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Sarah Lubik*
Dr Elizabeth Garnsey*

*Centre for Technology Management
Institute for Manufacturing, University of Cambridge
17 Charles Babbage Road, Cambridge, CB3 0FS
Corresponding author: sjl69@cam.ac.uk

Abstract

Advanced material technologies have received considerable attention from the media as potential engines of economic growth in an increasingly knowledge based economy. However, the extensive contributions of novel materials are not yet fully appreciated. Advanced materials have potential to enable other technologies and hence make a substantial and transformative impact on other industries and markets, including green technologies, healthcare, sustainable energy, construction, communications and defense. Like IT and biotech before them, advanced materials face many of the commercialization challenges of radical, generic technologies. Unlike their predecessor technologies, the value creation to which they could give rise is not readily demonstrated to their co-producers, customers or end consumers because of the complexity of their value chains and entrenched competition from incumbent products. This study investigates the market-oriented challenges facing AM University Spin-Outs (USO) and in particular, the evolution of their business models firm in response to other players. The choice of market and business model affects what value needs to be demonstrated to partners and can ultimately determine how much of a material's potential value to society is realized. We build on the concept of innovation ecosystems to address these upstream innovations. A case study approach is used to elucidate the challenges that these ventures face.

The findings highlight the way relationships between organizations can unlock the potential of entrepreneurial AM innovations. Partners are shown to be critical to a venture's market selection and value chain positioning, determining not only what resources the venture can access but also the resource-base it needs to build to attract such partners. While current wisdom is that innovative ventures with radical technologies centre their activity on market niches, our cases show that potential partners, often large incumbent firms, may not be drawn by niche markets. Where substitute products already exist, ventures must adapt their business models to secure partner cooperation and clearly demonstrate the value they can offer.

Introduction

Although new materials such as nano materials are receiving extensive publicity(OECD, 1998), the implications of these innovations are not yet fully appreciated. To recognise how important new materials are for designers, producers and users, we need only recall that periods of pre-history are named after materials (Stone Age, Bronze Age) which provide the essential substances used in artifacts. Materials are intermediate between the primary raw materials of nature and secondary manufactured products. New materials challenge the standard distinction between innovations in products and innovations in production processes (Utterback, 1994). Rather than representing a breakthrough in a specific production process, a new material supports many sequences of innovations along a number of value chains. To refer to materials as an ‘industry’ is to refer to a stage in the input-output (value) flow from primary producer to end consumer, rather than a product or process based industry. Because of their impact along many value chains, new materials have the potential to give rise to many further innovations, and indeed to transform the carbon-intensive paradigm of current industry.

To achieve the full potential of a new material may require changes that undermine the dominant product design as well as current production processes. For new materials, complex innovation systems, the ensemble of organizations and institutions that take part in enabling a technological innovation(Adner, 2006), lead from the lab to the market. How a company navigates these ecosystems may ultimately decide whether a new material innovation fails to reach market, enables incremental improvements or reinvents an industry. It has been demonstrated that for a process innovation, a new enabling technology (e.g. float glass method), like a major product innovation (e.g. the internal combustion engine) may become a new standard that transforms the industry. The enabling technology “incorporates many of the elements needed in a continuous production process and allows the focus of technological effort to shift to process improvements from product innovation and design”(Utterback, 1994). Current literature on innovation ecosystems has yet to examine enabling process technologies.

Many critical decisions regarding how to commercialize these radical and potentially revolutionary innovations start are made at the very beginning of the value stream: the university lab. Yet little work has been previously conducted on the area of Advanced Material University Spin-Outs (USO).

This paper extends the concept of innovation ecosystems, and combines this approach with Resource Based Theory (RBT) of the firm, to address the resource building cycle necessary to realize the potential of materials innovations. Enabling technologies make possible component and process innovations further downstream in their ecosystems. A conceptual framework is proposed around this concept, building on a literature review and applied to case study evidence. This is drawn from two exemplars from UK universities, with a focus on their commercialization strategies and routes to market. In conclusion, we offer contribution to the current literature and recommendations for management.

Literature Review

We begin with an overview of the sparse literature on advanced material commercialization from ventures, building on key ideas from RBT and innovation ecosystems to analyse the business model of the firm in relation to its business environment.

Challenges facing advanced materials ventures

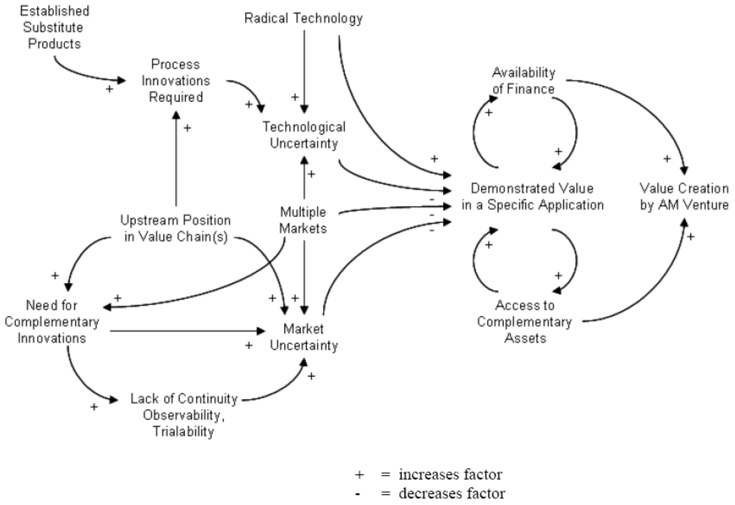
Although there is an extensive literature on entrepreneurship(Shane and Venkataraman, 2000), high-tech entrepreneurship (Shane, 2001) and New Technology Based Firms (NTBF) (Shane, 2001), there has been little research to date specifically on AM innovation commercialization. The majority of work on materials innovations has focused on incumbent firms rather than ventures (Maine and Garnsey, 2007). Little work has been found to date specifically on advanced material University Spin-Outs (USO). Extant research is summarized in Table 1.

Table 1. Past Research on Advanced Material Commercialization

Area	Key Authors
Industry level	Hagedoorn & Schakenraad(1991)
Production volume growth	Eager (1998), Clark (1997), Maine(2000)
Established firms producing industrial materials	Niosi and Bas (2001), Wield and Roy (1995), Hounshell & Smith (1988), Maine (2008),
Early experiences of advanced materials ventures	Niosi (1993), Hagedoorn & Schakenraad (1991), Maine & Ashby (2002)
Advanced materials ventures	Maine and Garnsey (2004), Maine and Garnsey (2006)

Advanced materials ventures and spin-outs encounter many of the challenges faced-by other high-tech ventures, together with a number of distinct technical, management and market challenges common to other firms attempting to commercialize radical generic technologies. These include the need for process innovations, the challenges of diffusing a radical technology, their upstream position in value chain, multiple possible markets and the need for other complementary resources. In addition to a lack of continuity, observability, trialability (Rogers, 1995) , they face the challenge of established substitute products (Maine and Garnsey, 2006) and their established value chains. This array of challenges and the firm's strategies to overcome them significantly impacts their ability to attract finance and access complementary assets (figure 1), ultimately affecting the firm's ability to create value.

Figure 1. Influence Model of Value Creation by AM Ventures



Source: Maine and Garnsey, 2006, p381

Addressing these challenges often requires not only external funding bodies (venture capitalists and business angels) but also corporate partners who offer varying levels of access and support. These partners have significant influence on which markets and/or applications are pursued by an AM venture. In this paper, we focus on these market-oriented challenges and the effects they have on a ventures ability to create value. Can the partnerships propel the new material into arenas where it can make radical and perhaps disruptive improvements, or will they limit the innovation to providing incremental improvements to established products? We show that the issue of partnerships is closely connected to the business ecosystem in which the new firm will operate, which can be particularly complex for a USO.

Many of these ventures have come from academic roots where they may have received research grants for basic research from government and university labs. Despite increasing importance being place on commercializing academic research(Gill, Minshall et al., 2007), the funds required for prototypes and pilot plants cannot usually be gained from research councils. As a result the scientist-entrepreneurs may sell their IP or set up a new firm in order to develop, fund and commercialize their business idea. If a venture is established, it will likely require strong linkages with the science base as well as providers of complementary resources and investors (Maine and Garnsey, 2007), creating a need for a new type of business model.

Pisano suggests that firms at the intersection of academia and business have created a new model attempting to make use of existing science, advance scientific knowledge and capture value (2006). This can lead to a number of challenges including conflicting objectives of stakeholders, such as the entrepreneur, the institution and other external parties. An academic entrepreneur’s objectives may include bringing their science to market, capturing wealth, or advancing their career (Clarysee, Wright et al., 2005). These may be at odds with the objectives of the university, which may be more inclined to license the technology to an established firm (Gill, Minshall et al., 2007). There may also be motivation to pursue short-term revenue for investors at the expense of major scientific advance (Pisano, 2006). Additionally, the objectives of potential partners and their view of the USO’s potential to create value for them also influences the direction a USO takes. While partnerships are often required to commercialize high-tech innovations, there is a risk that collaboration can be innovation-reducing (Dodgson, 1992) either as a strategic move to minimize a threat or an unfortunate side effect of changing the venture’s objectives to fit with those of partner.

The venture’s attempts to balance all of these objectives are revealed in their business models, and how it evolves to suit the changing environment and available resources. The evolution of a firm’s business model shows the venture’s responses to its perceived ecosystem. The business model aims to secure and create the resources necessary to demonstrate and create value for the firm. To do so it must reward also members of its environment, such as suppliers, co-producers, customers, investors and complementors (the producer of a complement product that is bundled with that of the firm by the user to utilize the firm’s offer (Adner and Kapoor, 2006)). Value created for these parties can be measured in revenue generated. The creation of useful artifacts, such as patents and prototypes can used to demonstrate potential value (Maine, Lubik et al., 2008).

Business model formation and evolution

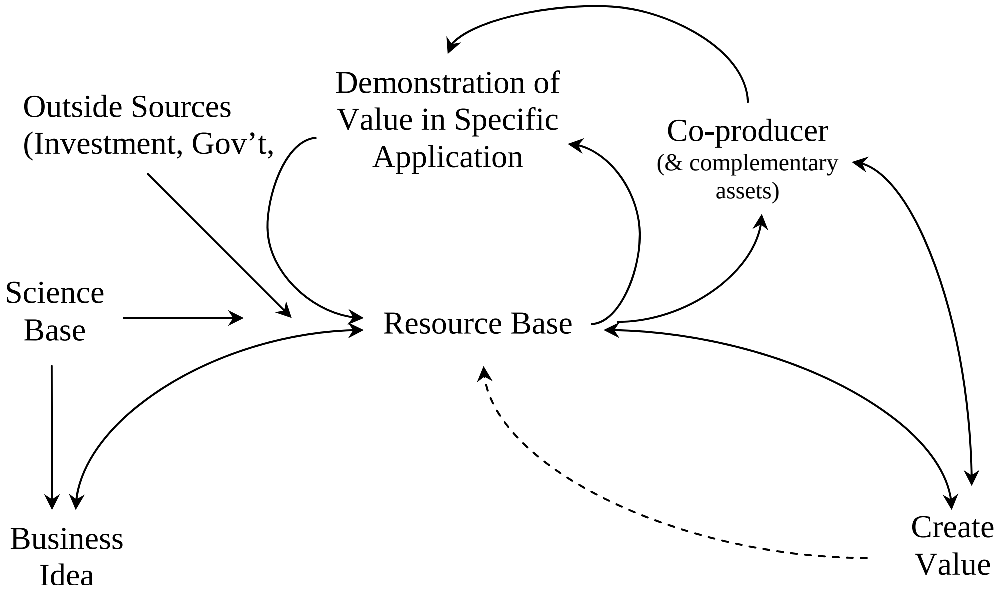
The initial business model of a venture depends on its perception and response to its chosen environment or perceived alternatives thereof. As Penrose explained, “the environment is treated, in the first instance, as an ‘image’ in the entrepreneur’s mind of the possibilities and restrictions with which he is confronted, for it is, after all, such an ‘image’ which in fact determines a man’s behavior”(Penrose, 1997). This can create challenges for scientist-entrepreneurs in terms of market identification and selection, as well as selection of appropriate position in the value chain. They may be inexperienced and attempt to fit their technology either to their aspirations for it or to target a market without awareness of the challenges various markets entail. They may also choose “a specific business model on the basis of resource endowments but this business model may not be a good fit with the emerging market opportunity, leading either to failure of the company or lower returns” (Druilhe and Garnsey, 2003). More positive outcomes are also possible. Iinnovative business models may arise to reflect the challenges that science-based and USO firms encounter, most notably resource constraints(Mustar, Renault et al., 2006). Hugo and Garnsey found that resource constrained entrepreneurs are driven to create innovative business models because they find it necessary to mobilize resources in unusual ways, gain leverage from limited resources, reduce their resource requirements (economize), create new resources (competences, technologies, etc.) or establish strategic relationships based on reciprocity (2004).

While academic entrepreneur may create a novel business model to secure and/or utilize resources, it still holds true that “a successful business model creates a heuristic logic that connects technical potential with the realization of economic value”. This encompasses strategic relationships, markets, value chain position, value proposition, revenue model, strategy (2002). Together these factors make possible the creation and exploitation of resources to create and capture value. In this way, the business model depicts how resources will flow out of and into the firm in order to create value.

The ability to secure access to resources has been shown to be an important factor in the creation of successful advanced material business models (Maine, 2006). This involves the identification of and interaction with other players in the firms’ business environment. This is congruent with another current stream of literature that emphasizes innovative firms’ relationships with customers, particularly the participation of active customers and lead users, in value creation(Prahalad and Ramaswamy, 2004). In the area of advanced materials, it is critical to engage a number of other parties who usually require a demonstration of value in a specific application. This demonstration of potential value creation is what convinces co-producers and customers to interact and exchange resources with the venture(Lubik, 2008). Initial opportunities are shaped these partners and the resources they control, but these partners are not always in the most obvious markets or the markets where the material can make the most scientifically significant impact.

The new firm builds its resource base, including IP, personnel, investment knowledge, scale-up capabilities, etc., (figure 2) by engaging with partners and/or investors that may be interested in using the firm's innovation for an application other than the entrepreneur's ideal.

Figure 2. Resource building cycle



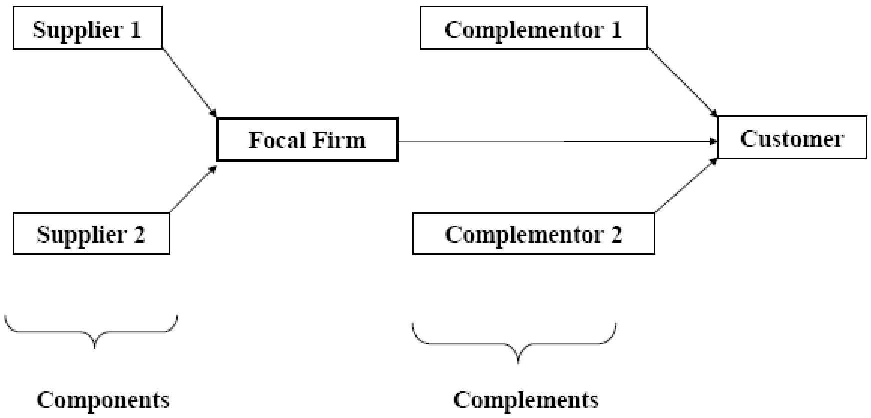
Adapted from Lubik, 2008

Regardless of whether they are interested in the most significant or revolutionary of the material's potential application, these initial partners contribute to the resource building cycle, allowing the venture to demonstrate and/or create enough value to attract other members of its current ecosystem or members of other ecosystems. This process involves the development of the firm's innovation ecosystem, which in turn represents the business environment in which the value creation cycle is actualized.

The innovation ecosystem

Beginning and sustaining the value creation cycle involves the creation of or entry into a complex value web of other players in an industry or industries which actively exchange resources to create value for customers(Moore, 1993). Adner defines this innovation ecosystem as “the collaborative arrangements through which firms combine their individual offerings into a coherent, customer-facing solution”(2006). Adner and Kapoor’s depiction of the innovation ecosystem (figure 3), demonstrates how complementary products, or complements, are often required or bundled by the customer, or next user in the value chain, in order to create a complete solution.

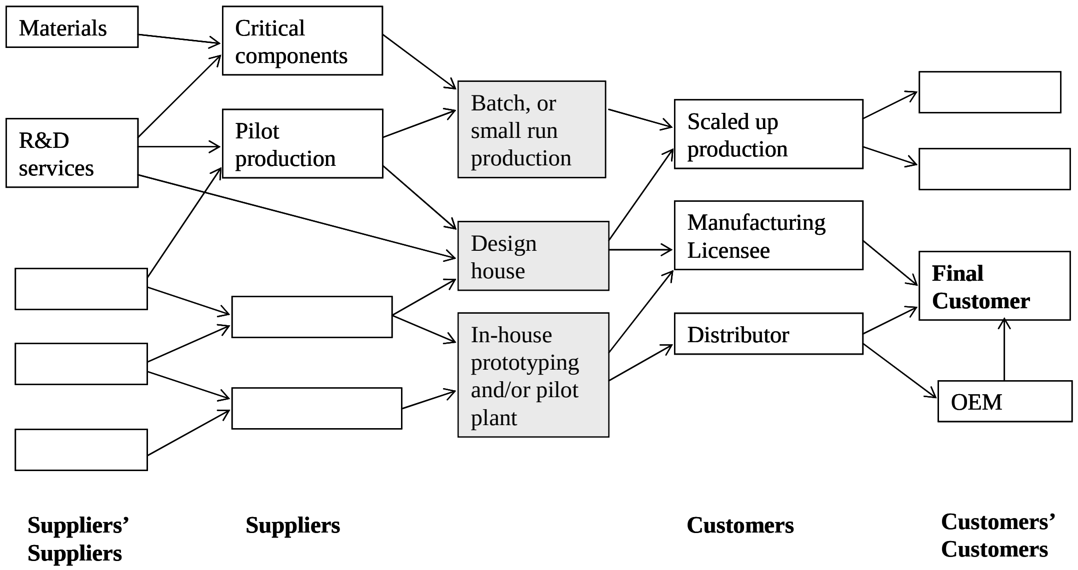
Figure 3. Generic Innovation Ecosystem



From: (Adner and Kapoor, 2006, p.52)

As noted previously, advanced material innovations often require complementary innovations and/or process innovations by other firms or co-producers in order to demonstrate value in a specific application and ultimately get their innovations to market. However an advanced material firm may also have the option to produce those complementary or process innovations itself in a vertically integrated business model (Moore, 1993). This can also be necessary if the complements in questions have yet to be invented or appropriate partner firms cannot be found or convinced to cooperate. Alternatively, these factors can lead firms to adapt to a position farther down the value chain in order to produce a more complete system and decrease challenges in assessing consumer needs and managing market experimentation and feedback (Christensen, 2004). Advanced material firms may also compete in the market for technology by pursuing a licensing strategy(Gans and Stern, 1993). Any of these choices result in particular opportunities within different environments and may require a different set of relationships. These key relationships and resource exchanges may occur with a variety of interconnected parties such as the parent university, investors, co-producers, distributors, government agencies (Dosi, 1982), business support services and/or technology transfer offices (Lockett and Wright, 2005). The result is an ecosystem that is even more intricate than the one Adner and Kapoor describe, illustrated in the example shown in figure 4.

Figure 4. Example Value Chain of High-tech Venture



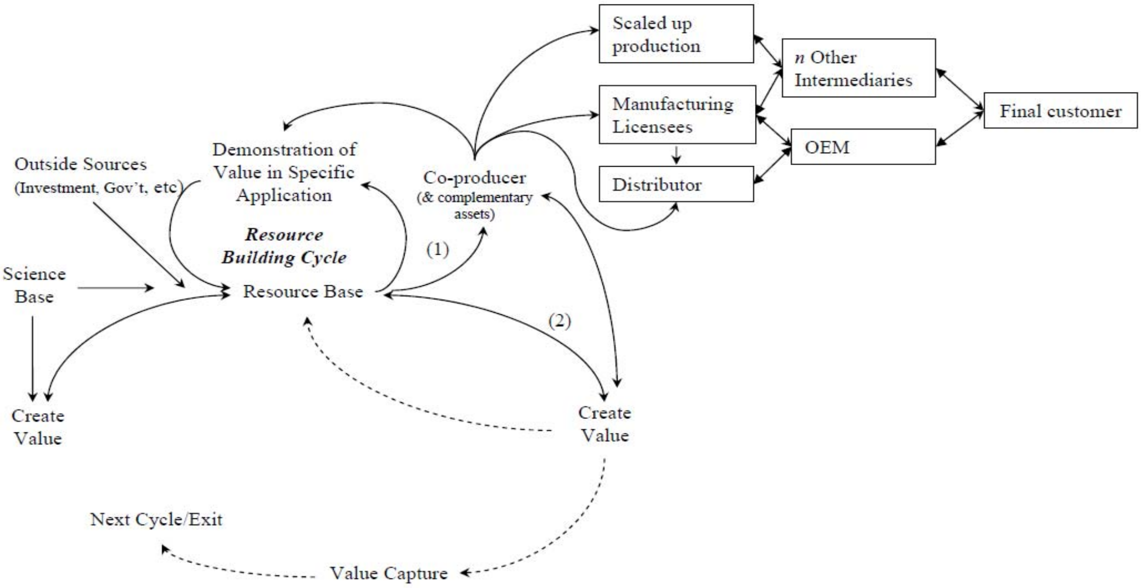
The wide range of applications available to an advanced material venture often mean they must select from a number of potential markets, and select the most appropriate position in the corresponding value network. Accordingly, an advanced material venture must consider market opportunity, competition, regulation, requirement of additional innovations, realistic development timelines and ability to attract appropriate partners (Maine and Garnsey, 2004). The ability to identify and participate in an appropriate environment and to create and capture value within it is critical to the success of an advanced material venture and to the full realization of a new material's potential.

These concepts suggest the innovation ecosystem and the value creation cycle of an advanced material USO are interwoven and that a conceptual framework that depicts them as such would be useful for analysis. This framework must also show the flow of resources and show the firm as an open system within a business environment. By this means we can better understand the challenges of commercialization and how they can be overcome.

Conceptual Framework

Based on the literature above, we present a conceptual framework (figure 5) for describing and examining the resource building cycle of a venture and the flow of resources to and from parties in their ecosystems.

Figure 5. Resource Building and Exchange for AM Ventures



Adapted from:(Lubik, 2008, p33)

This framework shows that in order to complete the resource-building cycle and create value, an advanced materials USO must engage in the complex exchange of resources and access to complementary resources and innovations with customers, co-producers, investors and/or parent institution. Depending on technology and business model, some firms will enter an established ecosystem, while others will have to create one proactively(Garnsey and Leong, 2007).

Our framework combines RBT (Barney, 2001) and innovation ecosystem theory (Adner, 2006) with an open systems perspective (Wolstenholme, 1993). This type of model facilitates insight and understanding into how resources flow within and between the individuals and organizations in such complex environments in order to create value. In order to operationalize this model, we identify the variables therein, using proxy indicators where necessary. Demonstration of value can be seen as the development of artifacts, such as patents and prototypes (Maine, Lubik et al., 2008), which are used to secure access to complementary resources and building the resource base, continuing the resource building cycle until some of that value can be appropriated as profit. While measurements of value vary in literature(Amit and Schoemaker, 1993), value creation cycle for an AM USO relies on its initial customers who are often co-producers. Revenue is used as a proxy for value created because it demonstrates that a customer has been convinced , to actively engage and exchange resources with the venture.(Lubik and Garnsey, 2008). These variables are discussed in relation to our evidence.

In the following sections, case studies will be used to further investigate the challenges faced by AM USOs attempting to select and enter appropriate innovation ecosystems and the strategies they use to navigate those challenges. We analyze our case findings informed by the framework outlined above.

Methodology

Case studies have been selected as a method that can be used to explain, illustrate, explore or evaluate phenomena. There is currently a lack of primary data on these spinouts, which further indicates that inductive methods of analysis, such as case studies, are suitable(Eisenhardt, 1989). The two case studies presented have been selected from a larger dataset previously prepared by the authors (Lubik, 2008). Each case was selected to demonstrate how materials firms' create and adjust their business models in response to their perceived and changing innovation ecosystems. Both companies have had to select from multiple possible markets and have survived long enough to change business model several times. The selected firms have chosen to enter established business environments rather than to create new ones. These studies provide detailed evidence on the challenges that advanced materials firms face and illustrate how the USOs have circumvented challenges and pursued opportunities. They draw on both secondary and primary information, interviews with the founding entrepreneurs and with other stakeholders.

Our unit of analysis in the following cases is the firms' business model, which creates a heuristic logic connecting how the firm uses its asset base to create value with how the firm relates to its value network(Chesbrough and Rosenbloom, 2002). However, this unit of analysis may be viewed from a multi-level perspective. We examine the subject matter at the level of the business ecosystem, the level of the firm and the level of the entrepreneur. Because the survival and growth of a new firm depends on how resources are accumulated and used to interact with the environment (Penrose, 1995), it is not sufficient for our purposes to focus exclusively on the firm. While a study of a single technology, firm or industry may be suitable for some purposes, a multilevel analysis is useful to understand innovation and technological advance in context(Venkataraman and Henderson, 1998).

Evidence

The following two case studies detail the experiences of two UK-based advanced material USOs. One is a spin-out from the University of Cambridge and one spun-out of the University of Bath. Both have had to interpret their business environments, create an appropriate business model and adapt to its challenges and opportunities in order to create value. Theses cases are then compared and contrasted as the basis for the conclusions of the paper.

Case Study 1: Metalysis

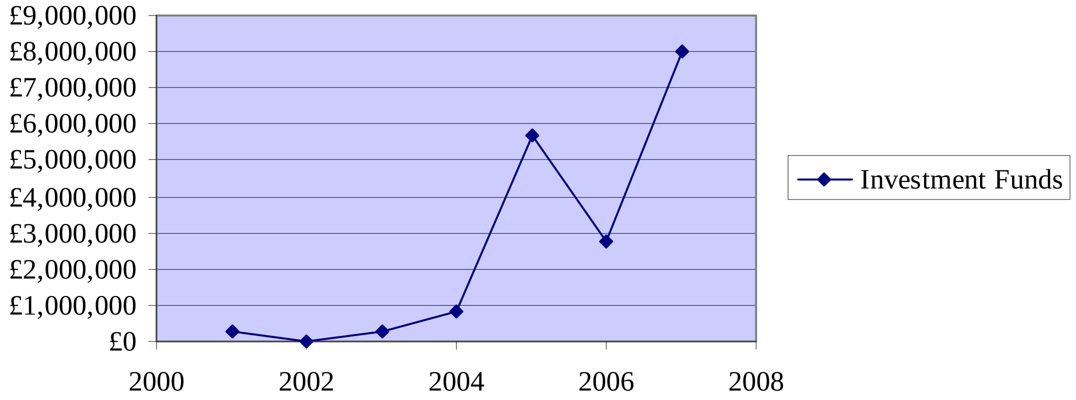
Metalysis (FFC Ltd until 2003) was spun out of the University of Cambridge to commercialize the Cambridge FFC Process developed Fray (Cambridge), Fathering (former Cambridge student),and Chen (Cambridge) (Process Engineering, 2003), to use molten salt electrolysis to convert titanium dioxide directly into titanium, a previously complicated and expensive process. The process can be used on most metal oxides, and offers a number of advantages over conventional metal-processing techniques including producing metal powers directly from metal-oxides. This lowers processing costs, allowing production of near net shaped products, decreasing the need for potentially costly machining in further production processes, removing the need for melting and allowing for potential new alloys and the production of valuable, customized materials. Moreover, the process significantly decreases environmental impact. By lowering temperatures, using fewer toxic chemicals and avoiding toxic by-products, the FFC Cambridge process also avoids many of the harsh environmental consequences of traditional metal processing methods (Metalysis, 2007).

To patent the process, Dr Fray approached Cambridge Enterprise Ltd., the University technology transfer office (TTO). Peter Hiscocks, who was involved with Cambridge Enterprise when Metalysis received its original funding, explains that the Cambridge TTO did not have the resources to handle the licensing so it licensed the process to both FFC Ltd and QinetiQ. QinetiQ was to handle any further licensing of the FFC process and licensed the rights for the development of the process with titanium to British Titanium (BTi), another of Dr. Fray's companies.

While potential metals for the process included chromium, tungsten, cobalt and silicon (Process Engineering, 2003) Metalysis originally focused on tantalum, a metal needed for cellular phone components. Tantalum is only required in small amounts and very costly to produce. The FFC process would offer large value added because the process reduces costs greatly. According to Dr. Fray "it [did not] require huge quantities, it is more reasonable to be able to get a significant portion of the world's market" (Fray, interview, 2006). Metalysis estimated the world's market to be roughly 2000 tonnes per year. If they later extended into metals where larger amounts were required, then they would require an appropriate partner. The CEO at the time, Dr. Graham Cooley, did not favour creating specific market applications. He explained the company's easiest entry point was to provide continuity by producing the metal powder already in use instead of introducing a completely new product (Cooley, interview, 2007).

Since spinning out, Metalysis has received a many grants, awards and investment funds. These included £500,000 from the University of Cambridge Challenge fund, over £3 million from Yorkshire Forward and over £18 million in venture capital. Metalysis' investment record is shown in figure 6.

Figure 6. Metalysis investment funds



The company had also generated some early revenue from development (Metalysis, 2007).

Some complementary innovations were required and in 2005, Metalysis was awarded an EPSRC research grant, together with British Titanium, the University of Cambridge and the University of Leeds Institute of Materials Research (the principal investigator). The purpose of this three year grant was to develop an inert anode to replace the carbon anode that was being used in the FFC process at the time. The carbon anode would react with metal oxides to produce carbon-dioxide and other green-house gases, as well as forming carbides to contaminate the final product(EPSRC, 2009). While Metalysis was a named partner, this research was primarily conducted between the universities, and little of the resulting science has gone directly to Metalysis. Relationships with other academic institutions have been more directly beneficial. Metalysis has established relationships with the universities of Sheffield, Hallum, Birmingham, Newcastle, Manchester and Warwick universities, for a variety of purposes including scale –up, post processing, metal characaterization, modeling and a number of other tasks through (pers. com, Harry Pepper, CFO, 2009).

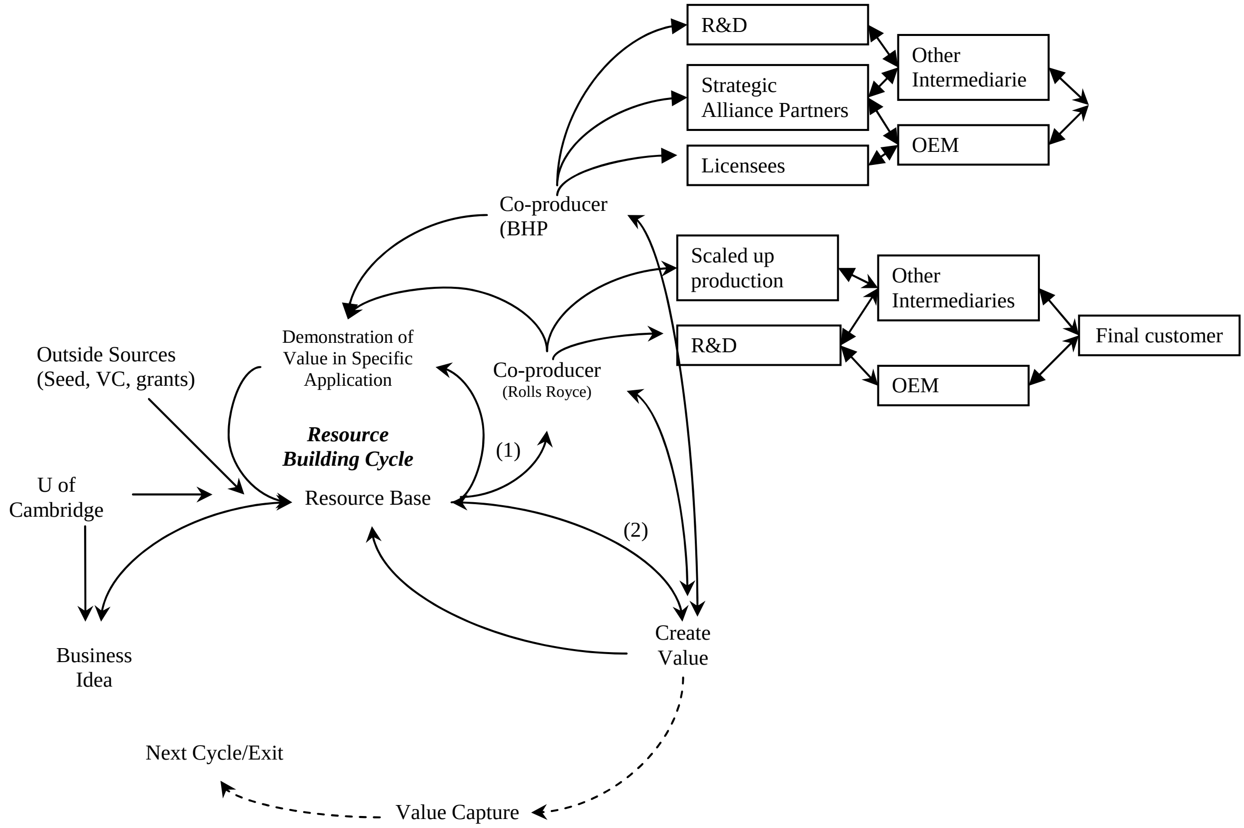
In 2006, Metalysis announced agreements with two major incumbent firms: Rolls-Royce Plc and BHP Billiton. In the agreement with Rolls-Royc, the incumbent firm would provide funding for the R&D activities and scale-up as part of its offset programme in Malaysia (Metalysis, 2007). Another joint-venture occurred as Metalysis acquired BHP's polar process, an alternative method for processing titanium. In exchange, BHP received a minority stake in the new joint venture, Metalysis Titanium Inc. This venture helped to accelerate the development of strategic alliances which could lead to other joint ventures and licenses for rapid market penetration while concurrently enabling the production of titanium and bulk titanium alloy products (Metalysis, 2007).

In addition to these partnerships, Metalysis also maintains in-house manufacturing in their Rotherdam plant, concentrating on high-grade alloys, focusing on directly alloyed powder, near net shaped products, production of highly-pure alloys from minerals and processing of impossible or hard-to-melt alloys, the development of which will be partly funded by DTI and EU grants (Metalysis, 2007).

Metalysis' relationship to the TTO was both helpful and hindering, strainging the relationships between the company and its parent university. Titanium was the most attractive metal identified to use the process on because its processing costs could be reduced by the most significant ratio. In due course, the university chose to transfer the full legal rights for the process to Metalysis, requiring due diligence before once more licensing to QinetiQ. Metalysis proposed to issue BTi with a non-exclusive license for titanium, but representatives of the university also decided that BTi was making insufficient progress commercializing the process (Hisocks, interview, 2006). British Titanium responded in February 2006 by taking legal action against QinetiQ for breach of contract and against QinetiQ and Metalysis for conspiracy to cause breach of contract, claiming damages of $400million. Metalysis and QinetiQ opposed the allegations as without merit and their actions as entirely lawful. BTi was unable to cover its incurred debts and entered administration in April 2006. Metalysis has successfully filed to strike the case out, and now holds the uncontested global rights to the process (Metalysis, 2009)..

Figure 7 depicts Metalysis' innovation ecosystem and demonstrates how dependent its resource building cycle is on the exchange of resources with other players.

Figure 8. Metalysis' Resource Building and Value Creation Cycle



Case Study 2: NanoMagnetics and Apa Clara

This case study is primarily the account of NanoMagnetics from the perspective of Dr. Eric Mayes, company founder and CEO. It is based on a number of interviews with Dr. Mayes unless otherwise stated.

NanoMagnetics spun out of the University of Bath in 1997 to develop and commercialize the PhD work of Eric Mayes. This involved a nano-scale process of removing the iron from Ferritin, an iron-storage protein found in living organisms, and using the resulting cavity to produce a mold for uniform magnetic nanoparticles. Ferritin self-assembles from 24 identical subunits into a 12nm sphere with a 8nm cavity. Reducing and removing the iron, allows the the cavity to be used as a mold for uniform magnetic nanoparticles. The particles created had a number of diverse properties which included uniform size and shape, generation of osmotic potential and magnetic charge, biocompatibility for non-toxic preparation for drug delivery and isolation of particles to prevent melting together at high temperature. This allowed NanoMagnetics to build a wide IP portfolio with applications that can be divided into 7 generalized groups, explained in table 2.

Table 2. NanoMagnetics' potential applications

Technology Group	Potential Applications
Magnetoferritin	Forward osmosis and medical resonance imaging (MRI) contrast enhancement agents
Ferrofluids	Sealants, separations, heat transfer agents, damping fluids, security marking and printing inks, transducers and pressure sensors
DataInk™ Devices	Data storage
Microwave Absorbers	Cellular phones and microwave antenna
Enhanced Nanoparticles	Filtration and magnetic separation methodologies.
Nanoparticle Films	Ink-jet printing
Semiconducting Nanoparticles	Solar cells, bio-labelling, laser diodes, optical fibre communication modalities, etc

Adapted from: (Patent Navigation Inc., 2006)

Although the technologies based on Ferritin were potentially useful in a number of industries including data-storage, water purification and drug delivery, Mayes' awareness of opportunities in the data-storage industry led him to begin with the development of DataInk™ technology, growing magnetic material inside the protein, confining its growth and making uniform particles for disbursement onto disks and other information storage media. In the data storage industry, thin films were being deposited on disks for information storage, but the current processes were beginning to reach the limits as to how much information could be stored per unit of area on the disk. Each year disks doubled their capacity, but the methods for depositing thin films onto the storage media did little to control the crystalline or granular structure of the materials, limiting further increase in capacity. Mayes saw this as an ideal opportunity for his technology, which could potentially constrain particles to the much smaller grain size the industry was heading toward, allowing for larger disk capacity. There was also interest in the industry in the potential to have the grains in precisely defined locations, as opposed to the random distribution of particles being used at the time, another potential capability of the protein.

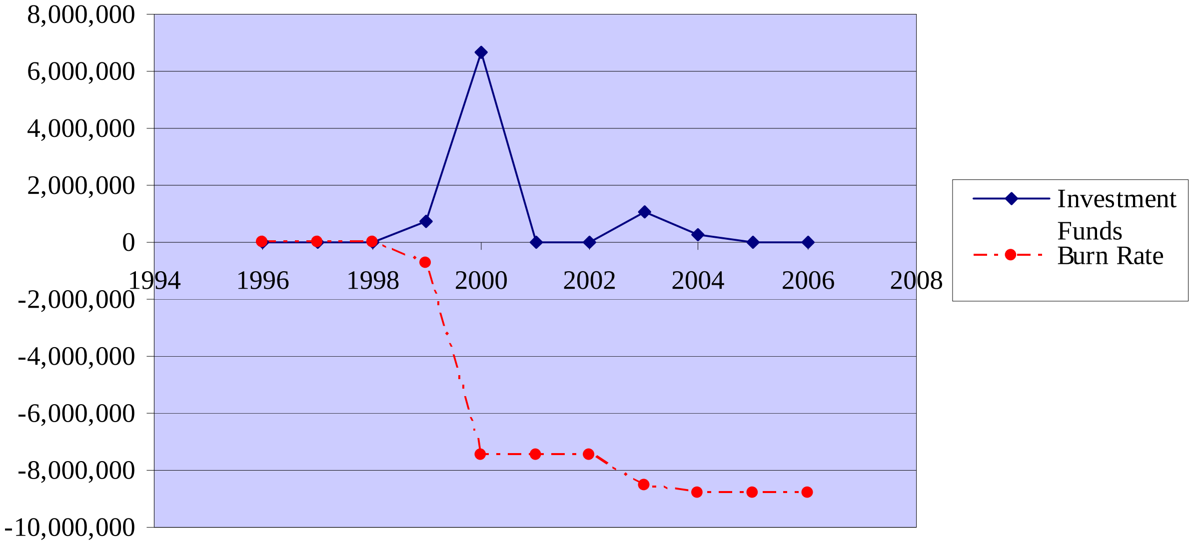
Initially, the University of Bristol offered a vacant office and access to many resources including electron microscopy and the ability to maintain a relationship with the department of physics, lowering initial capital requirements. The University did not take any equity in the company, but Mayes made a number of “back-scratching” arrangements. Instead of paying rent, NanoMagnetics upgraded pieces of lab equipment in exchange for their use. This situation also allowed the start-up access to specialists in chemistry and physics. But although these experts were scientifically knowledgeable, none had knowledge in production processing. NanoMagnetics had to find more specialized personnel.

At the end of 1996 and 1997, the company began approaching San Francisco Bay Area data storage companies as potential partners. The companies expressed interest but asked to see more development, including a process to lay down the material. The necessary process and performance development would require a bigger R&D team to develop a prototype, requiring estimated financing of £750,000. As there was no technology transfer program at Bath University, NanoMagnetics had to identify other sources of seed funds. In 1998, the company met with a series of seed capital fund managers. In

January 1999, Cambridge Research and Innovation Ltd. (CRIL), Amadeus and Prelude became their first investors, committing £650,000 in two phases: (1) demonstrating proof of concept and finding a chairman and a CEO, then (2) demonstrating magnetic recording on a material. To add to the funds available, NanoMagnetics competed for a SMART grant and were awarded £133K

In 2000, NanoMagnetics raised a further £6.7 million when IBM published an article in *Science* on the use of magnetic nanoparticles in data storage, which described a process similar to NanoMagnetics' technology. Although raising potential IP conflicts, IBM's article provided validation, renewing investor interest. These funds would be used to manufacture material samples for industry testing, bring in manufacturing expertise, and fund a necessary clean room and a facility for building a prototype production line.

Figure 8 shows these investment figures.



During this time, the data storage industry was becoming increasingly turbulent. Companies were merging or acquiring each other in an attempt to deliver a product with twice the capacity at the same cost every year. This pressure caused suppliers to decrease their margins until they either exited or were bought by more established companies. This made it difficult for NanoMagnetics to attract the attention of possible partners. By the end of 2003, despite continued technical progress and another £1M from investors, NanoMagnetics started searching out alternative markets for possible development partnerships in order to access new investment. Possible markets identified included flexible media, medical imagining, water purification

NanoMagnetics examined the flexible media industry, finding a point in the supply chain where firms bought in particles. Entering at this point would require fewer process innovations by others. They could simply supply their partners and/or customers with different kinds of particles to use in their current processes and/or existing manufacturing lines. At this point, NanoMagnetics were running low on cash and chose to commit their remaining resources to the flexible media industry and decrease their numbers to about ten people. But as 2004 continued, no deal was yet in place, making it necessary to decrease the head count further. NanoMagnetics spun back into the university to lower overhead costs.

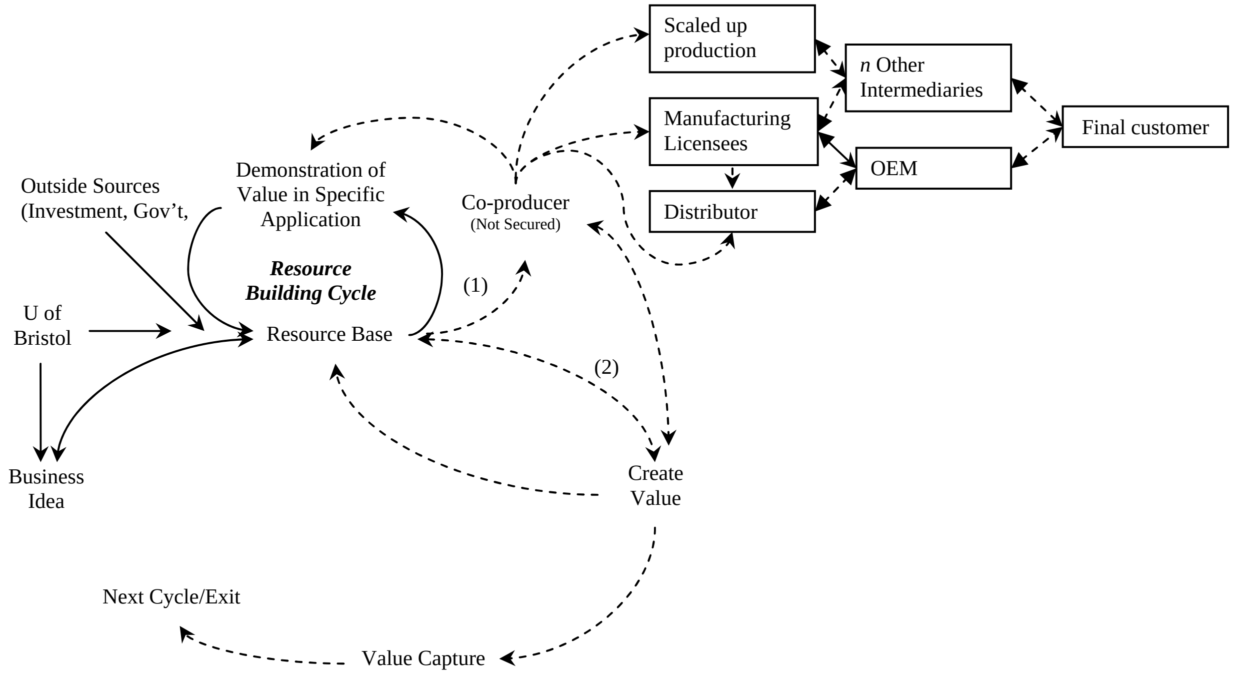
At this time a small, private US company called Cascade Designs came across one of NanoMagnetics' patents. A manufacturer of high-end camping equipment, they were interested in using the materials in a relatively slow, osmotic process to purify mountain/lake water, and were curious as to whether NanoMagnetics' materials could be used in this way. NanoMagnetics' scientists doubted whether the particles could be used to generate the necessary osmotic pressure, but Cascade was insistent that they find out. The trials worked far better than anticipated.

Cascade seemed the ideal partner. They were "not overly aggressive, not direct competitors and did their own manufacturing". In addition, they were a manufacturing channel partner, selling directly to consumers in the US, but also having a significant military market. Mayes explained that "[Cascade] don't fund their own R&D. They generally get government support for it" through SBIR (Small Business Innovation Research) grants. At that time, funding for research into water purification had been increased, and the money was being received and distributed by the Office of Naval Research. In 2005, the two companies jointly applied for a £500,000 grant to support the development of the new product.

In mid-2005, despite a tacit agreement that additional investment would be forthcoming if the SBIR award was granted, many of the investors had already lost interest or were reluctant to invest in view of the unexpected shift from data storage to water purification. The company's funds were exhausted, and Mayes was becoming personally exposed. He had to resign in December of 2005 and put the company into administration in January 2006.

Figure 9 demonstrates how dependent NanoMagnetics' resource building cycle was on the players within the multiple ecosystems that it explored before Cascade led the way to a new environment for a previously unexplored application.

Figure 9. NanoMagnetics' Resource Building and Value Creation Cycles



The birth of Apaclara

Despite the demise of NanoMagnetics, Cascade remained interested in taking the water purification application forward, so in January of 2006, Mayes founded a new company: ApaClara. The company continued to used the SBIR grant awarded to their partner, Cascade, to develop and commercialize the some of NanoMagnetics' technology in a water purification application, using field-separable osmotic agents (FSOA) to purify water using Forward Osmosis (FO)(Apaclara, 2007). The venture originally intended to use ferritin as the osmotic agent, but it was later discovered that other nanoscale, magnet-type particles coated with charged, organic material that generates osmotic pressure could produce the same functional properties at far less cost. This solution requires less energy than most current water purification techniques, and thus potentially lowers the cost of water purification. Comparing traditional economic models of sea water desalination with FO showed a 30% decrease in cost.

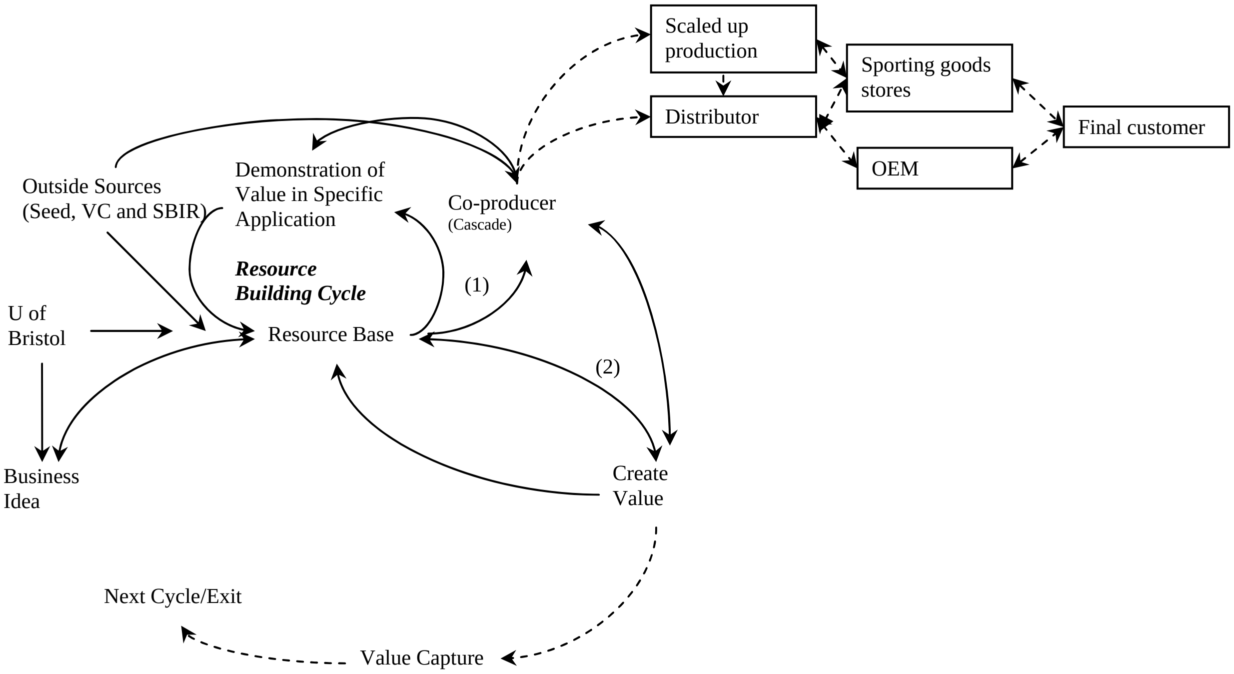
All of these material specifications have been combined into a single comprehensive patent filing, which can be separated into a number of more specific patents further into development. Initially, Cascade will be the manufacturer, licensing the use of the materials from Apaclara. Development has been completed on the first product, but it is not yet available(Mayes, 2006b).

As stated, original access to development funds, roughly £35,000, came through their US partner in the form of an SBIR grant, which was matched with £65,000 from a UK Regional Development Grant (SWEEDA) (Mayes, 2006b). Currency values at the time meant that, "this matching [was] particularly important as the money from the US goes only half as far in England" (Mayes, pers comm., 2006). For the purpose of this SBIR funding, ApaClara was treated as a subcontractor for Cascade.

Before NanoMagnetics went into administration, Eric had made another agreement with the physics department at the Univeristy of Bristol whereby Apaclara could receive support for a year in return most of the equipment that NanoMagnetics had previously owned. In this exchange, Apaclara received free use of the lab, their equipment and the help of research fellows. In addition, the lab was affiliated with the Colloid Centre at Bristol University, a quasi-commercial interface between the University and the business world.

Figure 10 depicts how Apaclara's value creation cycle is dependent exchange of resources with a number of parties. The access to SBIR funds that Cascade allowed Apaclara further complicates that ecosystem but furthers the resource building cycle.

Figure 10. Apaclara's Resource Building and Value Creation Cycles



Discussion and Analysis

These two cases studies have highlighted a number of challenges and opportunities that advanced material USOs are likely to encounter. Both ventures were founded to exploit the invention of a process which had potential to create value in a variety of applications. They came from two different universities with different initial access to resources as well as different commercialization strategies and business models. Table 3 compares these cases in terms of the conceptual framework, operationalized in the first column as factors identifiable from the case evidence. These factors, and the degree to which they affect the venture, are often influenced by the challenges presented in the firm's innovation ecosystem (as interpreted to us by the entrepreneur and/or management team). They influence how the firms' business models evolve.

Table 3. Comparison of strategies and variables for case companies

	Metalysis	**NanoMagnetics**	**Apaclara**
Founded	2001	1997	2006
Technology	Metal refining process based of molten salt electrolysis	Process for removing iron from ferritin and constraining particle growth	Water purification through forward osmosis and field-separable osmotic agents
Technology Base	University of Cambridge	University of Bristol	University of Bristol
Established Substitutes	Yes	Yes	Yes
Primary type of innovation	Process	Process	Process
Patents	2	12	1
Prototype before partnership	Yes	No	No
Complementary innovations required?	Yes	Yes	Yes
Markets pursued	3 • Tantalum • Titanium • Near net shapes	4 • Data storage • Medical imaging • Flexible media • Water purification	1 • Water purification
# of business models	3	3	1
Current market(s)	• Tantalum • Titanium • Near net shapes	N/A	• Water purification
Most recent business model	Mixed-Licensing, joint ventures, in-house manufacturing	Mixed-Development and Licensing	Mixed-Development and Licensing
Business model requires co-producers?	Yes	Yes	Yes
Sufficient value created to attract co-producers?	Yes	No	Yes
Co-producers secured?	Yes	No	Yes
Access to complementary resources	Scale-up (Rolls Royce) R&D (Rolls Royce) Additional Processing method (BHP) Strategic Alliance (BHP) Market access (BHP)	Lab (U of Bristol) Proof of Value(IBM)	Lab (U of Bristol)
Total external funds raised (as of November 2007)	£22,785,000	£8,808,000	£165,000
Value Created? (Revenue Generated?	Yes	No	Yes
Value Captured? (Profit)	No	No	No

Analysis of the evolution of these companies in response to interactions with their environments has identified key factors that impact how and how much of the scientific and commercial potential of the novel materials process is realized. While the scientist entrepreneurs were interested in applying their innovations in challenging and significant applications, their selection of and ability to enter ecosystems in order to pursue markets were heavily influenced by the availability of partners with the appropriate complementary resources. However, in order to secure this access to resources, they were required to demonstrate that their technology was capable of delivering value to customers; whether they could do so was affected by the venture's ability to adapt their business model to suit the needs of their partner, and often required the creation of new complementary resources.

Accessing complementary resources

Metalysis' earliest funds came from their parent university, soon followed by regional development funding from Yorkshire Forward, research grants and significant venture capital. The value of the process had been demonstrated early in the company's development and the potential of further value creation was sufficient to draw one of the largest rounds of VC funding in the UK for years. The venture's perceived potential drew partnership opportunities from different markets and further funding from corporate partners. Metalysis currently has few links with its parent institution, but in its early stages experienced both advantages and disadvantages from the assistance of the university TTO. However, the firm's performance and relationships with agents of the university ultimately allowed the firm to regain control of the process for the high value metal, titanium, which allowed the partnership with BHP and entry into a promising ecosystem.

In the early days of NanoMagnetics, the maintenance of close ties and creative arrangements with the University of Bristol gave significant access to complementary resources. However, these arrangements were not sufficient to maintain the growth of the company. Entering the mature and competitive environment of the data storage industry proved difficult and made the formation of alliances with a venture offering a potentially disruptive technology that was not fully developed far less attractive to potential partners. This led the company to target another market, flexible media, and select a more appropriate value chain position, but only after their resources were running dangerously low.

Partner identification and ecosystem selection

Early in their development, both firms identified a number of potential markets and chose to pursue a single market strategy for applications with which they felt they could create the most value. Metalysis illustrates some of the costs of partnering; the team chose an initial market in which they were less likely to need a corporate partner in order to decrease uncertainty from reliance on incumbent partners. As their technology achieved proof of concept, they were able to pursue multiple markets through partnerships, gaining access to complementary resources such as scale-up facilities, partnership opportunities and access to market from their two major industrial partners. In response to the opportunities these collaborations created, their business model was adapted to involve licensing and joint ventures.

While NanoMagnetics chose a market where their technology, if proven, would be superior, it was also a market dominated by large incumbent firms who would require demonstration of significant value to secure cooperation. NanoMagnetics' strategy increased their need for complementary innovations and process innovations and put them in direct competition with established substitutes from both competitors and potential partners, greatly increasing their technological and market uncertainty. Their ability to demonstrate sufficient value to potential partners was impaired, and this inhibited their ability to gain access to complementary assets and finance more especially as the industry faced a downturn. As the reincarnation of NanoMagnetics, Apa Clara was brought into a very different ecosystem (water purification, recreation) by a new US partner which identified NanoMagnetics' technology through its patents.

While both firms achieved access to finance in their early stages, NanoMagnetics later suffered from a downturn in their target market, which made it difficult to secure partnerships. Previous research suggests that alliance strategies can be detrimental to a firm if there is a negative shock to the market (Mitchell and Singh, 1996). While their initial investors were willing to provide funds prior to proof of concept and demonstration of value, further funds were only secured after another firm, IBM, provided validation of the technology's value creation potential. After NanoMagnetics went into administration, Apa Clara gained access to finance through its incumbent partner and then matched funding through a regional development grant. By demonstrating potential value by means of their patents which attracted a new a partner, the second generation firm was then able to attract additional access to finance.

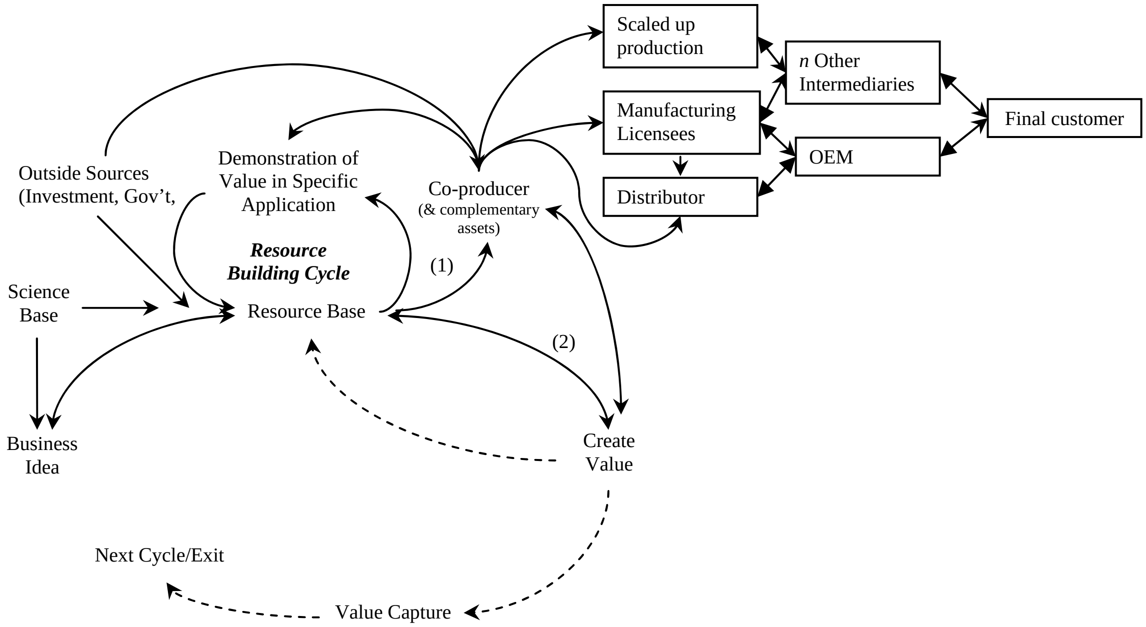
Demonstration of value

Metalysis had achieved a working prototype of the FFC process while still within the university and had selected a market which did not initially require a corporate partner, making the early innovation environment less complex. Instead of requiring the development of complementary innovations from potential incumbent partners, they used partnership with another university to produce theses complementary innovations for the process. The value that they demonstrated significantly improved performance over traditional metal processing methods and allowed them to attract partners in major markets. Metalysis then altered their business model in an attempt to exploit these new opportunities. A more complex and possibly uncertain innovation environment ensued (Moore, 1993), but one with more value creation potential. These new partners provided the necessary access to finance and access to complementary assets that would allow them scale-up to a level that the USO would have been unlikely to reach on its own. NanoMagnetics faced significant challenges in their attempts to demonstrate value because the application and market that they initially targeted meant facing many of the challenges outlined in figure one, including need for complementary innovations, need for further process innovations and long lead times before the technology was sufficiently attractive to potential incumbent partners in the mainstream industries of data storage and flexible media. Such partners, while interested in the innovation, need a stronger demonstration of value and a routemap to a suitable market, including necessary complementary innovations. Other advanced material firms have found it useful to identify and pursue a short-term objective or application which is not their primary technological objective or ideal ecosystem, but yields a revenue stream to support development.(Maine, Lubik et al., 2008) Had NanoMagnetics, early on identified an application and market which required less development of the core and fewer, less complex, complementary innovations, this might have assisted in generating early revenue to keep the company afloat while it advanced toward its primary application objective. However, as against such speculations, advances in incumbent technology are frequently a factor preventing an emerging technology from gaining ground(Utterback, 1994).

Conclusions

This paper explores how the relationships and interactions of advanced material USOs help them to create and access resources to unlock the potential of their innovation. Which market is selected and in which order can determine how much of the technology's potential is fulfilled, as this determines which partners are available, what value must be demonstrated before needed co-producers can be attracted and what resources will be made available to the venture. The importance of strategic relationships and alliances to the growth and survival of high tech companies has often been emphasized(Mitchell and Singh, 1996). In this context, the concept of the innovation ecosystem (Adner, 2006) advances understanding of the complex interactions between players in the firm's business environment. We have taken the concept further in examining the flow of resources between players in the value chains that make up a business ecosystem, and extend the reach of the concept of innovation ecosystem to encompass fundamental enabling technologies, and not merely component suppliers. The concepts were examined using a conceptual framework (figure 11) which was shown to be robust when used to interpret our case studies. In the light of the case evidence, we can depict an additional link between co-producers and other external sources of resources.

Figure 11. Refined conceptual framework



As we extend the concept of the innovation ecosystem further upstream in the value chain to include enabling technologies, management of complementary innovations become still more critical. It was found that while firms producing IT component innovations, such as printers (Adner and Kapoor, 2006) could allow customers to bundle their solutions with external complementary innovations, those launching advanced material technologies had to be more proactive. In order to encourage both investors and potential co-producers/customers, NanoMagnetics were asked to develop the deposition process needed to lay down their material on a substrate. Apaclara's materials were tested and had met their clients' needs, but they were required to develop a complete solution for customers. They needed resources from their partner in order to do so. Metalysis' were able to benefit from another of their partner's processes but also obtained assistance with key complementary innovations from other UK universities to prevent their corporate partners being deterred by having to develop these innovations. The cases show that to commercialise an emerging radical technology, it may be necessary for a firm to engage in or commission some of the activities that could be outsourced in a more mature ecosystem for their output, more especially if their enabling technology emerges upstream and has to be developed for downstream applications.

These cases highlighted the importance of partner identification and analysis as part of the process of entering an appropriate ecosystem. Some partners may limit the avenues available to the venture in the future and lead to increased risk of dependence.(Hagedoorn and Schakenraad, 1994) This threat appears to be outweighed by the reduced market uncertainty and increased access to complementary assets offered by a partnership model. When designing a business model, a partner-focused business model appears to be the most appropriate for these advanced material USOs, all of whom attempted to enter an existing ecosystem. Both firms that successfully entered these ecosystems did so with significant assistance from partner firms who provided necessary access to finance and complementary assets as well as clarifying future focus. The case evidence shows the need for a venture to balance its own objectives for scientific/R&D advances for future purposes with the objectives of partners who are seeking to further their own innovations and commercial returns. While it can be attractive to academic entrepreneurs to pursue the markets where their innovations can have the most radical impact, entrance to these environments generally requires the access to resources, in particular funding, scale-up and market access that only large players can provide. In order to engage with these incumbent firms, the potential to create value relevant to a specific application (and implied route to market) must be demonstrated.

Evidence from these spin-outs show why a technology with a strong scientific underpinning or the application with the greatest potential commercial value will not always be recognized and selected by the market. Timing, together with partner and market needs, obvious and latent, determine for a venture the most promising ecosystem. NanoMagnetic’s experience serves to highlight that while a firm may offer potential for significantly improving performance, choosing to enter an established market before having clearly demonstrated value will prove very difficult for a venture, especially in it requires complementary or process innovations

Comparing literature to practice, current literature on radical, generic technology suggests these technologies should target niche markets where they are safer from incumbent competition while they establish a point from which to grow(Christensen and Bower, 1996) However none of our case companies chose to start out as a direct player in a niche. While Metalysis views the market for titanium powder a niche, as it is a much smaller part of the titanium market, it is still a market where a small number of established incumbent firms dominate. There are some parallels to Abernathy and Clarke’s niche strategy, as Metalysis’ innovation strengthens the current dominant design(Abernathy and Clark, 1985) , but does not necessarily open emerging market segments. Niche building is difficult and time-intensive, while advanced materials ventures require external capital and resources that are absent in most niches. If they are available, it is likely to be through incumbent firms that have already entered and are in better position to compete directly(King and Tucci, 2002). Partners with sufficient resources for co-development and scale-up (such as IBM, Rolls Royce and BHP Billiton) are unlikely to contribute financing and assets over the required lead time unless the resulting process or product can be targeted at a large and/or lucrative enough market. Instead of targeting a niche to minimize the need for partnerships, these ventures may find it advantageous to identify the market where their innovation can produce the most value added for dominant players, many of whom are unlikely to be the end customer. However, this may require the identification and creation of complementary innovations by the venture, such as a process for laying down the new material. Demonstrating a clear route to commercialization will be critical for enticing potential partners, especially as the resources necessary to create these complementary innovations may not be available through external sources(Maine and Garnsey, 2007).

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