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11th PAGEV Turkish Plastic Industry Congress

Future of Automotive Industry and Innovation

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December 6th , 2016

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Key global automotive trends are driving OEMs towards light weighting and strength improvement of vehicles

Key Drivers of Emerging Alternate Materials

Key Global Trends

- **Emission norms** regulation
  - EUVI, BSVI and CAFÉ norms (CO2)
- Increased penetration of **alternate powertrains**
  - Hybrid vehicles (extra weight)
  - Dual fuel gas
- **Safety improvement**
  - Body & structural parts
  - Flexible cockpit

Key Implications for OEMs

- **Light-weighting**
- **Strength Enhancement**
- **Durability (Longer drive cycles)**

Alternate Materials

1. CFRP
2. GFRP
3. Ceramics
4. Others (Fe, Non-Fe)

Source: A.T. Kearney IC – 'Automotive material Industry Structure'

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Alternate materials offer weight & strength advantages but come at a cost of higher prices and manufacturing complexity

Alternate Materials Overview

	Material	Glass FRP[1]	Carbon FRP	Ceramics	High-end Plastics[2]	Non-Ferrous (Al, Mg)	High Tensile Strength Steel
	Parameters						
1	**Weight Reduction (to ordinary steel)**	• ~60% lighter	• ~60% lighter	• ~30% lighter	• LCP: ~75% lighter • PA: ~80% lighter • PC: ~75% lighter	• Al: ~40% lighter • Mg: ~35% lighter	• ~0-10% lighter
2	**Strength**	• 1500 MPa	• 750 MPa	• 200 MPa	• LCP: 100 MPa • PA: 80 MPa • PC: 70 MPa	• Al: 500 MPa • Mg: 150 MPa	• Bainitic Steel: 1200 Mpa (3x ordinary steel)
3	**Durability and Corrosion Resistance**	• Non-corrosive • Susceptible to high impact-breaking	• Corrosion resistant • Can withstand impact	• Can withstand high heat • Non-corrosive (electrical & chemical)	• Non-corrosive • Cannot withstand high temp	• Al: Moderate durability • Mg: High durability - good dampening capacity	• Durable but prone to corrosion
4	**Material Cost**	• ~4x ordinary steel	• ~12x ordinary steel	• ~7x ordinary steel	• ~4.5x ordinary steel	• Al, Mg: 2.5x steel	• Almost equal to steel
5	**Current Adoption Stage**	Nascent	Nascent	Nascent	Growth	Growth	Widespread Adoption
6	**Manufacturing Complexity**	High	High	Low	Medium	Medium	Low
7	**Recyclability**	Medium	High	Medium	Varies by type	High	High

1. Fiber Reinforced Polymer
2. PC: Polycarbonate, PA: Polyamide, LCP: Liquid Crystal Polymer
3. Compared to steel

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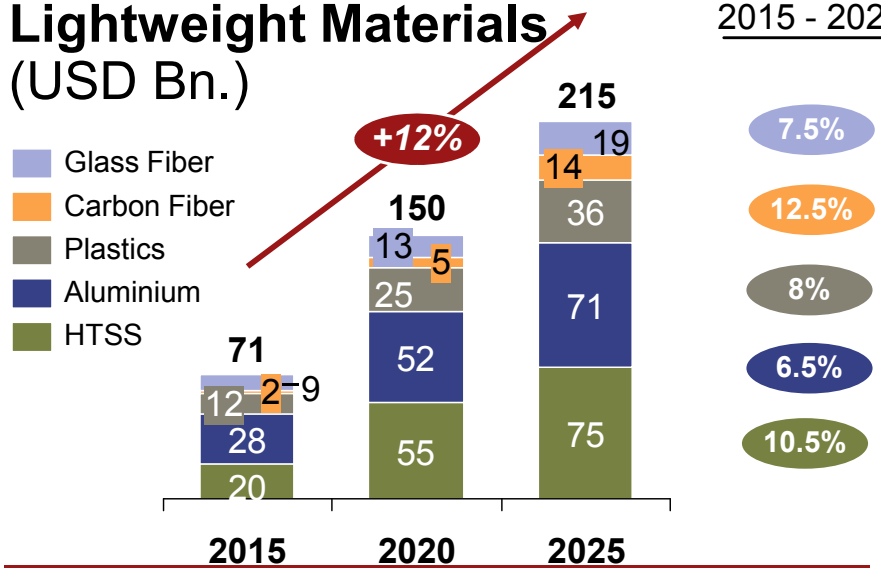
Lightweight material market set to grow at 12% CAGR over the next decade

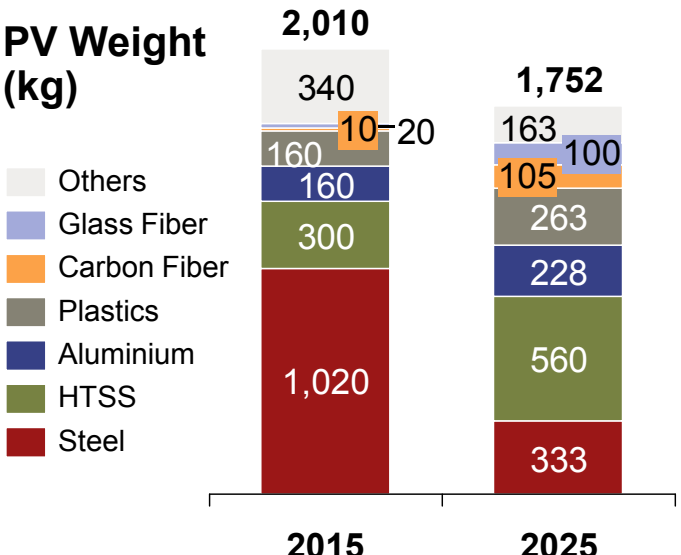
Market Size Of Auto Lightweight Materials (USD Bn.)



CAGR 2015 - 2025

- Glass Fiber: 7.5%
- Carbon Fiber: 12.5%
- Plastics: 8%
- Aluminium: 6.5%
- HTSS: 10.5%

PV Weight (kg)



CAGR 2015 - 2025

- Others: 17%
- Glass Fiber: 26%
- Carbon Fiber: 5%
- Plastics: 3.5%
- Aluminium: 15%
- HTSS: -10.5%

Key Automotive Systems driving growth

Powertrain

- Mercedes and Ford are using **Al-alloy** pistons in engine assembly for both PVs and CVs
- Bosch, Hirshvogel changing Common Rail (Diesel) from tempered steel to **Bainitic Steel**
- Testing of **thermoplastic** compressor housing by BMW, Mann & Hummel

Drivetrain

- Toray, BMW and Nissan have come out with a few models with **CFRP propeller shaft**
- Injection-moulded **GFRP in clutch pedals** by Porsche for its Spyder 918
- Oxide **Ceramic coated bearings** used for axle assembly, Resin gears in some models

Chassis

- Bosch using **ceramic brake pads** in sports-cars, Ferrari and Lamborghini adopting technology
- Wheel hubs and flanges for PVs changing from tempered steel to **Bainitic steel**
- Tesla Model S body made almost entirely from **Aluminium**, most lightweight design in HVs

Body and Interiors

- Audi A6 and Ford Focus (with Lanxess) built with **GFRP**, instead of steel
- Lexus using **CFRP** for latest LFA body exterior
- Molybdenum bearing dual phase **HTSS (DP 800 & DP 1000)** used for body pillar in Ford's PV Mondeo
- Honda and Porsche going for **hot-stamped HTSS pillars** for exterior of body

Source: Analyst Reports, A.T. Kearney

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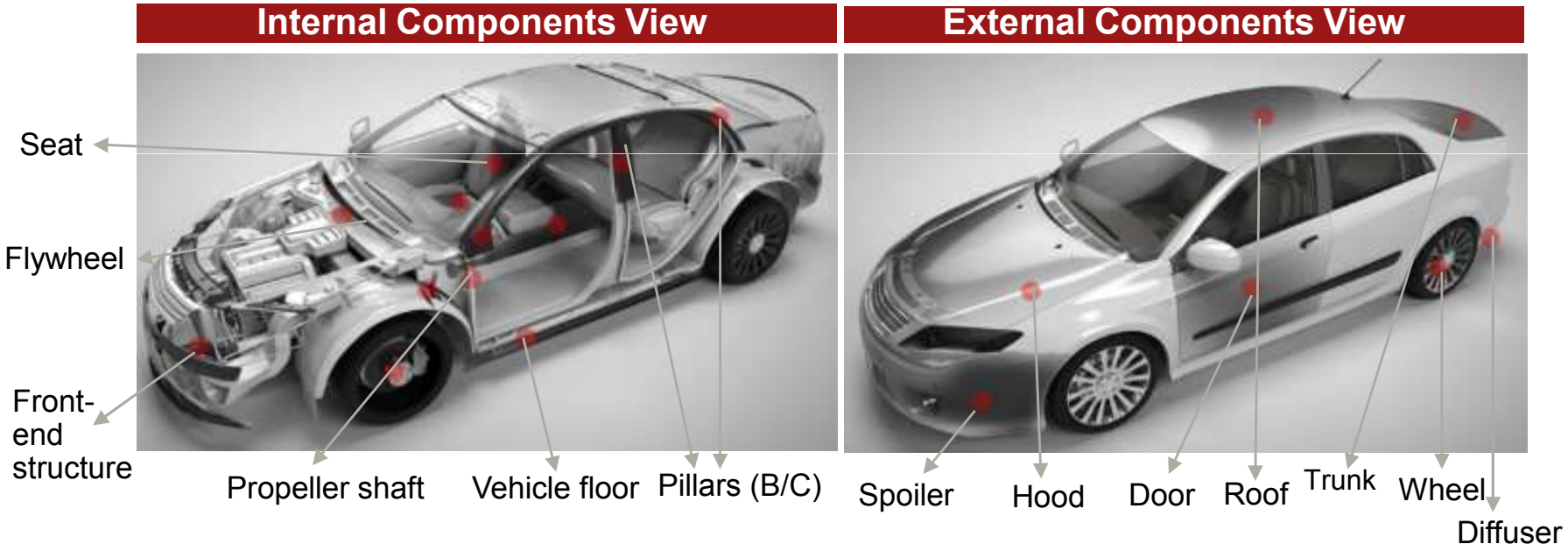
Carbon Fiber Reinforced Plastics (CFRP) are finding applicability in multiple auto components of a vehicle

CFRP Vehicle View



System	Powertrain		Drivetrain	Chassis		Body & Interiors		
Key Parts	 Flywheel	 Hydrogen Tank	 Propeller Shaft	 Wheel	 Vehicle Floor	 Mirror Case	 Hood	 Trunk Lid
OEM Examples	• Toyota Miray • Jaguar XF Saloon • Volvo S60		• BMW M3, M4 • Nissan GT-R, 350Z • Mitsubishi Montero	• Koenigsegg One:1		• Audi A4 • BMW i3, i8 • Ferrari 599XX		

Source: A.T. Kearney analysis

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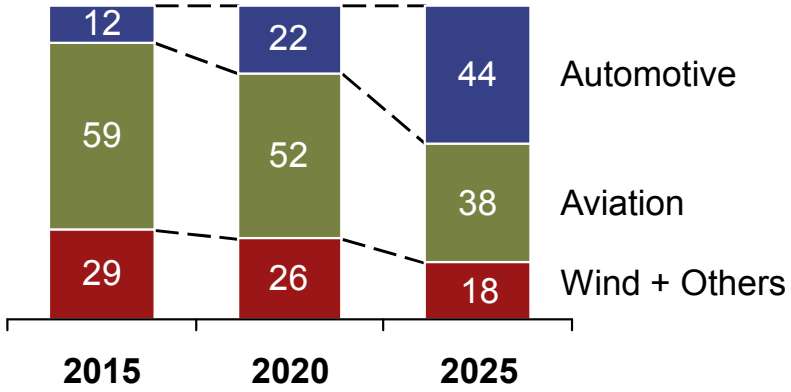
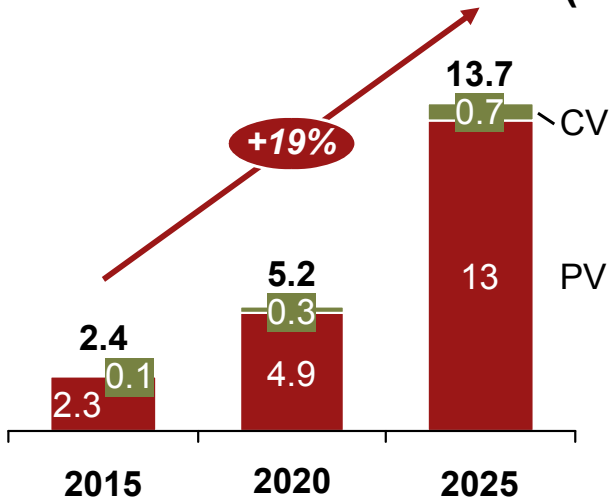
These auto applications will grow CFRP market at 19% CAGR (from 2015 to 2025) to reach ~$14 Bn. by 2025 globally

Auto Industry Split (%) and Global Market Size (USD Bn.)

CFRP Industry Split (%)



CFRP Auto Market Size Forecast (USD Bn.)



Key Insights

- Share of Automotive CFRP in 2025 is ~double than 2020
- Aviation parts technical knowhow will be transferable to automotive parts
- Auto OEMs and suppliers need to develop CFRP capabilities to become future ready e.g. BMW spent 10 years on developing CFRP

Key Observations

- Trend towards lightweight materials is driven by
  - need to improve CO_2 footprint
  - use of alternative powertrains
- Production will eventually reach sufficient volumes for mass production and guaranteed supply to OEMs by 2025

Source: A.T. Kearney analysis

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This market growth is driven by 50% lower weight and higher strength over steel; while cost remains a challenge

Benefits and Applicability of Carbon Fiber

Benefits (Carbon Fiber vs Steel)

Property	Ordinary Mild Steel	Carbon Fiber
Material Weight	x	0.3 - 0.5 x
Material Cost	y	8 - 10 y
Material Strength	z	8 – 10 z

CFRP Penetration

Year		2020		2025	
Geography		India	Global	India	Global
PV	Entry	○	○	○	◔
	Mid	○	◔	◔	◑
	Luxury	◔	◑	◑	◕
CV		○	○	◔	◔

○ Low ● High

Key Insights

- Weight reduction translates directly into fuel efficiency
- High cost barrier to be overcome through
  - raw material innovation
  - reduction in cycle time
- CFRP requires considerably less material thickness vs. steel to achieve the same strength characteristics

Key Observations

- CFRP will find applicability largely in PVs
- Within PVs, early adoption is driven by
  - Electric vehicles (BMW i3)
  - Fuel cell vehicles (Toyota Toray)
  - High-end cars (Audi R8)
- CFRP relevance in Indian cars is limited

Source: A.T. Kearney analysis

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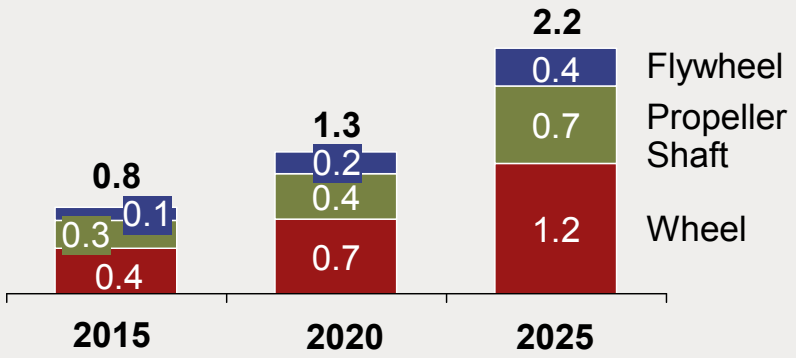
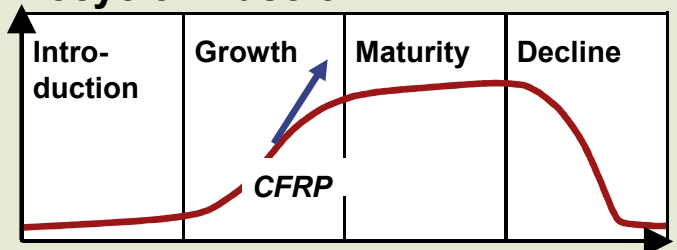
Increase in adoption of CFRP components is expected to take place over the next decade

Market Size of CFRP components (USD Bn.)



Lifecycle Phase of CFRP



- Few dominant players, but attractive for new entrants
- Moderate profits due to high investment and low sales

CFRP Component Manufacturers

CFRP Component Manufacturers	Component
Torotrak, Crompton	Flywheel
QA1, GKN Driveline, Precision Shaft	Propeller Shaft
Lacks, Carbon Revolution	Wheel
Gurit, Polytec, Sora	Body Parts

Key Observations

- OEMs collaborate with material/component makers on various purposes -
  - To secure material supply and demand stability
  - To share the material/component development cost

  e.g. **BMW** invest $135mn in **SGL** to secure the stable supply of CFRP for the BMW i3/i8 released in 2013

Source: Company information, A.T. Kearney

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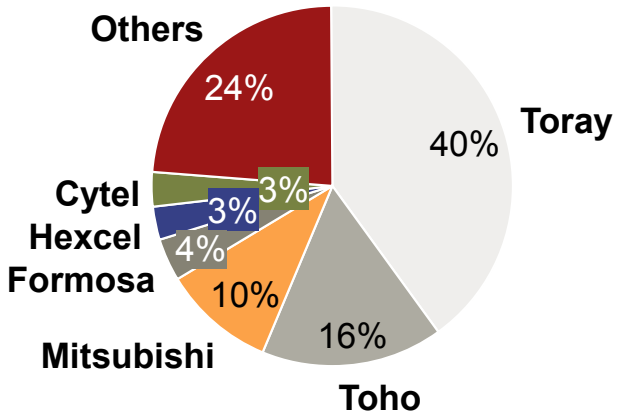
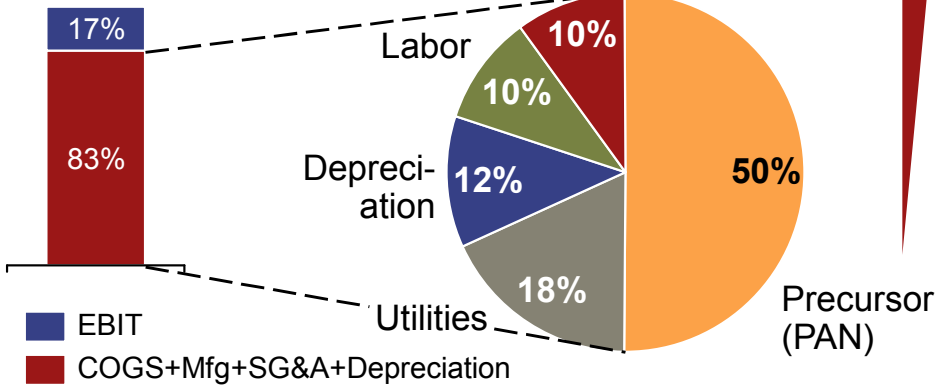
While market leader has moderate profitability; Raw material continues to be major (~50%) expense

Market Share of CFRP Players



Toray's CFRP Profitability



Cost Split

Key Insights

Supplier Concentration

- Supply primarily driven out of Japanese sources (>60%)
- Small suppliers with a market share of less than 2% account for one fourth of the market

Capex and R&D

- Despite high entry barriers (e.g. Capex requirements, deep R&D, high contract lengths), a number of new suppliers have entered the market recently
- Competitive advantage lies in R&D and continuous process innovation

Raw Materials

- Raw material (PAN) cost is 50% of final composite cost; to decrease in future years through material innovation

Profitability

- Moderately profitable segment, Suppliers need to lower cost for profitability improvement

Source: A.T. Kearney IC

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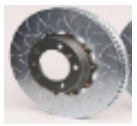
Glass Fiber Reinforced Polymers (GFRP) will find major applications in the powertrain and body of vehicles

Applicability across vehicle systems

System	Powertrain			Drivetrain	Chassis		Body & Interiors		
Key Parts	Engine mount	Cylinder head cover	Intake manifold	Pedal	Suspension spring	Brake disc	Front-end structure	Door module	Seat
									
	Holds the engine to the body	Valve cover over rocker arms in an ICE	Supplies fuel/air mixture to the cylinders	Lever to apply brake, clutch & accelerator	Absorbs shock and maintains ride stability	Part against which brake pads applied	Crash structure in the front of the car	Carrier on which door components fitted	Sitting surface on which cushion is placed
OEM Examples	• BMW i8			• Porsche 918 Spyder	• Audi A6 Avant		• Ford Focus • Mercedes Benz SLS-AMG		

GFRP usage will be applicable across both structural and non-structural auto components

Source: A.T. Kearney analysis

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This adoption will be driven by benefits such as GFRP's high strength to weight ratio compared to steel

Benefits (Glass Fiber vs Steel)

Property	Ordinary Mild Steel	Glass Fiber
Material Weight	x	0.3 - 0.5 x
Material Cost	y	2 - 3 y
Material Strength	z	4 - 5 z

Key Insights

- Strength to weight ratio is very high
- Since auto components use polymer reinforced with 30-40% glass fiber and not 100%, cost is not as high as it seems
- Although not as strong as CFRP, there is considerable strength advantage of GFRP over steel for structural components

GFRP Penetration

Year		2020		2025	
Geography		India	Global	India	Global
PV	Entry	○	○	◔	◔
	Mid	○	◔	◑	◑
	Luxury	◔	◑	◑	◕
CV		○	○	◔	◑

○ Low ● High

Key Observations

- GFRP is quickly finding applicability in PVs
  - 30% of intake manifolds are made of GFRP
- Early adoption is driven by PVs–
  - Electric vehicles (BMW i8)
  - Sports cars (Porsche 918 Spyder)

Source: A.T. Kearney Analysis

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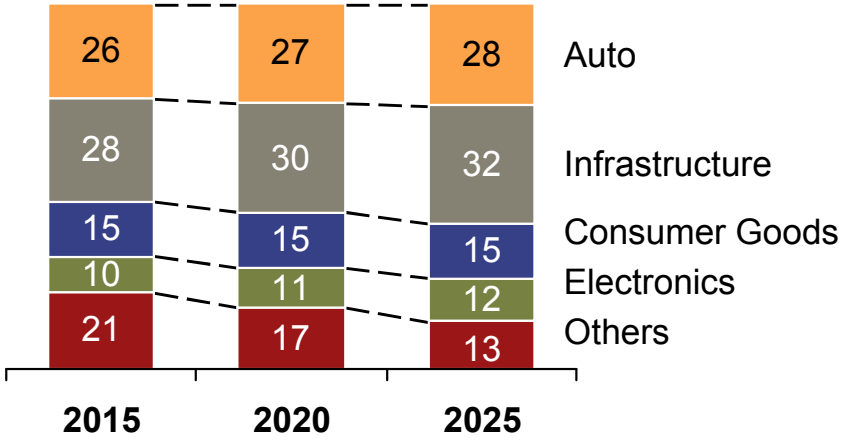
These auto applications will grow GFRP market at 8% CAGR (from 2015 to 2025) to reach ~USD19 Bn. by 2025 globally

Auto Industry Split (%) and Global Market Size (USD Bn.)

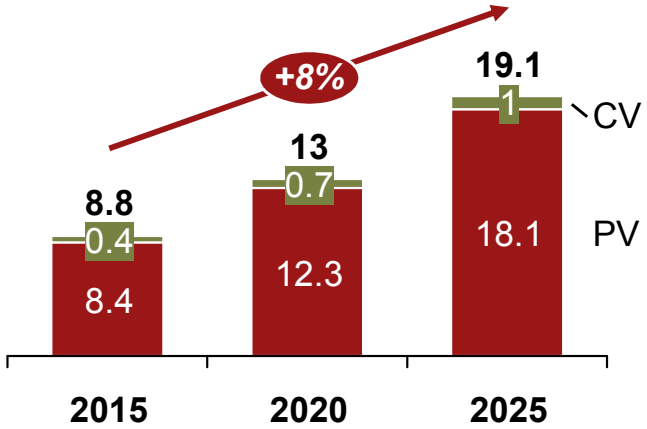
GFRP Industry Split (%)



Key Insights

- Share of auto is already significant; poised to slightly grow over the next decade
- With mass production capabilities, there will be increasing use of GFRP in large sectors such as construction & infrastructure

GFRP Auto Market Size Forecast (USD Bn.)



Key Observations

- Glass fiber composites will continue to emerge as the most cost effective composite in low to mid-value applications, especially in PVs
- Major adoption will be of hybrid GFRP parts and not pure GFRP parts

Source: A.T. Kearney analysis

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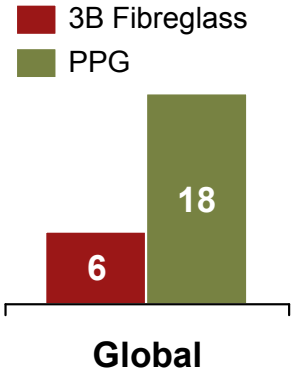
With growing market and moderate EBITDA margins, GFRP landscape is seeing acquisitions across the value chain

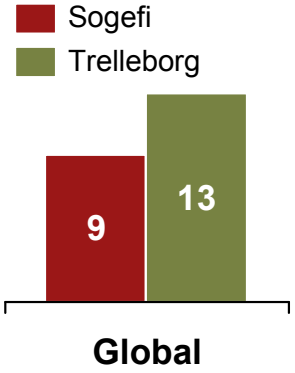
Profitability & Global Trends

Profitability (EBITDA %)

Glass Fiber Manufacturers



Component Manufacturers[1]



Key Acquisitions in GFRP

- **Solvay**, a chemical player, acquired **EPIC Polymers**' long-fibre thermoplastics business in 2015
- **Lanxess** acquired Germany's **Bond-Laminates**, a specialist in developing custom-made glass reinforced plastic composite sheets in 2012
- **Braj Binani Group**, an Indian conglomerate diversified into glass fiber by acquiring Belgium-based **3B**-the fiberglass company in 2012

EBITDA Margins

- EBITDA margins vary widely from -6-18% for glass fiber manufacturers

Raw Material Cost

- Innovation on the predominantly used E-glass fiber type to lower cost
- Trend of thermoplastic resin replacing thermoset resin to lower costs and manufacturing time

Machining Cost

- Composite tooling cost is only 40% of steel stamping tooling cost

Inorganic Growth

- Globally, companies are acquiring GFRP players to gain access to the growing market

Global Scenario

- US, China and Japan are largest producers and consumers of GFRP composites, accounting for >60% of the global market
- Europe and US are leading in terms of R&D

1. EBITDA is for the entire company and not just the division manufacturing GFRP components
Source: A.T. Kearney analysis

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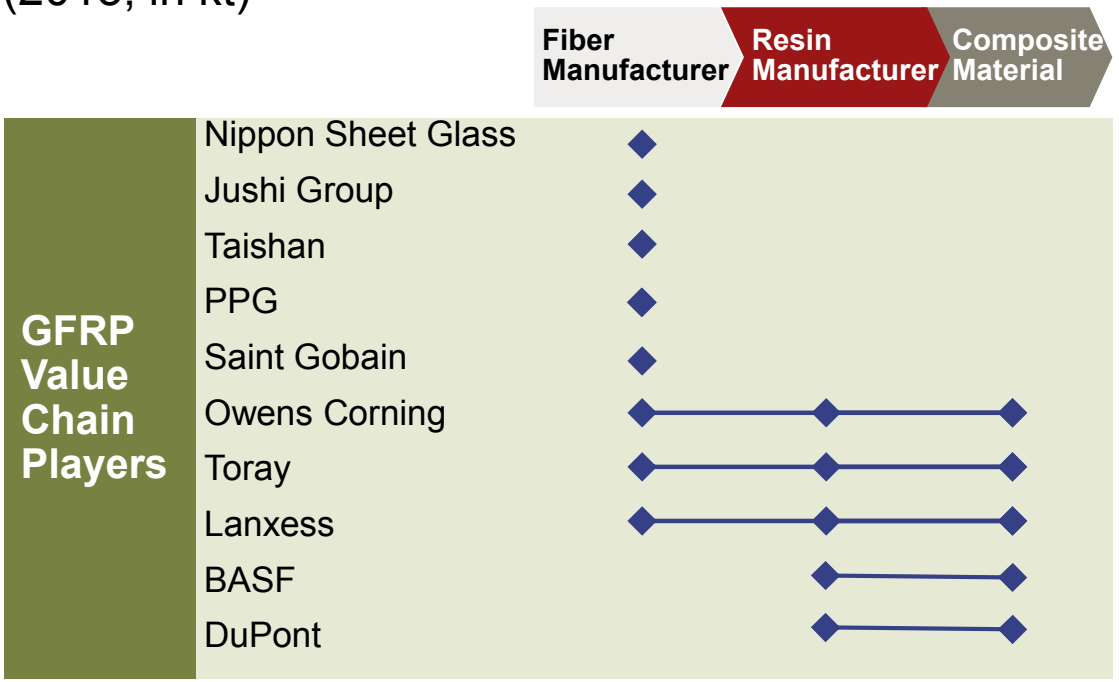
Thus, there are very few end to end players in the growing GFRP market; with players spread across the globe

Value chain coverage of GFRP Players
(2015, in kt)



Key Component Manufacturers

GFRP Component Manufacturer	Component	Composite Supplier
Montaplast, ZF, Trelleborg	Pedal	BASF, Lanxess
Sogefi	Suspension Spring	Owens Corning
BASF-VW collaboration	Front-End Structure	BASF, Sabic
Faurecia	Tailgate	-
Inalfa Roof Systems	Sunroof Module	Asahi Kasei
Denso	Radiator Tank	DuPont
Mahle	Intake Manifold	Borealis
Mann & Hummel	Turbocharger Housing	-

Source: Company information, A.T. Kearney

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GFRP manufacturing needs to be precise and requires different technological capabilities across the value chain

GFRP Manufacturing Process

1 Melting

- Melt the glass mixture - silica sand, limestone, kaolin, etc. into liquid form

2 Extrusion

- Extruded through bushings, which are bundles of very small orifices

3 Coating (Sizing)

- Help protect the glass filaments for processing and manipulation

4 Bundling

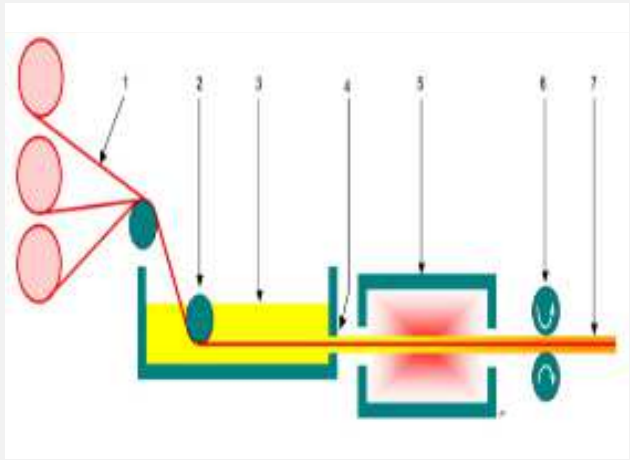
- Individual filaments bundled in large numbers to provide a roving

5 Weaving/Chopping

- Woven fiber or chopped strand mat created or left as a roving

6 Pultrusion

- Most common continuous process for manufacture of composite material



1 - Continuous roll of reinforced fibers or woven fiber mat
2 - Tension roller
3 - Resin Impregnator
4 - Resin soaked fiber
5 - Die and heat source
6 - Pull mechanism
7 - Finished hardened fiber reinforced polymer

7 Injection Molding

- Produce parts by injecting material into a mold

Source: A.T. Kearney analysis

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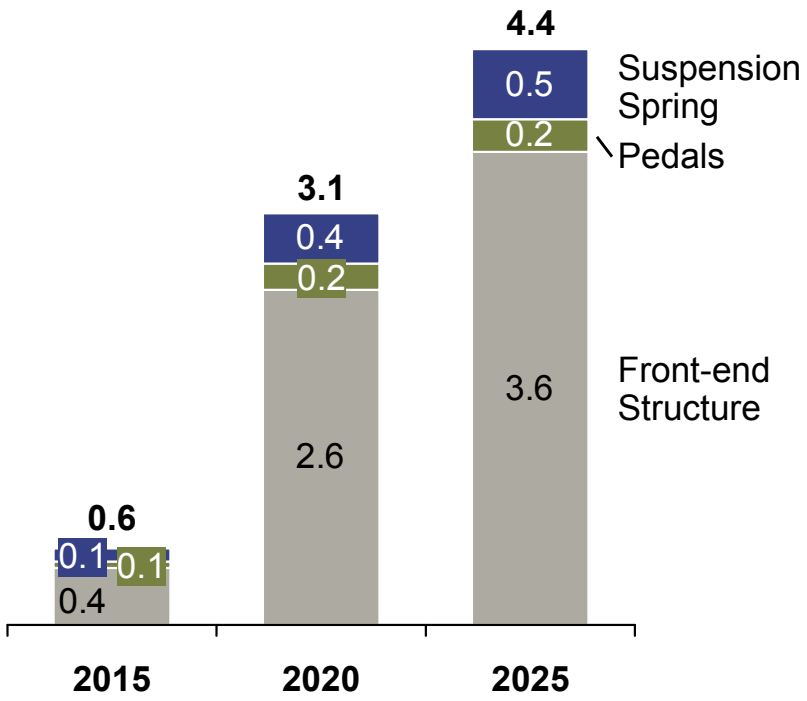
Innovative use of plastics reinforced with glass fiber will lead to a huge market size of certain auto components

Non-Exhaustive

Market Size of GFRP Key Auto Components (USD Bn.)



The market size of these auto components is expected to grow at a CAGR of 13% from 2015 to 2025

Suspension Spring

- **Sogefi**, an Italian manufacturer, has patented a new spring, which is 40% lighter and reduces the car weight by 4-6 kgs
  - Audi has collaborated with Sogefi to develop the spring and introduced it in its Audi A6
- **Owens Corning** introduced its composite material coil spring in the 2015 JEC show in Paris

Front-End Structure

- Innovation by **Lanxess**: plastic-metal hybrid to hydroforming-hybrid design to full plastic design
- **BASF** has helped Volkswagen develop a part designed entirely from GFRP (PA)
- Audi A6 Avant and Ford Focus use GFRP front-ends

Pedal

- **Trelleborg Automotive** makes a stamped hybrid pedal
  - Metal insert is over-moulded at the plastic injection stage, a process using water injection technology
- **ZF** manufactures a pedal based on PA 66 GFRP
  - Eliminates need for complicated forming, cutting and welding processes required with sheet metal

Source: A.T. Kearney analysis

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These top auto parts markets were analyzed across four dimensions, anticipating key automotive supply & demand characteristics

Automotive supply countries analysis framework

Top automotive supply countries

1. China	6. South Korea
2. Japan	7. France
3. US	8. Italy
4. Germany	9. Czech Republic
5. Mexico	10. Poland

For comparison purposes, Turkey was also included in the analysis

Supply & Demand dimensions

Cost	• Cost saving opportunities regarding labor, raw materials, energy, land, etc.
Innovation	• Rising innovation demands from OEMs • Need of product tailoring for local markets • Skilled labor and university networks
OEM proximity	• "Just-in-time" supply requirements • Joint product development/testing requirements
Government regulations	• Local content requirements, import tariffs • Tax schemes and incentives • Protected domestic markets

Suppliers may pursue expansion strategies proactively, driven by potential of new markets, but also reactively, pressured by OEMs to follow them

Source: A.T. Kearney

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Western Europe and US are attractive for suppliers due to technological capabilities and OEM proximity, but imply higher costs

Key supplier markets assessment (1/3)

NAFTA & Western Europe

	Cost competitiveness *(labor, raw materials, etc.)*	**Technological development** *(skilled labor, R&D infrastructure, etc.)*	**Proximity to OEM assembly plants**	**Government regulations** *(local content requirements, tariffs, etc.)*
Western Europe (Germany, France, Italy)	• Expensive labor • Access to raw materials at affordable prices (e.g. steel)	• Highly skilled labor force; potentially engineers shortage, but attract int'l talents • World-class academia, R&D	• The countries account for 15% of global car production • Germany is home of VW, world OEM leader	• High import tariffs for non-EU countries (varies by country) • Fiscal incentives especially for R&D activities
US	• High labor, but low energy costs • Access to raw materials • High facility costs	• Highly skilled labor force • World-class academia, R&D infrastructure	• Accounts for 6% of global car production • Home to GM and Ford (top 10 OEMs)	• Very high import tariffs (varies by country) • Fiscal incentives for high-tech components
Mexico	• Low labor cost and high productivity in dollar / hour terms • Low facilities cost	• Skilled workforce, but limited innovation infrastructure	• ~3% of global car production • Top OEMs assembling there: Toyota, Honda, VW, GM, Ford, Nissan, etc.	• Differentiated import tariffs depending on the country of origin • Valuable incentive packages for auto suppliers

Source: A.T. Kearney 2012 Automotive index, Desktop research, A.T. Kearney

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Asia is preferred by suppliers due to technological infrastructure and OEM plant proximity; cost attractiveness varies by country

Key supplier markets assessment (2/3)

Asia

	Cost competitiveness *(labor, raw materials, etc.)*	Technological development *(skilled labor, R&D infrastructure, etc.)*	Proximity to OEM assembly plants	Government regulations *(local content requirements, tariffs, etc.)*
China	• In top 5 most cost competitive countries • Inland regions more attractive as coast line becomes expensive	• Access to large pool of skilled engineers • Increasing technological infrastructure following FDIs	• ~25% of global car production • All major OEMs have assembly plants there • Also growing local OEMs (e.g. Geely)	• High import tariffs that obliges big suppliers to outsource here • Moderate government incentives for foreign auto suppliers • Protected domestic market
Japan	• Expensive labor force • Fuels and raw materials are imported rising costs	• Highly skilled labor force, yet aging population • High tech R&D infrastructure	• Accounts for 13% of global car production • Home of 4 out of top 10 car manufacturers	• High import tariffs • Incentives for foreign investments, including auto suppliers
South Korea	• Access to raw materials, but expensive labor	• Highly skilled labor force, esp. engineers • High tech R&D infrastructure	• Accounts for 6% of global car production • Global OEMs with local presence • Low percentage of imported cars	• Imports tariffs varies by country of origin • Moderate fiscal incentives

Source: A.T. Kearney 2012 Automotive index, Desktop research, A.T. Kearney

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Eastern European countries are increasingly attractive as they provide good costs, government incentives, and fair technological potential

Key supplier markets assessment (3/3)

Eastern Europe

	Cost competitiveness *(labor, raw materials, etc.)*	**Technological development** *(skilled labor, R&D infrastructure, etc.)*	**Proximity to OEM assembly plants**	**Government regulations** *(local content requirements, tariffs, etc.)*
Czech Republic	• Labor costs have risen with respect to past, low availability of manpower • Affordable raw materials	• Competitive technical universities → skilled labor • Enhanced R&D infrastructure	• Proximity to Germany and France, UK, Spain • Toyota, PSA, Skoda & Hyundai have local plants	• High import tariffs for non-EU countries • Investment incentives for foreign companies, including auto suppliers
Poland	• Low cost labor with high productivity • Access to affordable raw materials	• Competitive technical universities → skilled labor • Enhanced R&D infrastructure	• Proximity to Germany and France, UK, Spain • VW, Opel & Fiat have local assembly plants	• High import tariffs for non-EU countries • High investment incentives for auto suppliers
Turkey	• Low cost labor, but can further improve labor market efficiency • Energy import dependent • Internal capabilities for plastics, but less for auto specialty steel	• R&D infrastructure in place, but effectiveness potential not reached yet • Room to further develop skills of technical workforce	• Car production levels similar to those in Czech Republic • Fiat/Tofaş, Oyak-Renault, Hyundai, Toyota, Honda, Ford/Otosan have local plants	• Generous incentives for R&D investments (esp. for special technologies, i.e. EV) and auto suppliers investments • No local content requirements • No or low import tariffs • High tax on vehicles

Source: A.T. Kearney 2012 Automotive index,, WEF Global Competitiveness Report, Ministry of Economy Turkey, A.T. Kearney

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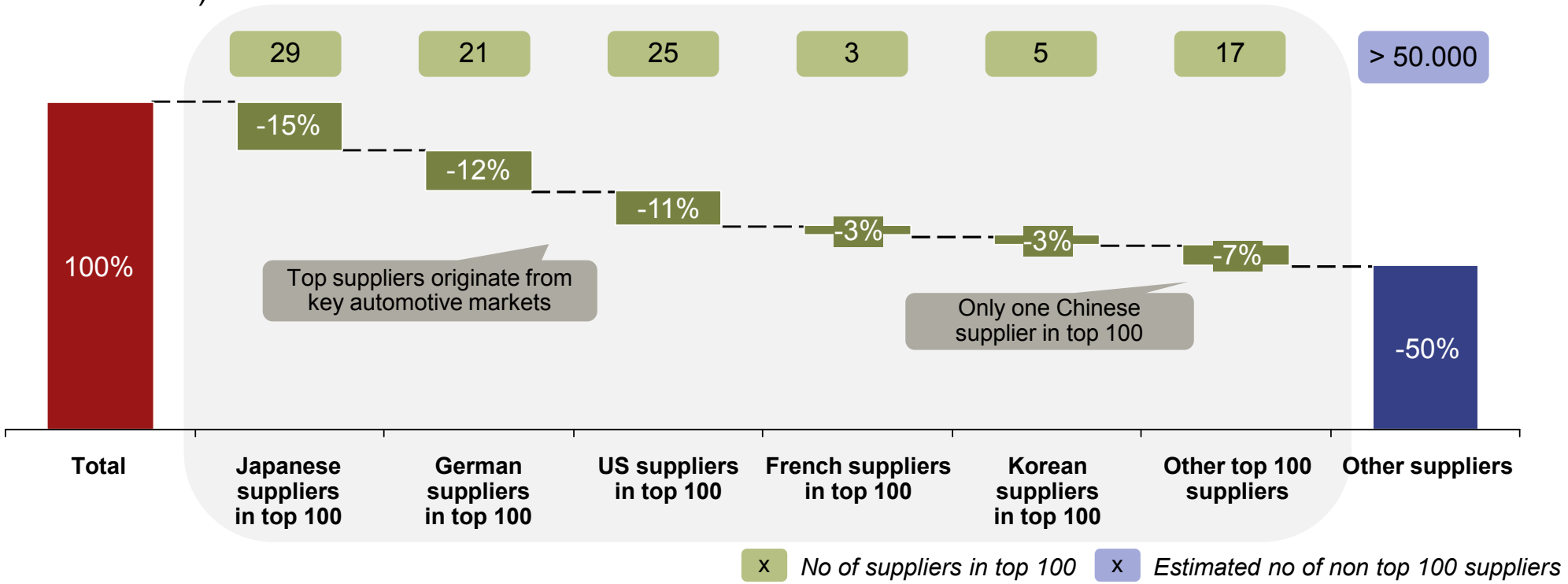
Top 100 suppliers represent less than 1% of total number of players but generate 50% of revenues, indicating strong market concentration

Auto parts industry concentration

Industry revenues by supplier origin [1]
(% of revenues)



Germany accounts for only 7% of car part production, but German players in top 100 generate 12% of worldwide revenues, outlining their global footprint

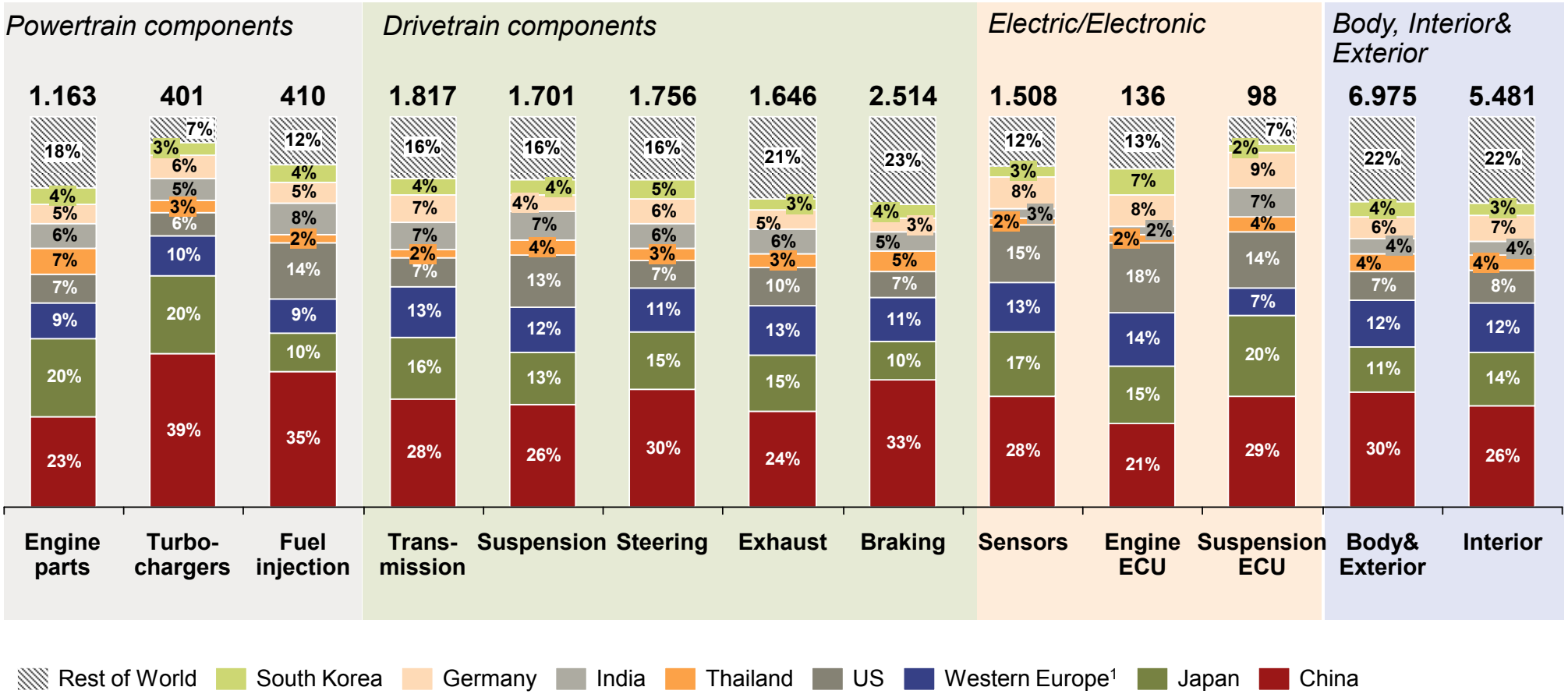
1.Estimate
Source: IHS, Autonews, A.T. Kearney

ATKearney

Highest number of suppliers activate in the area of less technology intensive components, while fewer offer specialized ECUs

Suppliers' distribution by component and region
(%of suppliers,)

Selected components



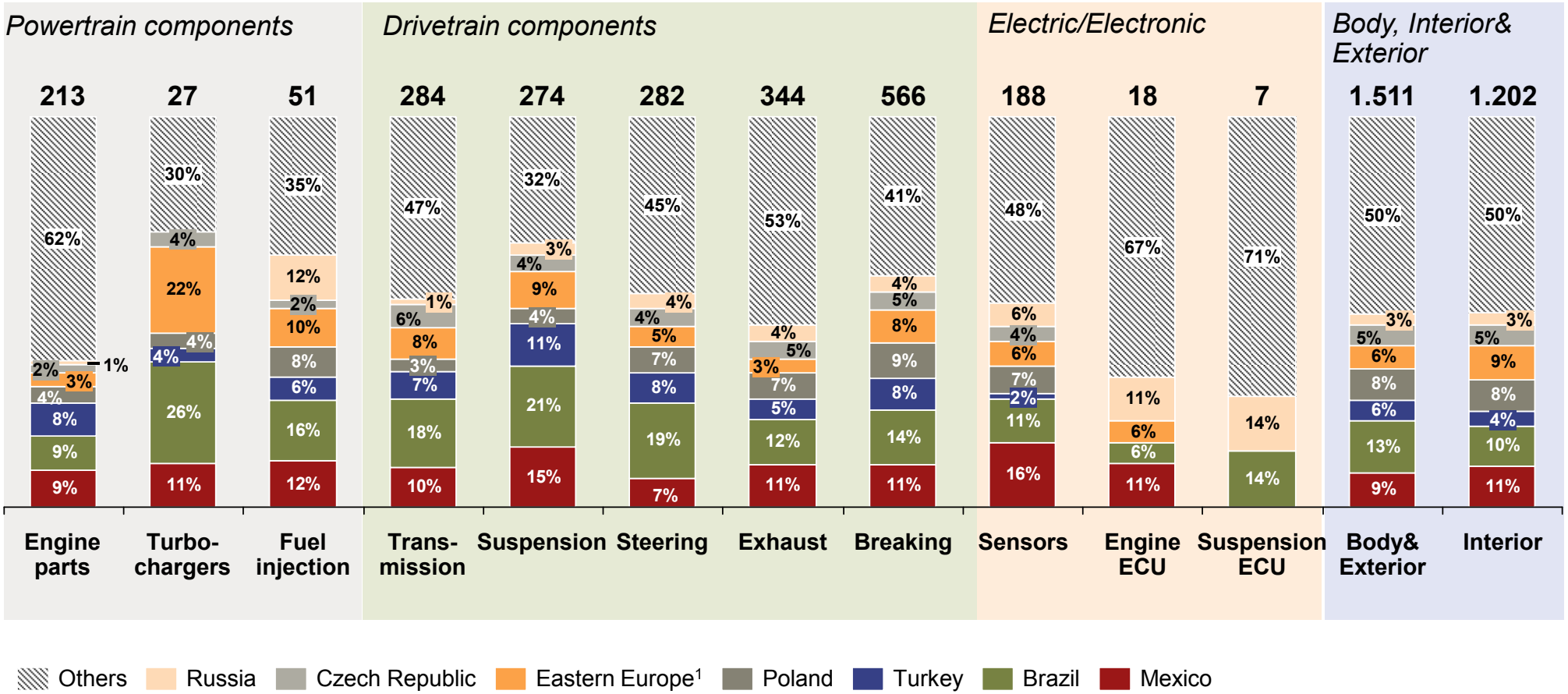
1. Western Europe without Germany
Source: MarkLines, A.T. Kearney

ATKearney

Suppliers in Turkey are offering primarily Body, Interior & Exterior parts, but are also active in Drive train components

Supplier' distribution in "Rest of the world"
(% of suppliers)

Selected components



1. Eastern Europe without Czech Republic and Poland
Source: MarkLines, A.T. Kearney