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Plastic Electronics

Putting the UK at the forefront of a new technological revolution

Written by:
Dr Zella King, AIM Innovation Fellow, University of Reading

EPSRC
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AIM – the UK's research initiative on management

The Advanced Institute of Management Research (AIM) develops UK-based world-class management research. AIM seeks to identify ways to enhance the competitiveness of the UK economy and its infrastructure through research into management and organisational performance in both the private and public sectors.

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about AIM

AIM consists of:

- Over 250 AIM Fellows and Scholars – all leading academics in their fields…
- Working in cooperation with leading international academics and specialists as well as UK policymakers and business leaders…
- Undertaking a wide range of collaborative research projects on management…
- Disseminating ideas and shared learning through publications, reports, workshops and events…
- Fostering new ways of working more effectively with managers and policymakers…
- To enhance UK competitiveness and productivity.

AIM's Objectives

Our mission is to significantly increase the contribution of and future capacity for world class UK management research.

Our more specific objectives are to:

- Conduct research that will identify actions to enhance the UK's international competitiveness
- Raise the quality and international standing of UK research on management
- Expand the size and capacity of the active UK research base on management
- Engage with practitioners and other users of research within and beyond the UK as co-producers of knowledge about management

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AIM research themes

Current AIM research projects focus on:

UK productivity and performance for the 21st century.
How can UK policymakers evaluate and address concerns surrounding the UK's performance in relation to other countries?
National productivity has been the concern of economists, government policymakers, and corporate decision-makers for some time. Further research by scholars from a range of disciplines is bringing new voices to the debates about how the productivity gap can be measured, and what the UK can do to improve the effectiveness of UK industry and its supporting public services.

Sustaining innovation to achieve competitive advantage and high quality public services.
How can UK managers capture the benefits of innovation while meeting other demands of a competitive and social environment?
Innovation is a key source of competitive advantage and public value through new strategies, products, services and organisational processes. The UK has outstanding exemplars of innovative private and public sector organisations and is investing significantly in its science and skills base to underpin future innovative capacity.

Adapting promising practices to enhance performance across varied organisational contexts.
How can UK managers disseminate their experience whilst learning from others?
Improved management practices are identified as important for enhancing productivity and performance. The main focus is on how evidence behind good or promising practices can be systematically assessed, creatively adapted, successfully implemented and knowledge diffused to other organisations that will benefit.

executive summary

The beginning of the 21st century marks the dawn of a new era of plastic as an *electronic* material, creating possibilities for a wealth of low cost, high functionality products and smart materials.

Companies in the consumer goods, retail, healthcare, transport, electronics and packaging industries need to start thinking now about how plastic electronics could change business models and create new sources of customer value.

To date, many of the innovations in plastic electronics have arisen as a result of technology-push, rather than market-pull. Now is the time for the UK's world-leading expertise to be channelled into the development of plastic electronics devices that are underpinned by strong business models. This will only happen where technology development is strongly led by companies with a vision for how to create customer value from plastic electronics.

To date, many of the innovations in plastic electronics have arisen as a result of technology-push, rather than market-pull.

Recognising these challenges, this report has been published by AIM with the following objectives:

- To provide a non-technical introduction to plastic electronics for businesses wanting to know how this emerging field of technology could generate new value for them and their customers along the value chain
- To identify why the UK is a good place to be involved in the development of plastic electronics
- To explain why achieving first-mover advantages in plastic electronics involves collaboration between technology developers and market-led end-users
- To offer practical advice to help companies find collaboration partners

Why is plastic electronics so valuable?

The production economics of plastic electronics are very different from conventional electronics based on silicon chip approaches, making it possible to consider products with radically different price points, performance and functionality. This in turn opens up the possibility for new applications and markets that are not accessible using rigid electronics technologies. Some of the applications envisaged are:

- Packaging that is intelligent and/or interactive, aiding in anti-counterfeiting and the protection of products, and helping to differentiate brands through eye-catching displays.
- RFID (radio-frequency identification) printed onto packaging, creating value from efficiencies in product inventory management and logistics.
- Displays and signage applications, including e-readers, that make use of low power, sunlight-readable, flexible large area displays that will last for days on a single charge.
- Lightweight, flexible power sources integrated into mobile devices, in or on buildings and in consumer accessories.
- Lighting panels of any size or shape manufactured as part of a building's architecture and infrastructure, or in automotive, aircraft and other transport systems.

The market value of flexible and conformal devices is predicted to be $335 billion by 2029.

It is now time for technology needs to be accelerated forward through the market pull of a wider range of intended product releases.

Bringing plastic electronics to market

Because plastic electronic products are typically made up of a series of layers of different electronic materials, their development involves a combination of competences in different technology areas. These include materials and inks, technology and design, equipment, process scale-up and the provision of components and services.

Complex scientific and technical challenges, spanning the disciplines of chemistry, physics, electronics, systems integration and process engineering, need to be solved. For successful market entry, these challenges have to be resolved via collaborative developments among partners with complementary core competences.

To help companies locate themselves, and their potential partners in the innovation value chain, AIM research has categorised companies and universities active in plastic electronics in the UK and Germany in terms of technology areas and business models. The resulting Competence Matrices for Plastic Electronics in the UK and Germany can be downloaded for free from www.printedelectronics.net.

Value chains in plastic electronics: where are the end-users?

AIM research indicates that as yet there are relatively few end-users who are buying finished components for incorporation into their products, or buying equipment and materials that would enable them to embed flexible electronic functionality into their own products.

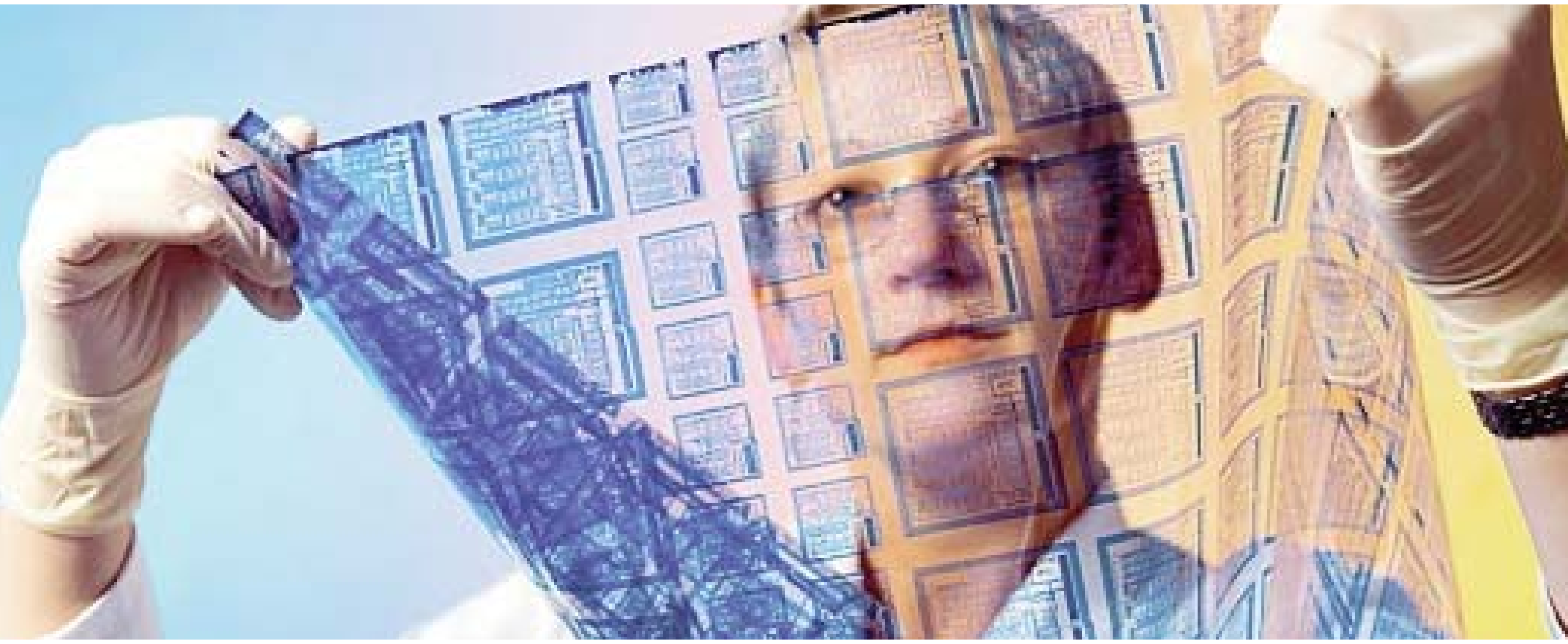
It is now time for technology needs to be accelerated forward through the market pull of a wider range of intended product releases. Manufacturers and service providers in the consumer electronics, retail, fashion, healthcare, energy, printing and packaging industries need to set specifications for performance, functionality and price points that will enable them to generate value for their customers.

Led by these specifications of user needs, materials developers and printing equipment manufacturers can start to identify how they can capture value from new market opportunities. End-user companies wishing to position themselves for the opportunity presented by plastic electronics face the challenge of finding, within a global innovation system, the technology developers who will be best equipped to work with them.

Why the UK is a good place to be involved in plastic electronics

With the US and Germany, the UK is leading the development of plastic electronics. UK-based companies cover the full value chain for plastic electronics, and research in UK universities lies at the forefront of global developments.

AIM research has produced a detailed analysis of the differences between plastic electronics capability in the UK and one of its most direct competitors – Germany – examining the scale at which research and development are being conducted, the application areas targeted and the business models and financing structures used to secure a position in the value chain.



The research indicates that, by targeting lower functionality markets such as RFID, packaging, games and disposable electronics German innovations are likely to enter the market more quickly, but UK innovations have greater potential to generate longer-term novel technologies and to deliver higher-end applications, such as high information content displays and solar cells.

How to know and be known in the UK plastic electronics community

Companies and individuals need to understand the landscape of plastic electronics, becoming aware of whom the key players are, and evaluating who offers technical knowledge and capability that meets their needs. The Competence Matrices examining key players in the UK and Germany provide a useful starting point for this.

They also need to establish themselves as features in that landscape, establishing their own credibility as a potential end-user of plastic electronics and/or as a potential research partner or customer. People often say that to become known in a technology community it is useful and important to be involved in various 'networking' activities, like those run by the Knowledge Transfer Networks (KTNs), funded by the UK Government.

But how effective are these activities and what value is there in them for organisations? AIM research looked at some of these issues with respect to the KTN serving the plastic electronics, displays and lighting communities. It was clear that actions by, and interactions between, individuals at KTN events were important for establishing attractiveness as a collaboration partner.

Conclusion

In this report, we have shown that plastic electronics has evolved from science-fiction to 'science fact', and that it is now ready for a wide range of end-user products and markets. The next step requires leadership by companies and individuals who can envisage how these new technological possibilities can create business value for their customers and for the end consumer.

introduction: plastic fantastic

Since the early 1900s, the use of plastic, as a mouldable, light-weight and low cost *construction* material, has revolutionised the way we live. Now, at the beginning of the 21st century, we are at the dawn of a new era of plastic as an *electronic* material.

Plastic electronics promises a wealth of low cost, high functionality products and smart materials. Everyday 'dumb' objects will become intelligent, changing the way we interact with the world. In the future, electronic objects will increasingly be flexible, low cost and distributed across large areas.

Figure 1:
Smart packaging

Using printed and plastic electronics, it will be possible to reach consumers through captivating point-of-sale displays and packaging, to identify the location of items or people in real-time using printed tags, to monitor the freshness of perishable goods using smart packaging (see Figure 1) and to produce disposable interactive games at costs low enough to use them for consumer promotions. Plastic electronics will make it possible to create low power illuminated wallpaper, to integrate lighting and displays into walls and windows, to print solar cells onto fabric, and to incorporate sensors into medical dressings.

The timescales over which some of these new applications are achievable are shown in Figure 2, while a selection of products enabled by plastic electronics, that are in the market, or ready for market entry, are depicted in this report.

Seizing competitive advantage

The pace of technological innovation means that there will only be a comparatively small window of opportunity for companies to take advantage of the new developments in plastic electronics to gain a competitive advantage.

Companies in the consumer goods, retail, healthcare, transport, electronics and packaging industries must start thinking about how plastic electronics could change business models and create new sources of customer value. There are opportunities to seize competitive advantage by being an early adopter, developing new concepts and cornering exclusive deals. Each application of plastic electronics will involve a different combination of functionality, performance, lifetime and price point, allowing a range of first-to-market opportunities to be exploited. First-mover advantages and opportunities can only be obtained, however, by working collaboratively with people who are developing new technologies.

Figure 2: Roadmap for Printed Electronics Applications (Organic Electronics Association)

Source: Organic Electronics Association, 2009

Creating durable electronic devices on flexible surfaces at a low cost means overcoming an intricate set of technical challenges. Technology developers have made great progress in the past couple of years towards overcoming these challenges, especially in the UK. To date, though, developments have occurred through technology-push, rather than market-pull. The result is great technology looking for an application. Now market-pull needs to come to the fore. Potential users of plastic electronics must stipulate what they need in terms of performance, functionality and price point.

It is time for the UK's world-leading expertise to be channelled into the development of plastic electronics devices that are underpinned by strong business models. This will only happen where the collaboration between technology companies, universities and other research organisations is strongly led by companies that have a vision of how to create customer value from plastic electronics.

Recognising these challenges, this report has been published by AIM with the following objectives:

- To provide a non-technical introduction to plastic electronics for businesses wanting to know how this emerging field of technology could generate new value for them and their customers along the value chain
- To identify why the UK is a good place to be involved in the development of plastic electronics
- To explain why achieving first-mover advantages in plastic electronics involves collaboration between technology developers and market-led end-users
- To offer practical advice to help companies find collaboration partners.

what is plastic electronics and why is it disruptive?

Some background information

Unlike pigment ink used in conventional graphics printing, the deposited materials have an electronic function, serving as conductors, insulators, or semiconductors.

Plastic electronics is a general term used to describe electronic materials that are put onto flexible surfaces such as paper, foil, fabric or plastic, and the processes used to deposit them. The materials used in plastic electronics are often described as ‘functional materials’. Unlike pigment ink used in conventional graphics printing, the deposited materials have an electronic function, serving as conductors, insulators, or semiconductors.

What is novel about plastic electronics is the combination of two developments in the electronics industry: the use of printing techniques and functional materials to deposit electronic components; and production techniques that permit the use of flexible surfaces.

The use of printing techniques such as inkjet and screen printing is not new to the electronics industry. Printing has been used for decades, for example, in the preparation of printed circuit boards on rigid surfaces.

The compelling advantage of printing, which opens up the world of plastic electronics, is that if electronic materials such as conductive inks can be deposited at low temperatures, the use of novel surfaces such as paper, fabric or plastic – which could not withstand high temperatures – becomes possible.

Innovation in printed and plastic electronics is occurring alongside wider developments in organic and thin-film electronics, and as a result a confusing array of partially overlapping terms – including printed, plastic, organic, polymer and flexible electronics – have emerged (see box on page 13). They are different terms used to describe a range of novel technologies and applications employing common sets of materials, processes, equipment and device architectures.

The language of innovative electronics

Broadly, **organic electronics** involves the inclusion, either through printing or some other technique, of an organic component within an electronic device. Organic components an be included in many different devices (including transistors and light-emitting diodes), which in turn can be found in a range of applications, including displays, sensors and solar cells. At present, 'organic' devices tend to include inorganic components such as metal contacts, together with an organic semiconductor.

Flexible electronics refers to devices and applications that are robust, thin, lightweight and non-rigid. The term 'flexible' is used to refer to the mechanical properties of the device. For example flexible displays could be:

- **Flat:** made on a non-glass surface in order to be thin and rugged. A display could be put onto the flat lid of a laptop, for example.
- **Conformal:** conforms to a curved surface and is fixed. For example, displays could be integrated into the curved surfaces of vehicle dashboards or hand-held devices.
- **Bendable:** could be bent or flexed many times during use, but not rolled up.
- **Rollable:** has flexibility, like thick fabric, and could be rolled and unrolled.

Many other functional components – not just displays – can be made on flexible surfaces. For example, sensors could be incorporated into stretchable fabrics for wound dressings and clothing.

Plastic electronics: the term we use here – generally refers to devices on flexible surfaces that make it possible to produce flexible, bendable or stretchable electronic products. Plastic electronics may make use of printing techniques, but can also be deposited onto flexible surfaces in other ways, so plastic electronics does not always mean a device is printed.

Likewise, printing techniques can be used to put materials on rigid surfaces, so printed electronics are not always on plastic or other flexible substrates. Fully printed electronics may represent the lowest cost route, suitable for disposable products such as packaging, while combining printed with conventional techniques might be appropriate where higher levels of performance and/or functionality are required.

Reel to reel printing of electronic materials www.polyid.de/en/press-images.php

Why is Plastic Electronics potentially so valuable?

Plastic electronics technology allows electronic materials to be formed into component and circuits using cheap core materials and low cost production techniques[1]. Flexible substrates offer manufacturing efficiencies, using reel-to-reel or reel-to-sheet production (like newspapers and magazines). Printing enables the highly accurate and efficient use of materials. Functional materials combined with printing techniques allow the manufacture of thin, lightweight, flexible and low cost devices.

The conventional manufacture of silicon-based electronic products typically requires high cost materials and factory equipment operated at high temperatures (see Figure 3). The lower costs anticipated for plastic electronics production means that very small production runs of highly customised electronic products may be cost-effective.

Figure 3: Differences between conventional processing of electronic materials, and processing in plastic electronics

Conventional processing of electronic materials	Processing of plastic electronics
Subtractive processes involving the deposition of layers of material that are then etched away (subtracted) to leave the required pattern	Additive continuous processes, printing material only in the required areas
Batch processes, with long production runs of the same product	Continuous processes, with flexible, short production runs
Processing in highly controlled environments	Processing in ambient conditions
High equipment, materials and infrastructure costs	Lower equipment, materials and infrastructure costs

Source: Cathy J Curling and www.printedelectronics.net

There are challenges associated with the production of flexible devices, as the various component layers must remain intact and bonded together when the device is rolled or manipulated, and exposed to heat or cold, air or water.

Nonetheless, the production economics of plastic electronic allows products with radically different price points, performance and functionality. It paves the way for creating new products and accessing new markets in ways not possible using rigid electronics technologies.

Some technology offerings made possible by flexible, light-weight and robust plastic electronic materials and low cost patterning processes include:

- **Visual output:** low power, sunlight-readable displays with a range of functionalities, performance levels, display effects and cost points. This includes animated labels and signs; high resolution mobile peripherals; large area thin, flat lighting that can be colour-tuneable; and large area displays that are updateable between images as well as switchable between opaque and transparent formats.
- **Intelligence inside:** distributed and large area electronic devices and data processing circuitry to enable smart and interactive functionality in and on products and at lower price points than would be possible with silicon chips.
- **Sensing and detecting:** devices that are sensitive to touch, or changes in chemical, biological or optical properties, or changes in pressure.
- **Power generation:** energy sources in a thin, flexible format that can be integrated into and onto surfaces over large areas.
- **Novel surfaces:** electronics fabricated on novel substrates and curved or non-curved surfaces – in and on flexible textiles, paper, plastic or metal foils.

Functional materials combined with printing techniques allow the manufacture of thin, lightweight, flexible and low cost devices.

Envisaging future sources of value

There are two sources of value likely to be derived from these developments in technology:

- Applications that enhance operating margins, by lowering labour costs, providing more efficient management of stock levels or reducing energy costs.
- Applications that provide sales lift or sustained sales growth by offering novel functionality, enhanced brand value and/or superior performance.

In the retail environment, operating margins could be enhanced through shelf edge labels that can be updated centrally providing real-time re-pricing, eye-catching promotional posters and banners at points of purchase, and interactive signs and displays on the floor or integrated into shopping trolleys, directing customers around the store.

Packaging that is intelligent and/or interactive will aid in anti-counterfeiting and protection of products, and will help to differentiate brands through eye-catching and attractive animated displays. RFID (radio-frequency identification) will create greater efficiencies n product inventory management and logistics.

In leisure and transport, electronic ticketing and security devices will incorporate displays showing remaining value, and disposable maps to detect and indicate current location. One-time pass code displays on smart cards could be used to authenticate secure transactions.

New functionality will be delivered in the form of electronic books and newspapers that provide digital content updated in real-time. These and many signage applications will make use of low power, sunlight-readable, flexible large area displays that will last for days on a single charge as power is only required to change the image.

Figure 4:
Large area signage;
An Electroluminescent Art Wall at Heathrow Terminal 5.
Manufactured by Elumin8

Wearable electronics will be developed for fashion, sports and medical applications. Displays and sensors can be integrated into clothing with a power supply, and wearable medical sensors could be developed for real-time monitoring by the clinician or patient. ‘Smart’ pill blister packs could monitor dosage behaviour.

Portable power generation and storage will be possible from thin film batteries and solar cells. Lightweight, flexible power sources can be integrated into mobile devices, in or on buildings and in consumer accessories (see Figure 4).

Lighting panels of any size or shape could be manufactured as part of a building’s architecture and infrastructure, or in automotive, aircraft and other transport systems.

Many corporations have set out visions of the future in order to illustrate technology needs for specific markets, including Philips[2], Siemens[3], Nokia[4] and mostly recently, Microsoft's vision for the year 2019[5]. All these visions and concepts encompass elements of plastic electronics that are already available, including: flexible displays on paper and textiles; displays curved around buildings; animated displays on smart cards; point-of-sale and electronics shelf edge labels in the retail environment and distributed intelligence and ubiquitous communication through real-time context-aware large area electronics.

Although market projections of the opportunities enabled by plastic electronics are difficult to make because the opportunities cross diverse and multiple market segments…

Applications covered in these corporate visions include: energy generation and supply; healthcare and wellness; sport and leisure; automotive; home and industrial architecture; and construction. This illustrates that many end-users and product integrators of plastic electronics will not be traditional electronics companies, but rather players and designers looking to add value to their existing product portfolio by pulling the technology through into their specific market application.

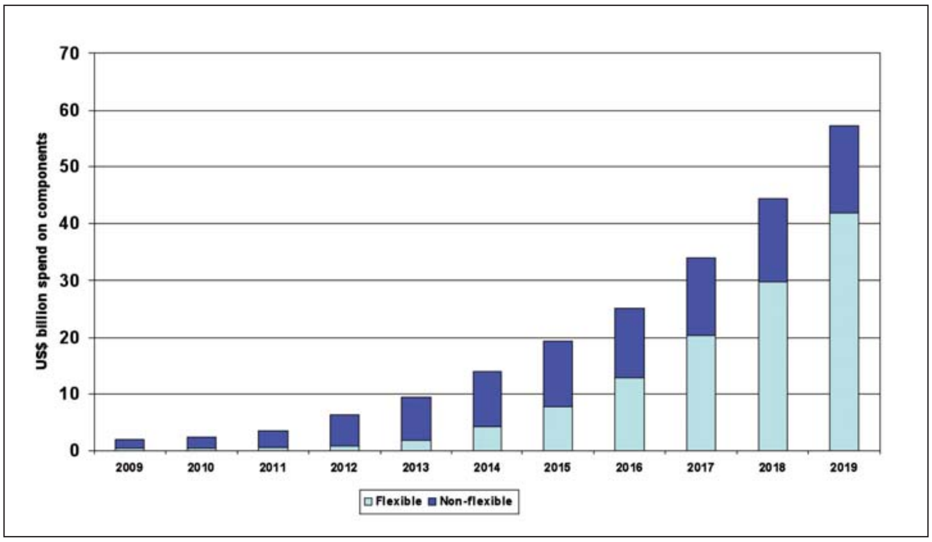
Market forecasts for plastic electronics

As the examples above show, there is huge potential for the use of plastic electronics in a wide range of industries. In their report *Printed Organic & Flexible Electronics Forecasts, Players & Opportunities 2009-2019*, market analysts IDTechEx anticipate considerable substitution of today's incumbent technologies in displays, of incandescent and fluorescent lighting, and the static and printed billboards posters and signage that we see today. In other areas, including sensors, power, logic and memory, they anticipate the creation of new applications rather than substitution of existing products.

Although market projections of the opportunities enabled by plastic electronics are difficult to make because the opportunities cross diverse and multiple market segments, Figure 5 shows predictions made by IDTechEx for the market value of flexible and non-flexible components between 2009 and 2019.

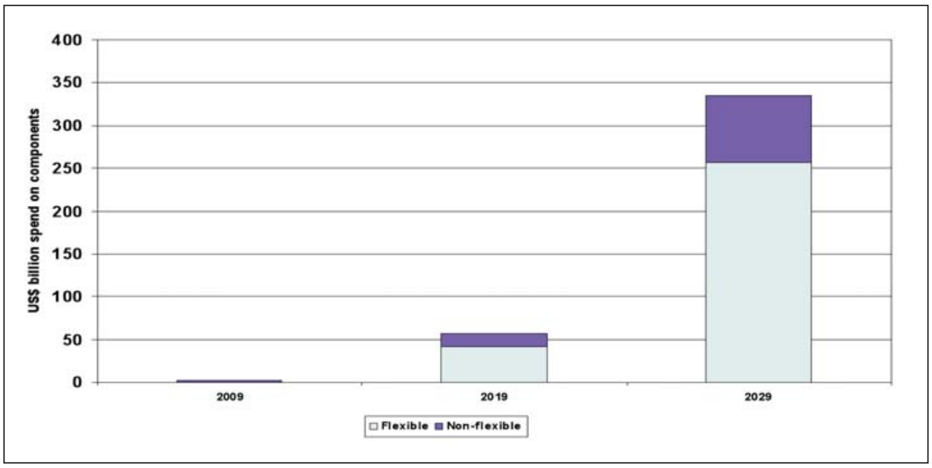
The market value of flexible components is predicted to exceed that of non-flexible components by 2017. The projections for 2029, relative to 2009 and 2019, are shown in Figure 6. By 2029, the total market value for flexible and conformal devices is projected to be $335 billion.

Figure 5: IDTechEx predictions of market value of flexible and non-flexible components 2009 to 2019



Source: Printed Organic and Flexible Electronics Forecasts, Players and Opportunities 2009-2019, IDTechEx, 2009

Figure 6: IDTechEx predictions of market value of flexible and non-flexible components 2009 to 2029



Source: Printed Organic and Flexible Electronics Forecasts, Players and Opportunities 2009-2029, IDTechEx, 2009

Because of its novelty in materials, manufacturing methods, lower cost points and the accessible applications beyond those of conventional silicon chips and glass-based displays, plastic electronics will impinge on almost all businesses from consumer electronics, medical, branding and anti-counterfeiting through to building design and construction.

For those outside the electronics industry, the projections and the hype around plastic electronics can be hard to fathom. In the following sections, three market and application opportunities are explained in more detail, demonstrating that plastic electronics had moved beyond being about inventions and basic research to the point where business customer value can be identified.

Opportunity 1: Electronic books and newspapers – the digital word

Increasingly, the world is based on digital content, with access to digital forms of music and video commonplace in our 'always on' mobile environments. Yet a truly digital world remains out of reach. The missing element is comprehensive digitisation of the written word. But not for long – this will soon be facilitated by plastic electronic technologies within electronic books, newspapers and magazines.

> The functionality of electronic reader devices is influenced by the market drivers of saving paper and distribution costs.

The functionality of electronic reader devices is influenced by the market drivers of saving paper and distribution costs. They must be light-weight, hold hundreds or thousands of books of information, be robust enough to be used as a mobile peripheral without breakage, consume little power, and be instantly updateable with the latest information via wireless links. Conventional glass-based displays are unable to deliver on all counts.

E-books and e-newspapers, however, use electrophoretic displays rather than the more common liquid crystal displays of today. Electrophoretic displays have excellent sunlight readability, and very low power consumption – only drawing power when an image is changed – with a typical battery life of more than 1 month (at 200 page turns per day).

The first e-paper animated magazine cover hit the newsstands in October 2008, when Esquire magazine's 75th anniversary edition was sold complete with an electrophoretic flexible display produced by E Ink. Over one million rigid e-book readers are in the market today[6]. Amazon's stock of wireless Kindle e-reader devices ran out within six hours of its debut[7], selling 500,000 units in 2008, compared to the iPod's units 300,000 in its first year of trading[8]. These figures show the potential consumer interest in electronic books.

Figure 7:
A4-sized Plastic Logic Reader device, and comparison with the Amazon Kindle.

All e-readers and products currently on the market in mid-2009 are produced on a glass substrate and are less than A4 in display size. In early 2010, however, Plastic Logic plans to launch its A4 sized display device, which integrates touch functionality, so that pages can be turned with a finger stroke instead of buttons or a stylus[9]. The device (see Figure 7) incorporates organic backplane transistors on a plastic substrate driving E Ink display media.

Opportunity 2: Medical devices – diagnostics and smart bandages

An increasingly elderly population means there is a greater need for more efficient disease diagnosis and treatment, enabling patients to lead healthier and longer lives in their own homes as part of a modern healthcare system.

The move to 'healthcare at home' also needs medical devices that are low cost, disposable and have built-in intelligence for everyday use by non-clinicians – plastic electronics driven devices.

Flexible electronics technology will lead to medical sensors that can be worn, or wrapped around the skin to monitor vital signs such as temperature, blood pressure, heart rate, electrocardiogram (ECG), respiration, etc.

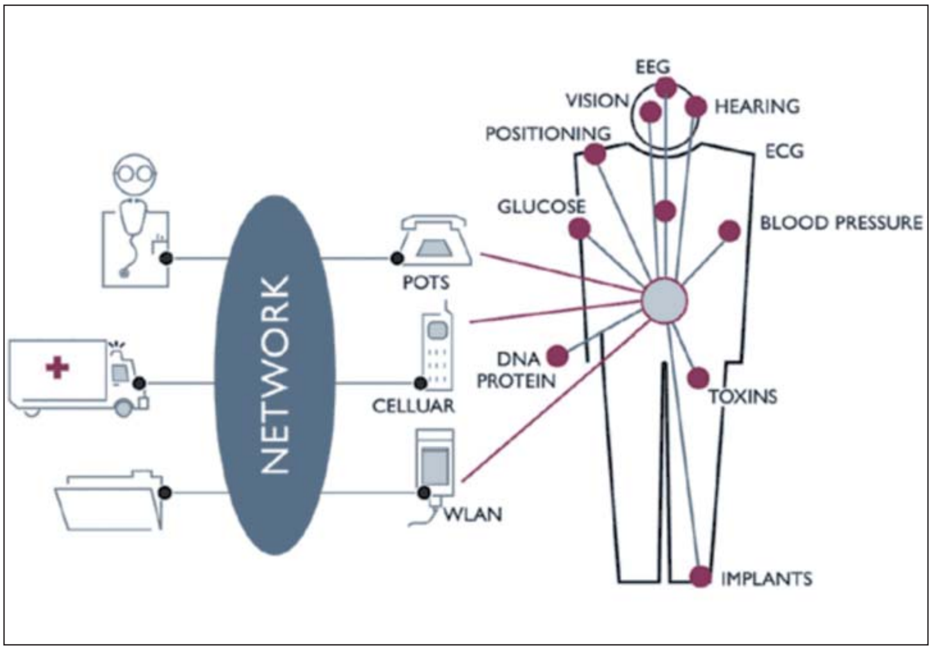


Figure 8: Wireless Body Area Network, providing real-time patent monitoring within the home environment.

Monitoring can be achieved using plastic electronic sensors and device circuitry to detect signal outputs, possibly as part of a 'smart bandage' delivering medication into the body. The development of flexible, light-weight, and non-obtrusive body-centric sensor systems (so-called WBAN – wireless body area networks), with low-cost disposable detector patches on the skin or as part of clothing will make it possible to access the cost points required for disposable medical devices.

Bulky and expensive hospital monitoring systems can be replaced with real-time patient monitoring within their own home environment.

Plastic electronic technologies could also lead to 'smart bandages'. Targeted dispensing of topical treatments will be achievable through the incorporation of light-sensitive drugs with flexible, low-cost, low power, robust and disposable light sources and control electronics, into a conformal wrapping around the patient's skin.

For example, photodynamic therapy (PDT) is an effective treatment, combining light-emitting materials and electronics, for acne, psoriasis and some carcinomas[10]. The photosensitive drugs enable deep dermatological penetration and activation of the agents in red light. Incorporating PDT into wearable applications allows sustained and effective treatment of local and distributed skin conditions by ensuring correct dosages are applied over time, thus reducing the time to heal.

Opportunity 3: Intelligent packaging

Smart packaging of products addresses brand enhancement through engagement at the point-of-sale (Figure 9) and protection across the packaging supply chain. The package can now have an active role in adding functionality to the product, communicating information about the product's consumption, convenience, history and/or security. 'Use by' dates could be automatically adjusted according to time and temperature through the incorporation of chemical sensing, simple electronics circuits and a low cost display. Packaging could also incorporate RFID to track product inventory and facilitate automated point of sale scanning.

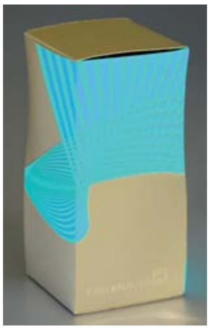


Figure 9: Luminescent packaging can provide a decisive competitive edge at point of sale.

Packaging will be able to sense as well as inform the consumer. Communication via thin film devices could provide sound and visual information in response to touch or some other means of activation.

In a medical application, intelligent packaging has an important role to play in compliance monitoring. Traditional medical diagnosis and out-patient treatments rely on dispersed consultations between clinician and patient, with little contact between sessions. For the clinician, assessment of a patient's condition is limited by the data that can be collected in a consultation of limited duration. For the patient, it can be difficult to take in and remember medication advice given in a short meeting.

According to SIMpill[11], interactive pill bottle manufacturers, recent studies from the UK and US show that only some 50 per cent of people on chronic medication take their medication as prescribed. Around 60 per cent of patients make errors in taking their medication, while some 50 per cent of patients stop taking their medication before being instructed to do so. This level of non-compliance can result in increased hospitalisation, higher medical expenditures (especially where newer and more expensive medication is prescribed) and an overall increase in usage of healthcare services. It also leads to significant waste in health expenditure, unnecessary morbidity and mortality, and in chronic infectious diseases, drug resistance creating future treatment difficulties.[12]

Smart pill blister packs can address this problem by prompting the patient to take medication, and permitting clinician feedback. Electronic sensor circuits are printed onto the packaging to detect when a dose of medicine is removed. Answer keys, an electronic diary of medication, and a beeper or a text message to remind the patient about the medication, are additional services made possible by this intelligent packaging approach.

It is easy to outline some of the market opportunities available for firms that embrace plastic electronics...

It is easy to outline some of the market opportunities available for firms that embrace plastic electronics, but what does it take to develop a device or object that incorporates plastic electronics?

Because electronic products – whether flexible or rigid – are typically made up of a series of layers of different electronic materials, their development involves a combination of competences in different technology areas, including materials, design and processes.

It is important to understand that the development of new technology in electronics involves complex interdependencies between material sets, processes, device design and the resulting functionality of the product. Changing the materials used in a device will affect the functionality of that device, changing its design will affect the process by which it is made and so on, as shown in Figure 10.

As a product is scaled up from single-unit lab-scale work to production in small volumes – 'process scale-up' – the materials, design, functionality and process all need to be developed in step, so that the product can ultimately be manufactured at suitable cost points, yields and quality.

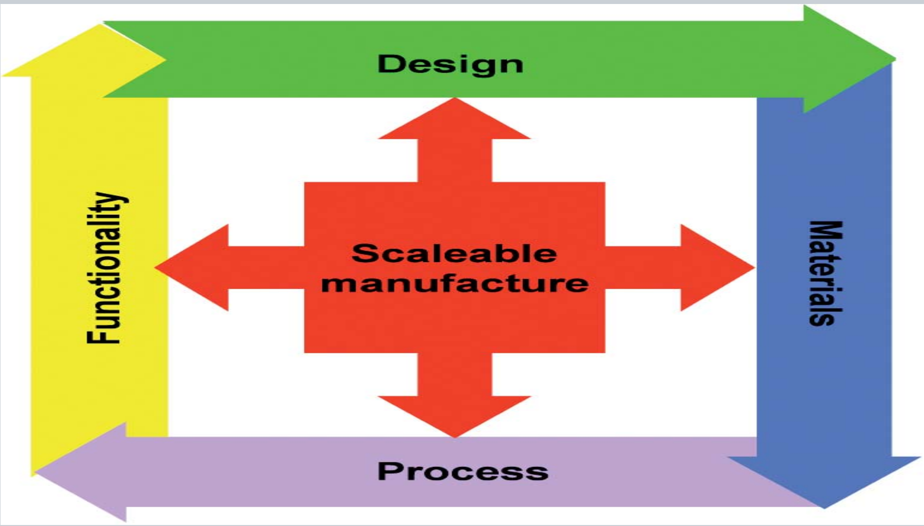


Figure 10:
The interrelation between design, materials, process and functionality for technology development and scalable manufacture
Source: Cathy J Curling

The challenges involved in process scale-up are particularly acute when many aspects of the materials, design, process or functionality are novel, which is still the case in many developments across plastic electronics.

Competences required for the development of plastic electronics

Materials and inks are the functional materials that make up the layers of a device, including the basic surface (known as a substrate) on which the other material layers are deposited.

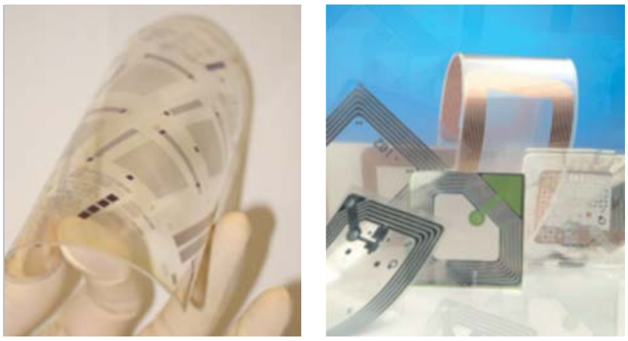


Figure 11:
Engineered plastic substrates (available from DuPont Teijin Films).

Technology and Design covers two elements: (a) the design of the electronics itself: such as the feature and pattern sizes of the various layers on the substrate, and (b) the methods used to deposit and define the layers on the substrate.

Equipment refers to the machines used to take the materials and inks and, following the technology and design specification, make the required electronic layers and patterns on the substrate. These can include ink printers and coaters, machines to handle substrates, kit for cleaning steps and test equipment.

These three competences combined can result in the fabrication of a very basic device in low volumes. Using relatively manual processes to produce very small volumes with uncertain or variable performance characteristics can be referred to as proof of concept stage.

A critical challenge in taking a product beyond proof of concept towards the proof of product stage is to stabilise the performance of the device so that its characteristics are invariant across multiple production runs, and to adjust the technology and design recipe to optimise desired performance and materials costs.

The fourth competence is therefore:

Process scale-up and/or early prototyping. This is the process of optimising the technology and design stage for making more than one test batch. Typically this involves scale-up of processes and equipment, early stage assessment of quality and yield under batch production and making greater use of automation in place of hand crafting.

Process scale-up demonstrates both internally to the company, and externally to investors and customers, that the technology can be ramped up from a few batches per week to tens or hundreds of validated components. >>

>> Output from this stage includes prototypes and engineering samples, so that field trials, focus groups, user trials and tests can be undertaken by the customer. At this stage, engineering samples will typically have no warranty or CE marking. Contractual arrangements under which samples are shared will reflect such uncertainties – including restricted use by in-house engineers and restrictions on deconstruction or reverse engineering of component elements and materials.

Process scale-up often takes place through Joint Development Agreement or early Joint Venture arrangements between an entity that intends to supply the technology, and the intended customer or product integrator.

Alongside these four competences run two other important activities: provision of **Components** and **Services** to support the development process.

Components are finished items sold with data sheets covering their formulation, processing and usage. For example one layer of a device might be supplied as a finished component.

The provision of **Services** addresses specific needs for designs, materials, equipment etc. This can range from the provision of a relatively standardised measurement or testing service to a consultative-style partnering relationship to develop bespoke solutions.

Figure 12 shows the route to market for a single product in plastic electronics. From inception to market, a number of steps through this process flow chain are required. Development and formulation of materials and inks is the primary concern in the initial stages, with iterations around technology and design as shown in the top part of Figure 12. At this stage, the interaction between a given materials component and other elements of the device is important (for example, ensuring that the layers of a device can be added without affecting the functionality of the underlying layers).

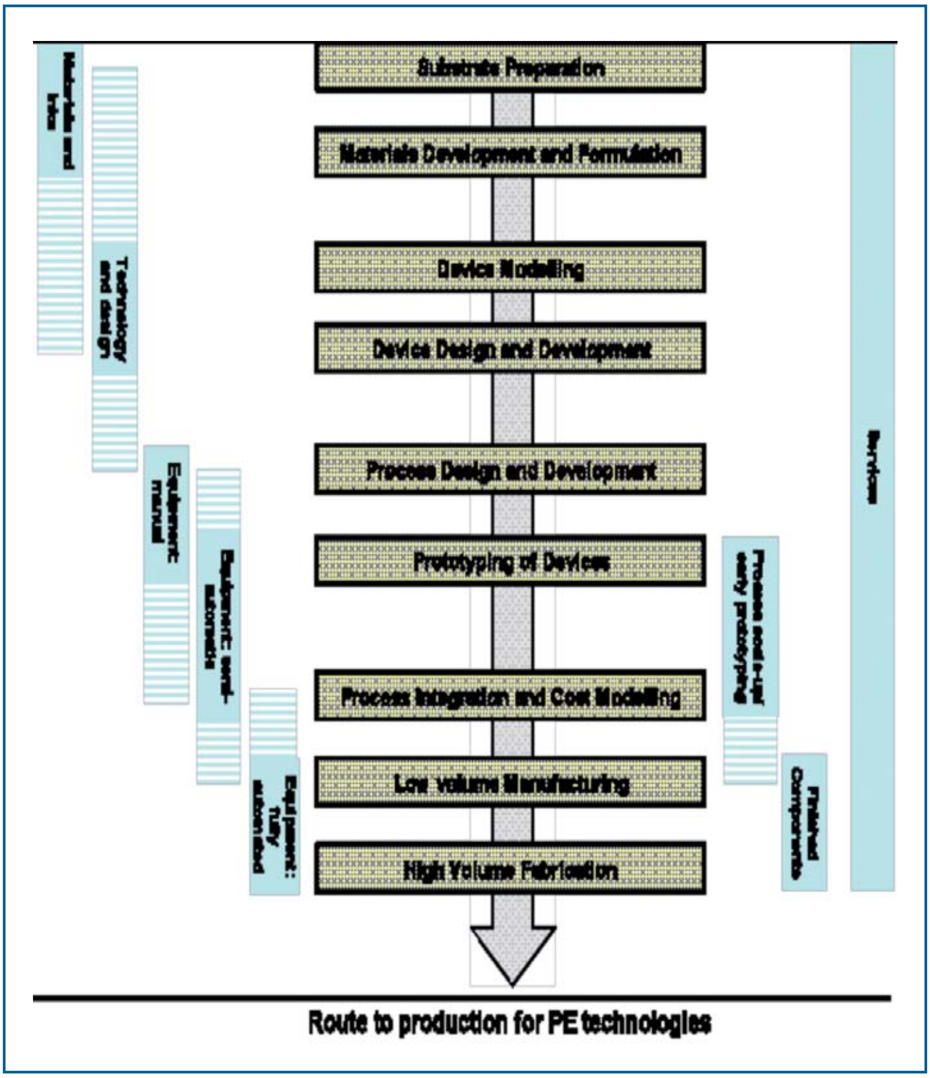


Figure 12:
Process flow chain for the development of new plastic electronics technologies

Equipment is relevant at all the stages shown in Figure 12, but development of equipment features more prominently as the device reaches the prototyping stage, with kit evolving from a manually-operated, hand-crafted operation carried out with considerable human intervention, to greater automation as the volume of items and batch sizes produced increases.

Process scale-up is undertaken when the basic parameters and processes for the device are in place, and requires attention to the relationship between costs and scale of production. Often at the process scale-up stage, issues relating to materials or design are identified, requiring further iterations through previous steps.

In the final stages, the process culminates in a finished component or product that can be manufactured in high volumes for sale to a product integrator or customer.

Value chains in plastic electronics: making technology solutions into market opportunities

The route to production is rarely undertaken by a single company. More typically there is a chain of innovation beginning with basic science in universities, and ending with companies of sufficient scale to manufacture at high volumes. Equipment manufacturers and service providers participate in the whole chain.

Each player – whether a university research group, a small venture-funded start-up or an established corporate player – has the opportunity to convert their technology solutions into market opportunities. Whether they are able to do this depends on finding a position in the value chain that enables them both to generate value for potential customers, and to capture some of this value for themselves. There are various models for capturing value: licensing or spinning out their intellectual property; supplying materials, technology or equipment; providing services or finished components to other players. The model adopted depends on the maturity of the technology, and the extent to which customer value can be demonstrated through the provision of field samples or demonstrators, and validation.

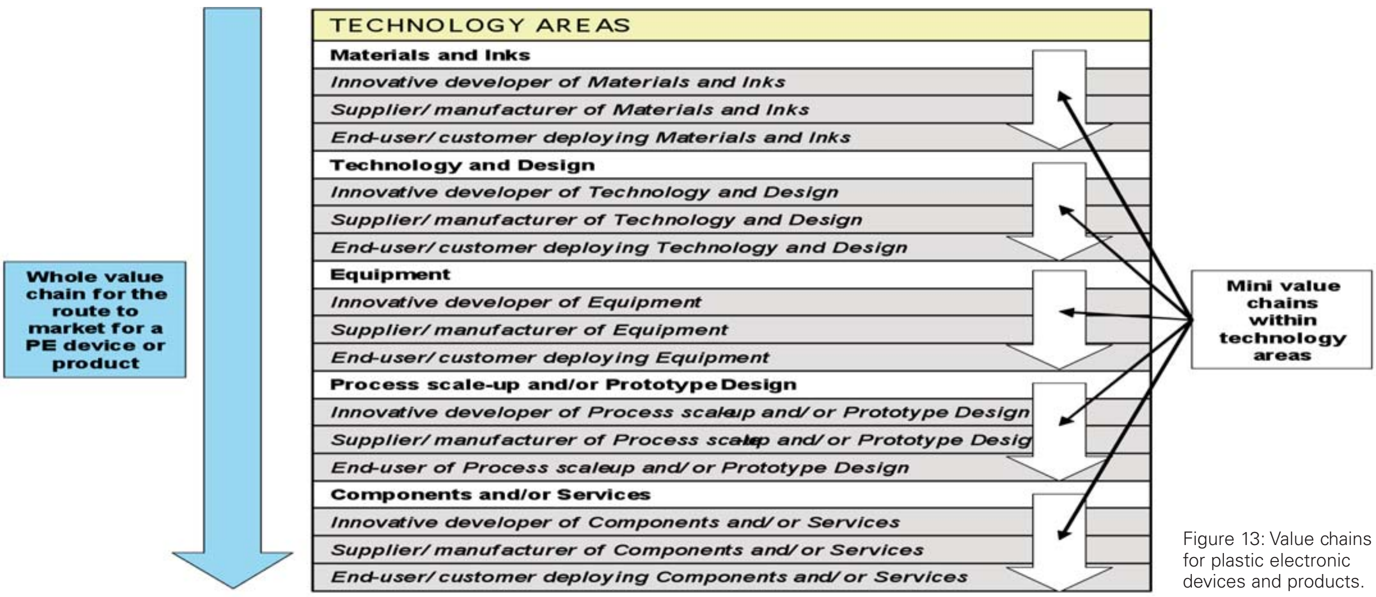


Figure 13: Value chains for plastic electronic devices and products.

AIM research has developed a methodology for mapping the position of companies and universities in the plastic electronics value chain using the framework shown above in Figure 13.

The arrow on the left hand side shows the whole value chain taking a plastic electronics innovation from its basic ingredients and recipe to point where it is ready to be sold as a finished component. Within each technology area there is a mini value chain shown on the right hand side, running from innovation through production to commercialisation.

In any given technology area, there are companies and universities who are:

- **Innovative developers:** early stage technology innovators, typically owning the base intellectual property surrounding a new technology. Entities in these categories are universities or research institutes, or companies with an intellectual property portfolio in the technology area.
- **Suppliers or manufacturers:** entities (usually companies) that make items – bottles of material/ink, technology equipment, consumables – and finished components. As the plastic electronics industry is in its infancy, being a supplier or manufacturer does not necessarily imply high volume to supply global markets. For the moment, being a supplier or manufacturer in plastic electronics is more likely to involve low volume, bespoke product manufacture.
- **Customers or end-users:** companies that sell complete products and systems (not components) in large volumes as a revenue-generating business. In plastic electronics, an end-user is the company that buys a finished component (such as a flexible display or a printed RFID tag) and assembles it with other components into a finished product ready for retail sale.

For the moment, being a supplier or manufacturer in plastic electronics is more likely to involve low volume, bespoke product manufacture.

A company or university research group can be a customer for one aspect of an emerging technology (e.g. materials), and a developer of another (e.g. process scale-up).

Collaboration in plastic electronics

Plastic electronics involves the convergence of industries and scientific disciplines. The new applications projected for printed electronics require collaborative projects across different types of boundary:

- **Collaboration across scientific disciplines:** organic and solution-based chemistries are at the heart of plastic electronics. Moving beyond materials to processes and devices, the problems and challenges span the disciplines of chemistry, physics, electronics, systems and process engineering. As biomedical applications are developed, collaboration with biochemists and clinicians is also necessary.
- **Collaboration across technology areas:** partners with complementary core competences will need to work together. For example, creating inks that can conduct electricity requires chemicals companies to partner with firms that have expertise in materials engineering, in order to ensure that the functionality of the materials is maintained when deposited in the thin layers necessary for electronic components. Likewise, developing printing equipment that can be used to deposit conductive inks in precise quantities requires collaboration between materials developers and equipment manufacturers.
- **Collaboration along the value chain:** as noted above, the innovation value chain begins with basic research, typically in universities, and with the development of materials, and extends through the development of components to the final assembly of devices and their integration within applications. Engagement with early end-user adopters through field trials and user-groups is important for successful market entry.

- **Collaboration across university-industry boundaries.** Much of the expertise in basic research is within universities, and some companies and spin-outs rely on business models that involve exploitation of university expertise and intellectual property.

One of the greatest difficulties in collaboration is finding the right partner to start with.

There are nonetheless many familiar risks and uncertainties associated with establishing collaboration including:

- Identifying where complementary expertise lies, and how best to exploit it.
- Trading off the ease of working with past collaborators and familiar people with the potentially greater returns – but also greater search costs and risks – of finding new partners.
- Balancing the benefits of working with a single supplier or customer to develop a bespoke solution against the constraints of exclusivity deals and the opportunities costs associated with not pursuing a generic offering.
- Protecting intellectual property rights, including prior art and new inventions generated from a partnership, without constraining partners' ability to collaborate effectively.
- Finding the right mode of funding the relationship, weighing up the value of providing one's own funding – and therefore having a greater degree of control over the relationship – against the lower costs of open innovation models and government subsidised relationships, but with weaker control over objectives.

One of the greatest difficulties in collaboration is finding the right partner to start with. To help companies locate themselves, and their potential partners in the innovation value chain, our research has categorised each company and university department active in plastic electronics in terms of technology areas shown in Figure 13.

We have also captured information on the applications each aims to address (if any), the extent to which it is engaged in component manufacture and supply, and its business model and financing. (Further details can be found on the website devoted to this project www.printedelectronics.net).

An extract from the resulting competence matrix, which includes data on over 50 UK companies and 30 university departments, is shown in Figure 14. A similar exercise has been undertaken for companies and universities, including the Fraunhofer institutes, in Germany.

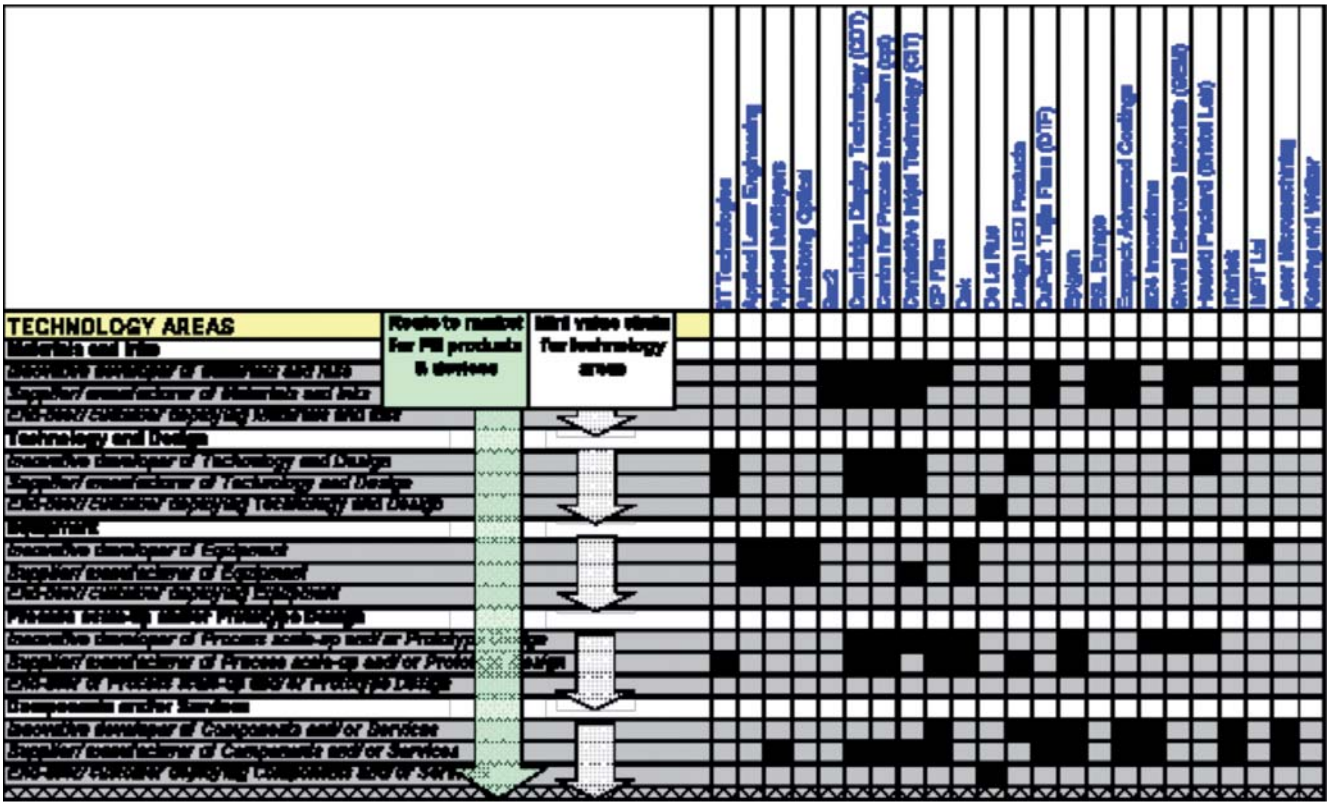


Figure 14: An excerpt from the Competence Matrix for Plastic Electronics in the UK (sub-set of companies only).

Source: Competence Matrix for Plastic Electronics in the UK, © University of Reading.

Full set of companies and university departments is available here: www.printedelectronics.net/blog.htm

Value chains in plastic electronics: where are the end-users?

It is clear from our analysis of plastic electronics players in the UK and Germany that companies and universities are starting to generate value by selling their solutions to other developers of technology. As yet, however, there are very few end-users who are buying finished components for incorporation into their products, or buying equipment and materials that would enable them to embed flexible electronic functionality into their own products.

There is an emerging consensus amongst industry observers that plastic electronics has reached a stage where the influence of end-users is needed. The technology needs to be accelerated forward through the market pull of a wider range of product releases.

Manufacturers and service providers in the consumer electronics, retail, FMCG, healthcare, energy, printing and packaging industries need to set specifications for performance, functionality and price points that will enable them to generate value for their customers. Discussing such specifications with industry insiders will help end-users clarify how mature the technology is for the market and application they have in mind.

Technology developers can use the specifications to identify what processes and materials would be required and whether existing equipment could be made usable for that purpose. For example, some low precision large area applications may already be feasible using graphics art equipment used in roll-to-roll printing of newspapers. Others may need a change of process and the development of new equipment. Led by these specifications of user needs, materials developers and printing equipment manufacturers can start to identify how they can capture value from new market opportunities.

End-user companies have a critical role to play in the development of plastic electronics markets and applications in the next decade, as consumer demand for novel functionality and performance escalates. Nonetheless, companies wishing to position themselves for the opportunity presented by plastic electronics face a number of challenges:

- Where to find, in a global innovation system, the technology developers who will be best equipped to advise and work with them.
- How to learn about and choose partners from the spectrum of companies and universities active in plastic electronics.

In the following sections of the report we consider first, why the UK is a good place to be involved in plastic electronics, and provide advice about how to find partners.

…In shaping the development of plastic electronics?

The UK is one of the countries leading the development of plastic electronics.

Some of the earliest breakthroughs in semi conducting materials occurred in the UK. Light-emitting polymers were discovered at the University of Cambridge in 1989. Two spin-outs from this work have grown into established plastic electronics companies: Plastic Logic's thin light-weight and flexible e-reader is due to be launched in 2010, and Cambridge Display Technology is a global leader in polymer light-emitting diodes.

Comparing the UK with other countries involved with plastic electronics, it is clear that the UK currently has a leading position.

With numerous materials and equipment companies such as Merck Chemicals Ltd, DuPont Teijin Films UK Ltd, Xennia/CIT Ltd and Xaar plc the UK is a global contender in plastic electronics. Including these and many new company entities that are now established in the market place, or are soon to enter, UK companies cover the full value chain for plastic electronics.

Research in UK universities also lies at the forefront of developments in plastic electronics. Three university-based centres of excellence offer open access facilities for accelerating product development in plastic electronics.

The Cambridge Integrated Knowledge Centre (CIKC) brings together the main research activities in the University of Cambridge in molecular and macromolecular materials, in a centre of excellence covering low temperature processing and fabrication of products using new materials.

The Organic Materials Innovation Centre (OMIC) at Manchester connects businesses in the UK with expertise in organic materials from several universities in the northwest.

In Cardiff, the Welsh Printing and Coating Centre's (WCPC) facilities allow for trialling of a number of printing and coating processes through open innovation collaboration.

Imperial College, London has also launched a Plastic Electronics Doctoral Training Centre, to offer inter-disciplinary training to doctoral students which builds on its strength in physics, chemistry, materials science and device engineering. [For more information about university departments and companies that are active in plastic electronics in the UK, see the Competence Matrix for Plastic Electronics in the UK, available on the project website at www.printedelectronics.net.]

Comparing the UK with other countries involved with plastic electronics, it is clear that the UK currently has a leading position. Figure 15 shows the number of global organisations, including companies, universities and research institutes, active in plastic electronics. The UK has the largest number after the US and Germany.

Recognising this, the UK government has identified printed and plastic electronics as a priority area for technology development[14], and has established a Printable Electronics Technology Centre (PETEC) in Sedgefield in northeast England, intended to help industrial and academic clients bring products to market. PETEC is another open innovation prototyping facility, housing a variety of equipment for device fabrication.

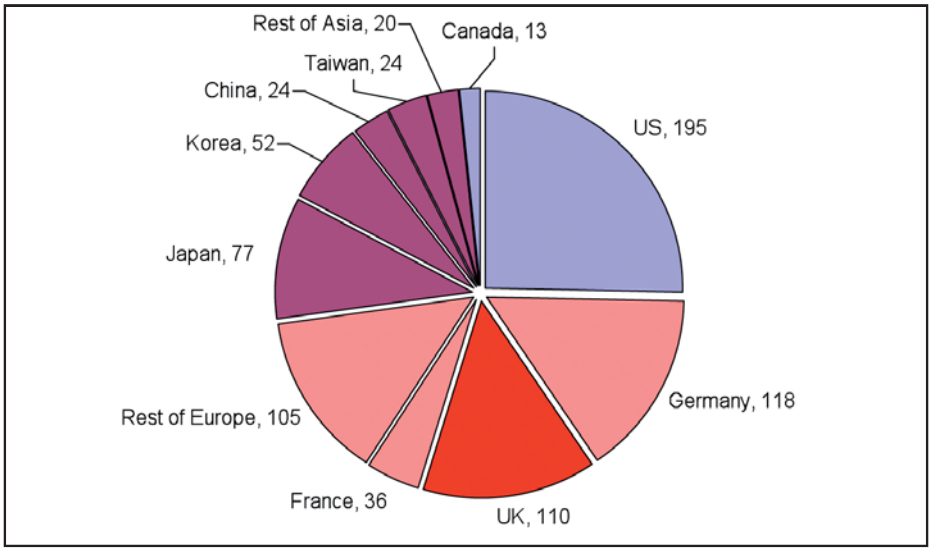
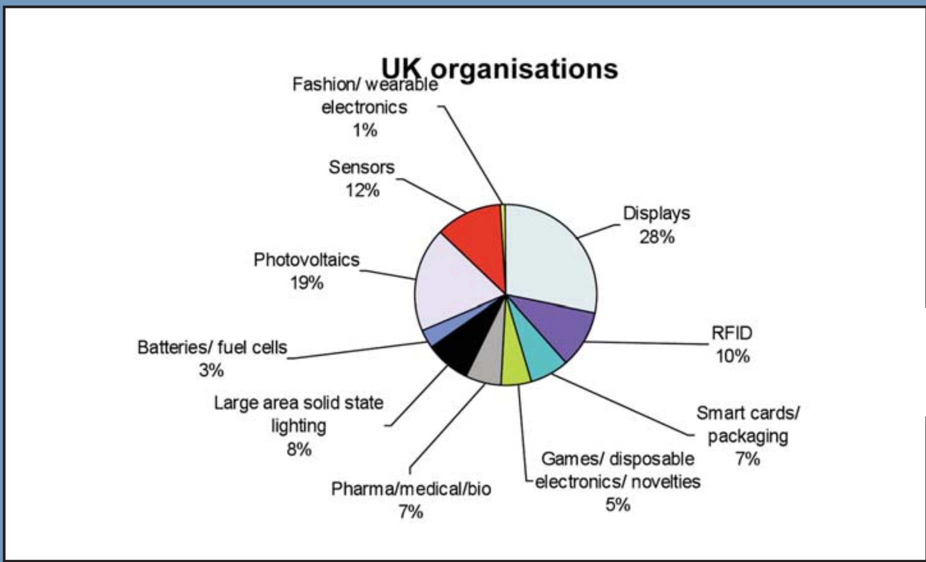


Figure 15:
Global Plastic Electronics Organisations by Country.
Source: Technology Strategy Board using data from IDTechEx and University of Reading, chart prepared June 2009.

We have conducted a detailed analysis of the differences between plastic electronics capability in the UK and Germany, examining the scale at which research and development are being conducted, the application areas targeted and the business models and financing structures used to secure a position in the value chain.
Our research shows that:

- In general, the core competences of UK organisations lie in high resolution, thin layers, novel materials and inks, while German entities focus on lower resolution and functionality.
- By targeting lower functionality markets such as RFID antennas, packaging, games and disposable electronics, German innovations are likely to enter the market more quickly, but UK innovations have greater potential to generate longer-term novel technologies and to deliver higher-end applications, such as high information content displays and photovoltaics (solar cells). This difference in focus is illustrated in Figure 16.
- UK organisations (both companies and universities) make greater use of licensing of early-stage intellectual property, while German organisations tend to focus on direct manufacture and supply of finished components.
- UK universities are more involved with joint development agreements and joint ventures with licensing partners to achieve the validation of their intellectual property at the proof-of-product stage. In contrast, the German Fraunhofer institutes are less reliant on joint ventures with licensing partners because they have high levels of funding for equipment, which means they can progress their intellectual property through in-house scale-up and validation.



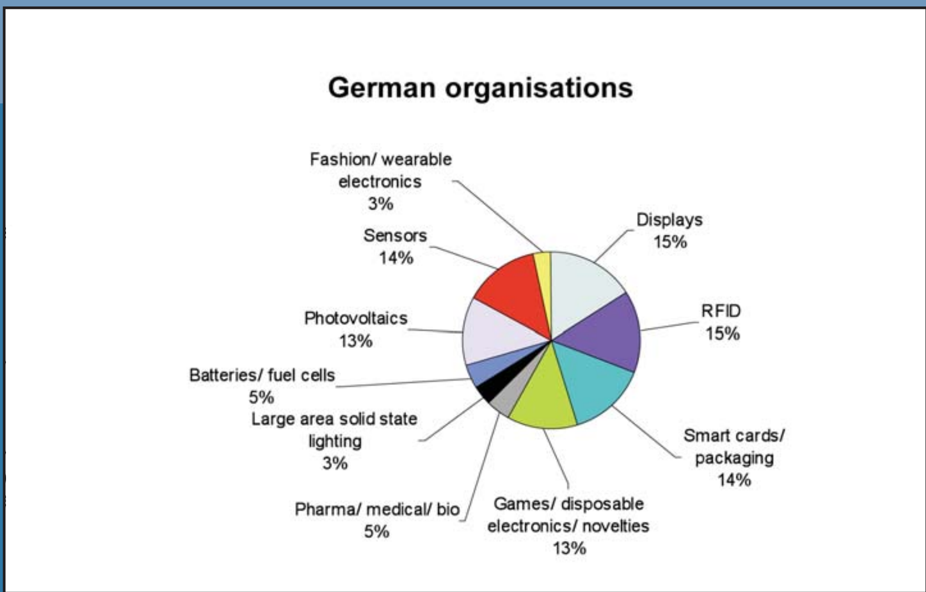


Figure 16: Comparison of application areas targeted by UK and German organisations active in plastic electronics.

Source: Competence Matrices for Plastic Electronics in the UK and Germany; see www.printedelectronics.net

In summary, findings from our research suggest that the UK is well positioned to become a global leader in the innovative development of high functionality products that incorporate plastic electronics. As the UK extends its leadership, it will become a fertile place for end-user companies to become involved in plastic electronics.

How to know and be known in the UK plastic electronics community

Companies and individuals interested in joining with and shaping a new area of technology face a number of challenges. First they need to understand the landscape, becoming aware of whom the key players in research and commercialisation are, and being able to evaluate which of these key players offers technical knowledge and capability that meets their needs. Second, they need to establish themselves as features in that landscape, establishing their own credibility as a potential end-user of plastic electronics and as a potential research partner or customer.

We summarise these challenges in Figure 17.

For the first challenge – knowing the landscape – the Competence Matrices examining key players in the UK and Germany described earlier in this report (see excerpt in Figure 14) provide a useful starting point. Beyond that, people often say that to become known in a technology community it is useful and important to be involved in various 'networking' activities.

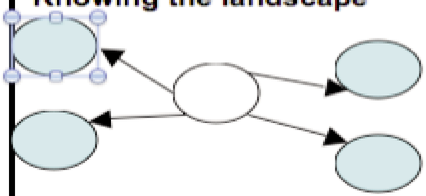
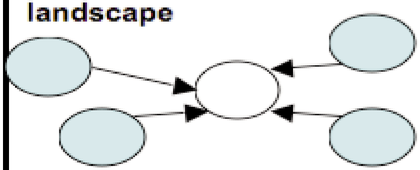
	Knowledge	Awareness	Value
Knowing the landscape 	Getting to know other members of the plastic electronics community	Becoming aware of the expertise of other members	Working out who is valuable to collaborate with
Becoming a feature in the landscape 	Being known by other members of the plastic electronics community	Other members being aware of one's expertise	Being perceived to be valuable as a collaborator

Figure 17: Networking challenges facing companies and individuals interested in joining with and shaping the emerging plastic electronics industry.

For example, Knowledge Transfer Networks (KTNs), funded by the UK Government are responsible for organising communications and events that allow people to exchange ideas and information, and meet potential suppliers, customers and collaborators. Attending such events is often thought to be a good way to meet influential people and speaking at meetings to be a way to increase an individual's profile in an industry.

But how effective are these activities and what value is there in them for organisations? AIM research looked at some of these issues with respect to the KTN that is specifically set up to meet the needs of the plastic electronics, displays and lighting communities. This KTN, which was known as UKDL until September 2009, had at the time of data collection a membership of 800 members from 500 plus organisations, including universities, small and large companies developing technology and end-users of displays and lighting.

The enhancement of reputation that comes from speaking spreads through the network without needing direct interaction with others…

We found that networking strategies had very different effects when we compared people in companies and universities that had already been involved in collaborative Research and Development (R&D) in plastic electronics, with those who had not – such as the end-user companies we focus on in this report. The findings for this second group are summarised in Figure 18.

The research shows that while interaction is necessary for potential collaborators to become aware of each others' expertise, that expertise is strongly personalised – to really understand what someone knows, it is necessary to hear that person speaking.

So those people who speak, or who are contemplating speaking, at a KTN event – or a similar networking and knowledge sharing event – should understand that presenting at events such as these only increases awareness of a person's expertise for those people who hear them speak.

The same is not true for reputation, however. The enhancement of reputation that comes from speaking spreads through the network without needing direct interaction with others, although this finding only held for members whose organisations were already involved in collaborative R&D. These members were more likely to be valued as collaboration partners, including by those who had not heard them speak.

It was also clear that actions by, and interactions between, individuals are more important for establishing attractiveness as a collaboration partner, than the prior involvement of an organisation in government-funded collaborative R&D alliances, or even an organisation's central position in a network of such alliances. For companies interested in connecting with the plastic electronics community, going to KTN events and taking opportunities to interact with other members may be a relatively efficient way to learn about potential collaborators.

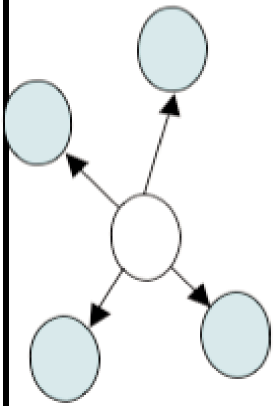
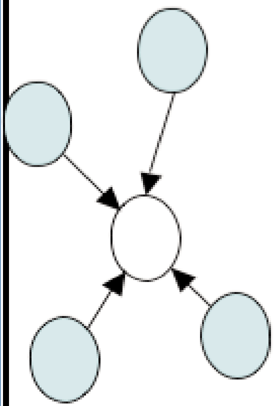
	Networking challenge	**Research evidence indicating how networking strategies can address these challenges**
Knowing the landscape 	Getting to know other members of the plastic electronics community	Attending events that require active participation by delegates (e.g. workshops, partnering sessions) increases the likelihood of knowing other members. People are much more likely to know others if they have attended events together in the past.
	Becoming aware of the expertise of other members	To really understand what someone knows, it helps to have attended the same event. Hearing a person speaking at an event makes it much more likely that you will really understand what they know.
	Working out who is valuable to collaborate with	People on the committees advising the KTN are much more likely to find other members of the network valuable to collaborate with. These individuals may be useful sources of information about who would be a potential collaborator.
Becoming a feature in the landscape 	Being known by other members of the plastic electronics community	Speaking at events increases the likelihood of being known by other members of the network, including members who did not attend the events you spoke at
	Other members being aware of one's expertise	Speaking at events makes it very much more likely that others who heard you speak at the time will be aware of your expertise later on. However, awareness of your expertise does not appear to spread beyond those delegates who heard you speak.
	Being perceived to be valuable as a collaborator	Attending and speaking at events does not significantly increase one's perceived value as a collaborator. R&D Managers, Principal Investigators and Scientists/Engineers were much more likely to be perceived to be valuable as collaborators than people in business development roles.

Figure 18: How networking strategies can help companies and individuals integrate with the emerging plastic electronics industry: evidence from AIM research.

For those interested in knowing more about plastic electronics, it is worth contacting the relevant Knowledge Transfer Network. From September 2009, this is the Photonics and Plastic Electronics KTN [see box], with a further merger of electronics KTNs taking place in 2010.

Photonics and Plastic Electronics KTN

The mission of the Photonics and Plastic Electronics (PPE) KTN is to support the photonics and plastic electronics communities in order that they become a beacon of successful UK wealth creation through knowledge, enhanced skills and collaborative partnerships.

The PPE KTN is a forum where individuals can meet people researching and developing photonics and plastic electronics technologies; those who are manufacturing and using them; and others who support the community by providing funding, professional services and market intelligence. Members come from universities, spin-outs, small companies and large corporate players.

PPE KTN offers the following services:

Meetings and events

- **Seminars** – presentations from invited speakers with networking opportunities
- **Workshops** – a focussed agenda where delegates are expected to contribute
- **Tutorials** – targeted at 'one-to-few' business engagement, company specific, on-site with tour of facilities.
- **Training Courses** – delivered on specific topics usually in collaboration with external organisations.
- **Brokerage events** – intended to help members form consortia for funding bids
- **Consultations** – workshops intended to inform the development of strategic plans and roadmaps
- **Policy inputs** – workshops intended to shape future policy and interventions

Other services

- **Webinars** – interactive live presentations with question and answer sessions and podcasts accessed via playback from the website.
- **Collaboration Spaces** – online forums and web space for document sharing.
- **Reports** – white papers, case studies, 'How to' guides, surveys.
- **Signposting to funding opportunities** – e.g. Knowledge Transfer Partnerships, CASE awards, SBRI, CR&D, FP7, Research Councils, RDAs.
- **Overseas Missions** – Investment, science and technology, trade missions.
- **Special Interest Groups (SIGs) and Focus Interest Groups (FIGs)** – working groups set up to service a particular sector or to solve a particular issue
- **Signposting and Brokering** – informing members where they can access services, technology, collaborations etc.
- **Competency Mapping** – detailed studies of the UK's capability including both companies and academic institutions.

Both UK-based and international members are welcome.
Membership is free, and members receive a discount on any of the events.
Further information is available at **www.ppektn.org**

conclusion: seizing the opportunity

For decades now the movie world has depicted science-fiction technologies and products that deploy flexible electronics across large areas. Recent examples include the large area, flexible updateable and animated version of the newspaper *USA Today* imagined in Spielberg's 2002 film *Minority Report*, and the *Daily Prophet* newspaper in the Harry Potter series of films.

There is no doubt that effective risk management is an essential organisational skill.

In this report, we have shown that plastic electronics has evolved from science-fiction to science fact, and is now ready for a wide range of end-user products and markets. Enabled plastic electronics applications are no longer visions of the future, but are the realities of today, with the potential to be the huge growth opportunities of tomorrow.

In the UK, collaboration between technology developers has accelerated the progress of many innovative ideas from the laboratory and into the factory for fabrication on an industrial scale. Some of the key components required for a wide range of plastic electronics applications, including flexible substrates, barrier layers and thin-film batteries, have achieved the vital final engineering hurdle of demonstrating scalable manufacture with process, yield and quality control, and are commercially available today.

Plastic electronics still needs a vision, however. Its next step requires leadership in the UK by companies and individuals who can envisage how these new technological possibilities can create value for their customers and for the end consumer. Only then will a plastic electronics-enabled world reach the fingertips of the average citizen.

Beyond that, the low cost, energy efficiency and organic composition of some plastic electronic devices may have the potential to address some of humanity's pressing concerns, including sustainable energy, scarcity of raw materials, pollution and energy security. Now is the time for users and technology developers to cross boundaries and work together to identify real money-making opportunities in plastic electronics.

Acknowledgements

Financial support from the Economic and Social Research Council (RES-331-27-0008) is gratefully acknowledged. The UKDL Knowledge Transfer Network and the Technology Strategy Board provided data to support the research project, and UDKL provided access to their membership. IDTechEx granted access to their 2009 report *Printed, Organic and Flexible Electronics Forecasts, Players & Opportunities 2009-2029*.

Cathy J Curling, working as a consultant under contract to the University of Reading, gathered the data for the Competences Matrices for Plastic Electronics in the UK and Germany (described in section 4). She also collaborated on the comparative analysis of the UK and Germany and contributed material and ideas for other sections of the report, especially section 2.

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Footnotes

1 IDTechEx (2009) Printed, Organic and Flexible Electronics Forecasts, Players & Opportunities 2009-2029 p. 7
2 http://sigchi.org/chi97/proceedings/briefing/rl.htm
3 http://w1.siemens.com/innovation/en/about_fande/corp_technology/research_technologies/technology_divisions/strategicmarketing.htm and https://w1.siemens.com/innovation/en/publikationen/publications_pof/index.htm
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6 www.eink.com/press/releases/pr115.html
7 www.displaysearch.com/files/Sample_Article_DS_200810_Emitter_eBook_ePaper_090618.pdf
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