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The Commercialization of Advanced Material Technologies by University Spin-Outs

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UNIVERSITY OF CAMBRIDGE

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ABSTRACT

The field of advanced materials (AM) is expected to experience considerable growth and has the potential to make a substantial impact on numerous industries, markets and applications. Much like IT and biotech before it, advanced materials face the many commercialization challenges of revolutionary, generic technologies. AM ventures face the additional challenge of competing with established substitutes. Though there has been limited prior research on AM commercialization, the specific challenges facing AM firms at the crossroads of academia and industry have not been previously addressed.

This study focuses on the challenges facing AM university spin-outs (USOs). The evolution of their business models is examined to investigate how the ventures navigate encountered challenges in order to create a resource base, create value for co-producers and customers, and attempt to capture value for themselves. A dataset of Cambridge-affiliated AM companies is used to frame and position six case studies of AM spin-outs in various stages of value creation. These cases are analyzed to gain insight into the main challenges the companies have encountered and solutions they have attempted. This evidence and analysis are used to refine the proposed conceptual framework.

This research highlights the importance for AM USOs of creating and developing a business model that enables them to select an appropriate market and application, identify and attract appropriate co-producers, and build and leverage both internal and external resources in creative ways in order to generate value. Successful strategies that have been identified through the case studies include creating a partner-focused business model, early market identification, demonstrating the innovation in a system, and altering target market or market position to one were complementary assets are either available or unnecessary.

Key words: *Advanced materials, open-systems theory, value creation, university spin-outs, academic entrepreneurship*.

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1. INTRODUCTION

Advanced materials (AM) technologies[1] are poised to have a significant impact on the economy, a broad range of markets and applications, and the environment. They have been called the third wave of generic, revolutionary innovation, the first waves being IT and biotech respectively (OECD, 1998; Oliver, 1999). However, in contrast to the first two waves, AM technologies also face the challenge of established substitutes in their markets.

Further, the commercialization of these technologies poses significant and unique challenges for a number of key agents, including managers, entrepreneurs and policy makers. It has long been recommended by national and international policy makers that development in these areas should be encouraged as they will become engines of growth in increasingly knowledge-based economies (OECD, 1998; Maine and Garnsey, 2006). However, in order to make useful decisions in both policy and management, this unique and complex sector must first be better understood.

Sustained market and technology risk combined with long lead times often discourages incumbent firms, those with adequate resources, from developing and commercializing the more radical materials technologies in-house (Maine, 2006). For this reason among others, many of these innovations come from university spin-outs, who often receive significant government funding (Gill, Minshall et al., 2007). However, the process of commercializing AM technologies from university spin-outs (USO) has not been specifically addressed in theory or literature to date.

Although AM USOs face both market and technological challenges, this paper focuses on the challenges they encounter from a market perspective. Both internal and external factors are addressed and an open systems approach is used. By tracing the evolution of business models of case companies as their environments and resources change, we can gain insight into the experiences, challenges and creative solutions of scientist-entrepreneurs in their journey toward value creation. Accordingly, this research proposes a conceptual framework for qualitative analysis of the value creation cycle of AM USOs, including a critical resource-building cycle.

[1] Advanced materials technologies, in this paper, refer to novel functional materials and/or process innovations which have potential to significantly improve cost, performance or both

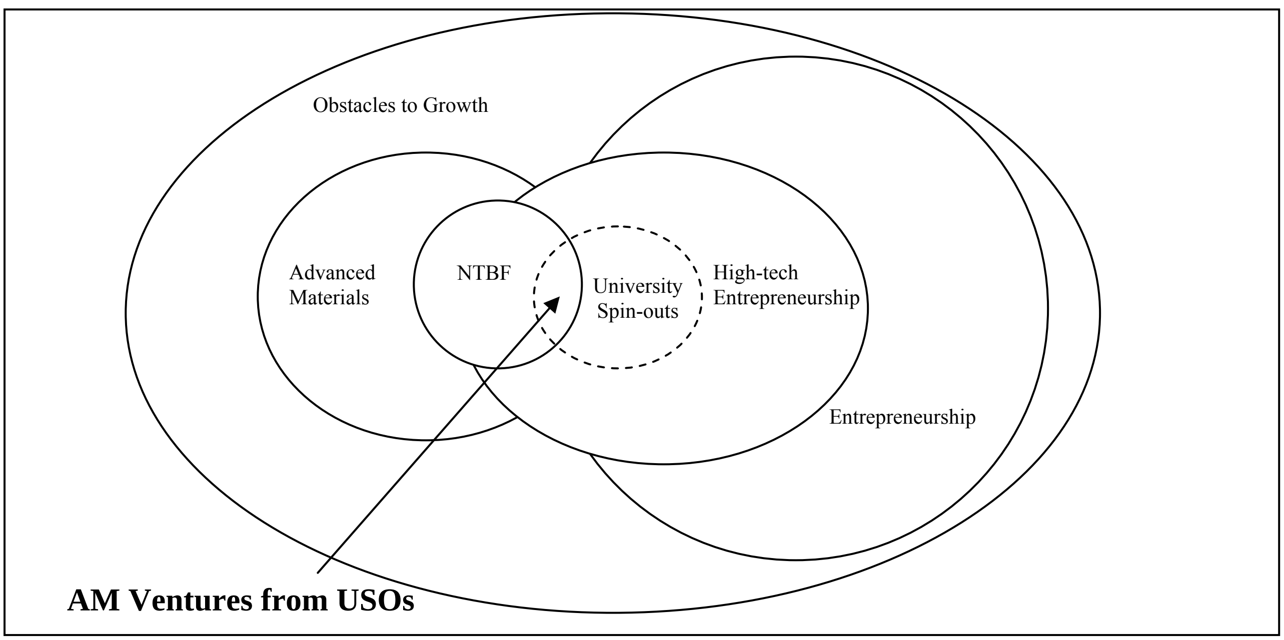
This paper attempts to identify what challenges advanced material university spin-outs face, how they endeavor to create value and how their business models evolve in response to these challenges.

We begin with an overview of literature in relevant areas, including advanced materials, university spin-outs, applicable theoretical approaches and value creation. Prior work is used to build a preliminary conceptual framework, to be tested and refined through a dataset of advanced material companies connected to the University of Cambridge. This dataset is then used to select a set of case study companies which faced similar challenges as many of the total sample to provide further insight and refinement of the conceptual framework. We conclude with an overview of the final proposed conceptual framework and outcomes for theory, practice and policy.

2. LITERATURE REVIEW

Many of the areas of literature that are relevant to frame and analyze the subject matter overlap, as shown in figure 1.

Figure 1-Map of Relevant Literature



Advanced materials literature provides the first point of inquiry, from which other areas have been identified.

2.1 Advanced Materials

Although there is literature on entrepreneurship, high-tech entrepreneurship and New Technology Based Firms (NTBF), there has been little research to date specifically on AM innovation commercialization. The majority of this work has focused on incumbent firms rather than ventures (Maine and Garnsey, 2007). There has been no work found to date exclusively on AM university spin-outs (USO). Research identified is summarized in Table 1.

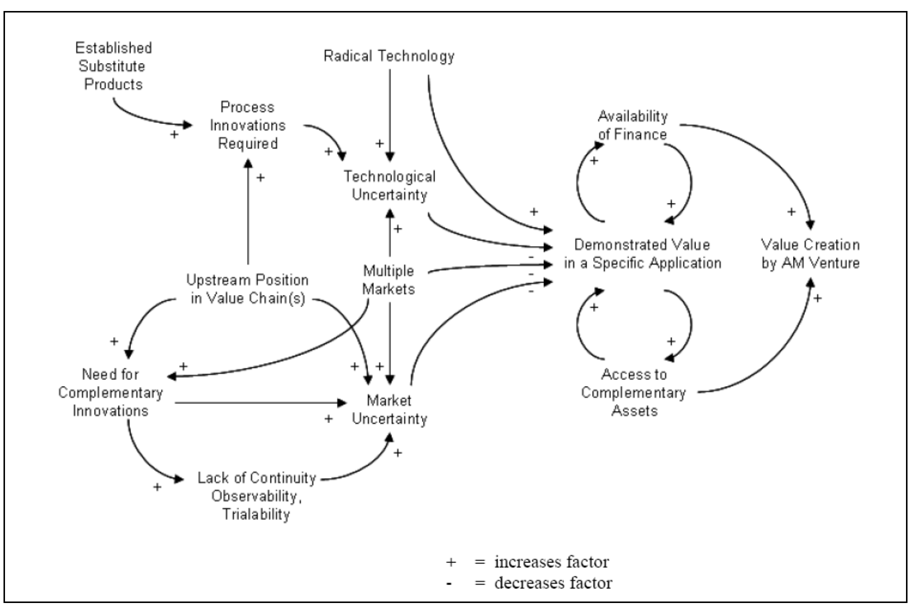
Table 1-Past Research on Advanced Material Commercialization

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)

Adapted from: (Maine and Garnsey, 2004)

Advanced materials ventures and spin-outs face a number of the same challenges as other high-tech ventures; however, they also face distinct technical, management and market challenges that make them unique. These are the combination of established substitute products, required process innovations, radical technology, up-stream position in the value chain, multiple potential markets, need for complementary resources and lack of continuity, observability and trialability (Maine and Garnsey, 2006). Maine and Garnsey use these factors in an influence model of value creation, Figure 2, which emphasizes the difficulties of demonstrating value in a specific application, without which AM ventures cannot reach value creation.

Figure 2-Influence Model of Value Creation by AM Ventures



Source: (Maine and Garnsey, 2006, p381)

This model, which is examined critically and modified later in this paper, demonstrates how these challenges influence each other in a complex system. This intricate value creation cycle, combined with challenge of finding funding after the stage for which most government research grants are intended, can mean the scientist-entrepreneurs must choose to either sell their IP or set up a new firm in order to develop and commercialize the business idea themselves. For these reasons "the advanced materials NTBF, with its more ambitious value creation goals, also requires strong linkages with providers of complementary resources, with investors and the science base" (Maine and Garnsey, 2007, p 4). What these relationships provide and lack for the AM ventures is summarized in table 2.

Table 2-Key Relationships for AM Ventures

Key Relationship with	Provides	Lacks
Science Base	-link to relevant research/knowledge base -funds for 'blue sky' research	-link to market needs -funds for commercial oriented research
Investors	-early stage funding (private and seed investors)	-In many cases, later stage funding (VC and incumbents) due to high technology and market risk
Co-producers/distributors	-access to complementary assets (manufacturing, marketing and distribution -threat of pre-mature lock-in (negative)	-Often, necessary willingness to go beyond their core competencies, and take on market and technology risks

Summarized from:(Maine and Garnsey, 2007)

Maine and Garnsey (2007) suggest that as AM technologies get closer to market, key relationships, market challenges and technology challenges need to be addressed, including prioritization of development objectives, strategic balance of short term and long term requirements, alliance building, and sufficient fundraising to overcome high development costs and long adoption timelines.

2.2 University Spin-outs

University spin-outs[2] (USOs), a form of academic entrepreneurship (Shane, 2004), are a specific category of spin-out and entrepreneurial endeavour, and are often viewed as a subcategory of NTBF (Mustar, Renault et al., 2006). In recent years, there has been a growing interest in university spin-outs as a form of technology-transfer[3], a potential source of university income, and this is a concern to policy makers (Lockett and Wright, 2005; Minshall and Wicksteed, 2005; Mustar, Renault et al., 2006). Spin-outs have the potential to create wealth, but they are also often responsible for the development of important technologies that are later acquired by larger companies (Shane, 2004).

[2] For the purpose of this paper, spinning out a company will mean when the technology (or ownership thereof) is transferred partly or wholly out of the parent entity.

[3] The term research-based spin-out (RBSO) is defined as "the creation of ventures based on the formal and informal transfer of technology or knowledge generated by public research organizations" (Mustar et al, 2006, p289) but used interchangeably with USO.

The importance of university spin-outs (USO)[4] is widely acknowledge through the literature, and recently their heterogeneity has been recognized (Clarysee, Wright et al., 2005; Minshall and Wicksteed, 2005; Mustar, Renault et al., 2006). USOs exist within a specific environment that has significant impact on the challenges they face and how they attempt to overcome them. These include entrepreneur-scientist motivations, links to science base, availability of finance and university environment (Druilhe and Garnsey, 2003). Other key aspects of USOs are summarized in table 3 below.

Table 3: Examined aspects of USOs

Aspect of University Spin-out	Relevant ideas and authors
Contrasting motivation for creation of traditional spin-out	– possession of potentially valuable technology either outside the core competencies and/or established markets of the parent (Chesbrough and Rosenbloom, 2002). – technology is valuable but risky and not sufficiently aligned with parents core capabilities (Maine, 2006)
Motivation of create USO	– self-employment, make an economic contribution, legal vehicles for technology development (Clarysee, Wright et al., 2005) – desire to bring science to market, desire for wealth, desire for independence or career oriented factors (Shane, 2004) – -additional objectives of other stakeholders such as University (Clarysee, Wright et al., 2005)
Development of USO	– overlapping stages and processes before and after spinning out require different actions on the part of both the parent and the entrepreneur (Clarysee, Wright et al., 2005) – development also requires dynamic process of resource acquisition and development by to continue create value (Penrose, 1995; Barney, 2001).
Theoretical perspectives for examination	– three main perspectives used for viewing USOs: resource-based perspective (which can be subdivided into technological, human, financial and social resources), business model perspective and institutional perspective – business model perspective can be combined with the resource-based perspective for more dynamic perspective (Mustar, Renault et al., 2006)

Although there are a number of theoretical perspectives that have been used to examine USOs, as shown in the previous table, many AM USOs are in the very early stages and still unclear on their applications, markets and strategies. Business models show how a firm views itself, its resources and its path to market. Thus analysis of the business model and evolution thereof is the selected mode of inquiry for this paper.

[4] Also called research-based spin-outs (RBSO) (Mustar, Renault et al., 2006)

2.3 Business Models

The business model can be viewed as a design, demonstrating how the firms view themselves and their opportunities within their environments. This includes strategic relationships, markets, value chain position, value proposition, revenue model, strategy (Chesbrough and Rosenbloom, 2002) and exploitation of resources to create value. But although selecting an appropriate business model is important, the evolution of that business model, as attempts are made to operationalize it, is also essential in creating and capturing maximum value as “the business models of new ventures are altered as entrepreneurs improve their knowledge of resources and opportunities” (Druilhe and Garnsey, 2003).

The relevant ideas and authors regarding business models are summarized in table 4 below.

Table 4: Relevant ideas and authors regarding business models

	Business Models: Relevant ideas and authors
Definition	– is not well-defined, often linked to strategy and exploitation of resources or opportunities (Amit and Zott, 2000; Chesbrough and Rosenbloom, 2002) – some ambiguity between the *business model* and *strategy* (Chesbrough and Rosenbloom, 2002)
Function	– “creates a heuristic logic that connects technical potential with the realization of economic value” (Chesbrough and Rosenbloom, 2002, p 529) – may “constrain the subsequent search for new, alternative models for other technologies later on” (Chesbrough and Rosenbloom, 2002, p529) – with creativity, can assist in mobilizing resources in unusual ways (Hugo and Garnsey, 2004). – determines a favorable position in the value chain (Chesbrough and Rosenbloom, 2002; Hugo and Garnsey, 2004)
Selection	– Emergence of “science-based” businesses have created a new model attempting to use existing science, advance scientific knowledge and capture value (Pisano, 2006) – Successful models for AM ventures include both possible near market and future applications, innovative organizational structures, and ability to attract partners and investment (Maine, 2006) – USO business model often determined by availability of resources which may not fit with market opportunities (Druilhe and Garnsey, 2003)

For this paper, business model will refer to *the architecture, meaning the underlying fundamental design, of a company’s activities and transactions leading to value creation, and ultimately value capture*. The business model is critically important to AM USOs because their choice of model will help to identify appropriate resource utilization, business strategy and position in the value chain well as having a great impact on ability to react to challenges and opportunities in the future. It must take into consideration the requirements of the various stakeholders including the entrepreneur, the parent/university, venture capitalists and customers. However, these further complicate business model selection and the path to value creation.

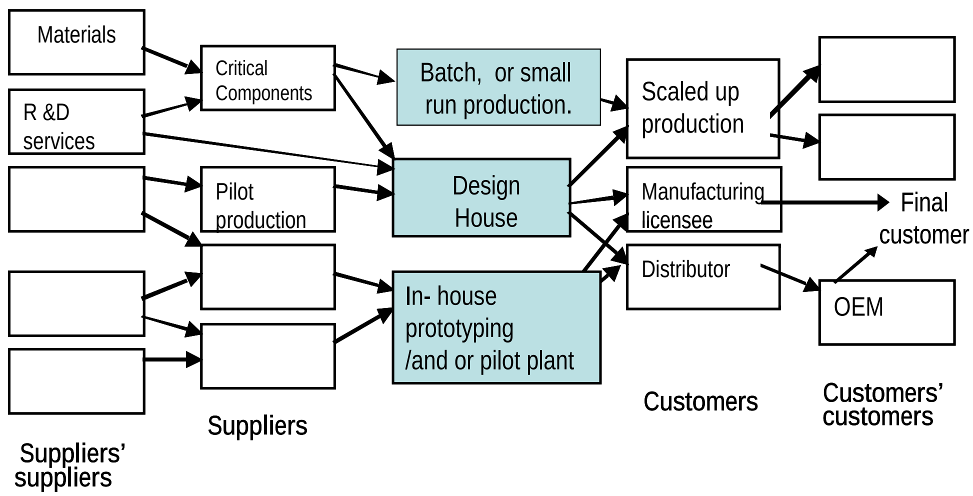
2.4 Relevant Theoretical Perspectives

There are a number of theoretical perspectives that can be used to examine USOs. Resource-based theory (RBT) is used in a number of studies as an appropriate way to view new ventures (Penrose, 1995; Mustar, Renault et al., 2006). As the literature and preliminary case evidence indicate, many tangible and intangible inputs can be used in different ways to create value for the firm (Wernerfelt, 1997; Barney, 2001; Mustar, Renault et al., 2006) However, if used incorrectly or inexpertly, factors or inputs that could otherwise be viewed as a resource will not contribute to value creation. For example, a large company manager with relationship management skills but no experience in a start-up may be detrimental to the firm, rather than serving as a resource. In this paper, resources will be defined as *any factor that can be used or leveraged to create value for the firm*.

As Penrose explains "in order to focus attention on the crucial role of a firm's 'inherited' resources, 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). However, Penrose's original argument also demonstrated that the external environment should not be ignored because "growth is governed by a creative and dynamic interaction between the firm's productive resources and its market opportunities" (Penrose, 1960, p1). For this reason, it appears an approach that incorporates both internal and external environment is appropriate.

Some of the key authors in evolutionary theory and RBT put forth ideas that implicitly or explicitly link the two perspectives (Penrose, 1959; Wernerfelt, 1997; Garnsey and Leong, 2007). When examining a typical value chain of a high-tech venture, such as that in Figure 3, it becomes apparent that neither view is complete. Although successful value creation is highly dependent on the AM USO's exploitation of their own resources, it is also heavily influenced by its position in the value chain and how it actively engages with its environment.

Figure 3-Example Value Chain of High-tech Venture



Source: (Garnsey, 2007)

For example, a new firm may have to leverage its own resources or its patents in order to gain access to the manufacturing capabilities of a partner firm. This creates a complex web of interactions which can be planned, unplanned, internal or external to the firm. An open systems model enables the boundaries of the firm to be shown while still describing the complex in/out flow of resources, impact of relationships and technological issues (McCarthy, 2003). Because of these blurred boundaries and complex relationships between parties, value creation in an open systems environment becomes complicated.

2.5 Value Creation

It can be argued that the creation (and ultimately the capture) of value, is the goal of any venture. But between many schools of thought, accounts of what value is and how it can be captured vary. The ideas from each of these perspectives are summarized in Table 5 below.

Table 5 Relevant ideas and authors in value creation

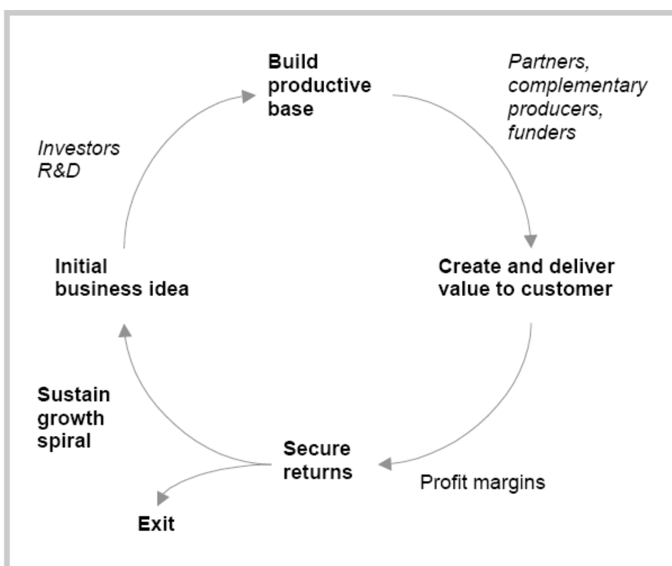
Perspective	Key ideas
RBT	- Value linked to utilization of resources (Amit and Schoemaker, 1993; Peteraf, 1993; Bowman and Ambrosini, 2000; Barney, 2001). - Two types of value: use value, "specific qualities of the product perceived by customers in relation to their needs" and exchange value, price (Bowman and Ambrosini, 2000)
Market-oriented	- Emphasis on the importance of relationships with other participants in the value chain, particularly active customers and lead users, in the process of value creation (Von Hippel, 1986; Prahalad and Ramaswamy, 2004)
Industrial	- Value created within the firm (Porter, 1985)
Accounting	- "Net present value" sets out how future returns can be currently valued (Wong, 2002).

The previous literature has highlighted the importance of the USO's utilization of resources as well as the importance of its place in and active interaction within the value chain, so a combination of RBT and market-oriented perspectives of value creation are appropriate. The delivery of value to the next player in the chain, whether they are the final customer or not, depends on their perception of the unique characteristics of this product or process, which will impact whether they are willing to trade their resources for it. By this definition, revenue is one indicator of value to customer, as is access to other complementary assets, such as manufacturing capabilities, financing arrangements or access to customers. But before this stage, in many high-tech ventures, there is a requirement for investment or other necessary resources which contributes to the resource base of the company. Gaining investment and access to complementary resources involves perceptions of future value, and accessing resources from partners, co-producers or investors is directly dependent on either the future use value they perceive or the future exchange value they perceive.

2.5.1 Entrepreneurial value creation

The capacity of an entrepreneurial firm to create value is dependent on the firm’s ability to build and mobilize an appropriate resource base (Druilhe and Garnsey, 2003). Garnsey, Ford and Dee (2006), suggest a framework, Figure 4, which illustrates the spiral process of value creation and capture in entrepreneurial firms.

Figure 4-The Entrepreneurial Process of Value Creation and Capture



Source: (Garnsey et al, 2006, p9)

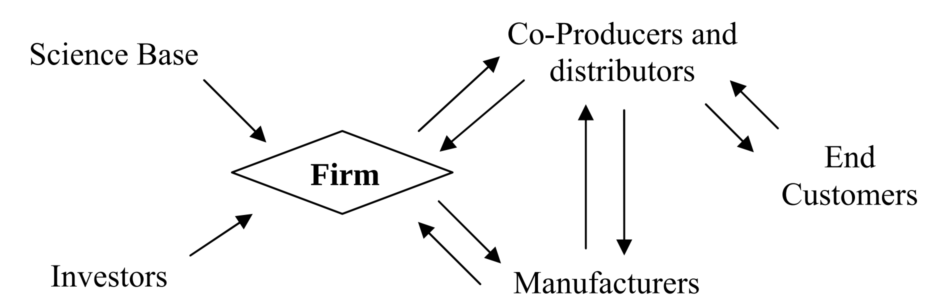
This model shows the simplified development of a firm as it attempts to create, deliver and, ultimately, capture value.

From the concepts discussed in this review, a value creation conceptual framework is proposed which incorporates the key frameworks and ideas regarding the challenges facing AM USOs, their business models and value creation.

3. CONCEPTUAL FRAMEWORK

Drawing on the literature, we aim to provide a framework that explains how the AM spin-outs create value, taking into consideration the particular challenges that they face, and how their business models and the evolution thereof reflect those challenges. The business model can be depicted at a point in time, in an open systems model, which clarifies their position in the firm's value chain or web, as shown in Figure 5.

Figure 5-Example Elements of a Business Model



Arrows show flow of resources

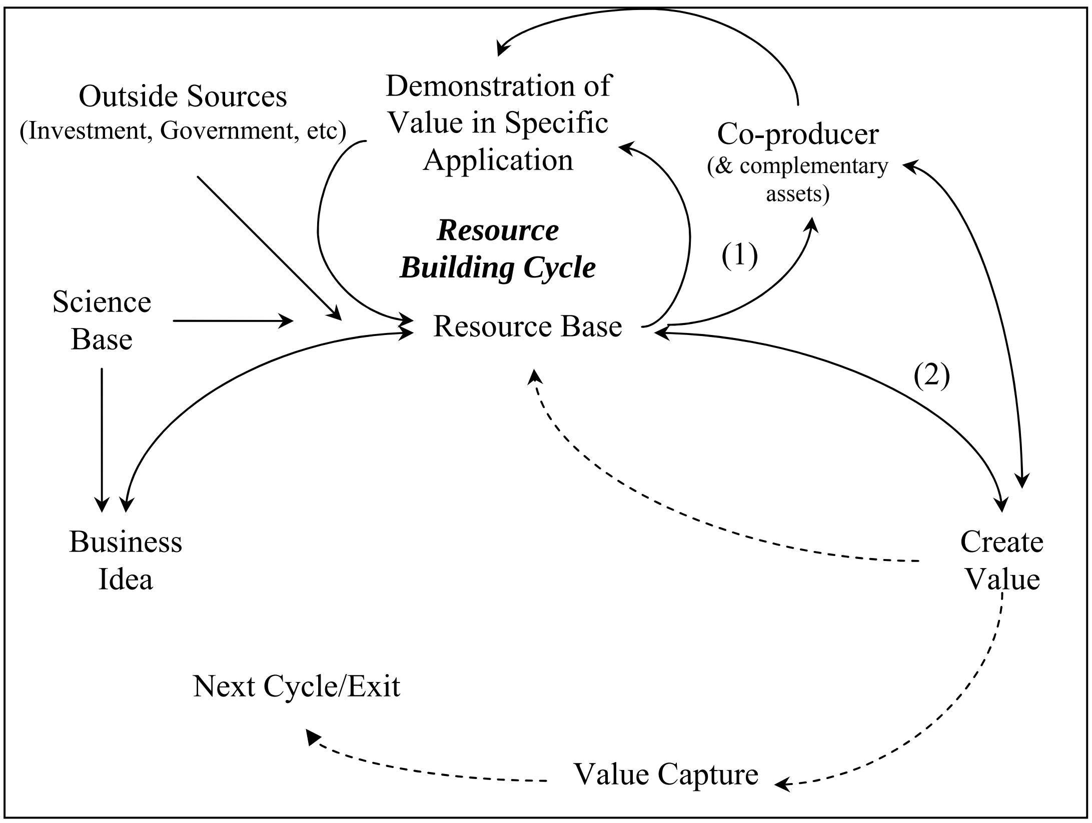
This depiction of the business model will be used as a basis for tracing the evolution of business models as their environments and resources change.

But as these spin-outs are subject to dynamic forces both internally and externally, they "progress through the continual interaction between shifting opportunities and emerging combinations of resources" (Druilhe and Garnsey, 2003). The framework proposed by Dee, Garnsey and Ford (2006), Figure 4, demonstrates the process of value creation and capture in entrepreneurial firms. This can be combined with the model proposed by Maine and Garnsey (2006), figure 2, which aimed to reveal the importance of the AM venture's chosen value chain for its prospects. This model makes the crucial point that AM ventures must demonstrate value in a specific application before they can create value, as supported by case evidence.

However, this model places *access to complementary assets* and *availability of finance* after this point, where literature and preliminary case evidence suggest that these are more interrelated than they appear here, and do not necessarily occur in a certain order. Instead, the firm is likely to go through an iterative cycle in order build its resource base to the point where it can begin creating value. This model also does not emphasize the importance of relationships to the spin-out's science base, investors and co-producers.

The proposed framework, Figure 6, attempts to use an open systems' perspective to enable the identification of the challenges and opportunities for new materials spin-outs as they attempt to create value.

Figure 6-Proposed Conceptual Framework



This framework demonstrates that before an AM spin-out can create value, it must first go through a resource building cycle (1), often driven by the interrelationship between demonstrating value in a specific application and securing access to the complementary assets of co-producers. The arrows represent the flow of resources (IP, personnel, investment, knowledge, scale-up capabilities etc). Resources from the co-producers, key drivers of the cycle, are traded for a share in promised future value. This works as a positive feedback loop, since the ability to attract partners has a positive effect on investment from other sources, often through the matching of funds. This 'resource building cycle' continues until the resource base reaches the point where that value, in the form of revenues, can be generated (2). Most of the firms in the sample selected for this paper have not yet reached the stage of capturing value, so the cycle until value creation will be used to analyze the evidence.

4. EVIDENCE

Case studies are one method that can be used to explain, describe, illustrate, explore or meta-evaluate phenomena. This can incorporate both qualitative and quantitative data depending on the specific research questions and objectives. There is currently a lack of primary data concerning these spinouts, which further indicates that inductive methods of analysis, such as case studies, are suitable (Eisenhardt, 1989; Yin, 2002). However, a larger dataset of AM companies related to the University of Cambridge is used to frame and select the case study to give a broader, more positivist perspective.

4.1 AM Dataset

A sample of 24 Cambridge associated companies was identified through university contacts and available databases. Although there are a greater number of AM companies connected to the university, it was not possible to identify all relevant companies from available databases, since most of these only provided information on department of origin, not on technology.[5] The dataset was constructed primarily through secondary data from company websites, press releases and other databases. Primary data was also gained from interviews by Dr Elicia Maine of Simon Fraser University and the author.[6] It provides a more detailed picture of the environment in which these companies operate, stages of development, prevalent business models and challenges faced thus far. To concentrate on more market oriented traits and activities of these firms, the characteristics examined also include sources of finance, number of market areas targeted and strategic alliances.

The companies have been divided by business model for analysis. Business models used were those identified in the literature: (1) manufacturing (including manufacturing with outsourcing and in-house manufacturing), (2) licensing and (3) combination.[7] Many of the companies identified included a degree of development in their business models, but all of those were in connection with a current or future intention to include or shift into manufacturing or licensing. For these reasons, 'development' is shown as a subset of combination models.

[5] Duration of the investigation was constrained to one year

[6] This data is almost entirely from secondary sources so knowledge of internal constraints is limited. Few firms specifically state their business model when providing evidence used as secondary information, so the business model for many of the companies has been inferred by the researcher and not necessarily discussed with the company.

[7] Of manufacturing, licensing and/or development

Table 6 provides a summary of the identified characteristics of the firms by business model. The sample shows that over half of the companies have a mixed business model, and that all but one have a strategy that depends on the involvement of partners. Table 7 then provides a summary of the challenges observed. Most have created a prototype, but only 16 of the 24 have demonstrated value in a specific application, which could mean a prototype with a specific application or gained access to assets of funds by demonstrating the value of the proposed product or process. 15 of the total 24 have begun generating some sort of revenue (through sales or R&D services). Only 7 have generated a profit, four of which are manufacturing firms.

Table 6-AM Dataset: Company Characteristics by Business Model

Business Model	Companies	Average Age (years)	Average # Markets Areas[8]	Strategy involves Alliances	Currently has Alliances	Funding			
						Self[9]	Government	Angel	Seed, VC or Corporate Funding
Licensing	2	11.5	1	2	2	1	0	2	1
Manufacturing[10]	8	21.4	2.9	7	7	5	1	0	5
Mixed[11]	14	5.7	1.6	14	9	2	8	1	9
Development	*10*	*4.9*	*1.5*	*10*	*6*	*0*	*6*	*0*	*7*
Total Sample	**24**	**11.4**	**2**	**23**	**16**	**8**	**9**	**3**	**15**
Case Companies	**6**	**6**	**2.2**	**6**	**4**	**2**	**3**	**0**	**4**

Table 7-Business Models and Challenges Observed

Business Model	Strategy involves Alliances	Avg. Access to Complem-entary Asset[12]	Has Prototype	Demonstrated Value in Specific Application	Created Value (Revenue)	Captured Value (Profit)	Process Innovations Required	Needs Complementary Innovations	Avg. Lack of Continuity/ Trialability[13]	Avg. Upstream Position in Value Chain	Has Established Substitutes	Avg. Radical Technology[14]
Licensing	2	2	2	2	2	0[15]	1	0	1	1	2	1
Manufacturing	8	1.5	8	7	6	4	2[16]	4	1.1	1.13	8	1.4
Mixed	14	1.2	11	7	7	3	3[17]	6	1.3	1.7	12	1.8
Development	*10*	*1.1*	*7*	*3*	*3*	*0*	*2[18]*	*4*	*1.4*	*1.7*	*8*	*1.8*
Total Sample	**24**	**1.4**	**21**	**16**	**15**	**7**	**6**	**10**	**1.2**	**1.46**	**22**	**1.6**
Case Studies	**6**	**1.33**	**4**	**4**	**4**	**0**	**2**	**2**	**1.2**	**1.7**	**5**	**1.7**

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[8] Market areas are broadly defined, ie military, electronics, textiles, energy storage, drug delivery, etc.
[9] Generating profits which can be reinvested
[10] Includes in-house manufacturing and manufacturing with outsourcing
[11] 11 include licensing their business model
[12] Scale from 0 to 2, 0 being no access, 1 being some access and 2 being access to significant resources (Maine, Lubik and Garnsey, 2008)
[13] Scale from 0-2, 0 being continuous from current technology, 1 being lack of continuity of the manufacturer or mainstream customer and 2 being difficult for both the manufacturer and the final consumer to directly trial the product before widespread release (Maine, Lubik and Garnsey, 2008)
[14] Scale from 0-2, 0 being incremental, 1 being significant improvement in performance attributes and novel technology, and 2 being potential for vast improvement in performance and highly novel technology (Maine, Lubik and Garnsey, 2008)
[15] One unknown
[16] One failed
[17] One failed
[18] One has gone out of business, one has not found alliances

As the database shows, there is a large degree of variation within the AM spin-out companies related to Cambridge. For that reason, the companies selected for more in-depth case studies also have some degree of variety. As most of the companies in the sample have yet to capture value (17), neither have the selected companies. Two spin-outs are second-generation[19] and, for contrast, two are corporate spin-outs. Some of the key characteristics of the case companies are contrasted in Table 8.

Table 8-Characteristics of Selected Case Companies

Company	Founding Year	Business Model	Needs Alliances?	Has Alliances?	Has Created Value?	Has Captured Value?
NanoMagnetics	1997	Mixed-Development and Licensing	Yes	No	No	No (failed)
Apaclara	2006	Mixed-Development and Licensing	Yes	Yes	Yes	Pre
Metalysis	2002	Mixed-Licensing and Manufacturing	Yes	Yes	Yes	Pre
Atraverda	1992	Manufacturing	Yes	Yes	Pre	Pre
AtraNova	2005	Manufacturing	Yes	Yes	Yes	Pre
Q-Flo	2004	Mixed-Development and Licensing	Yes	No	Pre	Pre

4.2 Case Exemplars

The following cases have been summarized and examined through the challenges they encountered, solutions attempted and the evolution of their business models in response to those challenges. The conceptual framework has also been tested by mapping the critical challenges and solutions in their observed progression toward value creation. Account of the business models, including market, customers and co-producers, are based on the perceived views of the firm at the time of case study because "the venture's business model is a response to the entrepreneurs view of the environment and the opportunities it offers"(Garnsey, 2003).

4.2.1 Case 1: NanoMagnetics[20]

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 the protein Ferritin, an iron-storage protein found in living organisms, and using the resulting cavity to producing a mold for uniform magnetic nanoparticles. Though there were a number of potential applications, data storage was chosen as the target market. Although the firm was able to access substantial venture capital in its early stages, market conditions and development challenges were major obstacles, leading to the downfall of the company. The

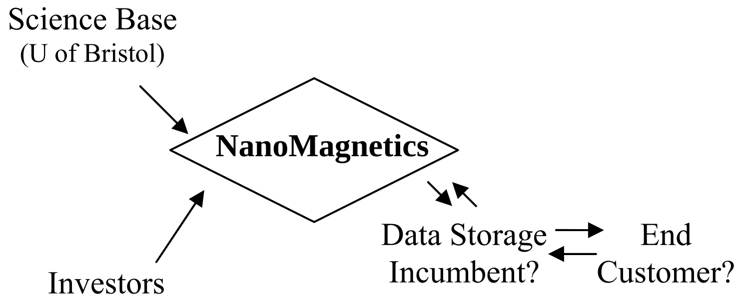
[19] Spin-outs which are one generation the company that spun out of the original parent entity
[20] This case is primarily an account of NanoMagnetics from the perspective of Dr Eric Mayes, company founder and CEO.

firm went into administration in January 2006, but not before the base was laid for a new company, Apaclara, using the technology in water purification applications. A summary of key challenges, solutions and the observed evolution of the firm's business model thus far has been depicted in Table 9 and it journey toward value creation was been mapped on the conceptual framework in Figure 7.

Table 9-Evolution of NanoMagnetics Business Model to Navigate Challenges

<table>
<tr><th>Business Model</th><th>Challenges (Solutions)</th></tr>
<tr><td>

#1: Development/Licensing (1997-2003)

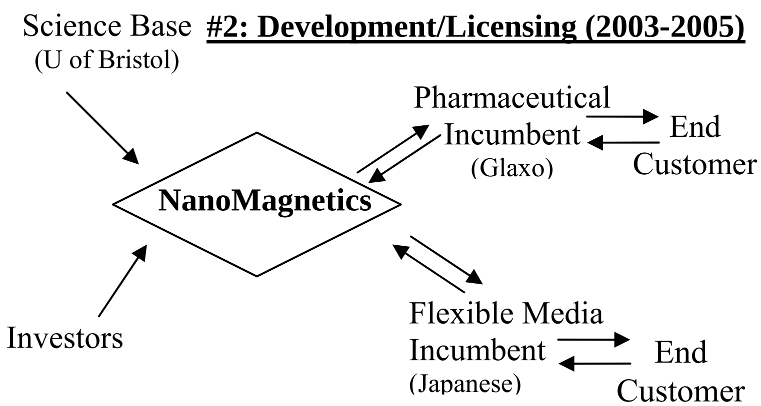


</td><td>

A- market selection (choice of 7 markets, including data storage)
B- access to finance ***(Move to Cambridge, found group of investors)***
C- need for complementary assets ***('back-scratching' arrangements with Bristol))***
D- appropriate personnel: hired experienced corporate CEO, poor match to a start-up
E- need for process innovations to lay down material on disks
F- inability to demonstrate value in specific application, no proof of concept

</td></tr>
<tr><td>

#2: Development/Licensing (2003-2005)

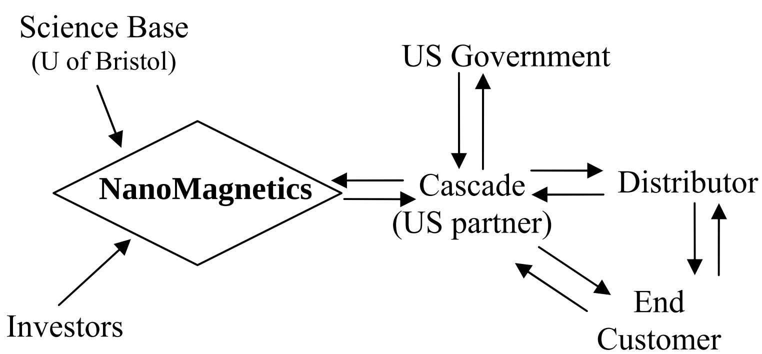


</td><td>

A- market selection, need to find another application to generate revenue or get more funding
B- access to finance: market downturn, investors becoming cautious
C- need for complementary assets ***(some still through Bristol)***
D- appropriate personnel: experienced CEO
E- circumvented by business model ***(Process innovation no longer required)***
F- inability to demonstrate value in specific application, still no proof of concept

</td></tr>
<tr><td>

#3: Development/Licensing (2005-2006)

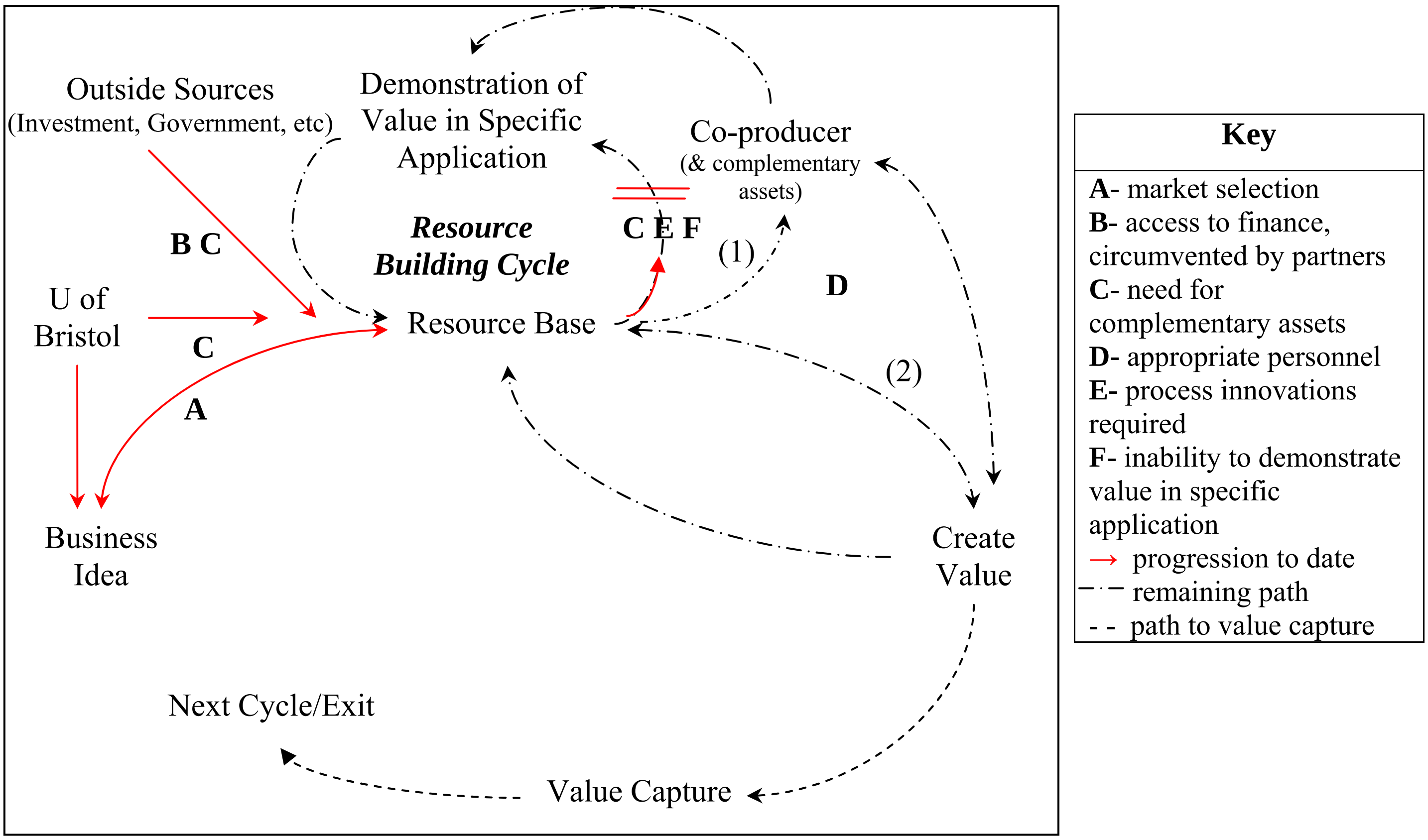


</td><td>

KEY CHANGE: Approached by US company Cascade for partnership
A- market selection ***(water purification with partner assistance)***
B- access to finance ***(Partners have SBIR funding)***
C- need for complementary assets ***(changed business model to focus on: partner and science base)***
D- appropriate personnel ***(change in focus did not require additional personnel)***
E- circumvented by business model ***(chose to produce whole system)***
F- exit before value could be demonstrated

</td></tr>
</table>

Figure 7-Case 1 Value Creation Cycle



4.2.2 Case 1b: Apaclara[21]

Apaclara rose from the ashes of NanoMagnetics, in January of 2006, using the SBIR grant awarded to their partner, Cascade, to develop and commercialize some of NanoMagnetics' technology in a water purification application. Cascade, a US-based sporting goods company, had come into contact with NanoMagnetics just before the company went into administration, and were enthusiastic to continue working with the technology and Dr Mayes. This access to patient complementary assets and funding has helped Apaclara produce a prototype and avoid many of the obstacles that faced its predecessor. The improved entrepreneurship knowledge of Dr Mayes and assistance of its partners was incorporated into its business model, as summarized in Table 10. This has allowed it to progress further through the resource building cycle, as shown in Figure 8.

[21] This case study is based on a number of interviews with Dr Mayes, company founder and non-executive unless otherwise stated.

Table 10-Apaclara's Business Model

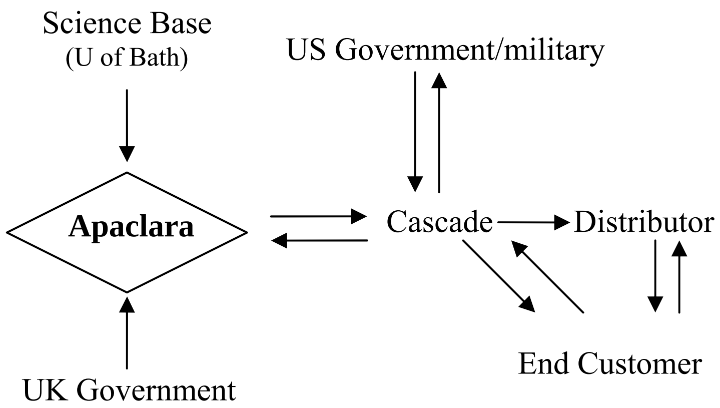
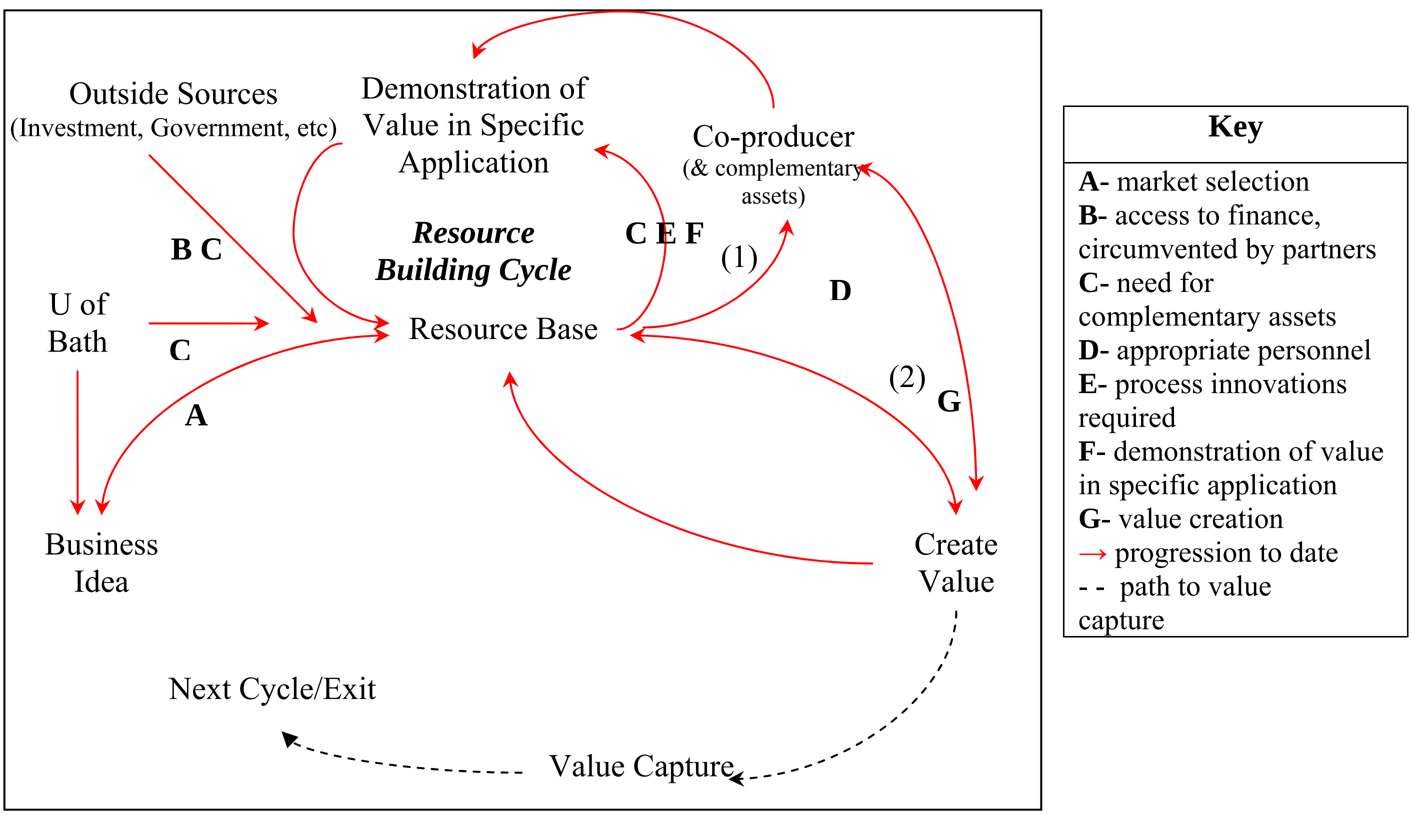
Business Model	Challenges *(Solutions)*
Development/Licensing (2006-present) 	**A-** market selection ***(direction of partner)*** **B-** access to finance ***(Received SBIR through Cascade)*** **C-** need for complementary assets ***(circumvented by partner-focused business model: partner and science base)*** **D-** appropriate personnel, ***(partner-focused business model also gave access to partner scientists)*** **E-** process innovations required, ***(produce entire system)*** **F-** demonstrated value in specific application ***(with access to complementary assets/ partner input)*** **G-** value creation ***(treated as subcontractor by Cascade)***

Figure 8-Case 1b Value Creation Cycle



4.2.3 Case 2: Metalysis

Metalysis (FFC Ltd until 2003) was spun out of Cambridge University to commercialize the Cambridge Fray, Fathering and Chen FFC Process developed by Cambridge researchers by those names (Process Engineering, 2003). This process uses molten salt electrolysis to convert titanium dioxide directly into titanium, a previously complicated and expensive process. Fray approached Cambridge Enterprise Ltd, the University technology transfer office (TTO), to patent the process. Peter Hiscocks[22] explains that the TTO did not have the resources to handle the licensing so it licensed the process to the Defense Evaluation and Research Agency (DERA), which in 2001 split into the Defense Science and Technology Laboratory and QinetiQ. QinetiQ would handle any further licensing of the FFC process. FFC Ltd then acquired the worldwide rights to the process for all metals, except titanium, the rights for which were licensed to British Titanium (BTi), another of Dr. Fray's companies (2007).

Metalysis received a great deal of government and VC finance and attracted a number of major industrial partners. Still, titanium was the most attractive metal identified because its processing costs could be reduced by the most significant ratio, and those rights had been licensed to BTi. However, agents of the University were of the view that BTi was not effectively commercializing the process and chose to retract the license.[23] In April 2005, Metalysis acquired the head license rights to the process from the University, giving the company the worldwide rights to all metal and alloys (Metalysis, 2007). BTi has brought legal action against Metalysis and QinetiQ, and a legal battle continues to this day (Fountain, 2007).

As regards to the particular challenges Metalysis faced, namely those related to IP, the university's TTO was central as both cause and the solution. The evolution of Metalysis' business model in response to the key challenges faced and methods to circumvent those challenges is summarized in Table 11. This also shows the importance of appropriate partners and their complementary resources in navigating the resource building cycle. The case company's journey through this cycle, and its progression through the conceptual framework, is also shown in Figure 9.

[22] Mr Peter Hiscocks was involved in Cambridge Enterprise when Metalysis received its original funding and assisted in the selection of Dr Cooley as CEO. He also worked for Generics, a major investor in British Titanium (BTi), when BTi was attempting to commercialize the FFC Process.
[23] Hiscocks interview, ibid

Table 11-Evolution of Metalysis' Business Model to Navigate Challenges

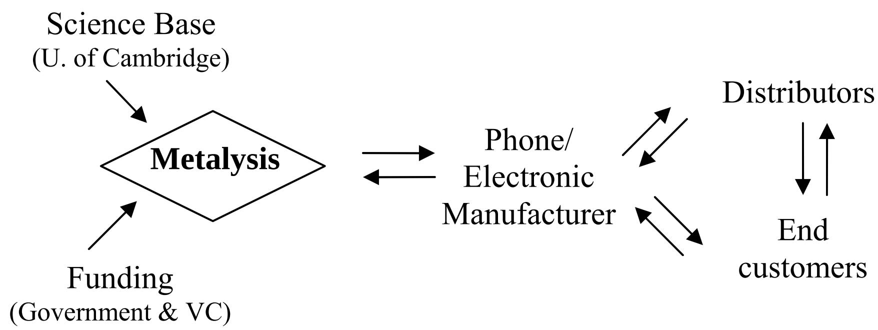
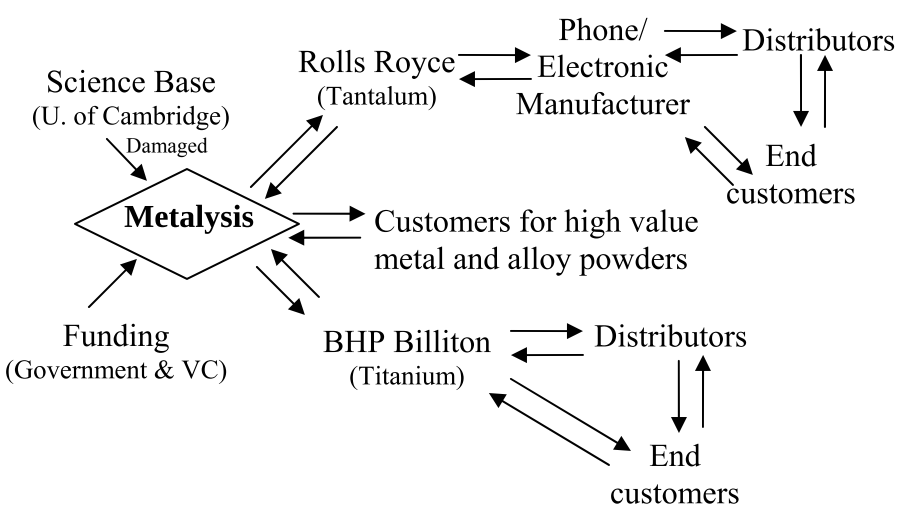
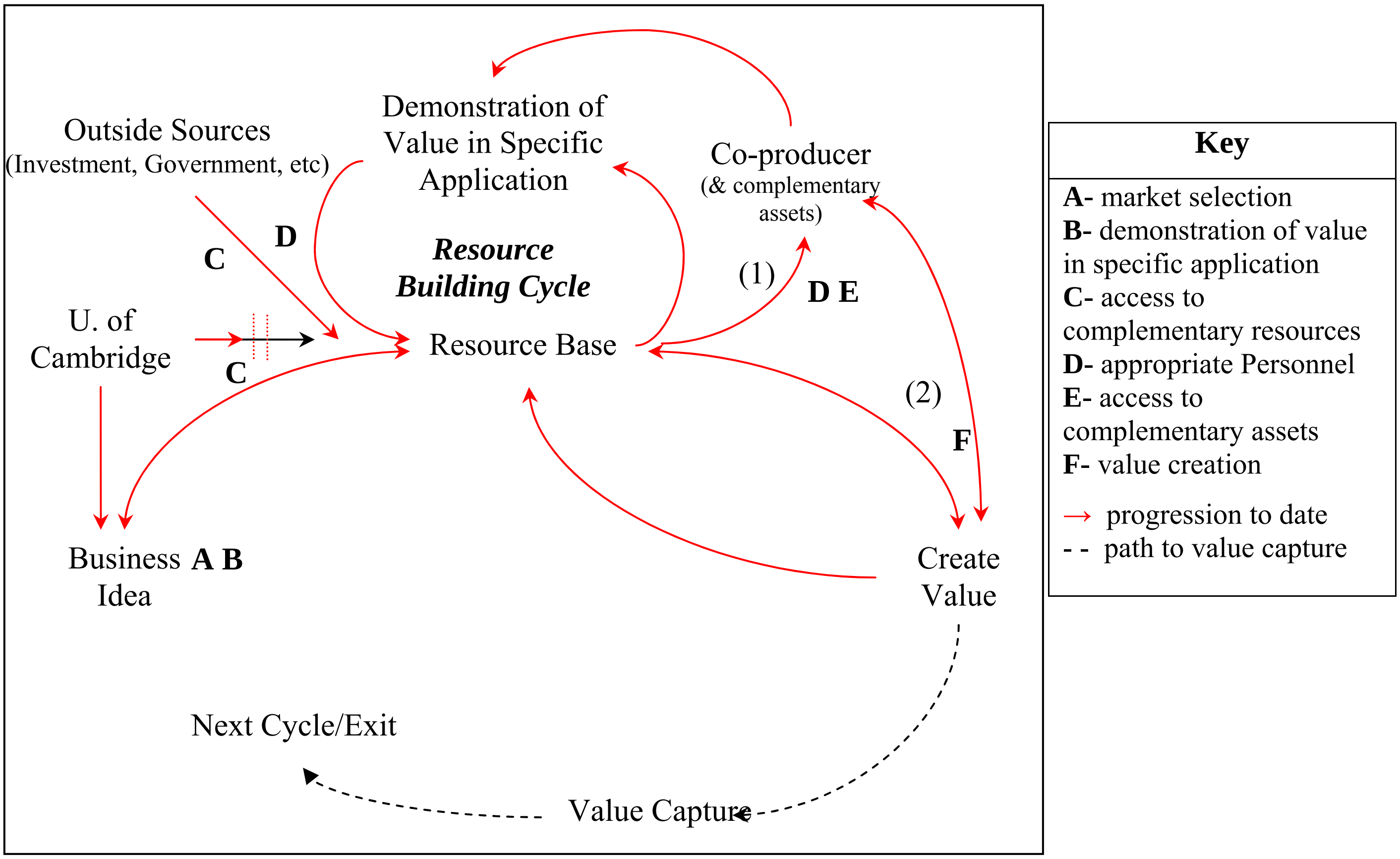
Business Model	**Challenges *(Solutions)***
#1: Manufacturing (2001-2006)  	**A-** market selection ***(began with founder knowledge/research focus that made market selection clear)*** **B-** demonstration of value in specific application *(Value of process a major breakthrough which drew investors)* **C-** access to complementary resources (IP) ***(through TTO licensing from University)*** **C-** access to complementary resources ***(adapted business model: selected part of value chain where smaller quantities were needed)*** **D-** appropriate Personnel: CEO ***(circumvented through business model. Close ties with TTO allowed them to help with appointment of appropriate CEO)***
#2: Licensing and Manufacturing (2006-present)  	**C-** access to resources (IP) ***(still through relationship with TTO)*** **E-** access to complementary assets: Scale-up capabilities and market access ***(circumvented by business model: focused on strategic partnerships)*** **F-** value creation (***through joint ventures with partners)***

Figure 9-Case 2 Value Creation Cycle



4.2.4 Case 3: Atraverda[24]

In the 1980s, while working at IMI Marston, Peter Hayfield invented Ebonex®, a titanium-oxide ceramic with a number of potential applications, including electro-chlorination, hydro-chlorate electrolyis, electrolytic water purification and lightweight batteries (Hayfield, 2002). But Ebonex®'s many applications were outside the remit of the company, so the IPR passed through a number of firms before Atraverda was founded in 1992, with the acquisition of the IPR and the files of Ebonex® Technologies Inc. Atraverda was subsequently purchased by Sagentia (Generics until 2006), who injected funding and personnel until 2004 when they began to seek additional external investment for the company. Atraverda is focused on using their Ebonex® ceramic in bi-polar, lead-acid battery technologies, particularly high performance applications such as uninterruptible power supply (UPS). According to Andrew Dixey, CEO of Atraverda, a working bipolar battery is seen as the "holy grail"of the battery industry, as it solves a number of significant issues, such as durability, battery-life and performance.

[24] This case study is based on an interview with Mr. Andrew Dixey, CEO of Atraverda, on August 30, 2007 unless otherwise cited.

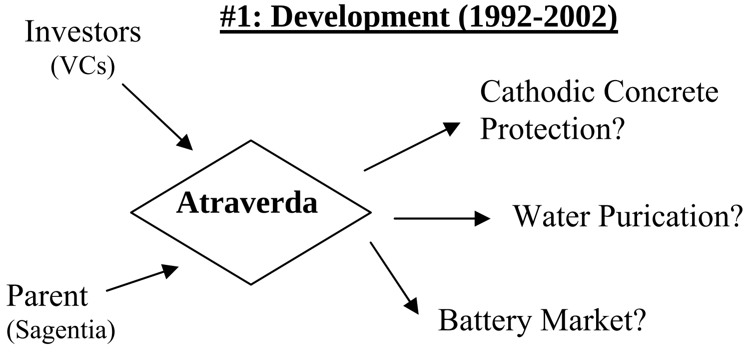
This potentially revolutionary technology attracted significant venture capital funding as well as a number of the key partnerships that Atraverda was seeking. From the start, Atraverda was not going to be a battery producer. Instead, it would manufacture the Ebonex® powder and the substrates used in the batteries, both of which are covered by patents. Dixey explains that they would work with a number of global battery partners to assist in building the substrates with the Ebonex® material into a bi-polar battery which will be produced by the partners, not Atraverda. They felt that they could also leverage existing sales and distribution channels through those partners, which would provide Atraverda with faster access to high growth opportunities and significantly reduce capital requirements.

Having spun out of and acquired by a number corporations before Sagentia, Atraverda's Ebonex® technology spent years in development before its corporate parent realized the technology's potential in battery applications. Table 12 summarizes the challenges faced by the company through its history, the solutions that were found and the evolution of Atraverda's business model. This demonstrates the importance of access to finance through their parent and, later, outside investors. It also shows the importance of the business model in identifying the most appropriate partners and position in value chain for successful navigation of the resource building cycle before value creation, as shown in Figure 10.

<u>**Table 12-Evolution of Atraverda's Business Model to Navigate Challenges**</u>

<table>
<tr><th>Business Model</th><th>Challenges (Solutions)</th></tr>
<tr><td>

<u>**#1: Development (1992-2002)**</u>

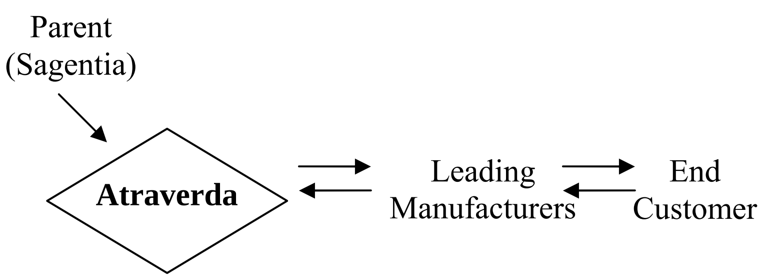


</td><td>

A- mismatch with parent market/ competencies
B- access to finance, ***(had one round of VC funding before being purchased by Generics (parent) which acted as an incubator)***

</td></tr>
<tr><td>

<u>**#2: Development/Manufacturing (2002-2004)**</u>

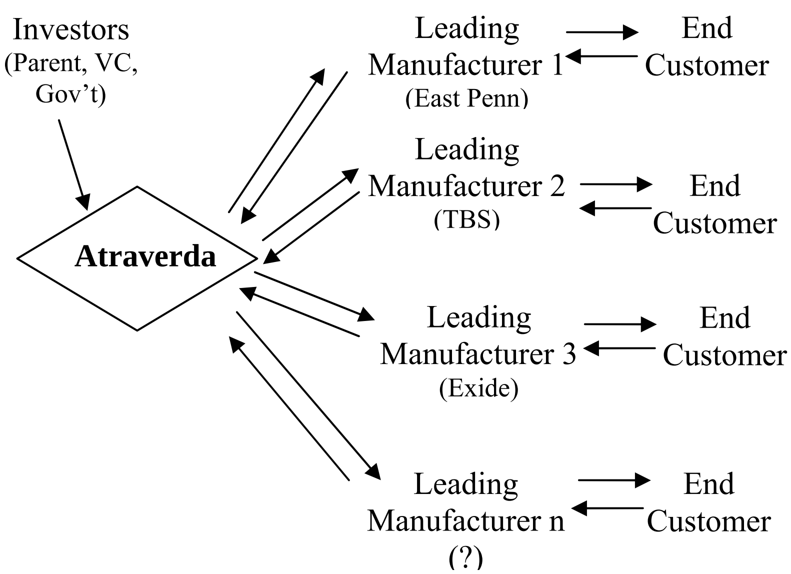


</td><td>

C- appropriate personnel: CEO ***(circumvented by business model/ parent involvement. CEO was selected from existing personnel to further development)***
D- market selection ***(parent involvement)***
E- demonstrate value in a specific application *(no prototype but continued development funded by parent)*

</td></tr>
<tr><td>

<u>**#3: Manufacturing (2004-present)**</u>

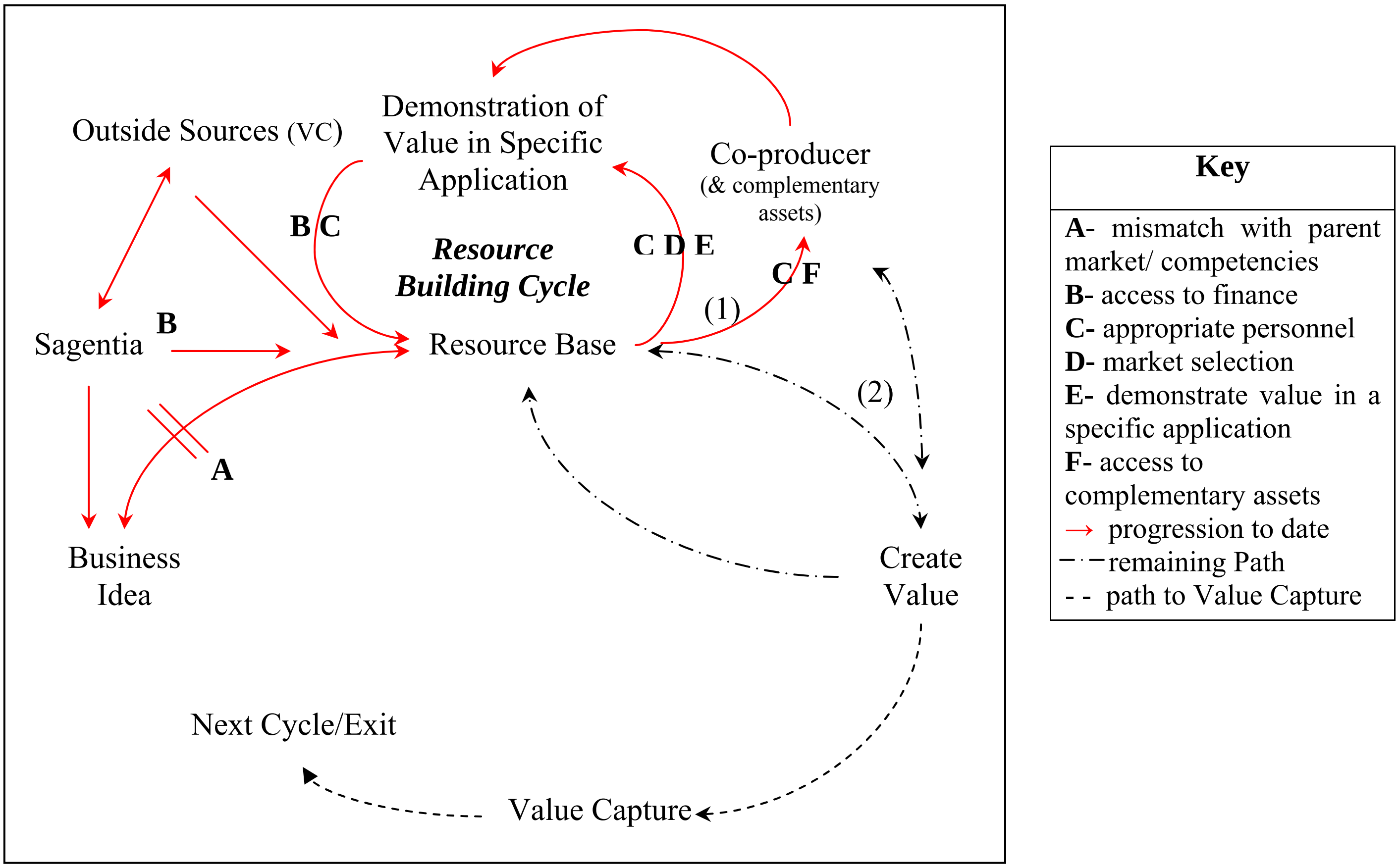


</td><td>

C- appropriate personnel ***(CEO becomes CTO to continue development, new CEO selected in 2007 for experience in raising funding)***
F- access to complementary assets ***(circumvented through business model: selection of innovative leaders as partners for manufacturing, scale-up and market access)***

</td></tr>
</table>

Figure 10-Case 3 Value Creation Cycle



4.2.5 Case 3b: AtraNova[25]

In 2005, AtraNova spun out of Atraverda. In the beginning, AtraNova was, according to their technical manager Paul Wilkins, a "backroom research team" within Atraverda, investigating the material and its properties further, with a focus on water purification and waste treatment. Although AtraNova were not originally a profitable group, Sagentia AG, who had an 80% investment in the Atraverda through their private equity arm, pushed for AtraNova to be spun out and produce a profitable product. The change was facilitated by the appointment of a new CEO, Alex Simpson, whose view was that the new company either needed to be made profitable or closed.

A significant, though unexpected, deal in with a company in Israel drove the company to complete design, prove and deliver a large number of their electro-coagulation devices in a very short period. These devices, which use the Ebnoex ceramic to charge and remove pollutants from waste water, were delivered for a

[25] This case study is based on interviews with Technical Manager Paul Wilkins in Autumn of 2006 and August 2007 unless otherwise cited.

specific amount, but further deals were made with a different revenue model. Instead of a lump sum, AtraNova receive a percentage of money the partner company saves on fees charged by the government for dumping waste. As their technology is still being refined, their clients also act as development partners. They also assist their clients to find ways to dispose of the resulting filtrates, such as selling it to bio-fuel companies. This complete solution allows them to facilitate product trial and adoption, which has also led to a number of referrals to new clients.

As a second-generation spin-out from Atraverda, AtraNova was strongly directed by the parent of its parent, circumventing the challenges of market selection, personnel selection and access to finance. They have adopted a customer-centric business model, shown in Table 13, which allows them to continually test and improve their technology while beginning to generate revenue. They have also progressed further through the conceptual framework, as shown in Figure 11.

Table 13-AtraNova's Business Model

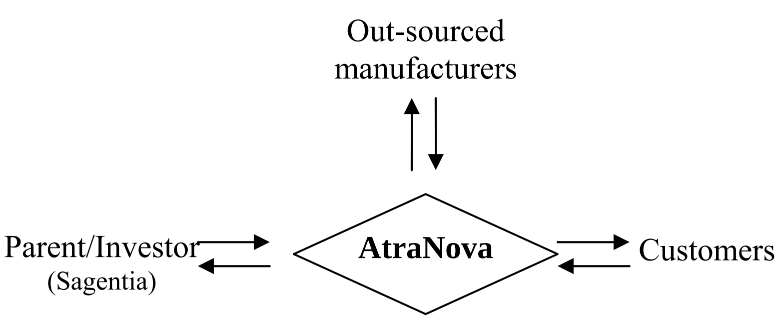
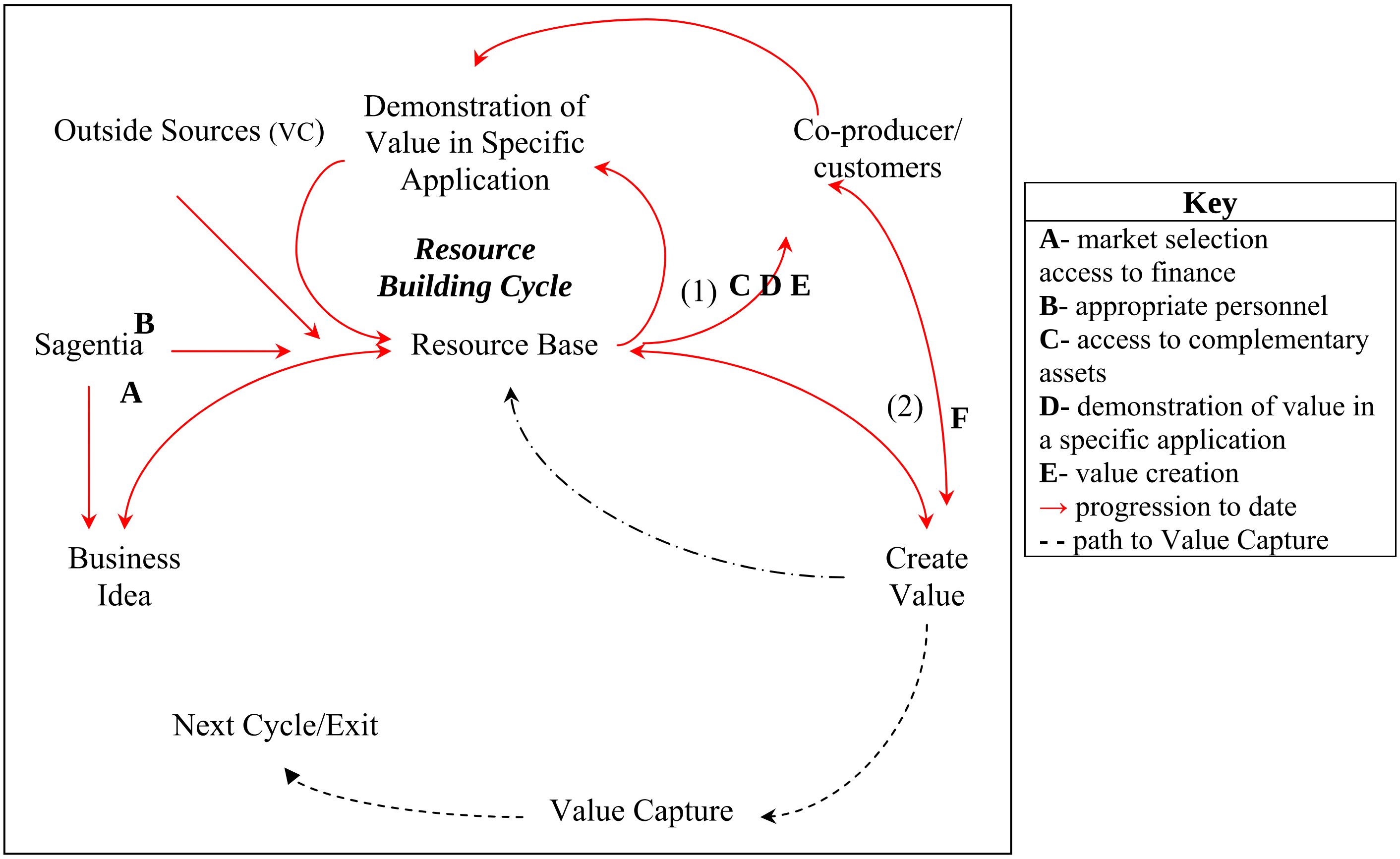
<table>
<tr><th>Business Model</th><th>Challenges (Solutions)</th></tr>
<tr><td><u>Manufacturing (2005-present)</u>

</td>
<td>A- market selection (through focused business model and with parent involvement)
B- access to finance (focused business model with parent involvement)
C- appropriate personnel (focused business model with parent involvement to select CEO with profit focus)
D- access to complementary assets (focused business model identified co-producers and customers)
E- demonstrate value in a specific application (customer-focused business model to encourage product trial)
F- value Creation (Business model and serendipity of deal with Israeli company)</td></tr>
</table>

Figure 11-Case 3b Value Creation Cyclex



4.2.6 Case 4: Q-Flo[26]

Q-Flo was founded in 2004 by Dr Martin Pick and Dr Alan Windle in order to separate the commercialization/entrepreneurship that arose in Dr Windle's research group from the research going on within it. Q-Flo currently has status as an 'embedded company' in the university as well as a 'pipeline' agreement with the Carbon Nanotube Research Group (Pick, 2007). Although there were a number of inventions that the new company felt had potential, the technology they have pursued is a novel process for producing carbon-nanotube (CNT) fibre. If the technology can be successfully scaled-up, Dr Pick believes it may be capable of producing some of the strongest material on earth.

The first challenge the company faced was gaining access to the required IP. The two licenses related to the process were held by Thomas Swan & Co. Ltd, who funded the research that produced them. The first

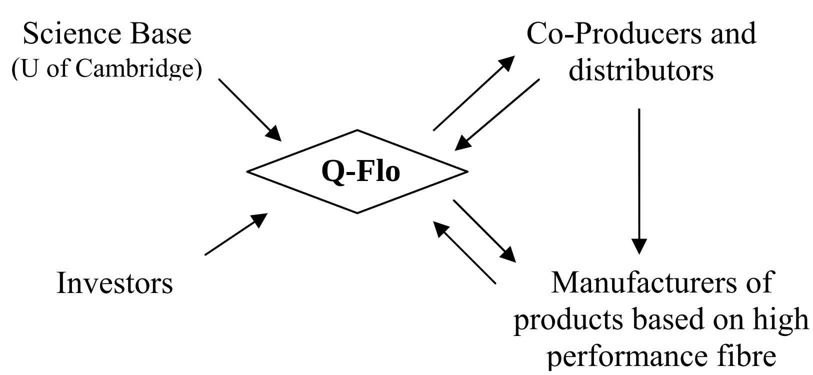
[26] Unless otherwise stated, this case is based on multiple interviews between Dr Pick and the author in summer 2006 and autumn of 2007, as well as an interview between Dr Pick and Dr. EW Garnsey in summer 2006.

twelve months of Q-Flo's existence was spent negotiating with Thomas Swan Ltd over their rights to the license. Although the standard university agreement gave Thomas Swan Ltd rights to the IP, the two parties were able to reach an agreement that satisfied them both. Thomas Swan, the individual, decided that although his company had put a great deal of money into the research, they had also got a process out of it which worked well. Dr Pick realized that this outcome "hinged around [their] relationship to Tom Swan."

Despite the potential value of this process in a variety of applications and markets, the company has yet to attract the capital or partnership necessary for scale-up trials. However, the university department has received a £1.2M EPSRC grant to investigate the fundamental technology. Dr Pick suggests that a lack of focus by the management, who all have other employment, along with technological uncertainty are serious challenges to the company. At this point, Pick is considering turning his attention to one of Q-flo's other patents in order to shift the company's focus and perhaps begin generating revenues.

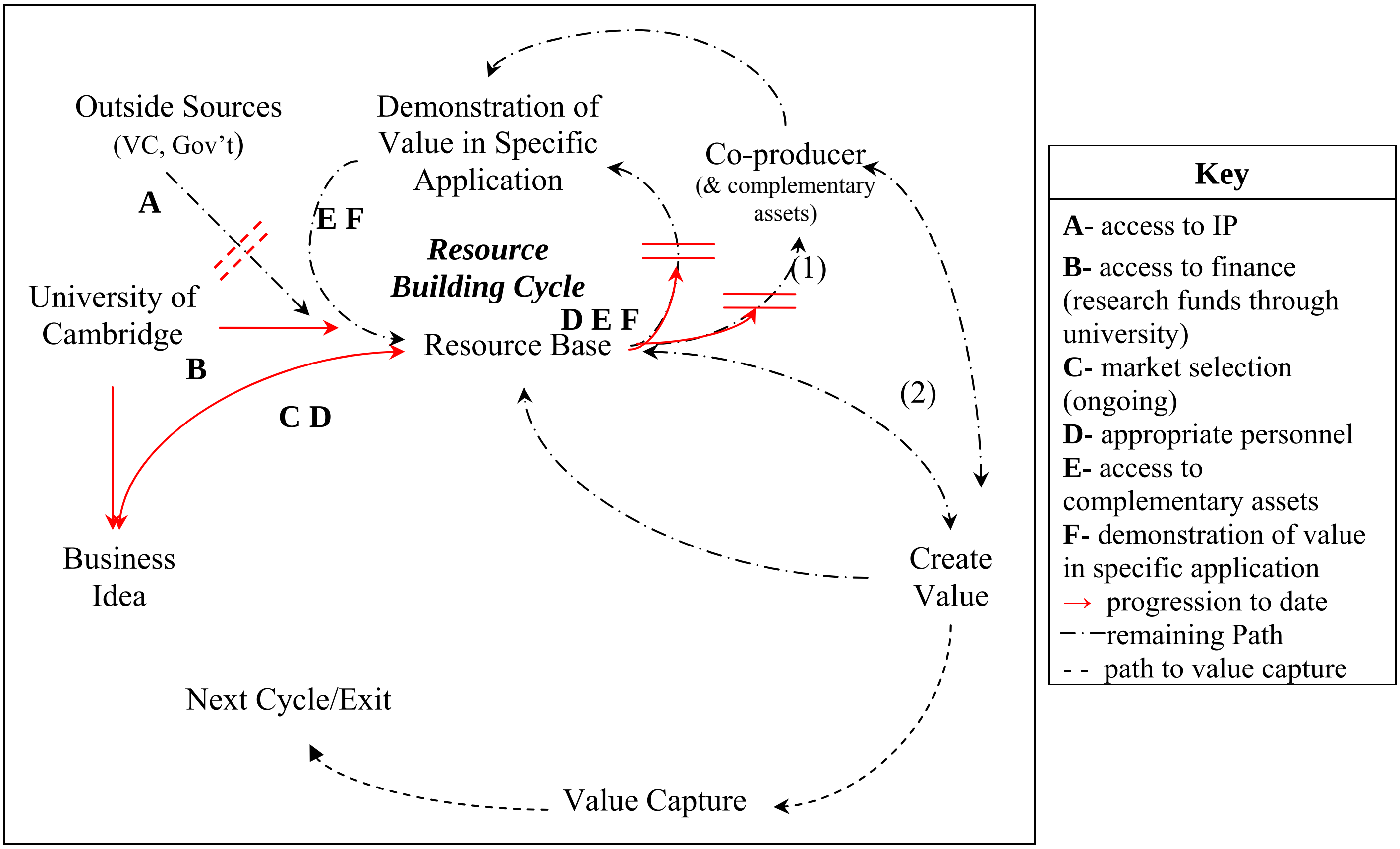
Q-Flo's current challenges, shown in Table 14, align with the literature suggesting that a single market focus is useful to a business with a radical, generic technology (Maine and Garnsey, 2004). It also demonstrates the interconnected nature of access to complementary assets through partners and demonstration of value in a specific application, as shown in Figure 12, which can cause a hazardous situation for a young firm.

<u>Table 14-Q-Flo's Business Model</u>

<table>
<tr><th>Business Model</th><th>Challenges (Solutions)</th></tr>
<tr><td><u>Development/Licensing (2005-present)</u>


</td><td>A- access to IP (entrepreneurs' relationship with IP holder)
B- access to finance (through relationship with university department)
C- market selection (ongoing as no market as been selected)
D- appropriate personnel (on-going but partially solved by personnel. Current board members are experienced, well-connected and methodical, but not not soley focused on Q-Flo)
E and F- access to complementary assets and demonstration of value in specific application. Not yet solved, interconnected and on-going)</td></tr>
</table>

Figure 12-Case 4 Value Creation Cycle



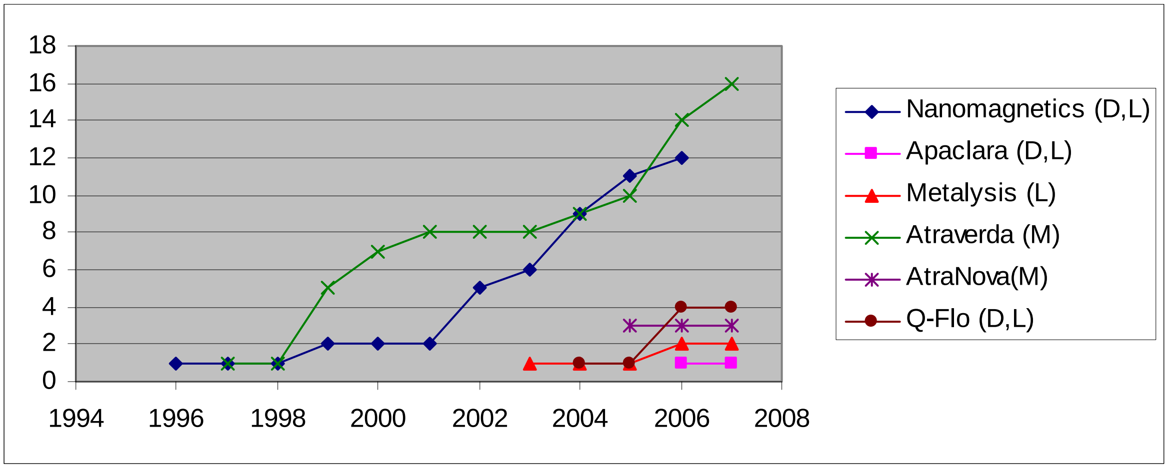
4.3 Cross-case Analysis

An analysis of the companies in both the database and the case studies shows a wide variety of growth patterns, business models, challenges and solutions. To further compare the case companies, their growth patterns are discussed, followed by the dominant challenges that have emerged.

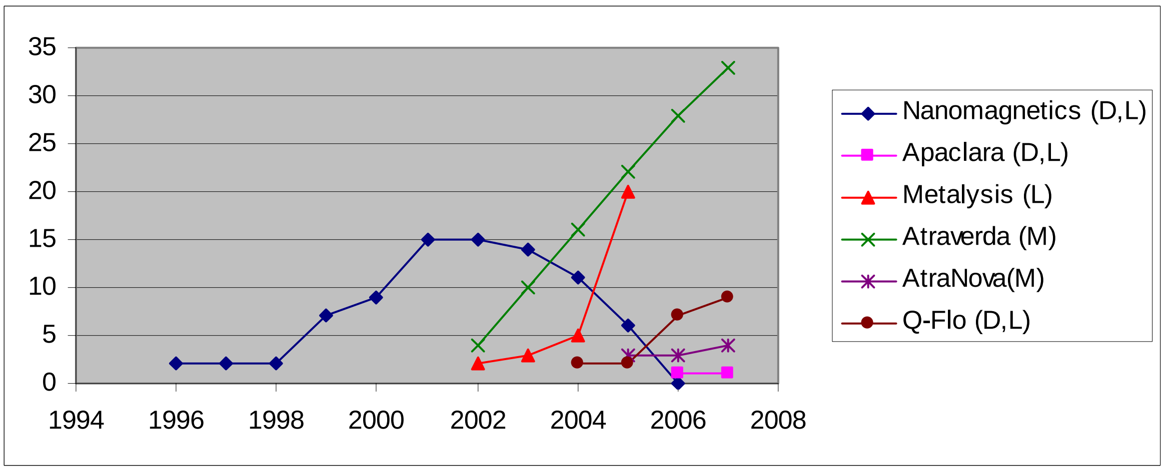
4.3.1 Company growth figures

A comparison of the case companies' growth figures, in Figures 13, 14 and 15, demonstrates great diversity. This is typical of firms in an emerging technology sector, which tend to generate a great variety of designs and practices.

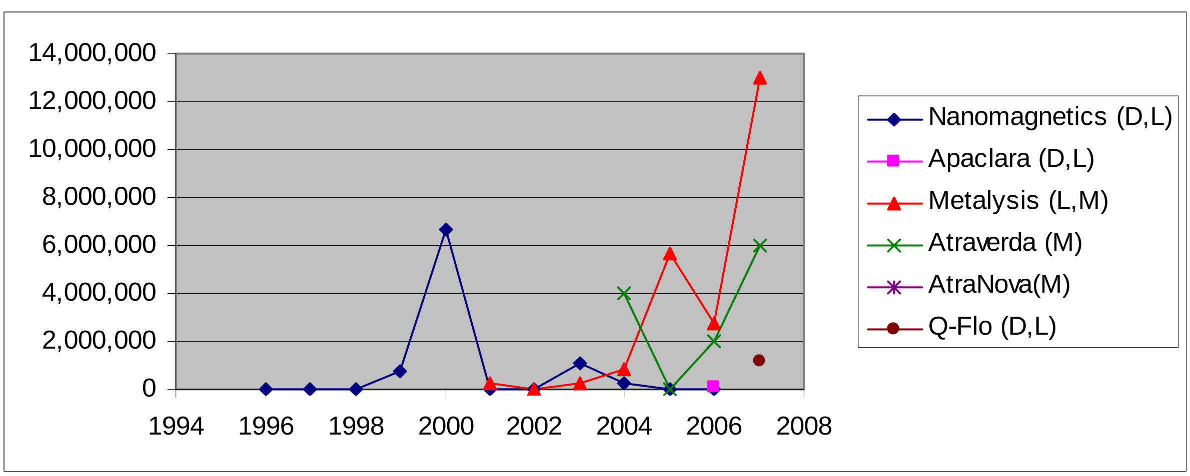
Figure 13-Cross-case Growth Figures: Cumulative Patents



<u>Figure 14-Cross-case Growth Figures: Employees</u>



<u>Figure 15-Cross-case Growth Figures: Investment Funds</u>



*Note: No funding information available on AtraNova

Although business model, funding, employment and patents are useful indicators of the evolution of individual companies, there do not appear to be general trends within the sample, except that all firms are engaged in trial and error searching for their most appropriate market, route to that market, and/or application. There is considerable variety and chance affecting when and which challenges appear. Company performance, in both short and long term, is influenced by complex internal and external factors: complex environmental factors such as current market trends and timing. Some notable internal factors are entrepreneurial ingenuity and making creative and/or efficient use of scare resources. Despite disparate growth patterns, several dominant challenges and solutions have emerged.

4.3.2 Dominant challenges and solutions

The dominant business models, challenges and solutions from the case studies are summarized in table 15. These include market selection, access to finance, selection and appointment of appropriate personnel, process innovations, demonstration of value in a specific application, access to complementary assets and value creation, generally through focus of their business model on the customer. Many of the challenges the companies have encountered are not so much solved by their business model as circumvented by the evolution of that business model.

Table 15-Dominant Challenges and Solutions in Case Exemplars

Company	# Business models	Current/Last business model	Challenges and *Solutions* Market selection	Access to finance	Appropriate personnel	Process Innovations Required	Demonstration of value in specific application	Access to complementary assets	Value Creation
Nano-Magnetics	3	Mixed-Development and Licensing	*Business model 3: partner focused*	*Before demonstration of value in specific application*	*Business model 3: partner focused*	*Business model 2: change position in value chain*	*Not solved*	*Business model 3: partner focused*	*N/A*
Apaclara	1	Mixed-Development and Licensing	*Partner-focused business model*	*Partner-focused business model*	*Partner-focused business model*	*Produced system*	*Partner-focused business model and links to science base*	*Partner-focused business model and links to science base*	*N/A*
Metalysis	2	Licensing	*Founder knowledge/ research focus*	*Business model 1 &2: Clear application and market identification*	*Involvement by TTO*	*N/A*	*While still in U of Cambridge*	*(IP) Hindered by capability of TTO then helped by TTO (scale-up) business model 1&2: partner focused*	*N/A*
Atraverda	3	Manufacturing	*Business Models 2 & 3: Parent assistance in selection*	*Business models 1,2 & 3: parent involvement then investors*	*Business models 2&3: parent involvement/current personnel*	*N/A*	*Business model 2 & 3: development and partner involvement*	*Business models 2&3: partner focused*	*N/A*
AtraNova	1	Manufacturing	*Parent involvement/ Customer-focused business model*	*Parent involvement*	*Parent involvement*	*N/A*	*Customer-focused business model*	*Identified in business model*	*Business model 1: Customer focused*
Q-Flo	1	Mixed-Development and Licensing	*On-going*	*On-going but development costs covered through university*	*on-going but partially addressed by personnel*	*On-going (scale-up process required*	*On-going*	*(IP) solved by personnel (scale-up) on-going*	*N/A*

Business model: Combination licensing and development business models appear to be the most dominant business models among USOs which appears to demonstrate the necessity of a more partner focused approach to the technology and market. Corporate spin-outs have the financial support and access to complementary assets necessary to adopt a manufacturing model, though theirs are still very partner-focused. The second generation spin-outs have experienced less evolution in their business models. It appears that learning has occurred in the first-generation spin-out beforehand. This allows the second-generation spin-out to acquire know-how, information and strategy from their parents, as well as assistance, access to resources and access to markets.

Market selection: The corporate spin-outs showed the most variation in position/timing of market selection. Atraverda did not select a market until they had already demonstrated value, while AtraNova, with the assistance of Sagentia, had a market at inception, as did Apaclara. The academic spin-outs also faced the same challenge, as many identified a number of possible markets and then benefited from outside involvement, such as research grants or co-producer involvement to choose a focus. This shows that market selection remains a prevalent issue for USOs.

Access to finance: Analysis shows that both where access to finance becomes a challenge and how it is overcome varies greatly by company. Some companies have managed to access finance even before demonstrating value in specific applications through their parent firms, science bases or even investors. The promised value of their intended innovation appeared to be sufficient. Q-Flo faces the double bind of needing finance to demonstrate value in a specific application and not being able to attract investment before doing so.

Personnel Selection: All of the spin-outs have required appropriate personnel to take their technology forward, but when and how these people are found was very situation dependent. In many circumstances, the skills and relationships of the entrepreneurs are valuable but in other situations, especially later in the company's development, additional and/or more professional skills and experience are usually required. Partner involvement can help, as can the TTO or the parent, allowing the spin-outs to benefit from their academic or corporate roots.

Complementary Process Innovations: Most of the overall sample and case study companies did not require process innovations, but those case studies that did either had significant challenges to find access to partners and/or finance. Successful solutions involved changes in the business model such as place in value chain or change in product, such as offering a complete system instead of just a material or component.

Demonstration of value in a specific application: This was shown to be critical before the resource building cycle could be completed. In some cases, the USOs' links to the science base either through research grants or continuing involvement overcame or decreased the challenge. However, a partner-focused business model appears to be a more useful in the typical interdependent and interactive value chain of an AM venture. As AtraNova focuses on their customer while refining their technology on existing sites, their customers act as development partners, therefore their business model can also be seen as partner-focused.

Access to complementary assets: As stated in the literature, USOs experience many challenges because of their origin, such as the capabilities of the TTO. In the case of Metalysis, the TTO was both a hindrance and asset, licensing the key patents to someone else, initially keeping Metalysis from accessing a potentially lucrative market. However, the TTO was also able to assist them in eventually getting it back. Q-Flo also experienced the challenge of getting the required IP from Thomas Swan Ltd, which they circumvented through their personal relationship to Thomas Swan the individual.

Companies that were successful at accessing complementary assets such as facilities, capabilities, finance and market, tended to adopt a partner-focused business model, working closely with their partner both before and after demonstrating value in a specific application.

5. CONCLUSIONS

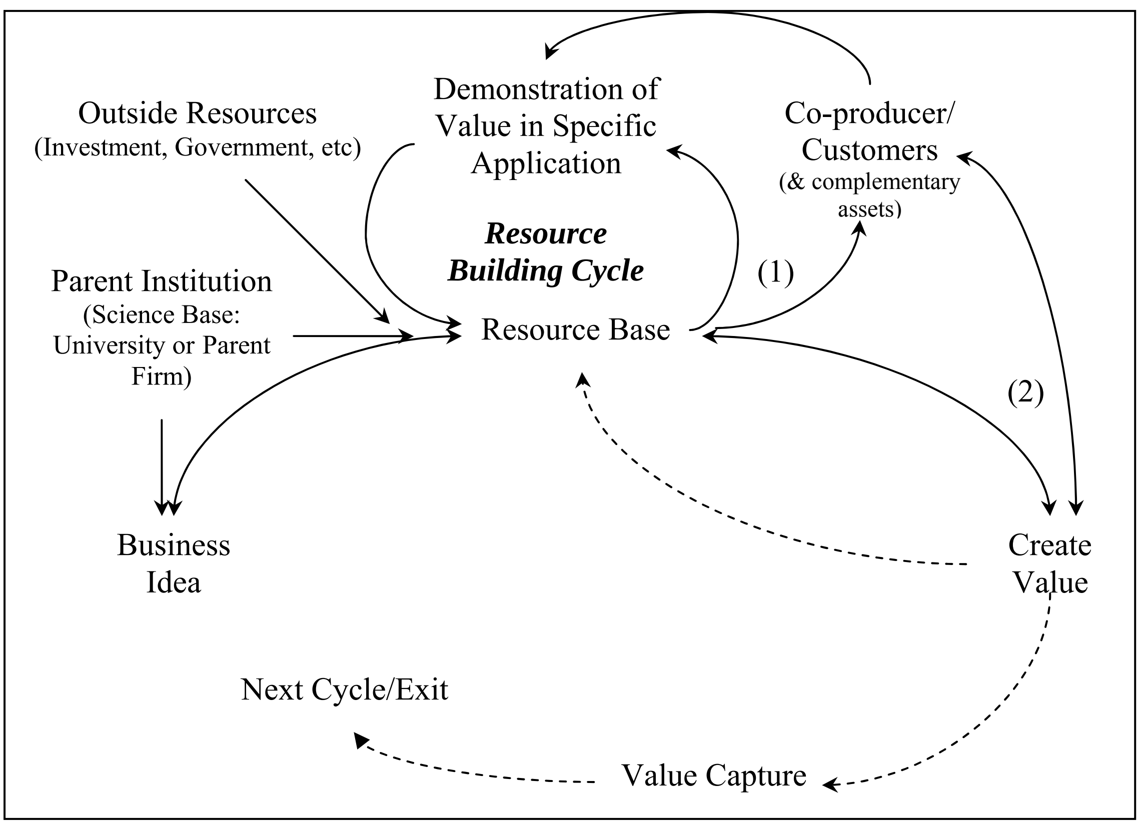
AM USOs face a number of challenges in their complex market and technological environment, most notably market selection, access to finance, appropriate personnel, required complementary process innovations, access to complementary assets and need to demonstrate value in a specific application. In particular, academic spin-outs, especially those with more generic technologies, have considerable difficulty in selecting a market and/or application, increasing the difficultly of attracting finance and appropriate partners. Without these, demonstration of value or potential future value in a specific application is unlikely, inhibiting the company's ability to build sufficient resource base with which to create value. Corporate and second generation spin-outs faced these challenges to a lesser extent, having had their predecessors navigate many of the challenges, including market selection (Garnsey and Heffernan, 2005).

Although the case companies presented have attempted to circumvent these challenges through a number of business models, no particular type of business model, such as manufacturing, licensing or development, was shown to be more effective at creating value than others. However, the business models that are most successful at lowering the considerable risks of AM commercialization and value creation appear to be those that focus on identifying the most appropriate position in the value network as well as key partners and relationships. The involvement of these partners often also shapes the creation and evolution of the start-up's business model. In addition to partner identification and focus, an effective business model enables the new firm to identify and choose its appropriate position in the value chain and leverage both internal and external resources in creative ways to build a sufficient and appropriate resource base.

5.1 Implications for Theory

The review of the relevant literature showed a need for a means to identify and address typical challenges AM USOs face while attempting to commercialize their innovations. For this purpose, the conceptual framework in Figure 16 has been proposed and refined.

Figure 16-Refined Conceptual Framework



The findings of this study have been incorporated into this framework, which, based on testing through the case studies, appears to be robust. A number of those findings that were congruent with prior knowledge found in the literature. As expected and indicated in the literature, demonstration of value in a specific application must occur before revenues are achieved through value creation, but the findings of this study suggest this does not necessarily occur before access to finance or access to complementary assets. Indeed, it is usually the access to complementary assets that allow for the market access and scale-up necessary to reach a level in the resource-building cycle where revenue can begin being generated. As expected, the close links to the parent entity and their complementary assets, including experience and technological resources, is beneficial to spin-outs before partnering activity has been necessary and/or possible. But it must be noted that lack of an experienced or well-resourced university TTO can be detrimental to spin-outs.

This work also offers some refinements to prior knowledge which inform our understanding on AM USOs. Building on previous value creation models identified (Garnsey, Dee et al., 2006; Maine and Garnsey, 2006), I propose that (1) a critical resource-building cycle occurs before value creation. (2) In this cycle, there is a complex interrelationship between the firm, parent institution, and co-producers/partners/customers as part of the effort to demonstrate the value of the technology of value in a specific application. A variant of this finding is found in Garnsey 2003 on biopharmaceutical ventures. Previous models and literature show the importance of resource acquisition and exploitation in entrepreneurial ventures (Penrose, 1997; Garnsey, 1998); however, this research highlights that one of the most crucial resources for AM USOs to acquire and exploit appears to be market knowledge. A small amount of this may be present at inception, but during the resource-building cycle market knowledge can be acquired and refined through interactions with the environment, partners and potential partners, and through trial and error. This knowledge can then be used to refine and evolve the firm's business model. In the case of second-generation and corporate spin-outs, much of this is provided by the parent entity.

As a refinement to Maine and Garnsey's 2006 model, demonstration of value in a specific application does always not have to occur before access to complementary assets. In some cases, prospects of a share in potential future value have been sufficient to attract partners or co-producers. In other cases, the complementary assets gained through relationships with the parent entity have been used to demonstrate potential value. This also emphasizes the importance of outside parties in AM commercialization from spin-outs.

6.2 Implications for Practice

This research has produced a number of insights which can be of use to entrepreneur-scientists and managers. When creating or refining their business model, a partner-focused business model appears to be the most appropriate for AM USOs, as shown by the case studies. This should also aid market selection, a prevalent challenge, as an appropriate business model includes a view of the entire value chain including partners, competitors and most viable point of market entry in each potential market. This should also aid access to finance because an identified market allows an early-stage spin-out to direct their exploration toward demonstration of value in a specific application, helping to attract investor finance before demonstration and partner investment after.

The need for complementary process innovations appears to pose one of the greatest challenges to the demonstration of value in a specific application and the coinciding attraction of co-producers/partners. This has been circumvented in two ways: either by being able to demonstrate the technology in a system or with the use of business model to select an alternative market or market position for which complementary assets are available.

Finally, the selection of key personnel has been shown to be a pervasive challenge to AM USOs, which can affect their ability to navigate other crucial challenges. The knowledge, connections and experience of the parent firm or university technology transfer office can and should be exploited for choosing appropriate personnel. However, the entrepreneurs' own unique skill set and experience through the birth of the technology can be useful in leveraging or developing relationships with key parties. But as the company approaches commercialization, its CEO will generally need to concentrate more on partnership management and post-seed fundraising instead of leading technological exploration or advancement. At that point, the first CEO, usually the entrepreneur, may operate more effectively as the CTO.

6.3 Implication for Policy

The experiences of these spin-outs demonstrate that a valuable technology offered by an innovative company will not always be selected by the market due to complex challenges, both internal and external, such as managerial experience within the venture or market evolution factors. Policy makers may be able to assist in a number of ways, which include providing support for the development of market assessment techniques, supporting and encouraging business training for scientist-entrepreneurs, providing incentives for incumbent firms to form partnerships with spin-outs and providing support and/or setting standards for technology transfer offices in IP management and personnel selection.

6.4 Limitations

As stated in section 4, the focus of this research was on understanding and explaining the challenges facing university spin-outs in the emerging industry of advanced materials technologies. Although the case studies used were selected to be illustrative of typical challenges, the database used to position them was not exhaustive. For this reason, these case studies were not necessarily representative. Instead, they provide a basis for the creation and refinement of theory and conceptual framework, and insight into the challenges facing AM USOs and potential solutions. Although the theory must be tested through further case replication in order to show it can be generalized, it seems likely that challenges, issues and solutions similar to those that have occurred among the sample companies will be found in other companies, clusters or industries involving generic technologies and relatively high capital costs for development and commercialization.

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