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Challenges Facing New Firms Commercialising Nanomaterials

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Abstract

This paper examines the industrial incentives for commercialising advanced materials and, in particular, nanomaterials with reference to issues raised in the technology strategy and technology entrepreneurship literature. We draw on longitudinal empirical data to show that smaller and newer firms are playing an increasing role in the commercialisation of advanced materials innovations. However, new technology based firms face substantial barriers to commercialisation, including access to the complementary assets of large firms and institutions. To illustrate these challenges, we examine a case study of a start-up firm commercialising carbon nanotubes. Through use of an open systems model, we characterize their alliances and interactions in attempting to commercialise their products in several markets. This analysis illustrates the daunting challenges facing start-up firms as they attempt to commercialise advanced materials innovations. The most difficult challenge appears to be one of prioritisation of development objectives and, subsequently, of alliance building. Proposed policy recommendations focus on supporting the entrepreneurial process of matching technology resources and alliance-building with market opportunities.

1 Motivation for Research

National and international science policy organisations have long recommended fostering growth in the areas of information technology, biotechnology, and advanced materials, all science based industries predicted to be emerging engines of growth for our evolving 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). In this paper, we examine the industry attributes and firm level interactions that characterise the commercialisation of advanced materials innovations. First we provide an overview of related prior work. Next, we describe the unique aspects of the industry environment in which advanced materials innovations are commercialised, and present an open systems model through which the transactions of advanced materials ventures can be examined. Lastly, we examine detailed evidence from a nanomaterials venture and interpret this evidence through our model.

2 Prior Work

There is an extensive literature on technology entrepreneurship (Shane, 2004; Gans & Stern, 2003; Garnsey, 1998; Roberts, 1991) technology industry evolution (Garud & Karnoe, 2003; Utterback, 1994; Pavitt, 1984; Freeman, 1982) technology firm growth (Niosi, 2003; Hugo & Garnsey, 2002; Almus & Nerlinger, 1999; Audretsch, 1995), and on technology innovation management (Cooper, 2001; Henderson, 1993; Von Hippel, 1988). However, advanced materials firms have unique features on the basis of which they merit separate attention. The limited management research to date has focused at the industry level using such measures as overall R&D alliances (Hagedoorn, 1991) and production volume growth of new materials (Eager, 1998; Clark, 1997; Maine, 2000). Established firms which are producers of industrial materials have been studied on the firm level (Niosi and Bas, 2001; Wield and Roy, 1995). 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 a case study on the investment attractiveness assessment of a start-up firm commercializing an advanced materials innovation (Maine and Ashby, 2002b). We define advanced materials innovations as the commercialisation of new functional materials as well as product and process innovations which significantly improve the cost-functional frontier of functional materials.

3 Unique Aspects of the Advanced Materials Industry

Although they share management challenges with ventures in other emerging industries, 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 so uncertain 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. 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, diverse regulatory hurdles must be surmounted, user reluctance to change specifications within an established product must be overcome, and process innovation plays a major role (Maine, 2000; Wield and Roy, 1995). Additionally, many advanced materials inventions are both radical innovations and examples of science-push, as were the laser and personal computers. Science-push innovations must feel their way through to substitution for current products and to the development of entirely new applications. This was certainly the case with much of the plastics industry, with polyethylene, for example, today producing revenues in excess of $50 Billion, taking 20 years to develop applications beyond insulation and radar housing. Similarly, it took DuPont 20 years to profitably exploit Kevlar, a revolutionary polymer fibre that eventually found its dominant application in lightweight body armour, after initially targeting automotive tire reinforcement and aerospace applications. Yet the potential impact of an advanced materials technology breakthrough to the economy is enormous, given the wide reaching nature of their applications. Nanomaterials, in particular, are anticipated to have wide ranging end uses across multiple industries (National Science and Technology Council, 2003).

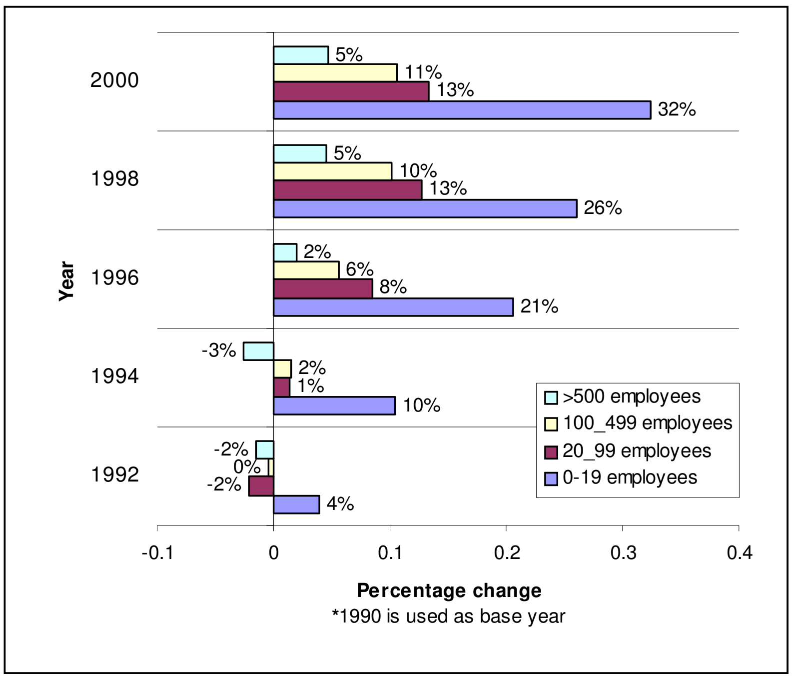

Figure 1: Changes in Numbers of Advanced Materials Firms in the U.S., by Size Class (1990 – 2000)

Conventional theory and empirical data suggest that the advanced materials industry should be dominated by large companies, who have the financial resources and complimentary assets to commercialise materials innovations (Pavitt 1984; Freeman, 1982). However, entrepreneurial start up firms appear to be playing an increasing role in the advanced materials industry as shown by the recent increase in the numbers of U.S. advanced materials firms with fewer than 20 employees (**Figure 1**). The presence of these very small firms increased by 32% in the time period between 1990 and 2000; whereas, the number of large advanced materials firms (> 500 employees) increased by 5%. This trend leads us to focus on the role of start-up firms in commercialising advanced materials innovations.

4 Commercialising Advanced Materials Innovations: An Open Systems Model

An open systems approach (Scott, 1987; Checkland, 1981) is appropriate for modeling the interactions of a new materials venture as it makes it possible to trace the way successful ventures both adapt to and also change their environment, in a form of structuration (Giddens, 1984). The most significant interactions we are investigating are those between the entrepreneurial firm as a complex open system and other players in their environment: the science base, their investors, owners of complementary assets, and potential customers (Figure 2).

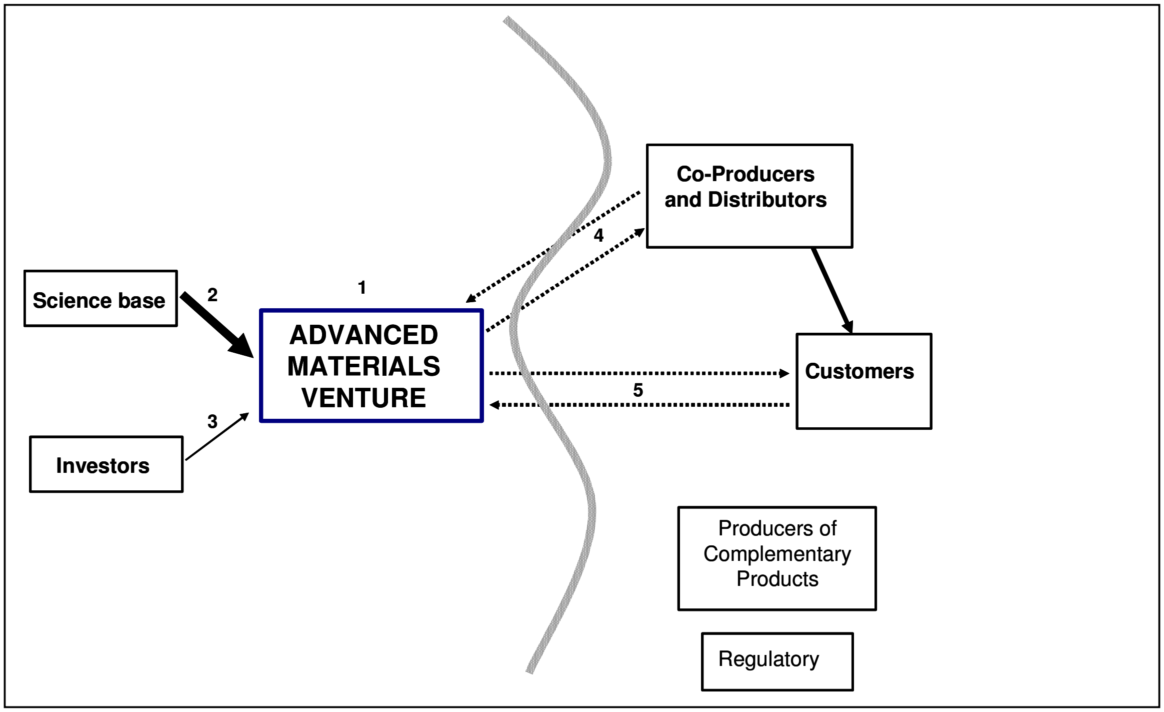

Figure 2: Interactions of Advanced Materials Ventures with Key Players

5 NanoMaterial Venture Case Study Analysed Through Our Model[1]

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

CNS is a spin out from prestigious American university. The founder, who is an expert in the production of fullerenes[2] by combustion synthesis (rather than the costlier carbon arc synthesis), started the company in 2001. Currently, CNS has grown to 11 employees and has 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

[1] This case study was developed from interviews conducted by the author with the founder and CEO in Nov., 2003, and with information from the company website.
[2] Fullerenes are a type of hollow, carbon molecule which includes "buckeyballs" and carbon nanotubes

channels, the university provided strong business mentoring services to the technology founder. Unofficially, the university was the source of key employees, of word-of-mouth references both for the CEO who was recruited and for angel investors, and of 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 production equipment available there. After the formation of CNS, the founder continued to supervise research at the university in order 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 same 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 that they should keep this initial investment as small as possible to "build the value of the company" and to "reduce the dilution of ownership." 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 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." However, the founder concedes "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, 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 customized 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 prioritize 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 which has since 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 very extensive, as are the number of potential partners and customers.[3] 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 Summary and Conclusions

This analysis of CNS illustrates the extent of the challenges facing start-up firms as they attempt to commercialise advanced materials innovations. The most difficult challenge appears to be one of prioritization of development objectives and alliance building. The entrepreneurial firm must be continuously matching the firm's technology and potential for strategic alliances for fit with potential market applications, and allocating their resources accordingly (Maine and Ashby, 2002a). . Policy to support the emergence of the domestic advanced materials industry should focus on supporting this exploratory matching process. With such a broad range of potential market applications, no one start-up firm can hope to capture all of the value from their advanced materials innovation. And given the very long gestation times for advanced materials innovations, the allocation of the limited time and financial resources of a start-up firm is of great strategic importance. There is a lack of dedicated venture capital funds for new materials ventures such as those funds which have emerged in biotechnology, another indication of the high levels of uncertainty facing these ventures. 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. Some of the uncertainties in technological developments could be addressed by providing or subsidising regulatory testing (e.g. at university or government laboratories) and by enabling new firms to play a part in technology standards-setting processes. Alliance creation could be facilitated by networking events and associations created in sectors with potential for new materials applications.

[3] Girish Solanki, a Frost & Sullivan analyst who follows nanotech developments, estimates that, for the composite materials market alone, more than 150 companies are considering utilizing carbon nanotubes.

Bibliography

Almus, M. and Nerlinger, Eric, "Growth of New Technology-Based Firms: Which Factors Matter?", *Small Business Economics*, 13, 1999, pp. 141-154

Audretsch, D. 1995. "Innovation, Growth and Survival," *International Journal of Industrial Organization,* 13, 441-457.

Checkland, Peter. Systems Theory, Systems Practice. Wiley, London, 1981.

Clark, Joel P. and Field, Frank III. ASM Handbook, Volume 20, 1997.

Cooper, Robert. Winning at New Products 3rd Ed. Perseus Publishing, Cambridge, MA, 2001.

Eager, Thomas W. "The Quiet Revolution in Materials Manufacturing and Production." *JOM*. April, 1998.

Freeman, Christopher. The Economics of Industrial Innovation. Frances Pinter Publishers Ltd. London, England, 1982

Gans, J.S. and Stern, S. "The Product Market and the Market for "Ideas": Commercialization Strategies for Technology Entrepreneurs." *Research Policy* 32, 333-350. Elsevier, 2003.

Garnsey, Elizabeth. "A Theory of the Early Growth of the Firm" *Industrial and Corporate Change*, Volume 7, No. 3, 1998. pp. 523-556

Garud, Raghu and Karnoe, Peter, "Bricolage versus Breakthrough: Distributed and Embedded Agency in Technology and Entrepreneurship", *Research Policy*, Elsevier, volume 32, issue 2, 2003, pp. 277-301

Giddons, A., The Constitution of Society: Outline of the Theory of Structuration. Cambridge: Polity Press, 1984.

Hagedoorn, J. and Schakenraad, J. "Inter-Firm Partnerships for Generic Technologies - the Case of New Materials." *Technovation*, 1991, 11, no. 7, pp. 429-444

Henderson, Rebecca. "Underinvestment and Incompetence as Responses to Radical Innovation: Evidence from the Photolithographic Alignment Equipment Industry." *Rand Journal of Economics*, 24, 2, 1993. pp. 248-271.

Hugo, Oliver and Garnsey, Elizabeth. "The Emergence of Electronic Messaging and the Growth of Four Entrepreneurial Entrants" in New Technology Based Firms in the New Millenium Volume 2, Pergamon Press, Amsterdam, 2002 (ISBN 00080441335) pp. 97-123

Maine, Elicia. "Innovation and Adoption of New Materials." PhD thesis from the University of Cambridge, 2000.

Maine, Elicia, and Ashby, Mike. Succeeding With New Materials: A Comprehensive Guide for Assessing Market Potential. Univeristy of Cambridge, 2002(a) (ISBN 1-902546-11-3)

Maine, E.M.A. and Ashby, M.F. "Applying the Investment Methodology for Materials (IMM) to Aluminium Foams." *Materials and Design*, Elsevier, 2002(b), pp. 307-319

National Science and Technology Council . National Nanotechnology Initiative. Research and Development Supporting the Next Industrial Revolution. Supplement to the president's FY 2004 Budget" (2003), p.1

Niosi, Jorge. "Alliances are Not Enough Explaining the Rapid Growth in Biotechnology Firms." *Research Policy*, 32, 2003 pp. 737-750

Niosi, Jorge. "Strategic Partnerships in Canadian Advanced Materials." *R&D Management*, 23, 1993. pp.17-27

OECD, 21st Century Technologies: Promises and Perils of a Dynamic Future, Organization for Economic Cooperation and Development, 1998, p. 40

Oliver, Richard W. The Coming Biotech Age. McGraw-Hill, New York, 1999.

Pavitt, Keith. "Sectoral Patterns of Technical Change: Towards a Taxonomy and a Theory." *Research Policy*, 13, 1984 pp. 343-373.

Roberts, Edward. Entrepreneurs in High Technology: Lessons from MIT and Beyond. New York: Oxford University Press, 1991.

Scott, W.R. Organizations: Rational, Natural and Open Systems, 2nd Ed. Prentice Hall, Englewood Cliffs, NJ, USA, 1987.

Shane, Scott. Academic Entrepreneurship: University Spinoffs and Wealth Creation. Edward Elgar, Northhampton, MA, USA, 2004

Utterback, James M. Mastering the Dynamics of Innovation: How Companies Can Seize Opportunities in the Face of Technological Change. Harvard Business School Press, Boston, MA, 1994.

Von Hippel, Eric. The Sources of Innovation. Oxford University Press, New York. 1988.

Wield, David and Roy, Robin. "R&D and Corporate Strategies in UK Materials-Innovating Companies." *Technovation*, Vol. 15, No. 4. Elsevier Science Ltd., 1995.