2nd Edition

Automotive Composites

The make-or-break decade for carbon and natural fibres

Adrian Wilson

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Automotive Composites

The make-or-break decade for carbon and natural fibres

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Chapter 1: Introduction: a paradigm shift

The global automotive industry's annual turnover is now approaching a value of US$1.8trn. To put this in context, only the nine richest countries in the world are worth more, with the tenth, Russia – with an approximate gross domestic product (GDP) in 2015 of US$1.9trn – about its equal.

The world's vehicle population is now more than 1bn (while in 2015, the world's population is estimated at 7.3bn). But there is currently a sense that this huge industry is poised to change as never before, opening up a wide range of new opportunities.

The key issues that have driven change for the past couple of decades most certainly include the ongoing global shift in mass vehicle manufacturing centres from the US, Europe and Japan to developing countries, notably China, and to a lesser extent Indonesia and India, and to lower-cost regions within Europe. There have been migrations in both the markets and the balances of power between the automotive manufacturers.

China

Just a decade ago, in 2005, it was widely predicted that China would account for approximately 50% of automotive growth in Asia between 2006 and 2010, and that some 6.5m vehicles would be made in the country in 2010.

This turned out to be something of an underestimate, and as automotive production collapsed in the US, Western Europe and Japan, 8.9m light vehicles were produced in China in 2008.

China then became the world's largest car market in 2009, when sales in the country climbed by 45% and production reached 13.6m units. In 2014, China's production of cars and commercial vehicles was 23.7m units.

Economic crisis

The economic crisis of 2007-08 also had far-reaching effects on the automotive industry and the way it now operates globally. At the same time, massive efforts continue to be required to harmonise requirements and technology, with marked differences from one country to another, resulting from different public policies, local conditions, infrastructures and economies of scale.

Beyond this, however, are environmental and social concerns that call for a paradigm shift – not only in the way the automotive industry is structured, but also in what it is producing.

Safety and environment

The two key factors influencing this – improving safety and reducing environmental impact – are nothing new in themselves, but while today there are more vehicles on the road than ever before, injuries and fatalities from accidents have fallen.

This is partially the result of advanced safety belts with pre-tensioning and energy absorption, frontal and side airbags, and energy absorbing structures. Also making a contribution are improved braking systems, high-performance lighting, and electronic driver assistance and warning systems.

Intelligent transport systems are now on the way, and will bring multi-way communication and interaction between vehicles and roads. Today, the smallest cars on the market carry levels of equipment, sensors, electronics and computer power that would have been unimaginable just a few years ago.

Meanwhile, Google continues with its self-driving car project and the use of autonomous vehicles has already been legalised in some US states.

A notable feature of the 2015 Consumer Electronics Show (CES) in Las Vegas, Nevada, USA, was the considerable presence with smart technologies of major car manufacturers including Audi, BMW, Ford and Mercedes – just days before the North American International Auto Show (NAIAS) in Detroit, Illinois.

The head of a collaboration between electronics maker LG and Audi used a smart watch to summon the driverless Audi Prologue onstage for the company's press conference. The watch, which will be available in 2016, started the car's engine with a single tap. The remote parking of a BMW i3 research vehicle via a smart watch was also demonstrated and this is clearly a field where progress will be rapid.

As far as environmental impact is concerned, the automotive industry has already, for example, developed sophisticated emissions control technology that is resulting in much cleaner vehicles, with catalytic converters significantly reducing smog-forming emissions from cars.

Evaporative emissions have also been dramatically reduced as a result of tighter gaskets and hoses and better petrol tanks, while computers have revolutionised clean vehicle controls by precisely metering the fuel and air that go into the engine.

The improvements in air quality will continue – even without further improvements to new vehicles – as older, more polluting cars, which are responsible for a large proportion of all vehicle emissions, are replaced with newer ones.

Another dramatic change taking place is the rapid development of alternative fuels, such as clean diesel, biodiesel, ethanol, hydrogen and compressed natural gas, in addition to vehicles that run on hybrid technology using both conventional combustion engines – petrol or diesel – and electric engines.

Chapter 4: The composites market

It has been calculated that the global composites industry will produce 11m tonnes of product in 2015, with a value of €80bn, and with an average value of €7.40 per kg. However, the per kg value of that product currently differs widely from region to region.

With a 39% market share by value and 34% by volume, the value of North American composites production is estimated at €31bn, equating to an average unit price of €8.20 per kg. Overall North American production volume in 2015 will be 3.8m tonnes.

In the EMEA (Europe, the Middle East and Africa), 3.1m tonnes will be produced in 2015, 32% of the market by value and 29% by volume, with a value of €26bn and an average unit price of €8.40 per kg.

In Asia-Pacific and the rest of the world (including Australia and South America), the average unit price of composites is much lower, at €5.50 per kg. The 4.1m tonnes on course to be produced in these regions in 2015 have a value of €23bn, representing 37% of the market by volume, but just 29% by value.

This is explained by the increasing use of primarily carbon fibre composites in higher-end applications in North America and EMEA, most notably so far in aerospace and wind energy, with consequently higher prices.

Table 8: The composites market by region, 2015

	Production volume (m tonnes)	Production value (€bn)	Share by volume (%)	Share by value (%)	Average unit price (€/kg)
North America	3.8	31	35	39	8.2
EMEA	3.1	26	28	32	8.4
Asia-Pacific/Rest of world	4.1	23	37	29	5.5
Total	**11.0**	**80**	**100**	**100**	**7.4**

Source: various

Growth similarly varies greatly by sector, with the smaller markets – by volume, though certainly not added value – continuing to grow rapidly. Between 2004 and 2008, for example, the wind energy market grew by 33% from 102,000 tonnes to 322,000 tonnes.

Wind energy

Europe certainly had an early lead in wind energy composites, with 82,000 tonnes produced by 2005 (Table 10). This grew to 140,000 tonnes in 2010, which represented still

Table 9: The composite market by region and end-use application, 2015

	North America		Europe		Asia		Global	
	('000 t)	**(%)**	**('000 t)**	**(%)**	**('000 t)**	**(%)**	**('000 t)**	**(%)**
Aerospace	190	5	155	5	41	1	440	4
Wind energy	76	2	217	7	82	2	330	3
Consumer goods	304	8	248	8	410	10	990	9
Electrical and electronic	570	15	403	13	943	23	1,760	16
Building and construction	1,026	27	651	21	1,435	35	2,970	27
Pipe and tank	152	4	186	6	410	10	770	7
Transportation	1,178	31	992	32	738	18	3,080	28
Marine	304	8	248	8	41	1	660	6
Total	**3,800**	**100**	**3,100**	**100**	**4,100**	**100**	**11,000**	**100**

Source: various

Table 10: Use of composites in wind energy applications, 2005-2015

('000 tonnes)	**2005**	**2010**	**2015**	**CAGR 2005-15 (%)**
North America	24	54	76	11
Europe	82	140	217	9.2
Asia-Pacific/Rest of world	34	66	82	8.3
Total	**140**	**260**	**375**	**9.5**

Source: various

impressive growth of 70% for the period. Between 2010 and 2015 growth was lower at 55%.

In Asia Pacific, the increase was from 34,000 tonnes in 2005 to 66,000 tonnes in 2010 – growth for the period of 94%, falling to just 24% between 2010 and 2015.

In North America, just 24,000 tonnes of composites went into wind energy in 2005, growing to 54,000 tonnes in 2010 – a 125% increase. Between 2010 and 2015 there has been a lower (40%) increase.

There are many question marks, however, over whether wind energy can achieve comparable growth in the coming years and much is dependent on government programmes and initiatives.

Aerospace

There is no such question hanging over the growth prospects for aerospace composites, with programmes already established for their use and expansion.

In aircraft, the use of carbon fibre has grown rapidly in recent years as the basis for composite parts. Twenty years ago it accounted for only 10% of an aircraft body. But in the

Chapter 7: Carbon fibre automotive applications

Carbon fibre reinforced plastic (CFRP) has a wealth of benefits as a material for a vehicle body. It is extremely corrosion resistant and does not rust, giving it a far longer lifespan than metal. Complex corrosion protection measures are unnecessary and CFRP retains its integrity under all climatic conditions.

In its dry, resin-free state CFRP can be worked almost like a textile and as such allows a high degree of flexibility in how it is shaped. The composite only gains its rigid, final form after the resin injected into the lattice has hardened.

The high tear resistance along the length of the fibres also allows CFRP components to be given a high-strength design by following their direction of loading. To this end, the fibres are arranged within the component according to their load characteristics. By overlaying the fibre alignment, components can also be strengthened against load in several different directions.

As a result, the components can be given a significantly more efficient and effective design than is possible with any other material.

The ability of CFRP to absorb energy is also unique.

Formula 1 and beyond

At the beginning of the 1960s, Lotus introduced the monocoque to Formula 1 (F1) racing by placing thin plates around the bars of the car frame to increase the stiffness of the chassis.

During the 1970s, aluminium was mostly used for these constructions, but when they proved to be not as resistant as required to deal with the downforce of the wings, a self-supporting chassis made with carbon fibre was introduced, initially by McLaren – the McLaren MP4/1.

This offered an unbeatable combination of strength and lightness. It had an immediate dynamic impact, with John Watson winning the 1981 British Grand Prix at Silverstone. It also proved an effective safety cell – Watson walked away from a dramatic high-speed crash at Monza, Italy, later that season.

Within a few years, every other F1 team had followed suit and today most parts of the racing car chassis – the monocoque, suspension, wings and engine cover – are built with carbon fibre.

The chassis is usually the first part of the car to be built, owing to the amount of time required, and F1 teams generally use the prepreg-in-autoclave method involving carbon fibres, a pre-impregnated epoxy resin and an aluminium honeycomb layer, which is sandwiched between two layers of carbon fibre.

The main chassis usually comprises around eight panels and the first stage of the established manufacturing process is to design a solid pattern from which a mould for the panel can be produced.

The moulds are constructed by laying a total of 10 layers of resin prepreg on top of each pattern. The production of the mould takes place in several stages, involving vacuum treatments, de-bulking and heating. The mould then has to be thoroughly cleaned and prepared for use.

The next phase is the actual fabrication of a car part, made from sheets of pre-cut, pre-impregnated carbon fibre, which are carefully laid inside the moulds. It is vital to orientate the carbon fibre sheets in pre-determined directions in order to achieve the desired strength. A total of five layers of carbon fibre are laid, forming the outer skin of the chassis – to achieve a final, cured thickness of 1 mm, a total of 3-4 layers of carbon fibre must be laid down.

The next stage of the process is to cure the carbon fibre in an autoclave. This exposes the carbon fibre to a number of temperature and pressure cycles according to the specific requirements of the materials and components being processed. During this treatment, the resin flows into the fibres and is activated, curing the material. Once the outer skin has been cured and cooled down, a honeycomb layer of aluminium is fixed onto the outer skin by a sheet of resin to ensure the materials stick strongly together.

The chassis panel then returns to the autoclave for curing. After having cooled down again, one more layer, consisting of a number of pre-impregnated carbon fibre sheets, is placed on top of the existing skin, and again treated in the autoclave.

Luxury sports cars

This autoclave and prepreg route has been the general method for F1 body parts over the past 25 years and it has also transferred to high-end luxury sports cars, but significantly a number of companies have recently been championing the resin transfer moulding (RTM) process as an alternative.

McLaren brought carbon fibre technology to road cars with the 1993 F1 supercar and then built on this experience with a carbon fibre chassis and body on the Mercedes-Benz SLR McLaren, produced between 2003 and 2009.

McLaren Super Series

In March 2011, John Watson was reunited with the McLaren MP4/1 at Silverstone as he took the opportunity to drive the McLaren MP4-12C – the first carbon-based road car from McLaren to feature a one-piece moulded carbon chassis structure called the MonoCell.

Chapter 8: Carbon fibre producers

Japan's Big Three – Toray Industries, Toho Tenax and Mitsubishi Rayon

The production of rayon (viscose) fibres in the early part of the 20th century, followed by the advent of synthetic fibres, can be considered a pivotal period in the industrial awakening of Japan, and led to the growth and development of three highly diversified multi-corporations of today – Toray Industries, Teijin (the parent company of Toho Tenax since 2007) and Mitsubishi Rayon.

Toray first emerged as a producer of rayon staple fibre in the late 1920s, before diversifying into synthetic fibres and other businesses. The Azuma Rayon plant, which was established even earlier (in 1915), spawned today's Teijin empire, while its subsidiary Toho began separate rayon production in the 1930s, as did Mitsubishi Rayon (then known as Shinko Jinken).

As previously noted, these three Japanese groups now account for a significant percentage of global carbon fibre production, with Toray claiming a leading share of around 30%.

There is now a major drive by the research and development (R&D) departments of all three companies to develop faster moulding processes for carbon fibre reinforced plastic (CFRP)

Toray Industries

With record 2014 sales of US$17.8bn, including a 40.6% year-on-year increase by its Carbon Fiber Composites business with profits also more than doubling to ¥16.9bn, Toray's activities by segment and percentage of sales for the year to 31 March 2014 are shown in Table 26; the company's net sales over the past five years are shown in Table 27.

Table 26: Toray Industries, net sales by business segment, 2014[1]

Business	Net sales (¥bn)	%
Fibres and Textiles	755.5	41
Plastics and Chemicals	470.5	26
IT-related Products	245.7	13
Carbon Fibre Composites	113.3	6
Environment and Engineering	180.2	10
Life Science and Other	68.2	4
Total	**1,833.4**	**100**

[1] year ended 31 March

Source: Toray Industries

Table 27: Toray Group, net sales, 2010-2014

Year[1]	Net sales (¥bn)
2010	1,359.6
2011	1,539.6
2012	1,588.6
2013	1,592.2
2014	1,837.8

[1] year ended 31 March

Source: Toray Industries

Automotive priority

As the world's largest manufacturer of carbon fibre, Toray has identified expansion in the automotive field as one of its top priorities, along with consolidation of its composites for aerospace business. The major announcements in respect of the company's acceleration of activities in these fields between 2012 and 2014 are summarised in Table 28.

Table 28: Toray Industries, major carbon fibre developments, 2012-2014

Date	Announcement
January 2012	Purchased Soficar shares from Arkema
March 2012	¥45bn expansion announced at sites in Japan, the US, France and South Korea
April 2013	Toray Carbon Magic established in Thailand
July 2013	Acquired a 20% stake in Plasan Carbon Composites (PCC)
September 2013	Acquired Zoltek for US$584m
February 2014	New expansion at Toray Composites America to meet Boeing demand
March 2014	Announcement of new US$1bn carbon fibre manufacturing plant in South Carolina, USA
May 2014	Further expansions announced in Japan and Thailand
November 2014	Expansion of contract with Boeing
December 2014	Acquisition of Saati

Source: Toray Industries

Boeing first adopted Toray's Torayca carbon fibre as a secondary structural material in the mid-1970s, and in 1992 began using it for important primary structural materials.

In November 2014, Boeing announced it would expand its current contract with Toray for 787 Dreamliner composites to include the 777X wings, cementing the supplier's dominant position in aerospace.

Toray established the Automotive Center (AMC) as a comprehensive development base for automotive applications in June 2008 and the Advanced Composites Center (ACC) a year later.

Chapter 12: Glass fibre composite automotive applications

As noted in Chapter 4, the transportation industry accounts for around 28% of all composite end-uses worldwide. The bulk of this consumption, however, is currently in public and industrial transportation vehicles, where applications include:

- large panels for trailer walls;
- floor panels for railway carriages;
- truck cabs;
- exterior body moulding;
- bus body shells;
- cargo containers.

The light weight, high strength, corrosion resistance and design flexibility afforded by glass fibre reinforced plastic (GFRP) translates into greater fuel efficiency, dimensional stability, greater cargo/passenger capacity, lower manufacturing costs, lower maintenance costs, enhanced aesthetics and parts consolidation in such applications.

A company such as VDL Fibertech (formerly Acrosoma) based in Belgium, for example, makes a substantial number of composite transportation trailers and containers with materials based on a patented process that combines pultrusion with an adapted version of the tufting technology generally used for the production of carpets.

This gives the company continuous production of around 150 m^2 per hour, or 250,000 m^2 annually, of continuous quality product. The resulting material is lightweight, with high buckling resistance, strength and stiffness.

The full benefits of GFRP composites in the goods transportation sector are defined in Table 43.

These advantages are particularly relevant when considering the challenges faced by the trucking industry, including:

- fuel costs;
- driver shortages and retention;
- government regulations in respect of weight, emissions, fuel economy and hours of service;
- congestion;
- motorway maintenance.

Table 43: Chief advantages of GFRP in industrial transportation/trucking

Better strength-to-weight ratio	Reduced emissions
Reduced vehicle weight by 20-35%	Better performance from hybrid engines
Increased revenue	15% increase in cargo
More flexible and aerodynamic vehicle design	Reduced number of loads, fleet size, drivers and miles
Increased body and chassis durability	Better fuel efficiency
Higher thermal insulation	Increased cargo capacity
Smoother ride	Reduction in lifetime capital costs by 15%
Reduced carbon footprint	85% less material fatigue
Reduced rollover	Reduced maintenance costs
Comparable to steel at 20% of the weight and 50% of the weight of aluminium	Non-corrosive material
Lower operating costs	Higher impact resistance
Smaller engine for 30-50% increase in fuel efficiency	Better energy absorption

Source: various

Exel Composites, headquartered in Mäntyharju, Finland, lists the GFRP profiles that it supplies for industrial transportation and trailers as:

- flooring;
- side panels;
- structural elements;
- side racks;
- external capping profiles;
- internal trim profiles;
- insulated panels for sectional doors.

Exel notes that the pultrusion technique allows the production of large external GFRP profiles of a uniform quality and strength, and these first started to be employed in buses and coaches in the 1980s.

The high impact resistance of the composites protects the surfaces from damage and scratching and their compatibility with paints makes it possible to obtain high-grade finishing. Bad weather conditions and air pollution do not affect the composite profiles owing to their corrosion resistance.

To keep an attractive surface, profiles can be cleaned with hot water, steam or chemicals. Typically, body panels are fixed to the frame using flexible polyurethane adhesives.

In bus and coach interiors, GFRP is employed in coves, air ducts, trim profiles and luggage

Chapter 16: Natural fibre automotive applications

The estimated options for reducing carbon dioxide (CO_2) emissions in vehicles include improving the powertrain to reduce consumption, improving drag via more aerodynamic designs and enhancing the rolling resistance.

Reducing vehicle weight, however, affords many opportunities to further cut emissions and the use of natural fibres in thermoplastic composites provides a number of them.

In door panels, for example, weight reduction of 25-30% is being achieved, but in addition, the tooling for producing natural fibre/polypropylene (PP) composites is up to five times cheaper than injection moulding alternatives and also ensures there are no sharp edges during a side impact collision.

A 35% weight saving is also being achieved in instrument panels with flax/PP constructions, in which small injected inserts are placed in the tool prior to compression.

Extreme light weight is achievable by employing flax/PP in headliners as an alternative to polyester felts and/or cotton shoddy, and this option is now being used in many small vehicles.

Certain original equipment manufacturers (OEMs) are also using flax/PP in wheel-arch liners, as well as in spare wheel covers, seatbacks and parcel shelves.

The return of the utilisation of natural fibres in automotive applications began in the 1990s, initially in Europe and a few years later in North America.

Car makers started advanced developments on door panels, headliners, package trays, dashboards and trunk liners based on natural fibre composites with a thermoplastic or thermoset matrix, challenging mainly glass fibre reinforced plastic (GFRP) composites.

Of particular influence was the introduction of the door panels in the Mercedes-Benz E class of 1994/5, in which the wood fibre materials previously used were replaced by a flax/sisal fibre mat embedded in an epoxy resin matrix.

A weight reduction of about 20% was achieved as a result, and the mechanical properties – important for passenger protection in the event of an accident – were also improved. In addition, the flax/sisal material could be moulded in complicated three-dimensional shapes.

Since then, the use of such natural fibre substrates has become relatively common, certainly in European cars, as illustrated in Table 58. Their comparative advantages and drawbacks are summarised in Table 59.

Table 58: Examples of established natural fibre automotive components, Europe

Manufacturer	Models	Applications
Audi	A2, A3, A4, Avant, A8, Roadster, Coupé	Seatbacks, side and back door panels, boot lining, hat rack, spare tyre lining
BMW	3, 5, 7 Series and others	Door panels, headliner panel, boot lining, seatbacks
Daimler/Mercedes-Benz	A, C, E and S Series	Door panels, windshield/ dashboard, business table, pillar cover panel
Fiat	Punto, Brava, Marea, Alfa Romeo 146, 156	various
Ford	Mondeo CD 162, Focus	Door panels, B-pillar, boot liner
Lotus	Eco-Elise	Sisal carpets, hemp Class A panels
Mercedes-Benz Trucks	various	Internal engine cover, engine insulation, sun visor, interior insulation, bumper, wheel box, roof cover
Peugeot	New model 406	Seatbacks, parcel shelf
Renault	Clio	Rear parcel shelf
Rover	Rover 2000 and others	Insulation, rear storage shelf/ panel
Saab	various	Door panels
Seat	various	Door panels, seatbacks
Toyota	Brevis, Harrier	Door panels, seatbacks
Vauxhall	Astra, Vectra, Zafira	Headliner panel, door panels, pillar cover panel, instrument panel
Volkswagen	Golf, Passat, Bora, Fox	Door panel, seatback, boot lid finish, boot liner
Volvo	C70, V70	Seat fillings, cargo floor tray

Source: ADAS

Biodegradability and recycling opportunities can certainly be viewed as a driver for the growth of such parts, and many of the present commercial applications play to it. The use of natural fibres to reduce weight is also seen as extremely valuable since, as mentioned, in 2015 the reuse and recycling of end-of-life vehicles must amount to a minimum of 85% by average weight per vehicle.

According to Johnson Controls, car weight reduction of up to 35% is possible with natural fibre composites, although other estimates are lower. This can be translated into lower fuel consumption and consequently lower environmental impact. Natural fibre-based composites also offer good mechanical performance, good formability, high sound absorption and material cost savings.

The adoption of these natural fibre components by each new car model platform could increase the demand for natural fibres by up to 4,000 tonnes annually, according to UK provider of environmental and rural solutions and policy advice ADAS.

Glossary

A-B-C pillar/column

The A-pillar or A-column is a name applied by car stylists and enthusiasts to the shaft of material that supports the windshield (windscreen) on either of the windshield frame sides. By denoting this structural member as the A-pillar, and each successive vertical support after a successive letter in the alphabet (B-pillar, C-pillar, etc.), this naming scheme allows those interested in car design to have points of reference when discussing design elements. In the most usual configuration, the C-pillar supports the rear window.

ABS

acrylonitrile butadiene styrene

ACC

Advanced Composites Center (Toray Industries); Automotive Composites Consortium (USA)

ACE

Advanced Composite Engineering

ACG

Advanced Composites Group (UK)

ACMA

American Composites Manufacturers Association

ACN

acrylonitrile

ACRC

Advanced Composites Research Center (Lamborghini, Italy)

AFP

automated fibre placement

AFRA

Aircraft Fleet Recycling Association

AFRECAR

Affordable Recycled Carbon Fibres (UK)

AGM

absorbed glass mat

AHSS
advanced high-strength steel

AITF
Alberta Innovates – Technology Futures (Canada)

AMC
Automotive Center (Toray Industries)

AMSCI
Advanced Manufacturing Supply Chain Initiative

AN
acrylonitrile

APFE
European Glass Fibre Producers Association

APP
atmospheric pressure plasma

ATI
Adherent Technologies (USA)

ATL
automated tape lay-up

BD
butanediol

BMC
bulk moulding compound

body-in-white
The stage in automotive design and manufacturing in which a car body's sheet metal components have been welded together, but before moving parts such as the doors, sub-assemblies and trim have been added, and prior to painting.

BRIC countries
Brazil, Russia, India and China

BSA
bio-succinic acid

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