National Composites Network

Technology Roadmap for

Composites in the Automotive Industry

ncn
National Composites Network

October 2005

Materials
Knowledge Transfer Network

dti

TABLE OF CONTENTS

1. EXECUTIVE SUMMARY

A group of experts were assembled to help draft this first stage of a roadmap in recycling of plastics, following accepted roadmapping procedures considering 4 stages:

- Where are we now?
- Where do we want to be?
- What is stopping us getting there?
- What needs to be done to overcome the barriers?

All points raised during the roadmap have been clustered, and the following main points have been identified for accelerated action or attention:

Technology:

- Although the UK has strengths in innovation and R&D, attention needs to be given to avoid repetition of R&D for each project.
- The UK is strong in the use of composites in niche areas of the automotive, aerospace and marine industries, and all would benefit from more interaction.
- Thermoplastic composite structures have the potential to replace metal parts but more attention is needed to better processing and automation. There is also a gap in the integration of metals, thermosets, thermoplastics and other hybrids.
- Close attention needs to be given to the repair infrastructure, and the use of smart materials for damage assessment and correction.
- Recycling issues for composites need to be addressed, with issues such as identification, bonding and de-bonding, and re-use needing development work.

Skills:

- Need for improved competence in computer aided engineering, in ‘crash’, durability, and cost models.
- Many of the skills are there, but they are not in the right place. There needs to be better coordination and improved collaboration, especially with universities.
- There is a skill gap in prototyping but not at graduate level.
- A better infrastructure is needed – the supply chain is disjointed.
- Project management is poor, and there is a lack of process, design and mechanical engineers.
- There is a skill gap in tooling and jigging.

Finances and Funding:

- Funding is inadequate; more is needed for small businesses – there is a lack of dissemination and a lack of university funding.
- There is a strong knowledge base in universities and industry but the universities are not supporting industry.
- There is a commercial incentive to arrange the supply chain sensibly.
- For this sector paybacks of 18 months are un-realistic.
- Tax incentives should be agreed with Government – following trends to less weight and better fuel economy.
- More emphasis should be given to commercialising R&D activities with IPR protection.
- A dedicated DTI call for work in material characterisation should be a priority.
- Government funding should address:
    - Durability and performance
    - High speed, high volume processing with a large demonstrator facility
    - Crash prediction and repair
    - Recycling
    - Processing issues such as preforming straight to laminate, resin infrastructuring, and reduced cycle times.

Awareness:

- The composites community needs a strong voice (NCN)
- OEMs and Tier 1s should have a better understanding of how to engineer in composites; and there is a need to re-define customer perceptions and perspectives on composites.
- The lack of political awareness of total commercial issue needs correcting with well reasoned political lobbying.
- The NCN should provide a multi-material design database, and a 'who's who' for the sector.
- Successes need to be promoted better

2. CONTRIBUTORS

The following people attended a meeting in Coventry on Thursday 3rd November 2005 to formulate the first phase of the National Composites Network's Roadmap in Composites:

Name	Affiliation	E-mail address
Andy Foreman	Qinetiq	adforeman@qinetiq.com
Oliver Tomlin	MIRA Ltd	oliver.tomlin@mira.co.uk
Alexander Aucken	Adavanced Composites	aaucken@acg.co.uk
Rob Backhouse	McLaren Automotive	rob.backhouse@mclaren.com
Graham Barnes	Engenuity Ltd	gbarnes@engenuity.net
Robert Tetrault	MCT UK	robert.tetrault@mctuk.com
Andrew Mills	Cranfield University	a.r.mills@cranfield.ac.uk
Paul Jackson	Lola Composites	pjackson@lolacomposites.com
Nick Warrior	University of Nottingham	nick.warrior@nottingham.ac.uk
Paul Burling	TWI	paul.burling@twi.co.uk
Mike Birrell	BI Plastics Division	mbirrell@bi-composites.co.uk
Dan Parry-Williams	Iquad Technology	dan@iquad.co.uk
Jonathan Greaves	Retrac Composites	greaves@retrac-composites.com
Deborah Pullen	National Composites Network	deborah.pullen@twi.co.uk
Alan Smith	Facilitator / MNT Network	SmithAZT@aol.com

3. METHODOLOGY

The methodology used for this roadmap is summarised in Appendix 9.1, following the procedures typically used for other roadmaps that have been produced.

Experts, in groups of around five, are asked to provide their thoughts and opinions for the four main stages of the roadmapping process:

- Where are we now?
- Where do we want to be?
- What is stopping us getting there?
- What needs to be done to overcome the barriers?

For each stage, large hexagon *Post-its* are used to gather each input. These are then clustered under common topics as a spokesman from each group presents their findings. This draws comments from the rest of the participants and generally arrives at a consensus of opinion.

Using adhesive stickers, priorities are given to what are considered the most important issues for the last three stages of the roadmapping process, enabling a key priority list to be established for each step.

The final outcome is a list of priority items that need action in order to enable the industry to progress in a more dynamic and competitive manner.

As with other roadmaps, once this first edition is produced, comments are sought from others in the field, so that ownership comes from the entire community.

4. CURRENT SITUATION

A number of recent publications have considered the future trends in the field of Composites for the Automotive Industry. By way of introduction, these were summarised in Appendix 9.2.

With a group of experts from such a wide cross-section of interests in Composites for the Automotive Industry (industrialists, academics, users and suppliers), the first stage of the roadmapping process, “Where are we now?”, raised the points produced in Appendix 9.3 and tabulated in Figure 1.

The clustered topics covered, addressed issues regarding markets, skills, finance, technology and general industry items, in response to prompts such as:

- What are the current trends?
- What are the main drivers?
- What is the competition up to?
- Who are present leaders in the field?
- What is the UK really good at? – what are our niche areas?
- What are the gaps in technology?
- Do we have the right skills?
- Is capital investment sufficient?

Figure 1: Current situation

Trends	• Cycle time optimisation • Increased processing legislation on emissions (e.g. styrene) • Trend to life-style vehicles • Legislation is a driver – end of life, lower weight, lower emissions • For the high volume end the trend is towards including crash performance (compatibility) • Towards hybrids for lighter weight and fuel economy • Looking at recycling for the high volume markets • An issue is pushing technology initiatives down the supply chain • Replacement of steel • To modular construction • Trends towards multifunctionality • There are distinct camps for thermoplastics and thermosets in the supply chain • Out of autoclave to lower cost for F1/auto • Cost reduction • Mixed materials are becoming more common (composite/metal, etc.) • A driver is the trend to intelligent vehicles • There is a drive to more technology input into higher volume markets • There is a step change (not evolution) to new processes in one jump
Strengths & weaknesses	• In the UK we have strengths in R&D, although Ford does not carry any out in the UK now • UK is good at super niche vehicles • UK is weak in innovation exploitation • The supply chain is too fragmented • UK has good innovators • UK is investment averse • UK strong in the F1 business which is worth around £5 billion to the UK • UK not good at implementation • There is SME protectionism • Transferable knowledge to other sectors should be possible • UK good at lower volume niche areas where the current industry can serve 25,000 units per year
Finance	• UK needs more wealth generation through IPR • A national perspective for jobs is needed
Gaps	• There is no coherent voice to OEMs • A cluster method of commercial collaboration is required to bid effectively • UK needs a high volume demonstrator (100,000 t) with IPR protection • Reliability of prediction tools would be a benefit • There is a design data gap • Need longer term blue sky activities • Need comparative data and benchmarking of competing technologies
Skills	• We need to understand the skills that have already been learned (PNGV FP3) • Better applied knowledge with ability to integrate academic knowledge into products • UK good at aerospace based technology which could flow down to automotive sector • Company multidisciplinary teams in the supply chain needed • There are tribal groups of knowledge which is difficult to access
Competition	• High labour intensive – opposition • There are faster, better funded developments in the Far East to high volume markets
Customers	• Mainstream cars • The public • Niche super cars which is low volume • Tier 1s (direct OEM suppliers – sub-assembly) • Motorbikes • OEMs • Commercial vehicles • Tier 1 and 2 (systems suppliers) • Off-road vehicles • After market accessories

The current status for Composites for the Automotive Industry was identified and is summarised in the following chart:

Trends and drivers with Composites for the Automotive Industry	
Trends and drivers	Cycle times are being optimised and general cost reduction. Legislation is a main driver: • end of life disposal (recycling for the high volume markets) • lower weight (use of hybrids for lighter weight and fuel economy) • lower emissions (e.g. styrene). Replacement of steel. Trend to life-style vehicles. Trends to move to modular construction. A driver is the demand for more intelligent vehicles.

Current key strengths and weaknesses in Composites for the Automotive Industry	
Strengths	• In the UK we have strengths as innovators and in subsequent R&D. • The UK is good at lower volume niche areas where the current industry can serve 25,000 units per year. • UK strong in the F1 business which is worth around £5 billion to the UK, and in super niche vehicles. • Transferable knowledge to and from other sectors, such as aerospace and marine should be possible.
Weaknesses	• Although strong in R&D the UK is weak in innovation exploitation and implementation. • The supply chain is too fragmented. • UK is investment averse. • There is SME protectionism. • There is no coherent voice to OEMs. • A cluster method of commercial collaboration is required to bid effectively. • There is no high volume demonstrator (100,000 t) with IPR protection in the UK. • There is a lack of comparative data and benchmarking of competing technologies.

5. FUTURE DIRECTION

For the second stage of the roadmapping procedure, “Where do we want to be?”, the technique was the same. During the first stage, looking at the current situation, some of the visions and aspirations of the participants were emerging. To stimulate further thought, the following questions were posed:

- What is our vision for the future?
- What should we be doing to maximise benefit for the UK?
- Are we doing something now that we should put more effort into?
- Are we doing something currently that we should drop?
- What is going to make a real impact on our activities?
- What new areas should we be working in?
- Are there opportunities for creating spin-out companies?

The ideas from the participants are shown in Appendix 9.3, and are reproduced in the following diagram (Figure 2), with dots (●) indicating the level of priority judged by the team.

Figure 2: Future Direction
(● indicates priority level)

Targets	• Full recyclability ●●●●
	• Lighter weight, fuel efficiency and safety ●●●●
	• Profit growth ●●●
	• All composite body structures ●●
	• Enhanced material impact performance ●●
	• A high volume demonstrator ●●
	• More environmentally friendly ●
	• Provide niche medium to high volume cars ●
	• Utility vehicles such as taxis, vans, buses ●
	• Quantify ‘Class A’ requirements (surface finish)
	• Look VPA
Technology	• Better processing and automation technologies would have a real impact ●●●●●●●
	• Repair strategy – repair infrastructure non destructive engineering ●●●●●●
	• Thermoplastic composite structures ●●●●●
	• Need bonding and de-bonding technology for recycling and integration and cost optimisation ●●●●
	• Low cost carbon (random fibre on continuous) – 100 t prepreg wanted per year ●●●●
	• Performing technology for high volume ●●●
	• Smart materials for damage assessment ●●
	• Modify or delete paint requirements ●
	• Focus on core industrial technologies ●
	• Effort on recycling materials for re-use ●
	• Low energy cost conversion of car types – efficient, less energy to convert steel to panel
	• Change body / drive train but not the chassis
Spin-outs	• Opportunities are high to form spin-outs
Awareness	• Technology know-how integration ●●●
	• OEMs and Tier 1s should have a better understanding of how to engineer in composites ●●●
	• Stop force fitting technologies
	• Customers need educating
	• We need to re-define customer perceptions and perspectives on composites
	• We need OEM acceptance of technology through a mindset change
Design & manufacturing	• Optimised and integrated design and development ●●●●●
	• Integrated vehicle structure (designing composites together) ●●●
	• Composite engineering design and analysis
	• Re-process materials to be used again
Infrastructure	• Mature moulding / mass producers
	• ‘Mature’ defined composite supply chain
Finance	• Tax relief on vehicles that achieve less mass and more miles per gallon ●●●●●●●
	• Protecting IPR ●●
	• Commercialise R&D activities
	• The available auto composites budget should be separate from other market funding

The main priorities raised are shown in the following diagram:

Main priorities for future direction for Composites for the Automotive Industry	
Targets	• Full recyclability. • Lighter weight, fuel efficiency and improved safety. • Profit growth. • All composite body structures. • Enhanced material impact performance. • A high volume demonstrator is needed.
Technology	• Better processing and automation technologies would have a real impact. • Repair strategy should be improved – repair infrastructure non destructive engineering. • More thermoplastic composite structures. • Need bonding and de-bonding technology for recycling and integration and cost optimisation. • Low cost carbon (random fibre on continuous) – 100 t prepreg wanted per year. • Performing technology for high volume. • Smart materials for damage assessment.
Awareness	• Technology 'know-how' integration needed. • OEMs and Tier 1s should have a better understanding of how to engineer in composites.
Design and manufacturing	• Optimised and integrated design and development. • Integrated vehicle structure (designing composites together).
Finance	• Tax relief on vehicles that achieve less mass and more miles per gallon • Protecting IPR better.

6. BARRIERS TO PROGRESS

Having arrived at a consensus of the future direction for Automotive Composites, the next stage was to determine “What is stopping us getting there?”.

Typical questions asked were:

- Do we have the skilled people we need?
- What are the gaps in our technology?
- Is funding likely to be adequate?
- Do we have the necessary infrastructure?
- What is inhibiting manufacture of nanoparticulates?
- Are patents inhibiting progress?

Again the results of using the Post-it brainstorming technique are shown in Appendix 9.3, and the main items are shown in Figure 3.

Figure 3: Barriers to progress

Skills	~ There is still a metal mindset – we should substitute composites for aluminium ●●●●●●
	~ We have the skills but they are not in the right place. They need collaborating and coordinating ●●●●
	~ A better infrastructure is needed – the supply chain is disjointed ●●
	~ There is a skill gap in prototyping but not at graduate level – we need more process engineers ●●
	~ There is also a skill gap in project management (there are plenty of poor managers but there is a lack of engineers) ●●
	~ Processing and automation – materials handling ●
	~ For thermoplastics the skill gap is in design and processing ●
	~ For liquid moulding technologies which is mature there is no skills gap but there is a general lack of understanding of RTM, it is different from part to part ●
	~ There is a skill gap in tooling and jigging which causes commercial issues ●
	~ For prepreg there is a lack of staff – laminators, trimmers, assembly, design ●
	~ For prepreg, it is still seen as an art and not as a science, especially when a problem occurs ●
	~ There is a general lack of mechanical engineers
	~ Need skill in high speed materials deposition
	~ Materials handling (robotics) and deposition
	~ A technology gap is the lack of information in Tier 1s since all the knowledge seems to be in specialist composite companies
Technology	~ R&D is repeated with each project - there is no hub ●●●●●●●●●●
	~ Better recycling technology required ●●●●●●●
	~ There is a lack of competence in computer aided engineering, in ‘crash’, durability, and cost models ●●●●●●●
	~ There is a gap in the integration of metals, thermosets, thermoplastics and other hybrids ●●●●●●
	~ Need funding for understanding durability and performance, with information on bonds ●●●●
	~ Process plants present a gap – there is still a requirement home build in-house ●●
	~ Gap is NDE for adhesive – glue or no glue
Awareness	~ Lack of political awareness of total commercial issue ●●●
	~ Well reasoned political lobbying is needed ●●
Funding and finance	~ Funding is inadequate; more is needed for small businesses – there is a lack of dissemination and a lack of university funding ●●●●●●●●●●●
	~ Large, amalgamated, cross-sector projects dilute the automotive focus ●●●●
	~ There is a strong knowledge base in universities and industry but the universities are not supporting industry ●●●
	~ Academic interaction with composites industry is poor – knowledge is brought in from Germany ●●
	~ We should license technology transfer ●
Infrastructure	~ Fibre supply commitments ●

The following table summarises the priority items that need to be overcome:

Main barriers in Composites for the Automotive Industry	
Skills	• There is still a metal mindset – we should substitute composites for aluminium. • We have the skills but they are not in the right place. They need coordinating and more collaboration would be a benefit. • A better infrastructure is needed – the supply chain is disjointed. • There is a skill gap in prototyping but not at graduate level – we need more process engineers. • There is also a skill gap in project management (there are plenty of poor managers but there is a lack of engineers).
Technology	• R&D is repeated with each project - there is no hub. • Better recycling technology is required. • There is a lack of competence in computer aided engineering, in 'crash', durability, and cost models. • There is a gap in the integration of metals, thermosets, thermoplastics and other hybrids. • Funding is needed to understand durability and performance, with information on bonds. • Process plants present a gap – there is still a requirement home build in-house.
Awareness	• There is a lack of political awareness of total commercial issue – we need well reasoned political lobbying.
Funding and finance	• Funding is inadequate; more is needed for small businesses – there is a lack of dissemination and a lack of university funding. • Large, amalgamated, cross-sector projects dilute the automotive focus. • There is a strong knowledge base in universities and industry but the universities are not supporting industry.

7. POTENTIAL SOLUTIONS

The fourth step in the roadmapping procedure is to determine “What needs to be done to overcome the barriers”. Generally at this stage the priority items are becoming obvious, and in this case most of the items are short term issues that need action:

Overcoming the barriers to progress for Composites in the Automotive Industry

Funding and finance

- We need cost modelling including tooling.
- Need forward view on raw material prices.
- Accountants should have a longer pay back target than 18 months.
- Tax incentives should be agreed with Government.
- There is a commercial incentive to arrange the supply chain sensibly.
- Need a dedicated DTI call for work in material characterisation.

Awareness

- Need a live, multi-material design database.
- Mixed National Composites Network messages should be clarified (need to promote SMEs).
- Need a who’s who database.
- Need to work with other industries (turn ‘key technology transfer).
- We should have a strong composite voice.
- UK plc political organisation to coordinate technology.
- Promote good activities better.

Technology

- Centre of excellence – universities should promote themselves better.
- Fibre resins matrix (carbon fibres, flax, carbon nanotubes).

Demonstrator

- More funding for high speed, high volume processing.
- Funding needed for bonding; crash prediction; durability; recycling; repair.
- Demonstrate the high volume application of low cost structural composites.
- Government funding should address:
- Preforming straight to laminate
- Resin infrastructuring
- Reduced cycle time

8. ACTIONS / RECOMMENDATIONS

The following actions and recommendations were forthcoming from the Roadmap on Composites for the Automotive Industry, and are listed under specific headings:

Technology:

- Although the UK has strengths in innovation and R&D, attention needs to be given to avoid repetition of R&D for each project.
- The UK is strong in the use of composites in niche areas of the automotive, aerospace and marine industries, and all would benefit from more interaction.
- Thermoplastic composite structures have the potential to replace metal parts but more attention is needed to better processing and automation. There is also a gap in the integration of metals, thermosets, thermoplastics and other hybrids.
- Close attention needs to be given to the repair infrastructure, and the use of smart materials for damage assessment and correction.
- Recycling issues for composites need to be addressed, with issues such as identification, bonding and de-bonding, and re-use needing development work.

Skills:

- Need for improved competence in computer aided engineering, in 'crash', durability, and cost models.
- Many of the skills are there, but they are not in the right place. There needs to be better coordination and improved collaboration, especially with universities.
- There is a skill gap in prototyping but not at graduate level.
- A better infrastructure is needed – the supply chain is disjointed.
- Project management is poor, and there is a lack of process, design and mechanical engineers.
- There is a skill gap in tooling and jigging.

Finances and Funding:

- Funding is inadequate; more is needed for small businesses – there is a lack of dissemination and a lack of university funding.
- There is a strong knowledge base in universities and industry but the universities are not supporting industry.
- There is a commercial incentive to arrange the supply chain sensibly.
- For this sector paybacks of 18 months are un-realistic.
- Tax incentives should be agreed with Government – following trends to less weight and better fuel economy.
- More emphasis should be given to commercialising R&D activities with IPR protection.
- A dedicated DTI call for work in material characterisation should be a priority.
- Government funding should address:
    - Durability and performance
    - High speed, high volume processing with a large demonstrator facility
    - Crash prediction and repair
    - Recycling
    - Processing issues such as preforming straight to laminate, resin infrastructuring, and reduced cycle times.

Awareness:

- The composites community needs a strong voice (NCN)
- OEMs and Tier 1s should have a better understanding of how to engineer in composites; and there is a need to re-define customer perceptions and perspectives on composites.
- The lack of political awareness of total commercial issue needs correcting with well reasoned political lobbying.
- The NCN should provide a multi-material design database, and a 'who's who' for the sector.
- Successes need to be promoted better.

9. APPENDICES

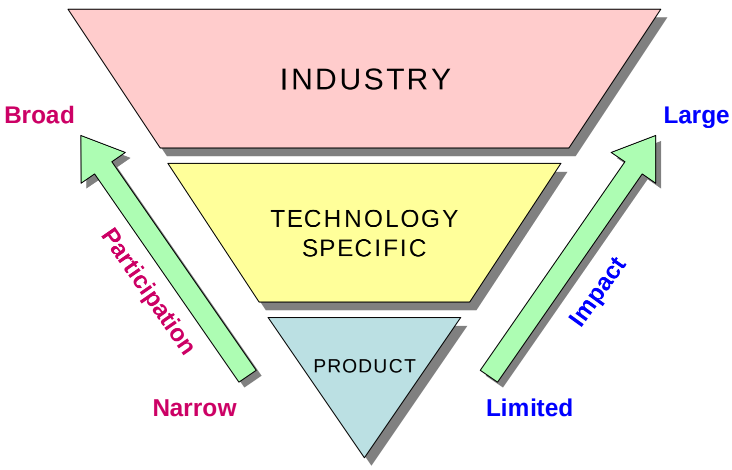
9.1 Methodology

What is Roadmapping?

Based on a Foresight model, roadmapping is a high-level planning tool to help both project management and strategic planning in any technically-based establishment, whether in academia or industry.

Motorola first coined the word roadmapping in the seventies, but only recently has it been widely adopted by both individual companies and industry sectors as an essential part of their future growth. Figure (i) summarises the types of roadmaps that have already been produced. They can be for industries such as “glass” and “petroleum”, or for specific technologies such as nanomaterials, biocatalysis, etc. Some roadmaps have been produced just for single product areas.

Figure (i): Types of roadmaps

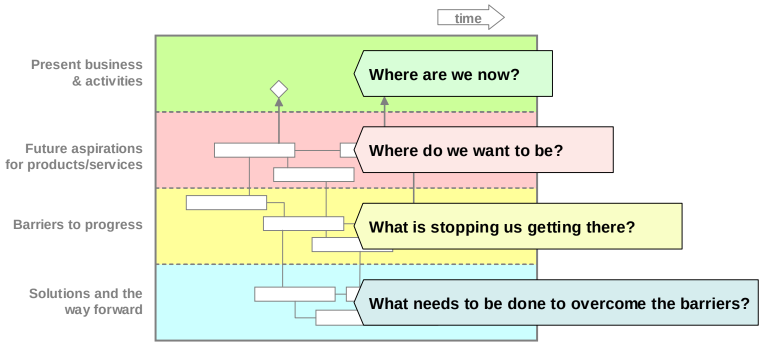


How are the Roadmaps produced?

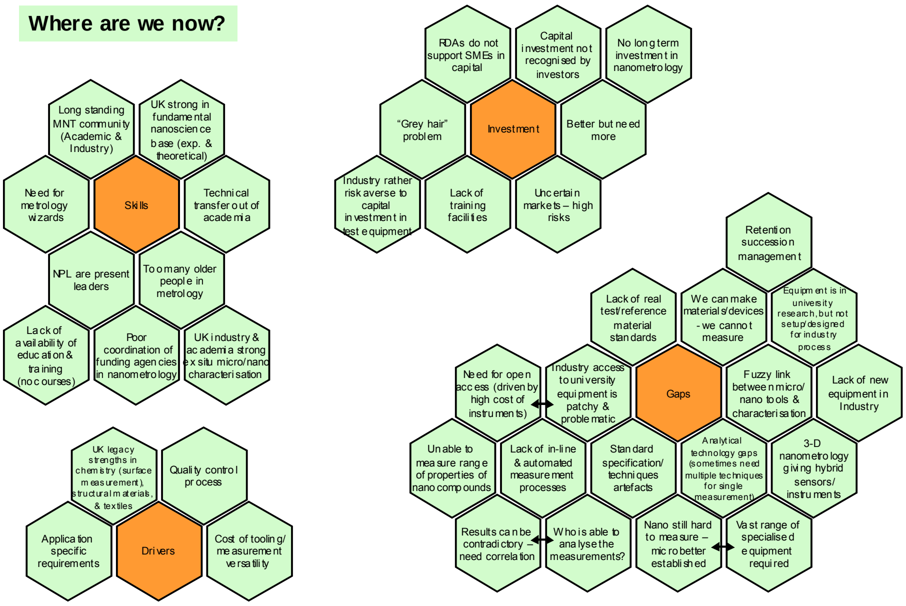
The process gathers together groups of commercial as well as technical experts, and takes them through the four stages that are shown in Figure (ii). The participants need to have sufficient information about the markets and the business to say where the topic under consideration is at the present time. The first step is to agree what the present situation is, and then to move on to provide a vision of where they see things going in the future - where they want to be during the next 20 years.

The third stage is to determine what the barriers to achieving the objectives and goals are. Finally decisions and proposals need to be made to enable the barriers to be overcome. These are arranged over a timescale, with short-term (0 to 3 years), medium-term (3 to 10 years), and long-term (> 10 years) goals.

Figure (ii): Stages in the Roadmapping exercise



Hexagon shaped Post-its (colour coded for each stage) are used to gather the participants' thoughts for each step. These are then grouped into topics, and a typical example is shown in Figure (iii). When a consensus is reached regarding the conclusions, "dot" stickers are added to indicate the main priority items.



Such roadmaps provide a collective opinion about the future strategy, with agreed objectives.

As soon as the roadmap has been completed, it can be sent out to other interested parties for their additions and comments.

Roadmaps are "live" documents and should be updated on a regular basis.

9.2 Summary of visionary publications in this field

BACKGROUND TO ROADMAPPING IN THE FIELD OF COMPOSITES IN THE AUTOMOTIVE INDUSTRY

In connection with the National Composites Network's activities to roadmap composites for the automotive sector, there are a number of roadmaps and strategy documents relating to composites, the automotive industry and the recycling of plastics. The following summaries highlight the main issues relating to composites in the automotive industry. They are arranged in the order they were published within the following sections, with emphasis on the use of polymer based materials:

- Composites
- Automotive
- Recycling.

Figures (http://europa.eu.int/comm/environment/waste/pdf/epec_report_05.pdf) from 2004 indicate the main users of plastics by industry sector throughout Europe. The automotive industry accounts for only 8% of the total.

COMPOSITES

Technology Roadmap for Low Energy Polymer Processing By RAPRA

In December 2003, Faraday Plastics, one of the Faraday Partnerships, produced a roadmap on low energy polymer processing (http://www.faraday-plastics.com/techroadmap.htm). Nanotechnology was not mentioned specifically.

Areas for research and development were identified and the main ones are listed below:

- Increased understanding of the energy balance in polymer processing
- Computer modelling of polymer processing
- Robust in-line melt temperature measurement
- Robust in-line energy measurement
- Supercritical fluid processing
- Single step processing
- Weight minimisation through micro-cellular foaming
- Fluid assisted processing.

Most of the above topics are now receiving attention, but a further 4 areas were identified as being worthy of R&D:

- Mixing technologies
- Process design for energy minimisation
- Intelligent processing additives
- In-line screw wear monitoring.

This particular roadmap resulted in over £3 million funding being obtained from the EU to progress certain aspects of the findings.

Thermoplastic Composites In Europe to 2025 by Coronet

Coronet, a European Research Infrastructures Network, produced in April 2004 a Foresight study into future research needs for thermoplastic composites (http://www.coronet.eu.com/DesktopDefault.aspx?tabindex=98&tabid=182).

A STEEP analysis identified Cost-effective Manufacturing as an important issue, with increases in productivity, lower part costs, reduced parts count, hybrids and advances in competing materials all falling into this category.

A trends analysis highlighted a number of key areas of research that will be needed to meet the expected trends in materials, processes and applications. In materials, these were:

- Natural fibre composites, including wood fibres
- Polymeric fibres such as PET, PP and PE
- Nano-reinforced fibres
- Self-reinforced polymers
- Reactive thermoplastics
- New commodity materials (e.g. PA, ABS, PBT, PET, and TPU)
- High performance materials (e.g. fluoropolymers, LCPs and PEKK)
- Bio-derived matrices
- Thermoplastic nanocomposites.

Modelling techniques and long-term performance characterisation of these materials is also needed. For processing technologies, the following were regarded as important research needs:

- Thermoplastic RTM
- New LFT injection processes
- Hybrid moulding processes (e.g. thermohydroforming) and structures
- Press and stamping processing routes
- Thermoplastic pultrusion and extrusion
- Diaphragm forming
- Filament winding
- Fibre placement and automated tape-laying.

Future needs in nanotechnology were identified below:

Materials	*Research*	*Infrastructure*
Self-reinforced polymers	Nano-reinforcement	Fibre spinning, continuous lamination lines, twin screw extruder
Nano-reinforced fibres	Self-reinforced polymers or other matrices, improved stiffness and temperature	Twin screw extruders, fibre-spinning
Nanocomposites	Enhanced fire properties; use with / without fibres, RTM with carbon nanotubes	Twin screw extruders, analytical equipment
Fire-testing	Fire retardance of nano-clays	Twin screw extruders, fire testing rigs

Towards Commercialisation of Nanocomposites And Hybrids, Faraday Plastics and Hybridnet

This roadmap (May 2004) focused on nanocomposites (http://www.faraday-plastics.com/techroadmap.htm). Processing was the first main point raised by the roadmap, stating that there is a lack of understanding of how polymers filled with nanoparticles or nano-clays behave under processing conditions.

The report identified a real need to establish the processing behaviour for a range of nanocomposite materials especially when processed on traditional polymer processing equipment. Reproducibility is needed, and processing capabilities for nanocomposites should run parallel to product development and the development of reliable Quality Control techniques.

The full list of research needs for processing nanocomposites was:

- Development of processing technologies that will give reproducible products
- Develop in-line monitoring and control technologies
- Uniformity of exfoliation, dispersion and distribution on the nanoscale must be achievable
- Increased processing knowledge is required e.g. what factors affect material integrity, and how can these be controlled?
- Parallel manufacturing developments such as micromoulding need to be developed in-line with developments in nanocomposites technologies
- Presently there is a lack of knowledge of the processing characterisation of materials and how machinery design can be optimised

- Techniques must be developed that allow processing on traditional machinery
- Process induced structuring of nanomaterials must be more fully understood
- Processing technologies must be developed that are cost effective
- Quality control methods need to be developed.

Chemical Industry R&D Roadmap for Nanomaterials by Design

In the United States, the Chemical Industry Vision2020 Technology Partnership, in December 2003, produced their roadmap on nanomaterials. The 93 page report was called *Chemical Industry R&D Roadmap for Nanomaterials by Design: Fundamentals to Function*. It is well worth viewing at www.chemicalvision2020.org/pdfs/nano_roadmap.pdf.

It is very comprehensive; having taken a large number of people a great deal of time and effort to prepare. The emphasis is on getting nanotechnology based products to market as rapidly as possible.

The report begins by saying that Nanomaterials by Design will require concurrent development of:

- Nanoscale fundamentals and synthesis
- Methods of manufacturing
- Multi-probe measurement tools for the nanoscale
- Reliable models relating nanostructures to properties

Additional supporting activities must address:

- Environmental impacts
- Safety and health
- Standards
- Technology transfer
- Infrastructure
- Education

Manufacturing and processing are seen as being particularly important to the US community achieving its objectives in nanotechnology. The following diagram summarises the essential elements of the research pathway to Nanomaterials by Design.

Under Manufacturing and Processing, the following priority issues are highlighted, with timeframes and relative expenditure:

Priority	*Task*	*Timeframe*	*Investment*
Top	Unit operations and robust scale-up and scale-down methods	5 years	$$$$
Top	Manufacturing techniques for hierarchical assembly	20 years	$$$$
Top	Dispersion and surface modification processes that retain functionality	5 years	$$
High	Process monitoring and controls for consistency	20 years	$$$
High	Integrate engineered materials into devices while retaining nanoscale properties	20 years	$$$
Medium	Impurity removal from raw material precursors	5 years	$

IMPACT OF NANOTECHNOLOGY

Nanotechnology will have a considerable effect on the automotive industry, enabling lighter weight materials and additional properties leading to new products.

The diagram shows the possibilities, and in fact some of these are already being used in some cars. With 20% weight saving over conventional parts, the Toyota Camry's air intake cover and the Mitsubishi GDI models engine cover both has a nylon/nanocomposite material rather than a metal part. This makes use of the heat deflection properties of nanocomposite materials.

The Chevrolet Impala uses 245 tonnes per annum of montmorillonite/polypropylene nanocomposite for its side body mouldings.

The final lacquer on a number of Mercedes models is silica nanoparticle based and provides a durable anti-scratch surface. Other coatings developments in the field of nanotechnology are for textiles, where easy-clean coatings are now being used on Hugo Boss suits.

Carbon nanotubes promise composites with 50-100 times the strength of steel and one sixth the weight!

AUTOMOTIVE

Plastics in Automotive Markets – Vision and Technology Roadmap

The American Plastics Council has carried out a roadmap on the future of plastics in the automotive industry which (www.plastics-car.com/roadmap/haveflash.htm). The web summary is set out as follows:

1. UNPRECIDENTED CHALLENGES

Today automakers are faced with formidable challenges:

- Consumers expect cars to perform better, have more features, and cost less
- Existing architectures are reaching their practical limit
- Globalisation and rapid manufacturing techniques are driving the industry to rapidly move innovative vehicles to market
- Design and assembly times must be compressed, and tooling and fabrication costs minimised
- Expectations for a clean environment and sustainable products are pushing automakers to be more responsible in the use of energy and materials

Automakers and designers have already embraced the versatility of plastics in such demanding applications as body parts, intake manifolds, safety devices, fuel systems and tanks, bumpers, structural applications and high performance racing cars.

While polymer use has increased dramatically, it has only just begun to use them to their full potential. The continuous drive to improve the bottom line will create even more opportunities for plastics in automotive applications.

2. A VISION FOR THE FUTURE OF AUTOMOBILES

The vision is that by 2020 the automotive industry will have established plastics as a material of choice in the design of all major automotive components and systems. To realise the vision, plastics producers and automakers will work to maximise the value of polymers throughout the supply chain and over the entire life cycle of the vehicle.

- Plastics will be the preferred material for enhancing component and system value
- Designing with plastics and composites will positively impact vehicle cost, environmental performance, and customer preferences
- Plastics will be the principal tool to produce safer, more affordable, stylish, durable, energy-efficient, and low emission vehicles in every market segment
- Rapid, cost-effective processing systems will provide automakers with the flexibility to respond to dynamic markets
- Polymer-based architectures will give automakers the freedom to create innovative vehicles that increase the value throughout the supply chain and for the driving public.

3. A STRATEGY FOR SUCCESS

To achieve the vision for the year 2020, a bold business strategy will be pursued, composed of 4 main elements:

- New applications for plastics – develop a portfolio of polymer-based tools that maximise the performance advantages of polymers and composites and allow the design and prototyping of new vehicle architectures
- Speed to market – shorten design and engineering cycles to fast-track polymer applications from concept to commercial product
- Enabling infrastructures – present automakers with a sound business case for plastics and built plastics
- Sustainable transportation – develop and use new plastics and composites to create sustainable vehicle.

4. TECHNICAL PRIORITIES

To achieve the strategic goals and vision a diverse portfolio of critical technologies will be pursued. Critical new technology development areas are:

- Advanced material systems
- Predictive engineering
- Automotive design
- Advanced manufacturing technology
- Business, market, and education infrastructure
- Environmental performance.

5. PARTNERSHIPS BRING VALUE

Achieving the vision will require resources beyond the practical reach of any single company. A coordinated strategy is essential, involving all stakeholders.

6. THE PATH FORWARD

In application after application, plastics have replaced conventional materials because they provide the functionality that engineers demand, the styling that designers seek, and the value that customers expect. Automobiles are no exception.

Foresight Vehicle Technology Roadmap

As part of the UK Government's Foresight exercise, the Society of Motor Manufacturers and Traders Limited produced, in 2004, a Foresight Vehicle Technology Roadmap (www.foresightvehicle.org.uk).

Technology targets are shown in the following table:

	0-5 years	*5-10 years*	*10-20 years*
Safety	• Selection of joining systems to match material performance capabilities	• Design/production and validation of 'smart' crash structures	
Product configurability and flexibility	• Component integration • Easier separation of materials for recycling or re-use • Effect of modular structures (and joining) on crash structures/NVH /stiffness • Robust engineering solutions for rapid modular reconfiguration	• Automotive industry relevant materials information database with all needs covered – one source • Management of customer customisation and effect on design process/homologation and supply chain	
Economics	• Reduce cost of moulded composites • Component performance beyond single vehicle life • Development costs • Re-processing of metal mixtures to give pure metals for re-use	• Disassembly techniques • Develop viable alternative to traditional paint finish for body panels	

	• A higher, safer and more environmentally sound vehicle development		
Environment	• Establish standards of environmental friendliness • Development of polymer separation techniques • ELV compliant composite materials • Reduce vehicle weight • Attachment strategies for dismantling • Wider understanding of materials in the industry • Overcoming energy saving vs. recycling perceptions • National system for re-use of components • Low cost CFRP panels and structures	• New magnetic materials for hybrid/ fuel cell powertrain • Develop re-use mechanisms/ methodologies • Identify higher value markets for recovered materials • National systems for materials re-use and recycle	• Solve H_2 fuel infrastructure issues to enable widespread uptake and use • Hardwearing, low friction coatings to eliminate lubricants from powertrains
Manufacturing systems	• Joining hybrid structures • Surface quality thermoplastic composites • Develop low cost composite manufacturing process • Cost effective joining/dismantling of mixed material structures • Cheap, environmentally friendly system to join steel, aluminium and magnesium without corrosion issues • Awareness of and access to process models and life cycle analysis • Establish central register of production routes to advise on potential facility sharing • Single piece structure development costs	• Coatings which survive production • Reduce time to manufacture for novel technologies • Materials that do not require paint protection • Convergence of business and technology research models • Flat pack/modularity requires ability to make cheaper, structural, sealed joints post-paint process	• Die-less forming

Monet Roadmap – Where does the future lead?

Monet is a European Centre of Excellence in 'artificial intelligence into industry', based at the University of Wales in Aberystwyth. It produced a report in June 2002 entitled *Model Based Systems in Automotive Domains: Applications and Trends* (http://monet.aber.ac.uk:8080/monet/docs/tg_minutes_and_reports/automotive/a1_report.pdf).

The approach taken has been through questionnaires to experts in the field. It claims that model-based reasoning has proved to be a very powerful technology for automotive applications for tasks such as diagnosis, design, and simulation. The general idea is that qualitative models can support several activities which are critical to the life cycle of vehicles: from analysis of the original design through on-board monitoring, diagnosis and recovery, to diagnosis and repair in the workshop.

RECYCLING

A Roadmap for Recycling End-of-Life Vehicles of the Future

This roadmap was produced in May 2001 for the US Department of Energy's Office of Advanced Automotive Technologies and the Argonne National Laboratory (www.es.anl.gov/Energy_Systems/Process_Engineering/Technologies/Documents/ELV%20Roadmap%20.PDF). It defines recycling as:

"Any cost-effective use of parts, components or materials from an obsolete car that would otherwise be landfilled, including parts re-use and remanufacturing, materials recovery for re-use in an original application or for use in any other viable application, and materials recovery for thermochemical conversion to fuels and/or chemicals".

The top factors affecting automobile recycling for the next 20 years were listed as:

- Economic value of recovered material and components
- *Material content of vehicles*
- Competing vehicle design requirements
- *Capability to separate and sort material*

- *Hazardous material and contamination*
- Capital availability to build infrastructure
- Collection costs, transport costs, and materials supply
- Regulations impacting recycling
- Consumer opinion
- Unforeseen factors.

All of these factors are likely to be important for the recycling of any material in most industry sectors. For the automotive industry it is estimated that End-of-Life Vehicles (ELVs) in 2020 will be:

- 75% metal
- 15% plastic
- 10% other.

However, since the report was written in 2001, there has been the beginning of a trend to nanocomposite materials in cars with consequential reduction in weight, as well as to other light weight materials such as ultra-light steels and aluminium. Looking specifically at technology changes, it is likely that recycling will have a strong influence on the choice of materials and the ability to remove and separate them at the end of their life (indicated in italics in the list above). The diversity and complexity of the materials used in vehicles presents many challenging issues.

Overall the drivers are economic and regulatory ones, and the roadmap lists the priority needs for ELV recycling as indicated in the following diagram:

Foresight Vehicle Technology Roadmap

The previously mentioned Foresight Vehicle Technology Roadmap (www.foresightvehicle.org.uk), is also concerned with recycling.

In the section on 'Environment' it looks at the re-use, recover and recycle aspects based on the European End-of-Life Vehicle Directive which is already in force. The targets are to improve re-use and recovery to > 95% vehicle weight, and re-use and recycling to > 85% by 2015, which will need significant development of materials and structures. Vehicle design will need to take account of the requirements for disassembly, as well as environmental management from cradle to grave, including reprocessing techniques. Legislation on electronic equipment is also considered in the document.

ELVs account for 1.8 million tonnes of waste in the UK every year, and with the cost of landfill increasing dramatically, together with European legislation on recycling and waste disposal, there will be a positive impact on vehicle design, manufacturing, financing, maintenance, and dismantling.

Performance measures and targets for re-use and recycling are:

2006: ELV targets 85% re-use and recovery
15% landfill

2015: ELV targets 95% re-use and recovery
5% landfill.

EBM Roadmap Summary

This summary document (www.wtec.org/loyola/ebm/usws/ind_summary.htm) looks at the US DOE/OIT and other roadmaps for steel, aluminium, castings, polymers, automotive, electronics, and mining industries. The summary overview deals with the major concerns in polymer manufacture and use, which are energy use and release of toxic emissions. Polymers have more dramatic separation and impurity problems for recycling, as there are generally more types of polymers that are more difficult to separate. Even characteristics such as colour can pose separation challenges, and for these reasons, polymers are commonly recycled into lower grade materials.

Production of plastics from recycled feedstock is typically around 20% more expensive that virgin production. Thermosets, which cannot be recycled, account for a significant fraction of polymers. As well as recycling into secondary applications, another approach is to chemically convert plastics back into their monomer constituents so that recycling back into the original polymer can occur. This is, however, more energy intensive. Another difficulty is that paint and other coatings may need to be removed.

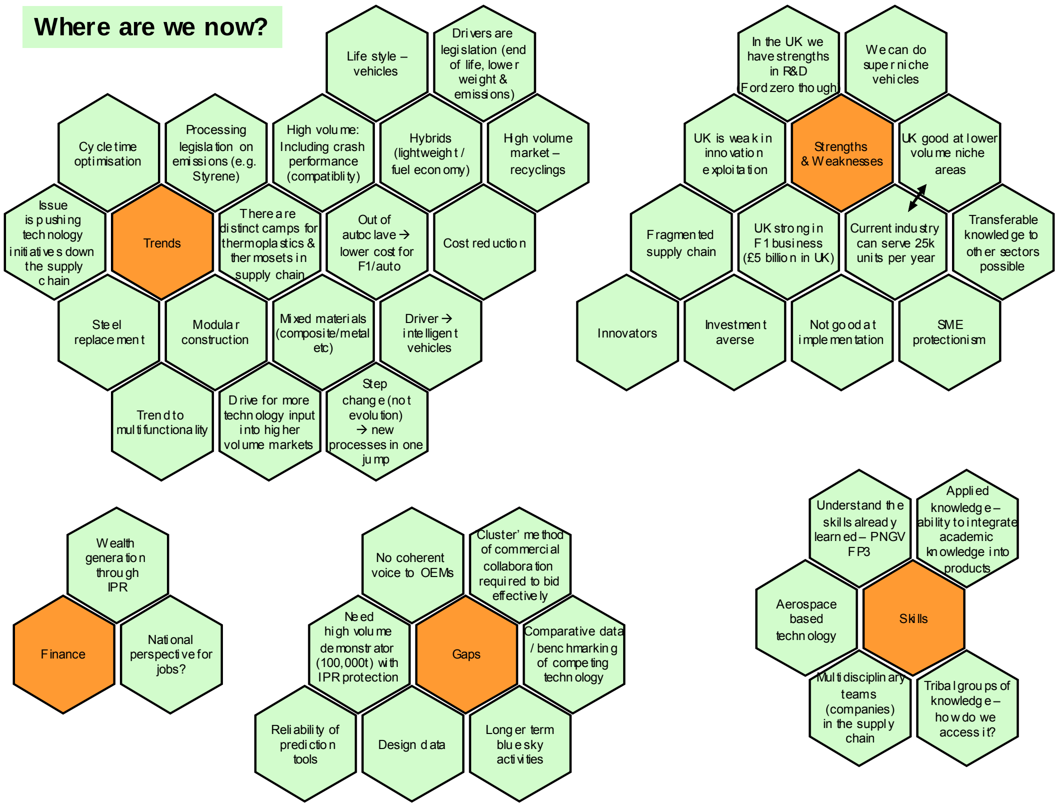
Under the section on the automotive industry the goal to increase recycling is highlighted and improving material separation technologies and reducing the quantity and incompatibility of distinct alloys and polymers contained in a vehicle is stressed.

Thematic strategy on the prevention and recycling of waste

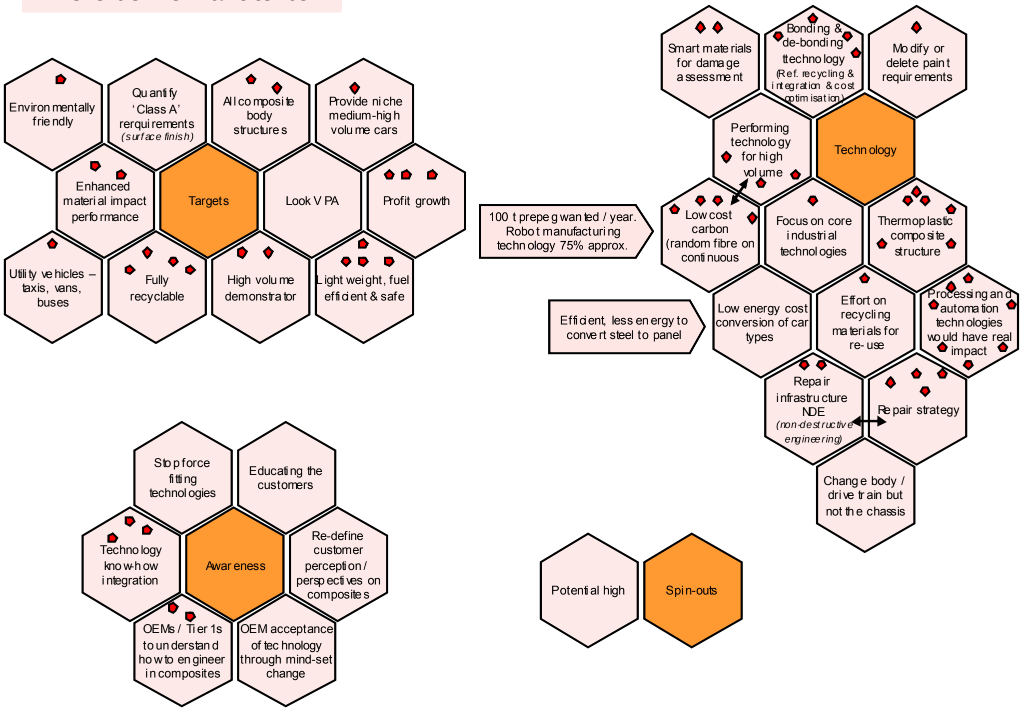
This 289 page EU report may be found at (http://europa.eu.int/comm/environment/waste/pdf/epec_report_05.pdf), and presents a comprehensive amount of data in chapter 6 on plastics recycling. As mentioned earlier, it is the packaging industry that is the largest consumer of plastics.

9.3 Results of the brainstorming with hexagons

Where are we now?



Where do we want to be?



What is stopping us getting there?