Window and Glazing Topics – New window materials

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Part 1 – The way behind

This series looks at what may be coming in terms of window materials for the future. Like all future gazing, it is bound to be inaccurate but hopefully it will stimulate thinking about where the industry could go and what you can do about it. New materials such as pultrusions, thermoplastic pultrusions, ABS/ASA composites, recycled materials with cellulose extenders and even PVC-U in other forms present both opportunities and threats to the existing industry. Failing to plan for these developments could well be the equivalent to planning to fail in the future.

1. The current attitudes

In the PVC-U sector of the window industry it is accepted wisdom that PVC-U will remain the main material for window construction for the future and there is a real complacency towards any threat from competing materials. This assumption is so ingrained that the Technical Manager of a leading systems company has been reported as stating that PVC-U is undoubtedly the best material and that there is no viable competition in the field of window frame materials. When the technical people start saying that then it is really time to worry!

Similar reactions come from other manufacturers. Consider the proposition 'What if there was a magic aluminium patio door that did everything you needed. Would you be interested?'. The Marketing Manager of another major PVC-U systems supplier replied 'No! We are PVC-U processors'. They define themselves primarily in terms of the material they process rather than in the function they serve. In any case real 'PVC-U processors' make things other than windows!

A similar narrow reaction would have been found in the companies making slide rules during the late 1960's (it is a sure sign of your age if you can remember what a slide rule is). During the late 1960's these companies saw themselves as 'slide rule manufacturers' and spent enormous efforts developing new slide rules with extra functions, developing methods for engraving thinner lines and other slide rule technologies. When 'electronic calculators' were developed, the slide rule people considered them inferior and dismissed the technology as unworthy of investigation. The existing investment in 'slide rules' was considered to be more important that speculative investment in electronics. How many of the slide rule manufacturers made the transition into calculators – None! They defined themselves in terms of their product (the slide rule) and not in terms of the market they were really in. They were actually 'providing means for calculations' but they didn't realise that until it was too late and their extinction was inevitable. They were not the only ones of course, the list could also include drawing board manufacturers, buggy whip manufacturers and many others.

Many PVC-U systems suppliers would be better placed for the future if they defined themselves as 'providing window solutions' rather than as 'PVC-U processors' and if they regarded their current investment in plant as a means to an end rather than the end itself. It is a small difference in words but a large difference in attitude. The alternative is to be like a frog in water. It is said (not that I've tried it) that if you drop a frog in hot water then it will rapidly jump out again. If you put the same frog in cold water and slowly heat the water then the frog will remain there until it is well and truly boiled. Conditions sometimes change so slowly that by the time we realise what is happening it is too late.

2. The current market and capacity

The current market capacity for PVC-U outstrips the current demand and consolidation is taking place daily at all levels of the supply chain. It is estimated that the over-capacity exceeds 40% at virtually all levels of the industry. The market demand is also forecast to decrease as the bulk of the windows suitable for replacement are replaced – the future for the industry is one of excess capacity and shrinking demand unless new strategies and growth areas are found quickly. The effects of over-capacity rapidly become critical as demand is reduced. Robert Palmer has recently suggested that a part of the solution lies in replacing the replacements but even this could be threatened by a new technology.

At the systems supplier end of the market, we see sales, mergers, take-overs and closures on an almost daily basis. Consolidation of the industry is taking place rapidly and the leading systems suppliers are rapidly gaining market share through acquisition. The same consolidation pressure is making itself felt at the fabrication end of the market where the driving forces of competition for market share, changing consumer behaviour and over-capacity have combined to considerably reduce margins. The fabricator response has been to improve manufacturing techniques, improve management skills and to look for economies of scale. In the early 1980's a large window manufacturer was making 200 windows per week – now a large manufacturer (the super-fabricators) is making 2500 windows per week and growing bigger. There is still growth for individual fabricators but the market will never return to the growth and price levels of the 1980's.

Price pressure in the industry is intense and in prices in the market are down to about 50% of the early 1980's prices, even ignoring the effect of inflation. In real terms the prices have dropped even more and the product being sold for these prices has improved in terms of security, quality and performance.

Consolidation is likely to continue because the long-term erosion of real price levels has reduced profitability and capacity has outstripped demand.

3. The current materials

Before reviewing the new materials, it is necessary to look at the strengths and weaknesses of the existing materials to see what competition they must face.

PVC-U

PVC-U is the dominant material in the market place and currently has the most to lose to the development of new materials. It is also the 'material to beat' for new materials developments.

PVC-U Windows	
Strengths	**Weaknesses**
• Low maintenance load. • Unaffected by moisture. • Good thermal insulation.	• Low mechanical strength/weight. • High thermal expansion. • Raw materials cost volatility.
Opportunities	**Threats**
• New finishes to provide colour options.	• Environmental pressures.

Timber

Timber is undergoing a renaissance due to initiatives being led by the British Woodworking Federation. The two important sectors, softwood and hardwood, have different strengths but new materials could outflank both sectors at the same time!

Timber Windows	
Strengths	**Weaknesses**
• Easily modified on site. • Good thermal and sound insulation. • End-user can repair and maintain. • Appearance can be modified by consumer	• High maintenance load for end-user if not treated correctly. • Moisture expansion can give interference problems on opening lights.
Opportunities	**Threats**
• Improvements in surface coating techniques. • Use of composite materials / layer techniques to give lower cost and more	• Growth of other materials in new-build sector. • Materials price and environmental issues

efficient usage.	for hardwoods.

Aluminium

Aluminium has suffered from the growth of PVC-U in the domestic sector. The mechanical strength/weight ratio has enabled the retention of a substantial commercial market and any new material will find it hard to displace aluminium from this market.

Aluminium Windows	
Strengths	**Weaknesses**
• High mechanical strength/weight. • Low maintenance load. • Unaffected by moisture. • Fire resistance.	• Low thermal insulation unless combined with other materials. • Raw material costs.
Opportunities	**Threats**
• Composite windows with good thermal properties and attractive finishes.	• Revival of wooden windows (with improved surface coatings).

Steel

Steel is concentrated mainly in the commercial sector where the particular mechanical strengths of the product are best utilised. New materials will take considerable time to displace steel in this area.

Steel Windows	
Strengths	**Weaknesses**
• High mechanical strength/weight. • Slim sight lines. • Fire resistance.	• Low thermal insulation unless combined with other materials. • Maintenance load.
Opportunities	**Threats**
• Excellent security and mechanical response. • Door products using high mechanical strength.	• Continued inroads by alternative materials.

Full SWOT analyses for each material are available from Tangram Technology on request (windowmaterails@tangram.co.uk)

4. So where do we go from here?

The existing materials meet the requirements well but all have areas where new materials can have substantial advantages. In new materials and new product development the advantage often lies with the attacker – they have less to lose and more to gain! The traditional materials are both well established and have well-developed distribution chains but this does not make them immune to new materials. In fact, the seeming strengths of the existing materials make them complacent and the threats may be all the more dangerous for this.

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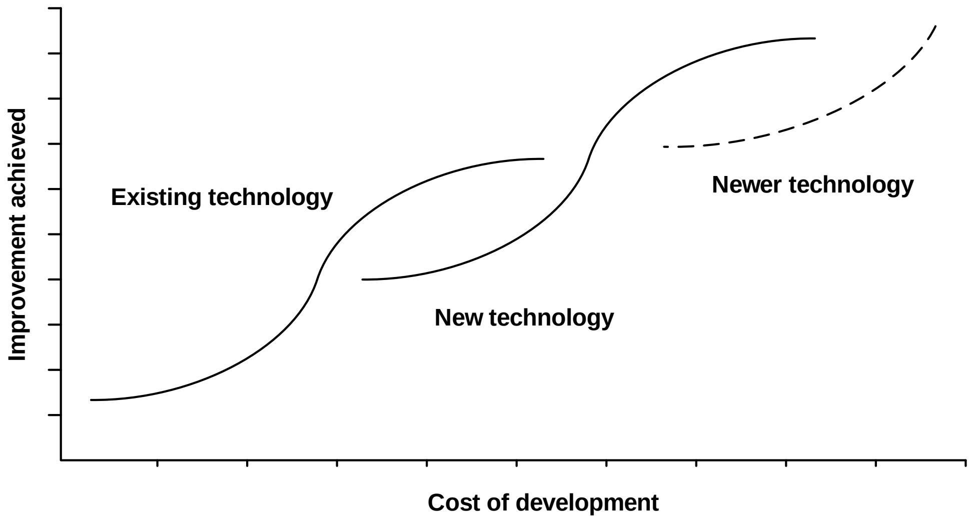
Part 2 – The way ahead

1. New technology development

The S-Curve

All new products, including window frame materials, follow an S-curve for return on the cost of development.



When compared with an existing technology, initial developments in a new technology are costly for little real improvement in operating performance. The initial performance may even be less than that of the existing technology in some important respects. As times passes the new technology enters a region where the improvements achieved are very cost-effective and the performance overtakes that of the existing technology. At the end of the cycle the cost of development increases for small improvements actually achieved and a newer technology is developed.

Many of the new window frame materials are at the lower end of the S-curve and, given the right conditions, are ready to experience the rapid growth section.

The market ecology

Superiority to existing technology is not the only requirement for a successful new product or technology. Superior products will fail if they do not establish themselves in the market ecology. Markets resemble complex ecosystems and if the product niche is already occupied then it is very difficult for a new product to establish itself and survive. The new product must compete with existing products and also displace them before it can become successful. It must achieve both the critical mass and also the route to market. Many companies realise that their existing technology investments could be rendered redundant by the new technology and there is resistance to the technology. If the everlasting light bulb were to be invented then would a light bulb company want to develop it? (This is a bit misleading since as of June 2000 there will be no incandescent light bulb manufacturers in the UK, still the concept applies). New materials will face more than technical barriers because better mousetraps do not always take the market by storm.

Despite this, new materials are the key to new technology. The companies that are fastest in the development of the new materials may well decide the future of the window industry (but I would say that – being a Materials Engineer by training).

2. The new issues

Whatever the new materials are there are new issues for window frame materials that will affect the whole market. The new materials may well be able to use these issues to gain crucial market advantages over the existing materials.

Environmental impact

Increasing pressures from environmental groups is starting to have an effect in the market. Life Cycle Analyses of window materials have concluded that there is no basis for recommending any particular frame material on environmental impact grounds. The environmental impact for products varies as much from factory to factory as it does from material to material and the production level impact for various materials is much smaller than the impact of the product over its lifetime. Despite this, environmental concerns will grow in importance and both existing and new materials will need to reduce their environmental impact in the future. Ignore the environment at your peril! New materials based on recycled products will reduce the environmental impact at the production level as well as establish good ‘green credentials’.

Thermal efficiency

A window is an ‘appliance’ that uses energy and generates CO_2 as a result. A new and important issue will be the thermal efficiency of the complete window and the way the material and design of the window affects this. Windows are often only seen as an energy loss to a building but correctly designed windows can minimise this and can actually add energy to the building. The concept of ‘window energy rating’ makes it possible to directly compare the thermal efficiency of the complete window unit for various materials and manufacturers. New materials may use energy efficiency as a method of outflanking the existing materials.

3. The ideal window material

In order to assess the new materials, it is necessary to first define what the requirements of the ideal material are. This ideal material meets the requirements of:

- Low and stable raw material cost.
- High flexural modulus to provide stiffness without reinforcement.
- Low thermal conductivity to provide energy efficiency.
- High resistance to corrosion and fungus.
- Easy to colour and match other architectural features.
- Easy to work with and manufacture (as well as low Health and Safety risks).
- High fire resistance.
- Low environmental impact.

This is illustrated in the diagram below:

Ideal Window Material

High	**Cost**	Low
Low	**Flexural Modulus**	High
High	**Thermal Conductivity**	Low
Low	**Corrosion/Fungus Resistance**	High
Difficult	**Colour**	Easy
Difficult	**Ease of Working**	Easy
Low	**Fire Resistance**	High
High	**Environmental Impact**	Low

Existing frame materials can meet many of these requirements but the market is not static and the right new material could change the market as dramatically as PVC-U did in the 1980's.

4. The new materials

The development costs and simple polymer chemistry make it unlikely that any new bulk polymer will be developed and used for window frames. Equally, the application of new metals to window frames is unlikely and there are no obvious candidates that have not already been used for frame manufacture.

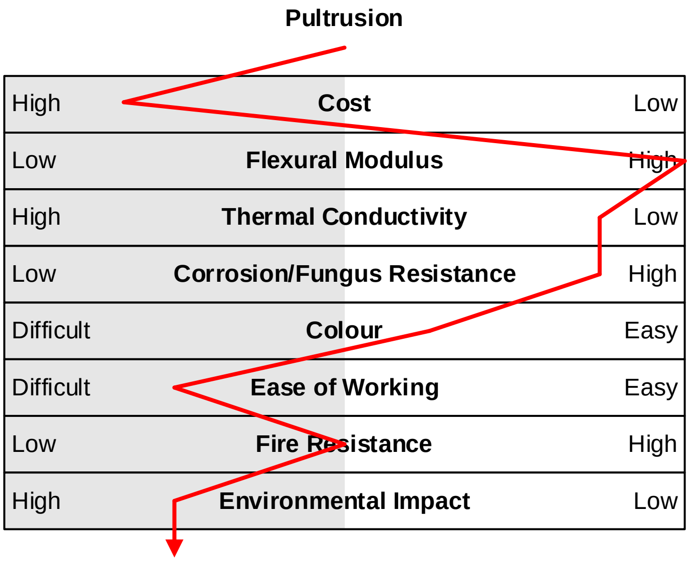
The areas to watch are those where polymer alloys and compounds of existing plastics are developed to modify and extend properties and to lower the cost. Iron was an 'old' material in the 19th century but the development of steel making extended the applications enormously. In a similar manner, existing plastics can be alloyed, compounded and filled to extend the properties and lower the cost. The new composites will use either low-cost fillers to marginally stiffen and fill the matrix or high-cost reinforcements to greatly stiffen and reinforce the matrix. Typical examples are pultrusions, thermoplastic pultrusions, ABS/ASA composites, recycled materials (PVC or PE) with cellulose extenders (wood flour, flax or other natural fibres) and other forms of PVC.

These new materials will sometimes defy the categories that we are used to. Is a material with 60% wood and 40% plastic a wood or a plastic? Will the timber window industry see resurgence whilst the PVC-U industry fights a rear-guard battle? Interesting times ahead.

Part 3 – The new composites (1)

Having set the scene, we can now look at the contenders for the label of 'the new PVC-U'. As a point of pure science (or pedantry) it is interesting to note that the term is 'PVC-U' and never 'PVC-u' or 'PVCu'. If you see either of these terms used you will know that the person or organisation that wrote or used them doesn't actually know what they are talking about – would you buy a car from a person who advertised it a 'Frod' on all their literature!

1. Pultrusion – resins and glass fibres



One of the most promising of the newer materials processes is pultrusion. The process has been investigated many times over the past 20 years but it is yet to achieve a strong market commercialisation in window frames. The extremely high dimensional stability, low thermal conductivity, high corrosion resistance, high modulus and colour possibilities make pultrusion an excellent candidate for some window applications.

The main disadvantages are high cost, low workability and historical difficulties in producing the fine surface details needed although there are significant improvements being made in surface quality to reduce this concern. These disadvantages have not stopped the development of window and patio door systems in both the UK and USA and products from this material will continue to be developed for products where the advantages offered far exceed the disadvantages. The cost of the pultruded profile itself may be higher than an equivalent length of PVC-U but the high stiffness means that no reinforcement is needed and this effectively reduces both the raw materials and labour costs for the final product.

An alternative to the standard pultrusion is the Owens-Corning process of CLM (continuous lineal moulding), which is pultrusion over an insulating core of dense glass fibre wool. This process greatly improves the thermal response of the product whilst maintaining all the other advantages of pultrusion.

Potential applications are for windows and similar products where high stiffness properties, high load bearing properties and extreme chemical or thermal inertness are required.

Pultrusion	
Positive	**Negative**
• High modulus. • Extremely high dimensional stability. • Low thermal conductivity. • High corrosion resistance. • Colour possibilities.	• High perceived cost. • Low workability. • Some difficulty with fine surface details. • Surface finish.

In terms of the ideal window material, pultrusion has great potential for window and door applications where the high stiffness greatly improves the product characteristics and provides substantial benefits.

2. Thermoplastic pultrusion – PVC-U and glass fibres

A PERA Craft Project involving a consortium of UK, German and Italian companies resulted in the development of a 'PVC-U extrusion locally stiffened by continuous glass fibre' and patents have been applied for the resulting process and products. This material uses a localised glass fibre reinforcing encapsulated via co-extrusion into a PVC-U matrix. The localised glass fibres allow precise placement of the fibres to give a high modulus composite with the glass fibres adding the strength and the PVC-U providing the matrix. The PVC-U enables details and surface finishes to be formed similar to conventional extrusions and the technology is essentially that of extrusion of PVC-U.

Thermoplastic pultrusion

High	**Cost**	Low
Low	**Flexural Modulus**	High
High	**Thermal Conductivity**	Low
Low	**Corrosion/Fungus Resistance**	High
Difficult	**Colour**	Easy
Difficult	**Ease of Working**	Easy
Low	**Fire Resistance**	High
High	**Environmental Impact**	Low

The product cannot be structurally welded as with standard PVC-U because of the presence of the glass fibres but a cosmetic weld is possible. Mechanical strength requires additional fastening.

Potential applications include conservatory roof bars and similar products that do not require welding to form a frame structure.

Thermoplastic pultrusion – PVC-U and glass fibres	
Positive	**Negative**
• High modulus. • Conventional PVC-U surface details possible. • Conventional process technology. • Other properties as per PVC-U.	• Cannot be structurally welded. • Development project only, no current commercialization.

This is a process with potential for specific projects such as conservatory roofs and similar products.

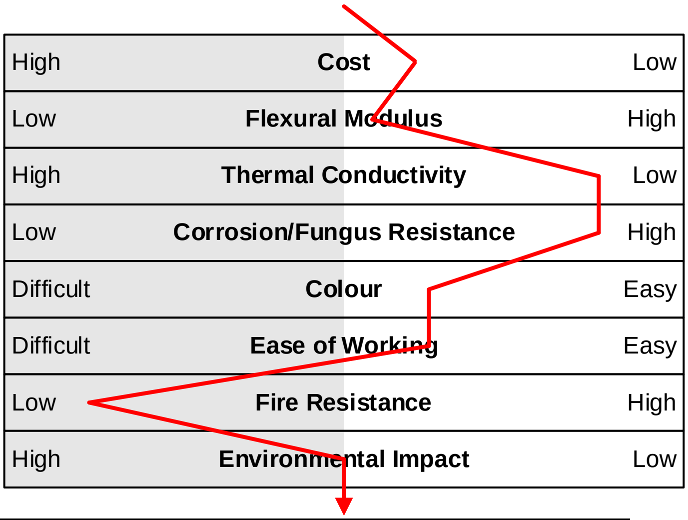
3. Polystyrene based materials

Extruded polystyrene structural foams (sold under a variety of trade names) have frequently been proposed as possible window frame materials. These materials have a good 'wood like' finish and have advantages such as workability similar to wood, low cost and the ability to be produced on conventional single screw extrusion lines from a variety of recycled and virgin materials.

The greatest disadvantage is the fire response of the product, adding fire retardant to the product improves the fire response and the material can achieve Class 2 of BS 476: Part 7: 1987. As with any polystyrene-based material, the products 'drip and burn' when subjected to real flame testing and this may restrict the potential for window frame applications.

This is a process that has been in existence for some years and current products suffer from the experience of poor performance with earlier similar products.

Polystyrene based materials



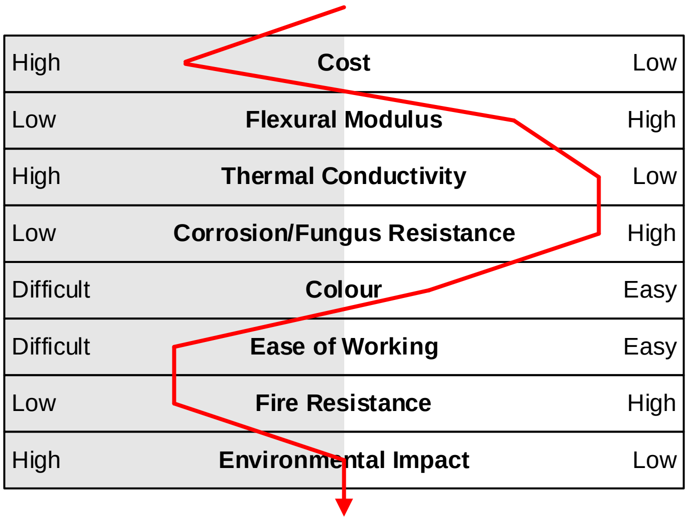
Polystyrene based materials	
Positive	**Negative**
• Good workability. • Low-cost tooling and processing. • Wood-like finish.	• Some concerns with fire response. • No successful commercial window applications known to date.

4. ABS/ASA materials

In the USA, GE Plastics promoted the use of ABS/ASA as a window frame material, this composite uses ABS as an inner layer and an ASA co-extruded outer layer to improve the weather resistance to usable levels. Despite the current price difference between PVC-U and ABS/ASA, it is claimed that the ABS/ASA composites can use much the same production machinery but products can be thinner walled, run 30–40% faster and have better physical properties than the equivalent PVC-U products.

The process has been developed and tested with trial products in the USA but little progress has yet been made in Europe with these materials.

ABA/ASA materials



ABS/ASA materials	
Positive	**Negative**
• Lighter weight than PVC-U for same stiffness. • Conventional process technology but runs faster than PVC-U. • Good surface finish.	• Higher cost than PVC-U. • Needs ASA layer for UV and weather resistance but exceptional performance is achieved. • Cannot be structurally welded.

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A conventional process using a newly developed material and technology in an attempt to enter the window market. Probably matched in all benefits by other materials that are better established and cheaper.

5. Overview

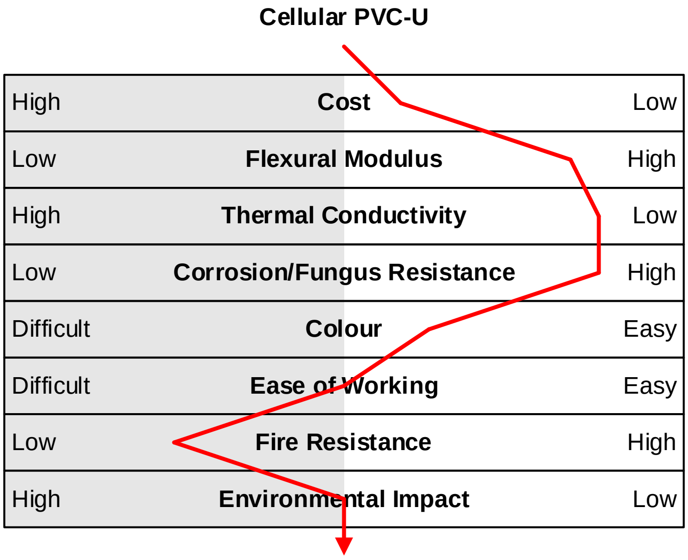
Many of the new composites suffer from cost disadvantages when compared to PVC-U but specific markets will begin to use other plastics as their advantages in terms of stiffness become more important.

Part 4 – The new composites (2)

6. Cellular PVC-U products

Cellular PVC (PVC-UE) has long been used in the UK for many types of trim and finishing applications but is now being used in the USA for main frame window products. The products can be treated like wood (nailed, planed and screwed) but have many of the properties of PVC-U with regard to corrosion and fungus resistance.

The cost is low, the mechanical properties good and the technology is common with the existing extrusion technology.



Cellular PVC-UE products	
Positive	**Negative**
• High thermal efficiency. • Can be nailed, screwed and treated as wood. • Conventional process technology. • Other properties as per PVC-U.	• Cannot be structurally welded. • Lack of detailed surface features. • Price may be a disadvantage.

A process already used for 'roofline' and trim products but not yet used in the UK for full window and door systems. Good possibilities for the future if the market wants to move in this direction.

7. Plastics and cellulose material composites

Plastics and cellulose materials represent a new area and the range of materials being developed in this area is wide and exciting. The new materials cover a wide range of polymer matrix types as well as a wide range of cellulosic fillers and stiffeners. The plastics being used include PP, PE and PVC and the fillers used include wood flour, flax, jute and other cellulose based fibre fillers. This gives a wide range of properties and only a summary can be attempted in this article. The high wood flour content of some products (up to 70%) may lead to some confusion in the market – is it wood or is it plastic? The wood and plastics window industries may not only reach an accord but also come together in a more intimate sense as both the wood and plastics processors transform themselves into composites companies. Application of these composites is not restricted to window products and several car companies are investigating similar materials for use in body panels and other parts such as parcel shelves. Cellulose based composites may well be the material of the future for more than just the window industry!

The majority of the current work on windows is being carried out in the USA and significant advances are being made. In fact, finished products are already being released onto the market. As yet there is little commercial activity in the UK but this will come as the benefits of the materials are recognised. Reliable information on the exact technology is difficult to obtain because of both commercial sensitivity and some ongoing patent disputes.

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In some cases, the producers are existing timber window manufacturers who have access to large quantities of cellulosic materials (sawdust and scrap wood products) that are suitable for treatment and inclusion in this type of product. This means that no wood resources are depleted in producing the products and waste products that used to cost £25 per tonne to dispose of are now a valuable resource – recycling can become both profitable and ethical. The sources of the base plastic vary depending on the process but range from recycled PE bags and PP battery case materials to the use of virgin polymer. The recycling ethos is to use materials from short life cycle applications in long life cycle applications.

Cellulose composites

High	**Cost**	Low
Low	**Flexural Modulus**	High
High	**Thermal Conductivity**	Low
Low	**Corrosion/Fungus Resistance**	High
Difficult	**Colour**	Easy
Difficult	**Ease of Working**	Easy
Low	**Fire Resistance**	High
High	**Environmental Impact**	Low

One of the major barriers to development is the difficulty of combining a hydrophobic material (most plastics) with a hygroscopic and hydrophilic materials (most cellulose based fibre products). This results in difficulties in compounding of the materials and poor stress transfer characteristics of the combined products. The general technique is to use a 'compatibiliser' or 'coupling agent' to improve the blending of the products and the interfacial interaction of the two phases. A typical compatibiliser is maleic anhydride modified polypropylene (MAAP) that is used to treat the plastics and cellulose products. This gives improvements in the processability and mechanical strength of the final product. The exact content of most compatibilisers is confidential and MAAP is generally not the only agent used in the compound.

PE based products are cheaper, have a higher heat distortion temperature and are less stiff than PVC based products but the PVC products do not suffer from the low surface energy of the PE products which makes painting and post-treatment difficult. In both cases the cellulose products improve extrusion speeds because of the higher heat transfer rates from the cellulose materials.

These composite products can generally be nailed, painted and otherwise treated as wood whilst retaining many of the benefits of plastics in the areas of fungus and corrosion resistance.

Cellulose based materials reduce costs, increase production rates and offer a host of benefits to the profile production. One of the virtuous areas is that the more cellulose material that is added, the lower the price of the raw material and also the higher the stiffness of the raw material. Lowering the cost actually improves the performance!

Plastics and cellulose material composites	
Positive	**Negative**
• Low cost and plentiful raw materials. • Recycled raw materials. • Hybrid materials – combine the best properties of both the biological materials and polymers. • Good stiffness.	• Compatibilisers raise costs. • Affects all current technology investments. • Need to learn how to handle new materials (powder and dust).

These stand the best chance of being the 'new PVC-U' that the windows market has been waiting for. The materials have lower and more stable materials costs, are environmentally friendly and have a wide range of features and benefits for all sectors of the market. The timber window may well come back in another form to compete with (and possibly defeat) PVC-U.

8. What now?

Low-cost materials will revitalise, threaten and change the industry and give a huge advantage to the first companies to develop the products. Many companies in the UK are not developing products purely because of their current investment in existing technology. This will change in the future as low-cost materials enter the market and compete against the existing materials. Staying in a particular technology simply because of your investment in the technology is not a recipe for success in any fast-moving market and the window market is no exception.

9. Conclusions

The way ahead for plastic and composite windows is not a simple one. Market forces of security, standards and increased environmental pressures will meet an industry struggling with low margins, consolidation, new materials and a decreasing market. It may not be a rosy future but it will certainly be interesting.