National Composites Network

Technology Roadmap for

The Metal-Matrix Composites Industry

March 2006

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Materials
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1. EXECUTIVE SUMMARY

A group of experts were assembled to help draft this first stage of a roadmap in metal-matrix composites, 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?

The following actions and recommendations were forthcoming from the Roadmap on Metal-Matrix Composites:

- The UK has some strengths in MMCs:
    - It has a good record of creativity and innovation
    - There is expertise in aluminium MMCs
- There is, however, no critical mass at present. The aim should be to achieve critical mass by 2010.
- There would be many benefits to the UK's MMC community if there was a strong network in place. This would enable sharing of best practice, with improved communications, and should lead to faster development times.
- There is a lack of knowledge about what is happening generally, and what the capabilities are in this field in the UK. The National Composites Network is in a strong position to provide databases, and the following were suggested:
    - Directory of capabilities
    - Guidelines on design and machining
    - Certified database of materials properties
- Although it was thought that a central Titanium MMC Institute would be beneficial to the community, it was felt that money would be better spent on demonstrator programmes.
- There is a gap in knowledge about how MMCs can, and are, being used. More publicity, in the form of exciting articles, should be undertaken. It was also suggested that the Design Group of the Institute of Materials, Minerals and Mining should be given an illustrative presentation on MMCs.
- A set of case studies on MMCs would also be useful for promotional purposes.
- Risk aversion among engineers inhibits progress, and in addition, there is reluctance by government to invest in this area because of the current size of the market. There was discussion about working through EU Framework Programme 7 (FP7) since MMCs are more likely to be strategically important to the European Community as a whole.
- Future initiatives (such as UK Partnerships) should be longer term; in the past they have only been for 3 years.

2. CONTRIBUTORS

The following people attended a meeting in the Bosworth Hall Hotel, Market Bosworth, Warwickshire on Thursday 2nd March 2006 to formulate the first phase of the National Composites Network's Roadmap in Metal-Matrix Composites:

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3. METHODOLOGY

The methodology used for this roadmap is summarised in Appendix 8.1, 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 second stage of the roadmapping process, enabling a key priority list to be established for subsequent steps.

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 Metal-Matrix Composites. By way of introduction, these were summarised in Appendix 8.2.

With a group of experts from such a wide cross-section of interests in Metal-Matrix Composites (industrialists, academics, users and suppliers), the first stage of the roadmapping process, “Where are we now?”, raised the points produced in Appendix 8.3 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 and drivers	~ Conservatism and caution because of past failures ~ Trend to lower emissions, reduced energy usage, faster time to market, improved durability, and better image ~ The funding situation at the moment is DTI setting regions versus regions competing for jobs, with no national plan ~ Moves to low mass, recyclability, reduced size, specific properties, cost efficiency, and reduced noise ~ Legislation, cost effectiveness, marketing, and performance differentiation are principal drivers ~ There is a requirement to dual source ~ Engineers tend to be risk averse ~ Industry and university activities are fragmented, leading to missed opportunities
Competition	~ Main companies are LAF (UK), Rolls-Royce (UK), AMC (UK), Dunlop (UK), CMT (UK), Saffil (UK), Qinetiq (UK), Tisic (UK), 3M (US), DWA (US), MMCC (US), Duralcan (US), Sumitomo (J), Nippon Carbon (J), NHK (J), FMW (US). The leaders are not in the UK. Not known what China is doing. ~ Design guidelines are available for monolithic materials ~ UK is good at creativity and innovation ~ UK has strengths in Al MMC ~ Competition is very broad, with structural materials, and polymer matrix composites ~ It takes a long time to introduce new materials, especially for aerospace applications
Markets	~ High speed machinery, aerospace, motorsports, sporting goods, marine, transport, space, electronics, telecommunications, and automotive ~ US market is larger and difficult to access
Skills	~ The skills base is getting worse, and it is not a popular career choice ~ Marketing of MMCs is poor
Gaps	~ More could be achieved if there was an MIL handbook (US book for design engineers) ~ There is stagnation in the UK because of a lack of critical mass ~ The cost / volume equation is limiting growth. It is a chicken and egg situation ~ Materials data is fragmented ~ The supply chain in the UK is immature, especially for Ti MMCs
Technology needs	~ End users are moving away from the UK for high volume manufacture ~ We need a systems approach for new materials

	~ Need to develop material for a product (identify applications) ~ Need cost effective products and processes ~ R&D is carried out on a shoe-string ~ Prototyping should be available ~ Need design database for MMCs ~ We need a coherent voice for MMCs, with more collaborative work, between industry and academia, as well as between industry sectors and organisations. Currently they are ineffective and non-existent ~ Research funding has moved away from MMCs as it is not seen as being exciting. Nanotechnology might help.

The current status for Metal-Matrix Composites was identified and is summarised in the following chart:

Trends and drivers for Metal-Matrix Composites	
Trends and drivers	There is conservatism and caution because of past failures. Trend to lower emissions, reduced energy usage, faster time to market, improved durability, and better image. The funding situation at the moment is DTI setting regions versus regions competing for jobs, with no national plan. Moves to low mass, recyclability, reduced size, specific properties, cost efficiency, and reduced noise. Legislation, cost effectiveness, marketing, and performance differentiation are principal drivers. There is a requirement to dual source. Engineers tend to be risk averse. Industry and university activities are fragmented, leading to missed opportunities.

Current key strengths and weaknesses in Composites for the Automotive Industry	
Strengths	UK is good at creativity and innovation. UK has strengths in Al MMC.
Weaknesses	The leaders are not in the UK. US market is larger and difficult to access. The skills base is getting worse, and it is not a popular career choice. Marketing of MMCs is poor.

	There is stagnation in the UK because of a lack of critical mass. End users are moving away from the UK for high volume manufacture. R&D is carried out on a shoe-string. No design database for MMCs in UK. No coherent voice for MMCs, with more collaborative work, between industry and academia, as well as between industry sectors and organisations.

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 8.3, 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)	
Technology	~ Part of current industry developed into a centre of excellence e.g. a Ti MMC Institute ●●●●●● ~ Breakthrough is needed into high volume application for particulate Al MMC ●●●●● ~ Need cost effective materials processing, with joining, assembly, and machining ●●●● ~ Areas for examination are: nano-MMCs, fibre reinforcement, perform manufacturing, rapid solidification ● ~ Academic research is needed on behaviour in applications, and it must be driven by industry needs ● ~ Do not develop any more new materials until the problems with the present ones have been solved ~ Determine whether fibre reinforced superalloys are possible
Drop	~ Drop current fragmented approach to material process and product development – need a co-ordinated approach ●●●●
Business	~ Need cost effective manufacture throughout the supply chain ●●●● ~ Need cost effective manufacture of fibres and reinforcement ● ~ Need a high value business based on intellectual property ● ~ Need to achieve critical mass in the UK by 2010 ●
New areas	~ Reduce cost of fibres; infiltration of performs at very low or atmospheric pressure, allowing use of current production equipment ●●●● ~ Need improved NDT for MMCs in manufacture and service; higher toughness materials; improved high temperature fatigue; better machinability ●●●● ~ Need pro-active rather than reactive use of MMCs. Must avoid adverse publicity for MMCs ●●● ~ There is potential to reduce maintenance inspections ●● ~ Infiltration of performs under low / zero applied pressure ● ~ Emerging MMCs e.g. particulates in Ti in steel – Mg based ● ~ Require UK based manufacture and research on advanced fibres, driven by end user applications ● ~ Need new generation of SiC fibres ● ~ Need cost effective fibre perform design and manufacture ~ FEA / modelling needed for better understanding of mechanical behaviour of MMCs ~ Require low cost rapid solidification technology for particulate composites
Vision	~ Put more effort into interdisciplinary teams to develop a system using an MMC

	●●●●●●● ~ Need a sustainable, profitable business, with co-ordinated academic / industry work on MMCs ●●●● ~ Ti MMCs need real applications with commitment from users, supported by pump priming from government ●●● ~ Must support UK manufacturing business in MMCs, based on applications not materials. Should finance and encourage a systems approach to MMC solutions ● ~ Need a networked coherent UK industry ● ~ Require a vibrant manufacturing industry supported by academia and RTOs ● ~ Must have co-ordinated government support for MMC business development in the long term, without expectation of quick returns ● ~ Improve the MMC product range, extending the potential applications – lower density, higher stiffness, higher temperature, and at lower cost ● ~ Need case studies to be made available on demonstrator applications ~ Need an integrated supply chain especially for Ti MMCs ~ Need buy-in from a large manufacturer by using a multidisciplinary co-ordinated approach of academia and SMEs
Spin-outs	~ Should support those helping MMC development ● ~ A centre of excellence for MMCs would help spin-outs ~ Likely areas might be NDT, end users, new reinforcements
Funding	~ Need support for the industry via low cost loans ●●●●●●●

The main priorities raised are shown in the following diagram:

Main priorities for future direction for Metal-Matrix Composites	
Drop	Drop current fragmented approach to material process and product development – need a co-ordinated approach.
Technology	Part of current industry developed into a centre of excellence e.g. a Ti MMC Institute. Breakthrough is needed into high volume application for particulate Al MMC. Need cost effective materials processing, with joining, assembly, and machining.
Business	Need cost effective manufacture throughout the supply chain.
New areas	Reduce cost of fibres; infiltration of performs at very low or atmospheric pressure, allowing use of current production equipment. Need improved NDT for MMCs in manufacture and service; higher toughness materials; improved high temperature fatigue; better machinability. Need pro-active rather than reactive use of MMCs. Must avoid adverse publicity for MMCs.

Vision	Put more effort into interdisciplinary teams to develop a system using an MMC. Need a sustainable, profitable business, with co-ordinated academic / industry work on MMCs. Ti MMCs need real applications with commitment from users, supported by pump priming from government.
Funding	Need support for the industry via low cost loans.

6. BARRIERS TO PROGRESS AND POSSIBLE SOLUTIONS

Having arrived at a consensus of the future direction for Metal-Matrix Composites, the next stage was to determine *"What is stopping us getting there?"* and deciding *"What needs to be done to overcome the barriers?"*.

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?
- Are patents inhibiting progress?

Actions needed to overcome the barriers (shown in blue) are also included in the following table (Figure 3), and are taken from the priorities shown in Appendix 8.3.

Figure 3: Barriers and Possible Solutions

Drop	**1. Drop current fragmented approach to material process and product development – need a co-ordinated approach.**
Barriers	• Competition between institutions and companies drives a fragmented approach • There is a lack of communication, networks, time pressures, and confidentiality
Next steps	• The UK needs to be better networked. This should be provided by the National Composite Network

Technology	**2. Part of current industry developed into a centre of excellence e.g. a Ti MMC Institute.**
Barriers	• Cost, lack of short term return on investment, with no co-ordinated approach • Lack of funding • Lack of co-ordinating role • No agreement on location and objectives
Next steps	• Better to spend money on demonstrators • Difficult to have a good pay back • Not a priority to take forward

Technology	**3. Breakthrough is needed into high volume application for particulate Al MMC.**
Barriers	• Cost versus performance is too high • There is a lack of knowledge of MMC solutions that are possible • There is no design database • Need to identify suitable applications • There is a lack of a certified database of material properties
Next steps	• NCN should provide databases

Technology	**4. Need cost effective materials processing, with joining, assembly, and machining.**
Barriers	• There is little knowledge transfer – we need to share best practice • There is no directory of expertise • UK only has low volume production at the moment
Next steps	• NCN should provide a 'Yellow Pages' • Need to provide better design and machining guidelines

Business	**5. Need cost effective manufacture throughout the supply chain.**
Barriers	• The small volume MMC market in the UK keeps costs high • There is a lack of incentive to invest in new production of MMC components • UK has limited facilities and has a strong reliance on overseas parts of the supply chain
Next steps	• Must provide links to FP7 funding • Need to publish business case applications

New areas	**6. Need pro-active rather than reactive use of MMCs. Must avoid adverse publicity for MMCs.**
Barriers	• There is risk aversion and conservatism on demonstrator components • There is little access available to design data • Availability of rapid supply of materials is poor • There is pressure in industry to solve current problems and to reduce costs
Next steps	• Databases needed • Must have co-ordinated publicity for MMCs • Design guidelines needed

New areas	**7. Reduce cost of fibres; infiltration of performs at very low or atmospheric pressure, allowing use of current production equipment.**
Barriers	• This is too difficult to do because of the intrinsic cost of the process • There is limited expertise and no UK manufacturing base • Capital cost of a fibre production facility is a barrier • Quality control would be problematic
Next steps	• Blue sky and costly, as well as being long term • This might be strategic for the EU rather than for the UK

New areas	**8. Need improved NDT for MMCs in manufacture and service; higher toughness materials; improved high temperature fatigue; better machinability.**
Barriers	• Lack of design guidelines • There is fragmented data and poor communication in industry • No one knows who to ask • Engineers do not understand compromises that are necessary with MMCs
Next steps	• A database should be a priority • NCN fund free days to help • Better communication is needed

Vision	**9. Put more effort into interdisciplinary teams to develop a system using an MMC.**
Barriers	• Designers do not understand MMCs • There is fragmented R&D for these materials and products • Confidentiality is an issue • There is a lack of communication and resource • There is poor collaboration throughout the supply chain to make things happen
Next steps	• Better promotion of MMCs is essential • NCN have a major role to play in getting teams talking together through a formal network • A presentation on MMCs should be given to the designer group at the Institute of Materials, Minerals and Mining

Vision	**10. Need a sustainable, profitable business, with co-ordinated academic / industry work on MMCs.**
Barriers	• There are few applications to encourage others • UK has low market presence • The research funding system needs to be changed to encourage collaborative work • A materials development emphasis is required rather than product development
Next steps	• Must provide a higher profile for MMCs • Sponsored secondments should be provided • There is a strong desire for a call for an MMC demonstrator programme

Vision	**11. Ti MMCs need real applications with commitment from users, supported by pump priming from government.**
Barriers	• Government policy does not help • There is no incentive to manufacture in the UK
Next steps	• More commitment is needed from industry • Drivers come from Airbus and Rolls-Royce and MMCs are only a small part

Funding	**12. Need support for the industry via low cost loans.**
Barriers	• Government policy is not conducive to progress • There is slow pay-back in aerospace • There is insufficient industry presence in government and the civil service • The financial sector has a short term focus • Government also has a short term focus
Next steps	• The ‘Partnership UK’ initiative is too short – it should be greater than 3 years

7. ACTIONS / RECOMMENDATIONS

The following actions and recommendations were forthcoming from the Roadmap on Metal-Matrix Composites:

- The UK has some strengths in MMCs:
  - It has a good record of creativity and innovation
  - There is expertise in aluminium MMCs
- There is, however, no critical mass at present. The aim should be to achieve critical mass by 2010.
- There would be many benefits to the UK's MMC community if there was a strong network in place. This would enable sharing of best practice, with improved communications, and should lead to faster development times.
- There is a lack of knowledge about what is happening generally, and what the capabilities are in this field in the UK. The National Composites Network is in a strong position to provide databases, and the following were suggested:
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  - Guidelines on design and machining
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- Although it was thought that a central Titanium MMC Institute would be beneficial to the community, it was felt that money would be better spent on demonstrator programmes.
- There is a gap in knowledge about how MMCs can, and are, being used. More publicity, in the form of exciting articles, should be undertaken. It was also suggested that the Design Group of the Institute of Materials, Minerals and Mining should be given an illustrative presentation on MMCs.
- A set of case studies on MMCs would also be useful for promoting them.
- Risk aversion among engineers inhibits progress, and in addition, there is reluctance by government to invest in this area because of the current size of the market. There was discussion about working through EU Framework Programme 7 (FP7) since MMCs are more likely to be strategically important to the European Community as a whole.
- Future initiatives (such as UK Partnerships) should be longer term; in the past they have only been for 3 years.

8. APPENDICES

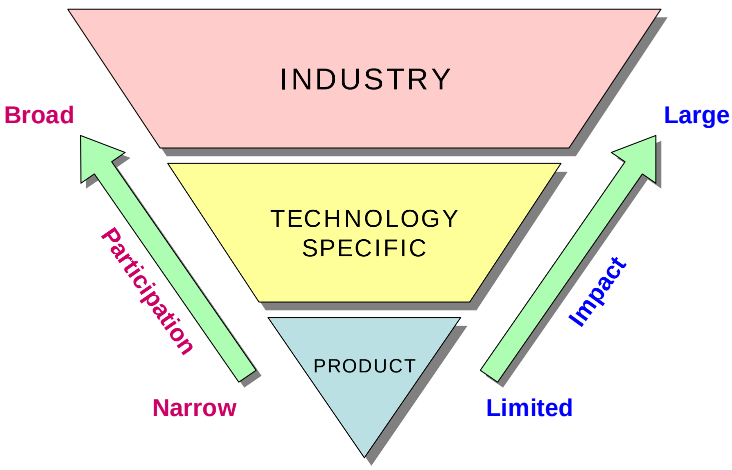
8.1 Methodology

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

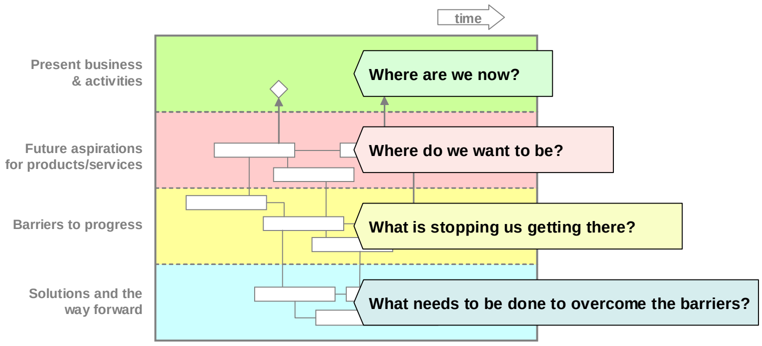


How are the Roadmaps produced?

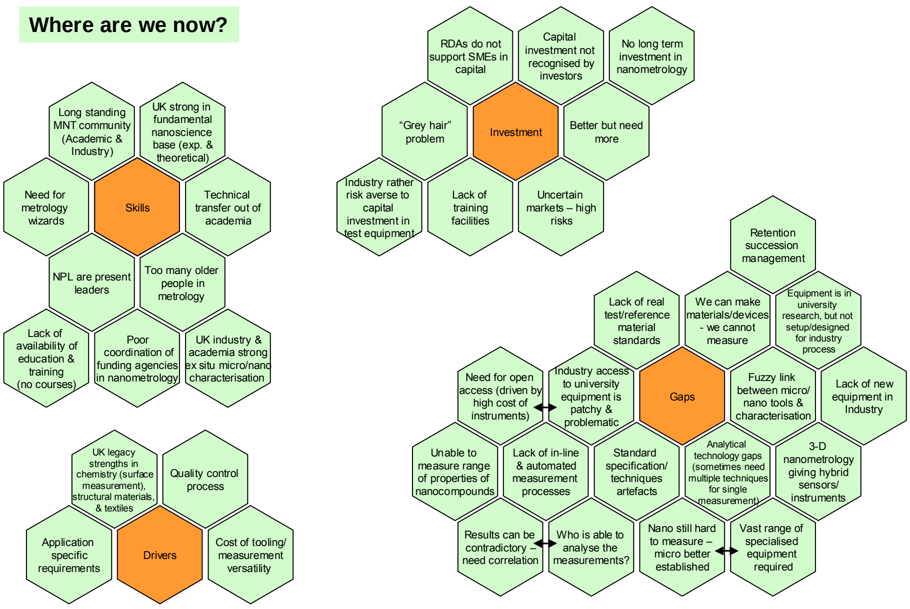
The process gathers together groups of commercial as well as technical experts, and takes them through the four stages that are shown in Figure (ii). The participants need to have sufficient information about the markets and the business to say where the topic under consideration is at the present time. 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.

8.2 Summary of publications on Metal-Matrix Composites

BACKGROUND TO ROADMAPPING IN THE FIELD OF METAL-MATRIX COMPOSITES

A number of reports are freely available relating to the field of Metal-Matrix Composites, and these are summarized and referenced under the following headings.

EUROPEAN WHITE BOOK ON FUNDAMENTAL RESEARCH ON MATERIALS SCIENCE

This book was published in 2001 and emanated from the Max Planck Institut fűr Metallforschung Stuttgart (ISBN 3-00-008806-7). It contains a great deal of useful information and proposes a list of subjects that should be covered by European Centres for Materials technology. These are:

- Structural materials
- Nanomaterials
- Bio and soft materials
- Advanced functional materials
- Complex composite processing
- Coatings, surface modification
- Hybrid and smart materials.

There are chapters on interface science and nanomaterials, all of which give comprehensive summaries of activities up to that time.

A theme throughout the book is the importance of modelling which merits strong emphasis in many of the chapters. There is a specific chapter on *Metal-Matrix Composites: Challenges and Opportunities* by A Mortensen of the Swiss Federal Institute of Technology (Lausanne) and T W Clyne of the University of Cambridge (http://www.mpg.de/pdf/europeanWhiteBook/wb_materials_210_213.pdf).

The priorities for European research are given as:

- A need to advance the understanding of processing fundamentals, especially in established processes such as squeeze filtration, liquid phase sintering, and powder metallurgy.
- Property improvements should be sought, particularly in ductility and toughness.
- There is clear scope for improvements in the properties of reinforcements.
- Challenging issues are welding and machining, and the definition of recycling strategies.
- To date a great deal of effort has been focused on aluminium, but copper, magnesium and iron-based matrix composites offer promise in specific applications.

ASSESSMENT OF METAL MATRIX COMPOSITES FOR INNOVATIONS

Prior to that, in 1998, a thematic network within the European programme Brite Euram III, with 21 partners, was started with the title *Assessment of Metal Matrix Composites for Innovations*. The leadership was provided by Vienna University of Technology, with active UK participation from:

- Bill Clyne, Department of Materials Science and Metallurgy, University of Cambridge
- NPL Management Ltd, Teddington
- EA Technology, Capenhurst.

Activities of the network may be found at http://mmc-assess.tuwien.ac.at. The need for weight reduction of moving systems, operating at elevated temperatures where polymer matrix components cannot be used, was stressed. Examples of actual and possible applications were listed as:

- Parts of combustion engines
- Brake systems
- Stiff beams and load transfer elements in vehicles or aeronautic applications
- Thermal management parts in high power electronics and thermally cycled components
- Components of increased wear resistance at low weight.

METAL MATRIX COMPOSITES: MATRICES AND PROCESSING

In 2001, Bill Clyne had a chapter in the Encyclopaedia of Materials: Science and Technology edited by A Mortensen and published by Elsevier, which was entitled *Metal Matrix Composites: Matrices and Processing*. It provides a good summary of the advantages and disadvantages of the different processing routes. The lowest cost routes are generally those in which particle-reinforced aluminium is produced using liquid metal handling, particularly stir-casting. This represents a substantial proportion of the MMCs in commercial use.

At that time other materials and processes were gaining in importance, such as melt filtration techniques to produce components for automotive engine and electronic substrate applications, along with powder processes used for aerospace applications.

ALUMINIUM METAL MATRIX COMPOSITES ROADMAP

The Aluminium Metal Matrix Composites Consortium has completed a technology roadmap for Aluminium Metal Matrix Composites (2003). The Consortium, representing suppliers, end users, and key US government technologists, produced the report to focus on market growth. By aluminium industry standards, the shipments of aluminium MMCs are small, and the suppliers are disaggregated.

Key strategic goals were identified as:

- Reduce the cost of discontinuously reinforced aluminium MMC to be compared with existing alternatives by 2010.
- Develop the necessary infrastructure to provide design confidence for use of aluminium MMCs.
- Increase the market size for aluminium MMCs ten times by 2005 and twenty-five times by 2010.

With this background, stakeholders from the corporate, academic, and government sectors came together to identify the key barriers to achieving the strategic goals and necessary R&D to overcome the barriers. Emerging from the discussions was a number of common R&D themes that can be summarised as follows:

- Materials development, especially engineered materials.
- Critical process development, especially rapid prototyping capability.
- Machinability.
- Database development.
- Modelling of processing, product performance and cost.

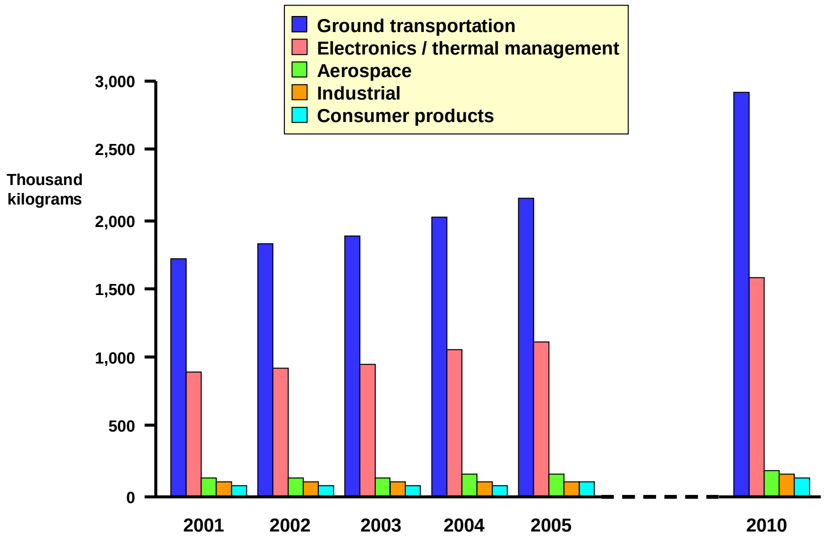
METAL MATRIX COMPOSITES IN THE 21ST CENTURY: MARKETS AND OPPORTUNITIES

In October 2005, Calvin Swift of Business Communications Company (BCC) published a report on the markets and opportunities for metal matrix composites in the 21st century. The report is summarised and advertised on their web site (http://www.bccresearch.com/advmat/GB108N.html), and costs $3,950.

The summary reports the highlights as:

- The overall metal matrix composite market will rise at an average annual growth rate of 6.3% through 2010 to 4.9 million kg.
- The growth rate represents acceleration from that experienced between 1999 and 2004.
- The industry is relatively small, with only $185 million in global revenue.
- Graphically, the most rapid growth in MMC consumption will occur in China.
- Electronics / thermal management and industrial MMC markets will experience the strongest growth, as indicated in the following diagram.

GLOBAL METAL MATRIX COMPOSITES BY APPLICATION SEGMENTS



A previous report from BCC (2000) indicates that previous projections fell short of expectations. A summary of that report by M N Rittner, entitled *Expanding World Markets for MMCs*, may be found in JOM, November 2000, page 43.

COMPOSITES-BY-DESIGN

There is an up-to-date assessment of the current situation for MMCs on the web with the title *Composites-by-Design* (http://www.composites-by-design.com/metal-matrix.htm).

It summarises the situation for a number of different MMCs:

- Aluminium matrix composites are produced by casting, powder metallurgy, in-situ development of reinforcements, and foil-and-fibre pressing techniques. Consistently high-quality products are now available in large quantities, with major producers scaling up production and reducing prices. Applications are in brake rotors, pistons, other automotive components, golf clubs, bicycles, machinery components, electronic substrates, extruded angles and channels, and a wide variety of other structural and electronic applications.
- Superalloy composites reinforced with tungsten alloy fibres are being developed for components in jet turbine engines that operate at temperatures above 1,830^{o}F.
- Graphite/copper composites have tailored properties, are useful to high temperatures in air, and provide excellent mechanical characteristics, as well as high electrical and thermal conductivity. They are easier to process than titanium, and lower density compared with steel. Ductile superconductors have been fabricated with a matrix of copper and superconducting filaments of niobium-titanium. Copper reinforced with tungsten particles or aluminium oxide particles are used in heat sinks and electronic packaging.

- Titanium reinforced with silicon carbide fibres is under development as skin material for the National Aerospace plane. Stainless steels, tool steels, and Inconel are among the matrix materials reinforced with titanium carbide particles and fabricated into draw-rings and other high temperature, corrosion-resistant components.

The following table presents the advantages and disadvantages of using MMCs:

Advantages of MMCs over polymer matrix composites	Disadvantages of MMCs compared with monolithic metals and polymer matrix composites
• Higher temperature capability • Fire resistance • Higher traverse stiffness and strength • No moisture absorption • Higher electrical and thermal conductivities • Better radiation resistance • No outgassing • Fabricability of whisker and particulate reinforced MMCs with conventional metalworking equipment	• Higher cost of some material systems • Relatively immature technology • Complex fabrication methods for fibre reinforced systems (except for casting) • Limited service experience

The summary also goes into some detail regarding the five major categories of MMC reinforcements:

- Continuous fibres
- Discontinuous fibres
- Whiskers
- Particulates
- Wires.

With the exception of metal wires, reinforcements are generally ceramics.

It is the appropriate selection of matrix materials, reinforcements and layer orientations that tailor the properties of the component needed to meet a specific design, which is invariably not possible with monolithic materials.

REPORT OF THE NORTH AMERICAN DEFENSE INDUSTRIAL BASE ORGANISATION (NADIBO)

NADIBO sponsored an assessment of MMCs to identify opportunities to enhance the level of joint effort between the US and Canada in creating and sustaining a viable MMC marketplace. An executive summary appears on the web site for the Defense Technical Information Centre (http://www.dtic.mil/natibo/docs/mmc_es.html).

The study assessed the technology base, detailing the production capabilities, process and product developments, the current marketplace, and future and potential markets and applications. Facilitators and barriers affecting the MMC sector were outlined, and roadmaps of actions designed to enhance MMC development activities.

Nine major North American companies supplying MMCs were identified:

Company	Material	Sales volume / year (lbs or units / year)	Production capability (lbs or units / year)
Duralcan / Alcan	Low volume particulate reinforced metals	1,000,000 lbs	25,000,000 lbs
Amercom	Boron/aluminium Graphite reinforced metals	400 lbs / Space shuttle minimal	3,600 sheets (32"x122") 200,000 units
DWA	Particulate reinforced aluminium Graphite reinforced metals Monofilament composites	Proprietary	150,000 lbs 1,000-5,000 lbs 3,000-5,000 lbs
ACMC	Whisker reinforced aluminium	Proprietary	150,000 lbs
Textron	Fibre reinforced metals	800 lbs 100% T&E	2,000 lbs
3M	Fibre reinforced metals	Minimal 100% T&E	Minimal

Alcoa	Low volume particulate reinforced metals High volume particulate reinforced metals	15,000 lbs 1,000 parts	500,000-800,000 lbs 10,000-30,000 units
Lanxide	Low volume particulate reinforced metals High volume particulate reinforced metals Fibre reinforced metals		500,000 lbs
CKC	Whisker reinforced metals	Minimal 100% T&E	Minimal

The MMC marketplace was broken down into two distinct areas:

- Continuously reinforced (non-broken filament) MMCs
- Discontinuously reinforced (chopped fibres, particulates and whiskers) MMCs.

The distinctions between continuous and discontinuous MMCs are shown in the following table:

Continuous	Discontinuous
• Usually net or near net shape • Improved properties over monolithic alloy o High toughness o High strength o High stiffness • Expensive to manufacture • Tailorable properties o Mechanical o Physical • Requires accurate fibre placement • Thermal conductivity management applications • Tailorable CTE • High temperature applications	• Property improvements over matrix by 2x • Improved properties over monolithic alloy o Good wear resistance o High stiffness o Low toughness o Low strength • Tailorable properties o Mechanical o Physical • Low cost of manufacture • More reliance on matrix • Tailorable CTE • Higher volume % of reinforcement utilises net shape process • At lower volume % levels can use conventional methods to produce wrought products • Structural applications are generally reinforced < 25% volume • Maintain near design and fabrication characteristics of matrix

Applications were broken down into five specific categories: military, aerospace, automotive, commercial and recreational. MMC applications were described as sparse and fragmented.

Significant technology advancement and policy barriers affecting the MMC area were tabled:

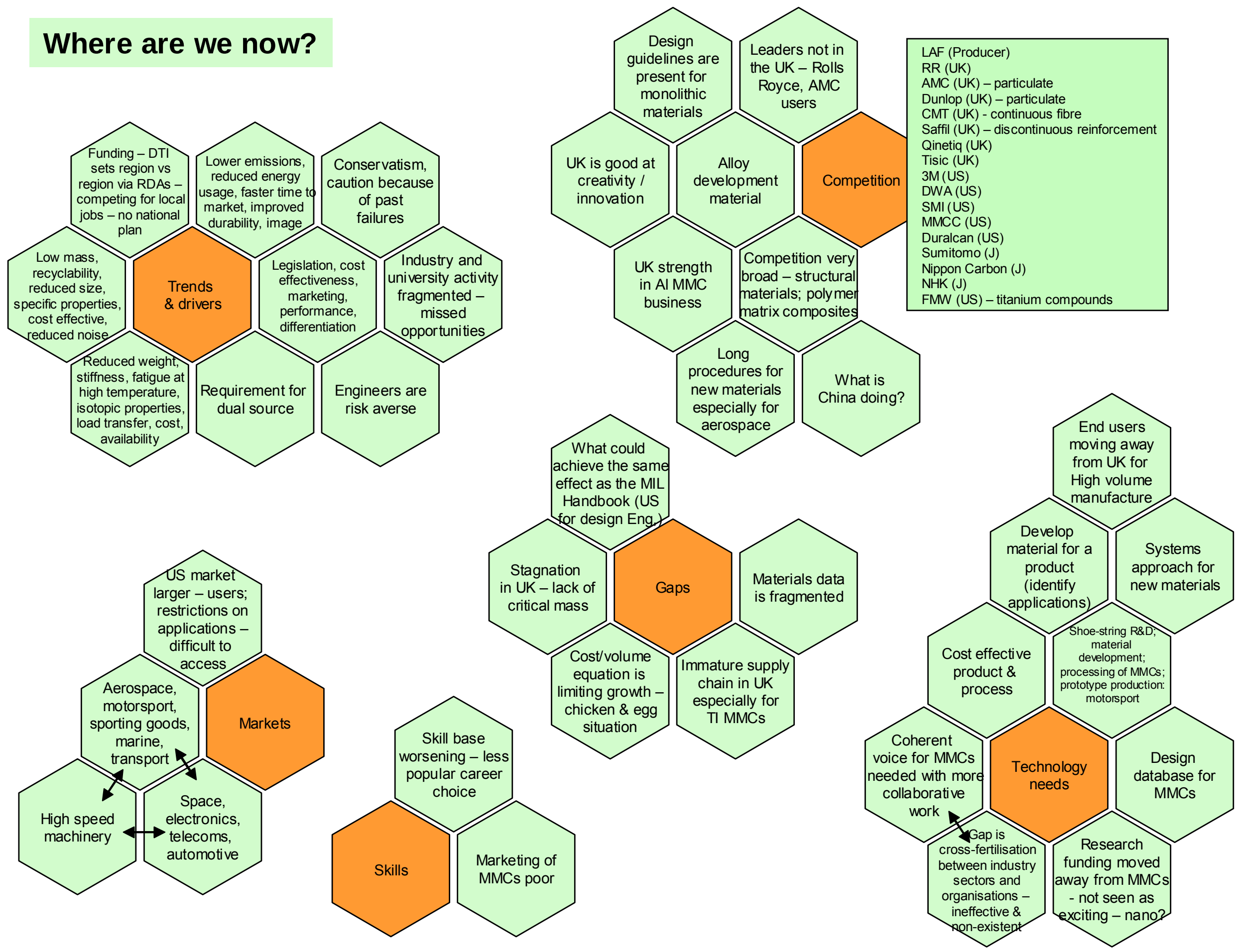
Technology Advancement Barriers
• Cost • Lack of commercial applications • Lack of standardisation test procedures • Lack of reliable analytical modelling techniques • Lack of widely accessed MMC material techniques • Lack of Federal and industry standards • CTE mismatch between matrix and reinforcement • Lack of non-destructive evaluation techniques • Lack of repair techniques • Lack of recycling techniques

Policy Barriers
• Large capital investment required – lack of investment incentives • Long incubation time between need identification and product commercialisation • Government policies and regulations • Lack cohesive planning process • Intellectual Property Rights concerns • Protection of proprietary information • Import controls

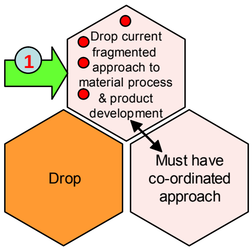
Four goals for advancing MMC technology to support industrial base needs were identified:

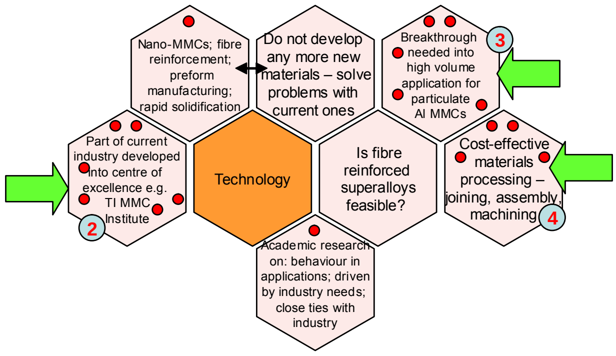
- Lower cost of producing and using MMCs
- Improve communications between Government, industry, and academia
- Improve the commercial viability and increase the commercial demand for MMCs
- Strive to overcome the shortcomings of MMCs.

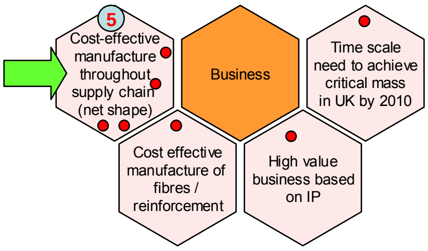
8.3 Results of the brainstorming with hexagons

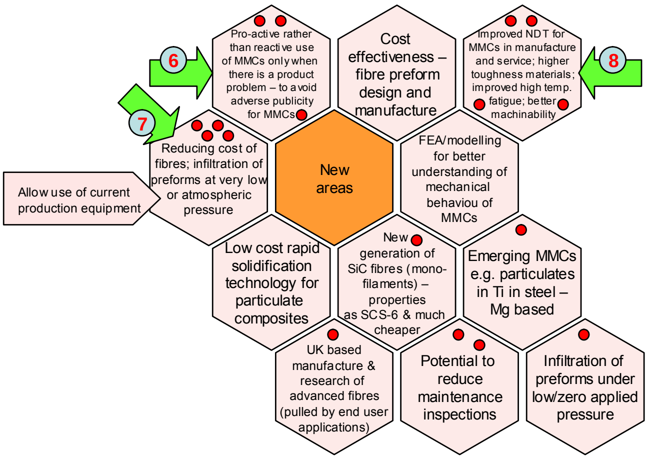


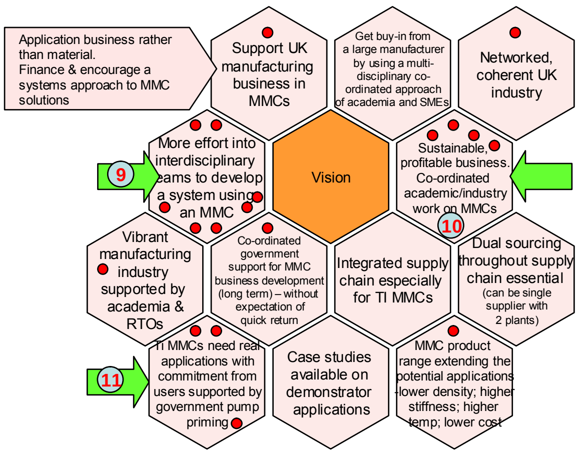
Where do we want to be?

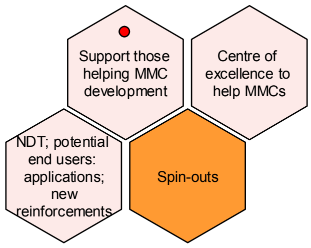


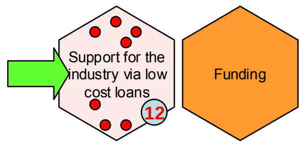




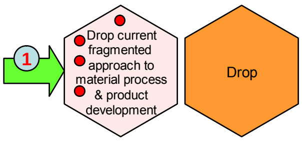




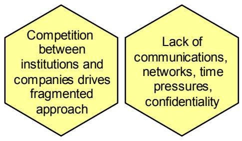




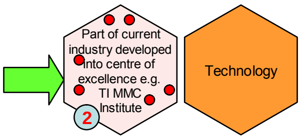
Priorities – Barriers and Actions:



What is stopping us getting there?



What do we do to overcome the barriers?



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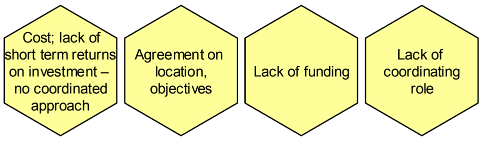
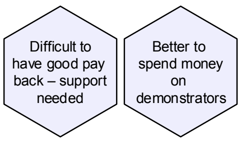
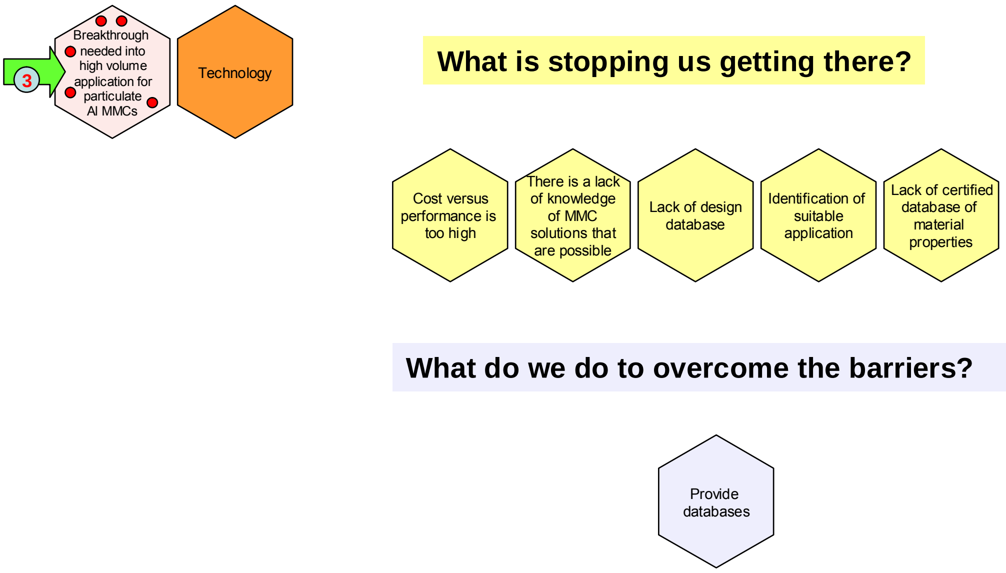
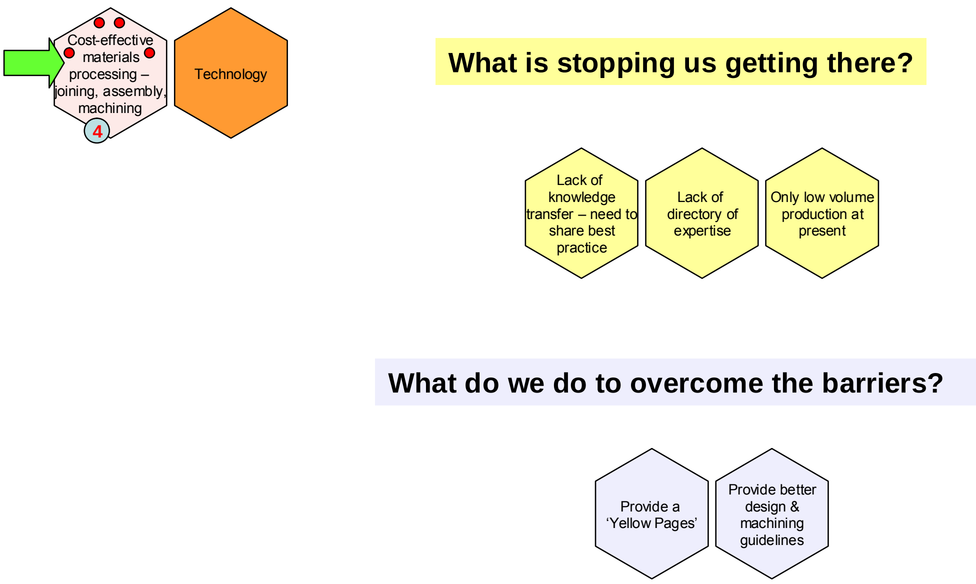
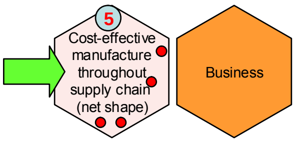


What do we do to overcome the barriers?




3
Breakthrough needed into high volume application for particulate Al MMCs
Technology
What is stopping us getting there?
Cost versus performance is too high
There is a lack of knowledge of MMC solutions that are possible
Lack of design database
Identification of suitable application
Lack of certified database of material properties
What do we do to overcome the barriers?
Provide databases


Cost-effective materials processing – joining, assembly, machining
4
Technology
What is stopping us getting there?
Lack of knowledge transfer – need to share best practice
Lack of directory of expertise
Only low volume production at present
What do we do to overcome the barriers?
Provide a 'Yellow Pages'
Provide better design & machining guidelines

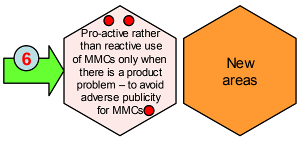


What is stopping us getting there?

- Small volume MMC market keeps cost high
- Lack of incentive to invest in new production of MMC components
- Reliance on overseas parts of supply chain, limited UK facilities

What do we do to overcome the barriers?

- FP7 links required
- Need business case applications

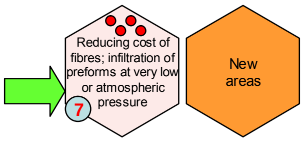


What is stopping us getting there?

- Risk aversion – conservatism on demonstrator components
- Access to design data
- Availability of rapid supply of materials
- Pressure in industry to solve current problems and reduce cost
- Lack of visibility of MMC solutions

What do we do to overcome the barriers?

- Databases
- Coordinated publicity
- Design guidelines

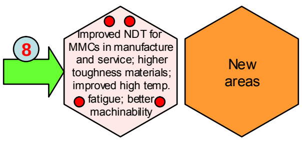


What is stopping us getting there?

- This is too difficult to do! (intrinsic cost of process)
- Limited expertise and no UK manufacturing base
- Capital cost of fibre production facilities
- Surface tension/ chemistry of fibres
- Quality control
- Temperature control of preforms

What do we do to overcome the barriers?

- Blue sky – costly - longer term
- 1 UK SiC supplier
- Strategic for EU rather than UK

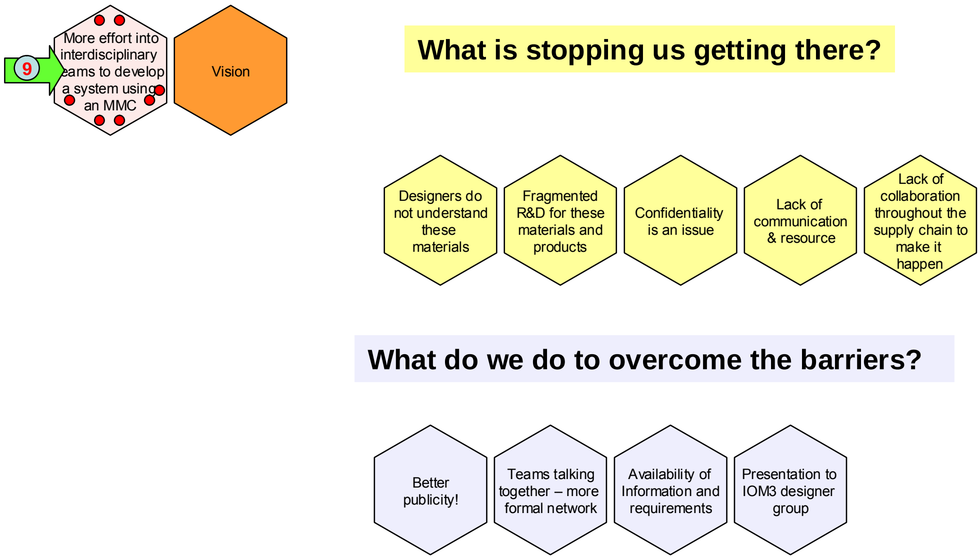


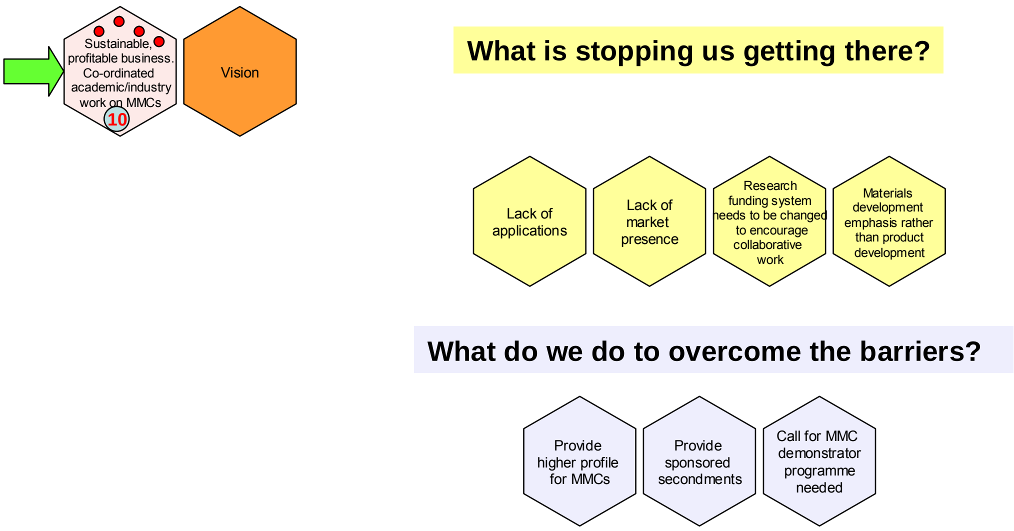
What is stopping us getting there?

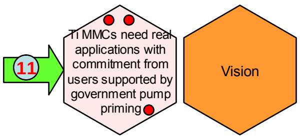
- Small market size stops development of NDT techniques
- Lack of data-base showing material benefits/ disadvantages for successful product design
- Lack of design guidelines
- Fragmented data and poor communication in industry
- No one knows who to ask
- Engineers do not understand compromises necessary with MMCs

What do we do to overcome the barriers?

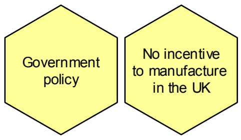
- Database should be a priority
- NCN funded free days should be used
- Communicate better


9
More effort into interdisciplinary teams to develop a system using an MMC
Vision
What is stopping us getting there?
Designers do not understand these materials
Fragmented R&D for these materials and products
Confidentiality is an issue
Lack of communication & resource
Lack of collaboration throughout the supply chain to make it happen
What do we do to overcome the barriers?
Better publicity!
Teams talking together – more formal network
Availability of Information and requirements
Presentation to IOM3 designer group

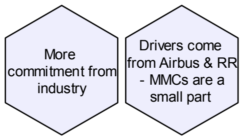

Sustainable, profitable business. Co-ordinated academic/industry work on MMCs
10
Vision
What is stopping us getting there?
Lack of applications
Lack of market presence
Research funding system needs to be changed to encourage collaborative work
Materials development emphasis rather than product development
What do we do to overcome the barriers?
Provide higher profile for MMCs
Provide sponsored secondments
Call for MMC demonstrator programme needed

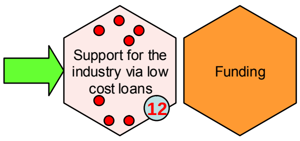


What is stopping us getting there?

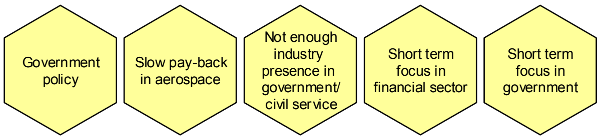


What do we do to overcome the barriers?





What is stopping us getting there?



What do we do to overcome the barriers?