The Emergence of Commercial Inkjet

Barriers and enablers in the development of new technologies and markets

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IfM MANAGEMENT TECHNOLOGY POLICY

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1 Introduction

Investigating the past history of a system allows an improved understanding of the factors that have influenced its development and how these factors may affect – or even recur in – the future. This has been the focus of research in the "Managing creation and transitions" project, part of the Emerging Industries Programme (EIP) at the Institute for Manufacturing.

Building on this EIP research, the Centre for Technology Management and the Inkjet Research Centre have conducted research to better understand the emergence of the commercial inkjet cluster in Cambridge. The objective of this project is to draw insights from the historical barriers and enablers that have inhibited and supported the emergence and evolution of the Cambridge inkjet cluster. This report describes the work that has been undertaken in this project to date.

We begin in Section 2 by providing a summary of the research of the "Managing creation and transitions" project and the rationale for selecting the Cambridge inkjet cluster for study.

In Section 3 we describe the *Expert Scan* interviewing method that was used to collect data for this report. We then go on to describe the consolidation of the 13 individual maps into a 'meta-map'. This map provides an overview of the evolution of commercial inkjet in Cambridge.

This meta-map was presented at the "Inkjet Printing for Non-Graphical Applications" workshop that was held at the Institute for Manufacturing on 6th December 2010. During this workshop, a strategic roadmapping activity was conducted, with opportunities for commercial inkjet identified. This led to the creation of four emergence roadmaps around 3D printing, power generation and bio applications. This workshop is described in Section 4, with the four emergence roadmaps included in Appendix A.

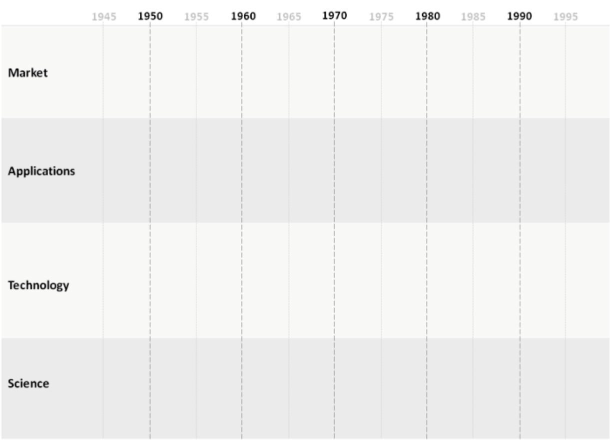
In Section 5, we go on to summarise the barriers and enablers to the development and commercialisation of commercial inkjet technologies that have been identified through the interviews. Then in Section 6, we reflect on the research to date, feedback received from practitioners, and future research activity.

2 Background: Emerging Industries Programme

The Emerging Industries Programme (EIP) is an interdisciplinary research programme at the Institute for Manufacturing that is investigating how new industrial systems emerge from the development of scientific and technological knowledge. Within this programme, the "Managing creation and transitions" project has used established roadmapping-based approaches to map the journeys and characteristics of technology-based industrial emergence.

Roadmapping frameworks, such as in the figure below, generally comprise two key axes: (a) time on the horizontal axis (traditionally running forward into the future for strategic roadmaps); and (b) a set of 'perspectives' or themes on the vertical axis, which capture the characteristics of the system. The key events, features, processes, barriers and enablers which govern the evolution of the system are then plotted on the map. The strength of roadmapping is that it can be customized for a broad range of strategic, industrial and innovation contexts, as has been done in configuring it for mapping industrial emergence.

Over 40 industrial quick-scan pilot maps have been created using this mapping approach, allowing the identification of common characteristics of industrial emergence, together with important dimensions and a focus on a chain of demonstrators that delineate the various phases and transitions.



Building on these insights, a suite of four tools has been developed that firms can use to capture historical learning and explore future opportunities.

1) Industry Scan (IS): a method for mapping, understanding and communicating patterns, enablers and barriers associated with historical industrial emergence, supporting policy, strategy and innovation processes.
2) Expert Scan (ES): an interview-based method for capturing personal perspectives of historical industrial emergence, which can be combined to understand patterns, enablers and barriers, as an input to strategy, policy and innovation processes.
3) Organisation Scan (OS): a workshop-based method for mapping and sharing experience of historical emergence, to understand patterns, enablers and barriers, as an input to strategy, policy and innovation processes.
4) Emergence Roadmap (ER): a workshop-based roadmapping approach, configured to support organisations to navigate science and technology based industrial emergence, supporting decision-making and action.

The second tool, the *Expert Scan*, was developed through investigation into commercial inkjet and this process is described in this report. Commercial inkjet was selected for investigation because Cambridge-based firms are acknowledged to be at the leading edge of commercial inkjet development, significant technical development has occurred in the region, and new inkjet technologies continue to lead to the emergence of new markets.

For more information on this research and the tools that have been developed, please refer to the "Managing creation and transitions" project website, http://www.ifm.eng.cam.ac.uk/imrc/eip/transitions.html

3 Mapping the Industrial Emergence of Commercial Inkjet

3.1 Expert scan

Between June and September 2010, data was collected through 13 interviews with industry experts (listed in the table on the right). During these interviews a visual interview tool, the *Expert Scan*, was used to capture how the commercial inkjet cluster in Cambridge emerged and evolved. In this section we describe the data collection process.

Name	Position	Organisation
Graham Martin	Director	Inkjet Research Centre
Bill Baxter	Former CEO	Inca Digital
Debbie Thorp	Business Development Director	Global Inkjet Systems
Paul Drury	Technology Manager	Xaar
Steve Temple	Former CTO	Xaar
Mike Willis	Managing Director	Pivotal Consulting
Peter Walsh	Business Manager	FFEI
Niger Caiger	Director, Global Digital Technology	Sun Chemical
Lee Metters	Strategic Product Director	Domino
Guy Newcombe	CTO	Tonejet
Tim Phillips	Marketing Manager	Xennia
Steve Thomas	Product Engineering Director	Conductive Inkjet Technology
John Corrall	Managing Director	Industrial Inkjet

3.1.1 Pre-interview

When interviewees were contacted, they were provided with a summary overview of the mapping process, together with an example map of the type expected to be developed during the interview. These 13 interviewees are listed in order of interview in the table below. Following confirmation of their participation, the interviewees were provided with a one-page briefing note that described the exercise in greater detail.

3.1.2 At the interview

All but one interview was conducted face-to-face by Simon Ford and Michèle Routley. The one exception was the interview with Niger Caiger, at which only Simon Ford was present.

During the mapping process, interviewees recorded the events and activities that they considered to have significantly contributed to the emergence and evolution of the sector or their organization onto Post-it notes, positioning these on the map against chronological (horizontal) and categorical (vertical) axes. These axes provided a semi-structured canvas onto which their narrative notes could be positioned. The chronological axis was determined through consultation with the interviewee over the scope of the interview. Three general categories were used at the beginning of each interview on the categorical axis: technology, application and market. In some interviews other themes were found to be significant and extra categories were added. These included resource, company and business categories.

As the interview proceeded, the lead interviewer was principally engaged with the interviewee, while the second interviewer recorded the narrative associated with the Post-its. At the end of the interview, the map was reviewed and the interviewee was asked if anything else should be added or reorganised, to draw any notable interlinkages between the Post-it notes, and to highlight the most significant enablers and barriers.

3.1.3 Post-interview

After the interview, a digital version of the map was created using PowerPoint software, along with a 2-3 page supporting synopsis of the interview. These were sent to the interviewer for validation to check that their comments had been correctly captured, with revisions made as a result of their feedback. In some of these, additional symbols and images were introduced to highlight the significant enablers or barriers that were described by the interviewee.

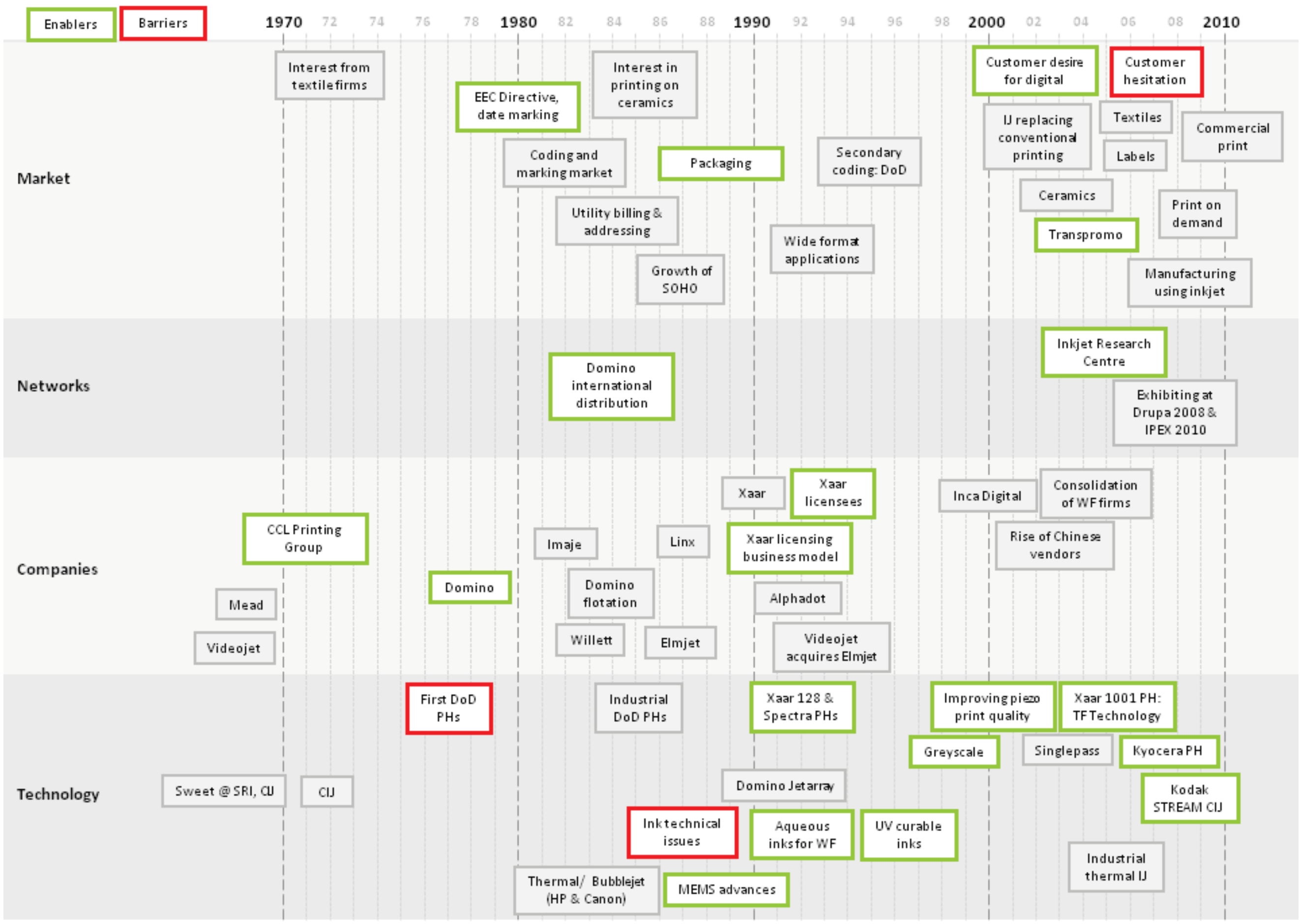
3.2 Meta-map of the industrial emergence of commercial inkjet

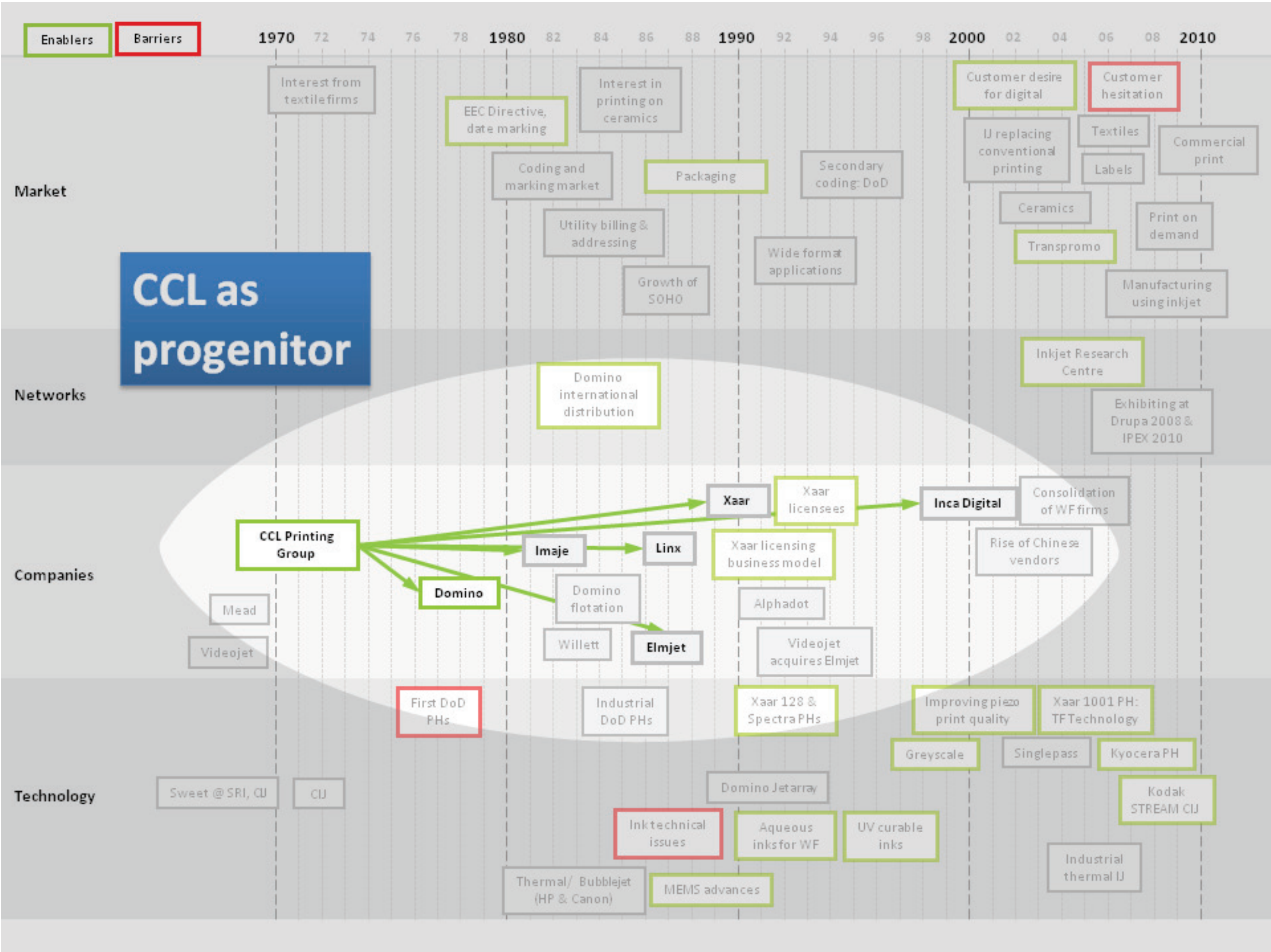
Following the completion of the 13 interviews with inkjet experts, the maps have been consolidated into a single 'meta-map' (below). The process for this consolidation involved searching for occurrences of replication in the individual maps. If two or more individual maps included a particular feature then this was included in the meta-map.

Consequently, this map provides a visual representation of the technologies, companies, networks and markets that experts consider to have significant contributed to the industrial emergence of commercial inkjet.

The map is divided into four categories on the vertical axis: market, networks, companies and technology. Time is depicted on the horizontal axis. The boxes on the map show developments that occurred in two or more individual maps. Those developments that were identified as key enablers are highlighted with a green border, while those identified as key barriers have a red border.

In the following sections we describe some of the key historical narratives that lie within this map: the importance of Cambridge Consultants Ltd (CCL) as progenitor, and how the meta-map represents the developments of the two main inkjet technologies, CIJ and DoD.



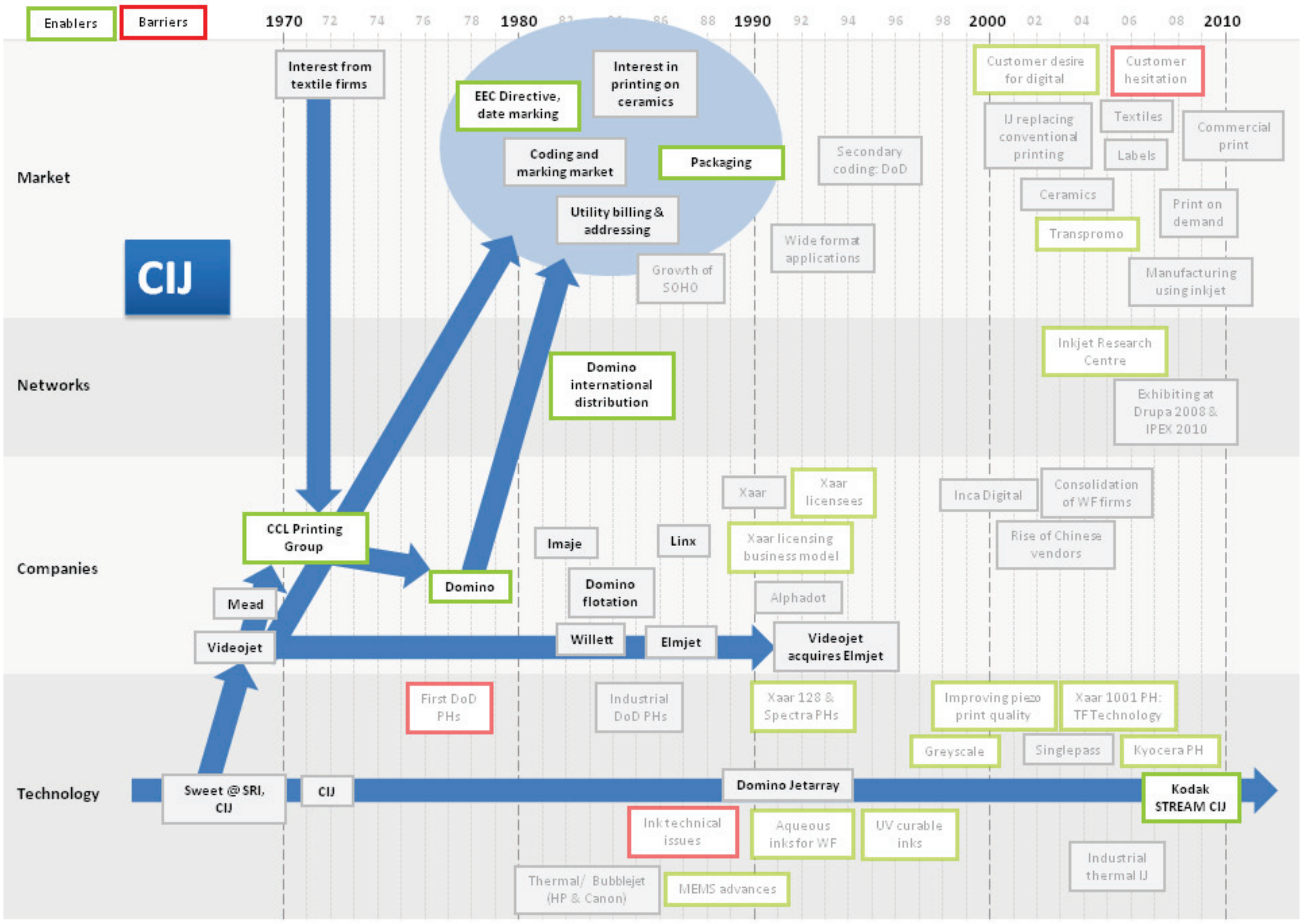


3.2.1 CCL as progenitor

From the late 1960s to the mid 2000s, Cambridge Consultants Ltd (CCL) maintained an interest in inkjet printing through its Printing Systems Group (PG). Technical knowledge developed by this group has resulted in a number of spin-outs, in most cases led by a CCL PG Group Leader.

The first spin-out was Domino in 1978, led by Graeme Minto, around a single-jet continuous inkjet technology (CIJ). Mike Keeling was the next Group Leader. He left CCL to join Willet before going on to found Linx Printing Technologies. Later, Graham Martin became head of the group, leaving CCL when he led the spin-out of Elmjet with Will Eve.

The next spin-out was Xaar, led by Steve Temple and Mike Willis. In contrast to the earlier spin-outs on CIJ, Xaar was developing drop-on-demand (DoD) technology. Finally, Will Eve returned to CCL, before going on to found Inca Digital with Bill Baxter to address the wide format market.

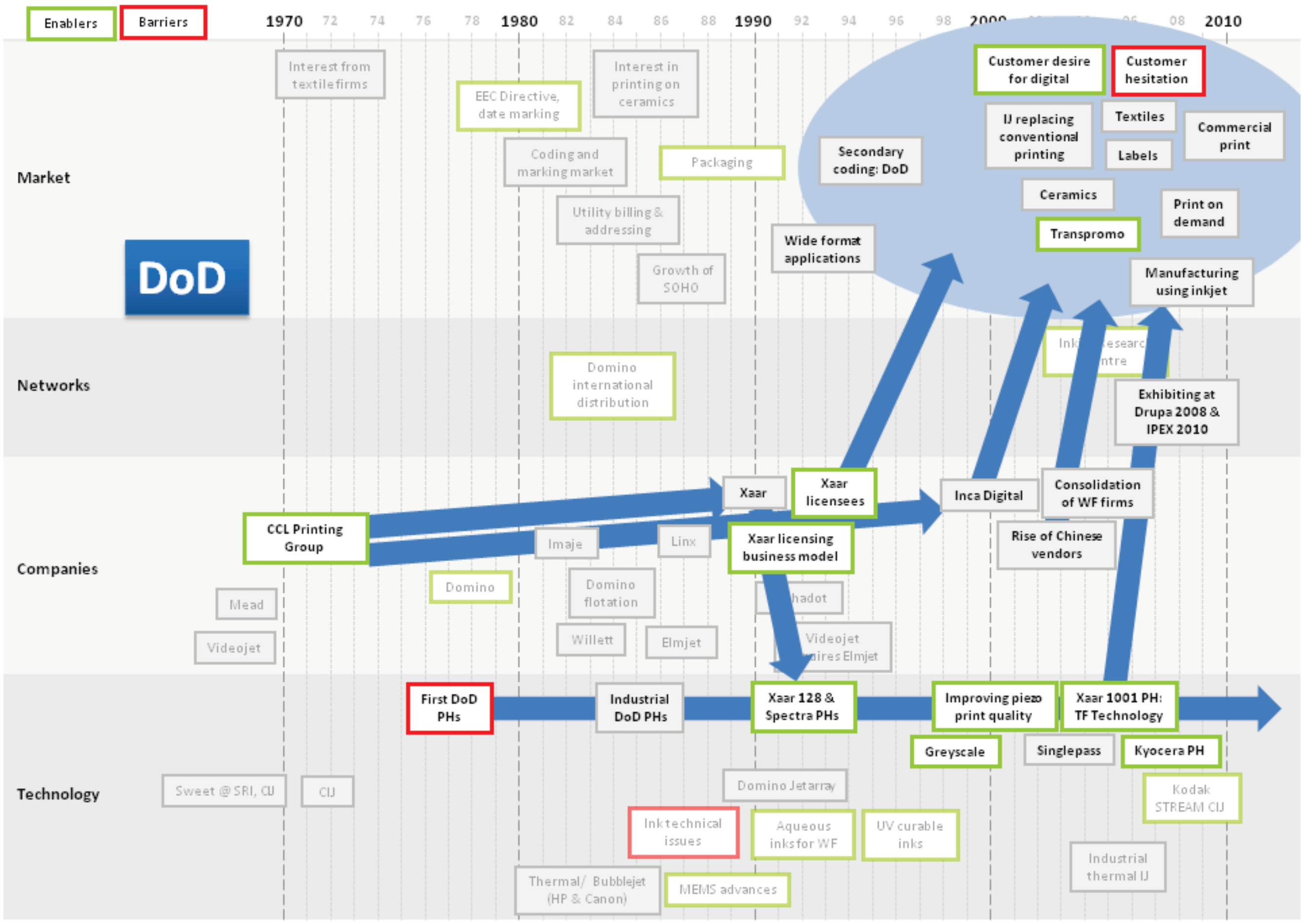


3.2.2 Continuous inkjet (CIJ)

Continuous inkjet (CIJ) was developed in the 1960s by Richard Sweet of the Stanford Research Institute (SRI). However, the first two firms to develop the technology were Cambridge Consultants Ltd (CCL) and American Can. These created the first two players in the industry: Domino, which was spun-out from CCL in 1978, and Videojet. Both were using similar technology: single nozzle CIJ using solvent inks.

In the period 1975-8, European legislation came into effect that required dates to be marked on products. At the time there were no printing technologies that could print on a moving, cylindrical object. CCL PG Group Leader, Graeme Minto saw the potential opportunity that the legislation represented and this led to the formation of Domino to capitalise on the opportunity. This was the origins of the 'coding and marking' market that CIJ firms continue to address.

In the later 1980s, the use of multiple printheads in inkjet printers opened up another market in billing and addressing, and led to development of array CIJ (also known as binary inkjet).



3.2.3 Drop on demand (DoD)

While the first piezoelectric DoD printheads were developed in the late 1970s by Kyser and Sears at Silonics, it was some time before they became commercially viable. It was not until another CCL spin-out, Xaar, and Spectra began to produce more robust printheads that their application began to grow. Central to this growth has been the initial licensing model that Xaar used, with early licensees including Toshiba Tec, Minolta, Seiko Instruments and IBM. Many of these licensees have contributed to the development of the technology.

The improvements in DoD printhead reliability and print quality led to its application in wide format printing, and more recently in transpromo, labels and textiles. There are numerous new markets that DoD technology might enter in the future. The development of recirculating ink systems such as the Xaar 1001 printhead improves printhead reliability further. However, these new markets are already served by traditional printing technologies and, despite recognition of the flexibility and customisation advantages of inkjet, customer are reluctant to invest in relatively unproven technologies.

4 “Inkjet Printing for Non-Graphical Applications” Workshop

On the afternoon of 6th December 2010, 15 inkjet professionals gathered at the Institute for Manufacturing in Cambridge to review the early stage outputs of the interview data and to explore and discuss future applications of inkjet technology. The workshop was organised by Simon Ford, Michèle Routley and Rob Phaal of the Centre for Technology Management at the Institute for Manufacturing. The workshop participants are listed in the table on the right.

The main focus of the workshop was the identification, prioritisation and development of future opportunities for next generation inkjet printing applications. Through use of a strategic roadmapping tool, more than 60 opportunities were identified by participants, with 3D printing, power generation and bio applications voted the most promising.

To explore these opportunities, the *Emergence Roadmap* approach developed by the Centre for Technology Management was used to facilitate the development of these opportunities. This led to the creation of four emergence maps: 2 groups explored 3D printing, with one group each exploring power generation and bio applications. Each of these emergence maps focuses on a particular market opportunity, identifying potential demonstrators that could be developed and actions taken in pursuit of these opportunities. These emergence roadmaps are in Appendix A.

Commercial considerations and concerns over confidential material prevented openness and limited discussions. Consequently the use of the Emergence Roadmap tool was not as successful as hoped. However, the experience provided us with valuable insight into the application of this tool and that its use should be limited to opportunity analysis at the intra-firm level.

Name	Organisation
Rob Harvey	AtomJet Ltd
Mark Crankshaw	CDT
Steve Thomas	Conductive Inkjet Technology
Lee Metters	Domino
Peter Walsh	FFEI
Bill Baxter	Inkjet strategy advisor
Carole Noutary	FUJIFILM Sericol
Debbie Thorp	Global Inkjet Systems
Ian Hutchings	Institute for Manufacturing
Graham Martin	Institute for Manufacturing
Mike Willis	Pivotal Consulting
Steve Jones	Printed Electronics Ltd
Guy Newcombe	Tonejet
David Chapman	Xaar
Tim Phillips	Xennia

5 Discussion: Barriers and Enablers

In this section we summarise the barriers and enablers to industrial emergence that experts identified during the interviews.

5.1 Barriers

5.1.1 Financial resources

The source of funding affects the pace of technical development. In soft start-ups, income from consultancy work can help fund projects. However, the specifications of these are subject to the requirements of the customer and can lead to the firm following the source of funding more than is desirable, slowing the pace of development.

For new technology-based ventures, venture capitalists (VCs) are a notable source of funding. However, VCs that do not possess specific sectoral knowledge can fail to recognise the potential of new technologies. This is often the case in emerging industries where technologies are immature and markets are uncertain.

In normal business conditions, sales revenues provide the financial resources for technical development to occur. While using licensing as a revenue generation strategy can prove successful, it is less effective during the emergence of a new industry. This difficulty derives from there being few firms operating in the industry and the licensee market quickly becoming saturated.

5.1.2 People

Failing to recruit staff with the necessary technical expertise is often a barrier to the growth of the firm. There is competition between firms for acquiring the services of skilled professionals whose expertise is scarce. This competition becomes less intense and recruitment becomes easier during periods of economic depression (e.g. the manufacturing downturn), facilitating the movement of professionals between positions of employment.

5.1.3 Technology

Printheads, inks and the interaction between the two have been significant technical barriers.

Early piezo printheads for wide format printing faced issues of reliability and ensuring nozzle alignment. The development of wider printheads has been limited by the need to trade-off technical and economic considerations: wider printheads have a greater probability of manufacturing defects and nozzle blockage problems.

Low quality inks also represent barriers to the growth of new markets: even if the printheads are of good quality, the inks have not always been of the same standard. This barrier derives from the need to match printheads and inks for particular applications and substrates. Particular types of printheads are limited to using certain types of inks (e.g. aqueous inks in thermal printheads) and this limits the scope of potential applications. Each ink requires its own formulation and it is expensive to customise the ink to the printhead. As a consequence of the low volumes currently required for emerging applications, ink suppliers have limited interest in these specific inks, instead preferring to sell into markets that are already established.

A persistent barrier to the development of new inkjet technology has been the development and integration of complementary technologies and peripherals. High speed printing requires a high speed datapath and places demands on software and electronics, with advances in these often lagging behind the advances in mechanical functionality.

Other technical barriers have included the lack of understanding of the basic science of inks (e.g. reduction or elimination of micro-satellite formation), the complexity of ink management systems (e.g. aqueous inks for transpromo), and nozzle failure and reliability issues.

Overcoming these technical challenges is non-trivial and it often takes longer to complete R&D for a technology or system, requiring greater financial resources than budgeted. The costs of development and integration are significant barriers.

Furthermore, to introduce a new product can take significant time and resources. Consequently, under resource constraints, technology development follows particular performance trajectories and this can create blindness to new possibilities.

5.1.4 Customers

In markets for new technologies there is uncertainty about the timing and growth of these markets. This often results in firms maintaining a watching brief and concentrating on existing markets, a situation which may result in insufficient market leadership. When the market does emerge and become more complex, there is then the challenge of identifying and working with the best partners.

When attempting to sell into existing markets, regulations and testing requirements can prove significant barriers to entry. When the market opportunity itself is new, new design rules may need to be established before industry consensus can be achieved.

Market conservatism has been a recurrent problem for inkjet firms as they have attempted to enter new markets. In established industries where technical change is slow and investments are long-lasting, customers prefer to work with those suppliers with whom they have existing relationships.

A lack of customer belief represents a barrier to the growth of these new markets. Customers do not want to take on a disruptive technology until they can see that it works. It is difficult to prove that it works, in terms of robustness and reliability in volume, until a customer has taken it on. This vicious circle proves a barrier for business development.

A lot of work is necessary to convince customers in these industries that they should switch from conventional printing technologies. Such customers need to see multiple demonstrations of the technology as it is developed before they are reassured of its capabilities and reliability.

One of the main benefits of inkjet is the ability to produce short runs. To take advantage of this benefit, customers may need to change their business model, a step they may be hesitant to take. The structure of the value chain also presents a barrier to the customer's acquisition of an inkjet system because they do not always experience direct financial benefits. For example, in textiles printing, it is the textile printers that need to market the investment in inkjet equipment but the savings from reduced inventory arising from flexible short runs are made elsewhere in the value chain.

Some of the barriers to inkjet adoption derive from the perceptions of inkjet technology. These perceptions are coloured by reliability issues of early industrial inkjet printers and the knowledge of the low throughput of desktop inkjet printers. In some cases when customers have seen the potential of inkjet technology they have attempted to develop the technology in-house and failed. Their failures have contributed to perceptions of the reliability of inkjet. In other cases, customers have placed too many demands on the specification of their equipment. In attempting to satisfy these demands, inkjet firms have tried to squeeze too much out of the technology and the resulting technology has not been fit for purpose.

Selling into global markets leads to different approaches being needed in different regions, with pricing, distribution channels and intellectual property protection of significance.

5.1.5 Competition

The increasing maturity of the existing markets in which they operate prompts firms to explore new applications of their technical capabilities and new markets. As the SOHO market has matured it is expected that HP and Canon will become more interested in the currently fragmented field of industrial inkjet.

When established companies such as HP and Canon enter new markets in which smaller inkjet firms are already operating, they often cannot match the technical quality being offered by the smaller firms. However, their brand, distribution channels and capability to offer finance deals provides them with a different competitive edge.

These large firms invest heavily in R&D to improve their products and file thousands of patents each year to protect their competitive position. Accumulating these vast portfolios of patents allows the firms to claim infringement against competitors with similar technologies.

5.2 Enablers

5.2.1 Financial resources

Funding is a key enabler for new venture success. A number of different mechanisms have been used by firms to secure the financial resources necessary to fund technological development and the growth of the venture.

Firms following the 'soft' start-up approach to developing new ventures have used consultancy work, drawing on their client networks. Grants and licensing income have also been effective at funding development.

Flotation on the stock market has occurred in the case of several firms. These have generally come once the initial products offered by a venture have had commercial success. Once floated, firms gained the capital necessary for further technical development, and manufacturing and distribution expansion.

5.2.2 People

The story of commercial inkjet in Cambridge is characterised by the high degree of entrepreneurial activity, with a large number of these new ventures being spin-outs from Cambridge Consultants Ltd (CCL). Graeme Minto, Mike Keeling, Graham Martin, Will Eve, Mike Willis, Steve Temple and Bill Baxter are among those that have led spin-outs from the Printing Systems Group at CCL, leading to the development and commercialisation of the technology in ways that wasn't possible within CCL.

The success of a new venture is affected by the previous experience of its members and the balance between technical and commercial expertise. One founder had experience of running his own business and managing large interdisciplinary projects, and had attended courses on contract law and accounting.

The ability to recruit new staff with the necessary skills and competences has been critical to the growth of new ventures. The elimination of R&D or closure of facilities by other firms within the inkjet industry and downturns in other industries has each provided skilled individuals for other firms to recruit.

Partnerships and collaborations can help identify individuals that possess specialist knowledge that is valuable to the firm. Recruiting such individuals allows the firm to develop in-house capacity rather than rely on external partners who may not share the same motivations. Bringing these individuals into the firm is particularly important during the early stage of industrial emergence when there is great technical and market uncertainty.

5.2.3 Technology

5.2.3.1 Printheads

The emergence and constant evolution of DoD piezo printheads has been a key enabler in the application of inkjet technology in new markets. These printheads have become faster and more cost effective, with smaller drop volumes and higher nozzle density. Importantly, they have also become more robust and reliable. The incorporation of greyscale technology into these provided a significant advance in the apparent resolution of DoD from 360dpi to over 1000dpi.

From the mid 1990s, the availability of a reliable source of robust piezo printheads from Xaar and Spectra that could use solvent and UV curable inks allowed OEMs to innovate and develop new products. The availability of these printheads was a critical element in the emergence of new firms in the wide format and flatbed graphics sectors. The decision of Xaar to license the printhead technology (the XJ128) enabled the wider adoption of the technology.

To overcome problems with system reliability and improve the performance of DoD technology, a number of firms, including Xaar, Dimatix, Epson, HP and Xennia, have developed recirculating ink systems. Released in 2007, the Xaar 1001 printhead was a significant milestone in the development of piezo printheads because its use of a recirculating ink system made it the first reliable printhead for reel-to-reel technology.

Technical advances in wide format in East Asia (with those by Kyocera of note) have led to improvements in print quality by increasing the nozzle density on the printhead and producing a significant speed improvement.

The availability of a range of reliable printheads from technology suppliers means that development costs are no longer as significant a barrier when developing an inkjet system.

5.2.3.2 Inks

The development of new inks has allowed inkjet printing onto new substrates and for new markets to be entered.

- In the 1990s it became possible for roll-to-roll inkjet printers to use aqueous inks, creating a new wide format market for indoor posters. This wide format aqueous market spawned the textile market.
- Solvent inks allowed wide format and grand format printing of 2-3m on vinyl substrates. These solvent inks allowed large scale outdoor applications without any stitching of images.
- The development of UV curable inks by Sericol and SunChemical enabled the growth of wide format, including point of sale and signage. These inks improve system reliability, particularly for single pass inkjet printers, because UV curing after printing means that these inks don't block the printheads. Their application in the flatbed printer market also made it possible to print onto rigid substrates.
- Most recently, novel inks have been developed for functional inkjet applications. One example is nanosilver ink, which is used to print conductive tracks.

5.2.3.3 Print systems

In the early years of CIJ, the development of binary inkjet and array format printheads was a substantial improvement over single nozzle inkjet, offering much greater speed and higher print quality.

Simplification of print systems has been an important step in the wider adoption of inkjet. Improving the ease of operation has meant that inkjet systems could be operated without specialist expertise.

Developments outside the industry have provided barriers and enablers. Inadequate processing power for page array printing had been a barrier for some time until the development of parallel processes. This advance enabled colour print processing. Similarly, in the mid-1980s, MEMS advances were necessary before inkjet advances could be made.

5.2.3.4 Science

In 2005, the Inkjet Research Centre was founded at the Cambridge University Engineering Department to investigate the basic science of inkjet. A 5-year project, funded by the EPSRC and an industry consortium, provided insights into the fundamentals of inkjet performance, identifying ways of improving the speed and reliability of DoD inkjet. The Inkjet Research Centre was extended for another 5 years in 2010 with the award of a Programme Grant to investigate colloidal inks, drop surface interactions and the inkjet drop ejection process from printhead to substrate. As a pre-competitive consortium, it provides its members with an improved understanding of inkjet science that they can use in their R&D activities.

5.2.3.5 SOHO technology

The development of thermal DoD inkjet printers for what became known as 'small office, home office' (SOHO) was led by HP and Canon. Enablers in this development path included the invention of bubblejet in 1978 and the disposable inkjet printhead in 1981/2. This latter development led to the adoption of a business model in which revenues were generated from the sales of an expensive consumable. The development of systems in 1987 that could print on standard plain paper enabled the further adoption of these products.

5.2.4 Product advantages

Inkjet products offer a number of advantages over conventional printing systems. These advantages include increased flexibility, productivity and cost effectiveness, along with the non-contact nature of the print process.

Inkjet printing provides much greater flexibility, allowing variable data to be printed and short runs to be produced. The ability of variable data to be printed allows versioning and can be used to produce almost infinite variety in decorative applications. The capacity to produce short runs allows highly customised printing.

The flexibility of inkjet often provides cost advantages over other printing methods. For example, CIJ is used in applications such as direct mailing because it is more cost effective than laser printing.

The use of non-contact printing is particularly important in applications where the substrate is uneven or brittle and liable to fracture. For example, in the ceramic tile market, edges and uneven substrates give inkjet advantages over conventional printing. One method of solar panel printing involves printing onto very thin silicon, a substrate too delicate for contact printing.

The versatility of inkjet extends to the greater variety in the range of inks that can be used. It also has advantages over alternative printing processes in that inkjet systems have much smaller physical footprints, produce less wastage due to their customisation, and require less skilled operators.

5.2.5 Collaborations

Technical collaborations, both regionally and internationally have been enablers of the development of commercial inkjet technologies. They are most often formed when firms seek to access expertise from the partner(s) and have proven effective means of developing technologies when the interests of the partner are strategically aligned.

Some joint ventures result in the formation of new firms when the project outcomes do not fit well within the scope of the parent companies' business activities.

Consortia involving many partners are most effective at the pre-competitive stage. Examples of these include the Inkjet Research Centre at the University of Cambridge and EU Framework Programmes.

Along with technical development, collaborations have also been used to improve market access. These have most often been used directly with customers or companies that already sell into that market.

5.2.6 Companies

Technology consultancies have been a significant source of expertise in the development of inkjet technology. Most notable of these is Cambridge Consultants Ltd, which from the 1960s to the mid 2000s, maintained an interest in the development of inkjet technology. This expertise was maintained despite the knowledge losses stemming from the spin-outs of multiple new firms, including Domino, Elmjet, Xaar and Inca Digital. Creating a supportive business environment has been important in allowing technical advances and venture development. These new firms and others have been founded to exploit opportunities in the market.

5.2.7 Legislation

The first major application was in the coding and marking of packaging using CIJ. This was enabled the introduction of European date-marking legislation in 1980. This was a key development in the emergence of continuous inkjet, introducing a strong legislative market driver that allowed Domino to establish itself in the market.

5.2.8 Customers

Customer interests in the application of inkjet technology have provided a market pull for the development of inkjet technology. Customers have appreciated the advantages of inkjet: flexibility, productivity and cost effectiveness. Using inkjet technology allows these customers to offer something different to their own customers, either in the final product or in marketing materials to support its sale.

The first significant adoption of piezo DoD technology was in the wide format market. Current market pulls are from customers interested in the following areas:

- Labelling
- Flexible, filmic packaging
- Industrial décor (e.g. ceramic tiles, laminates)
- Transpromo
- 3D modelling
- Deposition of functional fluids (e.g. printed electronics, photovoltaics, biostructures)

Internationalisation is currently a key market driver in FMCG. Producers need to be able to label products in different languages for different destinations. 'Versioning' using inkjet is desirable as the producers do not then need to re-organise the manufacturing line.

6 Conclusions

The emergence of new industrial activity is characterised by the interaction between firm capabilities and market opportunities, between the development of new technologies and the satisfaction of customer needs. Within the commercial inkjet cluster in Cambridge, this process continues to unfold as new applications are developed.

In this reported we have summarised ongoing research activity in this area. We have described the *Expert Scan* interviewing method, the meta-map that was developed from this interview data, the workshop at which the *Emergence Roadmap* tool was used to explore future opportunities for inkjet, and summarised the barriers and enablers that have affected the emergence and evolution of commercial inkjet in Cambridge.

The feedback we have received regarding the Expert Scan interviews and the meta-map has been largely positive. Individuals have reported how useful it has been for them to reflect on the history of the system of which they are a part.

It is worth noting that because the meta-map was created primarily from interviews with practitioners in the Cambridge area, it is dominated by activity associated with spin-outs from CCL. It therefore lacks a global perspective on the emergence of commercial inkjet but is instructive in terms of understanding the origins and evolution of industrial activity within the UK.

Feedback on the *Emergence Roadmap* tool used in the workshop was more mixed. Competitive issues prevented openness and what was disclosed was not considered surprising. For future workshops it was suggested that topics should be more focused around themes such as a particular technology, application or value chain, or through broadening participation beyond Cambridge-based firms. It was also considered essential to identify ways through which firms can work together when commercially sensitive information is being revealed.

A number of lessons can be learned from an examination of the historical barriers and enablers identified in this report. In a second report that will follow later in the year, we intend to further expand the analysis to examine the supply-demand coupling and role of demonstrators in greater depth.

If you have comments on the content of this report, would like to use the Expert Scan or suggest further avenues for research, please contact the authors, Simon Ford sjf39@cam.ac.uk and Michèle Routley mjr88@cam.ac.uk.

Appendix A: Emergence Roadmaps

Opportunity: 3D Printing Team: BB, DC, LM, SJ

				Summar
A) Successful opportunity capture	Market	Automotive Toys Low volume product Impossible to tool structures	Only specifications written for "normal" PCBs Electronics multilayer structures Antique/classic spares for collectables	Opportur Active p low tech Flexible
	Application	How to interest printhead manufacturers? Active poster is one example	Prototyping Prediction: small batch Volume production R-T-R	First demonst Point of stand
	Technology	UV inks Platform Drop size: femtolitre UV structural materials	Affordable 3D print systems Mix of structure conductor fluid paths Battery technology	
B) Steps toward opportunity	Market Application Technology	Replace static POP displays Active packaging Cheaper display technology Transistor technology Printable battery Fluids not well developed Design tools		Actions Feasibilit study (cc
C) Success factors	Enablers & Barriers	Process: substrates print finishing All needs further development	CAD technology that integrates Printable OLED backlight	

Opportunity: 3D Printing Team: GM, MC, RH

					Summar
A) Successful opportunity capture	Market	Low volume, low cost plastic parts Low volume, high value parts "Impossible" parts Flexible manufacture			Opportur Bespoke parts – [LEGO
	Application	Toys Personalised stuff: phones/shoes Distributed manufacture	Medical fitted prosthetics Skin/bone Teeth	Rapid prototype Art Learning aids	First demonst Demo prototyp distribut
	Technology	Powder/glue water Direct phase change Aqueous fluids High viscosity printheads			
B) Steps toward opportunity	Market Application Technology	Fashion items e.g. shoes/handbags Many nozzles	Toy parts like LEGO High productivity MOD	3D printer on the corner 3D printer in the home Support material	Actions Investiga regulatio Price poi Get exist stuff & de
C) Success factors	Enablers & Barriers	Enablers: Pester power	Barriers: Regulation Safety Quality	Unlabelled: Price delivery "CAD" software	

Opportunity: Power generation   Team: GN, ST, TP

A) Successful opportunity capture

Market
Primary function - what?
Generation of useful power as secondary function
Regulation? Anti-battery, anti-fossil fuel
Useful? Electricals feeds into product (local) on grid
Standards? Yes for electrical prods grid system
E.g. Clothing, football pitch, PV printable device

Application
Customers? Consumer, Government led trend/demand

Technology
Production technology? Inkjet? Other printing?
Chemistry: cheap, efficient, organic
Barrier: layer materials
Printing technology
PV materials: efficient, stable, cheap
Transparent conductor

B) Steps toward opportunity

Market

Application

Technology

Launch product?
• Clothing?
• Pitch?
• Sahara desert?
Demo 1: Cheap, efficient PV. Demonstrate energy payback
Demo 2: Product = jacket / phone
Demo 3: Artificial grass → energy
Demo 4: The Sahara

C) Success factors

Enablers & Barriers
Enablers:
Government regulation / investment
Environment crisis
Independent energy
Barriers:
See technology

Summar

Opportur
Cheap
indepen
clean en

First
demonst
Cheap,
efficient
enough I
(paybacl

Actions
Establish
value cha

Opportunity: Bio   Team: DT, IH, MW, PW

A) Successful opportunity capture

Market
Exact dosing
Non contact
Flexibility
Low cost disposable materials (?)

Application
Drug testing and evaluation
Drug delivery
Drug, sensor manufacturing
Consumer testing
Healthcare professionals
Aerosol delivery

Technology
Dispense bio materials without destroying the function
Biochemical innovations required
Signal detection
Immobilisation techniques

B) Steps toward opportunity

Market

Application

Technology

Abbott Roche glucose sensors
Applied IJ for bio research
Take existing bio system & repurpose for IJ
Work with microfluidics companies
Work with diagnostic developers
Take IJ & try new biochemistry

C) Success factors

Enablers & Barriers
Enablers:
Very low cost jetting
Low waste, small dead volume
Aqueous compatible
Barriers:
Shelf life
Regulatory
Safety
Product liability
Route to market

Summar

Opportur
Health
monitorin
Platform f
next gene
healthcar

First
demonst
Pre-clini
validatio

Actions
Analyse
market
opportun