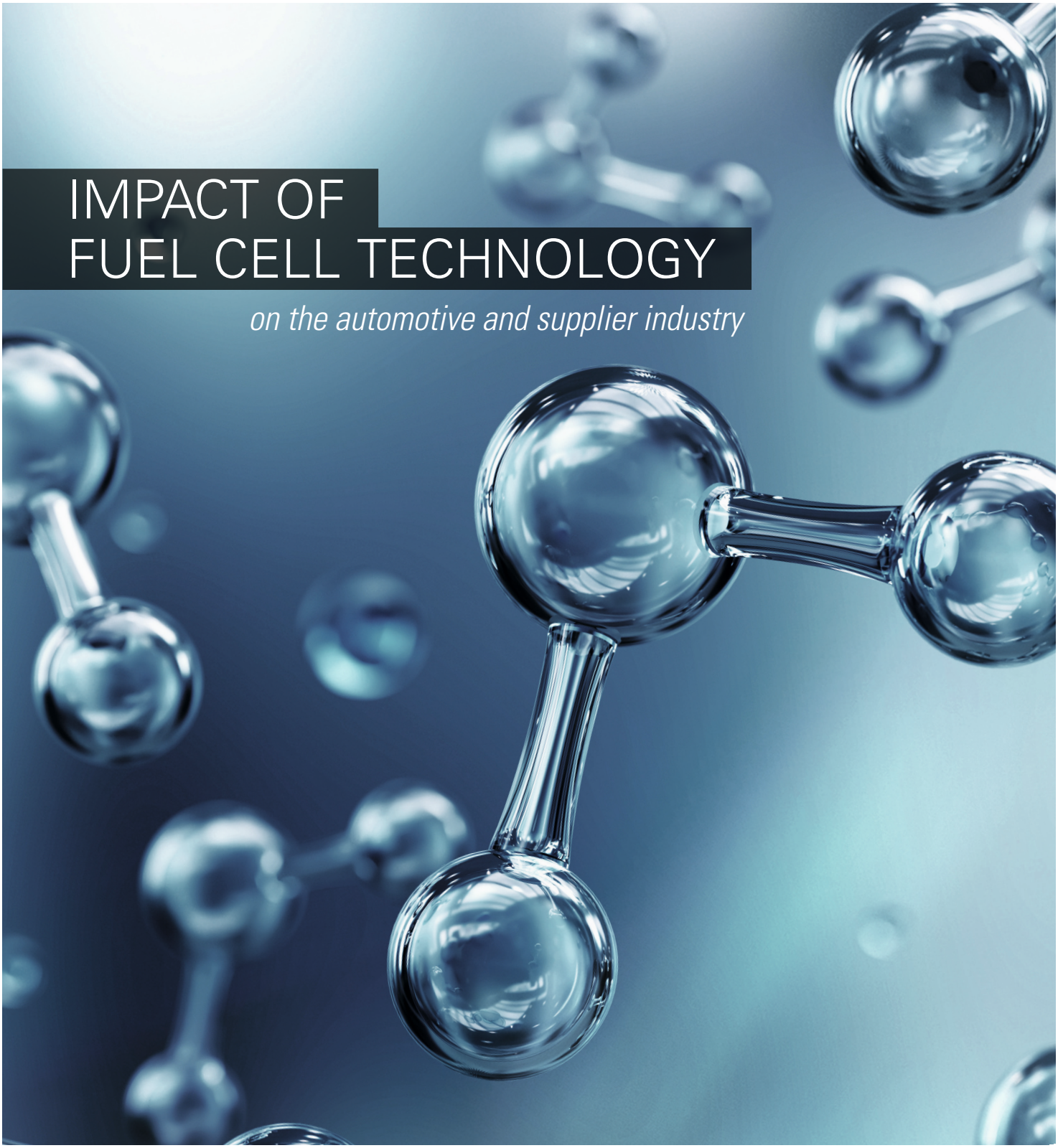
IMPACT OF FUEL CELL TECHNOLOGY

on the automotive and supplier industry



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GLOBAL MARKET DEVELOPMENT

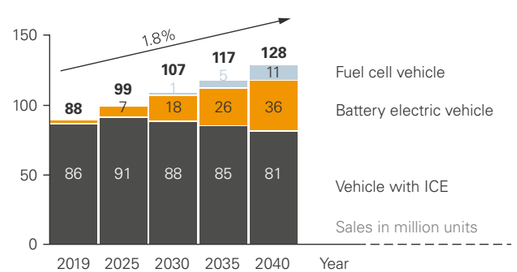
PASSENGER CAR MARKET

Global passenger car markets are expected to shift towards electrified powertrains in the next years. Starting from 2030, electrification will also be supported by the introduction of over 60 million fuel cell vehicles. Japan and South Korea are expected to be the first movers towards fuel cell vehicles showing already significant market shares by 2030.

The three major passenger car market regions China, USA and Europe are expected to follow the first mover markets from the late 2020s onwards. This is also indicated by our Zero Emission Vehicle Index for Fuel Cell Passenger Car vehicles. It reaches 100 index points, i.e. a comparable level of attractiveness to conventional powertrain, in the early 2030s.The combined market share of these five key market regions will reach 12% by 2040, however with different regional market shares:

- Japan should achieve 6% fuel cell market share in 2030. Continued growth in popularity results in over 20% by 2040.A strong govern mental and societal push towards a hydrogen society is also supported by stringent well-to-wheel CO_2 emission regulation
- South Korea is expected to have a market share of 3% by 2030 which will rise to 14% in 2040, also mainly driven by governmental push
- China is expected to show a market share below 2% in 2030 as currently especially battery electric vehicles are subsidized. However, the market share will rise to 14% until 2040 displacing plug-in hybrid vehicles and conventional powertrains
- USA and Europe and will only show limited market shares of fuel cell vehicles in 2030 of below 1%, which are expected to rise to 10% until 2040 due to further tightened emission regulation also mainly displacing plug-in hybrid and conventional powertrains

GLOBAL LIGHT-DUTY[1] VEHICLES SALES FORECAST



1) including passenger cars and light commercial vehicles up to 3.5t gross vehicle weight

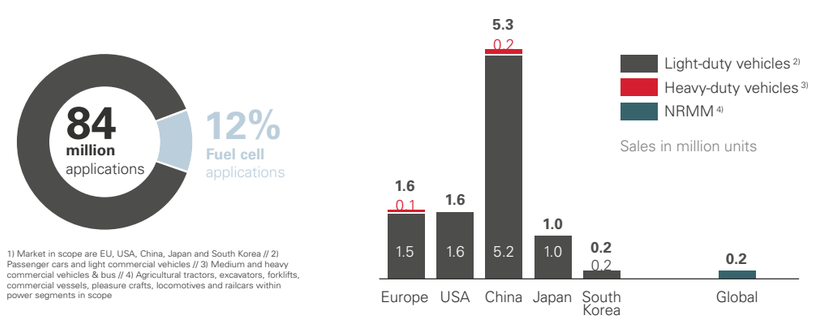
OTHER INDUSTRIES

Within other industries, fuel cell applications are expected to be introduced by 2030 and rolled-out towards 2040. Regarding on-road commercial vehicles, the heavy-duty vehicle segment will be a key driver, for example in Europe, due to the implemented stringent CO_2 emission regulations, but also in Japan and South Korea. Due to the comparably high energy throughput by commercial vehicles in general and heavy-duty vehicles in particular, the build-up of hydrogen filling stations is driven by the commercial vehicle segments.

Amongst non-road applications especially forklifts, rail and marine applications have a high likelihood of larger fuel cell sales shares. Already today, forklifts are equipped with fuel cells to extend operating time. Until 2030, we expected a further roll-out within the forklift market segments, also in higher power segments above 19 kW.

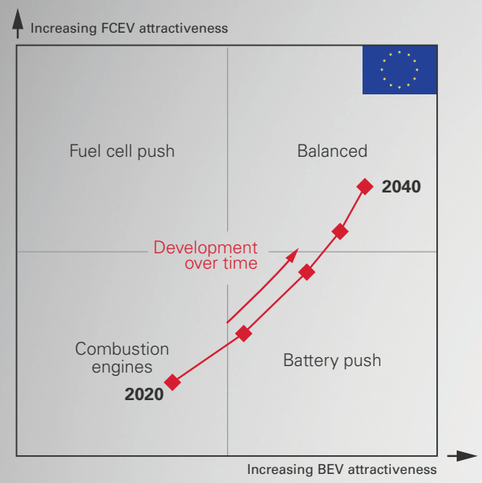
However, because of the limited total market size for these applications, sales volumes of fuel cell variants are expected to be smaller than those in the passenger car market by an order of magnitude.

GLOBAL MARKETS[1] FUEL CELL SALES IN 2040



1) Market in scope are EU, USA, China, Japan and South Korea // 2) Passenger cars and light commercial vehicles // 3) Medium and heavy commercial vehicles & bus // 4) Agricultural tractors, excavators, forklifts, commercial vessels, pleasure crafts, locomotives and railcars within power segments in scope

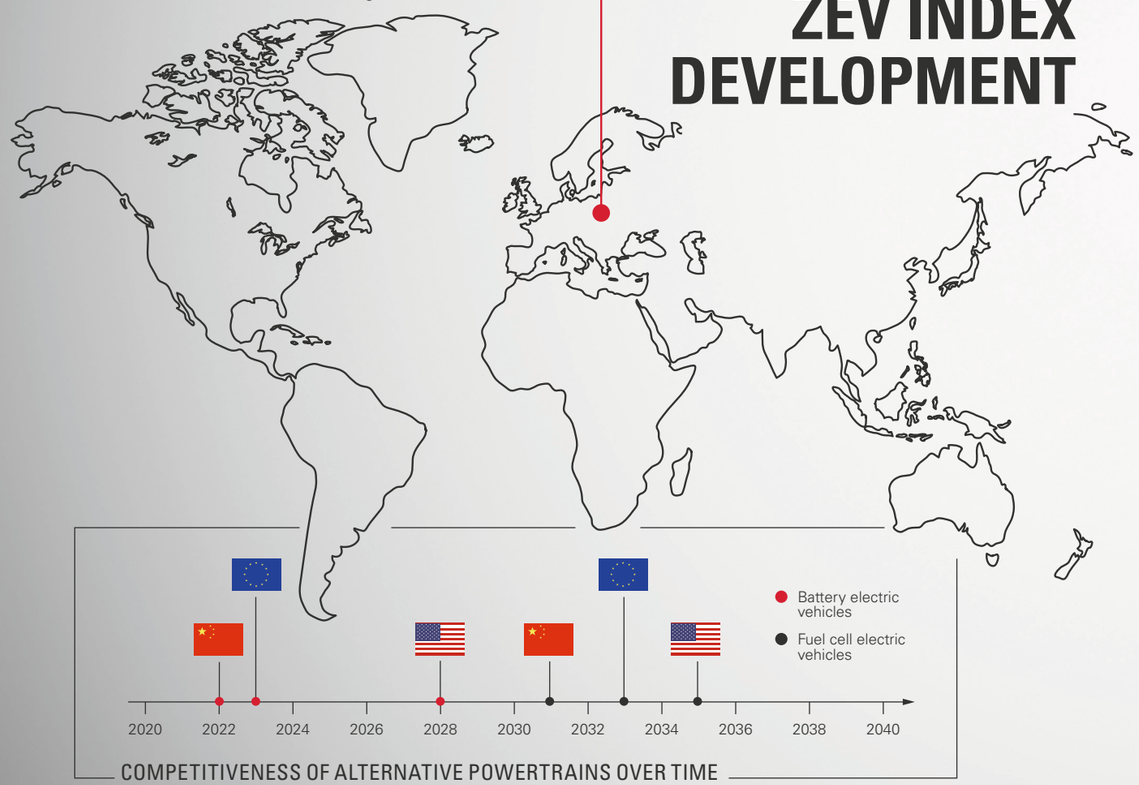
ZERO EMISSION VEHICLE INDEX



EU

GLOBALLY OVER
5 billion €
ANNUALLY R&D INVESTMENTS
IN THE NEXT YEARS

ZEV INDEX DEVELOPMENT



1.000 H_2 STATIONS
PLANNED TO BE IN OPERATION IN CALIFORNIA & GERMANY IN 2030

11x MORE ENERGY THAN BEV
HIGHER HYDROGEN GRAVIMETRIC ENERGY DENSITY COMPARED TO BATTERY[1] FITS BETTER FOR APPLICATIONS WITH HIGH ENERGY DEMAND

3-4 Minutes REFUELING TIME
A HYDROGEN FUEL CELL CAR NEEDS NEARLY THE SAME AMOUNT OF TIME AS A CONVENTIONAL CAR TO REFUEL

The Zero Emission Vehicle (ZEV) Index is our multidimensional framework to determine the competitiveness of alternative powertrains in comparison with conventional ones.

Currently, battery electric vehicles are gaining attractiveness and should be very competitive in Europe and China within next two years. The market USA shows some improvement space for electric vehicles on a country average level. Hence, the equal competitiveness status is achieved in the late 2020s.

By the early 2030s, fuel cell electric vehicles will be a viable alternative and attractive option. Their popularity should increase particularly in vehicle segments where consumers require longer driving range and fast refuelling.

100 ZEV index points indicate that the market and industry boundary conditions as well as the consumer attractiveness are on a similar level as for conventional powertrain. The evaluation is based on over 40 key indicators covering the six dimensions: regulation & policies, technology, infrastructure, industry, economics and social.

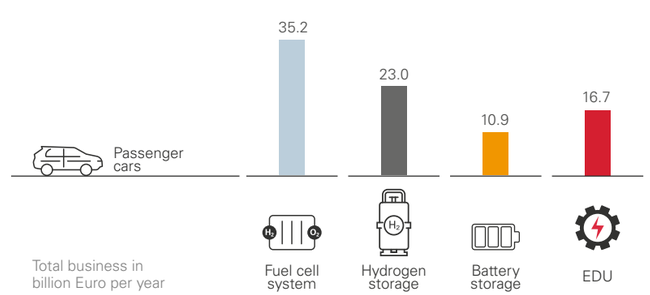
ZERO EMISSION
NO POLLUTANT AND CO_2 EMISSION WITHOUT RANGE ANXIETY FOR CUSTOMERS

VALUE CREATION

On the one hand, fuel cell powertrains comprise sub-systems and components which are new in automotive applications. On the other hand, well-known parts and components are also applied.

Especially the fuel cell stack, mainly consisting out of the bipolar plates and membrane electrode assemblies, will require new manufacturing technologies to be implemented. However, to operate the fuel cell stack, additional components are required that are summarized as Balance of Plant. These components in principle show higher similarities with existing components, like turbochargers, cooling systems or pipes, fittings and valves. For the hydrogen storage system, high manufacturing capacities of carbon fiber reinforced plastic will be required. In addition, each fuel cell electric vehicle also requires a (larger) battery and an electric drive unit, similar to the ones used within hybrid and electric vehicles.

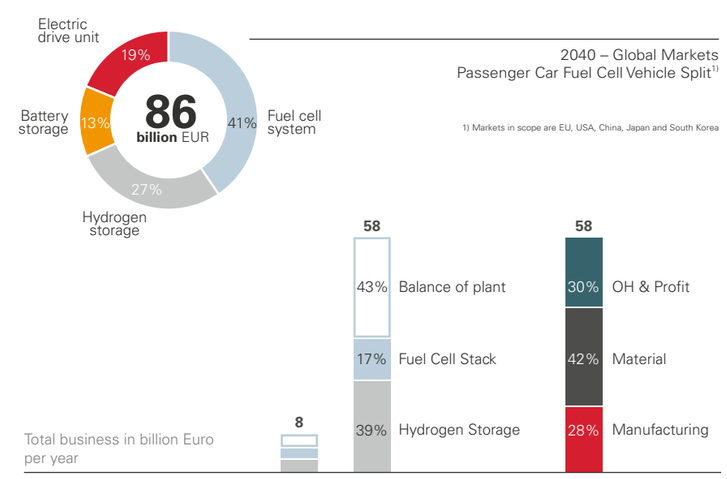
BUSINESS POTENTIAL BY POWERTRAIN IN 2040



For the considered market regions, the total business potential is expected to rise to nearly 86 billion Euro per annum for passenger cars by 2040. 32% of the business potential are generated by the electric powertrain, including the battery and the electric drive unit. Further 68% of the business potential is generated by the fuel cell and hydrogen system components reaching 58 billion Euro by 2040. Thereof 28% or 16 billion Euro per year is manufacturing value creation. Major drivers for the value creation are:

- Processes for forming, coating and changing material properties especially to produce the fuel cell stack components, with a total of 2.6 billion Euro per year
- Machining, especially for the compressor and expander modules used in the air system and the hydrogen guiding components and valves, with a total of 5 billion Euro per year
- Composite processing to produce hydrogen tank systems with a total of 1 billion Euro per year

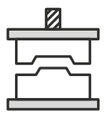
FUEL CELL POWERTRAIN SYSTEM



MANUFACTURING PROCESS ANALYSIS

MACHINING

Machining processes generate over 6 billion Euro of manufacturing value creation in 2040. Major contributors are the balance of plant components (e.g. compressor-expander-motor unit) and the hydrogen feeding parts (e.g. manifolds, valves, lines) required in the balance of plant and hydrogen tank.

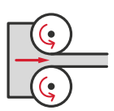


PRIMARY SHAPING

Primary shaping processes generate over 2 billion Euro of manufacturing value creation in 2040. Most of the value creation happens within the production of balance of plant components. Further value is created by housing components within the electric powertrain, for example the housings of the electric drive unit or the battery housing.

JOINING AND ASSEMBLY

Joining and assembly processes are present within many fuel cell vehicle components. Major contributors are the balance of plant and the hydrogen system due to the number of parts that are assembled. Also, the fuel cell stack generates nearly 1 billion Euro of value creation. The total value creation is expected to be nearly 6 billion Euro in 2040.



FORMING

Major forming processes within fuel cell powertrains are used for the bipolar plates and the hydrogen tank. Also, the air and hydrogen guiding systems within the balance of plant require forming processes. The total value created is expected to reach nearly 2 billion Euro in 2040.

COATING

Coating processes are primary applied to the fuel cell stack and required for example for the bipolar plates and components of the membrane-electrode-assembly. The total value is expected to reach 0.9 billion Euro in 2040.

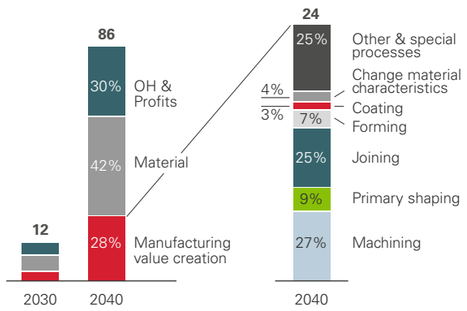
OTHER & SPECIAL PROCESSES

Other and special processes also account for nearly 7 billion Euro of value creation in 2040. However, the major contribution is the production of battery cells used within the fuel cell vehicles, followed by electronic components and the composite processing for the carbon-fiber tanks.

86 BILLION EURO TOTAL BUSINESS

BILLION EURO 24 VALUE CREATION

FUELL CELL ELECTRIC VEHICLE POWERTRAIN SYSTEM



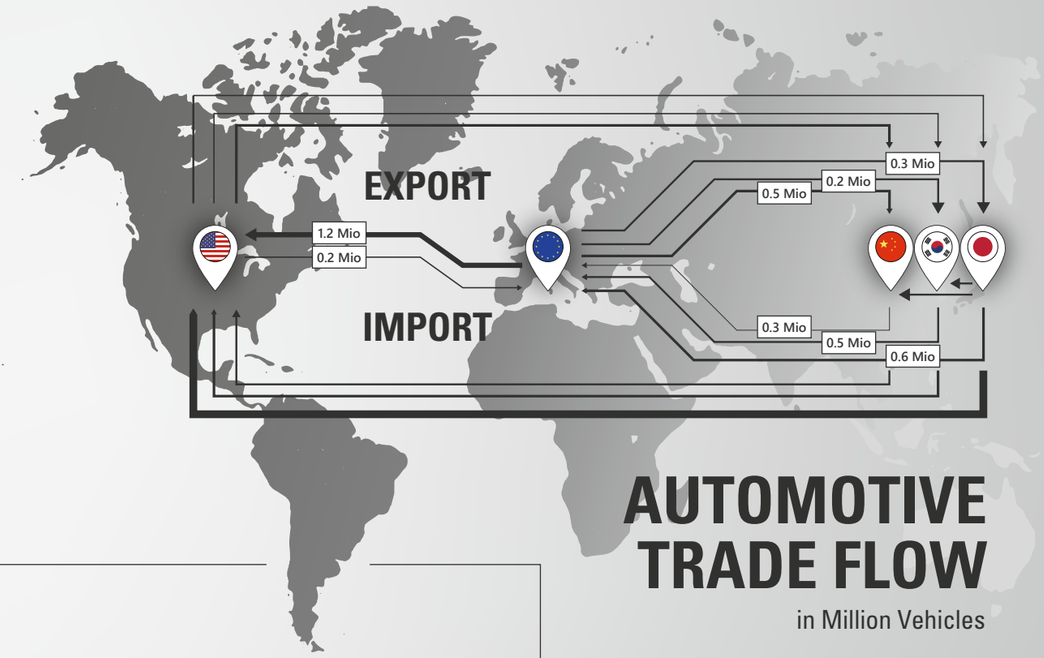
MANUFACTURING VALUE CREATION FCEV POWERTRAIN IN 2040

Total business in million Euro per year

			Machining	Primary Shaping	Joining & Assembly	Forming	Coating	Changing material properties	Other special processes
Fuel Cell Powertrain Systems	Fuel Cell System	Fuel Cell Stack	67	44	850	273	644	209	340
		Balance of Plant	2,378	1,049	2,066	637	145	152	1,105
	Hydrogen storage	Tank	335	21	0	0	0	246	760
		Others	2,214	463	1,428	320	0	0	612
Electric Powertrain Systems	Battery storage	Battery Cells	0	0	0	0	0	0	1,920
		Battery Pack	86	271	506	110	4	0	131
	EDU & Other Electronics	Electric Motor	555	139	353	0	2	233	658
		Traction Inverter	204	159	342	34	5	0	243
		Transmission	607	64	316	257	26	108	123
		Other Electronics	83	53	93	10	1	0	68

SUPPLY CHAIN ANALYSIS

The calculated manufacturing value creation is based on the vehicle's sales destination. For Europe, the number of vehicles sold is equal to the number of vehicles produced. Thus, the vehicle sales are an appropriate proxy to determine the vehicles produced. To further account for the design of a supply chain, two scenarios have been evaluated:



AUTOMOTIVE TRADE FLOW

in Million Vehicles

FUELL CELL VALUE CHAIN

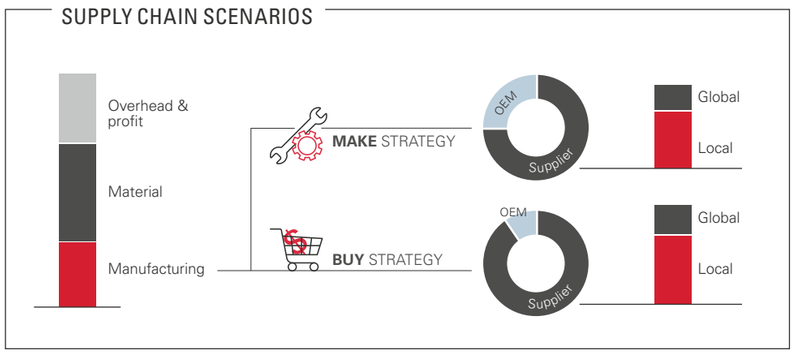
For the European automotive industry

DEVELOPMENT	FUEL CELL STACK COMPONENTS	SUBSYSTEM SUPPLIER & INTEGRATOR	OEM	INFRASTRUCTURE	RECYCLING & AFTERSALES
Globally over **5 bn** EURO annual R&D investments in the next years	**11 bn** IN 2040 EURO	Euro revenue from passenger car[1] passenuel cell powertrain components[2]		BELOW **5 Euro** per kilogram hydrogen fuel price[4] from 2030 onwards	More than 95% recycling of platinum used in MEA possible
	MORE THAN **68 k** jobs	jobs generated in the automotive industry, over 15 k in manufacturing[3]			
	OVER **8 bn** EURO INVESTMENTS	Euro of nominal invested capital required for manufacturing in 2040			

1) Comparably low impact of other applications on the entire economy
2) Fuel cell system (stack & Balance of Plant) and Hydrogen storage
3) Jobs generated as OEMs and suppliers producing components and systems as well as jobs within the machinery industry
4) Based on 1.3 EUR / kg production cost in 2030 assuming a moderate scenario with MENA production location boundary conditions

SUPPLY CHAIN STRATEGIES

The economic impact for Europe is analyzed by evaluating two supply chain scenarios. Within the scenarios we considered a production location, i.e. produced locally in Europe or elsewhere, for each component. Further, we determined whether the component is produced by the OEM or sourced from a supplier.



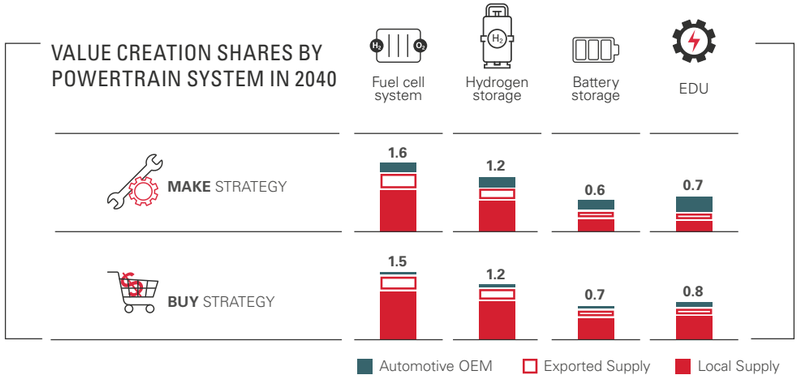
The total value creation in Europe differs between the two scenarios of the OEM value creation share.

On the one hand, the OEM make scenario leads to a higher share of OEM value creation which is expected to be local value creation. More value creation is being generated in Europe. On the other hand, the OEM make scenario reduces the share of supplier value creation which also limits the global automotive parts supply market, with has a negative impact on the value creation within Europe, since Europe is a net export region regarding this commodity.

In total, both effects counteract each other partially, such that the total impact on the value creation generated in Europe is below 5%.

OEM MAKE SCENARIO

This scenario is based on a higher share of components, produced by the OEMs in-house. In focus of the OEMs is the integration of the fuel cell stack components to a stack. In addition, some fuel cell stack sub-components (e.g. bipolar plates) are manufactured by most OEMs as well as the hydrogen tanks. Partially, also key components of the balance of plant are produced in-house, like the compressor-expander-motor unit. Furthermore, the integration and final assembly of the fuel cell system is conducted in-house. Most OEMs insource the manufacturing of the electric drive units, besides the electric components within the traction inverter. Also, the battery cell production and the battery module & pack assembly is insourced by approximately half of the OEMs.



OEM BUY SCENARIO

This scenario assumes a much lower share of in-house production by the OEMs regarding fuel cell powertrain components. OEMs concentrate on the integration of finished fuel cell system components, like the stack or Balance of Plant subsystems. The major value creation is generated by the suppliers which offer finished system solutions to many OEMs to further leverage production volumes. The same applies to the electric drive unit and the battery, which is offered as off-the-shelf solution by larger system integrator suppliers.

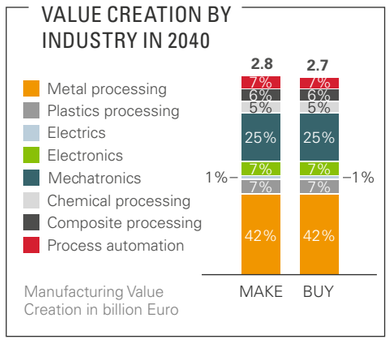
ECONOMIC IMPACT

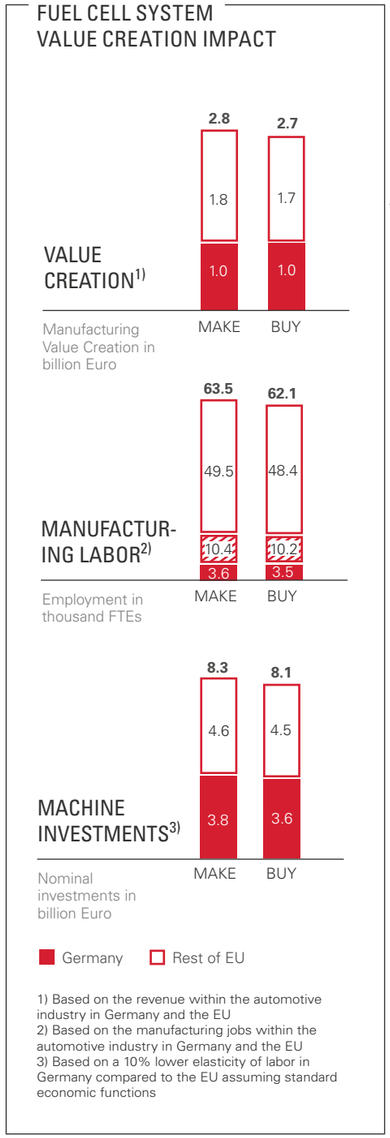
EUROPE

The manufacturing value creation of powertrains for fuel cell passenger cars sold in Europe by 2040 is expected to reach 4.3 billion Euro annually. In both supply chain scenarios, the related manufacturing value creation that occurs in Europe is higher, and is expected to reach up to 4.8 billion Euro annually. This underlines Europe's position as a net exporting region for automotive industry goods.

Although the OEM value creation is significantly lower in the "Buy" scenario, this is partially counteracted by increased local supplier value creation. In addition, the total exports of automotive parts are increased, resulting in a net positive effect in European value creation of roughly 50 million Euros annually. The share of exported supply varies between 21% and 24% of the total supplier value creation in the two scenarios. Major target export regions are China and the USA. In both scenarios, the fuel cell specific powertrain components (fuel cell stack, balance of plant and the hydrogen storage) account for over 50% of the value creation or over 2.6 billion Euro respectively.

The related business potential (i.e. revenue) of fuel cell powertrain system components is expected at over 11 billion Euros annually in both scenarios. Beside the manufacturing value creation, this includes material and basic components costs as well as overheads and profits of the entire supply chain. Based on the analysis of the industry sectors affected, the manufacturing value creation will generate over 60,000 jobs until 2040, of which over 15,000 will be manufacturing jobs. Further, nearly 8 billion Euro of net invested capital into machines and production equipment are required in 2040 to serve the expected market demand.





GERMANY

Germany traditionally has a strong footprint in the automotive industry. This is valid for the OEM perspective as well as regarding the supplier landscape. The same is true for the chemical industry, which certainly plays a role when it comes to fuel cell subcomponents production.

The overall share of Germany's value creation of the value creation with origin in Europe is expected to be nearly 40%, which results in 4 billion Euro annual revenue by 2040 for fuel cell powertrain components assembled in passenger car vehicles. This translates into nearly 1 billion Euro annual manufacturing value creation by 2040.

Regarding the manufacturing value creation mechanisms, there is a clear imbalance between the countries in Europe. Although Germany generates some 40% of the revenue streams within the European automotive industry, only 22% of manufacturing jobs are located in Germany. This means that the revenues and manufacturing value creation in Germany are based rather on capital than on labor. This is underlined by the high degree of automation and the high productivity of Germany as a high-wage country. Due to that, over 12 billion Euro of machine and manufacturing equipment investments are required in Germany until 2040 for production of fuel cell specific powertrain components, in order to realize the revenue and employment potential given the macroeconomic boundary conditions .

FEV AT A GLANCE

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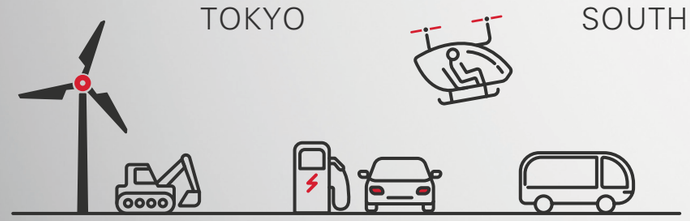
FEV GROUP OFFICES
IN EUROPE, NORTH AMERICA, SOUTH AMERICA AND ASIA



INDUSTRIES

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ANY QUESTIONS?

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WORK WITH 6500+ EXPERTS AROUND THE GLOBE

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