European Science Foundation
Standing Committee for Physical and Engineering Sciences
(PESC)

ESF PESC Exploratory Workshop

Environmentally Friendly European Composites Workshop (ENVIROCOMP)

Coventry, United Kingdom, 20 – 21 April 2004

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1.0 EXECUTIVE SUMMARY

The rationale behind the ENVIROCOMP workshop was built upon the underpinning proposition that the development of enabling technologies to address the problems of environmentally friendly composite materials requires a broadly based interdisciplinary approach, and that this type of approach is unlikely to arise spontaneously. Although there is a significant amount of work being done on this topic, it is currently being performed by isolated specialist groups. Progress is, therefore, slow, as for example, agronomists struggle to come to terms with the technicalities of polymer processing, and processing engineers learn about the variability of biological origin materials.

This workshop provided an inter-university, multi-sector and multi-disciplined forum to address emerging issues in environmentally friendly composites manufacture and use. The invited groups were drawn from a wide range of disciplines including: manufacturing technologies, chemical engineering, materials science, polymer chemistry, and agriculture.

25 invited participants were selected from European University's and research institutes and comprised of academics that are established in multi-disciplinary environmentally friendly materials research. There were also a number industrial support guests, representing four key industrial end-user groups, namely automotive, construction, electronic and telecommunication who provided industrial focus and opinions throughout the workshop.

The specific objectives of the workshop were:

- To capture, disseminate and demonstrate current technologies for environmentally friendly composites manufacturing and technologies emerging from the research programmes of network universities.
- To enable a pooling of research capability and infrastructure.
- To provide a forum of excellence to enable effective information exchange within and between academic and industrial communities.
- To develop an industrially driven research road map that addresses environmentally friendly composites manufacturing issues.
- To develop new research partnerships and multidisciplinary research proposals.

The main outputs from the workshop were a series of detailed roadmaps that captured the discussion and issues raised during the two days. The key findings of the roadmaps can be summarised as follows.

In the near future (the present to five years hence) there is considerable commonality in drivers. Legislation is thought to have the greatest potential to positively influence the uptake of environmentally friendly materials. In blunt summary, whilst one may desire to do good for the planet and our descendents, in the commercial world it is only possible to do this if it is possible to demonstrate a positive difference to the financial bottom line of the company. Such quantifiable differences in profit are only likely to be the result of legislation: for example, a reduction in landfill tax.

All sectors were highly cost sensitive, perhaps due to the need to minimise the risk associated with the introduction of new materials. The ideal sustainable composite should be cheaper than its fossil origin equivalent, as well as providing the benefits associated with its sustainability.

As we move along the time-line the opinion of the road-mappers is that requirements for development become more sector specific

However, all groups noted recurring gaps in the following fields:

Education – is required for workers in the industrial supply chain, so that designers, and specifiers will become aware of the long term advantages these new materials, and manufacturers will be come conversant with both the new techniques of manufacture and the fundamental similarities with existing materials. Education is also required for the consumers, so that the appropriate **waste management strategies** can be evolved. These strategies should move beyond the overly simplistic notion of recycling materials, with the inherent reduction in quality and quantity, and increases in costs, to a more sophisticated replication of the cycles already present in nature. Some workers have dubbed this approach the helix of sustainability, indicating that for satisfactory recirculation materials, end-of-life articles become part of nature's cycle of material use, rather than a pale and ineffective shadow of naturally evolved systems. It is clear that **Government policy requirements** are key to providing a milieu in which the uptake of such materials becomes a financially sound idea as well as a social and environmental benefit. The benefits of such policies are likely to include a revival in agriculture, and manufacturing industries. The notion of limiting the environmental impact of the manufacture and use of articles is likely to encourage the manufacture of goods close to the place of consumption. This will provide a limit on the damage to manufacturing economies caused by the extreme mobility of global capital, without the artificial barriers of protectionism.

Common themes with different time lines were also noted by the road-mappers. This is probably due to different time scales for product introduction in the various sectors. It is certain that there will be cross fertilisation between various sectors, as sectors with high added value and short development lead times will be first to adopt crop origin raw materials. This adoption will lead to an increase in the volume of use of the materials, with the consequent effect driving research into the lowering of costs of material production. This lowering of costs will allow lower margin sectors to adopt the materials.

2.0 SCIENTIFIC CONTENT - ROADMAPS OF THE FUTURE OF ENVIRONMENTALLY FRIENDLY EUROPEAN COMPOSITES

Process of Generation.

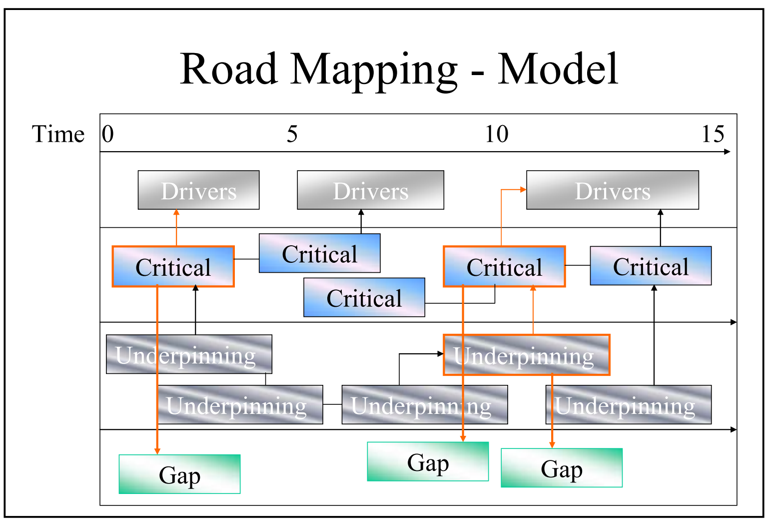
It should be noted that the road-mapping exercise should be considered as the first phase of a wider exercise that will expand throughout Europe and build on the contacts brought into being by the workshop.

The first stage of the road-mapping exercise was the presentation of position papers by the delegates. The purpose of this exercise was to bring the delegate team up to a common level of understanding concerning the scope and direction of current thinking on the emergence of a new type of industrial material, namely crop origin raw material (CORM) composites. As well as the knowledge transfer in the formal presentations, there were also opportunities for informal networking, and the general process of getting to know each other. The papers were themed into common groups, with an academic keynote address by Dr. Jalal Harun of Universiti Putra Malaysia, who was able to share the still somewhat unusual experience of having developed a composite material from an industrial waste stream (spent palm oil bunch fibre) in his laboratory, and bringing to the industrial market as a car parcel shelf.

The road-mapping exercise proper was conducted on the second day where the academic delegates were divided into three groups, with as near as could be managed, an even distribution of disciplines, experience, and nationalities. Each group was assigned a facilitator and a group of industrialists chosen to represent each market sector. The sectors chosen were:

- Packaging
- Automotive
- Telecoms and electronics

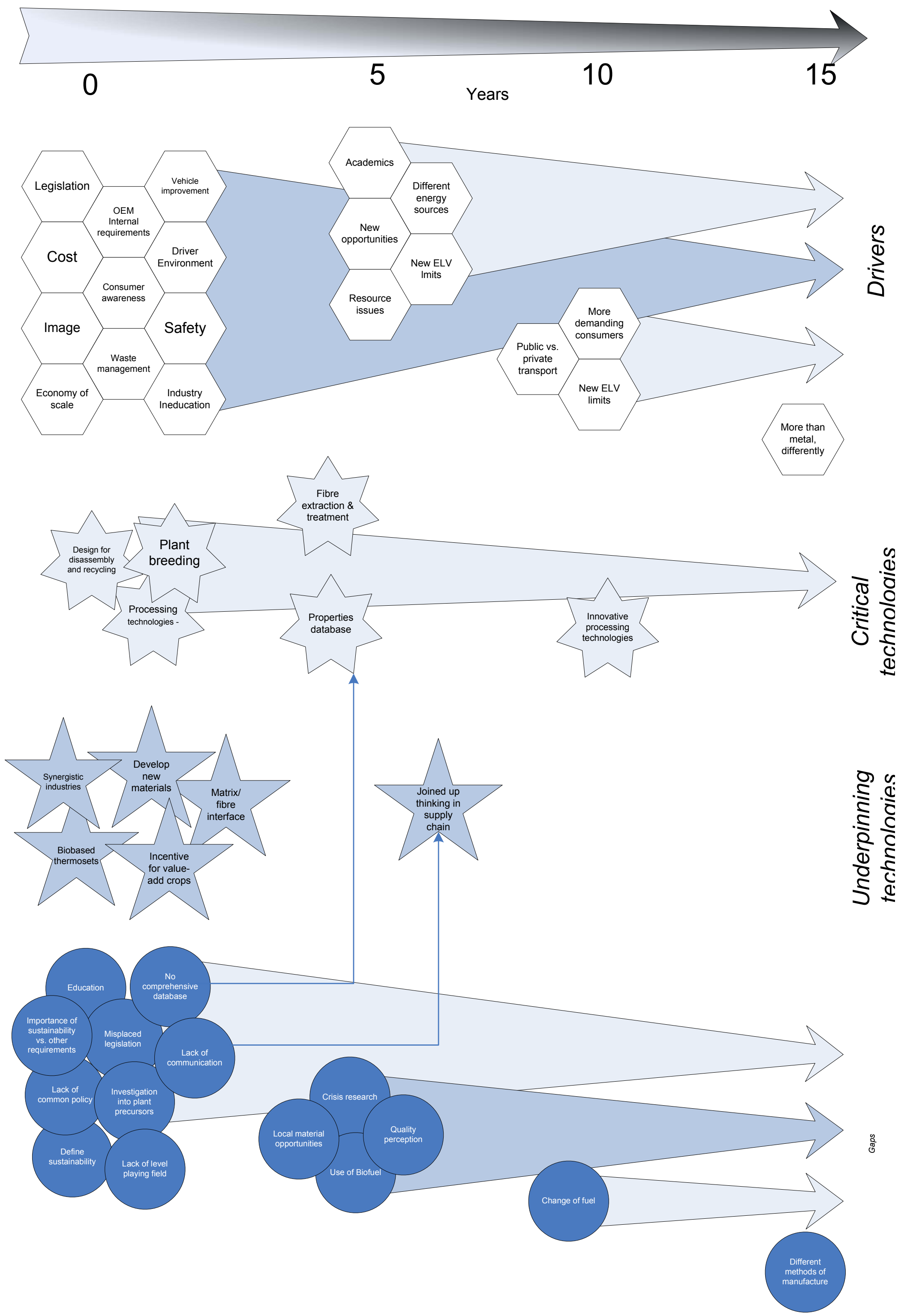
Each group was then encouraged to discuss the future of sustainable composites under the matrix shown below:



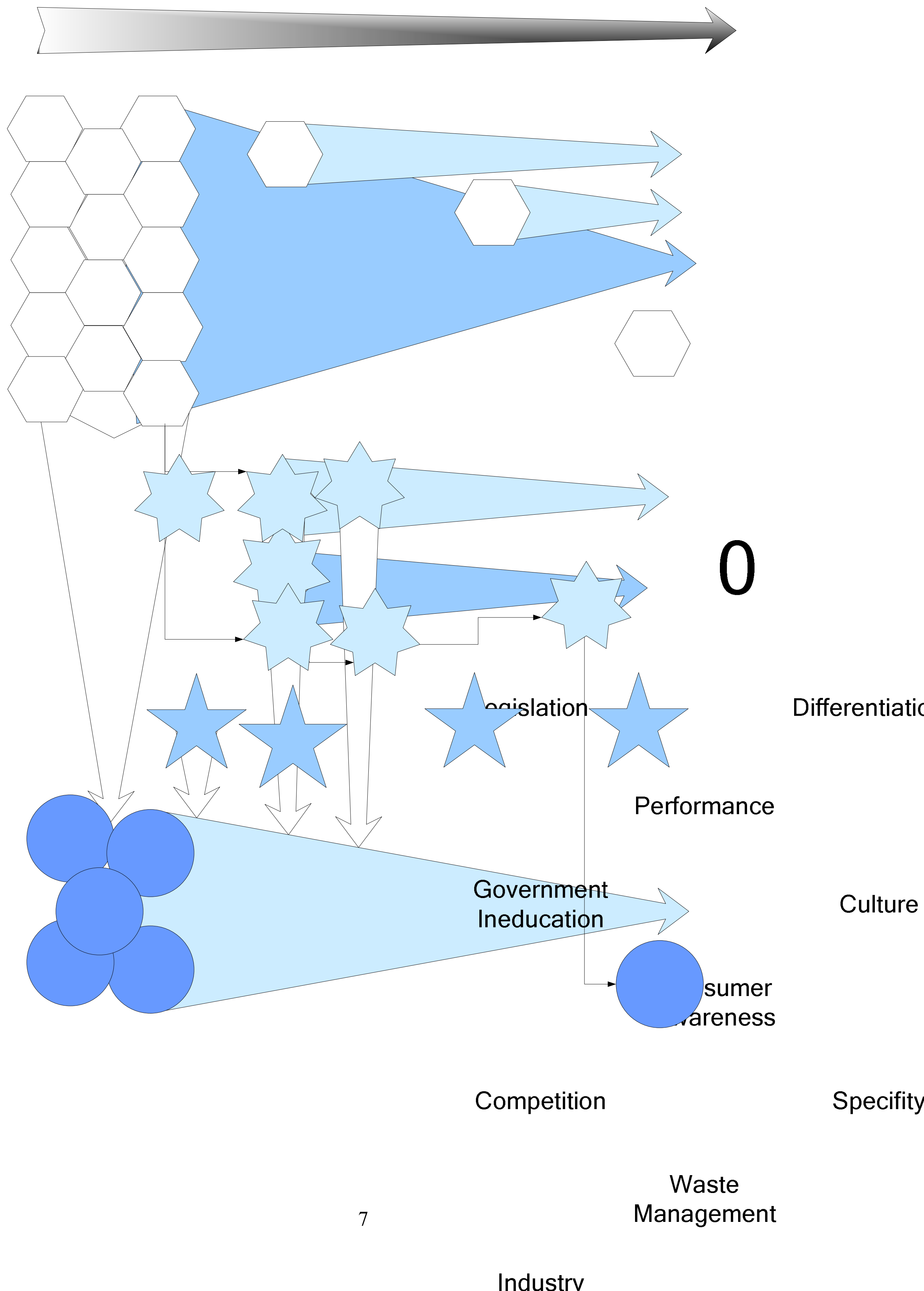
Each group of academics was allowed a session on each market sector. The industrial partners provided direction and feedback as to how useful the notions presented were likely to be, and what particular problems were felt to be of special importance to the sector.

At the end of the day, the provisional results were presented to the whole group for comment, discussion and revision.

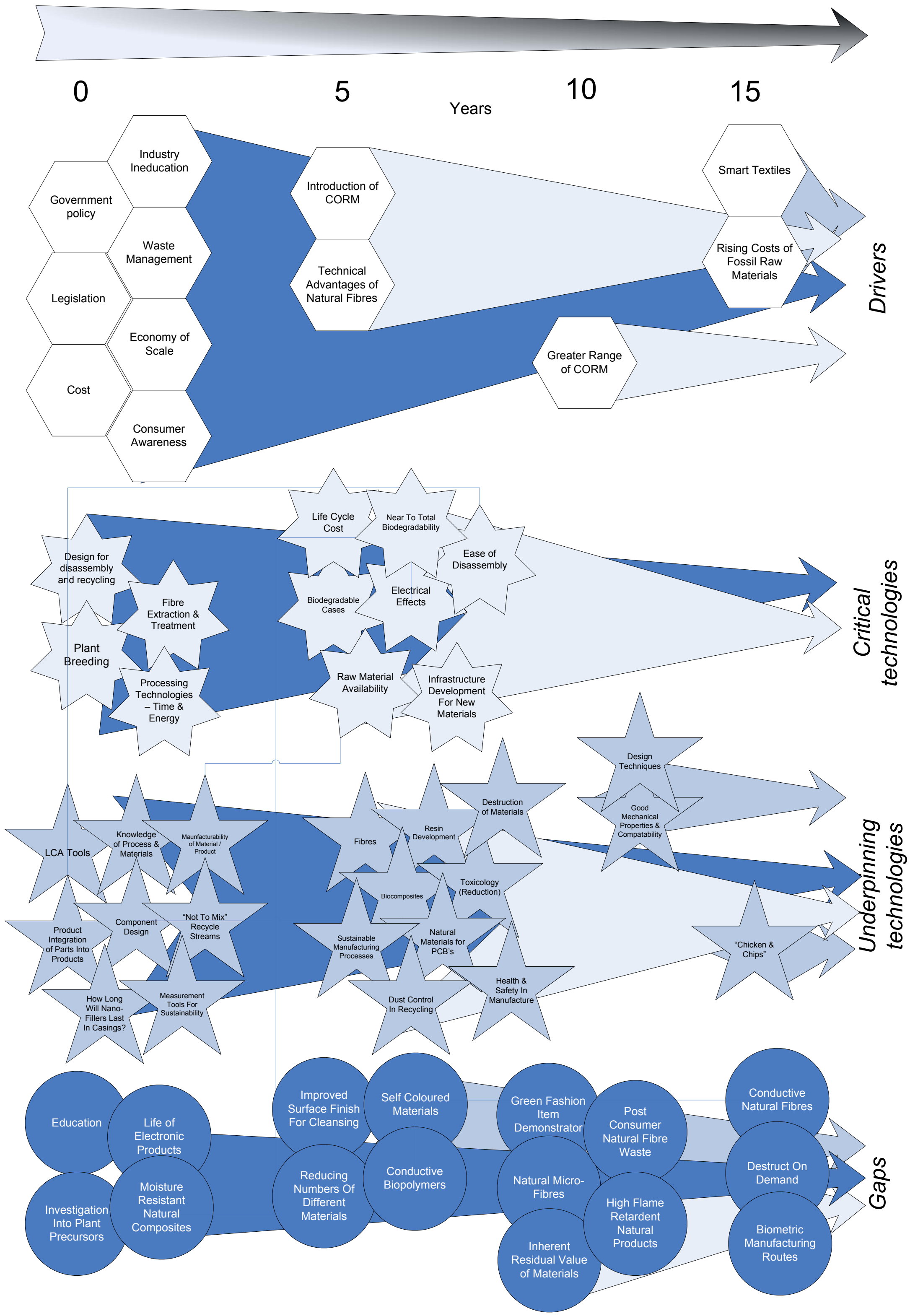
Roadmap of the Future of Environmentally Friendly European Composites within the Automotive Industry



Roadmap of the Future of Environmentally Friendly European Composites within the Packaging Industry



Roadmap of the Future of Environmentally Friendly European Composites within the Telecoms & Electronics Industry



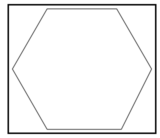
3.0 DETAILED ASSESSMENT OF THE FUTURE OF ENVIRONMENTALLY FRIENDLY EUROPEAN COMPOSITES

The key findings of the ENVIROCOMP workshop have been summarised into the three technology roadmaps presented in the previous section. The discussion contained within this section of the proceedings complement these roadmaps by providing greater insight into the issues captured.

It should be noted that the information included within these reports was based upon discussions that took place within the workshop and as such reflect the views of the industrial and academic delegates that were present.

Four separate reports are presented within this section; the first is a generic report that covers common issues that arose across all three roadmap technology areas. The remaining three reports discuss industry specific issues and discussion that was also captured.

Generic Summary of the Future of Environmentally Friendly European Composites



Drivers 0 > 5 Years

Legislation
Within all three industrial sectors considered, **legislation was thought to have the greatest potential to positively influence the uptake of environmentally friendly materials**. All three sectors are subject to end-of-disposal directives such as End-of-life Vehicle (ELV), Waste Electronics and Electrical Equipment (WEEE), Restriction of use of certain Hazardous Substances (RoHS) and the Packaging & Packaging Waste Directive and these are probable future incentives for industry to consider more sustainable materials.
Further increases in the number of articles of legislation affecting disposal and handling of waste was thought to have the potential to significantly influence the costs and disposal routes available.
However, positive legislation that might drive industry to really consider alternative materials was not thought to truly exist at present; there is no credit for sustainability, there is unfortunately no legislation or for example, tax breaks to encourage industry to realistically consider alternative materials.

Cost
All three industries are highly sensitive to cost, although cost should not just include purchase cost, but 'life' cost where processing and disposal (Waste Management) is taken into account. An overriding issue was that in order to make inroads into these industries, environmentally friendly materials **need to be of equivalent cost** (or cheaper) **with the equivalent properties of current materials**.

The cost of fossil based raw materials is expected to increase, the cost of crop origin raw materials is likely to fall. It is to be hoped that this evening out of costs will not be simply as a result of a decline in farm gate prices, but will be due to improvements in manufacturing technologies and the underpinning science associated with the production of crop origin based matrices and fibres.

Waste Management
There is a growing realisation that **the disposal of waste will continue to be an increasing problem** and as such there are moves being made towards a requirement for the OEMs to consider the implications of this. There is an amount of legislation and guidelines but at this moment in time there are inadequate facilities for the effective recycling of materials, there isn't a coherent plan for waste management.

In the majority of EU countries **the requisite infrastructure for the effective and economic management of bio-waste is not in place**. This **negates** many of the

positive aspects of environmentally friendly composites because without proper use and disposal, they are only a **marketing** tool.
It was considered that the **cost of recycling is likely to rise** in the future. The present day hand separation methods are unpleasant and labour intensive, whilst automated methods do not produce a sufficiently clean separation.

Once a cognisant, cradle-to-grave, complete supply chain strategy is formulated, this will lead to the establishment of the correct infrastructure. This needs to take into account environmental, economic and social factors to create the optimal waste management strategy. Part of this strategy is likely to be the establishment of large-scale composting facilities although other waste management technologies are also likely to be used. The Netherlands moved almost wholly to large–scale composting and discovered that they produced a glut of compost that had to be exported to other countries.

Consumer Awareness
The majority of consumers are becoming more aware of the environmental impact that traditional plastics have, but the majority are also **unaware of the availability and environmental benefits of the more-friendly alternatives**.
A key issue is **how to change the way people regard plastic articles**. They are currently iconic representations of all that is tawdry, and are associated with high environmental impact.
Plastics are also perceived as somewhat "**immortal**", there is a significant educational task associated with the introduction of polymers and polymer matrix composites with controlled limitations to life and use. **Improved consumer education** is also needed to enhance the efficacy of any future source segregation and disposal systems.

Further improvements in consumer awareness of the environment is likely to come on the back of perceptions of uncertainty with regard to stability of supply of fossil raw materials and general concerns over the damage being done to the planet. Such improvements in consumer awareness may lead to an associated increase in demand for the use of environmentally friendly materials due to factors such as guilt and the desire to appear to be green.

Economy of Scale
It was recognised that there exists a **vicious circle** where environmentally friendly materials are traditionally expensive due to relatively low production levels that exist because of reduced market demand which is in turn due primarily to the high material costs. It was felt that niche markets often lead the way for market sector growth and may provide a mechanism to break this cycle and increase production capacity. **New sustainable materials should also provide marketing opportunities**.

It was also recognised that at the moment there is a lot of effort in different areas of research into sustainable/alternative materials but there is a lack of economy of scale in any individual area. In order to facilitate the adoption of sustainable composites there needs to be a 'joining of forces' to achieve this economy of scale, drive down costs and promote the technologies, **targeted funding would help to develop the research**.

Industry Ineducation

Certain links within the supply chain are **unsure as to the availability, range and performance** of environmentally friendly polymers and composites. There needs to be education in the life cycle analysis that allows OEMS and consumers alike to have confidence that the true cost of a material has been accurately assessed.

Drivers 5 > 10 Years

See industry specific reports

Drivers 10 > 15 Years

See industry specific reports

Drivers 15+ Years

See industry specific reports

Critical Technologies 0 > 5 Years

Design for Disassembly & Recycling

There is a requirement for a **cohesive recycling strategy**; the technologies currently in use tend to be regarded in isolation with different European countries and different areas within these countries having different levels of success.

Recycling has long to medium term inherent high costs. Mechanical recycling of polymers is sometimes called "downcycling" because there is a loss in absolute mechanical properties and an uncontrolled increase in the variability of processing parameters.

Current objections to the uptake of crop origin PMC is that if they are included in an article with fossil origin polymers or PMCs, it is **usually not possible to separate out the crop origin material for separate disposal**. It is critical that new products are designed for disassembly so different materials may be separated for disposal otherwise the incorporation of natural fibres may reduce the recyclability of fossil origin plastics.

If segregation is not possible, then the addition of biodegradable polymers to non-biodegradable mechanically recycled fossil polymer may also introduce unwanted biodegradability into any new product.

Plant breeding

There is a **clear need** to develop new cultivars and **new crop species** for use as industrial raw materials. This may either be achieved by searching through the

acquisition libraries for existing varieties that are rich in the desired chemical fractions, or by encouraging the uptake of new species e.g. Euphobia as an epoxy resin precursor or self-retting fibre varieties
The plant breeding industry has immense experience in refining the properties of a plant to fulfil the requirements of the end user (for example increasing the percentage of a specific type of oil within the oilseed rape crop). This breeding obviously takes quite some time to achieve and they need to know the properties required by sustainable material manufacturers.

Fibre Extraction and Treatment
It was also felt that **existing routes of fibre extraction are generally unsatisfactory** in terms of producing a fibre of sufficiently high quality and consistency, at a sufficiently low price. There is a need to examine all aspects of the extraction process to minimise damage and maximise consistency. During harvesting there is a need to minimise damage due to handling, whilst it has been suggested that the blending of crops from a number of years may improve consistency.
Secondary fibre treatment processes including self retting, enzyme retting and standing crop retting methods may be complemented by both mechanical and bio-treatments to assist in achieving quality, consistency and the required fibre-matrix interfacial properties which was perceived as a critical requirement.

Processing technologies – time and energy
Time compression of processing technologies is vital in the adoption of sustainable materials, along with accurate analysis as to how much energy is truly expended when creating materials either from raw material or through recycling routes.
It was also considered that the use of biopolymers to directly replace fossil polymers eg PC/ABS would be provided an obvious route into industry by producing materials that are identical in processing properties.

Critical Technologies 5 > 10 Years

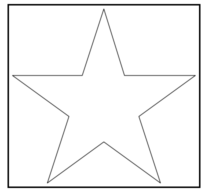
See industry specific reports

Critical Technologies 10 > 15 Years

See industry specific reports

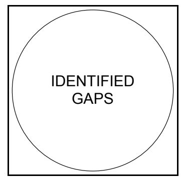
Critical Technologies 15+ Years

See industry specific reports



Underpinning Technologies

See industry specific reports



Identified Gaps 0 > 5 Years

Education
Education is required to inform all parties as to the availability, benefits and best-use of sustainable materials.

Investigation into plant precursors
There is **tremendous potential to breed plants** to align to the required properties; the breeders are just not told what those requirements are, hence there needs to be more communication. It also takes a long time to breed plants, so there needs to be more understanding as to exactly what can be achieved by breeding and how requirements can be aligned to this.

Identified Gaps 5 > 10 Years

See industry specific reports

Identified Gaps 10 > 15 Years

See industry specific reports

Identified Gaps 15 + Years

See industry specific reports

Summary of the Future of Environmentally Friendly European Composites within the Automotive Industry

Drivers 0 > 5 Years

One of the key automotive findings is that it has to be emphasised that due to the time taken for a new vehicle programme (in between 36 and 60 months) **a lot of the drivers within the automotive field that are going to be realised in the medium term need to be considered now**.

Image
Automotive industry **sales are highly image dependant**; general requirements for styling, performance, price and beyond that the whole 'life style' image. Again, consumers could be an ally in the adoption of sustainable materials if there is a requirement for a 'planet saving'/environmentally friendly lifestyle choice where vehicles are concerned. In some ways the younger generations seem more aware of their impact on the environment and world as a whole and may be more demanding of a eco-friendly imaged vehicle in the future as reflected in the consumer section below.

Consumer Awareness
The **consumer drives the market** through their support or otherwise of a manufacturer's vehicles, there is an increasing requirement for more 'green' products but at the moment there is a **reluctance to pay** any extra. This may change in the future as the current young people become old enough to purchase vehicles. **Education of the consumer** as to the true environmental cost of vehicles would help to inspire this driving force to act in support of sustainability.

OEM internal requirements
Choice of materials within the automotive industry is **influenced by a large number of internal requirements**, both in terms of the performance and business requirements including:

- Component integration
- Material rationalisation strategy
- Health regulations – COSHH etc.
- Internal design guidelines and procedures
- Design for breakdown – spare parts market
- Process guidelines
- Toxicology go/no-go lists

If the vehicle designers are to be drawn away from the status quo, sustainable materials will need to be an aligned to the requirements of the industry.

Vehicle improvement
In order to maintain and improve market share OEMs are always looking at improving the vehicle in many ways including:

- Vehicle performance
- Vehicle safety
- Vehicle durability
- Weight reduction
- Fuel economy
- Comfort

As such they are always **striving to improve** on what is already in existence. They are continually looking to innovate and gain advantages over their competitors and this will be with or without regard to sustainability so there needs to be a concerted effort to educate the OEMs as to the benefits of sustainable materials.

Driver environment
The interior 'feel' of the cabin is important to the driver perception of a vehicle. As such, anything that sustainable materials can offer in terms of advantages over synthetic materials in areas such as:

- VIAQ (air quality, smell etc)
- Allergens
- Toxicity

will attract industry attention. Again education as to the advantages of sustainable materials needs to be delivered.

Safety
With recent legislation (ENCAP) and an increased awareness of the safety of vehicles for both the occupants and pedestrians, **vehicle safety is becoming key** within the automotive industry. Natural and sustainable materials need to be able to demonstrate their performance in these areas and any properties where natural fibres can outperform synthetic ones need to be emphasised, for example fire retardant properties.

Drivers 5>10 Years

Academics
Not currently a driver, but should be. **Academics should be drivers**, always looking for **opportunities** to 'show off' the natural materials and make industrialists more aware of the capabilities and advantages that might be available to them.
This was highlighted by the comment of an industry based delegate ***"We seem to have the classic problem that industry is on one side of the fence not really knowing what is possible and can be expected from the natural materials and on the other side of the fence there is academia not really knowing what is wanted – there is a lack of communication"***

New opportunities
Constantly striving **to identify new opportunities is a requirement**, in terms of identifying new and appropriate areas of the vehicles in which to apply sustainable materials and matching the properties available to the components within the vehicle, e.g. the dashboard. Vehicles could have interchangeable customisable components that would have to be sustainable.

Resource issues
As the **developing world** continues to develop there will be a requirement for **more resources** in these areas, this **increased pull on the natural resources** will lead to a need for more and **more sustainable** materials.

Different energy sources
As research continues into **alternative energy sources** there may well be opportunities for the advancement of sustainable materials, e.g. if there are more crops grown for biofuel then there would need to be research into using the 'waste' products of these plants.

New ELV limits
The legislation that is already in place has targets that have to be met and these will tighten over time.

Drivers 10 > 15 years

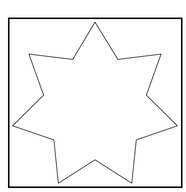
Public vs. private transport
With all of the demands on the transportation system, increasing congestion increasing vehicle excise duty and pollution etc. there **could well be a shift towards more public and less private transportation** and any **differing needs** for this sector need to be considered.

More demanding consumers
As mentioned earlier the **consumer of the future may very well have more requirements** for their vehicles to be eco-friendly and look for more sustainable transportation. Continual information/education of this younger generation will be an excellent opportunity to encourage this. As the vehicle programmes can take up to 60 months this needs to be considered quickly.

New ELV limits
The legislation that is already in place has targets that have to be met and these will tighten over time.

Drivers 15+ years

More than metal, differently
A driver for these new materials has to be that they can **offer different, improved properties** when compared to conventional materials (not solely metals but conventional composites as well). Totally and truly innovative materials created in different ways, materials that could be bred or grown.



Critical Technologies 0 > 5 Years

See generic report

Critical Technologies 5 > 10 Years

Properties database
In order for the automotive industry to utilise any new material there needs to be a **comprehensive and accurate database** of the properties of materials. Additionally to understand the materials and make comparisons, benchmarking of sustainable composites vs. conventional composites needs to be published.

Critical Technologies 10 > 15 Years

Innovative processing technologies
Currently sustainable composites are being processed using conventional techniques, in the **future processing techniques designed explicitly for sustainable materials** may lead to innovations in materials that are currently unrealised.

Underpinning Technologies 0 > 5 Years

Synergistic industries
Other industries may **have technologies and processing techniques to offer to the sustainable materials industry**, for example the paper industry and textile industry materials based on natural fibres that are of high quality and consistent.

Develop new materials
New materials with new properties once developed must also be **communicated** to the industry when there is knowledge, confidence and experience with the innovative materials.

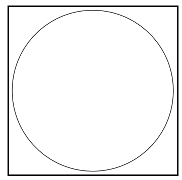
Matrix/fibre interface
There is a **need to investigate and improve the interaction between polymer matrices and fibres** used as reinforcements to improve physical properties of resulting composites.

Biobased thermosets
There is a **demand for the development of thermoset** polymers based upon biological origin sources.

Incentive for value-add crops
Farmers need to be **encouraged to grow crops** that add value to the supply chain of sustainable materials.

Underpinning Technologies 5 > 10 Years

Joined up thinking in the supply chain
There needs to **be joined up thinking, communication and legislation** dealing with everything from the plant precursors through to the recycling of the materials at the end of life.



Identified Gaps 0 > 5 Years

Importance of sustainability vs. other requirements
Again this is to an extent an educational issue, with a need to **emphasise the value of the world's resources** and the utilisation of sustainable materials.

Lack of common policy
There needs to be **communication** between all interested parties to ensure that there is a common policy such that there is a **coherent plan** for future research, development and exploitation.

Define sustainability
There is **not a common language**, i.e. different industry sectors and groups with different vested interests mean different things when they say 'sustainable'. There needs to be a widely agreed and distributed definition of what is meant by sustainability within the context of the automotive industry.

Misplaced legislation
Legal definition of landfill with regards to compostable composites –the result is 'green' compost but it still needs disposing of, so industry **still has to pay** landfill costs

Lack of level playing field
Due to **a lack of understanding** of all the implications of materials from manufacture to end of life in terms of energy required and their impact on the environment, there is **not a level playing field** between conventional and sustainable materials.

No comprehensive database
In order for designers to use the materials there needs to be a **comprehensive database** of the mechanical and physical material characteristics and properties.

Lack of communication
There appears to be a **lack of communication** in a number of different areas, between the plant breeders and the raw material manufacture, between the materials manufacturers and the OEM designers, and the sustainable industry as a whole and the consumer and governments.

Identified Gaps 5 > 10 Years

Local material opportunities
The Chinese will continue to eat rice (and a lot of it) research into using the husks and any other plant 'waste' from the crop to be used in the area where the plant crop is grown.

Crisis research
Question: How imminent does a crisis need to be in order for people to react to it?
Answer: Very.

Research into what sorts of crises might bring the need for natural materials to the fore and their estimated dates would be a **useful piece of research** to ensure that the technologies are ready to react before they occur (for example price (rather than lack of) oil, war) and any other crises, reducing water supplies may make it more difficult to grow natural materials along with an appreciation as to whether there will be physically enough space to grow the volumes required.

Use of biofuel
As there is an **increase in the usage of biofuel** there could well be a **spin off** as there would potentially be more fibres and so if there are more crops grown for biofuel then there needs to be research into using the 'waste' products of these plants.

Quality perception
There are a number of **different issues in the perception of quality** of sustainable composites including

- Material characterisation and properties – Mechanical, physical
- Consistency in the quality of fibres
- Quality control of fibres
- Homogeneity of the fibres.

An understanding and publication of the quality realised to educate material selection is needed.

Identified Gaps 10 > 15 Years

Change of fuel
As mentioned earlier on there are opportunities that will arise as the fuel being used for vehicles moves away from oil based fuels.

Identified Gaps 15 + Years

Different methods of manufacture
Current **processing techniques are generally directly 'borrowed'** from conventional composite manufacture there needs to be **research into methods of**

manufacture that are unique to sustainable materials as opposed to the adaptation of techniques for conventional materials, for example the possibility of spinning a fibre and matrix together for ease of processing.

Summary of the Future of Environmentally Friendly European Composites Within the Packaging Industry

Drivers 0>5 Years

Consumer Awareness
Recent work performed by Warwick Manufacturing Group on the uptake of biopackaging in the UK indicates that **improved customer education** would improve uptake.

Government ineducation
Currently **many governments in Europe are uncertain** as to whether biopackaging offer any benefits and the availability and range of materials available.

Competition
Increased competition will reduce prices and allow users a greater selection of biopackaging options, both of which will positively drive uptake.

Bag tax
If a **bag tax** were introduced in the UK, in a similar fashion to the tax introduced in Eire, that included provision for tax breaks for 'bio-bags', it **would drive uptake**.

Performance
Whilst cost is the overriding concern for the majority of packaging users, **improved performance** also goes some way to redressing this inequality. Increased performance may include improved barrier properties or greater strength (leading to increased packaging speed) both of which add longer term value to the product and/or process; reducing total cost.

Supply quality
Quality and consistency are key drivers for packaging and with the introduction of new materials and feedstocks this must be maintained.

Differentiation
As mentioned earlier in the generic report; without proper use and disposal infrastructure, biopackaging is **simply a marketing tool**. Whilst this is the case, it also serves the purpose of educating the consumer and differentiating the product from competitors. In the near-future, some companies may seek to differentiate their products by using biopackaging. An example is that for some of the organic produce in the UK supermarket chain, Sainsburys uses biopackaging.

Culture
Todays **culture is predicated by convenience** and this has dictated a wholesale change to pre-packaged goods meaning that greater and greater quantities of

packaging are being used. Can biopackaging be substituted effectively into todays 'disposable' culture or is some form of paradigm change required?

Specificity
Will **drive** biopackaging as it will be **substituted for existing materials** in products that require it. Examples include; plant pots and packaging that is polluted through contact with food.

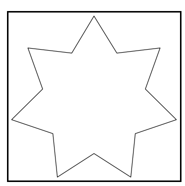
Communication
Is needed to **build awareness** of biopackaging and the issues that surround its uptake. It is needed at all levels in the supply chain.

Drivers 5 > 10 Years

Consumer greening
Over time **consumers in the EU will become greener** and greater numbers will begin to make purchasing decisions based on environmental issues. This will drive the uptake of biopackaging as they are perceived to be 'greener' than polyolefin based packaging.

Drivers 15+ years

Feedstock availability
In the long-term, **oil may begin to rise in price due to scarcity**, forcing the price of polyolefins up and allowing biopackaging to compete. Also, for biopackaging, the availability of certain, more requirement-specific, crops may increase allowing more functional and economical biopackaging to be produced.



Critical Technologies 0 > 5 Years

Who is the champion?
At the current point in time **no single body or organisation is truly pushing these materials** and instead a number of smaller bodies are following their own routes. A champion is required to ensure that all of the hard and soft technologies and issues that are required to ensure that biopackaging is used in the best possible fashion.

Critical Technologies 5 > 10 Years

Economies of scale
As companies **increase output** they will achieve **greater economies of scale**; reducing costs and making the material more price-competitive.

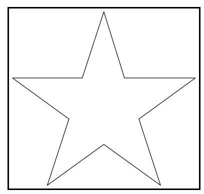
Simple LCA tools
Simple LCA methodology
Both of these factors will allow users to select the best product in terms of cost and social and environmental impact.

Infrastructure
The introduction of **large-scale composting technologies** and the requisite infrastructure is needed to ensure of the most effective disposal route for biopackaging.

Funding for strategy
This **funding is required** to pay for the waste management strategy discussed in the generic drivers section.

Critical Technologies 10 > 15 Years

Reliability and availability of LCA data
Will allow users to select the best product in terms of cost and social and environmental impact.



Underpinning Technologies 0 > 5 Years

Funding for strategy
This **funding is required to pay for the cognisant waste management strategy** discussed in the generic drivers section, critical in the medium-term but not in the short-term.

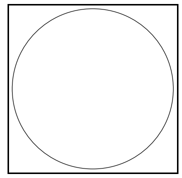
Bio PLA, transition-metal polyolefins and starch biopolymers
These materials are **currently available** in the marketplace and with greater quantities will close the price-inequality gap that currently exists.

Underpinning Technologies 5 > 10 Years

PHA and PHB biopolymers
These materials are **currently available** in the marketplace in **very limited** quantities and with greater quantities will close the price-inequality gap that currently exists.

Underpinning Technologies 15 + Years

Biobased versions of polyolefins
Using bio-architecture in existing processes is currently being researched on a small-scale but when it comes to market will allow bio-feedstocks to be used in existing processes and negate the need for the construction of new refineries and processing plants.



Identified Gaps 0 > 5 Years

In supply chain strategy
The entire **supply chain is not communicating** their needs to one another effectively. By doing this they will ensure that each of them are fairly represented and a copasetic solution is reached.

What is the best waste management method?
There is **no clear waste management (WM) strategy** in many EU countries, and this needs to be resolved in order to deal with the potentially large amount of biopackaging that comes into the system. If the best WM method is composting then biopackaging will successfully fit into the system but if the WM strategy encompasses a range of technologies then the best method needs to be considered. As discussed previously large-scale composting will drive uptake as it is the best disposal method.

Tax breaks
Without any other mechanisms to improve uptake, **tax breaks** for biopackaging could be applied to allow them to compete on price with existing materials.

Infrastructure
As mentioned on numerous occasions in this section, the **installation of the relevant infrastructure** will allow the best use of biopackaging. This infrastructure will not only include disposal facilities but also the requisite infrastructure for the effective collection and separation of biopackaging.

Identified Gaps 15 + Years

Total life cycle cost
This will allow users to calculate, using robust LCA data and methodologies, the true cost of materials and their use in a supply chain.

Summary of the Future of Environmentally Friendly European Composites within the Telecoms and Electronics Industries

Telecoms & Electronics Specific Report

Drivers 0>5 Years

Government Policy

It is expected that **government policy will move to encourage** the uptake of crop origin raw materials with combined aims of:

* A reduction of greenhouse gas emissions (as yet a not proven case for crop origin raw materials)
* Revitalising manufacturing industry and agriculture - food crop production and manufacturing industry are both in the doldrums - the crop origin raw materials provides an obvious and cost effective route to revitalising both sectors.
* There exists a somewhat artificial divide between agriculture and the rest of industry (in the UK exacerbated by the organisation of the government into the department of trade and industry (DTI), covering manufacturing industry, and the Department of Environment, Food, and Rural Affairs) DEFRA covering agriculture. Government policy will seek to reduce this divide as part of general policy supporting crop origin raw materials.

Drivers 5-10 Years

Introduction of CORM

The desire to maintain **high rates of product churn** (associated with technological development) versus the need (directed by legislation) to **reduce the environmental impact** of the product is paramount. The introduction of crop origin raw materials (CORM) is driven by this desire on two levels. First any use of CORM is useful in promoting the perception that the product is somehow "green". Second, the use of CORM, with articles manufactured by existing technologies e.g. injection moulding is a relatively easy way to reduce the environmental footprint of existing manufacturers.

Technical advantages of natural fibres

As biocomposites gain a foothold in the market the **technical advantages of natural fibres over glass fibres** will become important in further growth in applications: for example-

- Drilling holes – minimal tool wear compared to GRP
- Lasers - – low residue combustibility of these materials should prove an advantage here

Drivers 10 > 15 Years

Greater range of CORM

The desire to maintain **high rates of product churn** (associated with technological development) versus the need (directed by legislation) to **reduce the environmental impact** of the product is **still present**; however by this time **new designs** for reuse, designs for separation will be available. The driver for crop origin raw materials is that the designer is not limited to a small number of compatible polymers (to allow for some chance of mechanical recycling); with biodegradable materials, there are no compatibility issues for end-of-life, as the compost heap accepts any putrescable material.

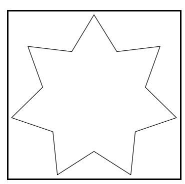
Drivers 15 + Years

Smart textiles e.g. clothes

The development and subsequent production of **smart textiles**, particularly within the clothing industry gives rise to interesting potential development for electrical and electronic equipment. Essentially, smart textiles can be described as those which act by themselves.

Rising costs of fossil raw materials

Fossil raw materials are a finite resource. This means that as the planet continues to expend these natural resources at an ever increasing rate, the **resource volumes will decrease**. Inevitably, this will lead to a **price increase** to combat this demand adding greater emphasis to the problem of alternative solutions.



Critical Technologies 0 > 5 Years

See generic report.

Critical Technologies 5 > 10 Years

Biodegradable cases

There are, at present, **significant penalties in terms of performance, cost and availability with regards to bio-materials**. The high cost and low volumes of these materials can mainly be attributed to low demand, which in turn can be attributed to the high cost and low availability– a true chicken and egg situation. The mobile phone market presents an **opportunity to break this vicious circle**, presenting a potentially high demand market if performance issues can be addressed. The high volume, low cost market which is in place due to the addition of mobile phone fascias and replacement cases is the ideal scenario for developing a product which will have significant benefits in promoting biopolymer usage, by actually getting a product to market.

Life cycle cost

It is important to take into account the **total life cycle cost** of a product when using it as a basis for comparison between materials. Whilst the fossil based material may have an initial cost saving attached to its use, this is lessened to a certain extent by the disposal costs which will inevitably occur due to usage.

Near to total biodegradability
An obvious route for **developing the market** for these materials, as it allows the use of as many dissimilar polymers (and other biodegradable materials) as are available, without any need for separation infrastructure.

Raw material availability
Consistent high volumes of material are an **essential requirement** for their take-up in high volume industry. Industry may well have an inherent distrust of crop origin materials due to a perception that materials availability may vary uncontrollably due to weather and cyclically due to seasons. However, raw material supply is never consistent due to cost lead supply fluctuations.

High volume industry is always struggling to reduce uncertainty in the manufacturing process; there will be barriers to be overcome in the introduction of new materials with even the perception of excessive variability about them. This is one of the reasons for the limited uptake of post-consumer recyclate.

Plant oil supply levels must match demand throughout the growing season.

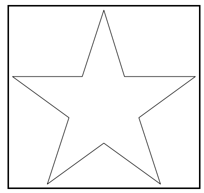
Ease of disassembly
Ease of disassembly will become **increasingly desirable** within the design of products with biopolymeric components. In order to initiate the separate waste streams system which has been suggested elsewhere in this report, the emphasis will shift towards products which are easily disassembled.

Cost of manufacture of material
Applications will be **limited to small volume niche markets**, until costs of manufacture match or better existing. Rises in fossil origin, and high specific energy raw materials are expected.

Electrical effects
Static electricity - in the days of the supremacy of CMOS chip technology, static electricity could readily destroy electronic circuitry. Current TTL technologies are more robust, but materials that prevent static build-up find wide application. One of the methods for preventing static build-up in polymers is to coat the article with a water absorbing layer. The water provides a sufficient level of conductivity to allow static charge to leak away. Inherently hygroscopic biopolymers are likely to exhibit this property without any additional surface treatment.
Specific Absorption Rate (SAR) -The exposure standard for wireless mobile phones employs a unit of measurement known as the Specific Absorption Rate, or SAR. The SAR limit set by the FCC is 1.6W/kg (see http://www.ctia.org/content/index.cfm/AID/333). Developments that minimise SAR are welcome, but attempt to incorporate SAR reducing shields have been largely ineffective.

Infrastructure development for new materials

It is **imperative that there are developments** with regards to infrastructure in order to capitalise on benefits obtainable with the use of biopolymers. Without the necessary infrastructure development, including the education of consumers, a change in culture and also potentially the addition of separate waste streams for the separate materials, the biopolymer opportunity is likely to fail. Currently we live in very much a disposable culture and this needs to be developed into a recyclable culture in order for any of the benefits to be seen significantly.



Underpinning Technologies 0 > 5 Years

Material/product manufacturability
The **uptake of new materials is clearly linked to supply levels** that match industry demand, both in terms of quantity and consistent quality.

Product integration of parts into products
It is necessary to include crop origin materials in such a way as to ensure that they **can be extracted at end-of-life**. This is particularly important where a mixture of CORM and fossil origin materials are used. Automated separation of different types of plastic and PMC's is particularly challenging because they are similar in terms of the physical and chemical properties used to make separations.

Knowledge of process and materials
Rapid and timely **knowledge transfer**, avoiding loss of critical IPR – either between researchers and industry, different industrial sectors, or by the formation of industrial clusters to promote general improvements in profitability for a given sector: this is critical in establishing a user base for these materials.

Component design
It is necessary for designers to gain an **understanding of the potential** of these new materials, and how they can be incorporated into designs to maximise the advantages available from their introduction.

LCA tools
Development and validation of life cycle analysis tools is **critical** at the early stages of the uptake of these materials. If a clear quantification of the social and environmental benefits of CORM are available, this may help to offset difficulties with the high initial costs of CORM.

Need "not to mix" recycle streams
Infrastructure development is needed to make sure that in-process and end-of-life biodegradable scrap is not mixed in with fossil streams – this may result in unexpected biodegradability in recovered materials

Measurement tools for sustainability
It is not enough merely to assert that the environmental impact of an article is "low", it must be possible to **objectively and quantitative assess environmental impact**. Valid testing and evaluation methods need to be agreed on, leading to technical standards that are internationally recognised and publicly understood.

How long will nano-fillers last in casings?
Uncertainty of life span **is common** to all new materials, predictive methodologies and accelerated life test will help reduce this uncertainty to acceptable levels.

Underpinning Technologies 5 > 10 Years

Fibres

- Treatment process – **high consistency, high volume, acceptable cost levels**. Note the need for any increased margins for new application materials to be spread evenly along the supply chain, to ensure that all supply chain members have incentives to take up the new materials and technologies.
- Extraction from source – as previous – a technical grade of fibres is required – somewhere between fine Irish linen (weight for weight dearer than carbon fibre!) and soil stabilising needled felts.
- Mixing / compounding – low temperature – avoiding thermal damage, low pressure – especially with thermoplastic matrices – avoiding fibre rupture and lumen collapse. $SCCO_2$ (supercritical carbon dioxide plasticised melt processing) may well be a key technology here.

Resin Development
A **wider range** of thermoset resins are required – this may well involve looking at older resin systems –e.g. caseins and phenolics, as well as newer crop origin epoxies. Thermoplastics need to be more robust in terms of processing conditions. More special properties, such as electrical conductivity are required – matrix materials will need to meet fossil origin matrices head on in this, and other respects.

Biocomposites

- Recyclability – moving to exploit the minimal infrastructure and energy requirements inherent in using the natural material cycles for end of life disposal. **Recycling should still be viewed as a "third best"** choice after extended product life and reuse.
- Processability – ease of processing to match or exceed currently available materials. Ease of processing will also include some element of reduction in risks associated with operator exposure.
- Availability – to match demand

Toxicology (Reduction)
Although there will be some reduction in risk to operators and end users associated with the use of nature identical chemical structures, the following points should be noted. First, thermoset systems (even those of unprocessed plant origin such as cashew nut shell liquid) are by definition lower molecular weight, high mobility, highly chemically reactive systems. They must therefore be treated with appropriate

respect. Second, that not all natural or nature-similar chemical structures are harmless. Consider Curare (*Chondrodendron tomentosum*) and certain sex hormone analogues as examples, therefore biopolymers and biocomposites are not exempt to the normal considerations of product and raw material health and safety.

Destruction of materials

- Burning – expect a decline in combustion, perceived as a wasteful method of recovering values in end-of-life materials.
- Composting – development of a well established and economically viable (profitable) infrastructure for the production and USE of compost from non-food materials

Natural materials for PCB's

Either crop origin epoxies, or a return to the fibre reinforced phenolics of yesteryear. Development needed to match existing performance with "old fashioned" materials.

- Printed PCB's – development of conductive biopolymers to reduce the amount of metal values lost with the end-of-life disposal of PCB's.

Sustainable manufacturing processes

Expect a move towards "**clean manufacturing**". This may have a knock-on effect in reducing the mobility of global capital due to increasing acceptance of the triple bottom line

Dust control in recycling

The nature of composting may allow for a **reduction in the energy intensive processes** of crushing and grinding, hence reducing the production of air-borne particulate emissions.

Health & Safety in manufacture

Regulations to decrease risks to health associated with manufacturing are likely to increase rather than decrease – crop origin raw materials are well placed to exploit this.

Underpinning Technologies 10 > 15 Years

Good mechanical properties and compatibility

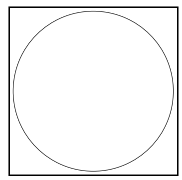
Biopolymers will never be successful unless they are **able to compete** with current properties achieved by fossil based raw materials. Whilst it is possible that there will be an initial wave of interest towards green alternatives, the chances of success are limited if they are not a genuinely competitive proposition.

Design techniques

Design techniques **require adjustment** if green alternatives are to be incorporated into the mainstream. Design for environment (DfE) becomes increasingly important as product innovation will become a total life cycle approach, with the ultimate disposal of the product considered at the initial design phase. This will include design techniques that cope with raw material property uncertainty with producing grossly over-engineered products

Underpinning Technologies 15 + Years

‘Chicken & Chips’
Chip encapsulation using biopolymers “chicken and chips” – research at the University of Delaware claims to be able to produce chip encapsulants (polyurethane based) from animal origin precursors – chicken feathers. The use of animal origin materials may provide a useful way to remove low grade animal by-products from the food chain (consider BSE, Foot and Mouth, etc)



Identified Gaps 0 > 5 Years

Life of electronic products
Casings need to match product life, or be reusable – life cycle of electronics is based on obsolescence rather than wearing out.

Moisture resistant natural composites
Ties in with control of biodegradability and static electricity

Identified Gaps 5 > 10 Years

Improved surface finish for cleansing
In order for the bio-products to be considered as genuinely competitive, they must be able to **at least match the properties** of the materials currently in use. To this end, there are a number of gaps which have been identified for this to happen successfully. Improved surface finish for cleansing is one such area.

Reducing numbers of different materials
By reducing the numbers of different materials employed within the marketplace, designers will be able to offer a **greater consistency** of product and by combining requirements and sharing development expenditure it may be possible to streamline the bio-development concept and strategy,

Self coloured materials
Self coloured materials will obviously be a key target for development within this area, but it also gives rise to the need to develop a suitable method of colouring or adding pigment to the product but at the same time retaining its “green” standard.

Conductive biopolymers
Conductive biopolymers will allow for huge market penetration by incorporating natural fibre composites which meet extended needs.

Identified Gaps 10 > 15 Years

Green fashion item demonstrator
E.g. car, high profile consumer electronics - iPod
It is important that with the increasing use and development of natural fibres, that there is **a fashion item demonstrator** which can be produced and enter the public domain as an example of the benefits and qualities attainable from the use of biopolymers and "green" materials.

Natural micro fibres
The development of natural micro fibres as use as an additive is already happening in the laboratory, but further development could well see this as a huge development opportunity –the **functional equivalent of nanotechnology** – exploiting the fundamental structure of crop origin materials.

Inherent residual value of materials
At the moment, and for the foreseeable future, very low compared with the value of the articles made with them – this fact should direct us to **extended use and reuse** rather than the economically disastrous recycling.

Post consumer natural fibre waste
Post consumer natural fibre waste is material that has been reconstituted from product waste which has completed its life cycle. The benefits to the environment are huge if this market can be developed and exploited offering the opportunity to use recycled rather than virgin materials.

High flame resistant natural products
High flame resistant natural products would obviously open up new sections of the market for the manufacturers of such materials to aim for. **Increasing the competitiveness** in terms of mechanical and physical properties is an imperative requirement if they are to be considered a genuinely viable alternative.

Identified Gaps 15 + Years

Conductive natural fibres
Conductive natural fibres will allow for **huge market penetration** by incorporating natural fibre composites which meet extended needs.

Destruct on demand
Ease of disassembly will become **increasingly desirable** within the design of products with biopolymeric components. In order to initiate the separate waste streams system which has been suggested elsewhere in this report, the emphasis will shift towards products which are easily disassembled, or even "destruct on demand".

Biomimetic manufacturing routes
By genetic control of crops, **grow articles** in the field rather than raw materials for manufacturing.

4.0 FINAL WORKSHOP PROGRAMME

Day 1

Time	Room 006	Room 008
09.00	Registration & Tea/Coffee	
09.30	**Welcome** (Professor Lord Kumar Bhattacharyya)	
10.00	**Outline of Days Activities** (Dr Nick Tucker)	
10.15	**Dr Jalaluddin Harun (University Putra Malaysia)** *Malaysian Kenaf Biocomposite Development*	
	Room 006	**Room 008**
10.45	**Prof. Dr Ryszard Kozlowski** *Natural Fibres Reinforced Composites*	**Prof Rui L. Reis** *Polymers and Composites from Renewable Origin for High-tech biomedical Applications*
11.15	Refreshments	
11.45	**Marek Kozlowski** *Materials from renewable resources at Materials Recycling Center of Excellence*	**Maurizio Avella** *A review on current research at Instituto di Ricerca e technologia delle Materie Plastiche*
12.15	**Joris Van Acker** *Recommendations concerning moisture impact, biodegradability and thermal degradation of differently treated flax fibres envisaging optimal reinforcement of composites*	**Prof. Tony Johnson** *Materials based on natural sources; going backwards or forwards?*
12.45	*Lunch and Poster Session*	
13.45	**Dr. John Summerscales** *The determination of the fibre volume fraction in natural fibre composites - A review*	**Prof. Rudolf Kessler** *Knowledge based production and product functionality design of high added value composites: vision and realisation*
14.15	**Chris Price** *Sustainable Technologies*	**Dr.Lilliana Voran** *Characterisation of multilayer structures 100% biodegradable*
14.45	**Jakko Pere** *Biotechnical modification of natural fibres for novel products*	**Dr. David Pink** *Crop Breeding for Industrial Use*
15.15	**Prof. Ton Peijs** *Purely Green Composites*	**Kirrell Kaveline** *Sustainable Composites for Automotive Applications*

15.45	Refreshments	
16.15	**Fredrik Thuvander** *The influence of damage to the wood fibre cell wall on the strength distribution*	**Mikael Srifvars** *A study of biocomposites based on flax fibers and polyhydroxybutyrate - interfacial modification, characterisation and processing*
16.45	**Martien van den Oever** *The Relation between Constructive Design and Environmental Impact*	**Claudia Koncsag** *The manufacture of composites in Romania*
17.15	***Close of Day 1***	

Day 2

09.00	Registration & Tea/Coffee		
09.30	***Welcome and Roadmapping Instructions***		
09.45	**Road Map Session 1**		
	Packaging (Room 006A)	***Automotive*** (Room 006B)	***Electronics & Telecoms*** (Room 008)
11.30	Refreshments		
11.45	**Road Map Session 2**		
	Packaging (Room 006A)	***Automotive*** (Room 006B)	***Electronics & Telecoms*** (Room 008)
13.00	*Lunch & Poster Session*		
14.00	**Road Map Session 3**		
	Packaging (Room 006A)	***Automotive*** (Room 006B)	***Electronics & Telecoms*** (Room 008)
15.30	Refreshments		
16.00	***Open Discussion, Conclulsions & Feedback***		
17.00	***Close of Workshop***		

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5.0 ACKNOWLEDGEMENTS

ENVIROCOMP's organisers would like to thank the following people for their valuable contributions:-

Professor Lord Kumar Bhattacharya, founder and director of the Warwick Manufacturing Group at the University of Warwick who summed up the reason for running this seminar in his keynote address by saying that environmentally aware manufacturing is the one remaining thing that can stem the quarter century long slump in volume manufacturing in the UK and Europe.

Dr. Gordon Smith, leader of the WMG materials group who has long encouraged the editorial team at WMG to develop our various research interests in the application and development of new and old polymers and polymer matrix composites

The leading academics, engineers and manufacturers from over dozen countries including the UK, Malaysia, Romania, Belgium, Germany, Spain, Italy, Holland, Denmark, Norway, Poland, Finland, Portugal, and Sweden who came together to share their knowledge, and construct the roadmaps found in this report

The European Science Foundation who provided funds and backing to allow the event to take place.

6.0 STATISTICS

ESF Participants only:

Total attendees: 30

Age

21-30	8
31-40	7
41-50	9
51-60	4
Over 61	2

Sex

Female	Male
5	25

Country of residence

UK	16	FI	1
ES	1	IT	1
NL	2	PO	1
PL	3	RO	1
DE	1	BE	1
SE	2		