BIS | Department for Business Innovation & Skills

PLASTIC ELECTRONICS: A UK STRATEGY FOR SUCCESS

Realising the UK Potential

Foreword
by the Secretary of State for Business, Innovation & Skills

There's a view that's far too common in this country that Britain doesn't make anything anymore. The reality looks very different. British manufacturing employs more people than the financial services sector. Britain is the sixth largest manufacturer in the world, and manufacturing is one of our biggest exports. What is true is that manufacturing no longer looks the way it used to. It is a high technology, knowledge intensive industry based on sophisticated skills and competing at the cutting edge of technology.

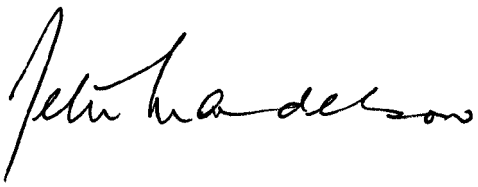
Our advanced manufacturing capabilities do not appear from thin air; they have to be nurtured and invested in, especially in technologies so new that their value has yet to be fully recognised by the market. Plastic Electronics, which allows electronic circuits to be printed onto a wide range of surfaces at relatively low cost rather than assembled, is one area with a huge range of applications. It is a sector in which Britain has huge potential for leadership, and with it employment and economic growth.

The UK is already a world-leader in this new technology, based on the strength of our science and skills base and the support made available by a variety of national and European initiatives. The government-funded Printable Electronics Centre in Sedgefield, will create up to 1,500 new jobs in the next five years. The potential is there and the opportunities are immense.

Now we need to build on that potential. The five Centres of Excellence are a part of that, as is investment in the specialist training and skills this sector requires. The new Innovation Investment Fund which will aim to generate £1 billion of venture capital funding will provide a vital new source of potential investment and UK Trade & Investment is developing strategies for promoting export and investment opportunities.

If we're serious about building a balanced future British economy based on sustainable growth, Britain has to concentrate on the fundamentals of industrial competitiveness. We have to invest in our industrial innovators. We need a government that understands the role smart government can play in helping pioneers unlock industrial potential.

Nobody understands how to do this better than the men and women who are leading it, so I was particularly pleased that Keith Rollins and his colleagues took up the challenge to help us develop this sectoral strategy. Our joint task now is to transform Plastic Electronics from a new technology into a ubiquitous one, and to ensure that Britain leads the world in getting there.



Peter Mandelson
Secretary of State for Business, Innovation & Skills

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Introduction

by Keith Rollins Chairman of the Plastic Electronics Strategy Group

For those of us who work in Plastic Electronics, it is pleasing that the UK's potential in the field has been subject to so much attention by Government and others. In particular it has become one of the priority areas of the New Industry, New Jobs strategy.

The Department for Business, Innovation and Skills engaged with us, a strategy group was formed, and we held formal meetings and consulted extensively with the broader Plastic Electronics community at workshops in London, Manchester and Cardiff. And it is this industry-led group that is pleased to put this document forward as a practical and pragmatic outline of the issues we face, and how they can be addressed.

In doing this we would wish to recognise two important constraints.

The first is that this is a new technology that doesn't just extend practice in one area, but demands a multi-disciplinary approach needing skills from areas that have hitherto not worked closely together. Physicists and printers, for example, have not had too much in common, until now. Because of this Plastic Electronics is a particularly dynamic sector, concentrating on the science just now but soon to become more pre-occupied with the process.
A five-year plan is not a practical reality, hence our call for a constant roadmapping activity to check where we are and where we're heading.

The second constraint is the familiar one. We are not alone in identifying the potential of Plastic Electronics, the world has noticed too. We have strengths in the UK that put us in a good position. And – unlike silicon electronics – the printed form does not demand huge capital outlays, so home manufacture is a very credible proposition. But we cannot go it alone. We need to look to the global supply chain, and attract inward investment to cross-fertilise ideas and experience with our own manufacturing and science bases.

It is an exciting prospect, an excitement I hope you will share. I hope too that you will find this an interesting document, and a valuable one. The credit goes to all who contributed, and to the Strategy Group members listed overleaf.

Keith Rollins
Chairman, Plastic Electronics Strategy Group

Strategy Group Membership

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Executive Summary

Plastic Electronics **allows circuits to be produced at relatively low cost by printing electronic materials onto any surface, whether rigid or flexible. It is very different from the assembly of conventional silicon-based electronics. It will lead to the creation of a whole new range of products such as conformable and rollable electronic displays, ultra-efficient lighting and low-cost, long-life solar cells. Its market value is forecast to rise from $2 billion today to $120 billion in 2020.**

Currently the UK is among the world's leading players in Plastic Electronics, and the opportunities to be a major part of a whole new manufacturing sector are both real and realisable. The UK has strengths in terms of research, development and commercial activity, and is well-placed to profit economically, in intellectual property obtained and in terms of manufacturing employment. Our vision is for the UK to build on its position as one of the leaders in this sector, with a vibrant mix of SMEs, larger indigenous companies and global electronics systems businesses.

The UK's confidence in this area is based on:

- The strength of the science base
- The strength and commitment of UK business
- A supportive investment environment
- The skills of the UK workforce
- A powerful network of publicly-funded Centres of Excellence and Knowledge Transfer Networks
- The commitment from national and EU funding agencies
- The strong support of the Regional Development Agencies and Devolved Administrations
- A proven ability to attract inward investment
- A strong global network to support commercial exploitation.

But the technology is challenging. It is multi-disciplinary, calling on skills from advanced materials to printing and systems integration, and so necessitating interaction between individuals and organisations that have hitherto not worked closely together.

This report by an industry-led strategy group identifies the key issues that must be addressed for the UK to continue to be a globally-leading supplier of Plastic Electronics, and it recommends solutions. In addition to maintaining and building on existing strengths, the following measures are proposed:

- To identify opportunity-rich areas for UK manufacturing in domestic and export markets, and potential areas of collaboration within global value chains
- Actions to encourage, co-ordinate and facilitate investment, including inward investment, and to support business growth
- Support for the relevant Centres of Excellence to develop demonstrators, and other mechanisms that showcase the benefits of embedding Plastic Electronics in new and existing products
- The identification and development of training strategies to ensure that the anticipated workforce has the multi-disciplinary skills needed
- The establishment of a Plastic Electronics Leadership Group (PELG) to champion the needs and raise the profile of the sector, and to drive the need for co-ordination and ambition among the UK's key stakeholders.

Plastic Electronics in Practice

Plastic Electronics (sometimes called printed electronics or organic electronics) describes electronics mainly based on semiconducting organic materials as opposed to silicon and other inorganic semiconductors. These organic electronic materials are often polymers which can be dissolved and printed using the basic processes of the printing industry. This gives rise to the prospect of manufacturing electronic circuits using low-cost printing processes on any substrate surface, whether rigid or flexible – something inconceivable using conventional silicon-based electronics. It will lead to the creation of a whole new range of products such as conformable and rollable electronic displays, large-area efficient lighting and low-cost solar cells.

The components of Plastic Electronics are organic molecules and polymers that give semi-conducting or light-emitting properties; inorganic materials such as metal nano-particles; a wide variety of substrates which will be application-specific; and process technologies drawn from either traditional high-technology manufacturing industries (such as liquid crystal displays) or from the printing industries.

The silicon-based electronics world is, of course, a very well entrenched, multi-billion dollar industry that offers increasingly impressive levels of processing power. But it also has the characteristics of very high capital needs (multi-billion dollars for silicon chip manufacture), potential over-specification for a number of applications, and design limitations in respect of flexible or conformable devices. Plastic Electronics will, on the whole, become a winning technology platform not by 'beating' silicon but by complementing silicon technologies or by facilitating the development of new products (like rollable displays) where silicon just cannot be used.

The benefits

Plastic Electronics offers electronic circuits and consumer devices manufactured using low-cost printing processes on any surface including flexible surfaces, and over large areas. This will lead to the creation of whole new generations of products characterised by:

- Product design which benefits in terms of flexibility, conformability, weight-reduction and robustness
- Low-cost manufacture based on the more efficient use of functional materials applied in an 'additive' (rather than wasteful 'subtractive') way. Roll-to-roll manufacture could also reduce costs
- A reduction in materials wastage and lower temperature processing resulting in a lower-impact environmental footprint.

The global market

The global market for Plastic Electronics is under $2 billion now, but is forecast to grow at an astonishing rate to as much as $330 billion in 2027. Recent market forecasts are summarised opposite:

Forecaster	Forecast period	Size ($Bn)
Nanomarkets[1]	2012	20
IDTechEx[2]	2019	57
FlexTech[3]	2020	120
IDTechEx[4]	2027	330

Judged on any scale, this would be an astonishing level of growth. Using the IDTechEx source data, the predicted growth over the next decade by application area is summarised as follows:

Application	2009 ($Bn)	2019 ($Bn)	CAGR* %
OLED lighting & displays	0.8	18.5	37
e-Paper displays	0.1	5	51
Photovoltaics	0.4	19.5	47
Transistors	0	8	95
Others	0.6	6	40

* Compound Annual Growth Rate

Other applications of Plastic Electronics include printed memory, organic sensors, flexible batteries, smart objects and smart textiles. Intelligent Smart Systems is an area in which UK companies have particular expertise.

Overall, it is the level of value growth – taken together with the product benefits and design flexibility offered by Plastic Electronics – which have generated such a high level of interest across the globe.

IN PERSPECTIVE

Plastic Logic

www.plasticlogic.com

Plastic Logic is working to transform the way we read the written word, with a backplane technology that enables a display to become flexible, thin and light in weight. A spin-out from Cambridge University's Cavendish Laboratory, its new manufacturing processes combine the power of electronics with the pervasiveness of printing. It's what Plastic Electronics is all about, and it's facing up to Kindle and the Sony e-readers in a market with one of the biggest prizes of all.

It's also a partner in the VideoFLICs project with Liquavista, having attracted a £6.1 million investment from the Technology Strategy Board. This aims to develop the first generation of full-colour, flexible video-rate displays – allowing products such as electronic newspapers that can show moving images. The potential market is estimated to be £4 billion.

Martin Jackson of Plastic Logic says. "We have the science and intellectual property to succeed, but that's not enough. We have to offer a complete solution for the consumer: the eReader, an online store and distribution together with the content itself. We are fortunate to have committed investors who recognise what is needed for the first-generation product, but also what is required in the future."

The UK Experience

Plastic Electronics has been subject to continued interest and scrutiny in the UK in recent years.

The former Department of Trade and Industry undertook an analysis of the potential of Plastic Electronics which showed that the UK had strengths in most elements of the emerging supply chain including:

- Materials, such as the light-emitting polymers developed by Cambridge Display Technology (CDT), and the flexible plastic substrates produced by DuPont Teijin Films
- Processing and manufacturing equipment, for example Plasma Quest's thin-film deposition kit and Timson's high-quality printing on unsupported flexible plastic films
- Device design and manufacture, for example Plastic Logic's flexible displays, and Thorn Lighting and CDT's OLED lighting panels
- Product design and integration, such as Hewlett Packard Labs' reflective colour display and Polymer Vision's rollable eReader.

There are two main approaches to plastic electronics: 'small molecules', where the organic molecules are usually evaporated onto a substrate in layers, and polymers, which are dissolved in solution and printed onto the substrate material. Much overseas activity, in the US, Korea and Germany in particular, has been on small molecules, whereas the UK has focussed on polymers and solution-processable molecules which, after addressing initial materials' issues, are showing the potential to deliver high-performance devices at much lower cost.

The UK has a clear competitive advantage in the development and application of these organic solution-processable materials.

An **Economic and Social Research Council (ESRC)**-funded research project[5] in 2008 built on the DTI's findings. It conducted a detailed UK capability-mapping exercise, and identified a vibrant supply chain in the UK. There are over 70 active businesses, putting the UK third in the world behind the US and Germany in terms of commercial activity. It also found that Plastic Electronics start-up companies had succeeded in attracting significant levels of venture capital funding.

A report entitled '*Strategic decision-making for technology policy*'[6] from the **Council for Science and Technology (CST)**, the UK government's top-level independent advisory body on science and technology policy issues, identified Plastic Electronics amongst its six priority technology areas that could produce real returns for the UK within a five-year timeframe.

Plastic Electronics has also been the subject of a specific case study by the **House of Commons' Innovation, Universities, Science and Skills Committee** review into Engineering during 2008/09[7].

The Committee's report highlighted the need to revise the structures used to support the growth of fledgling industries like Plastic Electronics. In the Government's recent response, reference was made to the need for an integrated national strategy to address the way in which UK plc would maximise its opportunity in this new industry: this document addresses that need.

Plastic and Printed Electronics was also selected as one of the five pillars of the UK strategy for Electronics, Photonics and Electrical Systems which was published by the **Technology Strategy Board** in October 2008[8].

The 'New Industry, New Jobs' initiative published in April 2009[9], which set out the Government's active industrial strategy for Britain, identified Plastic Electronics as one of a range of new industrial technologies in manufacturing in which strong UK capabilities should be a priority for Government attention and support. Recognising this, the **Department for Business, Innovation and Skills (BIS)** announced in July 2009 a £20 million expansion of the Printable Electronics Technology Centre (PETEC) in Sedgefield which is expected to create up to 1,500 jobs nationally by 2014. This investment will significantly enhance the open access product development facilities at PETEC with the introduction of new equipment capable of prototyping applications in printable flexible displays, solid-state OLED lighting and organic photovoltaic solar cells. Installation of the new equipment will commence in March 2010 and the expansion completed by March 2011.

IN PERSPECTIVE

Printable Electronics Technology Centre (PETEC)

www.uk-cpi.com/petec

The Printable Electronics Technology Centre (PETEC) at CPI is the national Plastic Electronics prototyping centre. Opened by the Secretary of State in March 2009, PETEC develops manufacturing processes at pre-production volumes to bridge the gap between smallscale laboratory demonstrators and highvolume production runs. As well as having this process expertise, PETEC also provides support in semiconductor materials integration and the vital barrier layer technologies.

The recent investment into PETEC of £20m by BIS and One North East will support and fund a state-of-the-art manufacturing facility, enabling the development of new innovations in markets such as ultra-efficient lighting and photovoltaic solar cells. The expanded PETEC facility will also accelerate the establishment of units for incubating start-up businesses within the centre.

Tom Taylor, Director of Printable Electronics, said, "PETEC has been created to help business do the hard work of testing and proving their processes, enabling them to try their concepts in a production quality facility before they commit to investing in expensive capital equipment. This de-risking of innovation is aided by our experienced team who are committed, pragmatic and results-oriented. We look forward to helping meet the challenges of UK companies that have the vision to be involved in this exciting technology."

UK strengths

The UK has sound foundations in Plastic Electronics, in particular:

- The impressive **skill-base** in this area – part of which has been developed specifically for the exploitation of this emerging industry, whilst other parts are highly relevant from adjacent industries, including semiconductors and pharmaceuticals
- The strength of **academe** – The UK has been leading much of the pioneering research and development in this area, funded by the Engineering and Physical Sciences Research Council (EPSRC). EPSRC is currently investing £68 million in academic projects of direct relevance to Plastic Electronics
- The strength of **national funding** – the former DTI and more recently the Technology Strategy Board have provided significant support, to date investing £52 million in conjunction with business in over 50 industrial collaborative R&D projects in the field. In addition, the European Union through its Framework 7 programme has also provided significant support, and proposals are being prepared for large ongoing funding support over the period 2011 to 2015 in the category of Organic and Large Area Electronics
- The strength of **regional support** – Business support has also been provided through the Regional Development Agencies (RDAs) and Devolved Administrations. One North East (ONE), Yorkshire Forward, North-West Development Agency and the Welsh Assembly Government have been particularly visible in their support. In addition, the three Northern RDAs are funding the Northern Way Innovation Programme – a £5.7 million programme to help develop the Plastic Electronics supply chain
- A network of publicly-funded **Centres of Excellence** contribute greatly to this area (*see right*)
- The Technology Strategy Board-funded UK Displays and Lighting Knowledge Transfer Network – now part of the merged **Photonics and Plastic Electronics (PPE) KTN** – has more than one thousand members drawn from 612 companies and 82 universities. The PPE KTN plays a key role in the facilitation of Technology Strategy Board-funded programmes including education, networking and the management of both inward and outward trade missions. The level of interest from overseas organisations in the UK's strengths in Plastic Electronics remains at a very high level.

Centres of Excellence – A key national resource

Five centres agreed a Memorandum of Understanding in 2008 to provide a focused cluster for technology development and prototyping, aiming to translate UK strengths into the industries of the future.

The **Printable Electronics Technology Centre (PETEC)** based at the Centre for Process Innovation in Sedgefield is the national Plastic Electronics prototyping centre. (see page 09 and www.uk-CPI.com/petec)

The **Welsh Centre for Printing and Coating (WCPC)** – a part of the School of Engineering at the University of Swansea – is one of the world's leading centres for the research and development of printing and coating processes. It covers all forms of printing processes, and also encompasses multi-roll coating technology. Research is undertaken through a number of channels including EPSRC, company PhD and MPhil projects, and through consultancy services. (see www.swan.ac.uk/printing/)

The **Cambridge Integrated Knowledge Centre (CIKC)** brings together the university's research activities in molecular and macromolecular materials and draws on the expertise of the Judge Business School, the Institute for Manufacturing and the Centre for Business Research to create innovative knowledge exchange spanning business research, training and specific exploitation. The portfolio currently includes major projects in Organic Photovoltaic Devices, Organic Thin Film Transistors, displays, printable waveguides and large-area transparent electronics. (see www-g.eng.cam.ac.uk/CIKC/)

The **Organic Materials Innovation Centre (OMIC)** in the School of Chemistry at the University of Manchester provides expertise in the development of new conducting, semi-conducting and dielectric materials and their formulation for controlled deposition – printing onto a wide range of substrates. It is bridging the gap between the knowledge which UK universities generate and that which businesses need in order to innovate and grow. It encompasses expertise in organic materials at other universities in the north west. (see www.omic.org.uk)

The **Imperial College Centre for Plastic Electronics** brings together wide-ranging research in the departments of Physics, Chemistry and Materials to address the design, synthesis and characterisation of PE materials, the design and fabrication of a wide variety of PE devices (including organic/inorganic hybrids) and the modelling of both. The Centre interacts strongly with industry and is closely integrated with the Imperial Doctoral Training Centre in Plastic Electronics, within which it seeks to train the PE technology leaders of the future. (see www3.imperial.ac.uk/plasticelectronics)

This combination of Centres of Excellence provides the UK with a world-class infrastructure and they have a critically important role to play in securing the UK's position in the coming year

Targeting Market Sectors

From the table on page 07 it can be seen that three of the major application areas of Plastic Electronics are Displays, Lighting and Photovoltaics. All are areas in which UK science and experience is relatively mature, and the Strategy Group sees them – and their combination in Integrated Smart Systems – as key targets for exploitation.

IN PERSPECTIVE

Hewlett-Packard Laboratories

www.hpl.hp.com/bristol

Hewlett-Packard Laboratories' European base is in Bristol, where work on Plastic Electronics is aimed at developing 'Information Surfaces' – plastic sheets that can display paper-like, print-quality information as well as interactive and video media. Senior Research Manager Adrian Geisow says "One of the key challenges is reflective colour – a display that is as bright and colourful as printed paper. But good quality colour currently requires high-energy consumption to generate light, and a glowing screen is less natural to read from than one using ambient illumination. We believe that highly-transparent conductive circuitry imprinted onto plastic substrates will deliver the best combination of low optical losses and a thin, robust and light-weight display.

"Plastic Electronics is core to what we do. We are active in Technology Strategy Board-funded projects which are developing printing processes and printing materials for plastic displays."

Adrian's group also regularly sponsors PhD students and post-doctoral researchers in relevant areas at UK universities and plans to grow stronger links with the Centres of Excellence. "The UK has built excellent foundations for this exciting area: with consistent and concerted support over the next five years, we can make sure that the commercial opportunities are fully developed here, rather than elsewhere in the world."

Displays

The growth of liquid crystal display (LCD) technology from small mobile formats to laptop PCs, monitors and flat-screen televisions demonstrates the demand for visual information accessibility and the ever-increasing quality of the display experience.

New display materials such as electrophoretic, electrowetting and Organic Light-Emitting Diode (OLED) displays are opening up an even broader range of display opportunities.
The continuing explosion of electronic content and growing ease of access to it will drive opportunities for ever more display surface in yet more places. Examples include:

- Large-area high-definition TVs
- Colour displays for mobile devices
- Monochrome displays in DVD players and white goods
- Automotive dashboards and navigation systems
- e-Book readers
- Large-area signage
- Retail point of sale systems
- Bio-medical and other chemical assay applications
- Novelty inserts for toys, greeting cards, gaming cards etc.

Plastic Electronics will enable displays to be used in an even wider range of application formats and environments.

IN PERSPECTIVE

Cambridge Display Technology

www.cdtltd.co.uk

Cambridge Display Technology (CDT) is a pioneer in the research, development and commercialisation of technologies based on solution-processible organic light-emitting diodes. It was spun-out from the work at the Cavendish Laboratories in the late 80s and early 90s.

The core work is on developing the materials and device structures to achieve performance levels suitable for high definition TVs and to ensure low-cost manufacturing using ink-jet printing. It is also working to develop organic thin film transistors and solar cells.
The technology is expected to pervade mobile applications and televisions, and CDT owns key intellectual property around associated materials, devices, printing and applications.

The company is also a key player in several Technology Strategy Board-funded projects including MOET, an optical enhancement project for OLED lighting and displays with University of Sheffield, and TOPLESS with Thorn Lighting and the University of Durham.

Eric Mayes, Director of Commercial Development, says, "The value of these and other Technology Strategy Board projects is that they bring together technology companies and institutions who would otherwise not work together to develop relevant UK technology in a focused way."

Lighting

A genuinely new lighting technology is emerging based on Organic Light Emitting Diode (OLED) technology. Its devices need less energy than conventional lighting, tolerate being turned on and off repeatedly as needed, give exactly the right colour of light for particular applications, and last much longer than incandescent light bulbs. They are more energy-efficient in their manufacture, avoid the use of hazardous materials such as mercury, and can be recycled at the end of life. They can also operate on low-voltage direct current, which can be valuable in many application areas and overseas markets. They provide large-area diffuse lighting and will be ideal replacements for fluorescent tubes.

The UK is well placed to exploit this technology. Cambridge Display Technology holds the fundamental patents on light-emitting polymers, devices and processes, and has the ability to scale material production accordingly as well as fabricate lighting panels for development purposes.

IN PERSPECTIVE

Thorn Lighting

www.thornlighting.com

Lighting accounts for around 20% of the electricity bill in most homes and for as much as 50% of the electricity bills in offices. For cost and environmental reasons, there is a drive for more efficient lighting, but not at the expense of light quality. And the emerging light-emitting polymer technology is proving it can deliver white light more efficiently and with much less environmental impact.

In a Technology Strategy Board-funded project, Thorn Lighting is leading a consortium – Project TOPLESS – to produce a single polymeric material and apply it to glass substrates, in a similar fashion to applying paint with a roller. The resulting layer is ultra thin (just 1/2,000th the width of a human hair).

Project leader Geoff Williams says, "TOPLESS is ready to move to production, although we will continue to need fundamental material research by our partners, the University of Durham and Cambridge Display Technology. We are looking to produce up to 9,000 square metres of solid-state lighting per year by 2013, which could then rise exponentially to between a half and one million square metres per year in a high-volume production facility by 2016. That is equivalent to 5% of the annual consumption of fluorescent tubes in the UK."

Photovoltaic (PV) devices

While current demand for photovoltaic electricity generation is mainly satisfied by crystalline silicon technologies, there is an increasing contribution from thin-film technologies and – just beginning – Plastic Electronics technologies including Organic PV (OPV) and dye sensitised solar cells. These offer benefits including:

- The use of much thinner layers of active material, resulting in thinner/lighter modules and facilitating their use in a very wide range of applications
- The opportunity for much improved manufacturing economics, especially where the benefits of roll-to-roll manufacture can be accessed. This will reduce the cost of solar cells and allow parity to be reached with grid-based power systems
- The possibility for a level of design flexibility and product form which is not achievable with conventional silicon technologies.

The need to improve the efficiency of OPV technologies and extend their lifetimes will be key R&D topics in coming years. Where OPVs will potentially have a real advantage is in reduced costs to manufacture brought about by the use of low-temperature roll-to-roll additive manufacturing processes. This should result in reduced energy consumed in the manufacture of the panels combined with less waste of active materials.

Lower cost per Watt per sq metre combined with the inherent flexibility of OPV panels should significantly enhance the market and offer the prospect of economic, flexible energy generation. OPV devices will become increasingly prevalent in applications world-wide.

Integrated Smart Systems

The ability to print basic electronic components (diodes, transistors, resistors, capacitors) to create circuits across large areas using highly-efficient manufacturing processes opens up a wealth of market opportunities. Much attention and effort has already been invested in developing Plastic Electronic versions of RFID/memory tags for item-level identification and product brand protection devices. These applications require relatively simple electronics circuits manufactured at very low cost: the ability to embed simple electronic functionality into even relatively low-value items will result in a dramatic expansion of the market for this type of 'smart packaging/product security'.

Market opportunities will also exist for products that incorporate a mixture of devices such as micro PV generators, printed batteries, sensors and light emitters. These could either be manufactured using hybrid circuits – a mixture of silicon and Plastic Electronics – or possibly entirely from Plastic Electronics. Fully-integrated Plastic Electronics solutions for all but relatively simple circuits will require several more years of research and development. The goal of cheaply-manufacturing more complex integrated circuits in large areas that can be subsequently 'sliced up' is worth pursuing.

Such technologies will not substitute or displace conventional electronics: they will open up entirely new markets for electronics currently inaccessible to silicon.

IN PERSPECTIVE

De La Rue International Limited

www.delarue.com

De La Rue is the world's largest commercial security printer and papermaker, involved in the production of over 150 national currencies and a wide range of security documents such as passports, fiscal stamps, travellers cheques and authentication labels. It is a leading provider of cash-sorting equipment and software solutions to central banks worldwide.

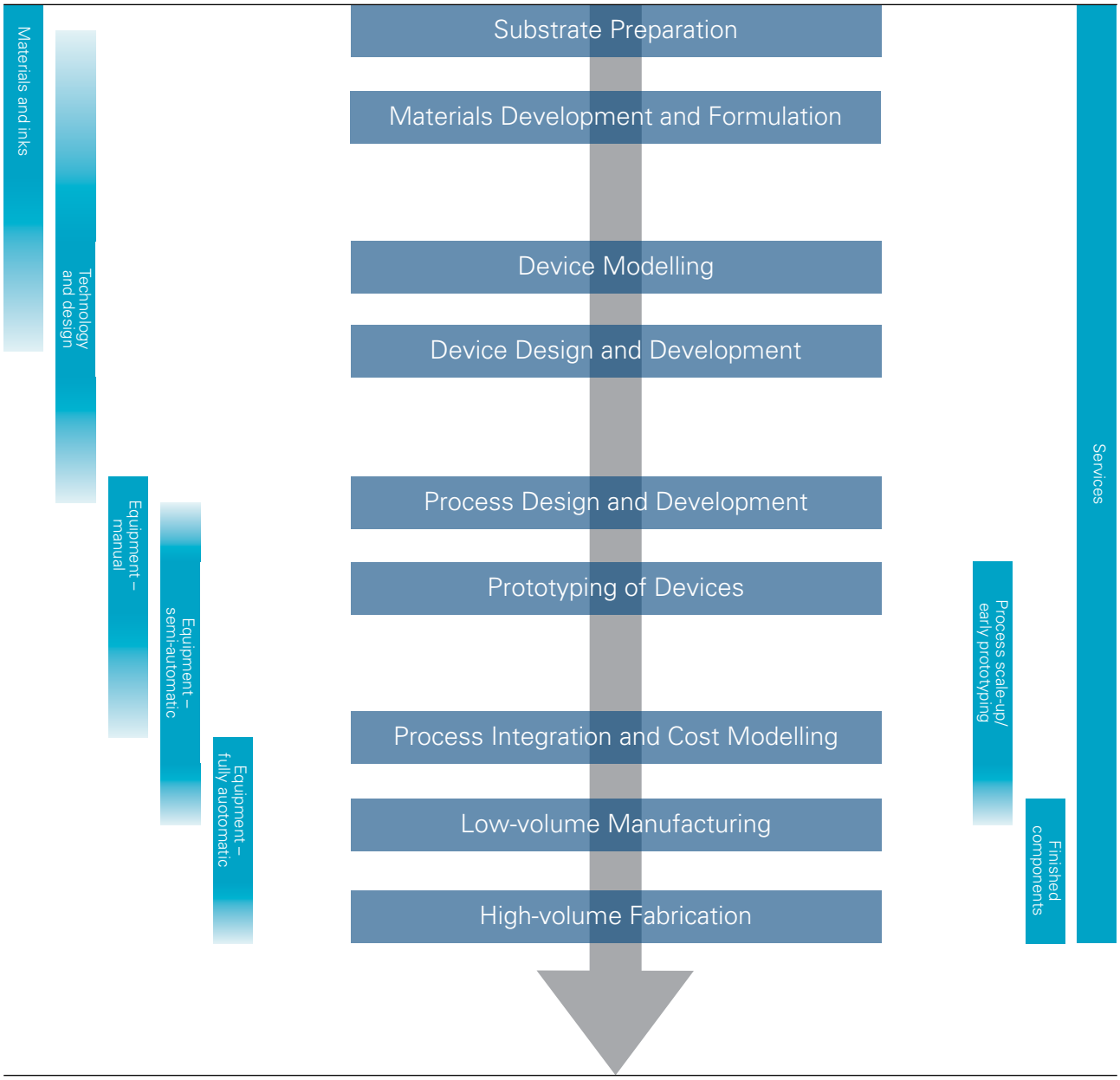
The company sees Plastic Electronics as an exciting enabling technology with a significant role across a wide range of its markets. The potential offered by Plastic Electronics to provide public engagement via displays and other interactive features on documents is compelling. De La Rue is also interested in the possible interactions between Plastic Electronics on security documents and automated inspection equipment.

With the support of the Technology Strategy Board, it is working in collaboration with others to build a platform of technologies, components and systems on which next-generation features can be built.

Philip Cooper, says, "Plastic Electronics for us is very exciting. The potential integration of printed power supplies, transistors, Organic LEDs and displays will enable – amongst many other things – the possibility to create highly-engaging features on our products which will open new and potentially significant markets".

Supply Chain Considerations

The supply chain for Plastic Electronics – though considered here from a UK perspective – will always have an international dimension. A recent study[10] described the emerging supply chain for Plastic Electronics as below:

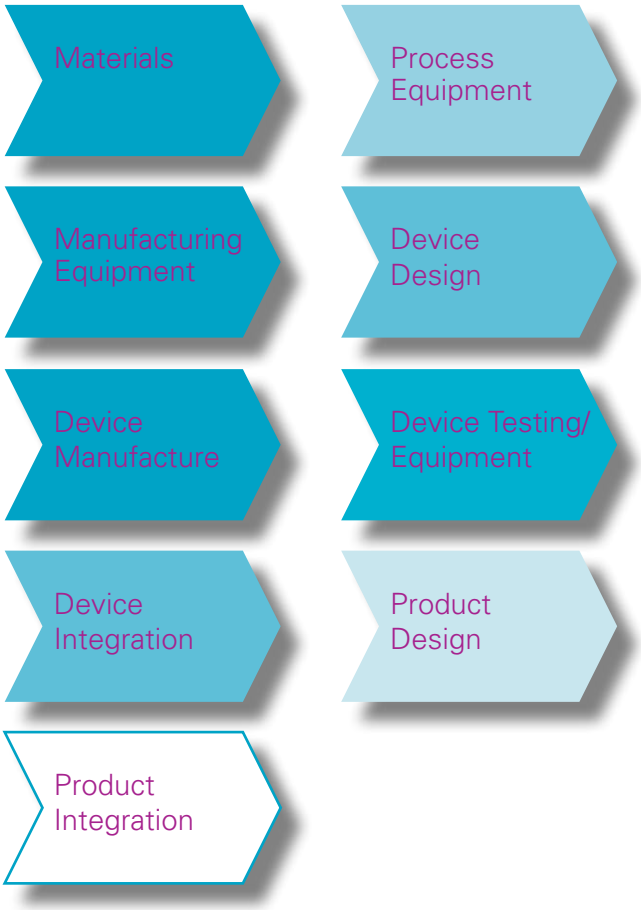


Route to production for Plastic Electronics technologies

This study identified a vibrant, emergent Plastic Electronic value chain in the UK. Recent results show that there are around 70 companies in the UK directly involved in, or closely related, to Plastic Electronics, putting the UK third in the world in terms of commercial activity behind the US and Germany.

UK-based companies and institutions are participating in this supply chain in a variety of ways, encompassing intellectual property generation and licensing, substrate and materials development and manufacture, equipment manufacture, device designs, prototype manufacturing and final device manufacture. The graphic below captures the intensity level (in terms of numbers of participants) involved.

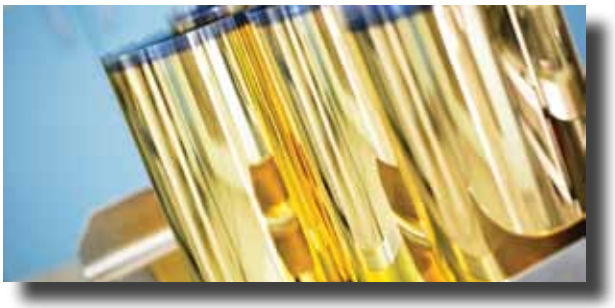
Note: darker coloration represents a larger number of companies active in this segment.



IN PERSPECTIVE

DuPont Teijin Films

www.duponteijinfilms.com



DuPont Teijin Films (DTF) is the world's leading supplier of polyester film products. But to stay at the leading edge, it continually identifies new growth markets where the benefits of its products and technology can be exploited.

During the early 2000s DTF became aware of the growing interest in Plastic Electronics – in particular the need for high-quality flexible substrates and the potential for roll-to-roll processing. It became apparent that film substrates tailored to meet the demanding requirement of dimensional stability at elevated temperatures – coupled with exceptionally smooth surfaces – would require the development of a dedicated family of films.

DTF embarked on collaborative programmes with leading developers to identify the property set required of the film, and to develop films accordingly. Government funding was a key enabler in bringing the key parties together and speeding up the collaborations, with a programme with the University of the West of Scotland adding particular value. The company has subsequently made a major investment in developing and commercially launching a family of films tailored for Plastic Electronics processes.

Keith Rollins, Global Plastic Electronics Business Development Manager, says, "Having identified Plastic Electronics as an exciting new opportunity, it is very pleasing to see the transition from R&D into a commercial manufacturing platform. The next three to five years will be an exciting period."

What is interesting is that many of the key players in the Plastics Electronics community are completely new to the world of 'functional materials' and 'electronics'. Many are coming into the area from the printing industries as the manufacturing processes being developed are more closely aligned with those of printing than conventional silicon semiconductor processes.

This emergence and convergence of technologies and techniques is typical as applications develop and are commercialised. The applications will spread throughout the ICT ecosystem with varying rates of absorption dependent upon market take-up, level of disruption and incumbent competition.

What is becoming increasingly noticeable is that the 'end-users' (companies looking to embed Plastic Electronics into their products) are starting to work more actively to understand the possibilities that printing functional materials onto flexible substrates open up. A number of companies involved in, for example, the packaging industry are now actively seeking to engage with the Plastic Electronics community in the UK – a sign that 'user pull' is starting to appear where previously there was only 'technology push'.

Taking an overview of the UK Plastic Electronics industry, the following sets of strengths, weaknesses, opportunities and threats emerge.

Strengths	Weaknesses
• World leading science & technology • Centres of Excellence • Agile and enthusiastic SME businesses • Extensive elements of the supply chain exist in UK • Strong intellectual property base	• More start-ups required to grow the industry • Lack of large UK electronic brands • Risk-averse capital
Opportunities	**Threats**
• Large global market potential • High-value UK manufacturing • Sustainable technology in terms of people, planet and profit	• UK could miss the market window • High-volume manufacturing not yet demonstrated • Market does not materialise at the forecast rate

Challenges Issues and Solutions

The Strategy Group's considerations were wide-ranging, but concerned four major areas:

- how to identify the business opportunities at home and overseas that would be most appropriate for the skills and experience we have in the UK
- for these opportunities to be pursued most successfully, how to ensure the best economic climate for both UK companies and inward investment
- given that the science base in the UK is a major strength, how to exploit that strength in manufacturing
- how to ensure that UK industry has the necessary multi-disciplinary skills to be able to succeed in manufacturing and so boost employment and revenues.

These four aspects are covered in more details here, as Challenges 2 to 5. But the Strategy Group saw the need for a body to champion and guide the new sector, and – because this would address responses to the four factors above – it is described here first as Challenge 1.

Challenge 1 – To create effective leadership and coherent communications for the UK's Plastic Electronics sector

Issues identified

1.1 Plastic Electronics is a multi-disciplinary field, drawing on competencies across chemistry, physics, engineering in all of its guises and extending to the creative and design disciplines. A common language, effective understanding and an agreed agenda are fundamental requirements.

1.2 The activity spreads across universities, Centres of Excellence, Government (central and regional), funding bodies (public and private) and knowledge transfer networks, and into all parts of the supplier and user industrial community. This complex set of stakeholder relationships, whose interests can both overlap and diverge, needs to be nurtured.

1.3 Activity levels around the world are rising – not just in other leaders like the US and Germany but also in Japan, China and Korea, for example. This is a significant threat to the UK's future in Plastic Electronics which should be countered by strategic leadership.

1.4 There is a gap between the technology development community and the end-users who might derive benefit from Plastic Electronics. It is critical that mechanisms are established to fill this gap.

Recommended solutions

It is proposed that a UK Plastic Electronics Leadership Group (PELG) be established to champion the needs and raise the profile of the sector, and to improve co-ordination among the UK's key stakeholders within a short, sharp period of intervention. It should be led by business, drawing membership from the key stakeholders in the UK including:

- Lead UK businesses
- Centres of Excellence
- Business, Innovation and Skills, UK Trade & Investment and other appropriate Government departments
- RDAs and Devolved Administrations
- Photonics and Plastic Electronics KTN
- Technology Strategy Board
- Engineering & Physical Sciences Research Council.

The PELG should be a relatively small but influential body, not replacing existing bodies that represent the numerous sections of the Plastic Electronics community but bringing them together in a co-ordinated and effective manner. An early priority would be to develop a delivery/action plan taking in all of the challenges and solutions identified here. It should identify responsibilities and accountability within a timetable of activity.

Challenge 2 – To identify business opportunities at home and abroad that will sustain the growth of Plastic Electronics manufacturing

Issues identified

2.1 The UK does not have the large indigenous electronics firms which, in previous times, would have been the natural catalysts to drive the exploitation and adoption of new technologies. There are, however, large user groups such as the National Health Service, supermarket chains and the aerospace and construction industries that could help create a demand for Plastic Electronics products.

2.2 There will be a significant number of opportunities for business start-ups in both small and large company environments. The multi-disciplinary nature of Plastic Electronics and the changing dynamics of the industry – from being largely technology-oriented to becoming process-based – will create new obstacles to success. Support will be needed to allow the value of R&D investment from previous years to be realised in jobs and economic growth.

2.3 As a result of the issues above, supply chain partners in the UK Plastic Electronics community are not as closely integrated as they would need to be in a fully-commercialised industrial environment.

Challenge 2 – Continued

Recommended solutions

The PELG, working closely with the Photonics and Plastic Electronics (PPE) KTN, should promote 'joined-up thinking' with suppliers and end-user organisations – big and small – to encourage the growth of promising markets and the UK's standing within them. They should investigate the opportunity to work with Government forward-procurement programmes, using the Small Business Research Initiative and other mechanisms, to identify opportunities to drive the market entry and adoption of new products – particularly those such as photovoltaic solar cells and ultra-efficient lighting which address the challenges posed by climate change.

The PELG and PPE KTN should also track the target application areas and parts of the supply chain where the UK can be most effective. It should draw inputs on the development of markets from a variety of sources ranging from commercial market forecasters to the UKTI and Science and Innovation global networks.

Closer liaison should be maintained with UK Trade & Investment's UK Technology initiative, which aims to provide a single, compelling voice to position the UK as a partner of choice in global ICT markets for trade and investment. The purpose of the UK Technology Marketing Strategy is to create an integrated marketing programme that is inspiring, maximises the impact of our resources and enables the UK Technology industries to achieve their full potential for international commercial success.

The strategy will set the scene for better co-ordination and demonstration of the strengths of the sector in a global setting. It aims to achieve:

- Increased trade with international customers for UK technology firms
- Increased investment into the UK from international technology businesses
- An improved reputation of the UK technology industry.

Based on the above and on input and resources available in the Centres of Excellence – for example the Judge Business School and the Institute for Manufacturing in the CIKC – a national Plastic Electronics roadmap should be developed and maintained. This would inevitably require a number of constituent roadmaps to cover techology and marketing across the breadth of applications identified in opportunity-rich areas.

The roadmapping reports and demonstrator programmes should be developed to address the needs of the supply chain. They should include competitive analysis to ensure the UK targets the areas of greatest opportunity.

Challenge 3 – To ensure that the UK remains an attractive environment for investment and business growth in Plastic Electronics

Issues identified

3.1 The current economic environment may slow the adoption of Plastic Electronics technologies. But there is support available, and considerable financial rewards for successful implementation. Obstacles must be overcome, and incentives optimised.

3.2 Larger companies operate in a global environment, with considerable choice as to where to locate R&D facilities and their own start-up ventures. It is important to seek to make the UK environment as globally-competitive as possible, and this needs an holistic approach taking advantage of the UK's strengths in its science base and developing skills.

3.3 With the creation of a new industry, there is an opportunity for the UK to build a significant new manufacturing base. Policies and incentives should be formulated to positively attract new manufacturing investment to the UK in addition to R&D and product design. This is particularly important for both systems integration as well as component and subsystems manufacture.

Challenge 3 – Continued

Recommended solutions

Support mechanisms are available. They include the Innovation Investment Fund, which is aiming to generate £1 billion of venture capital over ten years; Grants for Business Investment, a discretionary scheme that provides a capital grant to help businesses expand, rationalise, modernise or diversify; Enterprise Capital Funds providing equity funding to SMEs; Research and Development Tax Credits which provide business tax relief; and many others. But the PELG should ensure that their provisions are made more widely known to businesses.

As Plastic Electronics opportunities mature from the laboratory to full-scale manufacturing, so the funding requirements will inevitably change. Initial feasibility studies can be funded by grants etc. However, full-scale production requires significant investment and the PELG must work to ensure that the Government and the investment community understand both the amount and timescale of investment required.

Improvements in education and training, and in encouraging public sector purchasing to reflect the new opportunities, will also contribute to a more-positive environment. Within a limited timescale, the PELG should work with BIS, UK Trade & Investment, Regional Development Agencies, and Devolved Administrations and other Government departments to target support and the information available about it.

Targeted inward investment activities should be undertaken promoting the entirety of the UK's offering to existing and prospective inward investors. They should complement the roadmapping exercise to identify target areas where the UK can expect to be a globally-credible player, and with marketing input from a variety of sources including UKTI, the Science and Innovation global networks and commercial market forecasters. UKTI's UK Technology initiative is a pro-active channel with which the Plastic Electronics sector should work closely.

Challenge 4 – To exploit the science and research base in UK industry

Issues identified

4.1 The UK has an excellent science and technology position in Plastic Electronics that has been well-supported to date by the Engineering and Physical Sciences Research Council and the Technology Strategy Board (and DTI previously). The basic research and collaborative R&D programmes in the Plastic Electronics area have played a vital role in establishing this position, and it is important to ensure that funding is continued to convert these R&D activities into commercial applications.

4.2 The five Centres of Excellence will have a vital role to play in ensuring that UK companies have access to world-class academic expertise, combined with an environment in which start-up companies might be expected to emerge and be incubated. The Printed Electronics Technology Centre, particularly with the recent Government investment to expand its capabilities, will have a particularly important role to play in this area.

4.3 One of the key targets in demonstrating the benefits of Plastic Electronics technologies to end-users is the production of high-quality prototype products. These will be important in educating potential end-users and companies interested in using Plastic Electronics in their product design and development strategies.

Challenge 4 – Continued

Recommended solutions

An integrated delivery plan setting out longer-term funding provisions for research, development and demonstrator/ prototype activities - as informed by roadmapping and adjacent activities – should be produced. It should build on the progress and experience that has been gained from the Northern Way-funded Printed Electronics programme, which aims to produce a small number of 'first generation' demonstrators. Dialogue with EPSRC, the Technology Strategy Board, national and funding agencies and others including the Centres of Excellence should ensure a robust funding process to support the development cycle through to industrialisation.

The Technology Strategy Board remains committed to supporting the development of the UK's Plastic Electronics sector and, as part of this strategy, plans to launch a new £8 million competition for collaborative R&D and demonstrator projects. This will complement the Northern Way demonstrator programme and address some of the technical barriers to be overcome on the road to commercial exploitation. The programme will enable the Technology Strategy Board to facilitate new collaborations and strengthen the UK Plastic Electronics supply chain. By building on the success of earlier competitions, the Technology Strategy Board anticipates that this will offer a clear route to exploit the UK wealth potential of Plastic Electronics. Liaison by the PELG should support this.

The UK's five Centres of Excellence should be encouraged to develop a co-ordinated set of promotional materials that allow potential users to understand their capabilities and engagement models. Working practices should be developed to ensure that industry derives maximum benefit from the knowledge and expertise within the centres.

All parties should build on the experience of the European Union's Framework programmes and be prepared to take advantage of new initiatives being developed. BIS and some leading UK firms are actively engaged in the development of a European Strategic Research Agenda in the field of Organic and Large Area Electronics (OLAE). This should lead to opportunities for significant ongoing funding support for R&D on Plastic Electronics over the period 2011 to 2015.

Challenge 5 – To provide a skilled workforce appropriate to the needs of high-growth, advanced manufacturing in the UK

Issues identified

5.1 Plastic Electronics demands a highly multi-disciplinary approach to both develop and then exploit the core technologies, with disciplines blended in a new way. For example, it needs materials scientists and chemists who understand electronics; print/process engineers who understand materials science; and electronics engineers who understand chemistry.

5.2 In addition, the skills needs will change over time as the sector moves from basic research and early stage product development to a time when mature manufacturing processes are more prevalent. The requirement will shift towards the need for skilled technicians and engineers who have an understanding of operating high-quality, high-volume production process (printing) equipment.

5.3 The sector thus presents opportunities for people to add new skills and migrate from more traditional sectors – for example, silicon semiconductor fabrication engineers transferring their skills to operate different equipment sets or from experienced print engineers transferring their skills to work with 'functional' inks, perhaps in clean-room environments.

5.4 The UK has very good foundations from which to build this new approach, with particular strengths in fundamental materials development and functional ink formulation, manufacturing equipment (coating, printing, deposition) and electronics design. But, there are, as yet, few software design tools to enable electronics design engineers to work with Plastic Electronics, although these will be developed to enable the design process to be decoupled from knowledge of the manufacturing processes used. *(A TSB-funded project has recently announced the world's first organic thin film transistor EDA tool.)*

5.5 Business management and entrepreneurship skills may need to be made more accessible to emerging organisations as they will be critical to their development.

5.6 From the above it follows that we should be seeking to understand better the requirements and be building new integrated skills training to address them. But, as a new industry, Plastic Electronics has only very recently 'appeared on the radar' for those public bodies accountable for the development of training agendas.

Challenge 5 – Continued

Recommended solutions

The Sector Skills Council for Science, Engineering and Manufacturing Technologies (SEMTA) is the lead body in this area, working with other Skills Councils and outside agencies to define the critical skills and training required. A skills audit should ideally be prepared by 2011 and the requirements of the Plastic Electronics sector embedded in SEMTA's Sector Skills Agreement for Electronics.

The Centres of Excellence should continue to play a major role in training, with specific action items to be exploited including:

- The Welsh Centre for Printing and Coating to work with the printing community to develop its capabilities to a point where it can participate in the Plastic Electronics sector. This is best achieved through the already-active training programmes together with support for collaborative R&D via the Technology Strategy Board and others
- The Imperial College Doctoral Training Centre to be a source of trained multi-disciplinary scientists who will fuel growth
- PETEC is a key resource in providing the training infrastructure within which the next generation of scientists and engineers will 'learn their trade'. A sustainable model of funding provision needs to be developed to support this agenda
- There will also be a significant output of trained scientists/engineers in relevant technical skills from the CIKC, WCPC and OMIC Centres.

Within postdoctoral training programmes – including those in the Imperial Doctoral Training Centre – modules covering innovation and business management should be included. Senior industrialists should be encouraged to participate, thus encouraging a 'real world' dimension. The training provision in entrepreneurship through the Judge Business School and the Institute for Manufacturing should promote spin-outs from universities and the five Centres of Excellence.

The PELG should identify those universities leading the industry and work with them to develop and deliver the teaching of undergraduate modules in Plastic Electronics. The possibility of extending existing courses, such as Display Masters, should be explored.

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Institute for Manufacturing	www.ifm.eng.cam.ac.uk/
Judge Business School	www.jbs.cam.ac.uk/
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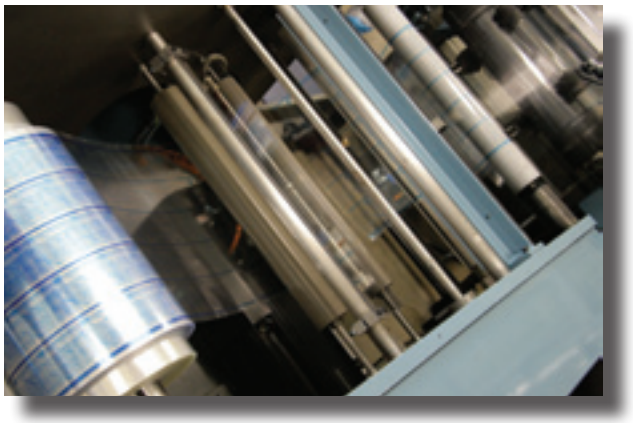
Photonics and Plastic Electronics (PPE) KTN	www.ppektn.org
Printable Electronics Technology Centre (PETEC)	www.uk-CPI.com/petec

Sector Skills Council for Science, Engineering and Manufacturing Technologies (SEMTA)	www.semta.org.uk/
Technology Strategy Board	www.innovateuk.org/
UK Trade & Investment	www.uktradeinvest.gov.uk
Welsh Centre for Printing and Coating (WCPC)	www.swan.ac.uk/printing/

See also:

PLASTIC ELECTRONICS IN THE UK – A guide to UK capability, URN 08/668	www.bis.gov.uk/publications
ULTRA EFFICIENT LIGHTING IN THE UK – A guide to UK capability, URN 09/1338	www.bis.gov.uk/publications
Capability mapping for Plastic Electronics	www.printedelectronics.net



Reel-to-reel flexographically printed electronics on the Timsons TFlex press installed at WCPC, Swansea University

Inspecting a test sample manufactured in the PETEC cleanroom

Flexible polymer light emitting diodes developed at Imperial College London using a new patterning procedure known as 'interlayer lithography'

Front Cover:
Photo courtesy of Richard Kirk, CEO of PolyPhotonix

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