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Abstract title**: Managing International Networks for Emerging Technologies – Plastic Electronics sector case study**

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Abstract

This research paper on *Managing International Networks for Emerging Technologies* focuses on identification of the key characteristics of successful nascent industries that may optimize opportunities for value capture through technology commercialization. A standard approach has been to adopt technology roadmapping; however, this method does not adequately address the role in which the industrial network of key actors plays in the development of new technologies into viable products and services. This research explores approaches to the mapping and analysis of value creation and capture to support the design of appropriate networks for the commercialization of new technologies. An industrial network value chain mapping framework, which aims to provide an overview of the structure of emerging technologies (identifying key players including institutional, sector specialists and the principal supply chain actors), is presented and applied in a Plastic Electronics (PE) sector case study context.

Introduction

One of the challenges facing emerging industries is that there is no defined strategy that a firm can follow. The lack of certainty in the environment and on consumer needs forces the entrepreneur to experiment with supply chain strategies through a process described as "effectuation" (Sarasvathy, 2001; Winter & Szulanksi, 2001). This process can be very time consuming and may increase time to market. Furthermore, this process makes it difficult to maintain a first mover advantage. Many authors in the literature suggest that in order to successfully grow a firm from the nascent to mature stages, various dimensions of the supply network, such as resources, partners, supplier, customers, etc. must all be coordinated (Leibold *et al.*, 2002; Sarasvathy & Dew, 2005; Voelpel *et al.*, 2004). In particular, manufacturing value networks are a central part of building an effective business model (Simchi-Levi *et al*, 2010; Hills & Sarin, 2003; Jaworski *et al*, 2000).

However, the design, setting-up and operation of such networks are poorly understood in the emerging technology context. Even at the single company level, the identification of potential value streams from emerging technologies is not a straightforward ‘formulaic’ activity requiring, as it does, skills in specification, design, creativity and development as well as consideration of alternatives. At the network level this task becomes even more challenging requiring interaction between different stages of the manufacturing value chain and across multiple businesses (i.e. a *multi-organizational system* context). This poses additional challenges of communication and co-ordination between partners who are often dispersed internationally, the creation and capture of value, as well issues of confidentiality and IP protection. Understanding international networks is particularly critical in this context because most of the early stage technology projects are currently focused on research activities and lack operational capabilities or skills necessary to transform research outputs into marketable products or services. Such capabilities or skills are often dispersed internationally to benefit from proximity to knowledge, technology, resource or customer bases. Effectively managing internationally dispersed networks, beyond the embryonic phase of technology projects and through to commercial exploitation and value capture is a fundamental driver for sustainable success. The aim of value network design and analysis, in the context of international networks, is to construct insights on the industry and develop mapping techniques for a more effective management of the supply chain and industry network.

A supply network approach can provide a set of techniques that offer insights on the interaction between various stages of the manufacturing value chain and allow entrepreneurs to manage their resources through effective supply chain strategies. The manufacturing value chain analytical framework (*see figure 1*), from R&D, through production and supply to end of product life management (*Srai & Shi, 2008*) forms the basis of the *industrial network value chain mapping* approach presented in this research paper.

Figure 1. Manufacturing Value Chain (Srai & Shi, 2008)

The aim of the approach is to provide an overview of the structure of emerging technologies (identifying key players including institutional, sector specialists and the principal supply chain actors) which may enable transformation of new technologies and ideas into innovative products and services. The mapping of the value chain can provide an opportunity for an emerging sector to develop sub-cluster communities in order to:

- Share best practice, and avoid having to reinvent/repeat routine work done previously
- Identify and devise ways to overcome bottlenecks in the rate of evolution of the new technology
- Develop and draw on a central repository of shared resource models that helps in realizing more rapid developments
- Explore further ways to improve visibility to help beneficial interactions and collaborations between various players.

Generic Industrial Systems Mapping Approach

This approach provides an initial overview of industrial system structure: identifying the key players including institutional, sector specialists and the principal supply chain actors. The approach can also be used to capture key linkages between industrial players and to identify firms involved in supporting major product categories.

A review of the literature on international industrial networks, specifically on historical approaches to industrial network/value chain mapping and analysis was conducted (summarized in *table 1*), and was used to construct the final industrial system mapping process.

Table 1. Summary of key industrial network/value chain mapping and analysis literature by type, objective and emphasis

Type	Objective	Emphasis	Reference
Functional Map	Process Mapping	Product & Information flows	SCOR '06
Tier 1& 2 Players	Network Structure	Relationships, Complexity	Lambert *et al* '98
Tier 1/2 Suppliers	Supplier Process Map	Supplier role, relationships (hard/soft)	Choi & Hong '02
Process Flows	Activities, Mechanics	Firm roles, leaders, push-pull point(s)	OR fields
Product Shape	Network Shape	Classification	Slack *et al* '95
Service	Thru-Life Management	Life cycle, design authority, services	Slack '05
Value Stream Maps	Value added/lost	Relative cost, quality, waste...	Hines & Rich '97
Full-S-Chain	Descriptive	Academic, conceptual	New '95, Jagdev '01
Lean Mfg Map	Component Flow	Lean/inventory reduction	Rother & Shook '99
Reverse Log's/Service	Directional Flows	Reverse Logistics & repair	Blumberg '99
Geometry	Network flow/logic	Alternative routes/options	Fine '98
Organisational	Organisation Network	Co-ordination	Bartlett & Ghoshal '89
Geographic	Geographical Spread	Co-ordination	Porter '86
Changing Ind. Structure	Industry Dynamics	Changing actor-scope profile	Jacobides *et al* '07
Supply Network Configuration	Supply Network Design	Structure, dynamics, relationships	Srai & Gregory '08
GVC Governance Models	Governance, Value capture	Governance	Sturgeon '08

The approach has been utilized in a series of Emerging Industry/technology Supply Network case studies based on industrial systems that exhibited different types of disruptive innovation (Srai *et al*, 2012) .The following industrial systems were examined:

- Technology Platform development in the UK Industrial Biotechnology industry (IB) (Srai, 2010)
- Emergence of product-service models within Defence Aerospace
- The transition of a Maritime cluster into a niche high-specification product supply
- The early evolution of firms supporting sustainable Built-Environments
- Product generation changes in global Photovoltaics (PV)
- New routes to market within Last Mile Logistics

These cases included a mix of industrial systems that demonstrate new markets, technology platforms, new routes to market, and new product/service delivery models. In some cases, where there were multiple product categories (e.g. IB) or co-existing product-generations (e.g. PV) within the chosen industrial system, at least one focal-firm from each product category/generation was used to capture the category-specific elements of industrial emergence. These mapping activities can be used to inform the creation of industrial ecosystem maps as relevant focal Firm, Government and country specific advantages were captured to capture the context in which emergence was taking place. Using this approach in a consistent manner also provides a basis for the mapping of emerging industrial systems and an initial basis for cross-case analysis.

The final methodology (Srai, 2010) involved the:

- **Identification of sector institutional players and secondary stakeholders** e.g. research, industry development, specialist firms etc
- **Development of a Value Chain Process Map** e.g. production processes and unit operations etc

- **Identification of the industry actors** e.g. supply chain actors, organisational types, linkages between organisations, material, potential information and value flows etc
- **Technology process and product types** e.g. Identification of substrates, process technologies etc

This industrial sector mapping approach was extended to map the Plastic Electronics sector, identifying focal firms operating at different (and multiple) points in the value chain and/or at varied stages of development with upstream and downstream focus, as part of this research.

Industrial System Mapping - Plastic Electronics

Plastic electronics (PE) is a branch of electronics principally based on polymers rather than silicon; electronic circuits can be manufactured at relatively low cost by printing electronic materials directly onto a range of surfaces including plastic, textiles and paper.

New firms have emerged with innovative manufacturing processes to deal with plastic substrates, whereas other firms have re-formed and made use of their existing capabilities in the electronics industry to diversify their product portfolio. It is also a technology that not only can be integrated in a wide number of applications, but also requires the integration of many processes and techniques developed in other industries. Therefore, companies at every position of the supply chain were targeted as part of this study, i.e. eight in-depth case studies were conducted, involving firms operating at different (and multiple) points in the value chain and/or at varied stages of development, in the context of PE. Focus was placed on selecting UK-based SMEs developing technology for OLED displays or OPV devices. In addition (although not based in the UK) two leading OLED display OEMs were interviewed as part of the in-depth case studies. These case studies are relevant because of their interaction with UK supply networks and as they also captured a critical international network dimension in the sourcing of materials. Furthermore, their size and experience in the electronics market provided valuable insight into international markets and, consequently, how the UK network should ideally be configured to capture value and participate within a global supply network.

Identification of sector institutional players and secondary stakeholders

Supporting infrastructure most influential on the development of the PE industry in the UK involves Government, Universities and Centres of Excellence.

Government has a large role to play in the coordination of the activities within PE ecosystems. Not only does it provide essential funding for start-ups, it also encourages strong networking activities through the Technology Strategy Board (TSB) and has the possibility to influence future markets e.g. by imposing regulations and tariffs on carbon dioxide emissions. Universities, in particular, play a very critical role at the R&D stage, (particularly, in development of novel materials and inks), a point confirmed by the large OEM case respondents interviewed as part of this study.

In addition to these two groupings, centres of excellence have been developed to support university research, start-ups, and other industry players. These centres provide essential facilities for prototyping and testing, manufacturing equipment and networking opportunities. The most influential of these groups is PETEC, the UK's National Printable Electronics Technology Centre. PE is a technology that not only can be integrated in a wide number of applications, but also requires the integration of many processes and techniques developed in other industries.

In the UK, PE is being tailored to meet the product specifications of applications such as photovoltaics, displays, lighting and smart sensors. Hence, the TSB has regrouped research areas (overlapping industries) into centres of excellence (e.g. Electronics, Sensors & Instrumentation and Photonics & Plastic Electronics) to work and network together. The three supporting groups that constitute the sector institutional players and secondary stakeholders map are illustrated in *figure 2*.

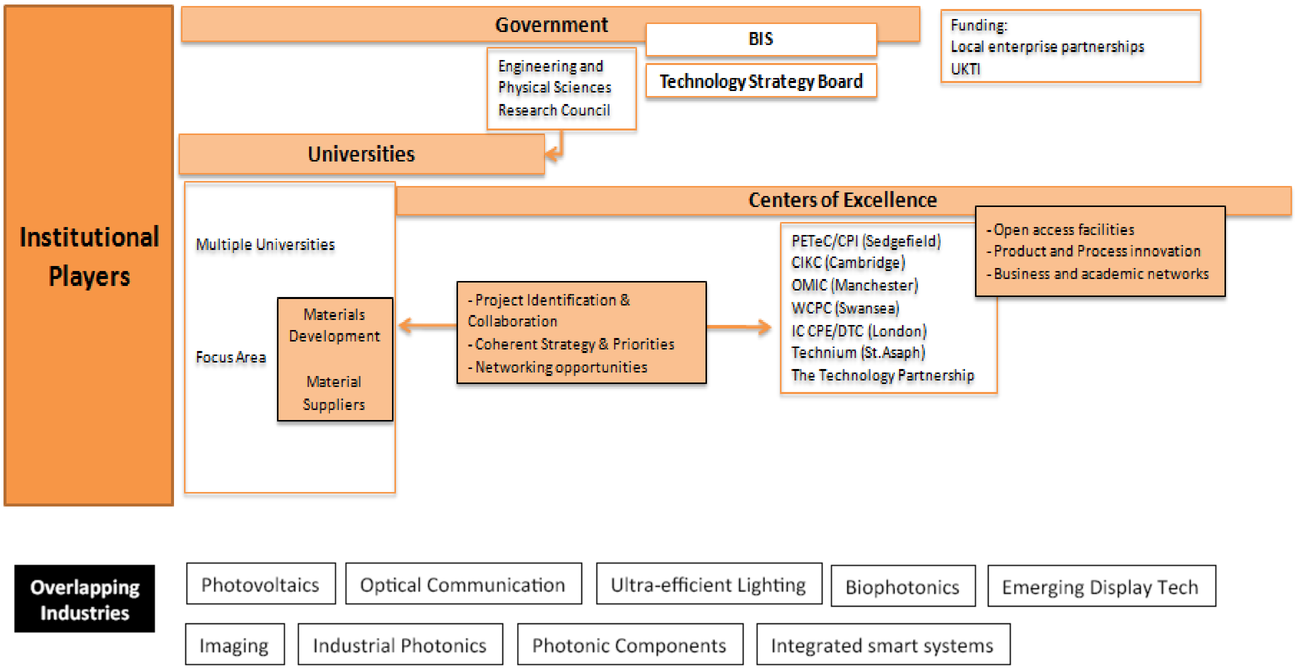

Figure 2. Plastic Electronics: Institutional players, secondary stakeholders and overlapping Industries

Development of a Value Chain Process Map

A manufacturing value chain, specific to the PE industry, was adapted based on this in-depth study of the PE industry. Changes from the conventional manufacturing value chain (Srai & Shi, 2008; Srai, 2010) are summarized in *figure 3*.

The supporting value chain process map (*figure 4*) was constructed using secondary data e.g. information available from centres of excellence, industry & company reports and then verified by the in-depth case study respondents. In addition to the processes, the main technological challenges to be overcome can be identified in order to highlight potential areas where value creation is possible and which may influence network configuration design.

There is potential for significant value creation at the beginning of the supply chain. Science and technology specialists are continuously trying to exploit and tailor the properties of materials such that final products meet customer expectation.

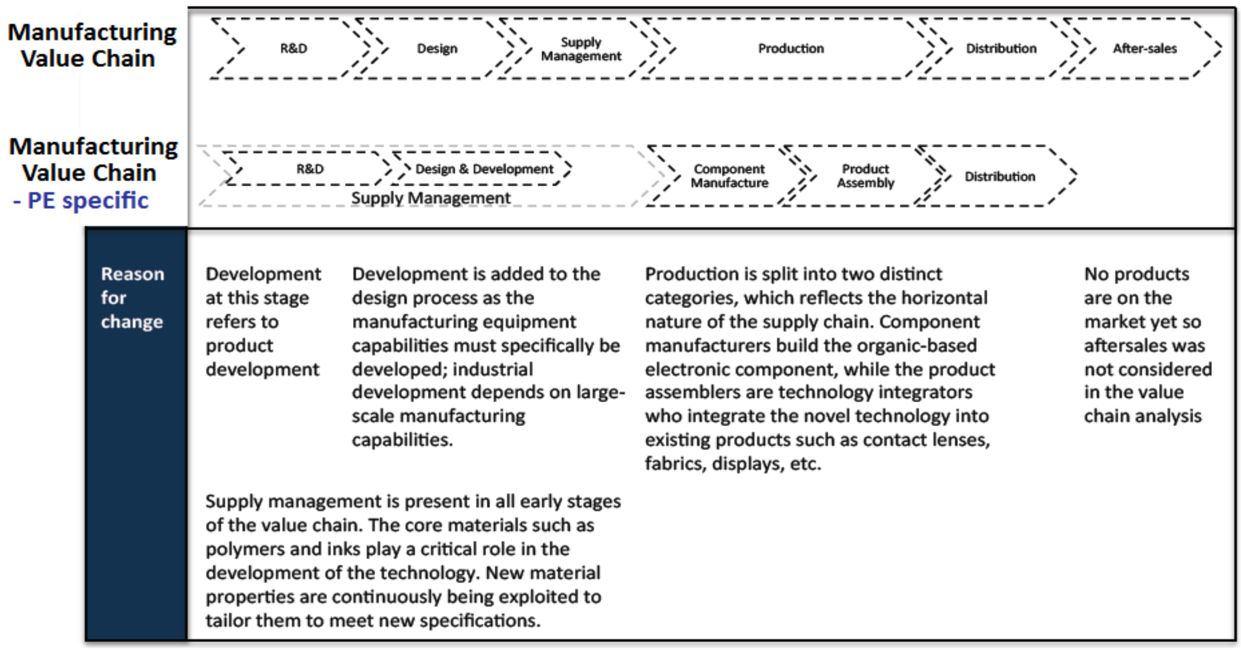

Figure 3. Manufacturing Value Chain specific to the PE industry

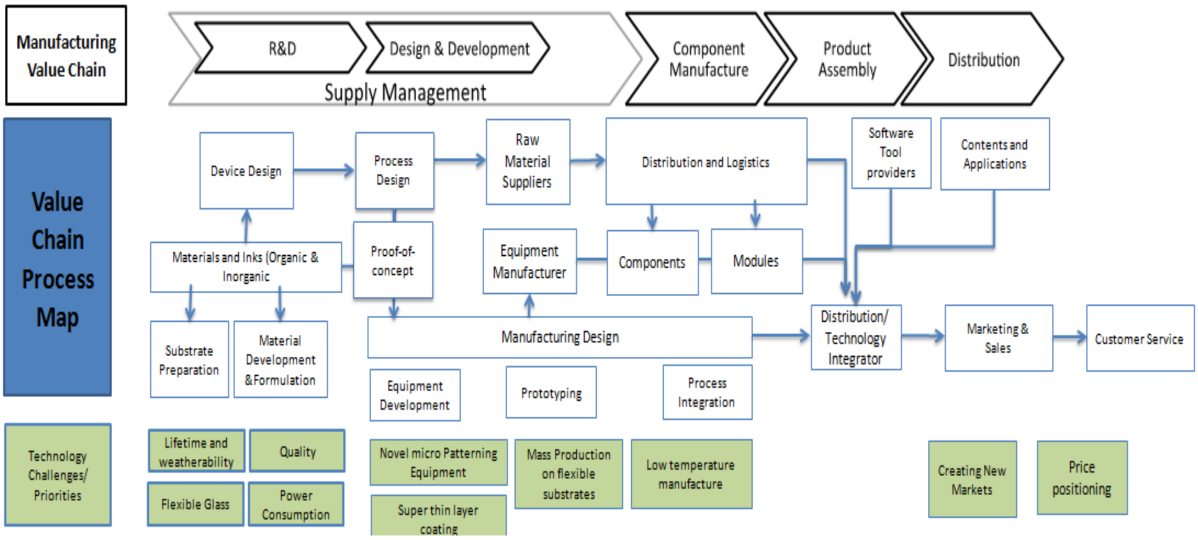

Figure 4. PE Value Chain Process map

There is also additional value that may be created in the design of equipment and manufacturing stages. Most of these challenges are fuelled by government incentives to reduce carbon emissions, water consumption and the use of toxic materials. However, the main challenge in this part of the supply chain is developing equipment that will enable the mass production of newly developed technology with high yield and throughput. The choice of manufacturing process is very influential on the technology selection as it, in part, depicts which materials can be chosen for a particular technology.

Towards the end of the supply chain, the price positioning of products could have a significant impact on capturing value. Academic literature highlights a distinction between face value and exchange value. The relationship between the two may not be defined, as customer expectations are not yet developed. However, it can be expected that the price of OLED displays, for example, will be twice the price of the equivalent LCD displays before stabilizing to a similar pricing. Manufacturers can retain more value as they develop more cost efficient manufacturing techniques, partly, by removing the need for glass support in the process.

Identification of the industry actors

The purpose of the industry actor map (*figure 5*) is to visualize the ecosystem in a structured way. The companies with the most influence in each part of the supply chain are listed based on information available through industry reports (dated 2009). It was noted that since 2009, a number of SME's have either ceased to exist, have changed names, or have merged with larger firms. Many companies have developed strong capabilities in more than one area of the supply chain, however, for visualization purposes; they were only listed under the process that best characterises their role and influence in the ecosystem. The relationships between the actors are complex as the processes and materials required for the development of product(s) are numerous. Therefore, only the critical relationships, in the development of this industry, are illustrated. Although the focus is, somewhat, limited to the industry in the UK, some Asian, European and American companies are listed under Product Assembly and Distribution (route-to-market).

The strong printing industry in the UK is very much reflected by the number of firms contributing to the design and development of printing equipment. It has been observed that the network around the manufacturing equipment companies is very strong. They must ensure that the materials, inks and films being developed are compatible with the equipment. These developments must then translate to large volume material suppliers, which are currently very limited in number in the UK. The current large volume material suppliers have successfully entered the PE ecosystem because they were already market leaders in the film industry, which has many applications other than plastic electronics. Firms in the Product Assembly category of the supply chain heavily rely on the material developers for unique technology. They do not have the capability of contributing to this part of the supply chain, therefore, joint ventures and strong relationships with the upstream players is critical in gaining a competitive advantage. Sourcing high-end materials and inks allows firms in the supply chain (downstream), through their research centres, to find new applications and innovative product features. The large OEMs mentioned in this section (Samsung and LGD) have expanded their technology portfolio without external funding. However, most of the other SMEs depend on venture capital funding.

The companies listed under the Distribution (route-to-market) process are relevant for the OLED display products. Smart phones may be the first products to integrate OLED technology, and tablets, such as Apple's iPad, are likely to follow. The distribution (route-to-market) network is very weak because current manufacturing capabilities are not yet developed to meet the global demand for such products. The firms in dotted boxes are potential customers of the product assembly manufacturers.

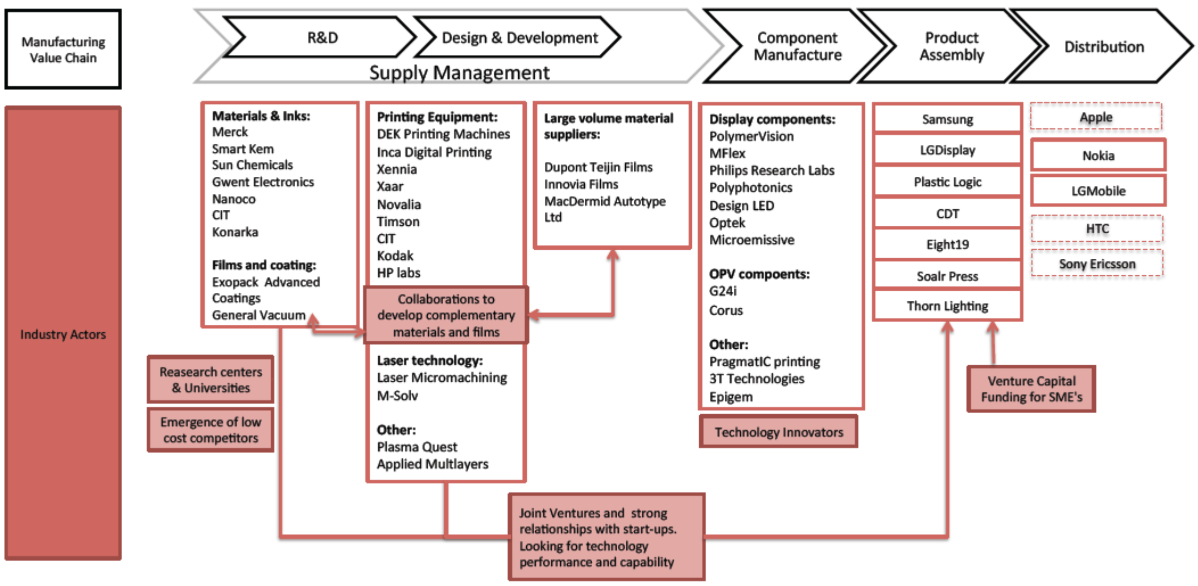

Figure 5. PE Industry actor sector mapping

Technology process and product types

A generic process technology map, which is an overview of the processes for a range of plastic electronics products, is shown in *figure 6*. The early process stages tend to be well developed, characterized by a continuous flow production line. Progression down the supply chain becomes more capital intensive, as novel processes are necessary to work with plastic substrates. Some of the final processes are labour intensive and require manual processing to ensure very high quality standards.

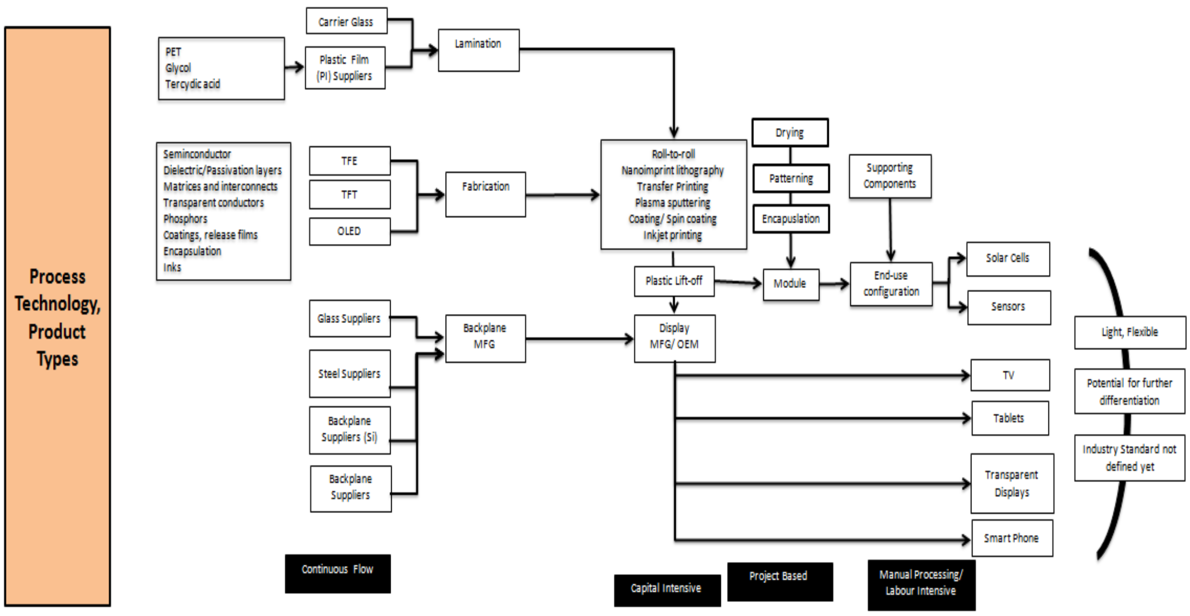

Figure 6. PE Technology process and product types

Conclusion

Previous academic research has described a well understood linkage between technology platforms and final product innovations. However, limited attention has been paid to the industrial system that ‘connects’ technology developments to final products.

The framework adapted and tested in this research can provide a basis for understanding the industrial system and the interconnections between actors that need to take place to enable industry evolution. The *Industrial System Mapping methodology* has been extended to and tested within a Plastic Electronics sector context.

The research outputs are also valuable for a range of industrial players as it provides:

- A visualization and communication tool for firms to evaluate competencies and how they interact with their ecosystem.
- A performance indicator of industry development as a whole across the dimensions of supply chain connectivity and know-how. It can be utilized to quickly spot weaknesses and opportunities in the supply chain and identify resources so that manufacturers can be more innovative and provide the required supply of products ahead of competition.
- Approach that can support supply chain strategies in terms of complex value networks. Likewise, it may inform the most appropriate supply chain configurations, to support specific industrial emergence modes.
- A powerful networking tool if used in Centres of Excellence, such as PETEC, UK's National Printable Electronics Technology Centre.

Future Work

This research describes approaches and frameworks for assessing the ways in which supply networks can influence and shape emerging industries. Future research opportunities includes the development of a conceptual framework linking technology evolution, network configuration and product by integrating supply network configuration and industrial system value chain mapping concepts, with product technology road-mapping frameworks, and/or scenario planning tools. The current study is limited by a small sample size of sector studies, and further industrial system case studies will be used to test and validate the mapping approach.

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