National Composites Network

IOM3/NCN Foresighting Working Group

Foresight Report 2007

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The Institute of Materials, Minerals & Mining

Materials
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The objectives of the report are to identify long term industry needs in each sector and to identify which areas represent cross-sector needs and which are industry sector specific.

The needs of an industry are first considered in terms of technology where the emphasis is placed on enhancing the capability of that industrial sector to compete against its rivals on the basis of a superior technology base. However, in many instances this implies a desire for enhanced competitiveness relative to other or alternative materials sectors. The issue of making the UK composite sector more competitive relative to other composite industries in countries throughout the world is equally important.

The second theme of the survey is therefore to identify the needs of the composite sector to be successful in terms of the UK versus its rivals. This part of the report has to consider the role of the composite industry in making the UK itself competitive. As an example, the value in making the UK Composite industry competitive in the aerospace sector is diminished if the UK's aerospace industry declines and OEM's based overseas are less inclined to purchase from the UK. Similarly however, the strength of the aerospace sector in the UK is strengthened by a strong composite sector supplying that industry.

The working party has identified the following generic sectors of the composite industry to be considered:

- **Defence and aerospace**
- **Rail**
- **Automotive**
- **Chemical and process plant**
- **Construction**
- **Marine**

Defence and Aerospace

This is a broad sector of the composite market which may be simplistically differentiated from other sectors in that performance has traditionally been a higher priority than cost. Certainly this has been true in the defence sector as a whole, but more so in the defence aerospace field than in ground and naval defence sectors. Civil aerospace has always maintained a greater interest in costs for obvious commercial reasons. In recent times the importance of cost has increased in all areas as defence budgets are under pressure. Nevertheless in the military field the trade-off between performance and cost cannot tolerate a reduced performance – the allowable options are improved performance but with higher costs or retained performance at lower costs.

The type of composites used by aerospace and land/sea defence military users also differs. Aerospace applications make lightweight a priority and carbon fibre based materials predominate, whereas in land/sea applications glass fibre composites are more prevalent.

The pressures on the military and civil aerospace composite sector are similar, although not identical. The scale of the structures involved is a major difference. The size of a full wing for the Eurofighter being of a similar scale to tail structures of a large Airbus. Manufacturing processes that are utilised for military applications may become uneconomic or simply unfeasible when considered for the wings of an Airbus A380 for example.

NCN Aerospace roadmap
In a recent NCN road mapping exercise, the UK aerospace composite industry was considered and the strengths and weaknesses identified as shown in the following chart:

Current key strengths and weaknesses in Composites for the Aerospace Industry

Strengths

UK is pragmatic and adaptable

UK strong in certain markets:
- Military products (missile / aircraft weapons)
- Airbus wings
- Commercial aircraft secondary structures

UK good at:
- Large complex loaded structure design
- Composite tooling
- Structures design
- Low readiness level innovation
- Materials innovation
- Systems integration (defence)
- Early investment in technology development

Increased use of composites, especially in critical areas e.g. primary structure

There are some good funding programmes, but there is no follow-up

Weaknesses	Movement of work to the Far East which is driven by cost and offset requirements Outside the UK there is government assistance with infrastructure investment and well funded technology demonstrators - this is a definite weakness. UK does not have a bold strategy that aggressively embraces composites There is little focus on industry / academic partnerships Supply chain not cohesive No massive investment in large structures in the UK (need another Concorde) R&D budgets in companies are reducing, so there is an increased requirement for government funding Large projects are expensive and can only be done transnationally. Similarly many companies are transnational or global (a factor more than a weakness). There is a lack of: technology demonstrators investment for long-term vision funding for infrastructure, machinery and equipment investment in market opportunities There is a skills shortage materials and process structures design materials scientists design / stress engineers for composite structures too few with large scale processing experience and generally there are insufficient numbers Materials are at the bottom end of an industry which is generally seen as unattractive

The main current technology gaps identified by the road map as needing urgent attention were mainly focused on manufacturing and included a need for new matrix systems suitable for out of autoclave processing and preforms. There was a call for better and more effective partnerships between academics and industry to support such developments, with some incentive needed for academics to engage in manufacturing related research. The development of regional research clusters was a concept put forward by the roadmap team.

There was also recognition that skills is an important element in UK competitiveness in the field. The report called for a “Better perception and recognition of engineering skills”.

The general view was that “Courses offered and industry requirements are not matched”. A better match between industrial needs and the courses offered by HEI's should be developed after a thorough survey of needs and capabilities with in general more composites courses on offer.

The need to promote composites would be partly achieved if there was a greater level of awareness of the materials developed by their inclusion in HEI programmes.

These research themes broadly mirror some earlier assessments of the need for the composites aerospace sector which were developed and published in 2004 by a consortium (ComposiTN) the aerospace section of which was led by EADS. This survey of future research needs addressed the sector at a European rather than a UK level. The report entitled "The Research Requirements of the transport Sectors to Facilitate an increase usage of composite materials Part 1: The composite materials research requirements of the aerospace industry" listed specific needs under the headings of:

1) Primary research needs
   - Manufacturing Technologies
   - Design, Analytical Tools and Simulation
   - Material Systems
   - Joining

2) Secondary research needs
   - Multifunctional Structures
   - Recycling

Their report identified improved manufacturing technologies as "The primary key to better affordability and quality. Higher degrees of automation, better quality control, reduced tooling costs and shorter cycle times have to be consistently attained".

The following topics were identified as the most promising to achieve these goals in the longer term:

- Textile preforming and fibre placement technologies.
- Non-autoclave injection technologies.
- Advanced curing technologies (eg microwave curing).
- Overall quality concepts.
- Thermoplastic technologies.
- Automated sandwich core material manufacturing technologies (eg folded cores).

There was also a call for better design tools that assimilated aspects both of materials and processing such that the simulation of complex fibre architectures, draping processes, mould filling, curing and joining, are developed into a single design tool.

The 2004 report highlighted areas for possible new materials developments including the use of nanomaterials which is already beginning to be exploited in a number of limited commercial applications. The joining of materials was also cited as a key area and one that is becoming increasing relevant for structures where multilaterals are being used. Joining of composite to composite has its complications but composite to metal, (and plastic and ceramic) joining is altogether more challenging and inadequately researched.

In the field of joining a number of key areas were identified namely:

- Low temperature paste adhesives.
- Advanced curing based on laser or microwave heating.
- De-bonding on demand for repair purposes.
- Adhesives with improved fire, smoke and toxicity properties.
- Assembly technologies.
- Environmentally friendly processes (eg Cr6, Cd, Pb free solder).

The Secondary Research Priority of Multifunctional Structures is linked to such areas as active damping, shape control and health monitoring. The idea of integrating actuators (eg piezo fibres or shape memory alloys) or sensors eg (piezo or optical fibre sensors) within a composite is not new but more applied research is needed, probably driven by demonstrator programmes, in order to tackle the problems of integrating a range of complementary technologies. The final Secondary

Research Priority is Recycling. At present this is not much of a problem for the aerospace sector now, but may assume a greater importance in the next ten years.

The Aerospace sector is set to increase its use of composites dramatically over the next few years. The advent of the A380 has increased demand and demonstrated a number of new structural applications. The forthcoming A400M will feature a composite wing. The biggest boost will however come from the Boeing B787 Dreamliner which is due to enter service in 2008 and its rival the Airbus A350 which is scheduled for 2012, both of which feature extensive use of composites (carbon fibre) in the wings and fuselage. This will ultimately push the agenda for recycling, but ill also present long term logistical problems.

The major problem for continued growth is likely to be the availability of materials at an economic cost. Capacity for carbon fibres has to grow to meet demand, but the cost of the materials must also be addressed. A long term goal for aerospace could well be the search for an alternative, low cost fibre to carbon or alternative methods of producing the fibres. A major drive for lower manufacturing costs will be pointless if the materials are either not available or are too expensive. Current predictions suggest that the cost of titanium metal is likely to be halved within ten years if the new FFC process replaces the Kroll methods of winning the metal from its ore. This could seriously affect the market share of composite materials unless the cost issues are tackled.

Defence: land and sea

The land and sea defence needs are complicated due to the very broad range of applications, from body armour to ship hulls, where low radar signature, blast resistance, lightweight, corrosion resistance and thermal insulation and fire protection, are all composite attributes that have different degrees of value in different contexts.

The importance of the materials, and the most relevant properties, will depend to some extent on the profiles of the armed forces that emerge as a result of changes in the country's defence needs and defence commitments. As an example, the need to develop lightweight armour for rapid deployment of an intervention force has diminished relative to the need for armour providing improved survivability as the army's commitments have changed with the current role in Iraq and Afghanistan.

This may also go hand in hand with the re-design of fighting vehicles. The classic tank design ensures protection for the vehicle moving forward towards an enemy, but such vehicles are always relatively more exposed to attacks from behind or below as might be expected when operating in a counter insurgency role.

Composites may have a role to play in reducing total vehicle costs by facilitating integrated manufacture using low cost moulding processes. Improved reliability, reduced maintenance costs may all have an increased importance in an era where defence budgets are under pressure and the capability is stretched.

Long term technology needs

The longer term technology needs of the defence and aerospace sector have been examined and are presented in the following table. This examines the needs on a sector basis and on a generic applications basis.

Defence and aerospace sector

Table 1

Sector Applications	**Requirements**	**Composite Demands**	**Research Requirements**	**Timescale**
Aircraft				
Civil-wings and fuselage	Light high stiffness low cost Robust, high damage tolerance good fatigue resistance, resistant to lightning strike survivability to impact damage	High often within a mixed structure	Development of new tougher composite materials Repair of composites NDE Techniques for composites Out-of-autoclave manufacturing techniques for large structures Development of sensor systems for inspection, corrosion and damage detection Materials and structural designs that lead to weight reduction with no cost or performance penalty Adhesive and joining methods Environmental degradation of composites Hydraulic ram Materials modelling associated with many of the above	Developments are required on all timescales
Military Wings and Fuselage	Light high stiffness low cost Robust, high damage tolerance good fatigue resistance, resistant to lightning strike low radar cross-section survivability to impact damage	High-skins, spars, ribs and UAVs	Development low cost materials and manufacturing Repair of composites, NDE Techniques for composites Out-of-autoclave manufacturing techniques Development of sensor systems for inspection, and damage detection Joining methods Blast and ballistic resistance with armour integration Materials with novel electro-magnetic properties Environmental degradation of composites Materials modelling associated with many of the above	Developments are required on all timescales

Table 1 Continued

Landing gear and brakes	Heavily loaded structure	Low-some potential for MMCs and C-C composite standard in brakes. Emerging PMC applications for struts and linkages		
Naval (ships)	Large structures Low radar cross-section Low fire smoke and toxicity Air blast resistance	Low for general structure, Medium for add-on structure (turrets, etc)	Development of new tougher composite materials Repair of composites NDE Techniques for sandwich laminates Out-of-autoclave manufacturing techniques for large structures Development of sensor systems for inspection, corrosion and damage detection Materials and structural designs that lead to weight reduction with no cost or performance penalty Adhesive and joining methods Materials with novel electro-magnetic properties Environmental degradation of composites Good FST without cost /performance compromises Materials modelling associated with many of the above	Developments are required on all timescales
Naval (submarines and props)	Large structures Underwater blast and shock resistance Damping characteristics Environmental durability	Low, but increasing	As above plus high damping noise/vibration damping	Developments are required on all timescales

Table 1 Continued

Land	Highly robust and damage tolerant structures, resistant to mine blast, high speed projectiles and other civil disturbance Low cost	Traditionally low, but increasing development of composite armoured fighting vehicles	Blast and ballistic resistance and armour integration Development of new tougher composite materials Repair schemes (including running repairs) NDE Techniques for composites Out-of-autoclave manufacturing techniques for large and high thickness structures Development of sensor systems for inspection, and damage detection Materials and structural designs that lead to weight reduction with no cost or performance penalty Adhesive and joining methods Environmental durability Materials modelling associated with many of the above	Developments are required on all timescales

Table 2

Sector Generic Themes	Requirements	Composite Demands	Research Requirements	Timescale
Manufacturing	Low cost manufacture of large, highly loaded structures	High	Newer, tougher resin systems New fibre architectures Out-of-autoclave manufacturing techniques Adhesive and joining methods	
Design	Highly loaded structures which will need Air certification	High	Materials and structural designs that lead to weight reduction with no cost or performance penalty	
Health and Safety	Low VOC Good fire resistance		Recycling and disposal solutions	
Inspection and Repair	Required in both controlled environment and in the field		Repair of composites NDE techniques for composites Development of sensors systems for inspection, corrosion and damage detection	
Performance	Extreme structural performance Battle damage High fatigue loading	High	Higher toughness and damage tolerance	
Sustainability	Increasingly required for long lifetime	High	Performance monitoring (e.g. Structural Health Monitoring) Condition monitoring	

Rail Transport

The rail vehicle manufacturing industry is dominated by a number of large, multinational systems integrators (eg Alstom Transport, Bombardier, Transportation, and Siemens Transportation Systems) who operate manufacturing/assembly facilities in a number of countries. These plants may in turn subcontract elements of the manufacturing to second tier supplies.

Currently, no single primary material dominates rail vehicle construction, with aluminium steel and stainless steel all prevalent. However, a given manufacturing plant will normally specialise in just one of these. The choice of which country to select for a specialisation in composites would be based on the availability of staff, and a strong local support network consisting of supplying companies, testing facilities, Research and Technology organisations and universities with relevant expertise and Intellectual Property. Cost would also be a factor.

The UK interest would therefore be best served by creating the conditions in which the UK was the logical place to site such a plant. Given labour costs, the best advantage that the UK could offer is likely to come from the quality of the workforce and the quality of the design expertise. If the UK developed a capability for large scale textile preforming, this might be an additional factor. This would suggest that education and training are critical as well as technology advances.

No NCN road mapping exercise has yet been completed for the UK rail sector, but NewRail led the rail component of the COMPOSIT European thematic network on “The future of composites in Transport”. This group reported in 2004 with “The Research Requirements of the Transport Sectors to Facilitate an Increased Usage of Composite Materials - Part III: The Composite Materials Research Requirements of the Rail Industry”.

The European perspective on long term research needs for the rail sector are applicable to the UK in most cases.

The primary needs were identified by COMPOSIT as:

1) Modelling, including:
    - Analytical techniques for the rapid, non-linear structural analysis of composite parts.
    - Prediction methodologies for estimating the long-term behaviour of composite systems.
    - Improved finite element packages that integrate realistic material failure and damage behaviour.
    - Improved modelling for dynamic loading.

2) Manufacturing technologies:
    - Improved process simulation for better optimisation.
    - Online monitoring/control technologies for improved process consistency.
    - Technologies for more cost-effective sandwich structure manufacture.
    - The application of advanced preform technologies to reduce lay-up times.

3) The development of comprehensive and accurate life-cycle analysis models for the use of lightweight composite materials in the rail industry to quantify their environmental and financial benefits.

4) Joining technologies – including the joining of dissimilar materials.

5) New fire safe resin systems that provide good all-round performance in terms of fire, smoke and toxicity, processability, mechanical properties, and surface finish.

There were also a large number of secondary research priorities, which included the following:

- The development of highly compatible multi-purpose repair materials (particularly resins) with long shelf lives.
- The development of better materials/structures for energy absorption.
- Improved understanding of the processing of highly filled resins.
- Efficient and effective non-destructive testing procedures for the assessment of bonded joints.
- The development of end-use applications for recycled composite materials.
- The development of low cost fire tests and the further development of guidelines for designing fire safe rail vehicle structures.

More general ideas for improving the competitiveness of composites within the rail industry itself were put forward by COMPOSIT. These focused on the need for standardisation that would put composites on a more equal footing to other materials for the specifier.Particular aspects identified were the standardisation of composites, composite material specifications (and hence data), and fire testing protocols.

The sector needs and research requirements are set out in the following tables, where application areas are identified as vehicle ends, vehicle bodies, bogies and interiors. Generic themes are then covered such as manufacturing, design, health and safety, repair, performance and sustainability.

Research timescales
* Immediate challenge for production implementation
** Solution required in production five – ten years
*** Future need (production 15+ years)

Long term technology needs

Table 3

Sector Applications	Requirements	Composite Demands	Research Requirements	Timescale
Vehicle Ends	Static proof loads.	Medium - high. Crashworthiness is probably the most demanding requirement.	Efficient tools for the numerical simulation of the crashworthiness of composite structures (ie tools that are cost / time competitive with metals).	*
	Crashworthiness.		Improved understanding and data for the behaviour of composites at elevated strain rates.	**
	Missile protection. Mounted equipment. Aerodynamic profiling. Maintenance of fitness for purpose under day-to-day operation (cleaning, repair, etc.). Fire performance.		Dynamic testing of full-scale demonstrators	*

Table 3 Continued

Vehicle Bodies	Static proof loads.	Medium - high.	Joining technologies for multi-material structures.	**
	Fatigue loads.		Life cycle analysis models for quantifying the environmental and financial benefits of lightweight structures in the rail industry.	*
	Mounted equipment.		Cost-effective manufacturing technologies for large bodyshell structures.	**
	Maintenance of fitness for purpose under day-to-day operation (cleaning, repair, etc).			
	Fire performance.			
Bogies	Static proof loads.	High.	Prediction methodologies for estimating the long-term behaviour of composite systems in demanding applications.	**
	Fatigue loads.		Low cost, high performance reinforcements.	*
	Mounted equipment.			
Interiors	Static proof loads.	Low - medium.	New fire safe resin systems that provide good all-round performance in terms of fire, smoke, toxicity, processability, mechanical properties and surface finish.	*
	Interior crashworthiness.		Efficient tools for the numerical simulation of interior crashworthiness (occupant protection).	*
	Maintenance of fitness for purpose under day-to-day operation (cleaning, repair, etc).		Prediction methodologies and low cost test protocols to support fire safe design.	**
	Fire performance.			

Table 4

Sector Generic Themes	Requirements	Composite Demands	Research Requirements	Timescale
Manufacturing	Low to medium production volumes (100 - 10,000) depending on part. Wide range of part sizes (interior component - bodyshell). Cost sensitive, with relatively low premium for weight saving.		Lower cost manufacturing processes for composite components.	*
			Technologies for the production and handling of very large composite structures (eg bodyshells).	*
			Improved understanding of the properties and processing of highly filled (fire safe) resin systems.	*
Design			Better simulation capability for the crashworthiness (structural and interior) of composite parts.	*
			Better tools for the specification and analysis of joints involving composite structures.	**
			Better tools for estimating the long-term behaviour of composite systems (ie effects of fatigue, impact, environment).	**
			Prediction methodologies and low cost test protocols to support fire safe design.	**
Repair			Highly compatible, multi-purpose composite repair materials with long shelf lives to reduce inventories improve availability and standardise repair procedures.	*
Sustainability	Lower vehicle mass to increase capacity and/or reduce operational energy consumption.		Life cycle analysis models for quantifying the benefits of lightweighting in the rail industry.	*

Automotive

From the standpoint of composite materials, the automotive industry is not a single sector, but consists of mass production passenger vehicles, niche vehicles, trucks and buses, all with different characteristics and needs.

The mass production industry is a big user of composite materials, but these tend to be short glass fibre reinforced thermoplastics, which are compatible with the production volumes required by this sector. Most of these components tend to be non or semi-structural parts, such as dashboards, manifolds, covers, radiator parts. Some examples of structural thermoplastic parts are emerging but these tend to be for relatively low volume versions of mass production cars- e.g. the composite bumper on the BMW M3. The only structural form of composite that is compatible in materials properties, cost and manufacturing speed, with volume production is sheet moulding compound, SMC. This material has had a long history with the industry and is well established, particularly with the SUV and "people carrier" segment of the market. SMC is more widely adopted in the USA than Europe, but it still features as a major component of the European industry. SMC panels often compete directly with steel where the final decision rests on the cost per part manufactured. There are many examples over the last 15 years where SMC has won out over steel when the production volumes are expected to be modest but where steel has replaced SMC when the volumes increase. The critical production volume (total and annual) will vary from application to application, but is generally regarded that SMC has a cost advantage over metal for annual production volumes of less than 80,000 and steel has the advantage when the volumes exceed 200,000. In between these figures the choices may be influenced by other factors. SMC does offer styling possibilities that cannot be easily matched by metallic parts and this is a feature and a significant advantage of all composite materials and process routes.

Resin transfer moulding is another process that is beginning to feature strongly in the automotive sector for the production of medium volume parts, often being used in combination with SMC to create assemblies for medium production vehicles such as the Renault Espace.

The niche sector of the automotive industry which encompasses special production versions of volume cars, sports cars, lower volume off-road and specialist vehicles, the top-end prestige cars and ultimately competitive racing cars, are more likely to utilise larger volumes of composites as the production volumes are more compatible with composite processing methods and there is a greater benefit to be gained from exploiting the properties of composites. These may include the styling benefits, lightweight, corrosion resistance, stiffness and crash worthiness. As the value of the vehicle increases, from say Lotus to Aston Martin to McLaren, the likelihood of increase usage of carbon fibre as opposed to glass also increases. The applications are also more likely to include fully integrated composite structures reaching the complete carbon fibre chassis adopted by all Formula 1 teams.

Trucks are of course larger and produced in smaller volumes than passenger cars. This has resulted in a significant uptake of composites for large panel components with many truck cabs and radiator grills made from glass fibre RTM or SMC. Once again however the choice of materials selected is dependent on the relative costs of steel and composite at the time the design is signed off. The shear size of the vehicles means that the composite tonnage can be quite high in any vehicle. The Ford Aeromax 9500 truck cab is quoted as comprising a total of 204 kg of composites making up the door panels, bonnet, roof and bumper.

The trailers for large trucks represent an emerging large market for composites with resin infusion of glass fibre thermoset now being seriously considered for the trailer beds and the wall panels produced from typically, GRP/foam sandwich sheets. Other composite elements such as pultrusions may be used in the assembly of the trailer. Both refrigerated and non-refrigerated trailers are being developed that are extensive users of composites, although this is exclusively based on glass fibres to date.

The final growth market for vehicles is the bus sector. Here composites are widely used for interior panels with the requirements, especially for fire and smoke performance closely mirroring those of the rail industry. The large size of buses means that when chassis and bodywork are being produced from composites (eg the Compobus from NABI in the USA) then a variant of vacuum infusion is the most common manufacturing process.

European needs
The UK position and foresight requirements for composites in automotive applications are similar in many respects to those of our European partners but with some difference in emphasis. The European Thematic Network ComposiTN also produced a study on the overall Europe wide needs for future research in Composites for the auto indusrty. This part of the network was led by Centro Recerche Fiat and the report was “The Research Requirements of the transport Sectors to facilitate an increase usage of composite materials Part 11: The composite materials research requirements of the automotive industry”.

Some of the overall trends identified included a continuing push for thermoplastic materials, but with long fibre thermoplastic (injection mouldable) LFT compounds supplanting glass mat thermoplastics, GMT for semi-structural medium volume parts. They also identified a downgrading of recycling as the number one priority but a greater emphasis on whole life considerations.

The Primary Research Priorities from the CompositeN European Network:

Some are clearly targeted at the use of composites in high volume applications. They include:

- The development of new composite material manufacturing processes suitable for high volume production.
- Composite materials suitable for high volume production (eg fast-curing thermoset).
- Composite material process automation, especially for the positioning of reinforcements. Automated processes are necessary to reduce manufacturing costs and cycle times, as well as for quality control.

For medium and low production volumes:

- Composite materials that can provide near-autoclave performance using out of- autoclave processing with fast cycle times.
- Carbon fibre price reduction and stability.
- Stability of carbon fibre supply (compared to the shortages of the mid-1990s).

And more generic needs identified included:

- Composite materials / processes that are sympathetic to the new European end of life vehicle regulations.
- Composite material test methods for the automotive sector. Test methods developed for aerospace applications are not always applicable to automotive products.

- Specific design procedures for automotive composites. All automotive manufacturers have developed design procedures for metal components but these are not generally transferable to composites.
- New composite material failure criteria. Existing failure criteria are not always applicable for new material developments.
- New numerical models for composite materials. The abilities of these models need to be judged in three respects: (i) the availability of the characteristic material properties, (ii) the accuracy of the material model, and (iii) the computational effort required.

Secondary research priorities

Some secondary research priorities were also highlighted in the report.

- New composite materials for more stringent fire safety requirements. Current automotive fire safety regulations are largely based on (non-flammable) metals. One can speculate that the increasing introduction of resin based materials might lead to new regulations in this area.

- The further development of integrated product/process analysis tools to reduce the number of experimental tests required during the development of composite parts. These kinds of tools are already employed in the automotive industry for parts fabricated from sheet metals, resin injection and SMC.

Curiously this report cited joining, particularly of multi materials systems and the issue of end of life disassembly as being critical areas for the industry, but did not identify any specific issue related to joining in their priority list!

NCN Automotive roadmap

The NCN has recently completed a Roadmapping exercise for the UK industry, which concentrated mainly on those sectors of the market where the UK had influence and was competitive. It is a fact that none of the large volume automotive producers currently operating within the UK are UK owned. Decisions on the selection and sourcing of composite parts will not necessarily be taken in the UK. The most relevant factors determining the health of the composites automotive component supply industry as far as the UK is concerned is to nurture strong component design capabilities, either within the laboratories of the prime auto companies based in the UK, or at supporting universities or RTO's and to link these design centres with UK component suppliers who are in a position to implement innovations quickly. An integrated design/manufacture infrastructure for components would increase the likelihood of parts production being contracted to UK companies and further underpin the maintenance of vehicle assembly in this country.

The sector of the market where UK investment in research and innovation is likely to pay most dividends is in the niche and specialist vehicle arena. This is where there is the possibility of more extensive use of structural composites and where there is ample scope for innovations in materials, processing and design concepts. It is also noteworthy that the SMC sector in the UK that supplies the automotive industry is small compared to the other major European economies.

The NCN Technology Roadmap for the Automotive Industry focused on this area, looking mainly at high added value products using carbon and glass fibre reinforcement.
The report cited a number of actions and recommendations under the headings of Technology, Skills, Finances and Funding and Awareness.

Technology:

- Processing of thermoplastics with greater automation.
- Integration of metals with composites.
- Repair and the use of smart materials.
- Recycling, including disassembly.

Skills: The roadmap identified the improved skills needs in crash, durability and cost modelling. In many instances skills existed but not in the right place – indicating a need for better communication, especially with universities and a less disjointed supply chain. Project management from an engineering standpoint is lacking in the UK and there is a lack of skills in the jigging and tooling area.

Finances: There is a perceived need for more money to support SMEs, and a lack of research funding at universities. A better set of Tax incentives could help the industry to support companies pursuing a lightweight-fuel efficient agenda.

Awareness: The industry needed a stronger voice, the OEMs and Tier one suppliers should become more aware of how to engineer with composites, a multi-materials design database is needed and there should be more promotion of industry success stories.

Long term needs

The longer term needs for the sector can be considered in two categories, Body structures and Components.

For body structures, the main challenge is to provide technology for lightweight vehicle, high volume production at minimised cost premium over steel. The drivers for this are:

- Tax incentives for low emission cars.
- Synergy with new power plant – for which lightweight is demanded.
- Improved crash safety.

The EU TECABS and Daimler Chrysler – McLaren SLR projects have demonstrated, though the use of textile preforming and various infusion technologies; the weight and safety benefits of carbon fibre composite structure together with the cycle time and manufacturing cost challenges for production above 10,000 – 20,000 vehicles PA. This niche volume is insufficiently valuable to encourage major industry investment in new composites technologies, whereas the value of the 20,000 – 100,000 annual vehicle production sector is of extremely high value. The UK can be considered to be in a leading position for automotive composite primary structure engineering and it would therefore be logical for the UK to build upon its strength in this area.

For components, including interiors, there is a much wider scope for composites applicability which includes:

- Bio composites.
- Fire resistant resins and fillers.
- Nano engineered coatings and fillers for heat conductance and wear resistance.
- Ceramic matrix composites for engine/power train/braking.
- Battery/fuel cell/gas containers.

LIGHTWEIGHT BODY STRUCTURE TECHNOLOGY CHALLENGES

The technology challenges for the sector are identified under headings of manufacturing, safety, configuration, repair, comfort, finish and sustainability, with timescales from the immediate to the long term.

Research timescales

* Immediate challenge for production implementation
** Solution required in production five – ten years
*** Future need (production 15+ years)

1. *Manufacturing*
   a) Automated preforming technology for direct tow – final shape *
   b) Low - in mould cycle time - processing*
      I. Resin chemistry
      II. Resin injection
      III. Mould tooling
   c) Affordable carbon fibre manufacturing technology – new techniques, new stiff fibre types**
   d) Tooling technology for assembly cost minimisation**
      I. Jig less / 'Airfix' approach
      II. Inserts integration / over moulding
   e) Joining of hybrid structures *
      I. To overcome thermal expansion, disassembly and crash / repair issues
      II. Fasteners
      III. Disbondable adhesive joints
   f) Durability of structures using thermoplastic and other new resins *
   g) Local vehicle assembly / micro factories with low capital investment ***

2. *Safety*
   a. Lightweight passenger cell robustness **
   b. Crash structures behaviour and prediction – especially off axis *
   c. Interiors **
   d. Ultra light urban / teen cars ***

3. *Configuration*
   a. Modular design and manufacture for quick model variant change / face-lifting *
   b. Design for joining and disassembly inc. hybrid material issues *
   c. Body structure refurbishment – life extension **

4. *Repair*
   a. Bonded joint – metal / thermoset and thermoplastic disassembly for replacement and re-use *
   b. Crash structure design for vehicle body (chassis / platform) damage prevention *
   c. Design for repair cost minimisation – damage zones / rapid disassembly *
   d. SMART Structure – embedded sensors for durability and damage awareness ***

5. *Comfort*
   NVH - self damping of stiff structure **

6. *Finish*
   a. In mould coatings / self coloured panels / textured surfaces*
   b. Nanotech coatings – self clean, non scratch, colour changing? ***

7. *Sustainability*
   a. Affordable disassembly and recycling *
   b. Re use of carbon fibre in vehicle bodies **
   c. Re use of resins ***
   d. Elimination of painting **

Proposed priority research fields

Based on the technology challenges, the perceived research needs are now listed under similar headings.

1. *Manufacturing*
   a. Oriented cut fibre and fibre placement preforming *
   b. In mould polymerisation materials and process technology *
   c. Assembly *
      I. Jig less – ‘Airfix’ type techniques
      II. Steel insert - thermoplastic composite body integration and disassembly
      III. Disbondable adhesive
   d. Durability study of thermoplastic matrix primary structure *
   e. Future fibres – affordable carbon, new stiff fibres **

2. *Safety*
   a. Lightweight safety cell design **
   b. Off axis crash study and prediction *
   c. Interiors **

3. *Configuration*
   Modular design and manufacture for quick model variant change / face-lifting *

4. *Repair*
   a. Bonded joint – metal / thermoset and thermoplastic composite disassembly for replacement and re-use *
   b. Crash structure design for vehicle body (chassis / platform) damage prevention *
   c. Design for repair cost minimisation – damage zones / rapid disassembly *
   d. Sensor techniques for damage / durability assessment ***

5. *Finish*
   In mould coating for IM body panels *

6. *Sustainability*
   a. Affordable disassembly and recycling *
   b. Re use of carbon fibre in vehicle bodies **
   c. Life cycle analysis for materials / manufacturing process selection / recycling *

Long term technology needs

Table 5

Sector Applications	**Requirements**	**Composite Demands**	**Research Requirements**	**Timescale**
Body panels	Surface finish Repair Thermoplastics	medium	Coatings –nano, in mould	immediate
Chassis/monocoques	Crash worthiness Repair Rapid assembly Lower cost materials	high	Design for crashworthiness Improved energy absorption Damage assessment Preforming and joining carbon fibres with better cost/performance ratio	Medium term Medium term Immediate Medium term
under bonnet	Temperature stability Durability	high	High temperature/low cost resins	Medium term
Truck cabs	Lightweight Rapid moulding	medium	Lightweight SMC	immediate
trailers	Low cost processing of large structural parts. Incorporation of inserts Thermal insulation	High low	Preforms for infusion Bonding of metal to composite Low cost foams	Medium term Immediate Medium term

Table 6

Sector Generic Themes	Requirements	Composite Demands	Research Requirements	Timescale
Manufacturing	automated preforming for final shape low cycle time resins affordable fibres (carbon) low cost tooling/jigging joining of hybrid structures		Fibre placement technologies In-mould polymerisation New precursors technology Jig-less manufacture New adhesives, surface treatments, de-bonding technology	Immediate Immediate Medium term Immediate Medium term
Safety	Robust passenger cell Improved Crashworthiness Interior safety Ultralightweight urban cars		Lightweight design concepts Off0-axis crash modelling Role f composite interiors Improved design/low cost materials	
Configuration	Modular design and manufacture for facelift/variant changes Design for joining Body structure refurbishment- life extension		Modular design concepts Multi material joining Repair/enhancement	Immediate Immediate Medium term
Repair	Bonded joint dissimilar materials Disassembly of joints Design for repair cost minimisation Smart structures- damage awareness/alerts Repair of crash structures.		Metal/ thermoset/ thermoplastic boning and disassembly Design for zonal damage Incorporation of appropriate sensors Damage assessment methods	Immediate Medium term long term long term
Comfort	Noise vibration harshness		Controlled damping	Medium term
Finish	In mould coating for body panels		In-mould coatings Nanotech coatings	Immediate Medium term
Sustainability	Affordable disassembly and recycling Re-se of carbon fibre in vehicle bodies Life cycle analysis		Techniques for recycling Reclamation of fibres Data for improved models	Immediate Long term medium

Process Plant

Process plant composites technology can be considered in three categories:

1. Tanks and silos.
2. Pipes.
3. Pumps, filters and other ancillary items.

For tanks and silos the main challenges concern the problems of making large FRP structures, whilst containing VOC emissions within ever stricter limits. Closed mould processing is often not practical, and resin infusion techniques, although gaining popularity in the boat-building sector, are not easily transferred to the manufacture of tanks because of the different geometries involved. RTM may be used for large, thin walled tanks for underground installation, but the technique is not well suited for large, thick walled, structural tanks.

In addition to providing improved working conditions, the introduction of more automated manufacturing methods also enables producers to improve the quality, consistency and efficiency of their operations at a time when a skilled workforce is becoming increasingly difficult to retain.

An alternative approach to "clean" processing may be achieved by adopting thermoplastic composites for tank and pipe manufacture. Thermoplastics are extensively used where the structural requirements are minimal, and have a good service record for resisting aggressive environments. Indeed, PP, fluoro-polymers and other thermoplastic liners have been used for many years to provide corrosion barriers to protect the structural composite backing from attack, but thermoplastic composites can offer both corrosion resistant and structural performance in the one material. So far, only PP, PA, PET and high performance, aerospace-type thermoplastic composites, are in commercial use, and developments would be needed to extend the range to other potentially interesting materials, such as PVC and HDPE. Of course, thermoplastic matrices would introduce other difficulties needing to be addressed, including creep performance, temperature limitations, fire and others, all of which will need to be considered in drawing up new design codes for their use.

Pipes already constitute a large FRP market, but the penetration of composite materials within the pipe sector as a whole still remains very low, at an estimated 2%. Apart from steel and concrete pipes, which continue to dominate this sector, un-reinforced thermoplastic pipes account for the bulk of the remainder. The scope for thermoplastic pipes is mainly limited by their performance under pressure and practical manufacturing constraints. The extrusion of plastic pipes is limited by heat transfer rates on exiting the die, and this limits throughput speeds and leads to restrictions on wall thicknesses for pressure pipes. Some use is made of adding chopped reinforcing fibres to the polymer melt to increase the pipe's strength and stiffness, but with only limited success because of the short fibre lengths and low volume fractions that are possible with this technique. Continuous filament winding of thermoplastic composite pipe, optionally with a co-extruded thermoplastic liner and/or outer covering, would enable larger diameter and higher rated pressure pipes to be manufactured economically, and so enable thermoplastics to challenge new sectors of the market.

It is difficult to identify overall research needs for the third category, since it is very diverse with many different requirements. The majority of needs are considered to be adequately catered for with existing materials and technologies, and so this sector is not considered further.

Proposed priority research needs
Research timescales

* Short term, < five years
** Medium term, five – ten years
*** Long term, 15+ years

1. *Manufacturing*
   f. Environmentally friendly manufacturing techniques for moulding large tanks using closed mould systems *
   g. Manufacturing methods for thermoplastic composite tanks & pipes **
   h. Increased automation during manufacture to ensure greater consistency and adherence to design specification **
   i. Assembly **
      I. Jointing techniques for composite to composite, composite to metal & composite to thermoplastic bonding
      II. Joining techniques suitable for use with thermoplastic composites
   j. Future materials – reduced embodied energy / ease of recycling **

2. *Safety*
   d. Eliminate VOCs from moulding and curing operations *
   e. Improved fire, smoke & toxicity ratings **
   f. Health monitoring sensors to monitor performance and anticipate impending failure *

3. *Design codes/specifications*
   a. Improved techniques for performance modelling needed to optimize design codes taking into account stress corrosion effects **
   b. More refined design codes needed to improve the cost effectiveness of composites **
   c. Extension of data base for generic materials & combinations to aid standardisation of design principles **

4. *Repair*
   Techniques for the effective repair of tanks (& pipes?) in the field to restore the original design specification *

5. *Performance*
   a. Improvements to ageing and weathering effects through better performing surface coatings *
   b. Improved resin systems for corrosion and fire protection, with low toxicity smoke risk **
   c. Increased toughness composites to reduce fatigue and impact risks - thermoplastics? **

6. *Sustainability*
   a. Affordable disassembly and recycling * [- Process plant has a defined service life, usually not more than 20 years or so. Although recycling is not identified as a major issue today, it could well become important in the future.]
   b. Low energy content materials ** [- All sectors will be faced with the need to reduce the environmental impact of their material choices.]
   c. Life cycle analysis for materials * [- Reduced maintenance costs could help to offset other economic or environmental factors.]

Long term technology needs

Table 7

Sector Applications	Requirements	Composite Demands	Research Requirements	Timescale
Pipework (pipeline and piping systems	Resistant to HPHT conditions	High	Qualification data to allow resistance to be quantified	Medium
	Easy to install	Medium	Development of new joint designs	Medium
	Can inspect	Medium	Development of inspection technology and assessment routines	Immediate
Coiled tubing/spoolable pipe	Resistant to HPHT conditions	Medium	Qualification data for polymers with high strain to failure under HPHT conditions	Medium
	Can inspect	Medium	Quantification of installation damage through coiling to long term performance	Medium
Lined pipes	Resistant to HPHT conditions	Medium	Qualification data to allow resistance to be quantified	
	Integrity	Medium	Development of new joint designs	
Composite repairs	Integrity	Medium	Greater understanding of the adhesion performance	Medium
	Can inspect (through)	High	Development of inspection techniques to see the steel substrate through the repair	Immediate
Risers	Integrity	High	Development of improved joint designs	Immediate

Table 8

Sector Generic Themes	Requirements	Composite Demands	Research Requirements	Timescale
Integrity	Improvement in joint designs	Simple to install yet improving integrity	Consequence of joint design in overall long term performance	Immediate
Inspection	Development of techniques to inspect typical types of damage experienced by composite	Ability to size and locate relevant defects, e.g. matrix cracking, delaminations, resin degradation, fibre breakage etc.	Development of relevant inspection techniques and interpretation routines	Immediate
Performance	Data and test methods to assess performance in hostile conditions	Qualification data	Test methods relevant to the loading conditions and environment	Medium
Modelling	Understanding the role of damage on long term performance. Linked with inspection requirement	Linkage between damage and long term performance	Improved degradation models	Medium

Construction

The construction industry is a major market for composite materials. Figures presented in 2001 by the NPL/Netcomposites estimated that the sector presented 11% of the total UK composite market, while reports from the USA at the time suggested that construction accounted for 20% of the US composite market. More recent 2005 figures put the percentage of thermoset glass fibre composites used in the construction industry at 46% of the total US market, equivalent to over 800,000 tonnes of material, with a global share of about 28%. The market share in Europe is a little below the global average at 25% in 2004. Applications range from structural to non-structural components for everything from new dwellings to bridges, towers, office blacks, railway and airport infrastructure and general urban furniture.

Composite provide some obvious advantages to the construction sector- load bearing structures can be relatively lightweight, the materials do not suffer from electrochemical corrosion, and manufacturing processes are sufficiently flexible to allow novel architectural features to be developed and traditional materials to be simulated. However at the same time the construction industry is notoriously conservative, extremely price sensitive and safety critical. Civil engineering design is largely dictated by design codes with procedures and safety factors built up from decades, if not centuries, of experience.

The industry is also massive. This could present logistical problems for the composite industry where, certainly for the more advanced and exotic materials, the demands of the industry would exceed the capacity of the composite sector to deliver.

Fire performance has traditionally been a concern for the users of composites in the construction industry but, despite the obvious fact that all materials with a polymeric matrix are combustible, fire is a manageable problem for composites. The materials generally have a low thermal conductivity making fire spread through a composite relatively slow. Careful selection of matrices can reduce the levels of smoke and toxicity that could cause problems in enclosed spaces (interior rooms, corridors).

A major attraction of composite materials in the current industrial climate is that they enable architects and engineers the ability to incorporate energy saving ideas, novel sensing technology and recycled materials while facilitating off-site prefabrication and reducing transportation costs and build times. Probably the major obstacles for continued expansion of the sector are the lack of design data coupled with inexperience and unfamiliarity with the materials from the construction sector as a whole.

The construction industry developed a significant champion with the formation of the DTI-backed Network Group for Composites in Construction, NGCC. This group which is now operating independently has participated with the NCN to undertake a road mapping exercise for the sector, which reported in June 2006. The results of that exercise are reported below.

NCN technology roadmap for the construction sector

A team of experts adopted accepted procedures to form a roadmap for Composites for the Construction Industry in June 2006. The following actions and recommendations were forthcoming from the Workshop:

More effort to be directed towards:

- Standards for QA and design, with provision of codes of practice for composites in construction. Industry groups should be established to develop standards. They should identify published standards relevant to the Construction Industry, and liaise with BSI and CEN. Use should be made of EU Framework awards for developing Eurocodes.
- Understanding joints and connections, through centrally funded programmes, and especially on research on durability of joints and characterisation of joint behaviour.
- Composites working in harmony with other materials. The composites industry must take a lead in showing what is possible, and should help provide demonstrators. Dialogue and discussions should be undertaken with bodies such as the Society of the Construction industry and the Concrete Society, and guidance should be developed on how to allow different materials to work together. More specifically, research is needed into the behaviour of FRPs with steel/concrete, etc.
- More R&D in specific areas, such as durability, life cycle analysis, whole life cost, and examination of the environmental footprint. Priorities should be set by the industry (as represented for example by the NGCC/NCN) and communicated to the funding bodies, and projects need to be taken forward in a coordinated manner from the 'centre'. Issues such as longer term funding of projects covering durability need to be addressed and funding for demonstrator projects is needed. The Materials KTN, via the NCN, should gather knowledge and disseminate it.

Vision for composites for the construction industry

- A stronger manufacturing base is required to grow the market in the UK in order to establish a more profitable sector with better production facilities than it has currently. Better marketing and public relations will give a stronger message for the UK, and a single, strong, coordinated presentation should be given to stakeholders. Clustering of companies should be encouraged (as is found on the Isle of Wight). Demonstrator projects are needed.
- At present architects and designers do not treat composites as part of their toolkit. There is a clear need for better promotion of composites, and training courses for engineers and architects. Composites should be introduced into all levels of education. A strong central function could disseminate knowledge and information to increase the use of composites in applications.

Skills

- It is essential to have an educated, skilled, well-trained, and enthusiastic workforce. Cleaner and higher technology processes would go a long way to attracting the right workforce. Government funding should be allocated to training schemes.

Technologies

- More R&D is needed in specific areas such as:
  - Durability of composites for very long term applications.
  - Life cycle analysis and the environmental foot print.
  - Whole life costs.

  The 'centre' needs to have dialogue with the funding bodies. It should coordinate and prioritise R&D requirements and should pass on information on R&D activities. A general funding issue is that three years is too short for some projects, and there should be more funding available for scale-up.

RE-BRAND COMPOSITES AND PLASTICS

- 'Composites' implies any two materials joined together to form a new material and causes confusion. 'Plastics' in the construction industry implies 'cheap and nasty'. Re-branding is required and lessons could be taken from the automotive, aerospace and marine sectors, which do not seem to have the same marketing problems. Better marketing and PR should be adopted as a priority and it was suggested that 'structural FRP' (fibre reinforced polymer) would be a suitable name.

Current situation

Table 9

Current situation	
Skills	~ Off-shore island mentality ~ Lack of designers – contractors do not know how to handle materials ~ There is an insufficient number of skilled people ~ Operator skills are lacking ~ Composites are not taught to engineers, architects or designers
Competition	~ The leaders are very fragmented and are industry specific – NGCC can bring together ~ Competitors are already active in modular design (BRE Innovation Centre) ~ There are imports from abroad – pultrusion ~ Competitors are alternative materials such as steel, concrete, masonry, timber, and aluminium
Capital	~ Capital investment is very limited, and active companies are mainly foreign ones ~ There is a lack of experienced, large moulders
Trends	~ Niche in: light weight , speed of installation, use where access is limited ~ Niche: shape flexibility design ~ There are trends to natural fibres and resins ~ Niche in strengthening applications ~ Niche in low maintenance and corrosion resistance ~ The industry is in its infancy, and has been for the past 30 years ~ There is a trend towards air tightness, driven by regulation ~ Process skills in: ~ Pultrusion, resin infusion, RTM, hand lay-up, spray-up, filament winding, open/closed moulding, vacuum bag ~ Niches in: insulating structures, non-magnetic, bridge repair, structural repair, tunnel repair ~ There is a trend towards low energy content and environmental sustainability ~ Trend towards modularity and off-site construction ~ Trend to recycling and re-use ~ Trend to alternative fuels – heating, etc. ~ Current trends to : off-shore fabrication/modular, shortage of traditional skills, ~ Light weight construction, ~ Life cycle analysis, ~ Increased combination of materials, increased regulation (fire, thermal insulation
Gaps	~ Data and QA ~ Codes – performance and prescriptive ~ Marketing skills, education, product development ~ Non-destructive testing ~ Converting technologies to applications

Table 9 Continued

	~ Durability, especially surface finish ~ Leaders: no academic focus, few specialist designers
Drivers	~ Off-site modular construction ~ Total environmental impact, life cycle analysis ~ Cost, regulations / environmental, social changes (more and smaller houses), emission trading ~ Creativity, urban regeneration, social trends, climate change ~ Speed of installation, regulations, risk reduction, safety and health ~ Cost first; whole life sustainability
Customers	~ Contractors and others ~ Buildings, housing, pipes, tunnels, bridges, transport infrastructure, masts / towers ~ Customers are asset owners and are very diverse ~ Moulders, contractors, developers, asset owners ~ Architects, engineers, professional clients, users

Future direction

Table 10

Main priorities for future direction for Composites in the Construction Industry (Priority ranking given in brackets)	
More effort needed	More attention to standards for QA and design, and provision of codes of practice for composites in construction (1). More effort needed on joints and connections (2). More effort should be directed to composites working in harmony with other materials (5). Increased awareness of the potential of composites, avoiding over-sell (11). Adequate production facilities in the UK are needed (12).
Vision	Architects, designers should treat composites as just another part of the toolkit (3). Strive for industry to become really profitable (7). We should strive for a strong manufacturing industry in the UK (8).
Drop	Stop using the name composites or plastics (10).
Skills	We need a better educated, trained, skilled and enthusiastic workforce (6).
Technologies	More R&D in specific areas is required, such as in life cycle analysis, whole life cost, and environmental footprint (4). Composites are needed that can be used for long-term applications (100 years) (9).

Strengths and weaknesses

Table 11

Current key strengths and weaknesses in Composites for the Construction Industry	
Strengths	There are niches in: insulating structures, non-magnetic, bridge repair, structural repair, and tunnel repair. UK has process skills in: pultrusion, resin infusion, RTM, hand lay-up, spray-up, filament winding, open/closed moulding.
Weaknesses	There is a shortage of traditional skills. UK has an off-shore island mentality. There is a lack of designers who know how to use FRPs, and contractors do not know how to handle materials. Composites are not taught to engineers, architects or designers. UK leaders are very fragmented and are industry specific. Competitors are already active in modular design. Competitive materials are: steel, concrete, masonry, timber, and aluminium. Capital investment is very limited, and active companies are mainly foreign ones. There is a lack of experienced, large moulders in the UK. No academic focus within the leading companies.

Long term technology needs

Table 12

Sector Applications	Requirements	Composite Demands	Research Requirements	Timescale
Refurbishment of bridges and buildings				
strengthening infrastructure	adhesive bonding of plates	depends on operating conditions	need proper standards and design codes	***
			need adhesives for all operating temperatures	**
	surface preparation - how to determine what level is good enough	depends on level of surface preparation and adhesive used	need guidance on surface preparation and acceptable limits	***
	testing of bond		need NDT methods for use on site - hammer test not good enough	***
New buildings				
housing	structural panels - possibly with various aesthetic finishes	high	design and testing of structural panels for modular housing	**
			demonstration structures to prove the technology and costings	**
windows and doors	structural performance of FRP	structural and durability important, range of aesthetic finishes	environmental rating, whole life costing	**
FRP with 'traditional' materials	joining materials together and in-service performance	depends on application and material used with	how FRP can work synergistically with 'traditional' construction materials - research needed on all aspects including durability, joining, structural evaluation, design etc	***

Table 12 Continued

Bridges all-FRP bridge	structural and aesthetic requirements	high	demonstration bridge structures to prove technology and dissemination of results	***
Sector Generic Themes	**Requirements**	**Composite Demands**	**Research Requirements**	**Timescale**
Manufacturing				
Disparate industry	need larger players		form 'groups' of manufacturing companies	**
Pultrusion	standard sections will raise confidence in use of composites		demonstration projects using pultruded components	***
Design				
Use of design software	architects and designers not used to working with composites		better education and dissemination at all levels	***
Repair				
Structures from other materials	need codes and standards for: application of FRP, adhesive use and surface preparation		development of codes and standards for construction sector	***
FRP structures	need codes and standards for repair of FRP structures		development of codes and standards for construction sector	**
Performance				
Long-term durability		depends on resin formulation and additives, and service environment	case study dissemination	***
Fire		depends on resin formulation and additives, and service environment	case study dissemination	***

Table 12 Continued

Sustainability				
Natural fibres and resins	good durability and resistance to UV and fire needed	depends on application but long term properties key	development and testing of fibres and resins	*
Environmental ratings	independent environmental ratings for FRP components	depends on application and manufacturing process	large publicly funded project to assess variety of FRP components and dissemination of results	***
recycling	technology developed but volumes and infrastructure to support not there	depends on component design	design for deconstruction	**
reuse	modular construction lends itself to reuse but no infrastructure to support this	depends on application and condition of FRP	design for reuse - standard sections in particular are suitable for reuse	**
OTHERS				
Terminology	Switch from using 'composite' to FRP (fibre reinforced polymer) to avoid confusion		Dissemination needed	***

Marine

The Marine Industry covers a number of different diverse businesses but all use, to a lesser or greater extent, the same materials and processes used across all other industrial sectors. In the majority of cases the volume of finished goods restricts the use of automated "mass production" processes. The industry is noted, with limited exceptions, to resist change which could be its downfall against emerging overseas competition. According to 2004 market data (NCN), in terms of size, the sector represents about 6.5% of the total tonnage of composite products, equivalent to some 400,000 tonnes of materials. In the USA the market for marine composite is comparatively large at almost 11% of the total while in Europe the market share is less than 5% of the total, almost identical in size to the market for wind turbines. Figures are not available for the UK where the market share is likely to be somewhat above the European Average, but even at USA levels this would only equate to a total tonnage of about 20,000 tonnes/annum.

The businesses include:

- Leisure industry small boats etc.
- Medium to large boats semi mass production.
- Bespoke performance boats, large yachts, special to purpose, one-offs.
- Work boats, police, customs etc.
- Military.
- Ships.
- Related large marine products eg oil and gas, renewables etc.
- Architectural mouldings, components etc.

In the majority of the businesses the sold product also includes the installation of equipment etc. The higher up the scale of product in terms of size, performance and complexity the less becomes the % value of the composite element and hence the need to optimise the material or process except for the specific needs of the product eg ships traditionally have been hand lay-up by the nature of their size and the fit out tends to be a significant greater cost element than the composite structure.

Whilst competition is strong between UK, European and Overseas suppliers, at the higher value end ability and reputation is more important than absolute cost. Examples are in the special racing yachts and luxury yachts and in certain of the military applications. The added value elements are where the UK scores, for the moment, over the Far East competition. In most cases companies market and sell a brand type, be it a yacht or workboat, the material it is made of is relevant to meet the requirements and tends to be what the customer requires ie it is recognised that yachts are made in composites and all the competition will be using the same type of material. Where there is direct competition between materials ie metal vs. composites, this is normally where composites are trying to break into a traditional metallic business. In these cases technology is often the driver and price is not necessarily key.

Composites are established in the traditional marine industries, while areas of offshore use, including ships, oil and gas etc. tend to use more traditional materials. Whilst the composite technology exists, the willingness from the project office to take on the risk is often less and hence stifles the use of the material. It is difficult to promote the use of composite against traditional materials unless there is a defined need to use them. This is even accepting that a considerable amount of composites is used on large vessels eg architectural use in cruise ships.

Within the UK, there is a number of recognised “large” users of composites but there are also a considerable number of small companies. In some cases the smaller companies offer a moulding service which is not specific to the marine industry. This results in a broad range of companies which apart from their common use of composite materials, is not a recognised “body” and as such is not able to “fight their corner”.

The traditional methods of manufacture are still very much in existence in the marine industry. Unless there is the need for closed mould technology eg special racing yachts, military etc. use is made of hand lay-up, glass reinforcement and polyester or vinyl ester resin. In the majority of companies the need to change to closed mould will only occur if they are forced by health and safety legislation, or if there is a justifiable cost benefit through scale of production or performance benefits. Change involves investment which is not available. It also involves design changes if the process is to be used to its best advantage, which also involves investment. If change is forced it could result in a reduction in the number of manufacturing companies either through closure, take over or their unwillingness to support the marine industry.

The supplier base to the industry in terms of resin and reinforcement in the traditional materials is becoming smaller through industry amalgamation and take-overs. The result will be the reduction in the influence that the marine industry will have in material development, supply and price. The supplier base will be “swayed” by those that “shout the loudest”.

Competition from overseas will increase, be it Europe or Far East. Price and delivery will be the drivers in most of the marine industries. Some special industries may not have this problem ie military. To resist the threat the composite industry needs unification to maximise its potential as an Industry. This will need to embrace the market and overseas competition, product design, process and the types of companies within the marine industry, to recognise what it is good at and to let go what is better done overseas. It will need to address working with the overseas competition. Lessons from other industries need to be considered eg car industry.

The composite marine industry needs to be recognised by the funding bodies for its employment levels and for its role in British/European industry, and not play “second fiddle” to the glamour industries ie aerospace. Bringing the marine industry together needs to be attempted if funding is to be realised, but to achieve this, caution will have to be taken to avoid the few dictating to the many. All the industry needs to see the benefits. The results from unification will be a stronger voice, more efficient organisation and practices and the ability to capitalise on the best future technologies.

A route to tackling the technology issues could be the formation of a Technology Centre of Excellence specifically for the marine industry to address its particular requirements. This would address issues of process technology, product development and design, production engineering etc. and would work with suppliers to achieve the best products for the industry. This would also allow the development of processing methods best suited to the type of product and the volumes within the marine industry, covering thermosets and thermoplastics, one-off and mass production, hands on and automated processes. Any change in process would require the product design to be reconsidered to optimise the benefits of materials and manufacturing technology changes. A Marine Technology Centre could tackle these issues which are not being faced at established technology centres that are focused on the automotive or aerospace industries.

Such a Centre would also study the issue of recyclability. Whilst this is not a mandatory issue for the marine industry at present the time will come when it will be enforced. This may present opportunities for the use of thermoplastics. Certainly rationalisation across the industry will allow for parts standardisation whereby the costs involved in establishing thermoplastic manufacturing may be justified. The use of thermoplastics for larger components, at the moment, will be limited currently due to the increased costs of tooling and large ovens for the high temperatures required in processing.

Whilst advocating the benefits of a stronger, unified and organised composite marine industry it should not become insular. The composite business across all industries has the problem of identity with some better than others eg aerospace. Lessons learnt in other sectors should be considered and developments in other sectors, which could be of benefit to the marine industry, should be adopted where appropriate. There is a need for an across industry collaboration, but without the "big brother" problems, that may be perceived at the present time, because the marine industry has no recognised voice. This not only affects the marine sector but also transport, civil engineering etc.

NCN marine roadmap

The NCN road mapping exercise (June 2006) for the Marine sector did not reveal much additional information on the specific needs of the marine sector. Most of the comments and needs identified were general issues relating to the composite industry as a whole.

There was a view that the materials used by the industry were moving towards an increasing use of high modulus materials, with advanced composites becoming more mainstream, although the use of carbon fibre is constrained by supply problems.

There were calls for closing the industry's skills gap in manufacturing with more investment in training and for greater cooperation between industry and universities and more investment in R&D in general.

The industry is making ever larger vessels in single step closed mould processes eg SCRIMP or related processes. The demands are likely to be for improved process modelling of large scale 3D infusion coupled with 3D textiles for structures up to 50m. Prediction of the properties of such materials in a manufactured state will be required.

There is also a general need for materials and design codes for improved fire resistance, low viscosity and process tolerant resins.

Long term technology needs

Table 13

Sector Applications	Requirements	Composite Demands	Research Requirements	Timescale
Hulls	Improved rigidity	High	Introduction of high modulus fibres Multi-materials design concepts	Medium
	Damage tolerance	High	Tougher resins and 3D textiles	Medium
	Low cost processing	Medium	Modelling of infusion processes	Medium
	Durability	medium	Improved resins/gel coats	
Superstructure	Fire resistance Lightweight	Medium	Fire resistant resins Fire modelling Improve processing, reduced tolerances	Immediate Immediate
Masts	Rigidity strength	Medium	Introduction of high modulus materials, (nanotubes?)	Long term

Table 14

Sector Generic Themes	Requirements	Composite Demands	Research Requirements	Timescale
Integrity	Improvement in joint designs	Medium	Durability of joints Joining of dissimilar materials	Immediate
			Joining of core to skins for sandwich construction	Medium term
Blast resistance	Ability to absorb shock loading	High	Energy absorbing cores Shock resisting joints	Medium term
Inspection	Development of techniques to inspect typical types of damage experienced by composite	Ability to size and locate relevant defects, e.g. matrix cracking, delaminations, resin degradation, fibre breakage etc.	Development of relevant inspection techniques and interpretation routines	Immediate
Performance	Data and test methods to assess performance in hostile conditions Improved fire resistance	Qualification data	Test methods relevant to the loading conditions and environment Fire testing	Medium
Modelling	Understanding the role of damage on long term performance. Linked with inspection requirement	Linkage between damage and long term performance	Improved degradation models	Medium
	Fire modellin	Ability to predict reaction to fire and resistance to fir	Fire models	Medium

General cross-sector foresighting issues

The preceding sections have attempted to look at the major industrial sectors in the UK that comprise the composite industry. Some sectors that could claim to be major components of the composite industry world-wide have perhaps not been identified explicitly, eg, the off-shore and wind energy industries. These sectors are significant but it is assumed that most of the requirements of the off-shore sector are included within the marine industry, and those of the wind energy sector within the construction sector. There are some specific needs in both cases – the off-shore sector has specific environmental needs with a major emphasis on fire properties, the wind sector is critically dependent on fatigue properties. In common with the other sectors both are looking to reduce manufacturing costs and reduce weight.

The individual assessments of the different sectors in the preceding sections of this report for have identified a number of themes where there are common requirements across the industry to meet the challenges of the future.

Some of the major issues linked to design, joining, repair and manufacturing are outlined below.

Design

Prediction methodologies for estimating the long-term behaviour of composite systems.

New numerical models for composite materials. The abilities of these models need to be judged in three respects:

- The availability of the characteristic material properties.
- The accuracy of the material model.
- The computational effort required.

Integrated design tools are required that take both materials and processing aspects into account. Basic fibre architecture, draping, impregnation, curing and bonding, as well as fibre and matrix properties, are the main factors that influence structural performance. It is necessary to optimise and integrate current isolated approaches to the simulation of complex fibre architectures, draping processes, mould filling, curing and joining, into one design tool.

- Improved understanding of composite material damage mechanisms and failure modes, and the integration of this understanding within commercial finite element analysis software.
- New composite material failure criteria. Existing failure criteria are not always applicable for new material developments.

Joining

Improved understanding and the availability of tools for:

- The selection of joining technologies.
- The design and simulation of joints.

It is essential that these tools should accommodate joints between dissimilar materials (eg composite – metal hybrid structures) to support the evolutionary adoption of composites by industry.

- Efficient and effective non-destructive testing procedures for the assessment of bonded joints in composite and hybrid structures.
- The provision of the necessary information and education to allow engineers to specify adhesives with confidence.
- Low temperature paste adhesives.
- Advanced curing based on laser or microwave heating.
- De-bonding on demand for repair purposes.

- Adhesives with improved fire, smoke and toxicity properties.
- Assembly technologies.

Repair

The development of highly compatible multi-purpose repair materials (particularly resins) with long shelf lives. These would help to optimise the variety of materials employed for composite repair. It would also facilitate the standardisation of repair procedures, thus reducing the risk of low quality repairs.

Manufacturing

Manufacturing technologies that improve the overall efficiency and cost effectiveness of composite processing.

- Improved process simulation for better optimisation.
- Online monitoring/control technologies for improved process consistency, the application of advanced preform technologies to reduce lay-up times/textile preforming and fibre placement technologies.
- Thermoplastic composites technologies.
- Automated sandwich core material manufacturing technologies (eg folded cores).

Composite material process automation, especially for the positioning of reinforcements. Automated processes are necessary to reduce manufacturing costs and cycle times, as well as for quality control.

These general areas are outlined in the table below as cross cutting themes under the titles of joining, design tools and repair. Materials, separated into resins and reinforcements are also listed, as is sustainability.

Manufacturing is not separated in this table as the requirements to support manufacturing are covered under the other headings.

Longer term materials issues

In the longer term additional technical advances may be possible by the extension of the composites industry to incorporate nanomaterials as nano-composites.

The exploitation of nanomaterials in some form is no longer a fanciful research orientated concept, but a practical reality. The use of carbon nanotubes to reinforce resin matrices and improve toughness has been demonstrated, although the cost/performance ratio of this form of composite has not yet been shown to produce benefits that would become commercially interesting. Nevertheless, the use of nano-clays as additives to enhance fire performance in resins is certainly well established in the area of thermoplastic polymers and may well prove significant for thermosets. Nano-additives for gel coats, and surface coatings in general could prove beneficial for self cleaning actions and for improving or modifying frictional and barrier properties. Self healing composites can be envisaged using nano-encapsulation of resins, and extraordinary research growing carbon nanotubes onto the surfaces of carbon fibres is promising to change interfacial properties dramatically.

Predicting the overall impact of the incorporation of nanomaterials into the composites industry is difficult and will justify a separate study when some of the pioneering research has been allowed a little more time to mature.

Table 15

Cross Cutting Research Themes				
Research Requirements		**Sectors**	**Comments**	**Timescale**
JOINING				
	Metal-composite	auto, rail, construction	General bonding of composites ot other materials, surface treatments, joint design, durability	Short term
	Composite-composite	all	As above	Short term
	disassembly	Auto, maybe others	As above	Medium to long term
Design Tools				
	Textile design	Auto, defence	Control of weaving process to generate textiles, design of textiles to generate properties	Short to medium term
	Distortion during moulding	Aero, auto	Critical for autoclave moulding but also for volume production in auto sector using RTM etc.	Medium term
	Crash analysis	Rail, auto	Prediction of properties of structures	Short to medium
	Fire safe design	Rail, marine, construction	Modelling of properties during fire, fire development, heat release	Medium term
	Failure prediction and modelling	all	Better tools are required with more realistic failure criteria to predict mechanical failures	Medium term
	Long term durability	all	Prediction of properties in a range of environments- including fatigue conditions, high temperatures	Short to medium term
	Data	all	Data that is qualified or meets the needs of standards bodies, especially for construction, marine, but also applicable to other sectors	Medium term
Resins				
	Low viscosity	marine, rail	Resins for use in infusion	Short term
	Tough	All	Different degrees of importance but very important in aero/defence	Medium term
	Fire safe	Rail, marine	Smoke and toxicity and also fire resistance	Medium term
	thermoplastics	Auto, marine, aero	Development of thermoplastic matrix composites with genuine capacity for recycling, welding, disassembly.	Medium term
Reinforcements				
		all	3D weaving for ballistic and impact properties, net	Short term

Table 15 Continued

	3D weaving		shape	
	Low cost, high modulus/strength	Aero, Auto	Need for carbon fibres with different cost/performance ratio to encourage adoption by auto industry and provide different options for aerospace	Short ot medium term
	Natural fibres	Construction, auto	Use of sustainable fibres to reduce carbon footprint	Medium term
Repair				
	patch design	all		Short term
	patch materials	Auto. aero	Patch/repair materials with long shelf life	Medium term
	inspection and validation	all	Developments in sensors needed	Short to medium term
Sustainability				
	reduced emissions	all		Medium term
	recycling	auto, rail and aero (eventually)	This area could be crucial for auto industry in the short term but will influence all sectors in time.	Short term to long term (depending on sector
	sustainable resin	all	Resins from non-oil sources	Medium term
	Life cycle analysis	all	Data to allow realistic assessment of merits of composites relative to competitive materials	Short term

Strategic and supply chain issues

The other aspect of concern for the industry relates to developments that are not specifically technical, but impinge on the supply chain and the general infrastructure of the industry in the UK and are largely strategic in nature.

The UK is experiencing difficulties in sustaining a manufacturing capability in all fields in the face of commercial pressures from low cost manufacturing in the Far East and other developing nations. In all sectors businesses can look to reduce costs by re-locating manufacturing overseas. This should give concern to the UK and to the composite industry. While it is only prudent that companies should explore these opportunities and where necessary reduce their costs and increase their competitiveness, it is difficult to see a long term future in which the UK can sustain a high technology industry without substantial direct manufacturing at home. The notion that design leadership will be retained when manufacturing is exported, a view cherished by many, is flawed. The experience of the composite sector is to underline that design and manufacturing are part of a single integrated process and without direct experience of the manufacturing characteristics of the materials; the design is likely to be inefficient and uncompetitive. Furthermore, the low cost manufacturing centres are striving to expand their capabilities to introduce design and technology leadership, which they would reinforce with the existence of local manufacturing capacity. The composite industry is very much focused on niche products, high added value components, and one-off structures and not on volume production of stock parts. The exception perhaps is for items such as pipes and pultrusions where, once the product has been established, then manufacturing proceeds without change for a considerable period of time without the need for regular upgrading or modification.

In this context it is essential to retain as much manufacturing in the UK as is possible and the industry must look to ensure that factors other than price provide us with our competitive advantage. In some sectors this may rely in no small part on the existence of a supportive broader industry to which the composite sector acts as a supplier. The automotive and aerospace industries are examples. The composite sector in the UK can flourish in an aerospace environment, because there is a strong supply chain supporting Airbus, BAE Systems and Boeing. The UK is a raw material supplier, a supplier of intermediate materials, components and semi-fished assemblies. In this context the loss of part of the supply chain might reduce the effectiveness of the entire sector. The UK is vulnerable for example to the relocation of key programmes from Airbus such as the wing design and assembly for commercial aircraft. By the same token, the ability of the UK to retain such work is supported by the existence of a strong composite sector. The supply of sufficient carbon fibres to UK based composite manufacturing companies to meet short term orders for the aerospace sector is still an ongoing challenge.

Government support is important in these instances, not just in terms of direct support for the prime manufacturers or even for first and second tier suppliers, but also for raw materials companies and for the research institutes that supports the businesses. The establishment of the National Composite Network has been an example of support for the composite supply chain network, albeit with a remit that covers all sectors of the composite industry.

Additional support is necessary in order to train the competent engineers and scientist that the supply chain needs to function. Companies that form part of the supply chain will increasingly need high quality staff to provide the technical competence that allows them to compete with low wage economies and this implies that universities are supplying an adequate number of people with the right skills in design and knowledge of materials and manufacturing. In this context supporting University research is not only vital in terms of generating new technologies, but also in terms for generating the highly educated graduates that industry needs. However, skill development at all levels is critical if the industry is to be able to deliver the right parts at the right cost in a reliable timeframe: A manufacturing company with a full complement of PhD-level staff but nobody trained to undertake a vacuum infusion moulding or to laminate a part properly will not last long!

A well educated competent workforce, existing as part of an integrated supply chain serving major industrial companies is a sound recipe for success in the aerospace and automotive sectors. However this will not be sufficient if the industry cannot source those materials it needs to manufacture parts. At the present time the UK has manufacturing capacity for glass fibres, thermosetting resins, intermediate products such a prepregs and fabrics. It does not however have a significant capacity to manufacture carbon fibres. Recent problems in the supply of carbon fibre have highlighted that this can pose problems with the country reliant on supply from external countries (Japan and the USA) whose priorities are not always the same as our own. Any opportunity to redress this deficiency should be considered to be a strategic move destined to support not just the composite industry but those industrial sectors important to the UK economy such as aerospace, and motorsport which are significant users of the materials.

The development of an industry is often a product of environment, economic factors and accident. It is rare that a developed country takes a strategic view on developing or even creating a new industry. In the composite sector there is now an opportunity for the UK to establish new industries based on the recycling of composites. This is a theme which has emerged as important in all industrial sectors, not just automotive. Aerospace is facing the prospects of a recycling need in the longer term which will involve carbon fibres as well as glass. Investment in recycling technologies could present new opportunities for UK companies. Scale is usually the major drawback in making a recycling technology economical viable. The companies that establish a practical network for accessing and concentrating scrap parts in quantity at an early stage will secure a business opportunity that will be increasing difficult for late entrants to access. Targeted government research funding would assist in giving UK industry a head start in this field.

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