a CAGR¹⁾ of 1.0%* (accelerated scenario) to 1.7%* (base scenario) – key reasons:<ul style="list-style-type: none">– Strong Chinese market growth and increased powertrain complexity in all markets, over-compensating the reduction related to the shift to pure electric powertrains
Component Supplier	<ul style="list-style-type: none">■ Reduction of conventional powertrain components results from shift to pure electric powertrain, in addition, reduction of average cylinder count from 4.3 to 4.0 by 2030 is expected (average of Europe, USA and China)■ Conventional powertrain efficiency technologies and electrification increase the complexity and require enhanced production processes as well as new competencies; trend towards automated transmissions (AT, DCT) in Europe■ For hybrid and pure electric powertrains 43 million units of electric traction motors are expected in year 2030

*excl. value creation of battery cell production (11 billion € in 2030); 1) CAGR = compound annual growth rate
Source: FEV

Electrification is driven by light commercial vehicles – moderate growth of manufacturing process related value creation (CAGR of 0.5%) is expected

KEY TAKEAWAYS – COMMERCIAL VEHICLES



Market

- In the base scenario key implications regarding powertrain electrification for the four analyzed commercial vehicle segments, light, medium and heavy duty as well as city bus are:
 - In Europe 27% of all newly registered commercial vehicles are expected to be battery electric vehicles by 2030, in China a share of 37% and in USA of 6% is expected
 - Light commercial vehicle applications (LCV, <6 tons) are the key driver for pure electric powertrains, as the business case is expected to become attractive with decreasing battery costs for many use cases
 - City Bus applications as well as selected use cases for medium duty vehicles (MCV, 6 to 16 tons) are expected to become attractive with regards to total cost of ownership (TCO)
 - Hybridization typically shows high fuel economy benefit in use cases with low annual mileage, hence, the total fuel cost savings are moderate and further benefits are required for business case to become attractive

Machinery Industry and Component Supplier

- Change of value creation in the analyzed commercial vehicle segments is dominated by LCV, as those are counting for more than 90% of the total hybrid and electric applications (approx. 5.2 million units in 2030)
 - Electric powertrain approx. 50 to 60% less manufacturing process effort (year 2030)
- Combined EU, USA and China manufacturing process related value creation is expected to increase by a CAGR¹⁾ of 0.1%* (accelerated scenario) to 0.5%* (base scenario) – key reasons:
 - Moderate market growth in Europe and China (constant for USA) and increased powertrain complexity by hybridization in all markets are compensating the reduction related to the shift to pure electric powertrains
- However, manufacturing process related value creation of conventional powertrain components is decreasing by a CAGR¹⁾ of 0.6% (China) to 0.9 % (Europe) in the base scenario

*excl. value creation of battery cell production (2.5 billion € in 2030); 1) CAGR = compound annual growth rate
Source: FEV

Electrification in the NRMM segment is expected to be moderate – key driver are cost competitiveness and increased productivity

KEY TAKEAWAYS – NON-ROAD MOBILE MACHINERY (NRMM)

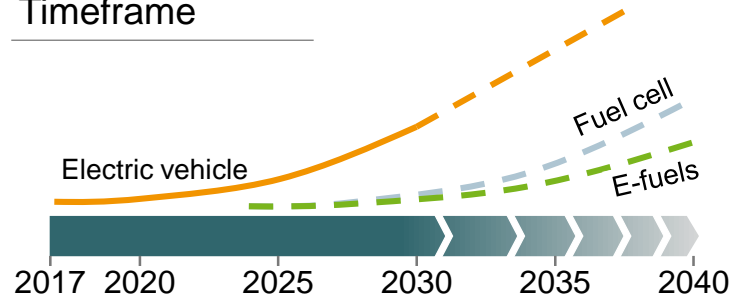


- Objectives of NRMM analysis within this study:
 - FEV and VDMA jointly decided to focus on developing electrification forecasts for six different vehicle segments within the NRMM category: Tractors (small / large), Excavators (small / large), Wheel Loaders (small / large)
 - Analysis of electrification on the value manufacturing process related value creation was not conducted
- Key results:
 - In the NRMM segment main driver for innovations of the powertrain such as electrification is reduction of total cost of ownership and/or improved productivity combined with regulatory compliance
 - In terms of TCO battery electric powertrains are not expected to become competitive for the majority of use-cases in the analyzed segments; BEVs expected only in selected applications
 - Hybrid powertrains are expected to become cost (TCO) competitive in the excavator and wheel loader segment due to substantial fuel consumption reduction potential; in the tractor segment hybridization is driven by electrification of implements
 - It is expected that construction equipment is not significantly impacted by zero emission zones by 2030
 - In comparison to on-road vehicles boundary conditions for NRMM use cases (e.g. long operation hours over useful life, dust, high temperatures, etc.) pose challenges regarding durability of electric propulsion components
 - Electrification is expected to be moderate in the analyzed segments: Up to 5% hybrid market share for small tractors, excavators and wheel loaders in EU and USA; 10% - 15% hybrid market share for large tractors, excavators and wheel loaders in EU and USA; up to 8% electric (battery or cable) market share in China

Source: FEV

Focus of the study

Timeframe



- Focus of the study: 2030 timeframe
- Post 2030 further technology trends could change the powertrain systems and have an impact on the automotive supply chain:
 - Fuel cell technology and alternative fuels might play a major role; also autonomous driving is expected to have substantial impact
 - Battery (cell) innovations such as solid state batteries can further drive the electrification trend

Vehicle systems










- Focus of the study: Powertrain system
- Further vehicle systems such as Chassis, Body in White, Interior and Exterior are expected to change with future vehicle technology trends and the influence of new mobility solutions
- Key trends: Autonomous driving, weight reduction, safety, new features

Market regions



- Focus of the study: Europe (EU-28), USA, China
- Further markets are expected to transition towards electrified powertrains
- Emerging market such as India are expected to become more relevant
- Japan potentially leads the fuel cell development pursuing a “hydrogen society”

Overview of vehicle segments considered and analyzed in this study

	Passenger cars	Commercial vehicles			Non-road mobile machinery		
	Passenger cars	Light commercial vehicles	Medium commercial vehicles	Heavy commercial vehicles	Tractors	Excavators	Wheel loaders
Gross vehicle weight (GVW)	0 - 3.5 ton	0 - 6 ton	> 6 - 16 ton	> 16 ton	N/A	N/A	N/A
Vehicle examples							
Market volume (EU+USA+CN)	54.7 million	7.6 million	0.5 million	1.2 million	0.6 million	0.08 million	0.12 million
Comment	For EU and China all vehicles registered as passenger cars (M1) are considered; for USA all light-duty vehicles (< 8,000 lbs. GVW)	For EU and China all vehicles registered as LCVs (N1) are considered; for USA all Class 2b - Class 5 commercial vehicles	-	-	Applications from 19 - 150 kW (rated engine power) are considered		

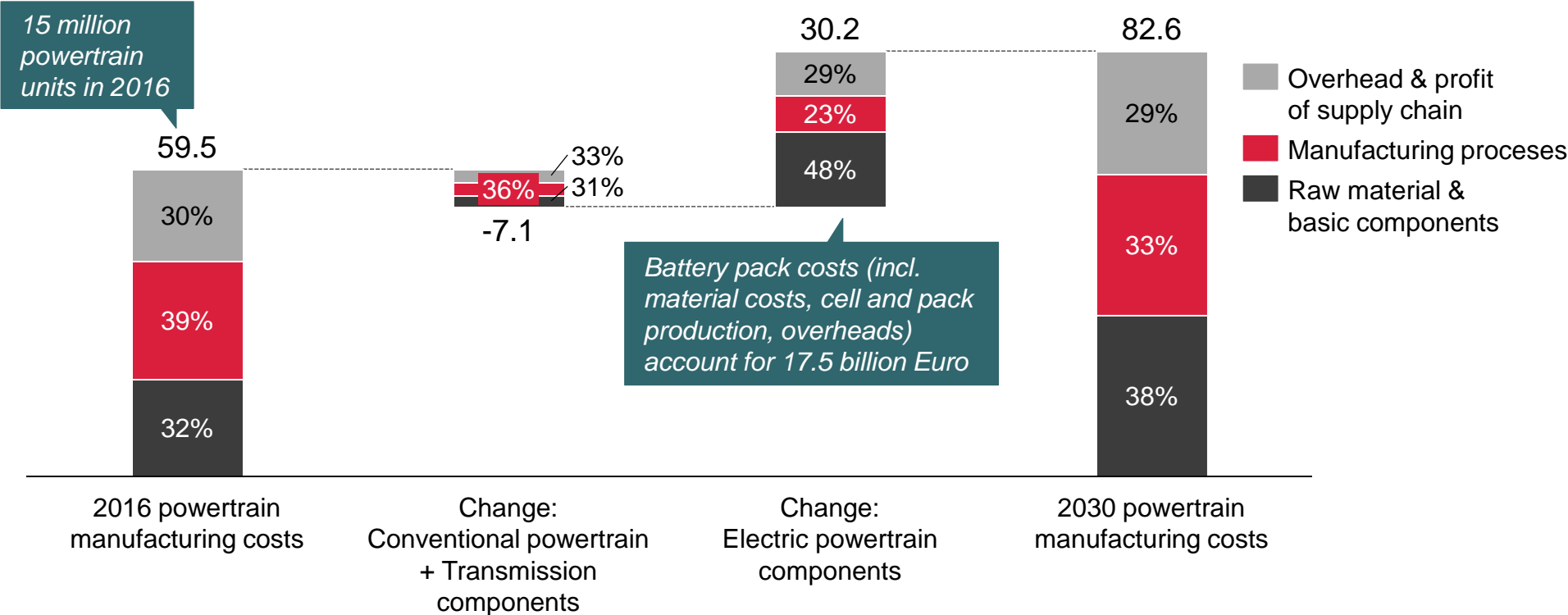
Focus of this study are manufacturing process costs of powertrains, which include direct labor costs as well as costs for machines and tools

CASE EXAMPLE



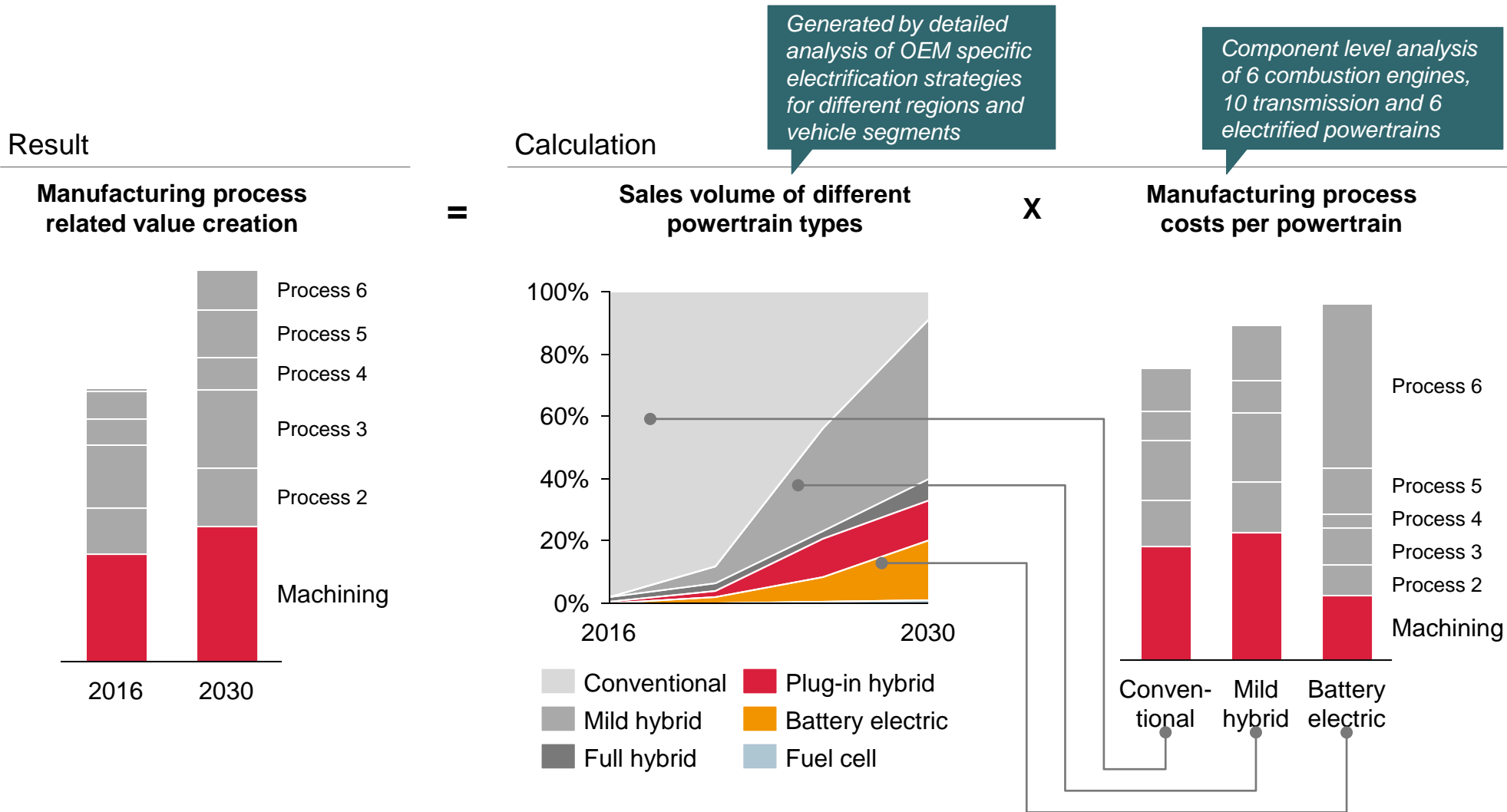
Total manufacturing costs for powertrains sold in EU passenger car market

in billion Euro



Note; 15 million powertrain units in 2030 assumed (22% of powertrains without combustion engine);
Conventional powertrains include combustion engine, intake and exhaust system, tank and cooling system, transmission, differential,
Electric powertrains include electric motor, battery, power electronics, charging system (if applicable) and cooling
Source: FEV

FEV calculated changes in value creation by combining the manufacturing process effort of different powertrains with their sales volume forecast



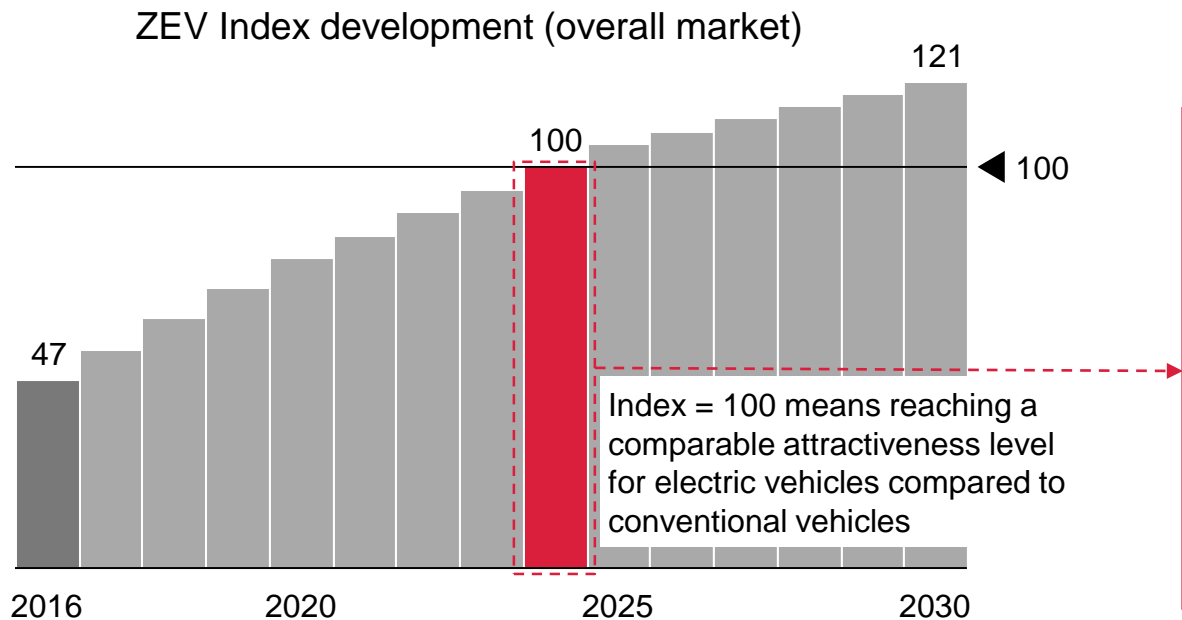
- Conclusions and study approach
- **Passenger car market**
- Commercial vehicle market
- Non-road mobile machinery
- Follow-up services
- Contacts

By 2024 FEV expects boundary conditions for the European passenger car market, in which an electric vehicle will be competitive

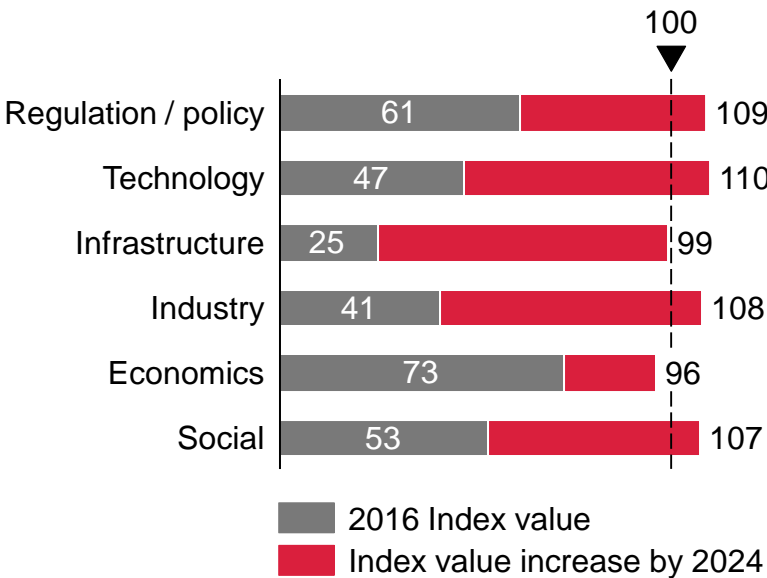
ZEV Index for USA and China available in the full report



ZEV INDEX FORECAST – EUROPE – PASSENGER CAR – BASE SCENARIO



2024 ZEV Index by dimension*



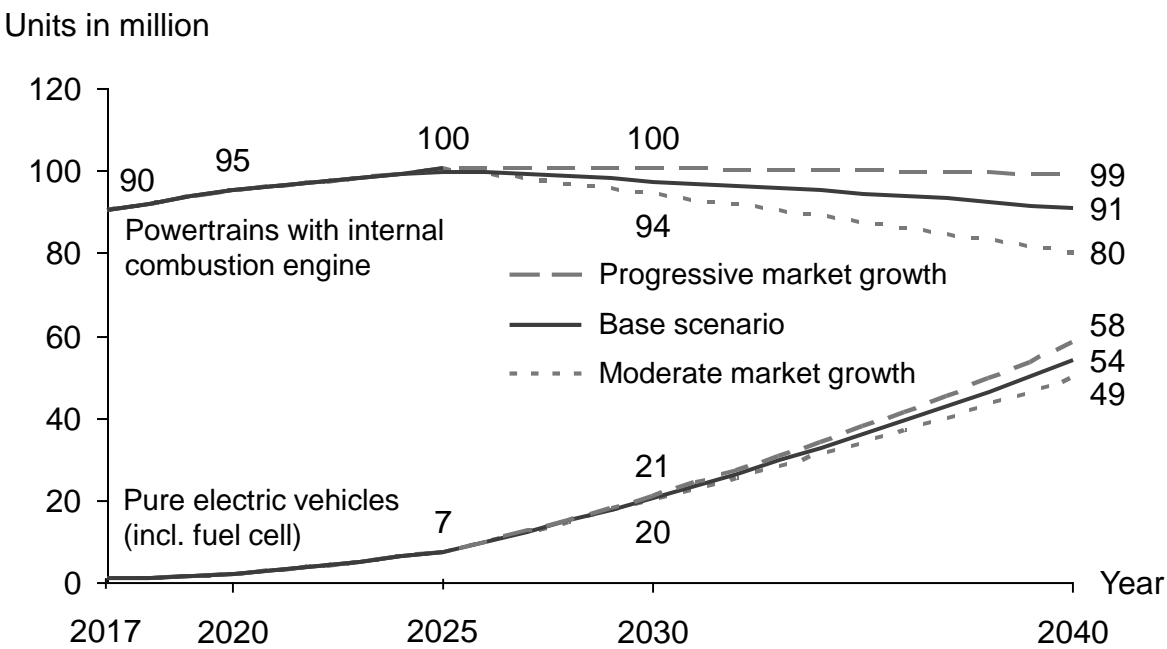
- Some dimensions will drive the BEV competitiveness, while others are expected to lag behind
 - Battery technology as well as the industry (in terms of available xEV models) are expected to be on track by 2024
 - Also a broad acceptance of xEVs across the majority of population is expected (index “social”)
 - CO₂ fleet emission target for 2025 and anticipation of first zero emission zones result in above-average regulation index for 2024
 - Insufficient infrastructure and battery cost forecast result in below-average index values for infrastructure and economic

*each dimension is weighted individually for the calculation of the overall ZEV Index
Source: FEV

Global sales volumes of internal combustion engines are expected to reach their peak in the 2025 – 2030 timeframe before declining in 2030+



Global light-duty* vehicles sales forecast



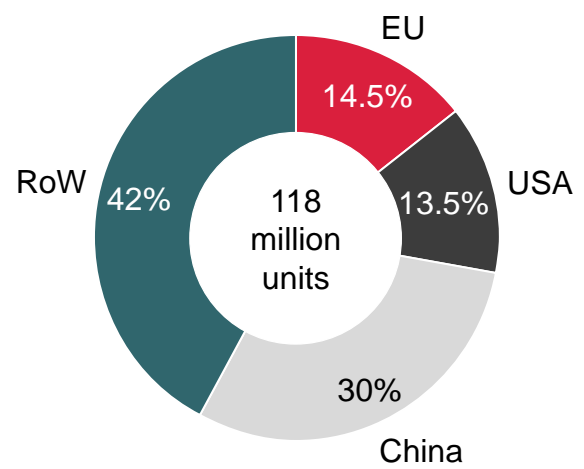
- Three scenarios were considered reflecting different market growth after 2025:
 - US and EU: Close to constant market volume in all scenarios
 - China and RoW: Market growth in all scenarios; extend varying between 1.5% - 4% CAGR depending on scenario
- Rel. share of electrified vehicles constant in all scenarios (FEV base scenario)

*including passenger cars and light commercial vehicles up to 3.5t gross vehicle weight
Source: FEV

Focus of this study

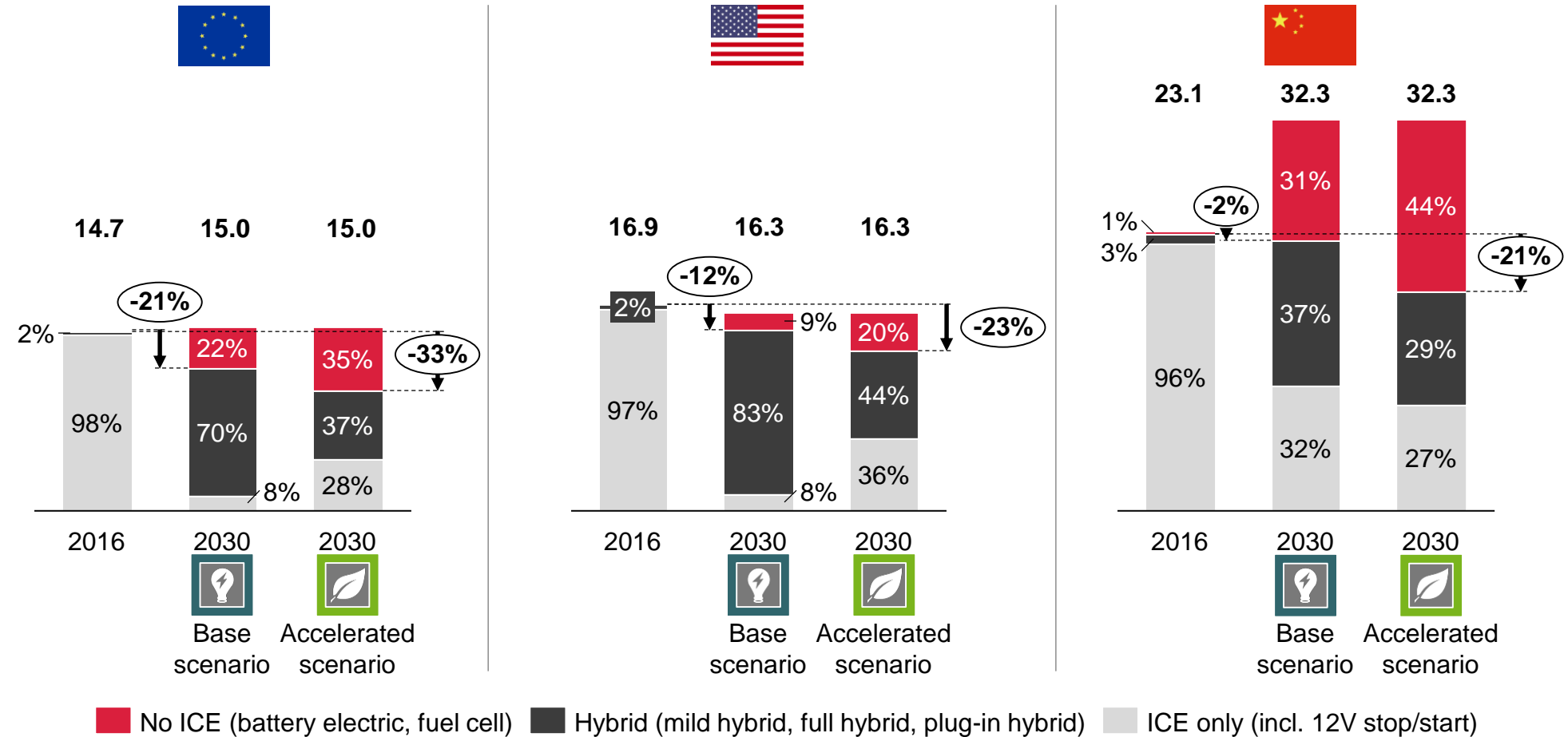
- In this study the impact of electrification **from the current status until 2030** is analyzed
- Focus of this analysis is on the **three main automotive markets EU, USA and China** accounting for 58% of global sales in 2030

2030 light-duty* vehicles sales (base scenario)



Compared to 2016 sales of combustion engines (ICEs) are expected to decline in all three markets EU, US and China in the 2030 base scenario

PASSENGER CAR: SALES OF POWERTRAIN TYPES IN MILLION UNITS



Source: FEV

Compared to 2016 sales of combustion engines (ICEs) are expected to decline in all three markets EU, US and China in the 2030 base scenario

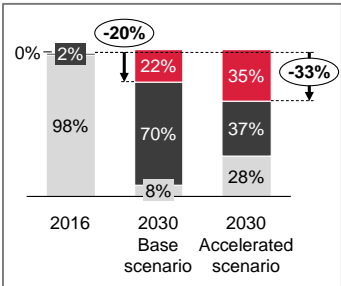
PASSENGER CAR: SALES OF POWERTRAIN TYPES IN MILLION UNITS

Detailed market forecast
for electrified powertrain
types in the full report



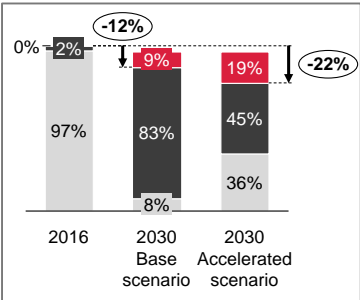
- In EU a substantial market share of electric vehicles (BEV) is expected
- In the accelerated scenario battery costs are expected to be lower (65 €/kWh) compared to the base scenario (90 €/kWh); additionally charging infrastructure is assumed to be denser and customer acceptance of BEVs is assumed to be higher
- The high share of BEVs in the accelerated scenario means that OEMs don't need to sell hybrid vehicles for regulatory compliance

(CO₂ fleet emissions) anymore and hence focus on less expensive conventional vehicles

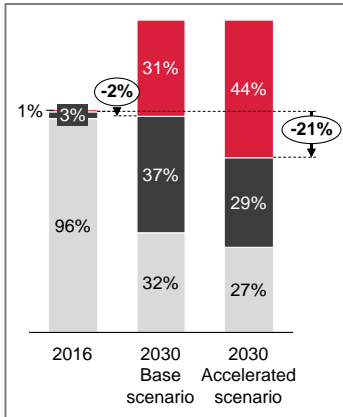


- In the US market share of BEVs is expected to be lower than in EU and China, because
 - US fuel economy regulation requires less electrification
 - Customer demand for BEVs expected to be lower
 - Slower build-up of infrastructure in many regions expected
- Similar to EU for the accelerated scenario higher share of BEVs results in regulatory

“over-compliance” (fuel economy and ZEV quotas) and allows for higher share of conventional vehicles, which are less expensive



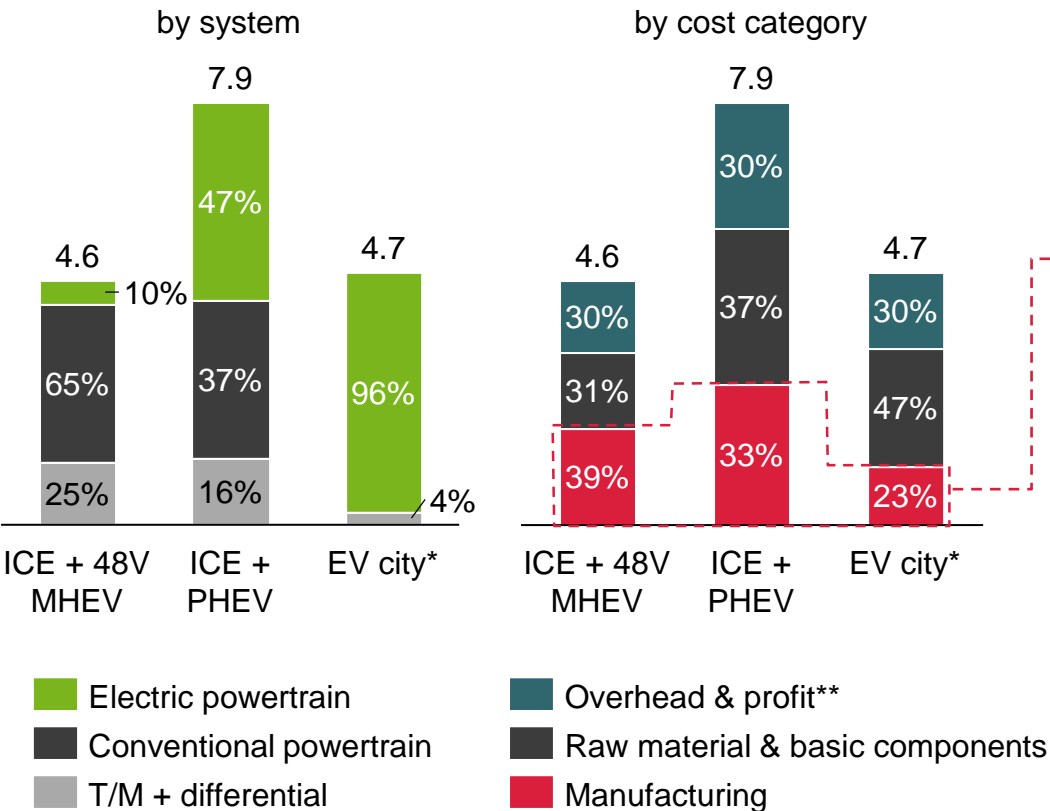
- In China a very high share of BEVs is expected, because the government's main focus is to achieve “smog free cities” (fuel economy 2nd priority), which can't be achieved with hybrid vehicles
- Boundary conditions in the accelerated scenario (lower battery prices, better charging infrastructure, higher customer acceptance) further increase BEV share



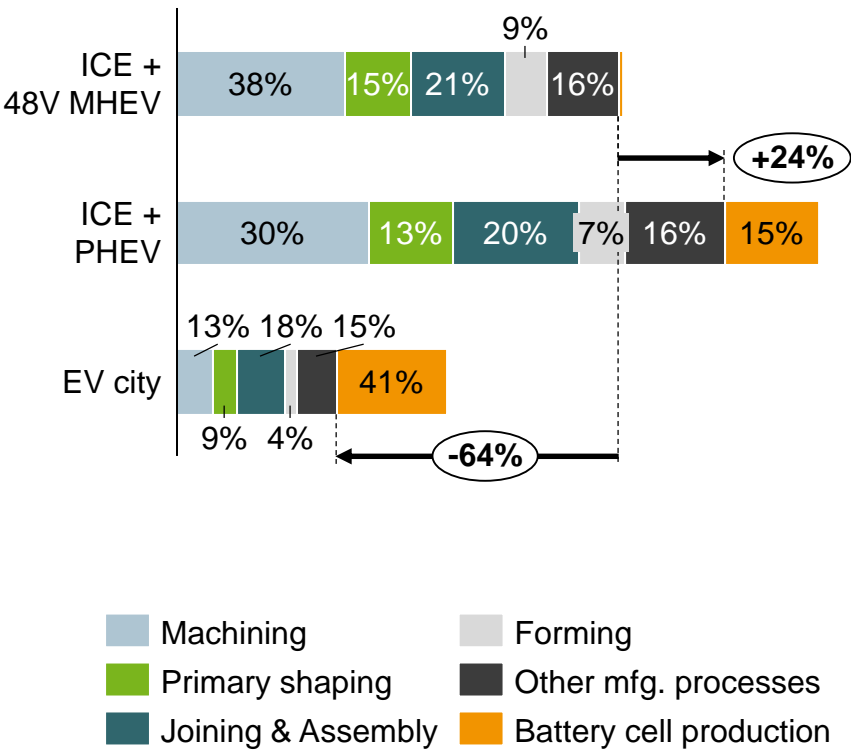
Manufacturing process costs of electric powertrains are significantly lower than conventional powertrain manufacturing costs; PHEV costs higher

COST ANALYSIS OF SELECTED COMPACT CAR POWERTRAINS IN 2030

Direct manufacturing costs of powertrains in thousand Euro



Manufacturing process costs

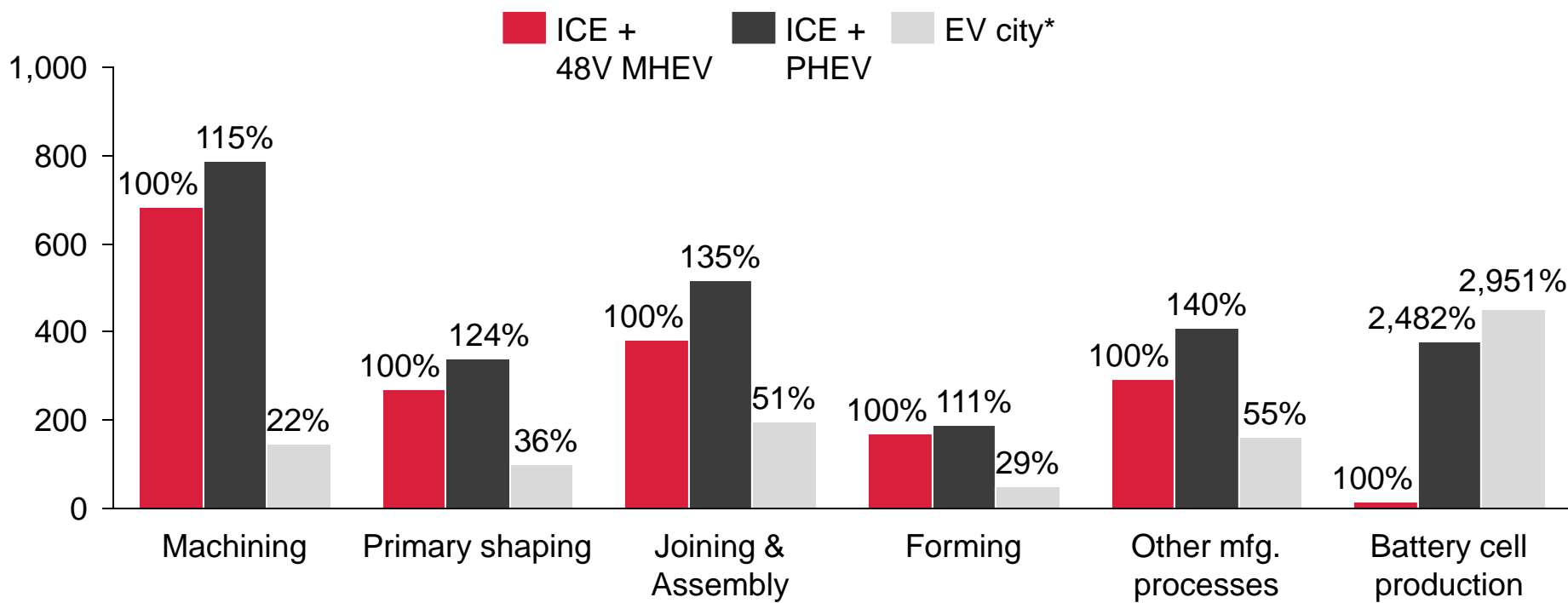


*: battery capacity = 32 kWh, electric power = 60 kW, fixed gear, battery cost assumption for 2030: 90 €/kWh (battery pack); **: Overhead & profit of supply chain
 Source: FEV

The manufacturing cost difference between conventional and electric powertrains varies significantly among the different process categories

COST ANALYSIS OF SELECTED COMPACT CAR POWERTRAINS IN 2030

Manufacturing process costs in Euro



*: battery capacity = 32 kWh, electric power = 60 kW, fixed gear, battery cost assumption for 2030: 90 €/kWh (battery pack); **: Overhead & profit of supply chain
Source: FEV

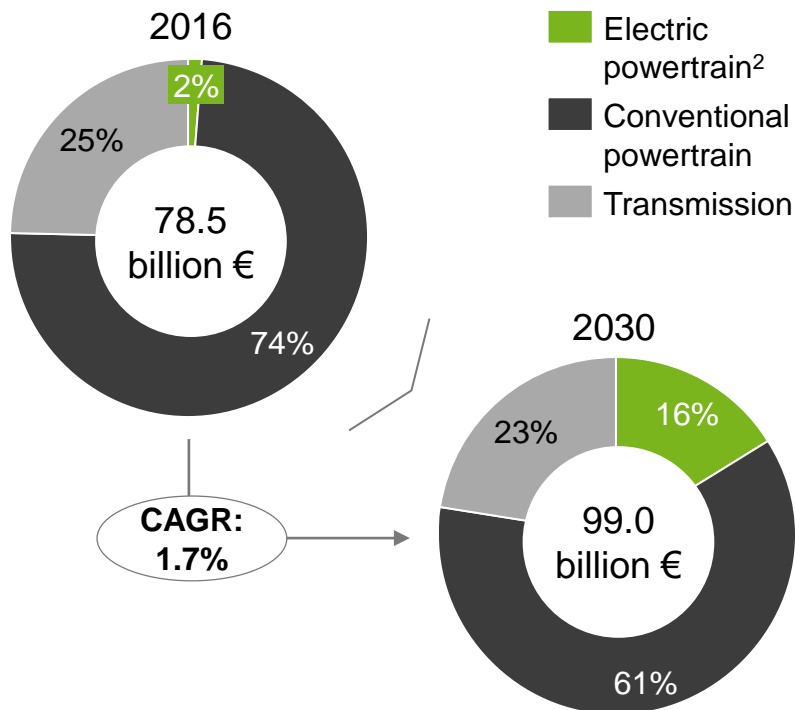
Manufacturing process related value creation (w/o battery cell production) for powertrain components is expected to increase by 1.7% annually

ANALYSIS OF PASSENGER CAR POWERTRAIN MARKET



Value creation¹ of powertrain by system

BASE SCENARIO



- The values reported in this chapter are costs (and therefore value creation), which are related to manufacturing processes only
- Value creation for battery cell production is excluded: VDMA and FEV jointly decided to exclude cell production when “overall manufacturing related value creation” numbers are reported
- In 2030 battery cell production is expected to account for value creation of approx. 11 billion € (not included in values on the left)
- Raw materials and basic components as well as overhead and profits are excluded in order to only focus on manufacturing process related value creation
- *Electric powertrain* components: includes all powertrain components of electric vehicles (BEVs) as well as those parts of hybrid electric powertrains (MHEV, HEV, PHEV), which belong to the electric propulsion such as e-motor, battery, power electronics
- *Conventional powertrain* components: includes all powertrain components of conventional vehicles as well as those parts of hybrid electric powertrains (MHEV, HEV, PHEV), which belong to the combustion propulsion such as combustion engine, exhaust system, etc.
- *Transmission* components: includes all transmissions of conventional, hybrid and electric powertrains

1) all manufacturing processes excluding battery cell production, values shown represent manufacturing process related value creation (excl. material costs, overhead and profit)

2) incl. components for electric propulsion of hybrid powertrains (e.g. e-motor of plug-in hybrid powertrain);

3) CAGR = compound annual growth rate

Source: FEV

Increase of overall value creation is driven by electric powertrain components and Chinese market growth; conventional powertrain in EU decreases

ANALYSIS OF PASSENGER CAR POWERTRAIN MARKET



Change in value creation¹ from 2016 to 2030 in billion Euro (CAGR)

BASE SCENARIO

<div> <div> $\Sigma = 20.5$ (1.7%) </div> <div> </div> </div>			
<div> <div>Electric powertrain²</div> </div>	<div> <div>4.2</div> <div>(22%)</div> </div>	<div> <div>3.2</div> <div>(18%)</div> </div>	<div> <div>7.7</div> <div>(21%)</div> </div>
<div> <div>Conventional powertrain</div> </div>	<div> <div>-2.9</div> <div>(-1.3%)</div> </div>	<div> <div>0.4</div> <div>(0.1%)</div> </div>	<div> <div>5.0</div> <div>(1.5%)</div> </div>
<div> <div>Transmission</div> </div>	<div> <div>0.4</div> <div>(0.6%)</div> </div>	<div> <div>-0.2</div> <div>(-0.2%)</div> </div>	<div> <div>2.7</div> <div>(2.2%)</div> </div>

- In 2016 value creation of electric powertrain components is below 1 billion € in each of the three markets – substantial increase towards 2030
- In China overall passenger car market growth and application of advanced technology results in further growth of value creation for conventional powertrains and transmissions
- Value creation of conventional powertrains in Europe is decreasing, because of
 - Reduced number of combustion engine sales
 - Technology level in 2016 baseline is already quite advanced (e.g. high share of turbocharged engines)
- Transmission value creation in Europe increases – main reason is shift from manual transmissions to automatic and dual clutch transmissions
- In USA these boundaries are different than in EU:
 - Conventional powertrains in 2016 have more potential for additional technology (shift from naturally aspirated to turbocharged engines)
 - Small share of manual transmissions in 2016

1) all manufacturing processes excluding battery cell production, values shown represent manufacturing process related value creation (excl. material costs, overhead and profit)
 2) incl. components for electric propulsion of hybrid powertrains (e.g. e-motor of plug-in hybrid powertrain);
 Source: FEV







In the accelerated scenario value creation for conventional powertrains and transmissions decrease in EU and US; overall growth rate of 1.0% p.a.

ANALYSIS OF PASSENGER CAR POWERTRAIN MARKET



Change in value creation¹ from 2016 to 2030 in billion Euro (CAGR)

ACCELERATED SCENARIO

<div> <div>Σ = 11.4 (1.0%)</div> <div>    </div> </div>			
<div>Electric powertrain²</div> <div></div>	<div>4.3 (23%)</div> <div></div>	<div>3.4 (18%)</div> <div></div>	<div>9.3 (23%)</div> <div></div>
<div>Conventional powertrain</div> <div></div>	<div>-5.0 (-2.3%)</div> <div></div>	<div>-1.2 (-0.4%)</div> <div></div>	<div>0.3 (0.1%)</div> <div></div>
<div>Transmission</div> <div></div>	<div>-0.4 (-0.7%)</div> <div></div>	<div>-0.7 (-0.7%)</div> <div></div>	<div>1.4 (1.2%)</div> <div></div>

- In the accelerated electrification scenario the overall increase of manufacturing process related value creation is limited to 11.4 billion € (equals annual growth rate of 1.0%)
- The increase in value creation in the accelerated scenario is almost entirely attributed to electric powertrain components
- For conventional powertrain components and transmissions a moderate growth of value creation in China and decreasing value creation in EU and USA is expected
- 2016 manufacturing process related value creation of conventional powertrain components in EU is 17.9 billion € - reduction of 5.0 billion € equals a decrease of 28% (-2.3% annually)

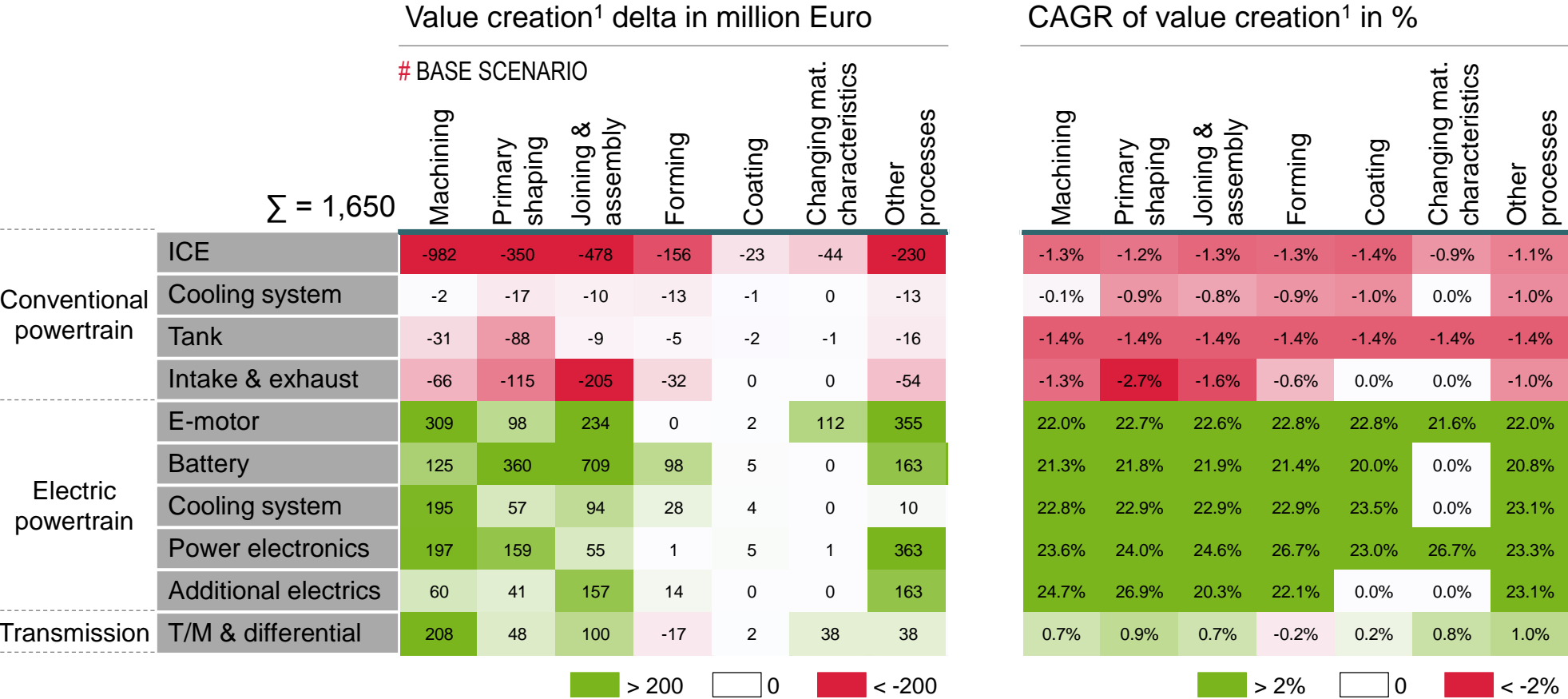
1) all manufacturing processes excluding battery cell production, values shown represent manufacturing process related value creation (excl. material costs, overhead and profit)
 2) incl. components for electric propulsion of hybrid powertrains (e.g. e-motor of plug-in hybrid powertrain);
 Source: FEV

In Europe significant increase of electric powertrain systems expected – however, reduction of machining value creation for ICE approx. 1 billion €



CHANGE IN VALUE CREATION FROM 2016 TO 2030

Full analysis (2 scenarios for EU, USA and China) available in the full report



CAGR of value creation¹ in %

	Machining	Primary shaping	Joining & assembly	Forming	Coating	Changing mat. characteristics	Other processes
Conventional powertrain	-1.3%	-1.2%	-1.3%	-1.3%	-1.4%	-0.9%	-1.1%
	-0.1%	-0.9%	-0.8%	-0.9%	-1.0%	0.0%	-1.0%
	-1.4%	-1.4%	-1.4%	-1.4%	-1.4%	-1.4%	-1.4%
	-1.3%	-2.7%	-1.6%	-0.6%	0.0%	0.0%	-1.0%
Electric powertrain	22.0%	22.7%	22.6%	22.8%	22.8%	21.6%	22.0%
	21.3%	21.8%	21.9%	21.4%	20.0%	0.0%	20.8%
	22.8%	22.9%	22.9%	22.9%	23.5%	0.0%	23.1%
	23.6%	24.0%	24.6%	26.7%	23.0%	26.7%	23.3%
	24.7%	26.9%	20.3%	22.1%	0.0%	0.0%	23.1%
Transmission	0.7%	0.9%	0.7%	-0.2%	0.2%	0.8%	1.0%

> 2%

0

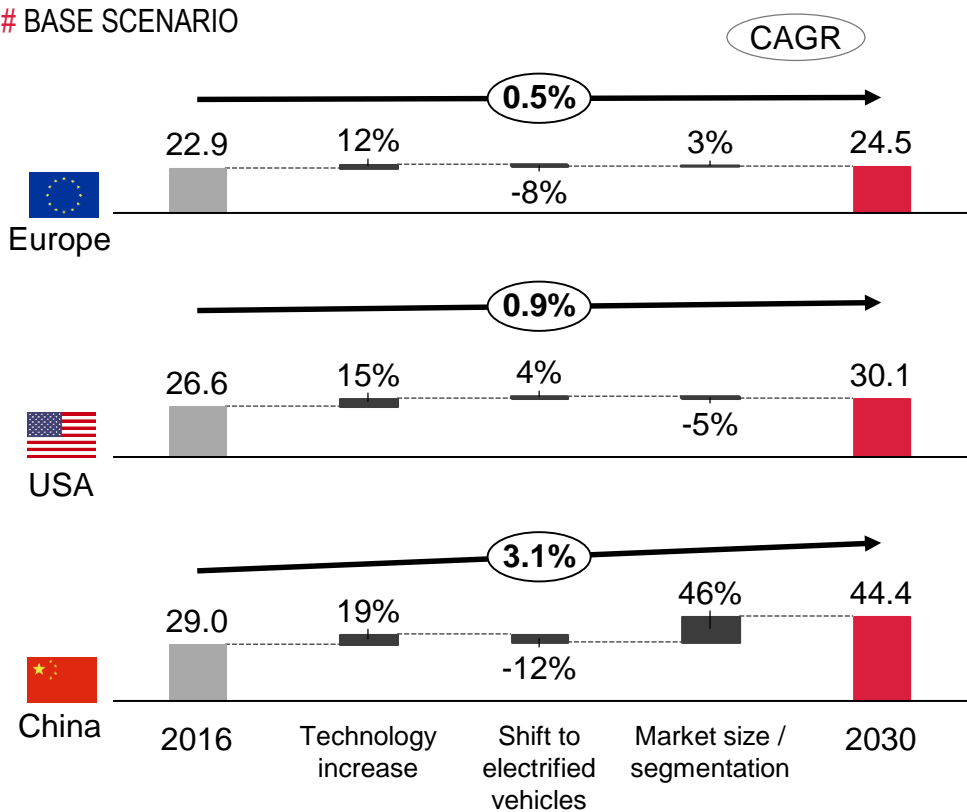
< -2%

Shift to electrified vehicles reduces annual value creation (w/o battery cell production) by 4.5 billion Euro in the base scenario

ANALYSIS OF PASSENGER CAR POWERTRAIN MARKET

Value creation¹ shift in billion Euro

BASE SCENARIO



- *Technology increase* shows the changes in manufacturing process related value creation of advanced powertrain technology application:
 - EU: Shift from manual transmission to automated transmissions (e.g. DCT, AT); application of engine efficiency technologies
 - USA/China: Continued shift from naturally aspirated engines to turbocharged engines; application of engine efficiency technologies
- *Shift to electrified vehicles* shows the effect of reduced number of conventional vehicles as well as increased number of electric and hybrid electric vehicles:
 - In EU and China the strong focus on electric vehicles, which require less manufacturing effort, results in reduced value creation
 - In USA a substantial market share of hybrid powertrains, which require higher manufacturing effort, results in slightly increased value creation
- *Market size / segmentation* has a major impact in China because of substantial market growths in terms of number of vehicle sales (*market size*) as well as slight shift to larger vehicles (*segmentation*)

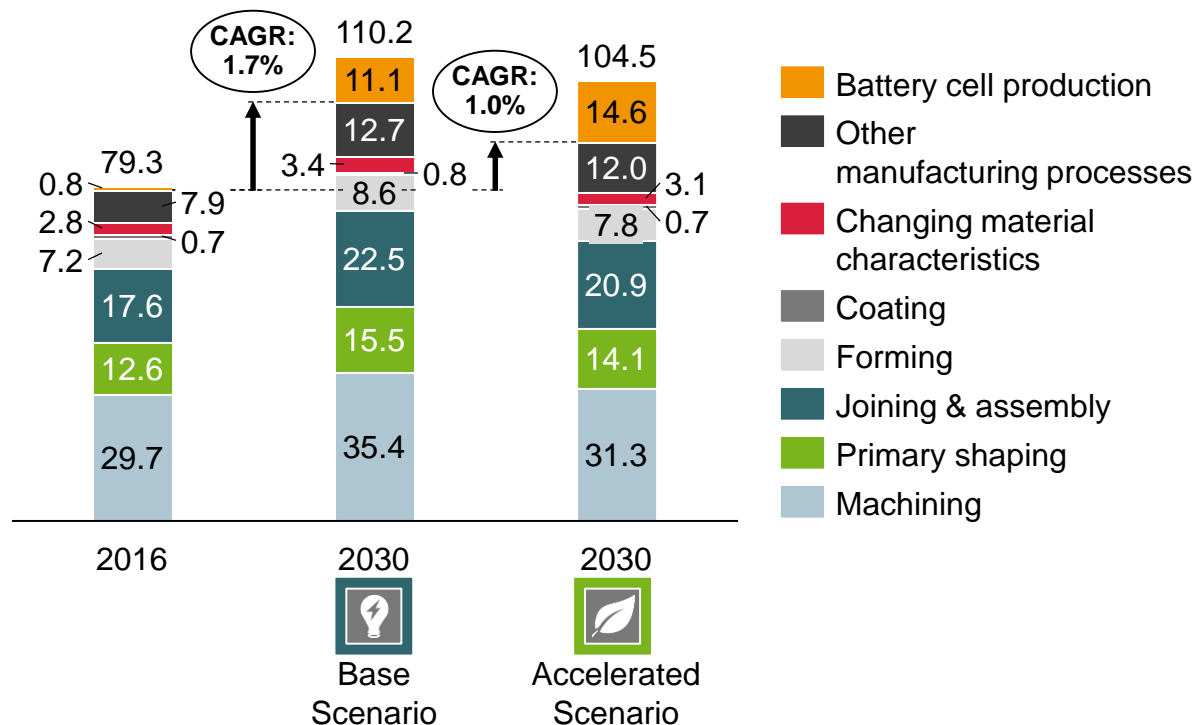
1) all manufacturing processes excluding battery cell production, values shown represent manufacturing process related value creation (excl. raw material and basic components, excl. overhead and profit), 55 million powertrain units in 2016; CAGR = compound annual growth rate
 Source: FEV

Value creation of each manufacturing process category is expected to increase – growth is limited in the accelerated electrification scenario

ANALYSIS OF PASSENGER CAR POWERTRAIN MARKET



Value creation¹ per manufacturing process in billion Euro















- Graph shows result of EU, USA and China market region
 - In total, 55 million powertrain units in 2016
- In both scenarios for 2030 manufacturing process value creation increases compared to 2016 – key reasons:
 - ↑ Increase of overall passenger car sales driven by the Chinese market
 - ↗ Powertrain electrification, i.e. mild and full hybrid powertrain as well as plug-in hybrid powertrain
 - ↗ Conventional powertrains with advanced technologies for efficiency improvement
 - ↘ Shift to electric powertrain
- Major difference of scenarios is the share of battery electric vehicle in year 2030
 - 22% in Base Scenario
 - 34% in Accelerated Scenario
- Overall sales volume is equal for both scenarios

¹ values shown represent manufacturing process related value creation (excl. raw material and basic components, excl. overhead and profit); CAGR = compound annual growth rate
Source: FEV

Improved engine efficiency and stronger emission requirements result in higher complexity, sales volume and cylinder count is decreasing

COMBUSTION PASSENGER CAR ENGINE COMPONENT TRENDS FOR EU, USA AND CHINA









Sales driver	Key powertrain components	2030 general technology trends	Implications
 Number of combustion engines	<ul style="list-style-type: none"> – Crankcase / cyl. head – Crankshaft / camshaft – Fuel injection system – Lubrication / cooling – Fuel tank system – Oil pan – Accessories – Intake / exhaust 	<ul style="list-style-type: none"> ■ Improved combustion engine efficiency by enhanced technologies expected ■ Variable controlled components, friction reduction and thermal management as well as light weighting ■ Increased requirements for exhaust gas aftertreatment 	<p>Volume*: </p> <p>Complexity: </p>
 Number of cylinders / pistons	<ul style="list-style-type: none"> – Piston – Conrod – Injector – Spark plug (gasoline engines) – Intake / exhaust valve 	<ul style="list-style-type: none"> ■ Specific power output for gasoline engine volume applications of 80 to 100 kW/l expected ■ Increased peak firing pressure for gasoline engines, Miller cycle with variable valve actuation (timing, lift) ■ Selected gasoline engine applications with cooled EGR systems 	<p>Volume*: </p> <p>Complexity: </p>
 Number of gasoline engines	<ul style="list-style-type: none"> – Gasoline fuel injection system – Boosting system – Gasoline aftertreatment system 	<ul style="list-style-type: none"> ■ Main volume applications with direct fuel injection systems (< 350 bar); trend towards boosted engines ■ Gasoline particulate filter in all application for Europe, selected applications in USA, China indifferent 	<p>Volume*: </p> <p>Complexity: </p>
 Number of diesel engines	<ul style="list-style-type: none"> – Diesel fuel injection system – Diesel aftertreatment system 	<ul style="list-style-type: none"> ■ Increased fuel injection pressure up to 3000 bar with multiple injections supports low raw emission ■ Real driving emission requirements addressed by exhaust aftertreatment systems with combination of LNT and SCR in addition to DPF in closed coupled arrangement 	<p>Volume*: </p> <p>Complexity: </p>

*Volume trend reflects change in sales volume from 2016 to 2030 base scenario
Source: FEV

Application of powertrain electrification requires the integration new components as electric traction motors and battery systems

ELECTRIC PASSENGER CAR POWERTRAIN COMPONENT TRENDS FOR EU, USA AND CHINA



Sales driver	Key powertrain components	2030 general technology trends	Implications
<div>  <div> <div>Number of mild hybrid vehicles</div> <div></div> </div> </div>	<div> <div></div> <ul style="list-style-type: none"> Belt starter generator (BSG) 48V e-motors 48V batteries </div>	<ul style="list-style-type: none"> Entry applications are expected with P0 architecture (Belt starter generator), P2 architecture (Integrated starter generator) mainly in larger vehicles expected 12 V board net will remain in parallel Mild hybrid technology supports exhaust emission compliance, particularly in real driving conditions 	<div> <div>Volume*:</div> <div>  </div> </div>
<div>  <div> <div>Number of full hybrid vehicles</div> <div></div> </div> </div>	<div> <div></div> <ul style="list-style-type: none"> High power batteries (limited capacity) High voltage e-motors (mainly < 50 kW) </div>	<ul style="list-style-type: none"> Power split and dedicated hybrid transmission expected as important trend Series hybrids with simplified high efficiency combustion engine expected in selected applications 	<div> <div>Volume*:</div> <div>  </div> </div>
<div>  <div> <div>Number of plug-in hybrid and electric vehicles</div> <div></div> </div> </div>	<div> <div></div> <ul style="list-style-type: none"> High capacity batteries (high capacity) High voltage e-motors (mainly > 50 kW) On board charger AC/DC converter </div>	<ul style="list-style-type: none"> Post Lithium Ion technology after 2025 expected, e.g. solid state technology Real world driving range for volume applications of battery electric vehicles > 350 km expected Fast charging up to 150 to 200 kW for volume applications expected, up to 350 kW for selected applications Direct and indirect cooling for electric motors expected 	<div> <div>Volume*:</div> <div>  </div> </div>

*Volume trend reflects change in sales volume from 2016 to 2030 base scenario
 Source: FEV

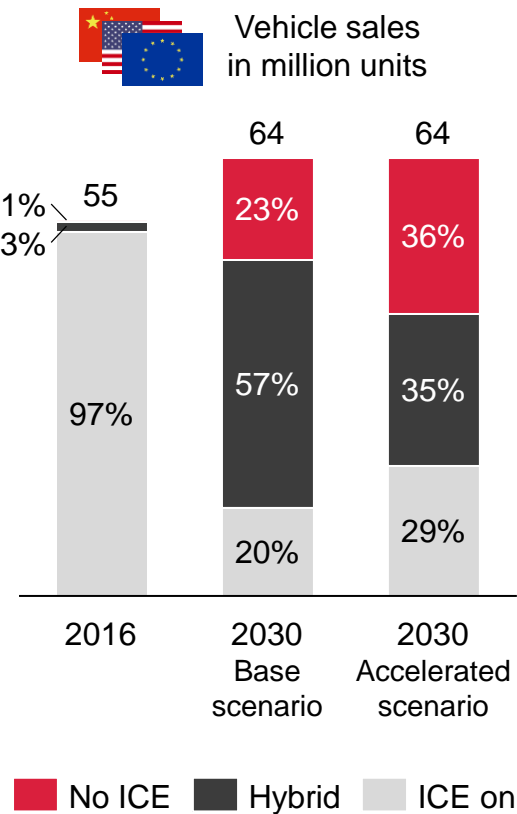
Sales of electric motors reach approx. 60 million units by 2030 – 45% of these have peak power below 25 kW (mainly used for 48V mild hybrids)

ELECTRIC POWERTRAIN COMPONENT SALES FORECAST

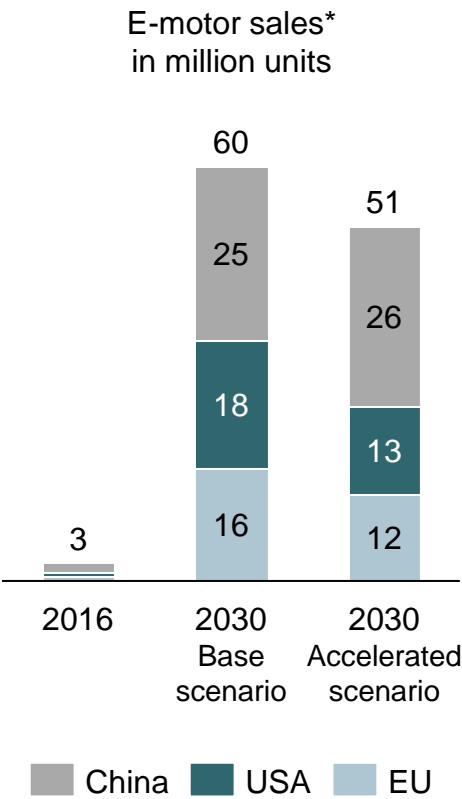
Analyses for further components available in the full report



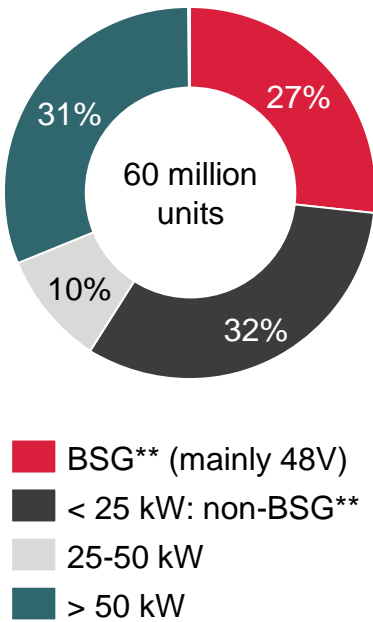
Driver: Electrification



Effect: Sales of electric motors (traction motors only)



2030 base scenario:
E-motor sales
by peak power level



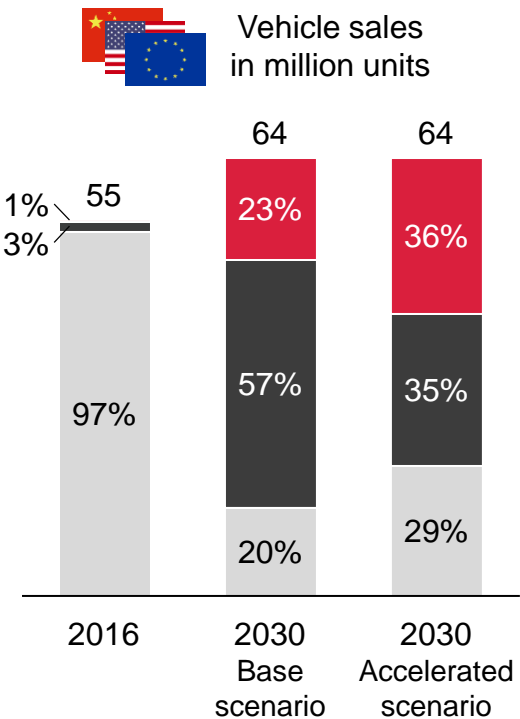
*in some electrified powertrains more than one e-motor is applied; **BSG = Belt starter generator
Source: FEV

Increasing level of electrification results in significant increase of overall tonnage of annually sold powertrains; battery weight has significant impact

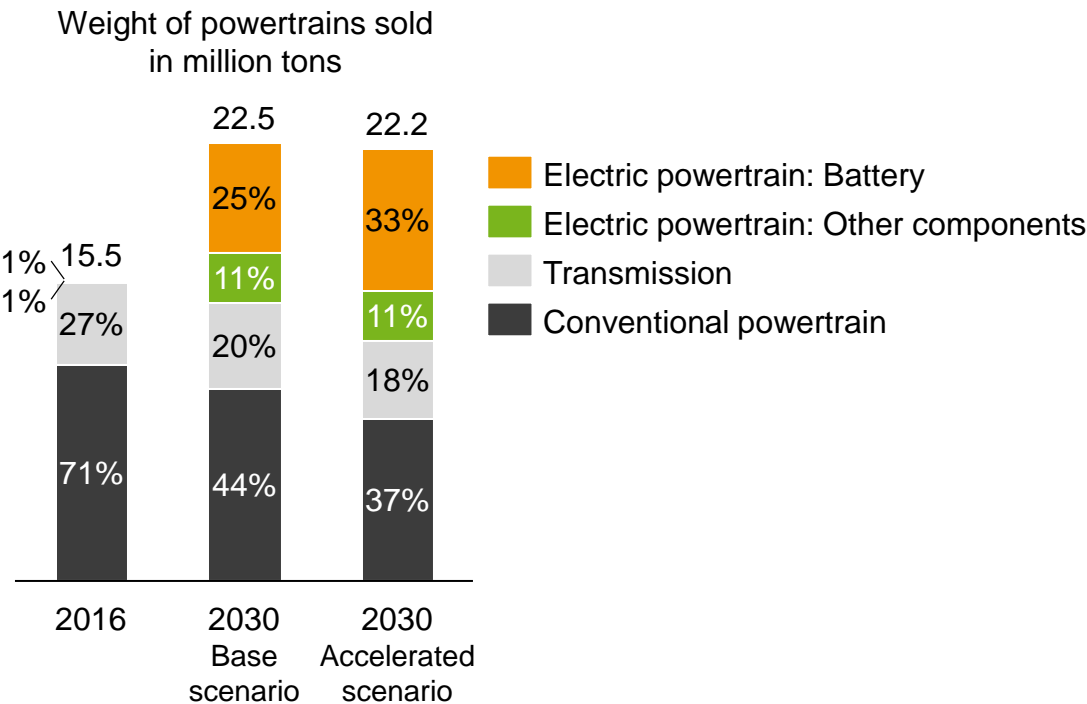
POWERTRAIN TYPE SALES AND WEIGHT FORECAST



Driver: Electrification



Effect: Development of overall tonnage of powertrains

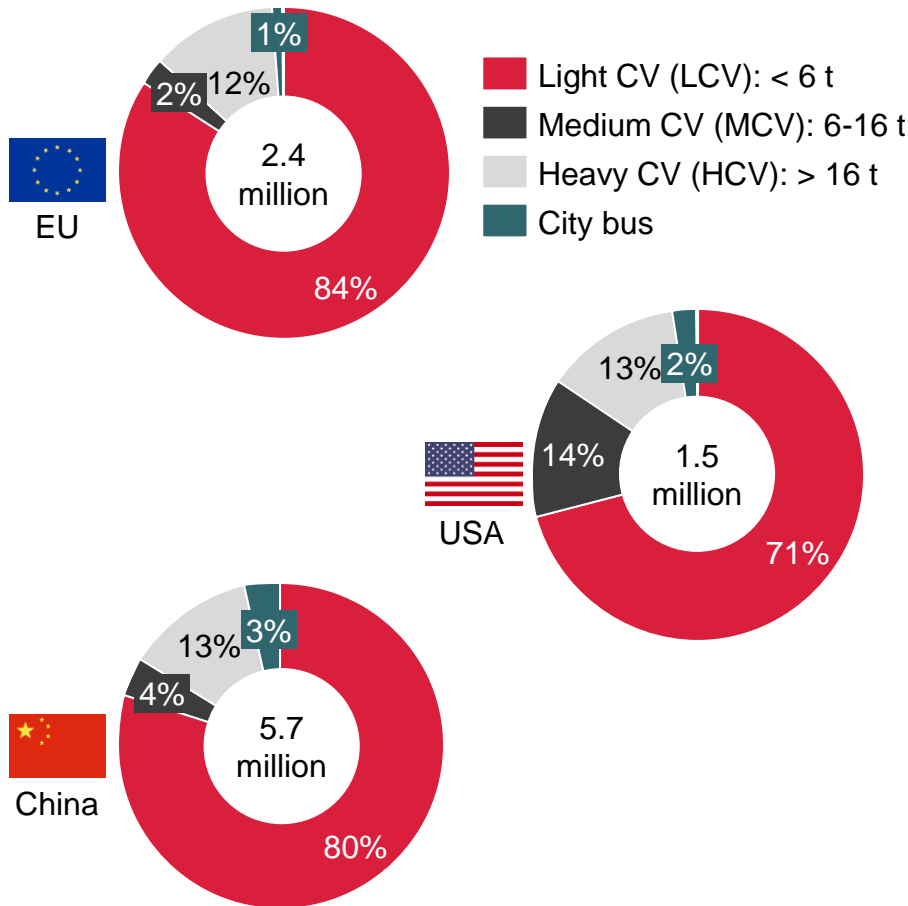


No ICE Hybrid ICE only

- Conclusions and study approach
- Passenger car market
- **Commercial vehicle market**
- Non-road mobile machinery
- Follow-up services
- Contacts

Within the commercial vehicle category light commercial vehicles account for the majority of sales in all three markets

2016 commercial vehicle (CV) sales



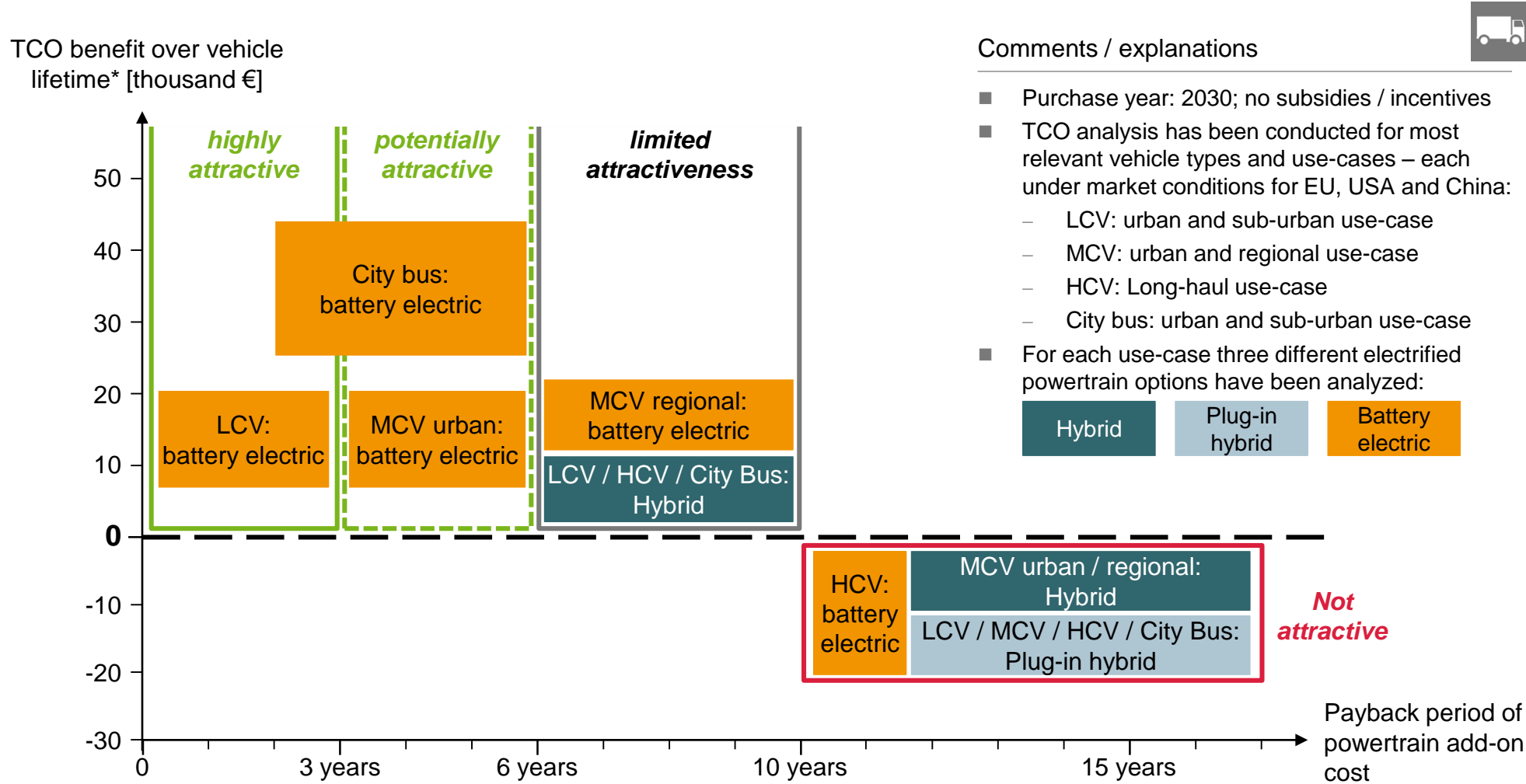
Source: IHS, FEV, fotolia

Key use-cases by CV segment



Segment	Typical drive cycle(s)	Vehicle examples
LCV	(Mainly) urban operation	
MCV	Urban delivery	
MCV	Regional delivery	
HCV	Highway operation	
HCV	Urban operation (e.g. refuse trucks)	
CITY BUS	Urban	

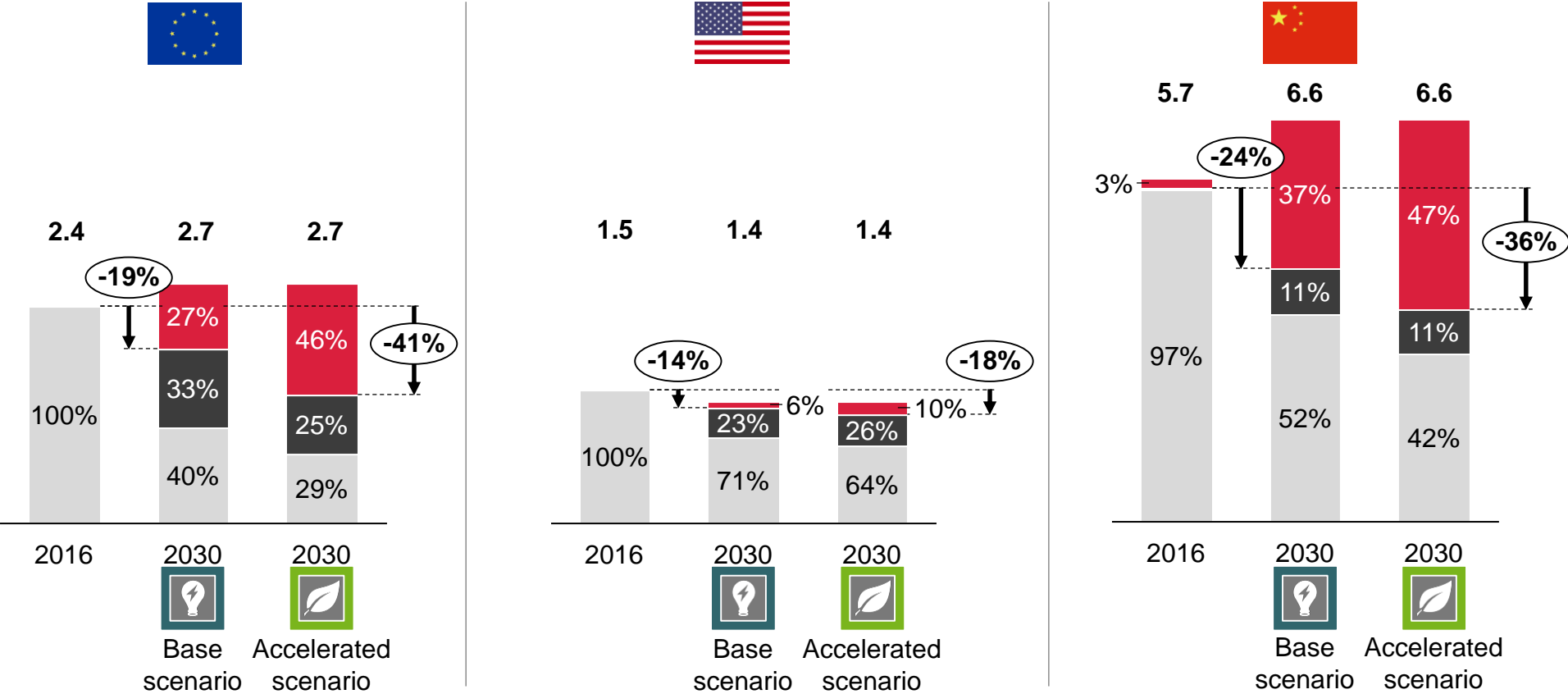
In terms of total cost of ownership (TCO) battery electric LCV and buses are most attractive in 2030; hybrid powertrains show poor TCO values



*compared to conventional diesel powertrain over entire useful life of vehicle (10 years)
 Source: FEV

Driven by electrification in LCV segment, sales of combustion engines are expected to decline by 2030 in all three markets Europe, USA and China

COMMERCIAL VEHICLES: SALES OF POWERTRAIN TYPES IN MILLION UNITS



No ICE (battery electric, fuel cell)

Hybrid (mild hybrid, full hybrid, plug-in hybrid)

ICE only (incl. 12V stop/start)

Percentage values in 2016 only displayed if >0.5%
Source: FEV

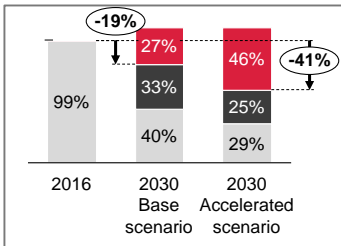
Driven by electrification in LCV segment, sales of combustion engines are expected to decline by 2030 in all three markets Europe, USA and China



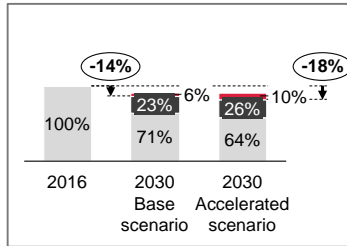
COMMERCIAL VEHICLES: SALES OF POWERTRAIN TYPES IN MILLION UNITS



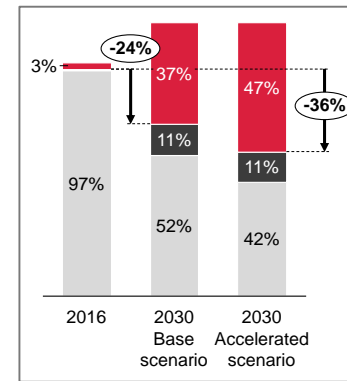
- Electrification of commercial vehicles is driven by LCVs (mainly vans ranging from VW Caddy class up to Mercedes sprinter class) and city buses – BEV share in LCV in 2030 expected to be 30% (base scenario) to 50% (accelerated scenario)
- In 2030 moderate electric vehicle shares in MCV segment (11%) and low in HCV (2%) – accelerated scenario 18% and 4%
- Majority of hybrid powertrains are 48V mild hybrids in LCV segment – also hybrids in MCV and HCV segments
- In 2016 gasoline share <10%; in 2030 gasoline share >20%
- Key reason for higher electrification in accelerated scenario: lower battery costs improve business case of hybrid and electric vehicles



- In USA LCV market is dominated by pickups, which show lower level of electrification compared to LCVs (i.e. vans) in EU and China
- In the 2030 base scenario battery electric vehicle share is 5% for LCV and MCV, 2% for HCV and 25% for bus segment
- Majority of hybrid powertrains are 48V mild hybrids in LCV segment – also full hybrids and plug-in hybrids in LCV, MCV and HCV segment
- In the accelerated scenario only moderately higher level of electrification is assumed, because use-cases of commercial vehicles in USA offer limited potential for hybrid and full electric powertrain adoption
- Among ICE powered vehicles approx. 50% gasoline and 50% diesel applications in 2016 and 2030



- Similar to EU electrification of commercial vehicles is driven by LCVs – 2030 BEV share in LCV between 40% (base scenario) to 50% (accelerated scenario)
- City buses: BEV share in 2016 already 70%
- In 2030 moderate electric vehicle shares in MCV segment (12%) and low in HCV (1%) – in accelerated scenario only moderately higher shares (21% and 4%)
- Clear focus on EV, low hybrid market share
- Diesel share approx. 40% in 2016 and approx. 25% in 2030



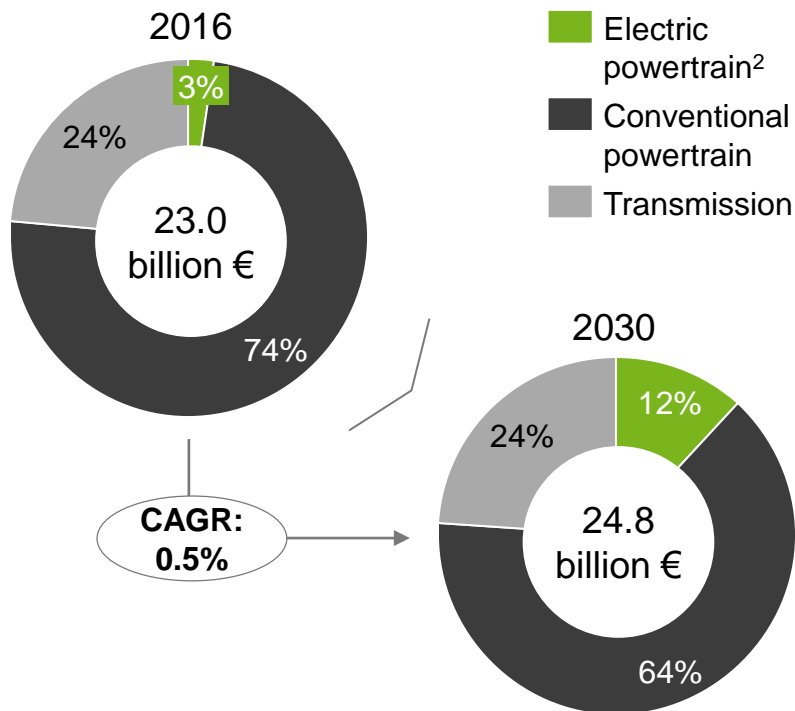
Manufacturing process related value creation (w/o battery cell production) for powertrain components is expected to increase by 0.5% annually

ANALYSIS OF COMMERCIAL VEHICLE POWERTRAIN MARKET



Value creation¹ of powertrain by system

BASE SCENARIO



- The values reported in this chapter are costs (and therefore value creation), which are related to manufacturing processes only
- Value creation for battery cell production is excluded: VDMA and FEV jointly decided to exclude cell production when “overall manufacturing related value creation” numbers are reported
- In 2030 battery cell production is expected to account for value creation of approx. 2.5 billion € (not included in values on the left)
- Raw materials and basic components as well as overhead and profits are excluded in order to only focus on manufacturing process related value creation
- *Electric powertrain* components: includes all powertrain components of electric vehicles (BEVs) as well as those parts of hybrid electric powertrains (MHEV, HEV, PHEV), which belong to the electric propulsion such as e-motor, battery, power electronics
- *Conventional powertrain* components: includes all powertrain components of conventional vehicles as well as those parts of hybrid electric powertrains (MHEV, HEV, PHEV), which belong to the combustion propulsion such as combustion engine, exhaust system, etc.
- *Transmission* components: includes all transmissions of conventional, hybrid and electric powertrains

1) all manufacturing processes excluding battery cell production, values shown represent manufacturing process related value creation (excl. material costs, overhead and profit)

2) incl. components for electric propulsion of hybrid powertrains (e.g. e-motor of plug-in hybrid powertrain);

3) CAGR = compound annual growth rate

Source: FEV

Value creation of conventional powertrains in EU and China is expected to decrease, overcompensated by increase in electric powertrain components









ANALYSIS OF COMMERCIAL VEHICLE POWERTRAIN MARKET



Change in value creation¹ from 2016 to 2030 in billion Euro (CAGR)

BASE SCENARIO

$\Sigma = 1.8$ (0.5%)			
Electric powertrain ² 	0.8 (28%)	0.2 (37%)	1.4 (9%)
Conventional powertrain 	-0.6 (-0.9%)	0.2 (0.3%)	-0.6 (-0.6%)
Transmission 	0.2 (0.6%)	0.1 (0.6%)	0.2 (0.5%)

- In 2016 value creation of electric powertrain components is less than 0.1 billion € in EU and USA and 0.6 billion € in China (mainly driven by city bus and LCV segments) – substantial increase towards 2030
- Due to significant shift towards full electric powertrains in LCV segment, value creation of conventional powertrains in EU and China is expected to decrease
- Different from passenger cars, market growth in China is expected to be moderate for commercial vehicles
- In USA lower level of electrification and focus on hybrid powertrains result in increase of value creation in all three powertrain systems

1) all manufacturing processes excluding battery cell production, values shown represent manufacturing process related value creation (excl. material costs, overhead and profit)

2) incl. components for electric propulsion of hybrid powertrains (e.g. e-motor of plug-in hybrid powertrain);

Source: FEV

In the accelerated scenario value creation for conventional powertrains and transmissions stagnate or decrease in all markets

ANALYSIS OF COMMERCIAL VEHICLE POWERTRAIN MARKET



Change in value creation¹ from 2016 to 2030 in billion Euro (CAGR)

ACCELERATED SCENARIO

<div> $\Sigma = 0.2$ (0.1%) </div>			
<div>Electric powertrain²</div>	<div>1.1</div> <div>(32%)</div>	<div>0.4</div> <div>(41%)</div>	<div>1.8</div> <div>(11%)</div>
<div>Conventional powertrain</div>	<div>-1.4</div> <div>(-2.6%)</div>	<div>0.0</div> <div>(0.0%)</div>	<div>-1.7</div> <div>(-1.6%)</div>
<div>Transmission</div>	<div>-0.1</div> <div>(-0.1%)</div>	<div>0.1</div> <div>(0.2%)</div>	<div>0.0</div> <div>(0.0%)</div>

- In the accelerated electrification scenario the overall increase of manufacturing process related value creation is limited to 0.2 billion € (equals annual growth rate of 0.1%)
- Higher share of battery electric vehicle results in stagnating or decreasing value creation for conventional powertrains and transmissions in all markets
- 2016 manufacturing process related value creation of conventional powertrain components in EU is 4.5 billion € - reduction of 1.4 billion € equals a decrease of 31% (-2.6% annually)

1) all manufacturing processes excluding battery cell production, values shown represent manufacturing process related value creation (excl. material costs, overhead and profit)
2) incl. components for electric propulsion of hybrid powertrains (e.g. e-motor of plug-in hybrid powertrain);
Source: FEV

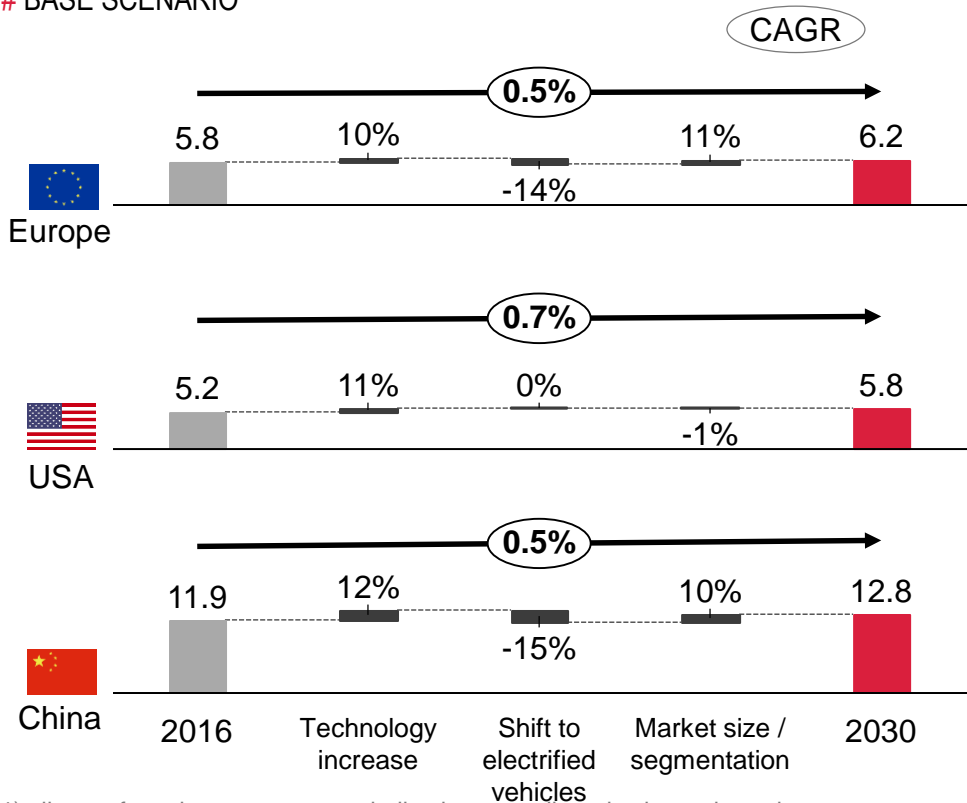
Shift to electrified vehicles reduces annual value creation (w/o battery cell production) by 2.6 billion Euro

ANALYSIS OF COMMERCIAL VEHICLE POWERTRAIN MARKET



Value creation¹ shift in billion Euro

BASE SCENARIO



- *Technology increase* shows the changes in manufacturing process related value creation of advanced powertrain technology application:
 - Shift from manual transmission to automated transmissions (e.g. AMT, DCT, AT)
 - Application of engine efficiency technologies
- *Shift to electrified vehicles* shows the effect of reduced number of conventional vehicles as well as increased number of electric and hybrid electric vehicles:
 - In EU and China the strong focus on electric vehicles (especially for LCV segment), which require less manufacturing effort, results in reduction of value creation
 - In USA this effect is neutral, because overall level of electrification is lower and besides pure electric vehicles there is also a focus on hybrid powertrains, which require high manufacturing effort
- *Market size / segmentation* has a positive impact in EU and China because of market growths in terms of number of vehicle sales (*market size*)

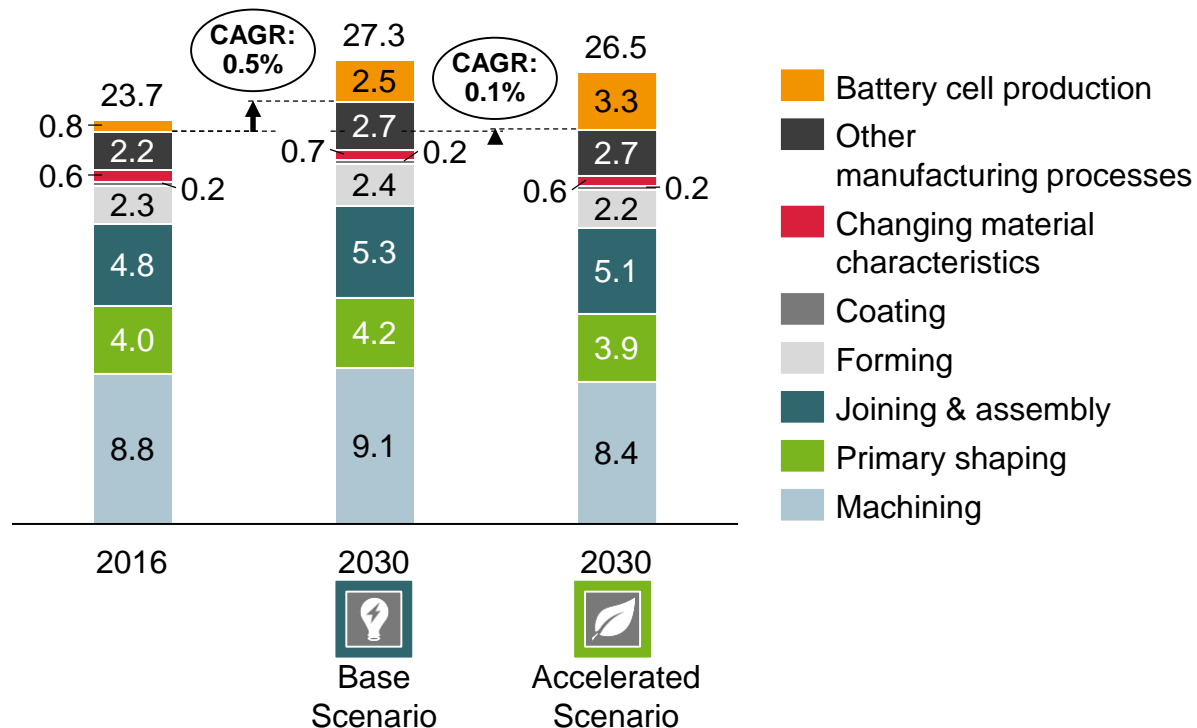
1) all manufacturing processes excluding battery cell production, values shown represent manufacturing process related value creation (excl. raw material and basic components, excl. overhead and profit); CAGR = compound annual growth rate
 Source: FEV

In the accelerated scenario value creation (w/o battery cell production) is stagnating - Machining, primary shaping and forming decrease



ANALYSIS OF COMMERCIAL VEHICLE POWERTRAIN MARKET

Value creation¹ per manufacturing process in billion Euro



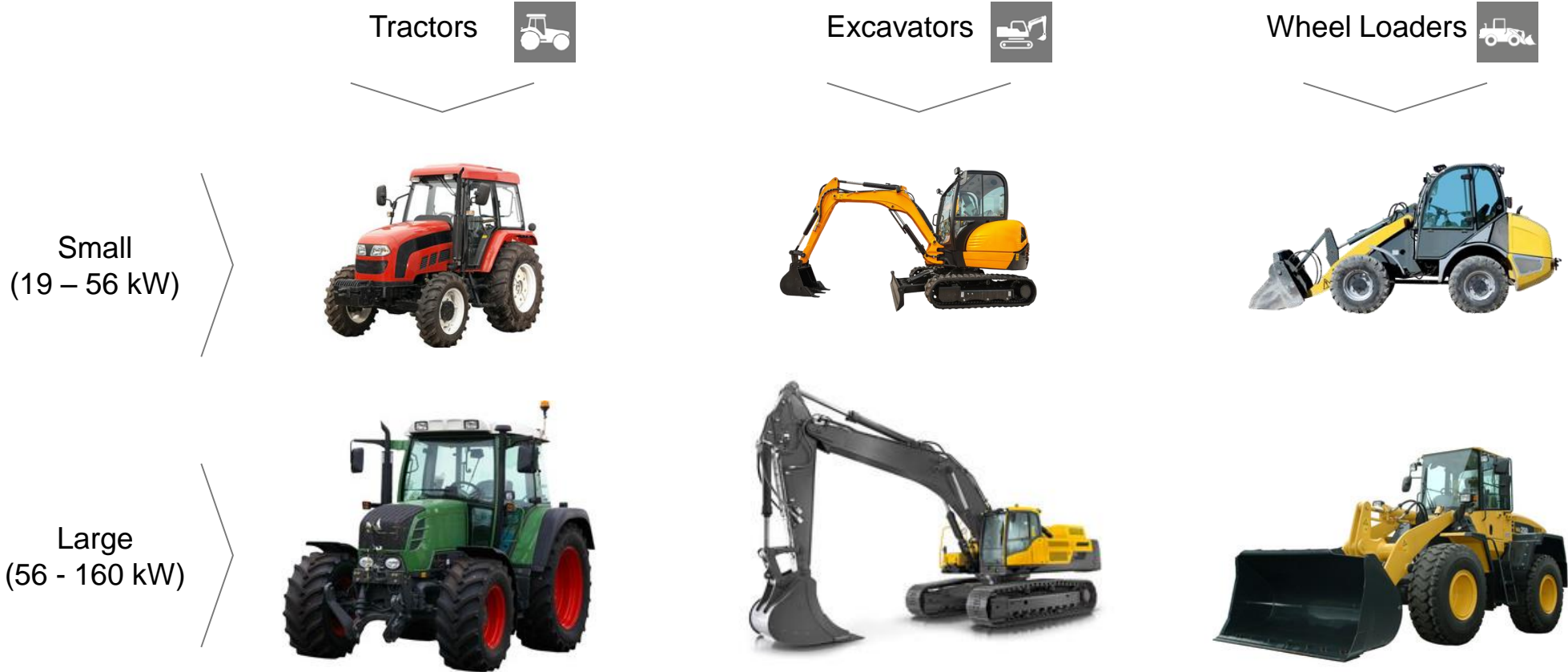
- Graph shows result of EU, USA and China markets
 - In total, 10 million powertrain units in 2016
- In the base scenario for 2030 manufacturing process value creation increases compared to 2016 – key reasons:
 - Increase of overall commercial vehicle sales driven by EU and Chinese market
 - Powertrain electrification, i.e. mild and full hybrid powertrain as well as plug-in hybrid powertrain
 - Conventional powertrains with advanced technologies for efficiency improvement
 - Shift to electric powertrains
- In the accelerated scenario overall manufacturing process related value creation is almost constant – Machining, primary shaping and forming decrease
- Major difference of scenarios is the share of electric vehicle in year 2030
 - 31% in base scenario
 - 42% in accelerated scenario
- Overall sales volume is equal for both scenarios

¹) values shown represent manufacturing process related value creation (excl. raw material and basic components, excl. overhead and profit); CAGR = compound annual growth rate
Source: FEV

- Conclusions and study approach
- Passenger car market
- Commercial vehicle market
- Non-road mobile machinery
- Follow-up services
- Contacts

VDMA and FEV jointly agreed on 6 segments to be investigated: tractors, excavators and wheel loaders, each divided in small and large applications

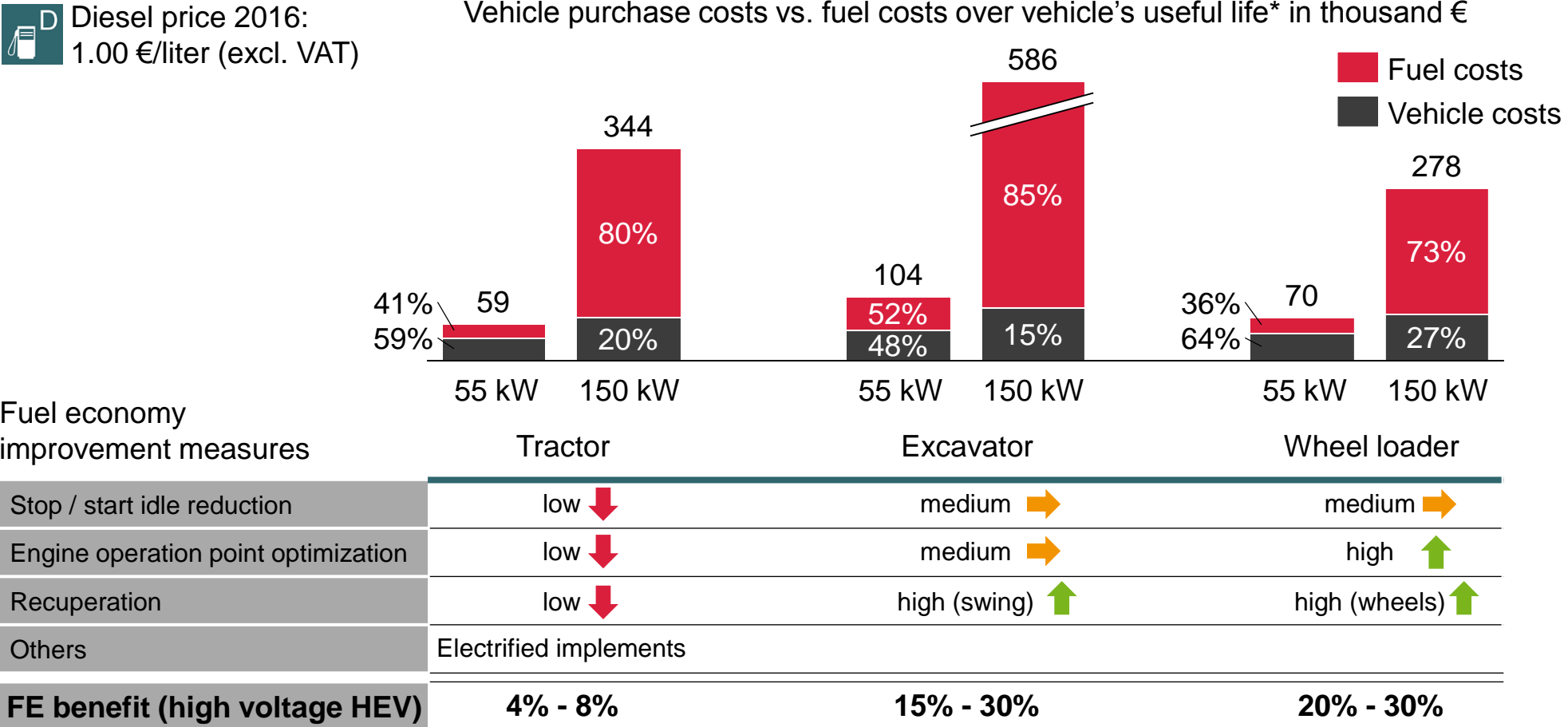
APPLICATION OVERVIEW



Source: OEM, FEV, fotolia

While fuel consumption reduction through hybridization is limited for tractors, excavators and wheel loaders show significant fuel economy benefits

FUEL ECONOMY REDUCTION POTENTIAL BY APPLICATION

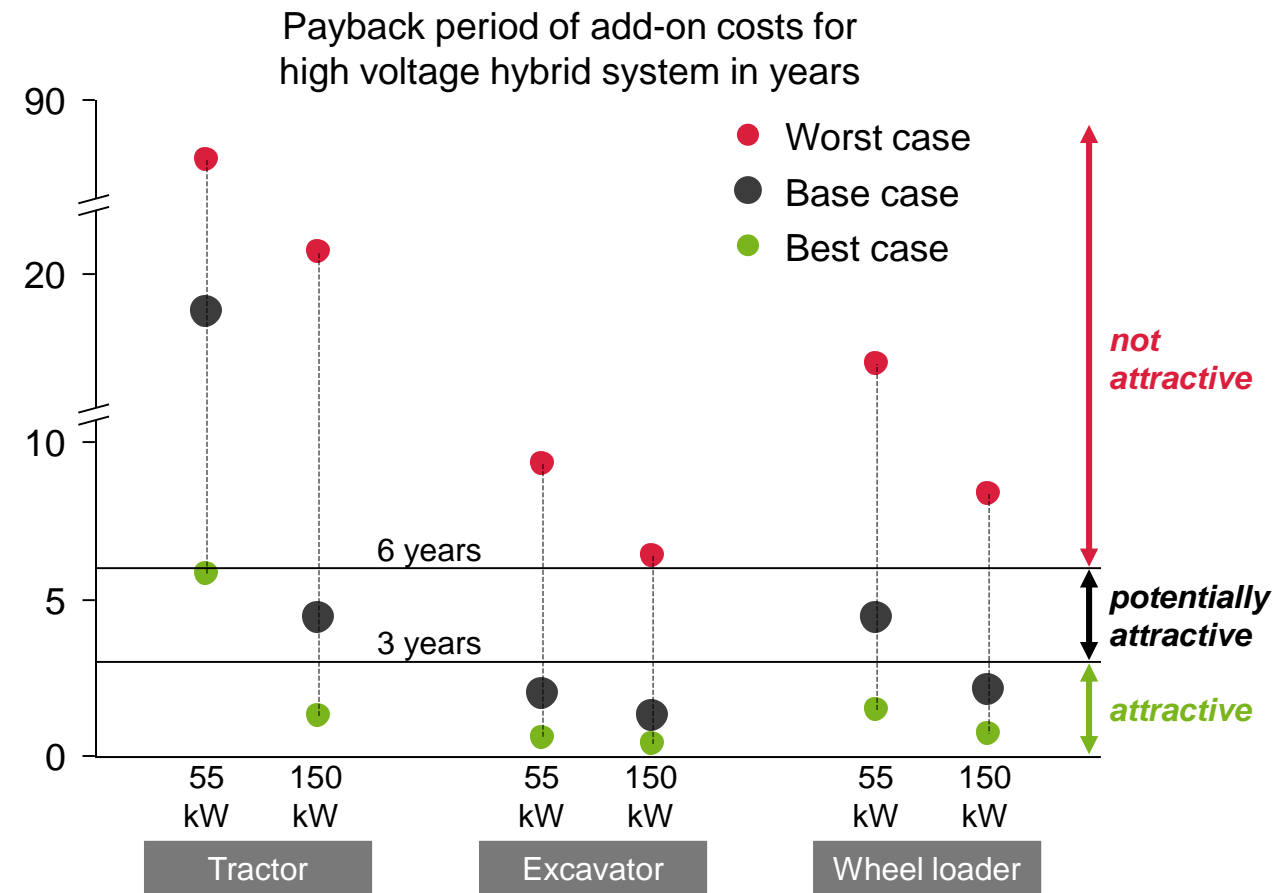


*useful life: 55 kW tractor: 8 years, 150 kW tractor: 10 years, 55 kW excavator: 8 years, 150 kW excavator: 12 years, 55 kW wheel loader: 8 years, 150 kW wheel loader: 12 years

Source: FEV

In terms of payback periods of add-on costs small and large excavators as well as large wheel loaders are most suitable for hybridization

TCO 2030: SENSITIVITY ANALYSIS – CONVENTIONAL vs. HIGH VOLTAGE HYBRID



- In general payback periods of add-on costs for hybrid systems up to 3 years are considered to be accepted by the customer and therefore considered attractive
- Payback periods longer than 6 years are expected not to be accepted by the customer
- In the base case small and large excavators as well as large wheel loaders achieve payback periods of less than 3 years
- Payback periods of large tractors and small wheel loaders are below 3 years in the best case scenario
- However, further drivers for electrification need to be taken into account (e.g. electrification of implements for tractors)

In addition to financial benefits (TCO) further drivers and inhibitors of electrification need to be taken into account

DRIVERS AND INHIBITORS OF ELECTRIFICATION IN NRMM SECTOR

Drivers

- Plug-in hybrid and full electric vehicle concepts allow for (partially) zero tailpipe emission driving
- Introduction of zero emission zones would drive fast introduction of battery electric construction equipment (e.g. excavator, wheel loader, etc.)
- However, in the base scenario FEV does not assume construction equipment to be significantly affected by zero emission zone regulations until 2030
- Hybrid or full electric vehicle concepts enable electrification of implements (tractor)
- In the construction segment noise regulations can be a driver for electric powertrains (e.g. allowance for electric construction equipment to operate over night)
- Hybridization concepts can enable cost savings for exhaust aftertreatment systems (e.g. by optimization of engine operation strategy, downsizing)

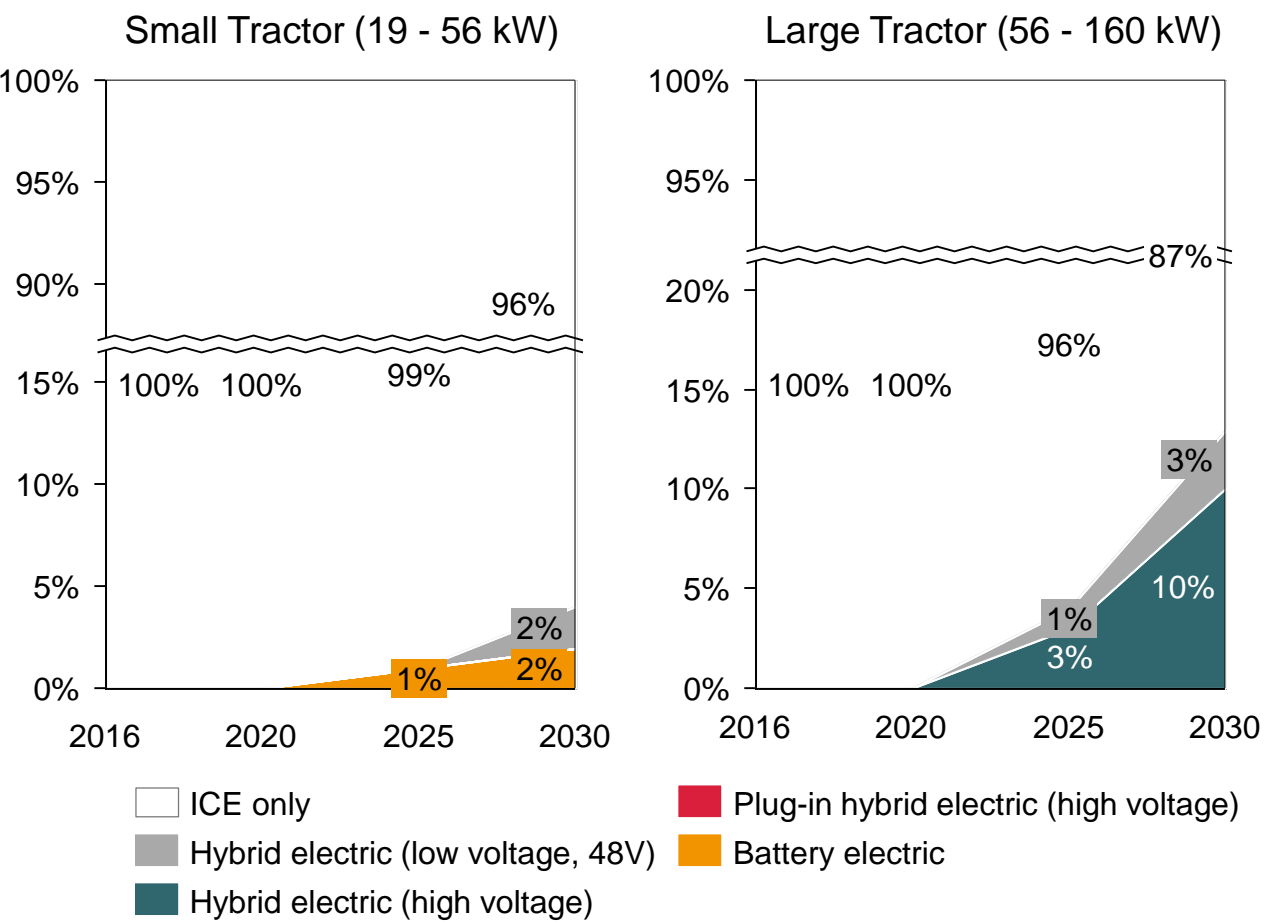
Inhibitors

- Smaller applications (19 - 56 kW segment) are often used as rental vehicles – hence the person / company, who makes purchasing decision does not use the vehicles and in turn is less interested in fuel economy
- High complexity of hybrid powertrain systems pose challenges regarding reliability and durability, which is a major buying criteria
- Boundary conditions for NRMM use-cases (e.g. dust, high temperatures, etc.) also pose challenges for durability of electric propulsion components
- Customers (esp. for construction) are skeptical towards electrified powertrain concepts mainly regarding their reliability and durability
- Comparably long development cycles need to be taken into account, when estimating market penetration of electrified vehicles

In large tractors low and high voltage hybrid applications are expected in the long-term mainly driven by electrification of implements



TRACTOR: ELECTRIFICATION FORECAST

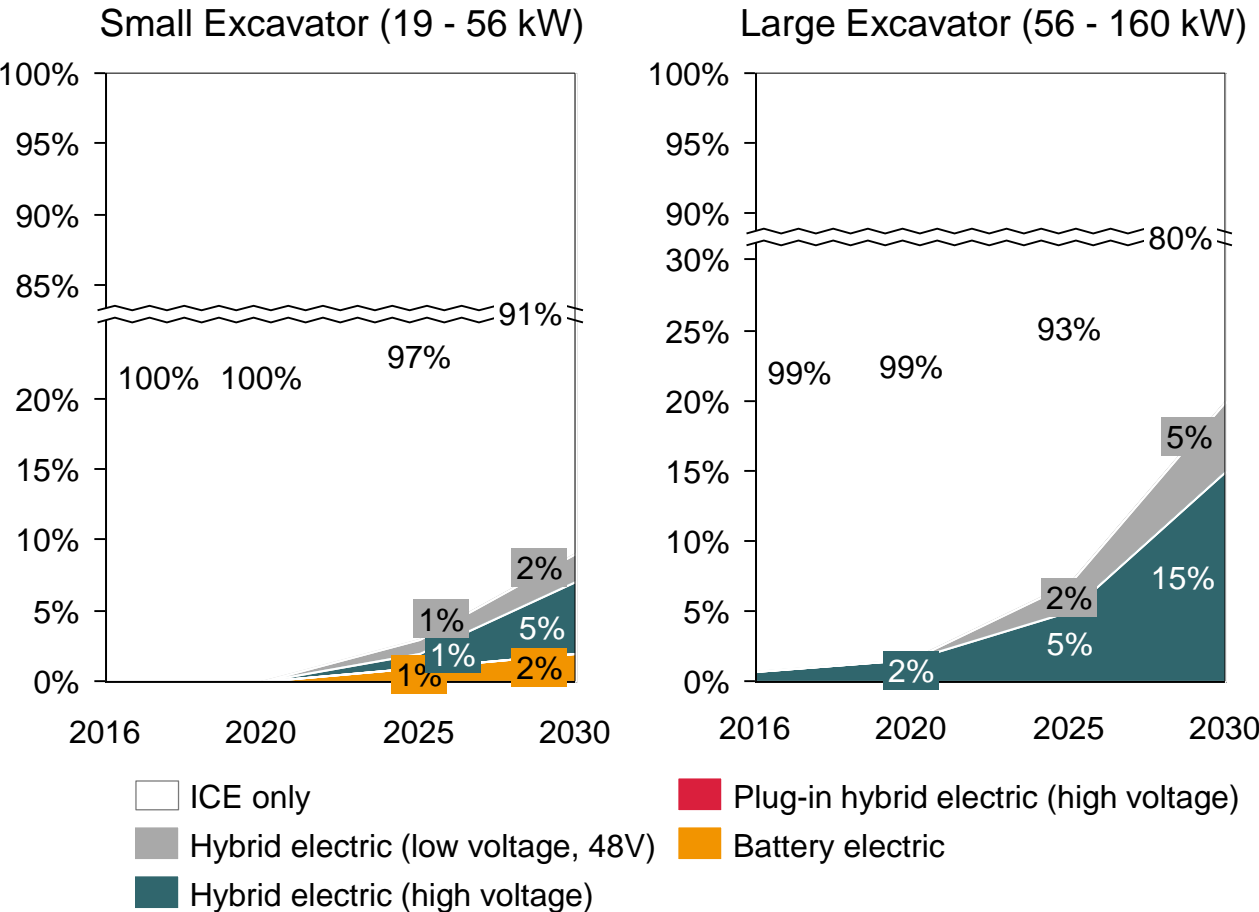


- Fuel economy reduction potential through electrification is limited for tractor applications – however electrified accessories expected to reduce fuel consumption
- Hence, electrification mainly driven by possibility to electrify implements
- BEV in small tractors can be expected for use-cases which don't require large battery capacities – main drivers are:
 - Less maintenance compared to conventional powertrains
 - Direct utilization of electricity generated on farms (e.g. solar panels)
 - Usage of technology applied in indoor construction equipment (forklifts, excavators)

Source: FEV

Driven by substantial fuel economy benefits hybrid electric applications are expected to gain significant market shares in excavators

EXCAVATOR: ELECTRIFICATION FORECAST

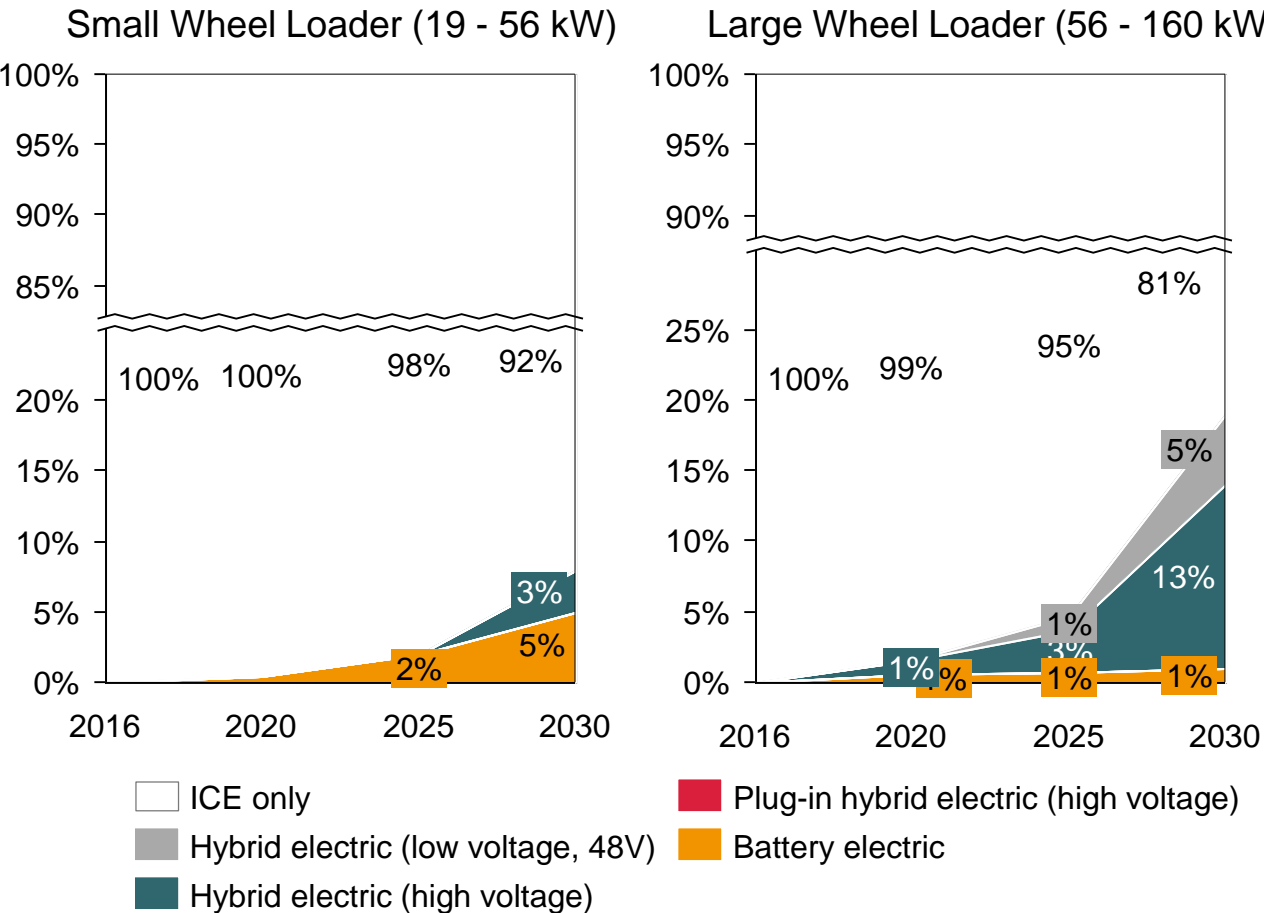


- Substantial fuel economy benefit of hybrid powertrains main driver for market penetration, mainly due to electrification of swing (incl. recuperation)
- Smaller applications (19 - 56 kW segment) are often used as rental vehicles – hence the person / company, who makes purchasing decision is less interested in fuel economy
- BEVs on lower end of 19 – 56 kW segment expected, because moderate battery size (< 50 kWh) is sufficient and low noise emission can be useful
- Durability/reliability of hybrid powertrains is major challenge as well as major concern of customers – hence acceptance and market penetration is long-term process
- No significant impact of zero emission regulation of construction equipment is assumed

Considerable hybridization in large wheel loader segment is expected in 2025+; full electric powertrains for underground mining applications

WHEEL LOADER: ELECTRIFICATION FORECAST

Full electrification forecast
(6 segments for EU, USA and
China) available in the full report



- Substantial fuel economy benefit of hybrid powertrains main driver for market penetration, mainly due to “peak shaving” and recuperation in highly transient cycle
- Durability/reliability of hybrid powertrains is major challenge as well as major concern of customers – hence acceptance and market penetration is long-term process
- BEVs on lower end of 19 – 56 kW segment expected, because moderate battery size (< 50 kWh) is sufficient and low noise emission can be useful
- BEVs in large wheel loader segment are underground mining applications
- No significant impact of zero emission regulation of construction equipment is assumed

Source: FEV

- Conclusions and study approach
- Passenger car market
- Commercial vehicle market
- Non-road mobile machinery
- Follow-up services
- Contacts

Based on the study “Wandel im Antrieb!?” we like to offer follow-up services which will be customized to the individual needs

EXAMPLES OF FOLLOW-UP SERVICES

#	Item	Description	Cost in EURO
1	Introduction of study	Presentation and discussion of study results within half day workshop on-site, provides additional background information; (reduced price exclusively for members of VDMA)	5,000.-
2	Client specific impact analysis	Analyzing clients product portfolio, e.g. manufacturing processes or components, regional and technology specific, deep-dive in requirements, production process organization and supply chain	PoR
3	Business opportunities strategy	Analyzing core competencies and capabilities to identify new opportunities within the area of electric powertrain systems and components, market potential, competitor analysis, idea creation workshop, development of implementation scenario	PoR
4	Implementation of transformation strategy	Evaluation and prioritization process, competence build up scenario, target screening, market entry strategy development	PoR
	Study results (full report)	The full report of the study will be available for download on March 1 st 2018 exclusively for members of VDMA (http://elektromobilitaet.vdma.org/)	Free
	Presentation of study results	Study results are presented at various events and meetings of the VDMA	Free / PoR

PoR = Price on Request
Source: FEV

- Conclusions and study approach
- Passenger car market
- Commercial vehicle market
- Non-road mobile machinery
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- **Contacts**



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