The Commercialisation Environment of Advanced Materials Ventures

Abstract

Advanced materials have been hailed as the third wave of revolutionary innovation after IT and biotech, but have been poorly studied in the management literature to date. Similarities and differences in commercialisation incentives and challenges have not been adequately addressed. What role do start-up ventures play in the advanced materials sector? How does an advanced materials venture differ from any other emerging technology venture? To address these questions, we first present longitudinal data on firm size, suggesting that smaller and newer firms are playing an increasing role in the advanced materials sector. We then develop an open system model of the transaction environment of advanced materials ventures and present evidence from two advanced materials ventures which reveals the distinctive potential and challenges of emerging firms in this sector. Whereas emerging technology ventures share many commercialisation challenges, this analysis reveals sector specific levels of complexity in these challenges and the resultant commercialisation processes. Proposed policy recommendations focus on the distinctive challenges facing advanced materials ventures.

1.0 Introduction

There is increasing emphasis by regional and national policy groups on the need to foster growth in the areas of information technology, biotechnology, and advanced materials. These science-based industries are widely viewed as engines of growth for a knowledge based economy. Advanced materials innovations hold the promise of a unique impact on the economy through their potential to transform a broad range of industries (OECD, 1998; Oliver, 1999; Maine, 2000). When using the term “advanced materials innovations,” we refer to the commercialisation of new functional materials together with product and process innovations which significantly improve the cost-functional frontier of these advanced materials. In this paper, the industry attributes and firm level interactions that characterise the commercialisation of advanced materials innovations are examined. The paper starts with an overview of related prior work which emphasises the unique aspects of the industry environment in which advanced materials innovations are commercialised. We then develop an open system model to identify the transaction environment of advanced materials ventures and present evidence from two advanced materials ventures which reveal the distinctive potential and challenges of emerging firms in this sector.

2.0 Literature Review

Although there are extensive literatures on technology entrepreneurship, technology industry evolution, technology firm growth, and on technology innovation management, advanced materials ventures merit separate attention. Several scholars have found that best practices in the management of technological innovation are contingent on technology sector (Winter, 1984; Senker and Faulkner, 1992; Gans and Stern, 2003b). Yet there has been very limited management research to date on the notably unique aspects of the advanced materials sector. Such research as there is has mainly focused on the industry and innovation levels, investigating the growth and decline of R&D alliances in advanced materials (Hagedoorn and Schakenraad, 1991), knowledge flows in the invention and commercialisation of a new material (Baba et al., 2004), production volume growth of new materials over time (Rothman et al., 1987; Eager, 1998; Maine, 2000), and customer utility for newly enabled material attributes (Mangin et al., 1995; Maine and Ashby, 2002a). Firm-level analysis related to advanced materials exists but has focused on large, established producers of industrial materials (Freeman, 1982, pp. 48-70; Wield and Roy, 1995) and large, established, chemical producers (Arora et al., 1999; Walsh and Lodorfos, 2002). These large firms have been the source of some advanced materials innovations but their stake in existing technologies makes them unlikely to be the source of many significant innovations (Christensen, 1997; Shane, 2001). Among the little evidence available on the early experience of advanced materials ventures is a small empirical study on the motivation for technical alliances among Canadian advanced materials firms (Niosi, 1993), a longitudinal study of the number of new alliances formed in various technology industries (Hagedoorn & Schakenraad, 1991), and case studies of a start-up firm commercialising an advanced materials innovation (Schuster, 1993; Maine and Ashby, 2002b). Thus, there is a need to better understand the commercialisation environment of advanced materials ventures and the distinctiveness of emerging firms in this sector.

Advanced materials firms face a unique combination of management challenges: high technical and high market risk; commercialisation that requires large capital investments, and often a period of decades between invention and significant adoption (Maine, 2000; Maine and Ashby, 2002a). The commercialisation of advanced materials inventions is subject to high levels of uncertainty because materials are an intermediate good with broad applications across multiple markets, including aerospace, automotive, consumer electronics, construction energy and communication infrastructure, sports equipment, marine applications and biomedical devices (Schuster, 1993). This results in a complex innovation environment, where multiple customer and distribution alliances must be formed, research and development specific to various industry applications must be performed and utilised, diverse regulatory hurdles must be surmounted, user reluctance to change must be overcome, and process innovation plays a major role. (Wield and Roy, 1995; Maine, 2000). Many advanced materials inventions are examples of science-push, sometimes leading to radical innovations. The eventual market applications of predominantly science-push innovations are unknown and often do not exist at the time the technology is developed. (Freeman, 1982, pp.64-65; Leonard, 1995, pp. 187-189) Even when science-push innovation results in the substitution of current products, new product performance attributes generally emerge. The market pull for these new product attributes develops slowly, even for extremely successful materials. Polyethylene, for example, today generates revenues in excess of $50 Billion; but it took 20 years to develop applications for polyethylene beyond insulation and radar housing (Freeman, 1982, pp. 65-67; Maine, 2000). Similarly, it took DuPont 20 years to exploit Kevlar profitably, a revolutionary polymer fibre that eventually found its dominant application in lightweight body armour, after initially targeting automotive tire reinforcement and aerospace applications (Hounshell and Smith, 1988, pp. 431-432; Christensen, 1998). And several firms have been attempting, largely unsuccessfully, to commercialise metal matrix composites (MMCs) for over two decades (Schuster, 1993). Yet the potential impact of an advanced materials technology breakthrough to the economy is very considerable, given the wide reaching nature of their applications. Nanomaterials, in particular, are anticipated to have wide ranging valuable end uses across multiple industries (National Science and Technology Council, 2003).

Conventional theory and historical data suggest that the advanced materials industry should be dominated by large companies, who have the financial resources and complementary assets to commercialise materials innovations (Freeman, 1982, pp. 49-52; Pavitt, 1984). However, there are disincentives for established companies to engage in radical innovation when it undermines their current capabilities (Abernathy and Clark, 1985; Christensen, 1997). Perhaps as a result, entrepreneurial start up firms are playing an increasing role in the advanced materials industry (Maine, 2000) as shown by the recent increase in the numbers of North American advanced materials firms with fewer than 20 employees (**Figure 1)**.

Small advanced materials firms can exist either as specialised suppliers, for example, tier 3 component suppliers to the automotive industry, as customised batch manufacturers for individual end consumers in such niches as boat building and customised sport equipment manufacturing, or as new technology based firms aiming to commercialise their own novel intellectual property. Both the specialised suppliers and the new technology based firms (NTBFs) rely heavily on larger firms as customers (Tidd, Bessant, and Pavitt, 2001, pp. 113-115, 359-361). The advanced materials NTBF, with its more ambitious value creation goals, also requires strong linkages with providers of complementary resources, with investors and with the science base. We contend that the interactions and dependencies of these advanced materials NTBFs are the key to understanding their situation as emerging knowledge-based businesses.

3.0 Commercialising Advanced Materials Innovations: An Open Systems Model

Organizations and their innovation processes are complex systems, which can be difficult to conceptualise and describe. They consist of a number of elements, with varying goals and attributes, which lead to different types of interaction and behaviours. To understand and explain the activity that constitutes an advanced materials venture we use a systems approach (Scott, 1987; Checkland, 1981). An open systems model can locate the emerging firm in its wider web of interactions, and recognize both the supplyside issues identified in resource-based models and the industry structure issues emphasised in the industrial economics and corporate strategy literature (Porter 1980). This approach also makes it possible to represent the system boundary, and constituent elements, inputs, outputs and relationships, while facilitating insights about the overall behaviour of the system as a whole and how it interacts with its environment (McCarthy, 2003).

Our open systems model centres around the advanced materials venture's quest to recognize emerging opportunities and to exploit them by mobilising the technological capabilities and the other complementary assets needed to appropriate returns from these opportunities. The interactions on which we focus between the advanced materials venture and other players in their environment are those with the science base, with their investors, with companies providing complementary assets, and with potential customers (**Figure 2).** The advanced materials venture and each of these significant interactions are numbered in **figures 2** and **3** and are discussed sequentially. **Figure 2** represents the firm in its environment, with waved lines indicating that the specific choice of market application by the advanced materials venture also requires a distinct choice of alliance partners with whom to interact. As very few of an advanced materials venture's potential alliance partners will span more than one of the venture's potential market applications, the choice of market application limits the choice of alliance partner and vice versa. For each market application chosen by the advanced materials venture, a cycle of commercialisation processes occurs. **Figure 3** depicts these processes, with numbered reference to the interactions (knowledge and resource transfers) with major players represented in **figure 2**. The remainder of this section describes these interactions and processes.

3.1 – Commercialisation Processes of an Advanced Materials Venture

When founding the firm, technology entrepreneurs typically have no resource base enabling production beyond their existing research knowledge, unless they have inherited relevant resources, e.g. from a parent company through spin-out (Garnsey 1998). They may have to build the capabilities and assets required to deliver prototypes or demonstrate the viability of their innovations to potential customers. But this is a costly process with highly uncertain rewards and, for entrants in technology development sectors, insufficient incentives exist for private firms to bear these costs on their own (Freeman, 1982, p.168; Rosenberg, 1990). Additionally, research councils in most countries do not cover the costs of 'near-market' R&D. Given the lack of dedicated external funding, entrepreneurs with advanced materials technology must compete with new ventures in other sectors, where there are more rapid returns on capital, when seeking external finance.

As the advanced materials venture is formed and attempts to grow, it must sell its intellectual property (IP) and/or commercialise one or more products from its IP to create revenues. To do so, the advanced materials venture goes through the commercialisation processes depicted in **Figure 3**, which include: opportunity identification and prioritisation, alliance formation, customised R&D and prototype production, surmounting regulatory hurdles, and pilot plant construction and experimentation with customers. These commercialisation processes are complicated by the high technical and market risk and uncertainty, by the high capital investment required, and by long product cycle times (Schuster, 1993; Maine et al, 2005). The initial opportunity identification and prioritisation of potential market applications is very difficult and uncertain (Schuster, 1993). However, this “matching process” is critically important. Advanced materials ventures may not survive if one or more of their initial target markets fail to come to fruition. Most financing is dependent on alliances and/or licensing deals that are largely worthless if the chosen market proves unviable as technological and market uncertainties are resolved.

3.2 - Linkage between advanced materials venture and science base

The commercialisation of advanced materials inventions requires that the entrepreneurial firm have access to the knowledge base of a university, government research labs, or, in some cases, the R&D labs of an established firm. Founders of advanced materials NTBFs are often scientists, ensuring some linkages with the knowledge base. Many advanced materials ventures have chosen their location on the basis of their access to a knowledge base.[1] The linkage with the science base is the strongest one for most NTBFs in the advanced materials industry, as symbolised in **Figure 2.** The interaction between the firm and the science base is less likely to be constrained by access than by the long duration of necessary R&D efforts and the many levels of scientific and technological endeavour required to commercialise inventions successfully in advanced materials.

The best chance for successful innovation occurs when the innovating firm facilitates interaction between the science base and current or evolving user needs. This may need to take place on an iterative, trial and error basis. Christensen (1997, pp. 165-166) argues that the existing market is an unreliable source for market research data on a disruptive innovation. It is possible to assess the value attributed to a sustaining

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[1] Interviews with 15 US advanced materials ventures conducted by the authors

innovation where customer utility is known in existing markets (Maine, 2002). But we concur with Leonard (1995, pp. 187-189, 204-207) that it is extremely difficult to predict the value of an innovation based on emerging technologies in emerging markets. Thus, despite the importance of this linkage between the innovating firm and the science base in improving the usefulness of the emerging technology (Shane, 2004), it is unlikely to be the determinant of innovative success.

Another shortcoming of the knowledge inflow into an advanced materials venture from the science base is that university R&D is largely concentrated on pure science. The R&D spectrum can be differentiated as ranging from blue sky research, (Tier 1 R&D) through an intermediate stage where broad applications are still being discovered (Tier 2) and on to R&D which is tightly focused on a specific application (Tier 3) (Hauser et al, 1998). Generally, Tier 1 research is supported by universities and government laboratories, as is some Tier 2 R&D. However, as the technology is brought closer to commercialisation, costly Tier 3 R&D, prototypes and pilot plants are required, which greatly exceed the mandate and budgets of research universities and laboratories. This Tier 3 R&D knowledge needs to be generated by the advanced materials venture or their network for each targeted market application and must be supplemented with process innovations before or during commercialisation, generally before a return on investment is achieved. Thus, for emerging markets, an advanced materials venture needs to invest in the most expensive stage of R&D before getting substantial feedback from their customers.

3.3 - *Linkage between advanced materials venture and investors*

The interaction between entrepreneurs and their investors is particularly problematic in the advanced materials sector. Advanced materials entrepreneurs need to attract substantial capital investment for long development cycles without the specialized sources of revenues or finance available to new enterprises in biotechnology.[2] This long time horizon is exacerbated by prolonged technology and market risk and uncertainty, layers of customised and process R&D, and the need for an unrestricted, experimental product strategy. Interviews with the founders or CEOs of 15 US advanced materials ventures demonstrate these entrepreneurs' perceptions that financial resources are the primary constraint on the growth of their firm (**figure 4**).

Currently, there are very few venture capitalists (VCs) dedicated to the advanced materials sector, and government programs are inadequate in many countries. It is mainly private investors and seed capitalists who provide early stage funding for such ventures, and while this source may support the initial development, it is unlikely to prove sufficient for scale-up to production facilities. Advanced materials ventures in the U.S. have benefited from the Small Business Innovation Research (SBIR) program, which has grown from $45 million in 1983 to over $1Bn (USD) in 2000,[3] roughly matching all other seed capital raised in the US.[4] Approximately 18% of the funds from this program supported advanced materials research. This granting program explicitly

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[2] Biopharm firms also need to attract substantial capital investment for long and uncertain development, but the industry has established dedicated VCs, who understand the risks and potential for value creation (see Rosenberg, 1990 for a good discussion of the incentives for investment in Biotech firms). These VCs invest in the highly risky biotech firms because there has been a history of acquisition by large pharmaceutical companies, which gives the VC a medium term exit strategy, and because many biotech VCs employ real options strategies for investment.

[3] Source: U.S. Small Business Administration, Small Business Innovation Research Program Annual Reports (Washington, DC).

[4] Source: US Science & Engineering Indicators – 2002 http://www.nsf.gov/sbe/srs/seind02/pdfstart.htm

supports early stage research companies with substantial funds (up to $850,000), and, critically, the first two phases of the program require no matching funding. Of a sample of the advanced materials ventures in the Boston metropolitan area, 6 out of 10 reported that SBIR funds had been extremely important in the formation and growth of their firm, and 2 of the remaining firms in the sample had been incubated within a larger firm (Maine and Garnsey, forthcoming). Materials ventures in Canada, the UK, and European countries are held back by the lack of an equivalent program and by the relative lack of seed capital.

Venture capitalists are wary of funding new advanced materials ventures because they face high levels of technological and market risk over a prolonged period of time. By technological *risk* we mean the chance of not achieving R&D objectives for a specific product, multiplied by the likelihood of failure for the firm if the project's R&D objectives are not achieved. By *market risk* we mean the perceived probability that the market will not adopt their product if the R&D project objectives are achieved, multiplied by the likelihood of failure for the firm if the market does not adopt that product. Interview data demonstrates that high levels of technological and market risk are perceived by founders and senior management of advanced materials NTBFs (**Figure 5**). By contrast, in the biotech industry, entrants experience high technology risk, and similar technology development times, but are exposed to lower market uncertainty: if clinical trials are successful, an endorsed drug has a higher probability of soon reaching a high margin market than does an advanced materials innovation.

In some other emerging technology sectors, incumbents in related fields or customers in chosen markets are a source of finance for the entrepreneur. However, the customers of advanced materials innovations are often in mature markets and are subject to the same short-term shareholder pressure that dissuades established firms from commercialising these innovations. Indeed, established materials suppliers may even take action to obstruct substitute products. Many market applications for advanced materials, such as the construction, automotive, aerospace, and healthcare industries, are dominated by very powerful buyers who exert intense price pressure and are not interested in co-developing an entrant's new technology for applications, especially those that might disrupt their market.

3.4 - Linkage between advanced materials venture and co-producers / distributors

Entrants in the advanced materials sectors with their enabling but risk prone technologies can rarely commercialise their innovations on their own. Rather, they need to acquire or access complementary assets to commercialise their innovation, generally through alliances with large firms. The main assets to which entrepreneurial ventures need access in order to appropriate value from their innovation are manufacturing facilities and know-how, and marketing and distribution capabilities (Teece, 1986). One of the "liabilities of newness" is that the entrant firm is likely to lack the reputation, credibility, and network of contacts required to establish a value network of this kind.

There is some evidence to suggest that establishing value networks is becoming less difficult for entrepreneurial entrants in the advanced materials sector (Maine, 2000), as IT infrastructure lowers the transaction costs of collaboration (Fowler et al, 2004) and R&D alliances between established and entrant firms have become more commonplace over the past two decades (Hagedoorn, 1990). However, as depicted in **Figure 6**, new R&D alliances in the advanced materials sector rose to a peak in 1986, and, despite a resurgence in 1993, have fallen ever since, resulting in only 25 new advanced materials alliances created in 2000.[5] By comparison, there were 184 new IT alliances globally in 2000 and 199 new biotechnology alliances.

This decrease in new advanced materials alliances can be attributed to at least two sources. Firstly, established “industrial materials” manufacturers, such as the major steel and aluminium and plastics firms, were influenced by the management trends of the late 80s and early 90s in focusing on core competencies and, hence, abandoning their diversified materials R&D. Secondly, established firms recognise that the length of time required to ensure market adoption of the much hyped advanced materials revolution is long, returns are uncertain, and appropriating returns is difficult. These are strong disincentives for making such R&D projects and alliances part of their technology portfolio.

This decrease in new advanced materials alliances is a problem for advanced materials ventures that require alliances to gain access to complementary assets and to pursue a commercialisation strategy appropriate to their environment and knowledge base (Gans and Stern, 2003a). Our research on a sample of 15 US advanced materials ventures has shown that key alliances are strongly correlated with their success, where ‘key alliances’ are defined as alliances with organisations which have the capabilities required to lower barriers to entry for the venture to commercialise their innovation and ‘success’ is measured by a combination of total revenues, total employees, and revenue and employee growth rates)[6]. This finding is consistent with studies of the

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[5] The source of this data is the MERIT-CATI database at the University of Maastrict. Interestingly, 21 of these 25 new advanced materials alliances were domestic US alliances.

[6] Primary interviews conducted by authors and complemented with annual reports and public press releases.

biotechnology industry that show biotechnology NTBFs depend heavily on alliances with large firms with complementary resources (Niosi, 2003; Baum et al, 2000). But contemporary advanced materials ventures have less access to complementary assets and to alliance partner investment than such ventures had in the 1980s**.**

Although relationships need to be made with one or more customers and providers of complementary resources to establish the NTBF within the value network of a specific application, there is danger of premature lock-in. If the entrant successfully establishes a value network, it is likely to be specific to the first market application and business model they have attempted. Hence the major advantage of small firms – nimbleness in response to changing market opportunities – may need to be sacrificed by advanced materials entrepreneurs to build the networks of complementary assets to commercialise their technology. New firms face the dilemma of whether to risk locking in to a network prematurely and so limiting their market experimentation, versus committing to a business network to build unique & non-imitable resources on a complementary basis. Without such commitment, they may not be able to exploit any opportunity and there is a danger of lack of focus.

3.5 - Linkage between advanced materials venture and potential customers

Entrepreneurial ventures are often better than their larger counterparts at matching their firm’s productive base with productive market opportunities as advocated by Penrose (1995). However, this process requires continual iterations between the venture’s initial business plan and the testing out of market opportunities. These iterations involve customised research and development, pilot plant construction and the development of alliances with incumbent firms which have complementary assets specific to a chosen market application – a process that is often time consuming and costly.

We argue that the matching of a firm's productive base with market opportunities is the key hurdle for entrants in the advanced materials sector. Freeman recognised this challenge for all R&D intensive organisations (Freeman, 1982, pp. 109-113). Within a large firm with dedicated R&D and marketing departments, this process is difficult enough. For a new firm with resource constraints, the uncertainty of this matching process often leads to firms with both viable and pioneering technology running out of resources and having to exit the industry. And in the specific case of the advanced materials industry, the high level of resources required over long time periods before the first expected returns intensifies the challenge of matching technologies to markets. Advanced materials ventures have to balance conflicting forces in their matching process. On the one hand, they must find a market application in which the product attributes achievable by the technology are valued, and can be developed without excessively long gestation times and without encountering obstructive regulatory barriers (Maine and Ashby, 2005). On the other hand, they must select applications where both the overall market size and the potential returns are large enough to attract external investment. It is rare for a single market application to meet all of these criteria, leading advanced materials ventures to target multiple market applications with limited resources.

As enabling technologies, advanced materials require complementarities in other innovations. For example, the rapid diffusion of silicon chip technology required simultaneous innovations in smaller circuitry and improvements in yields achieved by Japanese and Taiwanese semiconductor companies. Thus, innovations in other fields and serendipitous events can determine the success or failure of an advanced materials innovation. Proton exchange membrane (PEM) fuel cells, targeted at replacing the internal combustion engine in automobiles, are waiting on process innovations to reduce the cost of polymer membranes and fuel cell stacks, on infrastructure standards to be established, and on legislation reflecting the costs to society of pollution. Leonard (1995, p. 212) advocates a probe and learn, experimental strategy under such conditions. Yet funding constraints limit an advanced materials venture's ability to experiment in markets and to encounter new opportunities through serendipitous events.

4.0 U.K. Light Emitting Polymer Venture Case Study[7]

We now turn to two case exemplars to demonstrate our conceptual model with detailed and context specific managerial and commercialisation challenges. Two case studies have been selected representing different stages of growth of an advanced materials venture. The commercialisation challenges of each are organised on the basis of our open systems model (**figures 2 and 3**). In section 6, we compare the commercialisation challenges of the two case studies and describe each venture's strategy for overcoming these challenges. The first, more mature, advanced materials venture is presented and analysed in the remainder of this section.

4.1 Building a Resource Base at Cambridge Display Technology (CDT)

Cambridge Display Technology (CDT) was founded on 2 January 1992 after initial work at Cambridge University's Cavendish Laboratory led by Professor Richard Friend and at the University's Melville Laboratory led by Professor Andrew Holmes, who jointly

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[7] This case study is based on public information, on CDT annual reports, on the ICC database, and on primary interviews by the authors, conducted from June, 2000 to Nov, 2003.

discovered (in 1989) that Light Emitting Diodes (LEDs) could be made from polymers as well as from traditional semiconductors. CDT is a privately held university spinout company leading the research, development and commercialisation of polymer technology for flat panel displays, lighting and photovoltaic devices. The company is involved in licensing intellectual property and developing technology platforms and production processes for flat panel Organic Light Emitting Diode (OLED) displays that utilise Light Emitting Polymer (LEP) technologies. CDT's light emitting polymer (LEP) technology is targeted for use in a wide range of electronic display products used for information management, communications and entertainment. CDT has needed to overcome high technological and market risk and sustained high levels of capital investment. Coping with these challenges has required changes in strategic direction as the entrepreneurs and managers learned more about their environment. An analysis of this environment follows.

4.2 Interactions with Science Base

Interactions with the Cavendish Laboratory at the University of Cambridge have been critical to the founding and growth of CDT. The initial invention of LEPs occurred at Cambridge, where the inventors showed the entrepreneurial initiative to found a predominantly science push company. The fundamental patent to the light emitting polymer technology was granted to Cambridge University in 1989, and is recognised industry wide as being key to the exploitation of organic light emitting diodes**.** This fundamental patent has been acquired by CDT and complemented with other patents on materials and device structure, bringing the total up to about 140 patents worldwide. Entering the field early and filing patent applications on improvements has allowed CDT to extend its IP position in the market well beyond the expiration of the fundamental patent. When CDT was acquired in 2000, the US acquirer expected founding scientists to continue to provide CDT with IP in a stream of research. The principal academic founder demonstrated the relative autonomy of university researchers when he chose to set up another company, exploiting a different technology; however, CDT retains ownership in critical IP in light emitting polymers. With a licensing based model, a fully protected IP position and access to the latest developments impacting their core technology capabilities is essential for CDT. CDT has continued to co-develop application-specific R&D with their alliance partners.

4.3 Interactions with Investors

The initial strategic objective was to manufacture products for such applications as flat panel displays and back lighting for liquid crystal displays (LCDs). The potential of this technology in major markets attracted funding from the university and a seed capital fund, Cambridge Research and Innovation Ltd., together with high-profile private investors including the rock group Genesis. Within a couple of years it was clear that a sole manufacturing strategy was not viable and that a licensing strategy should be explored. An experienced CEO, Daniel Chapchal, was appointed and he finalized a licensing arrangement with Philips Components in 1996. Confidence in CDT was boosted when Intel Corporation’s VC fund bought an equity stake in CDT. By 1998, CDT was also able to announce a joint venture with the Seiko-Epson Corporation.

By this time the company had surrounded their fundamental OLED patent with other patents on materials and device structure; but the costs of development were still very high. In 1996, a UK venture capital fund specialising in light emitting polymers was formed that took out a 33 percent stake in CDT. Lord Young, former Secretary of State for Trade and Industry, became Chairman of CDT in 1997. These promising developments did not suffice to keep CDT independent. In 2000, an offer to buy CDT by two New York private equity funds, Kelso and Hillman, was accepted and generated $133 million. The current CEO was brought on at the time, Dr. David Fyfe, and a new US parent company was established, CDT Acquisition Corporation, as a privately-held company. Another $16 million was made available by Kelso and Hillman for R&D at CDT.

4.4 Interactions with Co-Producers and Distributors

After their switch to a licensing model in 1996, CDT and their new CEO, Daniel Chapchal, placed high priority on alliance creation with the owners of complementary assets. Chapchal immediately focused on the creation of partnerships with corporations which were developing LEPs for high information content graphics displays and flexible substrates. CDT’s new strategy was aimed at helping manufacturer partners to develop emerging market applications, and this continued to be main thrust of their strategy under CEO, David Fyfe. They have attempted to be at the centre of a close technology development network, providing the technology and IP needed to advance the commercialisation of LEPs. Their strategy involves infrastructure development for the emerging industry, including development of commercial material systems, production techniques and capital equipment, such as ink-jet printing and tuned polymer formulations. Central to this strategy is the creation of a supply of the highest quality LEP materials.

To this end, CDT currently licenses materials IP to Bayer, Covion, Dow Chemical and Sumitomo. This enables these companies to supply light emitting polymer materials to the market. CDT also licenses device electronic components to STMicroelectronics and polymer deposition technology to many other European, Japanese and US companies.[8] CDT has also formed commercial agreements with Philips, Uniax, Hoechst, DuPont, Seiko Epson, Delta Electronics, Sumitomo Chemical, and Hewlett Packard.

CDT did not relinquish the possibility of pursuing a manufacturing model entirely, however. CDT built a $25million R&D facility near Cambridge, UK for developing commercial scale production techniques and know-how. CDT also acquired three small firms in 2001 and 2002 with complementary manufacturing competences. One of these companies, Litrex Corporation, had the resources for the development of ink jet deposition technology for light emitting polymer displays. CDT's long-range mission for this stream of development is to provide inkjet technology solutions for precision manufacturing of electronics and electronic displays and become the world's leading manufacturer of Piezo Micro Deposition (PMD) equipments. However, CDT has since sold 50% of Litrex to Ulvac Inc., a Japanese company that has marketing capabilities in the Far East.

4.5 Interactions with Customers

The flat panel display market is a huge emerging market but with its limited resources, CDT cannot hope to compete directly with the established manufacturers of consumer electronic products. Instead, CDT has partnered with their eventual customers in order to generate some revenues and to develop prototype products to stimulate their market.

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[8] Including Dai Nippon Printing, Delta Electronics, DuPont Displays, Eastgate (Singapore), MicroEmissive Displays Osram Opto Semiconductors, Phillips and Seiko Epson.

CDT’s initial experiments in flat panel display and LCD back lighting manufacturing strategies were discarded within a few years because of the cost of developing these applications on their own and the challenge of penetrating markets dominated by powerful companies. CDT’s revised strategy involved licensing the core technology to key customers to enable them to use their expertise and resources to develop marketable LEP displays. The first licensing arrangement was with Philips Components, finalised in 1996. A joint venture with the Seiko-Epson Corporation, followed in 1998. This resulted in the first video display on LEP through a creative combination of CDT’s technology and SEC’s active matrix and ink-jet printing technologies (*Reuters News*, 16 Feb 1998).

CDT has established attractive development partnerships and licensing agreements with both material suppliers and with major display manufacturers. “This way we get licensing income on the original IP [licenses with material suppliers] and from end products we have been involved in developing,” announced then CEO Daniel Chapchal.[9] CDT’s alliance strategy has included materials suppliers,[10] auxiliary component manufacturers,[11] display manufacturers,[12] and fully-assembled product OEMs.[13] CDT has attempted to create a value chain for LEP-based flat panel displays and to appropriate as much value as possible.

Mobile and cellular phones using CDT’s LEP display had been made available to end consumers in 2002, through a partnership with the German company Osram Opto Semiconductors. Partnerships with Dupont Displays and a Hong Kong chip firm,

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[9] *Electronic Times*, 1999.
[10] Bayer, Covion, Dow Chemical and Sumitomo.
[11] STMicroelectronics, Plastic Logic, Dai Nippon Printing.
[12] Delta Optoelectronics, DuPont Displays, Eastgate (Singapore), MicroEmissive Displays, Osram Opto Semiconductors, Phillips, Seiko Epson, and CDT’s subsidiary, Litrex.
[13] Philips, Seiko-Epson, Samsung.

GDesign, and a licensing agreement with Trident Display followed with the aim of extending CDT’s displays in mobile phones globally. However, development costs remained very high and, in July 2003, a loss-making production line in their nearby production facility was closed and the decision made to restrict production to prototypes. The CEO, David Fyfe, announced, “Things are slower than we would have experienced two years ago and we don’t expect a business upsurge until 2005/6 when technology will find its way into large screens and licensees like Philips will have their big plans up and running. That’s when the royalties will be coming in.”(CDT website, July 2003).

In brief, CDT has experimented with manufacturing displays and selling to end consumers twice thus far. In its early days, a manufacturing model was seen as the way to prove feasibility to future potential customers. However, the investment was beyond CDT’s resources. In 2001 and 2002, CDT acquired three small firms with manufacturing capabilities. However, CDT moved away from that strategy with the sale of some of their new manufacturing assets and the formation of further licensing deals. This return to a licensing model is influenced by the scale of investment and time required for large-scale manufacture of displays and materials. CDT recognized that they could not create the LEP flat panel display market alone, and that they could not compete with alternative technologies, such as LCD displays, and plasma displays, without the backing of established consumer electronic firms with design, manufacturing and distribution assets. Thus, they have formed alliances with their intermediate customers who see the potential value of their IP and are achieving returns through licensing deals.

5.0 U.S. NanoMaterial Venture Case Study[14]

Our second case notes are of an advanced materials venture which is also a spin-off from a scientific university, this time in the US. Again the venture has a strong patent position which could enable emerging technology markets. As this venture is earlier in its lifecycle, the challenges associated with matching an emerging advanced materials technology to emerging market applications are highlighted.

5.1 Building a Resource Base at a Carbon Nanomaterials Start-up (CNS)

CNS is a spin out from a prestigious American university. The founder, who is an expert in the production of fullerenes[15] by combustion synthesis (rather than the costlier carbon arc synthesis), started the company in 2001. As of 2004, CNS had grown to 11 employees and had approximately 2 million US dollars of angel investment financing. The university played an active role in creating the management and customer network for CNS. Through official channels the university provided strong business mentoring services to the technology founder. Unofficially, the university was the source of key employees, credibility, word-of-mouth references both for the CEO who was recruited and for angel investors, and the introduction to their vital first customer.

5.2 Interactions with Science Base

As a spin-off, CNS was closely reliant on the university and its resources. The founder was a professor there. The company employs his former students, who are highly skilled and familiar with the refined combustion synthesis process and related technologies. CNS developed its technology at the university and continues to take advantage of the

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[14] This case study is based on public data and on primary research conducted by the author with the CEO and the founder of the firm. All quotations in this section are taken from this primary research, conducted in Nov, 2003. The identity of the firm is withheld by request of the CEO.

[15] Fullerenes are a type of hollow, carbon molecules which includes "buckeyballs" and carbon nanotubes

production equipment available there. After the formation of CNS, the founder continued to supervise research at the university to expand the technology base of the company and to achieve an order of magnitude of production cost reductions. The patent strength of the company has been assessed to be extremely strong. The university also provided the connection with CNS's first licensee. A senior executive of the licensee, who initiated interest in the technology, was formerly a professor at the university.

5.3 Interactions with Investors

CNS is a privately held company. The first round of funding was received through a number of angel investors, including the founder and the CFO. The CFO personally knew all of the other investors. The early investment was "a relatively small total amount." The founder had been given advice to limit early investment to "build the value of the company" and to "reduce the dilution of ownership." Atypically, CNS does not hold an SBIR research grant, but instead have relied heavily on their strong linkages with their founding university for R&D. According to its founder, CNS went through a cash-flow crisis in mid 2002 where investors and senior managers disagreed about the long-term value of the company and the company was nearly sold for a small amount. The founder and his backers convinced investors that "the future could involve very large demand for this material" and "this little company could be a very important company in the future." However, thus far, the level of risk and uncertainty has prevented venture capitalists from investing in the firm. The founder admitted to us that they were building the company around "a material without an identified market existing now." The logic of building the company was "the wave of demand coming. But it is not known how large the wave is or when it is coming.” The CEO feels the key to obtaining venture capitalist funding is bringing in revenues, which have begun to trickle in this year.

5.4 Interactions with Co-Producers and Distributors

The main strengths of CNS are its fundamental technology and its senior management. CNS requires complementary technologies, marketing and sales and distribution channels to access even a small amount of its extremely broad market potential. CNS’s carbon nanotube materials can enable applications in “electronics and semiconductors, specialty and conductive polymers, antioxidants for pharmaceutical and personal care products, to high-efficiency solar cells and other organic photovoltaic devices” markets. Not only are these markets too broad for CNS to tackle alone, but each individual market has barriers to entry, which CNS cannot overcome alone. Hence, CNS has developed relationships with another carbon nanotube producer with complementary technology and with a multinational pharmaceutical company. They are currently pursuing partnerships in several of the other market applications. Each market application requires customised R&D, such as functionalising fullerenes (adding other chemicals to enable properties) for specific applications. Thus, both the expertise and the indication of commitment from co-producers are required for CNS to prioritise an application. Additionally, the CNS management team has used a licensing business model to enter markets and they plan to add their own manufacturing as they grow.

5.5 Interactions with Customers

CNS has prioritised its technology development to industries where customer interest has been expressed. CNS was formed after interest from a Japanese multinational chemical company who has licensed CNS’s technology non-exclusively and has built a 40 metric tonne fullerene plant with CNS's technology. Concurrently, CNS is working with partners and potential customers in the personal care market, biomedical market and solar cell coating market. The total market potential is enormous, as are the number of potential partners and customers. Girish Solanki, a Frost & Sullivan analyst who follows nanotech developments, estimates that, for the composite materials market alone, more than 150 companies are considering utilising carbon nanotubes. Worldwide demand for nanotubes is expected to reach $600 million by 2010. The potential is much higher if the problems of large-scale manufacturing are solved.

6.0 Comparison of Ventures' Strategies for Matching their Resource Base to Productive Market Opportunities

Both case studies exemplify the challenging commercialisation environment facing advanced materials ventures. They have both chosen a predominantly licensing business model and have created or are creating a network of alliances to attempt to develop substitution products and co-create entirely new markets for their respective technologies. However, CDT has chosen to focus exclusively on one market vertical while CNS is attempting to negotiate several market verticals in order to fully exploit the potential of their technology. We compare and contrast their commercialisation challenges and strategies for overcoming these challenges in **Table 1** and discuss throughout this section.

CDT identified consumer electronics and, specifically, flat panel displays as their target market from the early days of the company. This focus on a single, very large and early stage industry avoided some of the challenges of developing alliances with a diverse set of co-producers, distributors and customers. Even with their focus on consumer electronics, they still faced diverse application requirements within this industry, from mobile phones to large TV screens. Their strong linkages with the science base and their network of materials and flat panel display co-producers and customers has helped them manage these development challenges. The radical nature of CDT's scientific breakthrough and their strong links with a prestigious university helped them secure early angel financing, with an initial strategy to manufacture flat panel displays in-house. However, the large-scale manufacture of displays and materials requires large-scale investment in plants and the accumulating of manufacturing knowledge and relationships. Moreover, the sale of electronics materials and equipment requires industry recognition which can only be established over time. If CDT had continued their initial strategy, they would have experienced more difficulty raising VC financing, because of the cost of attempting to recreate the core capabilities of established consumer electronics OEMs.

CDT's current objective is to enter mainstream flat panel graphics display markets, at present valued at over US$30 billion per annum from 2005. The company's exploitation route for the technology is through licensing and technology transfer, coupled with corporate partnerships, joint ventures and developments, and device manufacturing. With their unique expertise in LEP technology, covering novel material design, synthesis, materials systems, device architectures and production scale-up, CDT aims to establish LEPs as the technology of choice for many existing flat panel display applications and to enable entirely new applications. CDT has focused on two areas of licensing: first to manufacturers in the flat panel display industry, and second to materials suppliers and electronic equipment who will be suppliers to the emerging LEP flat panel display industry. CDT illustrates both the potential and the extensive challenges facing companies in a complex emerging sector fraught with technological and market uncertainty (see **Table 1**). Their strategy for overcoming these challenges is to focus exclusively on the consumer electronics sector, to create an alliance network to enable the adoption of LEPs in flat panel display applications, and to pursue a predominantly licensing business model that balances short term cash flow with long term value appropriation.

CNS is earlier in the commercialisation process cycle depicted in **Figure 3** than CDT and has targeted a far broader range of industries. CNS has experienced difficulty raising financing due to the high risk, high capital costs, and long timelines associated with their broad range of emerging markets for carbon nanotubes. CNS originally pursued a licensing strategy with a major Japanese materials supplier in order to bring in nearer-term revenues. But CNS realised, as CDT did earlier, that they would also need to help develop the emerging markets for their technology. Hence, CNS changed their strategy to help develop potential applications through R&D partnerships with established players in a number of market applications. They have prioritised the personal care market, the biomedical market, and the solar cell coating market, where they have been able to form strong alliances, but have aspirations to appropriate value in the longer term from an even broader range of markets, and, in particular, the extremely large markets of consumer electronics and semiconductors. CNS has been issuing non-exclusive licenses and still plans to incorporate a manufacturing business model once they have proven their technology in market applications and have accumulated sufficient resources.

7.0 Summary and Conclusions

We have explored the sector specific complexity of challenges faced by advanced materials ventures. Innovation in the advanced materials sector has traditionally emanated from large established firms, because of the cost, risk and timeline of commercialisation. Biotechnology ventures emerged in the pharmaceutical sector because they had new technology capabilities and a more innovative culture than established companies: similarly, new ventures appear likely to play an important role in commercialising a new wave of advanced materials innovation. We present longitudinal evidence that suggests this is beginning to occur. However our evidence and analysis show that advanced materials ventures face distinctive and substantial barriers to commercialisation.

The broad potential applicability and limited appropriability of their innovations distinguish the environment of advanced materials ventures from those in other emerging technology sectors. The distinctive challenge facing advanced materials ventures is the complexity of the prioritisation of their development objectives and subsequent alliance building in an environment of high technological and market uncertainty, high development costs, and long adoption timelines. The advanced materials venture must repeatedly match the firm’s technology and potential for strategic alliances with potential market applications, and allocate or re-allocate their resources accordingly (Maine and Ashby, 2002a). With such a broad range of potential market applications, no one advanced materials venture can hope to capture all of the value from their innovation. However, they can aim to commercialise their technology in multiple market applications, and betting on only one application will increase their market risk. Therefore, the allocation of the limited time and financial resources of a start-up firm is of great strategic importance. The strategy, employed by both of our case studies, of balancing short term cash flow through a licensing model with the long term value appropriation possible through a manufacturing model, is one way of reducing risk.

Policy to support the emergence of the domestic advanced materials industry should focus on supporting this exploratory matching process by assisting in the reduction of market or technological uncertainty. For example, the costs and difficulties of understanding emerging markets could be reduced by the provision of government sponsored marketing information relevant to advanced materials start-up firms. Alliance creation with potential customers and owners of complementary assets also helps lower market uncertainty and could be facilitated by associations created in sectors with potential for new materials applications. Some of the uncertainties in technological developments could be addressed by providing or subsidising regulatory testing (e.g. at university or government laboratories), by enabling new firms to play a part in technology standards-setting processes. The considerable benefits to advanced materials ventures of government grant and procurement policies along the lines of the US SBIR program should also be recognised.

Effective innovation policy needs to recognise the wider economic benefits of experimentation by emerging technology firms. Even if they do not succeed as expected, advanced materials ventures create new knowledge that can be reconfigured to benefit industry and investors in unexpected ways. The concentration of such firms in particular areas of knowledge intensive activity is testimony not only to their close links with the science base, but the contribution of the knowledge they generate to local economies, and ultimately to innovative performance in industry at large.

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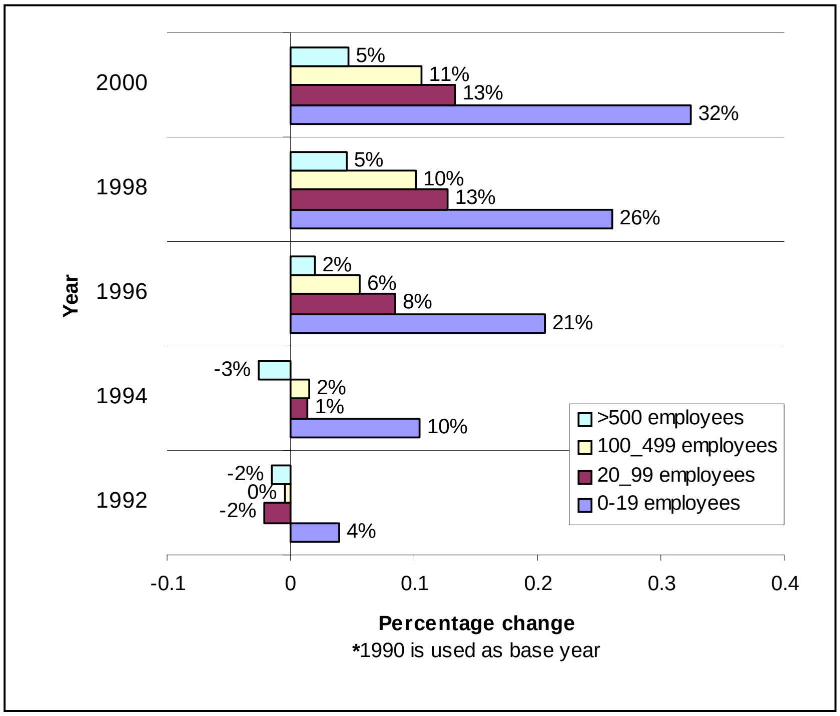

Figure 1: Changes in Numbers of N.A. Advanced Materials Firms, by Size Class (1990 – 2000) [16]

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[16] Author analysis from SIC and NAICS codes obtained from US Small Business Administration. SIC codes included in the advanced materials sector include author selected subcategories within Division D, Groups 22-26, 28-30, 32-39; Division G, Group 59; and Division I, Groups 87 and 89.

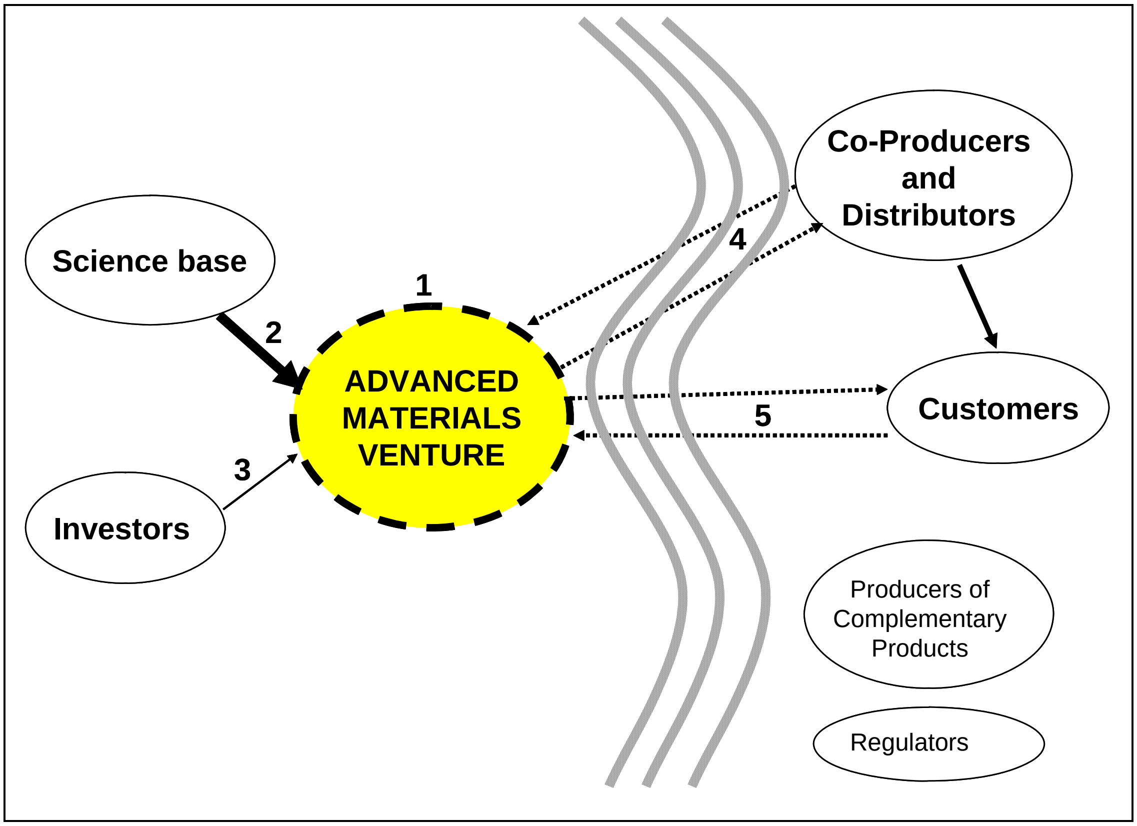

Figure 2: Interactions of Advanced Materials Ventures with Key Players

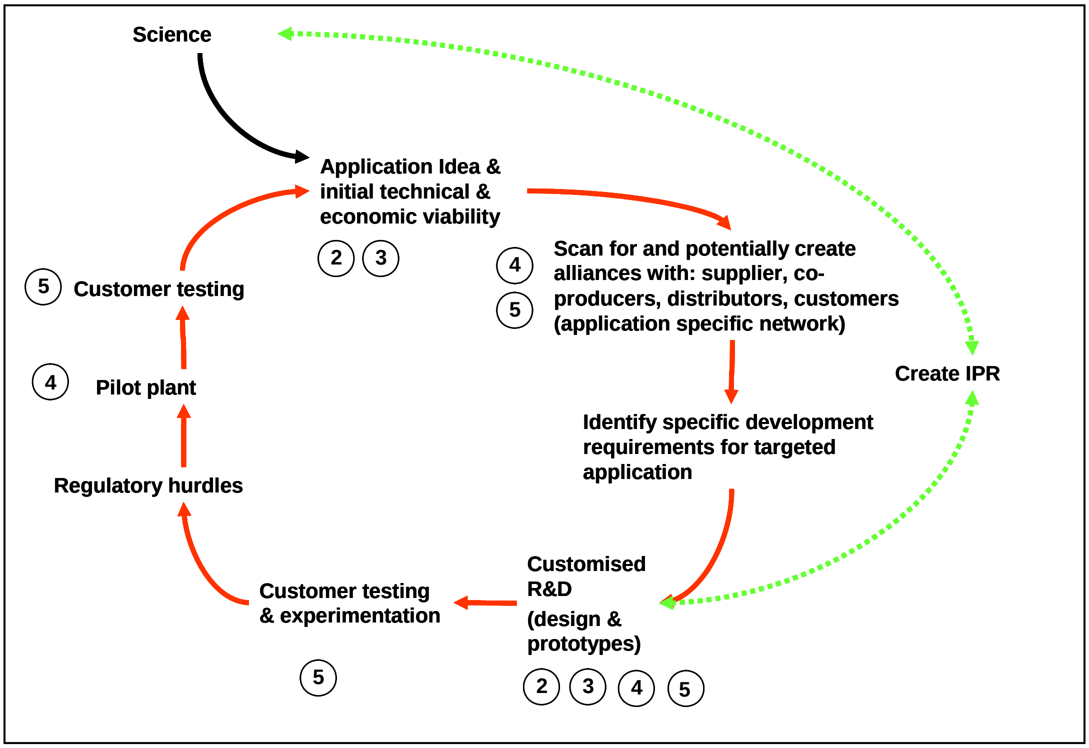

Figure 3: Commercialisation Processes of an Advanced Materials Venture[17]

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[17] The numbers on this diagram refer to the involvement in each commercialization process of the interactions labelled in figure 2

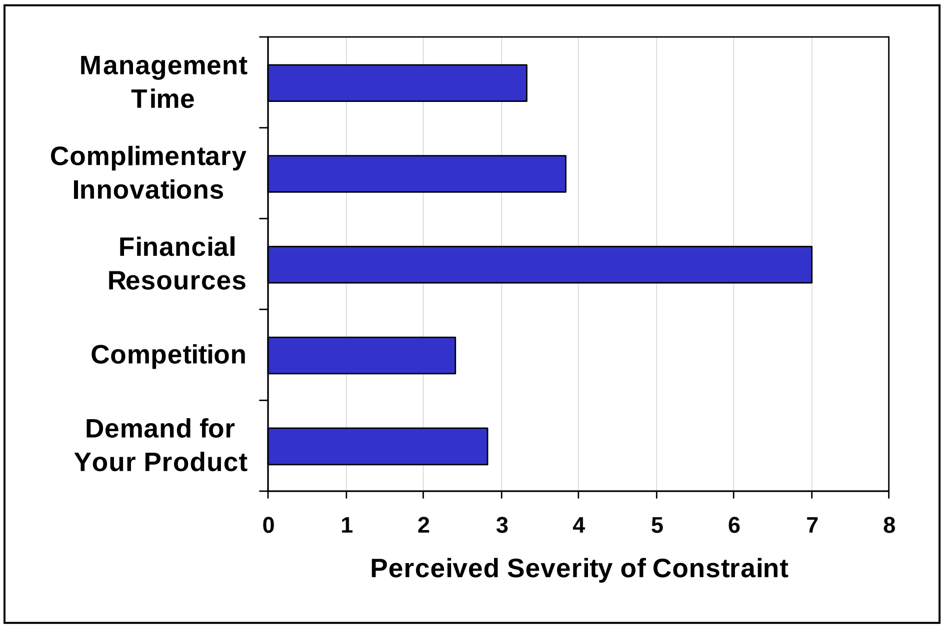

Figure 4: Perceived Constraints to Growth for Advanced Materials Ventures[18]

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[18] Primary source data collected by authors from a sample of 10 US advanced materials ventures. Perceived Severity of Constraint is measured on a scale of 1 to 10, with 10 indicating highest level of constraint

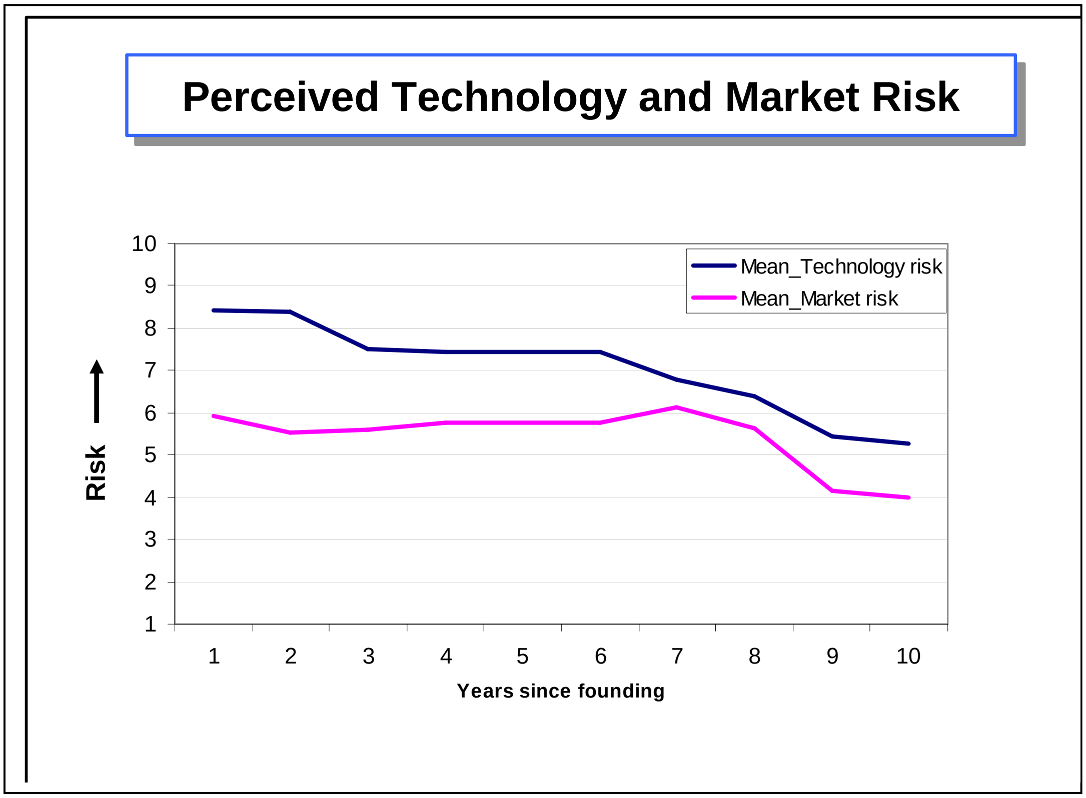

Figure 5: Perceived Technology and Market Risks Faced by Advanced Materials Ventures Across Time and Growth Processes[19,20]

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[19] Primary source data collected by authors from a sample of 15 US advanced materials ventures.

[20] By technology *risk* we mean the perceived probability of not achieving R&D objectives for a specific product, multiplied by the likelihood of failure for the firm if the project's R&D objectives are not achieved. By *market risk* we mean the perceived probability that the market will not adopt their product if the R&D project objectives are achieved, multiplied by the likelihood of failure for the firm if the market does not adopt that product.

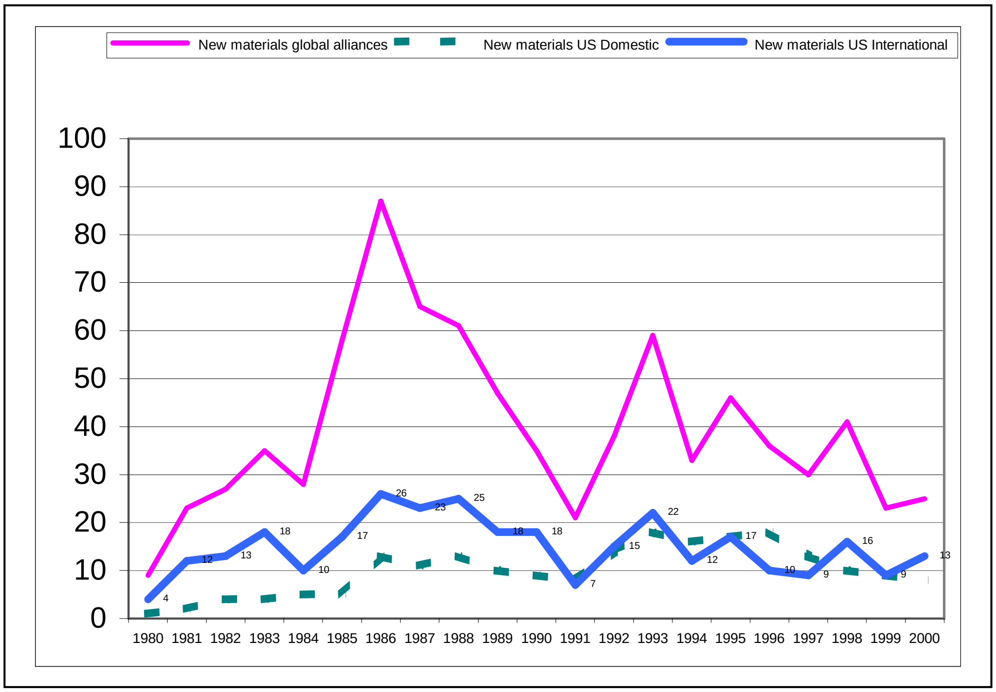

Figure 6: Annual Counts of New Advanced Materials Strategic Technology Alliances[21]

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[21] Sources: J. Hagedoorn, Cooperative Agreements and Technology Indicators (CATI) database, Maastricht Economic Research Institute on Innovation and Technology (MERIT), unpublished tabulations (Maastricht, The Netherlands, 2001) and U.S. Science & Engineering Indicators – 2002

	CDT	**CNS**
Advanced Materials Venture	- LEP company founded in 1992 - Targeting consumer electronics	- Carbon nanotube company founded in 2001 - Targeting a broad range of industries
Linkage with Science Base	- Very strong linkages - Very strong IP including 140 patents	- Very strong linkages - Strong IP
Linkage with Investors	- Angel Investors - Switches in Business Model - VC Investor	- Angel Investors
Linkage with Co-Producers and Distributors	- Has constructed a strong network of alliance partners with complementary resources	- Have developed alliance relationships in personal care, biomedical, and solar cell industries - Pursuing alliance partners in each market vertical
Linkage with Customers	- Has allied with major potential customers and formed development contracts - Has established two streams of IP royalties	- Developing licensing and product development relationships in several industries
Commercialisation Incentives	- The potential to appropriate a piece of the $30 billion flat panel display market	- The potential to appropriate a share of the anticipated $600 million carbon nanotube market
Commercialisation Challenges	- Lucrative manufacturing model too expensive and uncertain - Technological and market uncertainty effects on LEP's role in flat panel display industry and on future market size - Need to co-create emerging markets	- Lucrative manufacturing model too expensive and uncertain at present - Broad range of potential markets leads to prioritization challenges - Technological and market uncertainty on the future production cost of carbon nanotubes, product attributes, and customer demand in various industries - Alliance management across diverse industries - Need to co-create emerging industries
Strategy for Overcoming Challenges	- Focus on single emerging industry - Alliance creation and management to enable the adoption of LEPs - Predominantly licensing model, balancing short term cash flow with long term value appropriation	- Create alliances with co-producer and customers in existing markets. - Predominantly licensing business model and prioritize markets where strong alliances can be formed.

Table 1: Comparison of Commercialization Systems of CDT and CNS