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Innovation Management in Emerging Technologies – Case Study in the Aluminum Foam Industry

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I dedicate this thesis to my parents and my sister!

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Abstract

This thesis presents the theoretical background on effective ways of managing emerging technologies and then follows up with a case study on the aluminum foam industry. The goal of this paper is to illustrate all the relevant aspects of managing emerging technologies and conclude their real world impact in the case study. The aspects include the emergence patterns of new technologies, market forces and assessment, management tools, organizational structures and the financing of emerging technologies and innovations. The first section of the case study illustrates the development's history of aluminum foam as well as the technological basics on production, material properties and potential applications thereof. The second section is built on interviews conducted with leading firms of this industry. The insights gained from both sections of the case study are then synthesized in the conclusion of this thesis.

Kurzfassung

Diese Diplomarbeit präsentiert die theoretischen Hintergründe über effektives Management neu entstehender Technologien und schließt an diese mit einer Fallstudie über die Aluminiumschaumindustrie an. Das Ziel dieser Diplomarbeit ist es, alle relevanten Aspekte des Managements neu entstehender Technologien zu erläutern und deren Einfluss in der Fallstudie zu schlussfolgern. Diese Aspekte setzen sich aus den Entstehungsmustern neuer Technologien, den Marktkräften und deren Beurteilung, Management Tools, Organisationsstrukturen und der Finanzierung von neu entstehenden Technologien und Innovationen zusammen. Der erste Teil der Fallstudie veranschaulicht sowohl die Entwicklungsgeschichte des Aluminiumschaums, wie auch die technologischen Grundlagen der Produktion, Materialeigenschaften und potenzielle Anwendungen. Der zweite Teil stützt sich auf Interviews mit führenden Unternehmen der Industrie. In der Schlussfolgerung werden die gewonnenen Erkenntnisse beider Teile der Fallstudie zusammengeführt.

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Table of Abbreviations

AF	Aluminum Foam
AFS	Aluminum Foam Sandwich
ATC	Alcoa Technical Center
CAT	Computed Axial Tomography
DCF	Discounted Cash Flows
DEC	Digital Equipment Corporation
et al.	Et Alteri
HDD	Hard Disk Drive
IBM	International Business Machines
ICT	Information and Communication Technology
IP	Intellectual Property
IPO	Initial Public Offering
NPV	Net Present Value
NVG	New Ventures Group
OEM	Original Equipment Manufacturer
p.	Page
pp.	Pages
ppm	Parts Per Million
R&D	Research and Development
SAF	Stabilized Aluminum Foam
SWG	Saarländische Wagnisfinanzierungsgesellschaft
TPC	Technology Partnerships of Canada
US	United States
USP	Unique Selling Proposition
VC	Venture Capital
VCs	Venture Capitalist
VN	Value Network

1 Introduction

The commercialization of innovative emerging technologies plays a vital role in sustaining economic growth. And managing innovation and emerging technologies calls for a totally different set of rules.

The goal of this thesis is to illustrate the theoretical background on the management of emerging technologies, focusing on the features and challenges that brand emerging technologies. As innovation literature is largely based on case studies, the second section of this thesis is a case study of the aluminum foam industry. Aluminum foam technology, while under development for over 50 years now, is still on the verge of commercialization and serves as a good example for technological emergence. Parallels in the case study to the theoretical background will be drawn as they materialize.

Thesis Structure

The thesis consists of two main sections.

The first section explores the theoretical background of the management of emerging technologies. It begins with the evolutionary development patterns of new technologies to provide basic understandings of how technologies emerge in the first place. We will then focus on the inherent market forces and present, with the “Concept of Peripheral Vision” a holistic approach to identify and assess market opportunities. The difficulties of planning and valuing investment decisions under the high levels of uncertainty of emerging technologies are widely recognized. Scenario planning and real options analysis are two tools that perform well in uncertain environments and thereby support decision makers. Organizational structures have also changed significantly. With the need for more responsiveness and flexibility, organizations and their relations to one another change and alliances are play a central role. Finally we will evaluate financing options. The predominant problem of information asymmetries and the intangible nature of emerging technologies present two major challenges that define the aspects of financing options.

The case study on the aluminum foam industry will be elaborated in the second section. The historic development of this technology and the basic technological principles will be presented and evaluated. The core of the study are the empirical findings, which have been collected though interviews held with aluminum foam manufacturers. These findings are synthesized in the conclusion, consolidating all the knowledge obtained and underlining major aspects of the theoretical framework.

2 Emergence Patterns of Technologies and Innovations

2.1 Introduction

The evolution of emerging technologies is a very complex procedure. It is comprised of the interrelations of multiple factors and forces such as, basic scientific findings, company specifics and consumer demand.

The complexity in this field of research urged scholars to search for patterns of technological emergence. The resulting concepts of the technology S-curve or the sequence of product and process innovation enhance our understanding of how basic scientific findings evolve through product innovation to market fit applications. In addition to that, these concepts explain how technologies progress from one generation to the next through many intermediate steps of process innovations.

New technologies do not necessarily have to emanate from new scientific findings. They can be linage developments of an existing technology through a shift in the domain of application. Or especially in today's world with more and more applications being featured into one device, the convergence of two or more technologies can initiate to a completely new technology.

Understanding the processes that give rise to new technologies and shape their evolutionary path can fundamentally improve our ability to effectively manage emerging technologies.

2.2 Emerging Innovation Patterns

2.2.1 The Technology S-Curve

The concept behind the technology S-curve implicates that at the beginning of each new technological paradigm the trajectory of this new technology embodies an S-formed shape[1]. A technological paradigm can be understood as the solution of a selected technological problem within a technological architecture or design. Within this technological paradigm technologies evolve along trajectories through continuous incremental development. These incremental, also

[1] refer to Petrick, I.J., Echols, A.E. (2004), p. 83

referred to as sustaining, innovations improve product performance step by step after the new paradigm has been introduced.

Figure 1 illustrates a technological S-curve

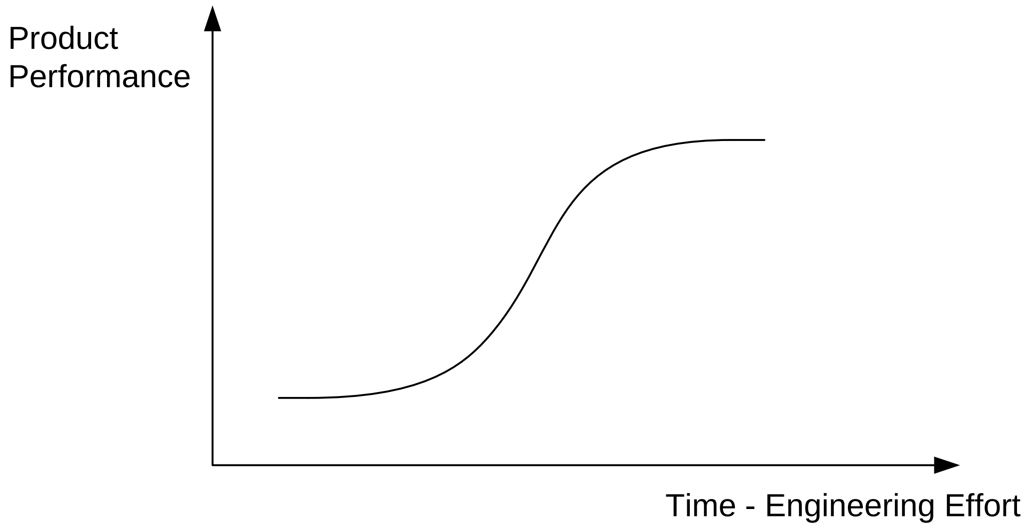

Figure 1: Technology S-Curve
Source: Christensen, C.M. (1992), p. 335, Figure 1

As figure 1 points out, the rate of progress in performance is relatively slow in the early stages of a new paradigm. Once the new technology becomes better understood, controlled and learning effects become apparent, the rate of improvement increases. In the following stage, called maturity stage, the rate of product performance declines again, reaching its physical barriers.[2] In these mature stages even small incremental innovations require high levels of engineering effort and time. Once this stage is reached, substantial advances require a shift to a new and superior architecture. These new technological paradigms become evident through a discontinuity in their trajectory of the S-curve.

[2] refer to Christensen, C.M. (1992), p.335

Figure 2 shows a depiction of three succeeding S-curves

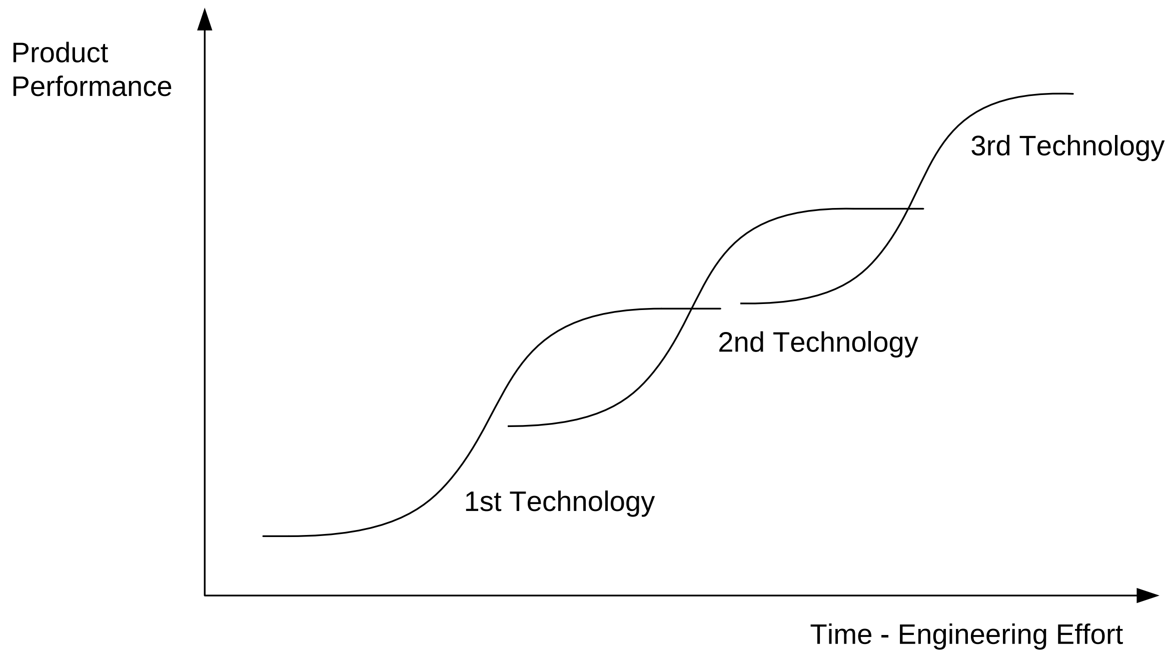

Figure 2: Discontinuing S-Curve Trajectories
Source: Christensen, C.M. (1992), p.340, Figure 3

Figure 2 shows how one technological paradigm or technological generation follows the other. Additionally figure 2 illustrates that the new paradigms that incorporate the new technological architecture do not deliver comparable performance than did the previous generation at the beginning of their trajectory. They are generally not able to surpass their predecessors before they reach the inflection point of their trajectory.[3] Consequently companies have to engage in R&D for the next generation well before the previous one reaches the stage of maturity.

2.2.2 Product and Process Innovation

The model of product and process innovation from Abernathy and Utterback is similar to the technology S-curve concept. This model describes that at the beginning of a new innovation or technological paradigm, the rate of product innovation is high. At this stage, product design is still in a fluid state and a wide variety of variations exist, up to the point when a dominant design prevails.[4] This dominant design, also called industry standard, considerably enhances market volumes since major uncertainties have been eliminated. This in turn leads to the

[3] refer to Petrick, I.J., Echols, A.E. (2004), p. 86
[4] refer to Adner, R., Levinthal, D.A. (2001), p. 614

entrance of new competitors in the market. Based on this new architecture, component and production processes are refined, while at the same time product innovations decrease. The innovative efforts of this stage are called process innovations.

Figure 3 illustrates the rate of innovation as a function of time for product and process innovation.

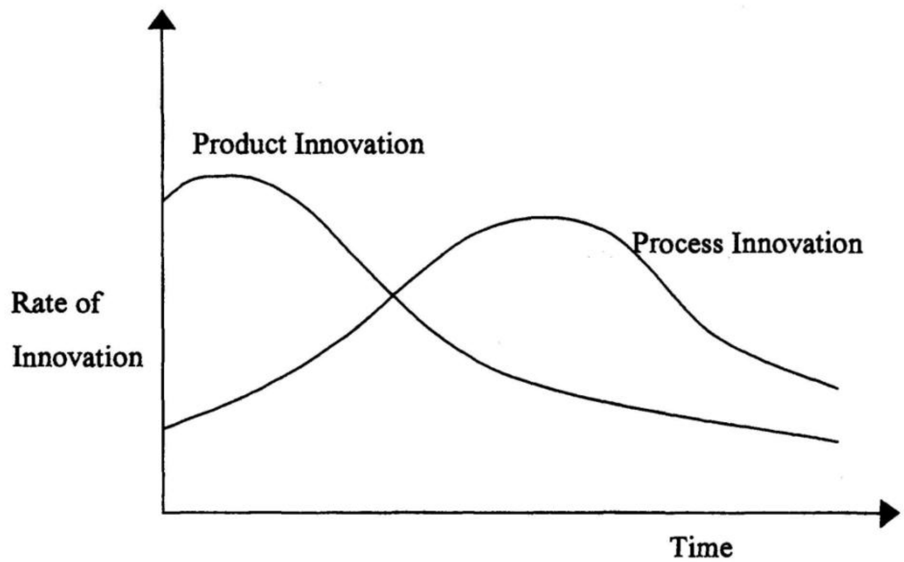

Figure 3: Dynamics of Product and Process Innovation
Source: Adner, R., Levinthal, D.A. (2001), p. 614, Figure 3

These competency enhancing (process) innovations carry on until a competency-destroying (product) innovation causes another discontinuity in the trajectory, leading to what Schumpeter called "creative destruction".[5]

2.3 Value Networks

Christensen (2006) states that value networks (VN) considerably influence the development of technologies. This concept of value networks embody the context within which a firm identifies and responds to customers, solves problems, procures input, reacts to competitors and strives for profit[6]. VNs are built upon the concept of technological paradigms. Subsequently a change in the VN further leads to a discontinuity in the trajectory of a technological paradigm. The boundaries of a VN are defined by the product features and performance attributes

[5] refer to Petrick, I.J., Echols, A.E. (2004), p. 83 and Anderson, P., Tushman, M.L., (1990), pp. 605 - 607
[6] refer to Christensen, C.M. (2006), p. 36

respectively.[7] These performance attributes mirror the VN through a specific architecture or design that is tailored to satisfy the demands of the targeted VN. While the VN of mainframe computers for instance embraces features like computing performance and storage capacity, the VN of laptop computers on the other hand embraces light weight and low power consumption.

2.4 Emergence Patterns in the Disk Drive Industry

2.4.1 Introduction

C.M. Christensen and R.S. Rosenbloom (1995)[8] conducted thorough research on the influence of VNs in the hard disk drive (HDD) Industry. The case study encompasses and highlights all the attributes of technology emergence that have been discussed in this thesis so far. Hence the evolution of HDDs for data storage demonstrates the discontinuity of trajectories, the rise and fall of technological paradigms, the sequence of product and process innovation and the influence of VNs.

HDDs are magnetic data storage devices. They basically consist of one or more magnetic spinning disks, a reading and writing head, motors, actuators, a control unit and a hermetically sealed housing. In the historical development of disk drives innovations occurred among the architecture (product innovation) as well as the components (process innovation). IBM introduced the first storage based on rotating disks in 1956, the *IBM 350 disk storage unit.*[9] The first so called HDDs emerged from a project called 'Winchester'[10] in 1973. The basic design principles of the IBM 3340 are still used in today's HDDs. IBM produced these first HDDs only for their own use and mainframes respectively. Around the same time the first OEMs entered the market. New innovations in components and architectures shall now succeed one another. Component innovations such as thin-film read-write heads improved performance of the drives

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[7] refer to Christensen, C.M. (2006), p. 40

[8] refer to Christensen, C.M., Rosenbloom, R.S. (1995)

[9] refer to IBM storage history - 350 (2007).

[10] The project engineers called the hard drive "30-30" (it consisted of two 30 megabyte spindles), the common name of a rifle manufactured by the Winchester Company. Kenneth E. Haughton, who led the 3340 development effort, is reported to have said: "If it's a 30-30, then it must be a Winchester." for further information refer to IBM storage history - 3340 (2007)

and were typically developed by incumbents. This process represents the development along the trajectory of the current paradigm and is driven by the notion of constant performance improvement. These component innovations sustained the established trajectories. Technological changes in architecture design were primarily driven by new market entrants and these changes in architecture in turn led to a shift from one technological paradigm to another. Both, the incremental sustaining innovations and the disrupting product innovations, played a critical role in the development of this industry.

2.4.1.1 The Four Technological Paradigm Shifts in HDDs

Figure 4 shows the trajectory of each technological paradigm in the hard disk drive industry.

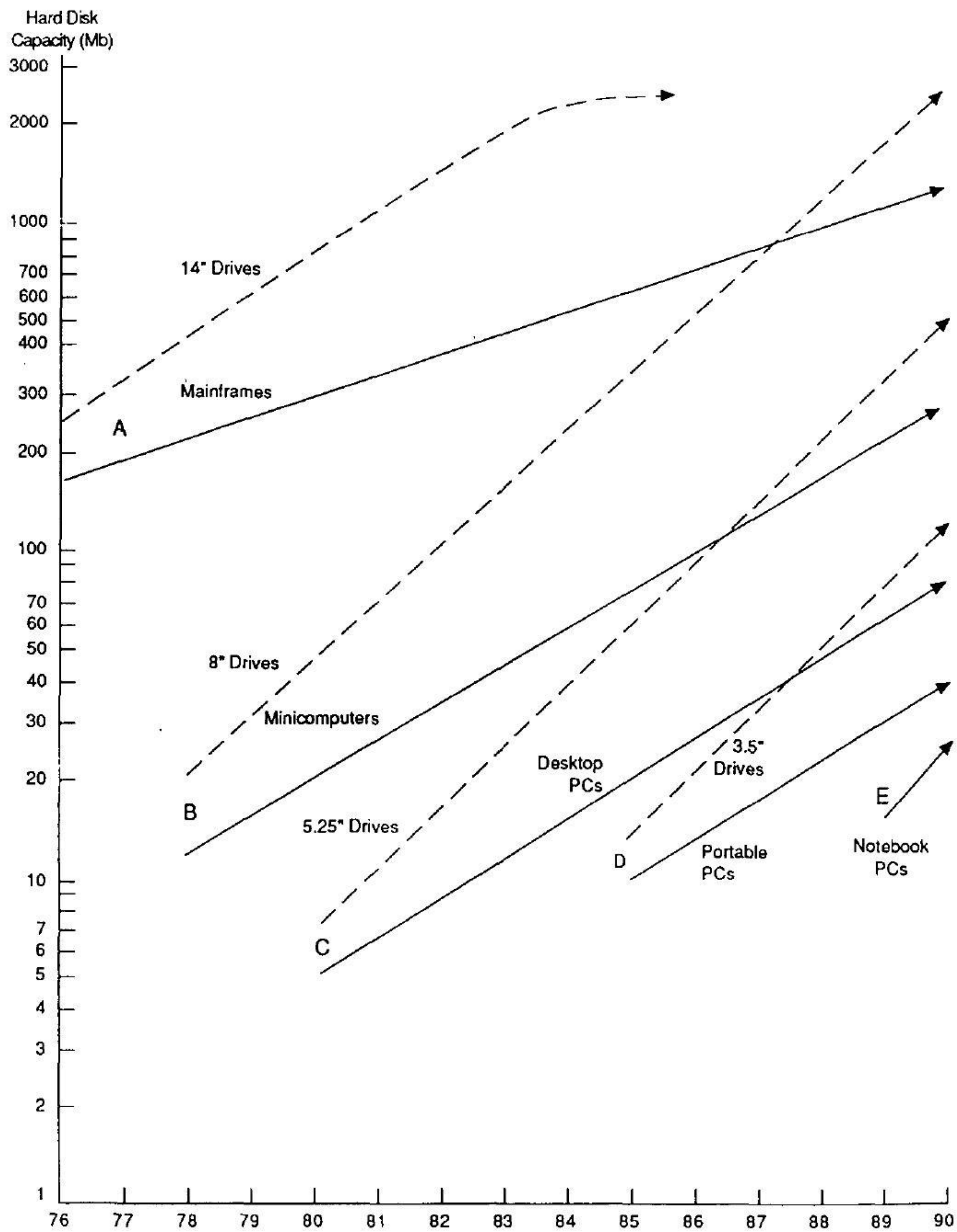

Figure 4: Comparison of trajectories of disk capacity demanded vs. capacity provided
Source: Christensen, C.M., Rosenbloom, R.S. (1995), p. 244, figure 4

The solid line shows the trajectory of the memory capacity of each architecture (technological paradigm) as computers are shipped and demanded by customers. The dashed line shows the maximum memory capacity increase attainable within each architecture (along the trajectory). The hard disk drive industries growth rate, in terms of storage, constantly outpaced the demanded capacities of the applications running on those systems.

Until the late 1970s only 14” drives, which were deployed in mainframe computers, were available. The capacity supplied and demanded, respectively grew at a rate of 15% a year. The technological capabilities on the other hand allowed an increase of 22% per year. This is displayed in figure 4 by the growing divide between the solid and the dashed line. The VN of mainframe computers demanded high capacities paired with short access times. The architecture of the 14’’ HDD and the incremental innovations that followed the product introduction focused on serving this VN.[11] Between 1978 and 1980 new market entrants among others Priam and Quantum introduced an 8-inch HDD. They were no match to the current 14” design in terms of capacity and therefore of no interest to mainframe manufacturers. But at the same time they were perfectly suited for a new application – the minicomputer. The Manufacturers DEC and Hewlett Packard integrated the new hard drives into their computers, even though the price per megabyte at that time was higher. Minicomputers provided a different VN that embraced the features of the 8-inch drive like smaller size and less vibrations and thus justified the premium in price. The lower capacities were not an issue in the VN of minicomputers as application on these systems did not utilize higher storage capacities. By 1981, three years after the introduction, producers of the 14’’ HDD entered the market of 8’’ HDDs. According to Christensen and Rosenbloom (1995) the strategic lag of entry by the incumbent occurred for the reason that they were held captive by customers within their VN. Mainframe manufacturers at that time had no need for 8’’ HDDs. Furthermore, they explicitly didn’t want it.[12]

The initial smaller capacities emanated from the components used in the 14’’ design. At the beginning of the new paradigm, manufacturers focused on developing a new architecture (product innovation) utilizing existing components. After the establishment of the new

[11] refer to Christensen, C.M. (2006) 15 – 18 and Christensen, C.M., Rosenbloom, R.S. (1995) pp. 244/245

[12] refer to Christensen, C.M., Rosenbloom, R.S. (1995) p. 246

paradigm and its market, the incremental innovations followed. Manufacturers of 8-inch drives realized that they can improve storage capacity at a rate of 40% per year. The market demand for storage in minicomputers was at this time only 20%. This went so far, that by the mid 1980', 8-inch drives could eventually fulfill the requirements of mainframe computers (see intersection of trajectories in figure 4), thus further growing in unit volumes. In the following three years 8-inch drives invaded the VN of 18-inch drives, making them obsolete in the end.

In 1980 the next architecture was introduced by a new market entrant called Seagate Technology. It was the 5.25-inch hard drive. Similar to the last shift, the first manufacturers of the next architecture were market entrants and the established companies again lagged 2 years behind. Yet again the capacities available at the product launch couldn't satisfy the needs of minicomputers. Instead they served another emerging market – the desktop computer. The rapid annual capacity growth through component innovations of 50%, which again was double as high as the demand growth in this sector, led to the replacement of 8-inch drives in minicomputers by the late 1980's.[13] The VN of this technological paradigm valued the further miniaturization and reduction of power consumption. This pattern was again repeated by Seagate with the launch of the 3.5-inch hard disk in 1984. But this time it took the company three years to successfully introduce the new architecture into the market. The reason was that the VN, portable computing, with its need for even more light weight and ruggedness, was not a viable application at that time and desktop computer manufacturers saw no benefits over the 5.25'' HDDs. Additionally the new 3.5'' HDDs incorporated lower capacities and a higher price-per-megabyte ratio. Therefore it took three years until sales to take off.[14] This highlights another important characteristic of emerging technologies and markets, namely market adoption and the selection environment. These two concepts will be discussed in detail in the following chapter. Other than that, the pattern repeated itself in the same manner as before, leading to the displacement of 5.25'' HDDs in desktop computers by the year 1988.

[13] refer to Christensen, C.M. (2006) 20/21 and Christensen, C.M., Rosenbloom, R.S. (1995) pp. 246/247
[14] refer to Christensen, C.M., Rosenbloom, R.S. (1995) pp. 247/248

2.4.1.2 Lessons from the HDD Industry

This case clearly shows the behavior of emerging technologies while they progress through an industry. First, the recognizable repeating pattern clearly shows that at the beginning of each new technological paradigm the level of product innovation is high compared to process innovation. After the dominant design or architecture is established the factors reverse while moving along the trajectory with process (component) innovation increasing and product (architectural) innovation decreasing. Practically all component innovations were accomplished within each technological paradigm with the intention of sustaining competitive advantage. But for the architectural change it sufficed to exploit existing components then with the intention to gain competitive advantage, by opening up a new market. Second, in the early stages the next paradigm coexists with the previous one until it surpasses the predecessor in terms of price and performance rendering it obsolete and replacing it. This is in line with the concept of one technology S-curve following the other.

Furthermore Christensen and Rosenbloom (1995) state that the incumbent firms, even though they lead component innovation, lacked commitment to engage in architectural innovation. The authors call this instance “being held captive by the customers” which in turn provided an “attackers advantage” for market entrants.[15]

2.5 Shift in the Domain of Application

The basis for any new application or innovation and the underlying technology are basic scientific findings and research. But new applications and products must not be developed upon novel technologies. It’s often a shift in the domain of application of an existing technology that nurtures innovation and technology development. Adner and Levinthal (2002) compare the evolution of technologies to speciation in biology. And they identify two critical features of speciation from which they conclude their analogies to technological emergence. One is that it is genetically conservative – that is, speciation is not triggered by a sudden transformation of the population. Second, the speciation event allows the two populations to grow quite distinct as a result of their now different selection environments.[16] The analogy to speciation in the

[15] refer to Christensen, C.M., Rosenbloom, R.S. (1995) pp. 246-253
[16] refer to Adner, R., Levinthal, D.A., (2002), p. 50

development of technologies is the change in domain of application. This shift does not necessarily happen through a sudden change, but rather as a consequence of permanent technological development. In some cases these occur without any technological change at all. The impact on the market after this splitting event can in contrast be enormous. The second analogy to speciation is that the two different domains follow their own independent trajectory towards further development. Distinctive selection criteria and the own resource pool of the linage development support the advancement in an entirely different direction.

Figure 5 illustrates this shift of application

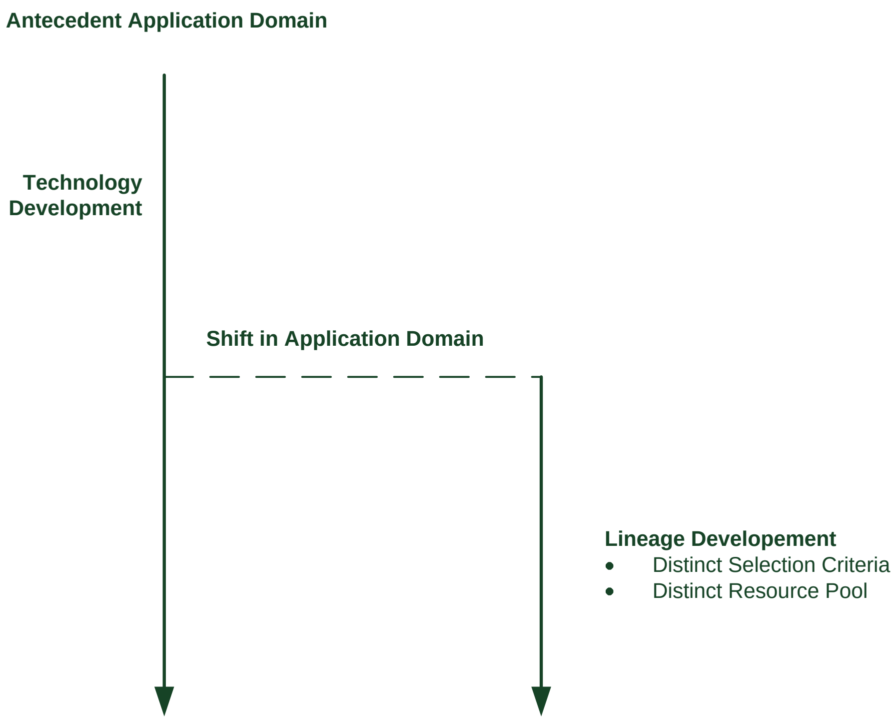

Figure 5: Shift in domain of application
Source: Depiction according to Adner, R., Levinthal, D.A., (2002), p. 53, figure 1

In Wireless communications a few apparent shifts in the domain of application eventually led to the development of the cellular phone. The first purpose of wireless communication was to serve as a measurement device in laboratories. Heinrich Rudolf Hertz tested Maxwell's theory on electromagnetic waves.[17] He developed an instrument to measure electromagnetic waves. The Italian Guglielmo Marconi pursued Hertz's research of sending and receiving

[17] refer to Brockhaus (1998), p 206

electromagnetic waves by building a device for wireless telegraphy. This was a totally different application that was based on the same technology of electromagnetic waves. It was first used for communication between ships and the lighthouses ashore. Accompanying this change of domain was the different technological path that Marconi's invention took after he started development towards this new application. Since distance was the primary matter in Marconi's application, this ultimately led to the development of more powerful transceivers and more sensitive receivers. The laboratory application from Hertz demanded reliable measurements and did not take on distance. The advancements based on Marconi's wireless telegraph ultimately led to the development of the vacuum tube which was the basic technology for the next application shift. Vacuum tubes allowed the transmission of continuous voice signals.[18] Broadcast radio was the first application followed by wireless telephony for public safety use and finally cellular phones. In every one of these applications the technological development shifted towards a different trajectory of further development. Although broadcast television and cellular phones exist side by side today and both are based on the same technological principal of electromagnetic waves, their technological state is totally different. Both, broadcast and wireless telephony technologies have taken a different path of development due to their varying functionality requirements. Wireless communication has gone a long way in the last 100 years and serves as a good example for technological evolution. The resulting applications are very different, but the underlying basic technological principle is the same in both of them.

Technologies adapt to the requirements of the field of use to which they are applied. The focus lies on features and specifics that are most valuable in this environment. Every domain of application calls for different technological requirements. This fact shapes the evolution of a distinctive technology as it alleges the predominant problems to be solved.

2.6 Technology Convergence

Another notion of technology emergence is the convergence of different technologies. Technology convergence is contrary to the concepts that have been discussed in the preceding sections of this chapter. Convergence in Technologies happens, when two or more technologies

[18] refer to Adner, R., Levinthal, D.A., (2002), p. 51

from different fields of research or industries merge to create a new product or application.[19] The resulting new technology can either take off in its market niche or it can replace one or more of its predecessor technologies. Hence companies should not solely invest in R&D with the intention of replacing an older technology. Furthermore they should also focus on combining existing technologies into hybrid technologies. Whereas the one approach is linear and competency destroying, the other is non linear, complementary and cooperative.[20] Although this happens more frequently in recent times, particularly in the ICT sector, the phenomenon of technological convergence was first observed in the industrialization process in the US between 1840 – 1910. At the time seemingly unrelated industries became very closely related.[21]

Hacklin et al. (2004) states that the convergence of technologies can be observed as an emerging effect of discontinuity in a globalized industry, motivated by four contributing factors:[22]

(1) The omnipresence of product components in a worldwide market,

(2) innovation opportunities based on an increasing amount of intersections and interfaces among technological solutions

(3) business opportunities for establishing innovation collaborations, and

(4) the customer need for full solution and service provisioning.

The development of the CAT scanner serves as a good example of technology convergence. A CAT scanner constructs three dimensional images of the internals of a human body by combining numerous two dimensional images taken by X-rays through rotation around a single axis. The combining process draws on significant computing power. This enhancement to the conventional X-ray technology was only possible due to the increasing advancement in computer technology.

[19] refer to Adner, R., Levinthal, D.A., (2002), pp. 55/56
[20] refer to Kodama, F. (1992), p. 70
[21] refer to Hacklin, F., et. al. (2004), p. 33
[22] Hacklin, F., et. al. (2004), p. 33

Figure 6 illustrates the process of technology convergence.

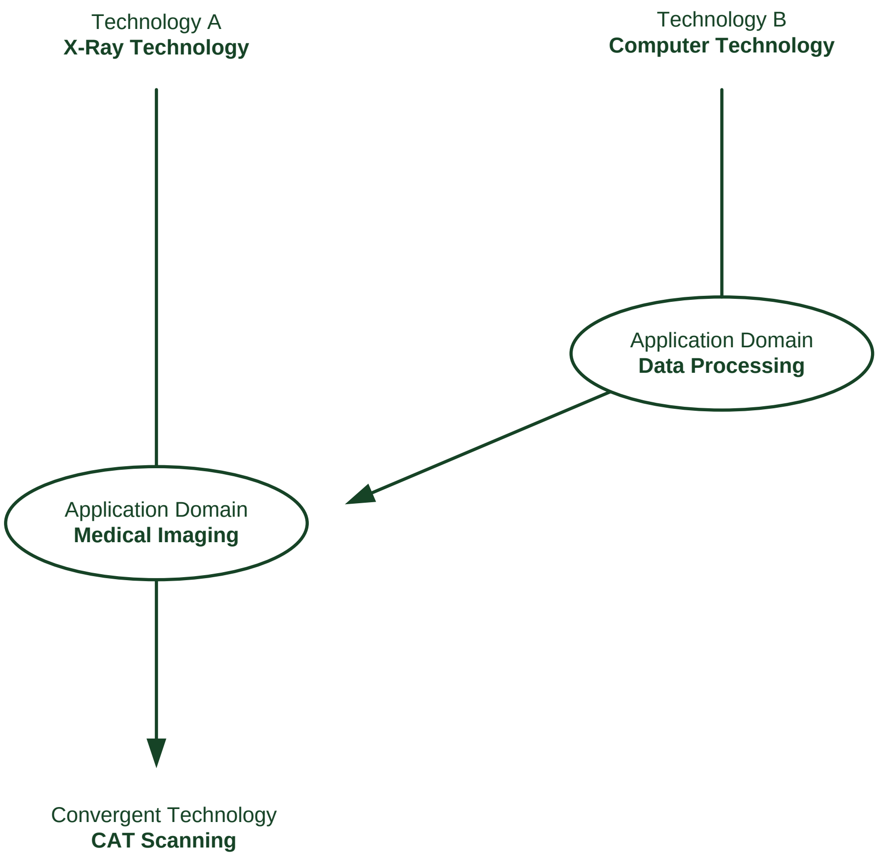

Figure 6: Technological Convergence in CAT Scanning
Source: Depiction according to Adner, R., Levinthal, D.A., (2002), p. 52, figure 2

Computer technology from a different application domain enhances the domain of medical imaging. In this case CAT scanning does not replace the conventional X-Ray because they still serve different VNs. A CAT scan is considerably more expensive and subjects the patient to a higher dose of radiation. As a consequence it is only used if a diagnosis requires it. Self-evidently the computer technology was not consumed by the convergent technology either. In some cases technology convergence really means - one plus one equals three[23]. Another example is Sharp Corp. which combined electronic, crystal and optic technologies to develop the first liquid crystal display for pocket calculators.

[23] Kodama, F. (1992), p.71

Convergence of technologies has become more important in recent years. The focus in many industries was to integrate ever more and different technologies into one device. For instance the walkman phone is a convergence of cellular phone technology with the mp3 player technology, or in a broader sense also the internet is a fusion of computer and telecommunication technology.

3 Assessing Technologies and Markets

3.1 Introduction

In chapter 2 we learned how technologies emerge and how their evolutionary path is shaped. Although we recognized that VNs have substantial influence in their development we shall now discuss the diffusion process.

Companies constantly seek new opportunities for growth and hence search for new technologies to invest in. Our scientific world provides us with countless new inventions every year, and while many of them seem to be promising, only a small fraction of them has the potential to deliver real economic value. In our fast changing world new trends and customer demands materialize constantly and identifying them has become an increasingly challenging task. Thus companies and their managers are faced with the difficult task of finding and assessing the most promising technology. The concept of peripheral vision is one approach designed by G.S. Day and P. Schoemaker to facilitate this process of identifying promising new technologies and will be discussed in detail.

3.2 Market diffusion

3.2.1 Adoption of New Innovations

New technologies take time to diffuse into markets. Different technologies diffuse into the market at different paces. While one technology may move very quickly, another technology might never make it. The differences in acceptance by the market depend on the application itself and more precisely on the following four characteristics[24].

- Perceived Advantage

  The perceived advantage, in contrast to the best available alternative, must be sufficient high to cover the switching costs that are associated with employing the new technology, and deliver additional value. Hence a calculation could look like this – relative value = perceived benefits – anticipated costs. Such switching costs are for

[24] Day, G. S. (2000), p.130/131

instance the redesigns of a structural part that become necessary when the material is changed.

- Perceived Risk

  Adopting new technologies comprehends several risks. New technologies are often at the beginning or in the middle of a standardization process. Adopting technologies at this stage bears the risk of passing the industry standard. Uncertainty about performance and other fears of economic loss further increase risk of adoption.

- Barriers to adoption

  Potential adopters face several barriers for the adoption of new technologies. Among these are previous commitments to other technologies or governmental regulation that can either foster or obstruct diffusion.

- opportunities to learn and try

  Potential adopters of the new technology must be provided with the opportunity to try the new innovation in order to be persuaded. Field studies that highlight the advantages or free trials are just a few of many means to provide the potential buyers with the option to learn and try the new technology.

3.2.2 Technology Push vs. Demand Pull

Before a new technology can diffuse into a market it has to be developed in the first place. There are two different stimuli that shape the way new technological paradigms are being developed, specifically technology push and demand pull.

In the case of a technology push, a new paradigm arises out of new technological knowledge obtained and R&D conducted. There is no market demand for this paradigm prior to its commercialization or market introduction. Therefore the demand for this technology has to be induced in the customers in the first place. Demand pull on the other hand practically works the other way round. New technological paradigms are created to satisfy the demand forces of the market. These demand forces or needs can for instance be triggered by an upcoming performance gap. Both forces are not mutually exclusive, the boundaries between them often tend to blur and both of them play an important role in innovation as well as in the development of new technologies.[25] According to Day (1998), companies that are technology driven mainly focus on technology-push. However in turbulent high tech markets they learned to appreciate that being market driven and incorporating a market-pull perspective rather complements than competes with their technology-push focus. Both perspectives are not an either or approach but, rather an enhancement of one by the other.[26]

Zmud (1984) argues that generally, need-pull (market pull) innovations have been found to be characterized by higher probabilities for commercial success than have technology-push innovations.[27]

3.2.2.1 Technology-push vs. Demand-Pull in Computing Technology

Technology push and demand pull indicate the direction of a certain signal that lead to the development of innovations. This direction can change over the course of time within a technological paradigm.

Van den Ende and Dolfsma (2005) conducted a study on the development of the computing technology to illustrate if either technology push or demand pull were the key drivers for the development in this industry. They however acknowledge that during the development process both signals were omnipresent, but point out that in different phases one of them played a dominant role. In the first phase, which they called *"growing demand (1900 – 1960)",* computing technology was applied in the fields of data processing, technical and scientific computing and computing for process control. The analog computing technologies in the 1930s embodied technologies that were known decades ago. The level of innovativeness was low. Even though the analog computer evolved during these years, no significant price-performance improvements accompanied this development. In 1962, Mauchly and Eckert, the famous builders of the ENIAC, the first electronic computer, stated that most of the knowledge they used was available 10 to 15 years ago. The authors conclude that in this phase demand-pull was the significant factor. The technological knowledge was available and the development and diffusion of computers took so long due to the weak demand.

[25] refer to Ende, van den, J., Dolfsma, W. (2005). p. 83
[26] refer to Day, G.S. (1998), pp. 6 - 7
[27] refer to Zmud, R.W. (1984), p. 728

The next period from 1960-1990, the "*diffusion of digital computers*", was highly influenced by new technological developments, most notably in the fields of solid-state physics and microelectronics. Price-performance ratios soared to a yearly 20% and newer products like the mini-computer and the desktop computer were introduced. According to Van den Ende and Dolfsma (2005), the gains in technological knowledge in this period stand out and account for the major inducements for innovation (therefore technology-push).[28]

In the third period from 1990 to present, the *connectivity period*, the convergence of two technologies, computing and telecommunications was significant. We already explored the topic of convergence in chapter 2.7. Even though the rising demand for connectivity and communication in this period augmented the demand for computers, developments in computer knowledge were critical as well. It generally became harder in this period to distinguish between the enablers of the new technological developments. Counterfactual reasoning actually showed that the technology would have been adopted earlier if it were available thus proving that the significance of technological knowledge as an enabler was higher (therefore rather technology-push).

3.2.3 The Selection Environment

Selection forces play a critical role, particularly in the early market launch stages of a new technology. Dosi (1997) states that selection is critical because different players provide different technical solutions for similar problems. Selection has to take place in order to distinguish the wrong ones from the right ones. The terms 'wrong' and 'right' must be understood as relative to the selection environment. The selection can be performed by the market or any institution – hospitals for instance define the selection criteria in the case of medical technology[29]. In some cases the goal of the selection process practically is to filter a dominant design out of several proposed technological solutions.

Selection is driven by exogenous and endogenous forces. On the one hand the selection environment is characterized by consumer's preferences, government policies and leadership of individual companies among other market factors. On the other hand companies attempt to get

[28] refer to Ende, van den, J., Dolfsma, W. (2005). p. 94
[29] refer to Dosi, G. (1997), p. 1542

themselves involved in the selection process through lobbying and negotiations with regulatory authorities in order to improve their own technologies position in the selection process[30]. In its simplest form, if several technologies deliver a very homogenous solution with minor technological difference and similar performance for a specific problem, the selection criteria would only be the price. In practice, selection incorporates multiple dimensions of decisions. The notion of withstanding the selection criteria of the market and outperforming competing solutions is referred to as the fitness of a certain technology.

Selection further impacts the competitive space, because “Selection mechanisms tend to increase the economic dominance (e.g. profitability, market shares) of some firms with particular innovation characteristics at the expense of others”.[31] It is possible that a regulatory decision can boost one company’s innovation while destroying that of another company. In extreme cases it is even a live or die decision.

Selection environments play a minor role in radically emerging technologies due to the poor understanding of the new technology and the missing clear definitions of an initial market. Once the new technological paradigm is well established and the trajectory is well defined, the selection environment is able to understand and value the incremental innovations and therefore selection forces intensify.[32] This lets us conclude that new radical emerging technologies for emerging markets, despite the fact that they face other major obstacles towards market adoption, are less exposed to selection environments.

3.3 Identification of Emerging technologies

Emerging technologies and markets hold the key for many opportunities. At the same time companies are challenged with the difficulty of identifying prospective technologies and of managing the market introduction. Frequent questions that emerging technologies provoke are for instance - Are there any known uses for this technology? What might this technology do that other technologies cannot do? Where is the path of this technology likely to lead? What factors

[30] Kash, D.E., Rycroft, R. (2002), p. 586

[31] Silverberg, G., Dosi, G., Orsenigo, O. (1988), p.1034

[32] Kash, D.E., Rycroft, R. (2002), pp. 590 - 594

might limit the use of this technology? – and so forth.[33] A comprehensive approach to deal effectively with these uncertainties will be discussed in the following section.

3.4 The Concept of Peripheral Vision

George S. Day and Paul J.H. Shoemaker (2007) developed the concept of Peripheral Vision.[34] The term peripheral must not be seen as a synonym but rather as a metaphor to the human eye.[35] The periphery is everything that lies outside of the current focus. The authors state that peripheral vision is essential to detect the perpetual weak signals that are all around us. And in those signals one can find the indicators for new technologies and markets. Whereas decades ago large corporations could set the tone for new technologies, standards and products, in the more chaotic environment of today innovation and customers' needs come from the customers themselves rather than being induced on them by companies. While searching for reasons why companies today miss the signals for emerging technologies, the authors detected a vigilance gap from which many companies suffer and which relates to the large proportion of focal vision in many companies. The sole purpose of this concept is to overcome this vigilance gap by broadening the peripheral vision.

[33] refer to Wheatley, K.K., Wilemon, D. (1999), p. 36

[34] refer to Day, G. S., Schoemaker, P. J. H., (2007)

[35] The retinal cells in the human eye that translate light into impulses that travel to the brain consist of rod and cone cells. Rod cells (for peripheral vision) account for 95% of the total cells in the retina. The remaining 5% are cone cells (for focal vision). This peripheral vision is vital and allows us to detect the weak signals for potential attacks and opportunities.

Figure 7 shows the seven step process to overcome this vigilance gap.

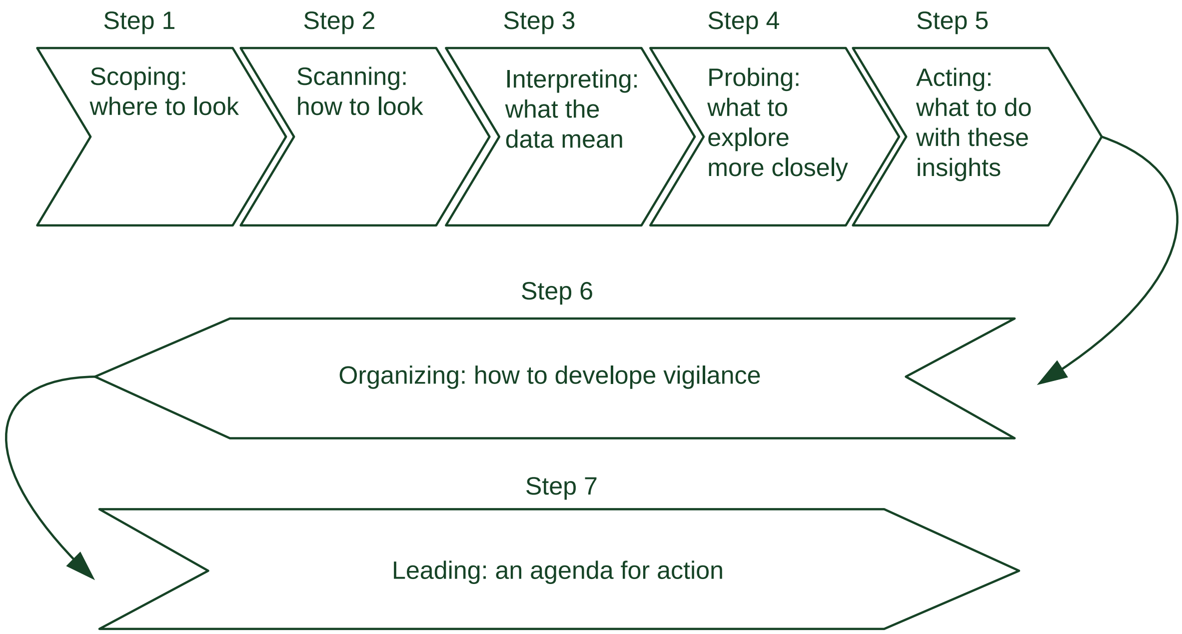

Figure 7: Seven steps to bridge the vigilance gap.
Source: Day, G. S., Schoemaker, P. J. H., (2007), p. 5, figure I-1

Steps one through five offer guidelines for improving and deepening peripheral vision. We will discuss these five steps in further detail. Steps six and seven support organizations to broaden their peripheral vision to overcome the vigilance gap. Organizational structures for emerging technologies will be discussed in chapter 5.

3.4.1 Scoping

Scoping is the first step of this process. Knowing ones targets and capabilities is the underlying principle that drives this process. Before starting to assess new technologies, a company not only needs to be familiar with its technological capabilities but also other constraining matters like financial- or human resources. And they have to have a clear vision where the company will be heading.[36]

[36] refer to Doering, D.S., Parayre, R. (2000), p. 80

The scoping stage is also a question asking process. Questions like "What have our past blind spots been?" or "What future surprises could really hurt (or help) us?" aim at deepening the understanding and broadening the vision for the problem at hand.[37]

To be able to spot new trends and developments, the boundaries of the scope will be set a little broader than a company's day-to-day focus. But still determining how broadly to look is not an easy task, especially today when the boundaries of different industries become more and more indistinguishable. Whereas a telecommunication company could focus on connecting people though landlines a decade ago, they now have to offer wireless services, paired with media content and global positioning systems among many other services. This new situation, where applications from many different fields of technologies are merged into one product significantly expands the scope for the search of new technologies. It is exactly for this reason of upmost importance to set the right scope encompassing everything relevant, but in order to make it manageable, leave out the irrelevant.

To set the right scope, an important place to look is definitively the customer. Also competing companies as well as companies who offer instructive analogies can be a central source of information. Altogether the authors suggest six peripheral zones to look for, which will be covered in the next step called scanning.[38] It is vital to set the right scope in order for the scanning step to be efficient and successful.

3.4.2 Scanning

Scoping defines the parameters of where to look. The scanning stage takes us a step further and tells us how, as opposed to where, to look for new technologies. There are many sources or zones to search for new promising emerging technologies.

(1) **Inside the Company:** In large corporations with their own distinctive research labs, the search should begin exactly there within the company. Many companies undervalue considerable amounts of their own scientific findings, and the essential knowledge of their research is often just not properly connected to the decision makers in the company.

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[37] refer to Day, G. S., Schoemaker, P. J. H., (2007), pp. 32 – 47

[38] refer to Day, G. S., Schoemaker, P. J. H., (2007), p. 53

(2) Customers and channels: Today customers are increasingly able to shape the markets themselves. Therefore it is very importance to scan customers and channels to get a grip on technological emergence. The authors suggest several approaches towards scanning this peripheral zone.[39]

- Monitor complainers and defectors.
- Track the trends
- Seek out latent needs
- Leverage lead users
- Seek instant feedback
- Hunt for precursors
- Effectively mine the available data
- Listen to channels

All these different zones can offer tremendous insights for a company. Complainers and defectors for instance express that their needs aren't met. Van Hippel (2005) observed an ongoing shift of innovation efforts from manufacturers to customers and users respectively. One explanation for this shift is the increasing demand for customized products. In addition to that he points out that lead users, users that hold significant information on the subject of important market trends far ahead of the majority of users in their population, are a rich source of knowledge with high levels of innovativeness[40]. Since more and more companies outsource their sales channels and sell their products though retailers and wholesale, they tend to lose the direct contact to their customers. Listening to them and analyzing their sales data if possible, can be a valuable source of knowledge.

(3) Competitors and complementors: Companies do quite good in observing their direct competition, tracking almost every move they make. But exactly this course of action is causing the myopia for the periphery. In fact they should divert some of the focus to track the upcoming competition of tomorrow. This strong focus on their immediate competition often leads companies to ignore the movements of new market entrants. They end up being surprised by their emergence. Also investments from a competitor in

[39] refer to Day, G. S., Schoemaker, P. J. H., (2007), pp. 57 – 62
[40] refer to Van Hippel, E. (2005), pp. 1 - 4

a certain technology can be a strong sign for technological emergence. Especially with products where standards and network effects play a central role, the actions of a competitor can provide useful insights. Complementors often provide insights for potential intentions of competitors.

(4) **Emerging technologies and scientific developments:** There are countless places to look for new technologies. It is important to scan broadly and tap into every source of knowledge that could be relevant. Among these sources are laboratories, both institutional and private, venture capital firms, public licensors, conferences and meetings. Technological convergence can also incorporate strong signs of emergence. Their importance on technological emergence was discussed in chapter 2.

Doering and Parayre (2000) identify another important notion when searching for emerging technologies. They call it "Sensing Technological Emergence" and they classified two different signals accompanying this concept.[41]

Strong signals present themselves in patent and literature citation on the one hand and in a competitor's action on the other.

Even though patents are "state-of-the-art" or common knowledge, the citations of patents offer rich opportunities to find patterns that might signal the emergence of a technology or market. The analysis of co-citations between different fields of research can clarify linkages between those technologies and may be a sign for technological convergence.

Weak signals are far more subtle. They can be found in knowledge networks which are often more informal than formal. It's the knowledge networks that form around certain fields of research that often have a clear understanding where one technology is heading. It is imperative that a company's researchers attend scientific meetings and conferences and tap into that rich source.

[41] refer to Doering, D.S., Parayre, R. (2000), pp. 83 - 86

(5) **Influencers and shapers:** Special lobbyist groups, cultural icons and the media can have an impact on new technologies. They are definitively worth a look, and their influence in certain situations should not be underestimated.

(6) **Political, legal, social and economic forces:** New legislations can have strong a impact on new technologies. Pharmaceuticals or the chemistry industry for instance are highly dependent on governmental rules and regulations. Environmental regulations for instance can boost some industries (e.g. wind power) while others (e.g. heavy industries) may suffer.

3.4.3 Interpreting

After scoping has been set and scanning within this scope revealed new relevant emerging technologies, interpreting is the next step. The scanning step was about gathering information, but the information itself is useless unless you are able to connect the dots and draw the right conclusions. Managers can use several tools to facilitate this process. One is scenario planning. This concept will be detailed in chapter 4.2. Another way to effectively interpret data is forming hypotheses. The best practice in this case is to form multiple competing hypotheses. It is very important to figure out alternative hypotheses in contrast to sticking to just one. This again nurtures constructive conflicts and dialogues that enrich this process through extensive idea sharing. According to Day and Schoemaker (2007) too many companies still share information on a "need-to-know" basis only.[42]

3.4.4 Probing

The probing stage is the testing phase of this process. The hypotheses developed and the assumptions made in the interpreting stage have to be proven in order to rule out the incorrect and further pursue the promising ones.

This objective can be achieved by designing experiments. The basis for that can be scenario planning where a number of sketched scenarios are measured against their impact on the company. Real options thinking provides a way to make small strategic investments to learn more about emerging technologies without committing oneself to a high level of risk. The topic

[42] refer to Day, G. S., Schoemaker, P. J. H., (2007), p. 95

of real options will be discussed in detail in chapter 4.3. In this step failures should not be avoided but rather embraced. Probing is a learning process and often many things can be learned through deliberately making mistakes or testing hypotheses that are assumed to be wrong. Experimentation methods like computer simulations drastically changed the way and the pace in which we can conduct experiments. Automobile manufacturers today conduct crash tests by means of computer simulation long before a model is built. As a consequence the cost of R&D and the innovation time span can be reduced significantly as failures are spotted in the earliest possible stage of development. Further it facilitates Innovation by allowing companies to conduct more testing.[43]

Summarized to probe effectively; first, use scenarios to learn; second, fail fast and cheap in order to accelerate learning and third, use real options.[44]

3.4.5 Acting

After learning in the probing stage, one or the other opportunity may present itself. The next logical step is to act on them. Even after extensive probing there may still be a lot of uncertainties residing and the question about the perfect time to engage in a new technology and enter the market may still remain.

Comparable to the probing step, a gradual approach with multiple small product launches limits the potential risks and still lets a company enter the market with a new technology. This tactic also allows entering the market more broadly, testing different applications and retreating early from the ones with the least chance of profitability.

Being the first to move not always pays off. In fact empirical evidence shows that only a few pioneers were able to hold on to their first mover advantages.[45] It's often the smart fast followers that dominate the market in the long run. It basically comes down to a question of timing. Depending on the circumstances, uncertainties and a company's capabilities, managers must decide on the appropriate time at which to commit to a new technology.

[43] refer to Thomke, S. (2001), pp 67 - 69
[44] refer to Day, G. S., Schoemaker, P. J. H., (2007), p. 116
[45] refer to Day, G. S., Schoemaker, P. J. H., (2007), p. 131

Doering and Parayre (2000) describe four different forms of strategic commitment.[46]

Watch and wait. This form applies to technologies where the fit is good but the risk is considered to be too high. The technology and competition must be closely monitored at all times. This approach delays the actual entry into this technology and market respectively. This strategy is perfectly suited if the company has the resources and the capabilities to be a fast follower in the market, thus letting the competition bear a greater share of the risk.

Position and learn. In this approach the company actively starts to engage R&D in a new technology. This can be compared with the small market launches we discussed earlier.

Sense and follow. In this case the company waits until it senses strong signals that a new technology is taking off. This is a rather passive and risk averse move toward entry into a new technology.

Believe and lead. This is probably the most aggressive form of commitment. The company decides on a technology, fully devotes a large portion of its resources and aggressively pushes the technology out on the market.

3.4.6 Conclusion

Day and Schoemaker (2007) developed this comprehensive concept through drawing on conclusions gathered at a special conference on peripheral vision at the Wharton School's Mack Center for Technological Innovation.[47] With the increasing complexity of managing new technologies, this concept delivers a sound integrated approach for the assessment of emerging technologies. The step by step bottom up process intends to alleviate the myopia of many managers in the course of identifying new promising technologies while at the same time it provides robust screening mechanisms to eventually pin down the most promising technologies and opportunities. It can be pictured like a pyramid turned upside down where the scoping step defines the length of the basis of the pyramid providing a broad but bordered space to search. While wandering along down the pyramid each consecutive step narrows the focus on relevant technologies through efficient evaluation methods.

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[46] D.S. Doering, R. Parayre (2000), pp. 94/95

[47] refer to Day, G. S., Schoemaker, P. J. H., (2007), p. 3

4 Tools for Managing Emerging Technologies

4.1 Introduction

Projects that emphasize on engaging in emerging technologies and markets are generally characterized by high levels of uncertainty. As a consequence the ability to predict future developments is low. This chapter focuses on enhancing the ability to handle this uncertainty. Many companies have a strong focus on financial planning and they operate planning tools such as forecasting through extrapolation. These tools emanated from a business environment that was much more predictable. With the rapid globalization, variables that influence the success of new technologies have multiplied. This circumstance challenges companies today with the fact that previous planning and forecasting tools are losing accuracy. Scenario planning is a comprehensive approach to support planning and strategy formation. What’s more, it helps creating learning organizations.

Another issue regarding the management of new technologies and innovations is the proper valuation of investment decisions. Due to the high levels of uncertainty it is virtually impossible to take any form of future cash flows for granted. Needless to say, conventional investment valuations often fail in these environments. We will discuss an approach to value investments under uncertainties called “Real Options Analysis”.

Both tools, scenario planning and real options analysis, complement each other in terms of perspective and type of analysis. This is illustrated in figure 8.

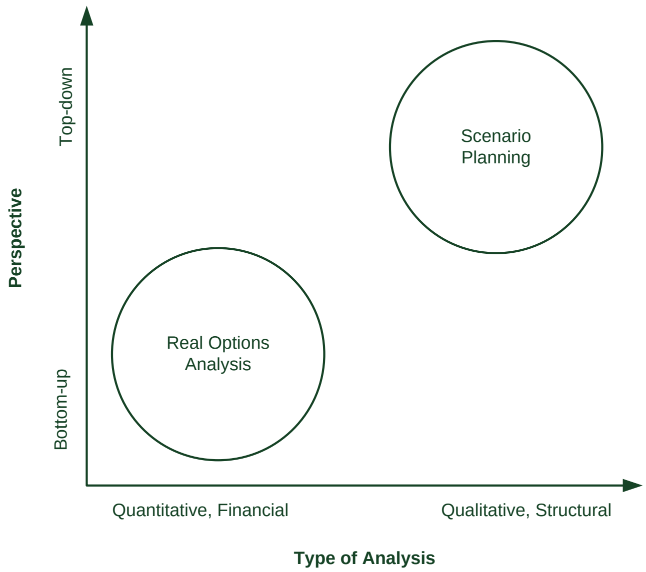

Figure 8: Perspective / Type of Analysis - Management Tools
Source: Depiction according to Mun, J. (2002), p. 65, Figure 2.4

4.2 Scenario Planning

4.2.1 Why Scenario Planning

Scenarios enable companies get more value out of the information they continuously gather. The same message may have different meanings in different scenarios. So what scenarios really do is they create learning organizations. Scenario planning helps examine the interactions between technologies and markets which shape the emergence patterns of technologies. It also helps to visualize their interactions.[48]

Schoemaker (1995) states that scenario planning is superior to other planning tools such as contingency planning, sensitivity analysis, and computer simulations. Contingency planning examines only one uncertainty at the time, whereas scenarios investigate the combined impact of various uncertainties. Sensitivity analysis on the other hand studies the effect in a system caused by the change of one variable, while all the other variables are held constant. This may be a sound approach if changes are small and when interactions of variables play a minor role. Scenario planning however changes multiple variables at a time without holding others constant, studying the occurrences that arise out of these changes. Computer simulations can

[48] Schoemaker, P.J.H., Mavaddat, V.H. (2000), p. 237

generate numerous outputs to search for patterns. However, in many cases certain developments cannot be formally modeled or they have to be oversimplified in order to function as a basis for a computer simulation. Scenarios can go further and include subjective interpretations.[49]

The objective of scenario planning is to help managers prepare for an uncertain future. To facilitate that, scenario planning helps managers come up with a set of possible futures for which they can prepare and align their strategy.

4.2.2 A Brief History of Scenario Planning

The first approaches to scenario planning were undertaken by Herman Kahn, a military strategist and futurist working for the RAND Corporation. He also founded the renowned Hudson Institute, a policy research organization. Herman Kahn was recognized for his studies on the possibility of thermonuclear wars and in the late 1960's and used scenarios for his research.[50]

Further development of scenario planning to support decision making was performed by Pierre Wack, head of the Business Environment Division of the Royal Dutch/Shell Group Planning Department, in 1971. Royal Dutch/Shell was the first company to fully integrate scenario planning in its decision making process and pioneered scenario research.[51] The Dutch/Shell Group felt that due to the long lead times in oil projects, they needed a reliable tool to support decision making in respect to future developments. Up until 1971 they employed a process called UPM (Unified Planning Machinery) which was basically a forecasting tool. Owing to the rather poor performance of UPM they decided to switch to scenario planning. Better said they went from trying to predict the future to thinking about the future.

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[49] refer to Schoemaker, P.J.H. (1995), pp. 26/27

[50] refer to Hudson Institute (2007)

[51] refer to Wack, P. (1985), pp. 73-77

4.2.3 Constructing Scenarios

This process for scenario construction is less of a strict procedure than a framework. The very nature of scenario planning builds on imagination and creativity. Still, this approach offers a point to start from, upon which a broad range of scenarios can be created.

Before starting the construction process of scenarios, a scenario team must be put together. The team itself can be flexible in terms of staffing. In particular when external forces are to be evaluated, it proves useful to integrate people from outside the company such as suppliers, customers, regulators, and/or analysts.

Schoemaker (1995) suggests ten-steps on the road to develop scenarios[52].

(1) Define the scope. The first step will be to determine a timeframe and the boundaries for the scenarios. The scope depends on the problem at hand. It is a process of asking the right questions. For example: “How long are the product life cycles?” and “Can it be concluded that the life cycle of the next generation will span over the same amount of time?” The result of this step for example would be to develop scenarios over a period of ten years for the North American market.

(2) Identify the major stakeholders. In order to make sure that no party is excluded which holds interest in these matters, the major stakeholders within the defined scope must be identified. This includes those who affect the company as well as those who may be affected by the company. Therefore searching should take place inside as well as outside of the company. Stakeholders for instance can be suppliers, customers, competitors, employees, the government or shareholders. It is of upmost importance to actually understand stakeholders, their needs and their agendas. It is not enough just to know who they are.

(3) Identify basic trends. All the basic trends within the defined scope should be evaluated and understood. They may be social, political, legal, economic or environmental trends. The important thing is to understand the impact of each trend on the organization. To

[52] refer to Schoemaker, P.J.H. (1995), pp. 28-30

facilitate this it can be helpful to chart an influence diagram[53]. The trends should then be listed in a table as shown in the example in figure 9.

		Impact
T_1:	Increased global competition	–
T_2:	Maturing US and global markets	–
T_3:	Increased opportunities in the Far East	+
T_4:	Continued high US labor cost	–
T_5:	Declining budgets in the military	–
T_6:	Increased overseas sourcing	?
T_7:	Weakening union power	+
T_8:	Consumer emphasis on high quality	+
T_9:	Increased product differentiation	?
T_{10}:	Labor component declining in product	+
T_{11}:	Technology shift toward simpler designs	–

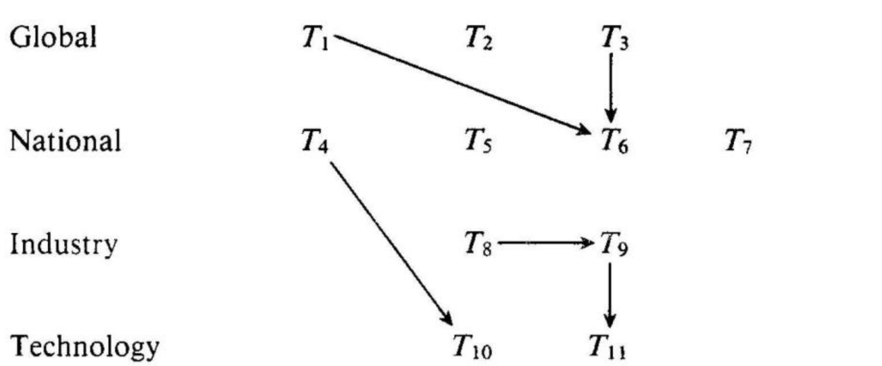

Figure 9: List of Trends
Source: Schoemaker, P.J.H. (1991), p. 553, Table I

If trends are apparent but their directions or impacts uncertain, then they don't fit with the list of trends and they belong in the next step. Identifying key uncertainties is a question of predictability. If predictability is high, it is a trend rather than an uncertainty and vice versa. Trends can be formulated as definitive statements, whereas uncertainties are more likely to be presented as questions.[54]

(4) Identify key uncertainties. This step is similar to the previous one except that the impacts or directions of events or outcomes are uncertain. Here again all relevant areas should be considered be it political, legal, environmental or so forth. If relationships

53 for further information on influence diagrams refer to Ross D. Shachter (1988)

54 refer to Schoemaker, P.J.H. (2002), p. 54

between uncertainties exist, they should also be identified as such. Once the uncertainties are identified they should be ranked as feasible as possible. The probable outcomes of these uncertainties should subsequently be identified. It is essential to keep these outcomes as simple as possible. For instance, the possible outcomes for the probability of stricter environmental regulations can be designated as "high" or "low". The key uncertainties should then be listed in a table according to their rank. Existing Intercorrelations, should be pinpointed.[55] An example of such a table with a matrix of intercorrelations is shown in figure 10.

		Impact
U_1: Dollar's strength against relevant currencies	(1) Much higher	– –
	(2) Higher	–
	(3) Same	0
	(4) Lower	+
	(5) Much lower	+ +
U_2: Fundamental technological change	(1) Much	?
	(2) Medium	0
	(3) Little	+
U_3: Change in industry concentration	(1) More	–
	(2) Less	+
U_4: Best place to manufacture	(1) USA	+
	(2) Far East	?
	(3) Europe	–
U_5: Level of service desired by customers	(1) High	+
	(2) Low	–

Intercorrelations

	U_1	U_2	U_3	U_4	U_5
U_1	1	0	−0.4	−0.8	?
U_2		1	?	0.6	0.4
U_3			1	–	?
U_4				1	?
U_5					1

Figure 10: Key Uncertainties
Source: Schoemaker, P.J.H. (1991), p. 554, Table II

(5) Construct initial Scenario Themes. Trends and uncertainties from steps three and four are the main elements of scenario construction. A simple way of obtaining extreme views would be to put all positive and negative (relative to the current strategy) trends and uncertainties together. All preferred ways of clustering uncertainties and trends that

[55] refer to Schoemaker, P.J.H. (2002), pp. 52 - 56

confront the problem will suffice. For instance possible outcomes can be clustered around the degree of preparedness.[56] Another way to construct scenarios would be to take the two top ranked key uncertainties and find, in order to keep it simple, two possible outcomes for them. Then confronting them against each other in a two-by-two matrix. The result would be up to four different scenarios.

Figure 11 shows a list of ranked uncertainties and the matrix of the two combined key uncertainties and their resulting scenarios.

Table 4 Global Uncertainties for Anglo-American Corporation

Part A Uncertainties

U_1 Trade conflict between the United States and Japan

U_2 Arms negotiations between the United States and the USSR

U_3 Proliferation of nuclear weapons

U_4 Spread of AIDS

U_5 Rise or fall of Islamic fundamentalism

U_6 Impact of Europe 1992

U_7 Deterioration of ozone layer

U_8 Middle East war (or third world war)

Note: These uncertainties are a subset of those Anglo-American Corporation examined in 1984 as part of its global scenario analysis.

Part B Two Uncertainties Combined

United States/USSR		United States/Japan: Trade Accommodation	United States/Japan: Trade Conflict
	Arms Race	Imperial Twilight	X
	Detente	Industrial Renaissance	Protracted Transition

Figure 11: List of Uncertainties - Scenario Matrix
Source: Schoemaker, P.J.H. (1995), p. 35, Table 4

[56] refer to Schoemaker, P.J.H. (1995), p. 29

(6) **Check for consistency and plausibility.** The initial scenario themes, constructed according to the previous step, are still not complete scenarios. They will probably lack internal consistency and a storyline. According to Schoemaker (1995) there are three tests that can be performed to rule out inconsistency. First, the trends have to be evaluated for their compliance within the given timeframe. Second, the combined outcomes have to be assessed for their plausibility. As seen by the "X" in Table 11 implausible scenarios should be eliminated. And third, the assumed actions of stakeholders have to be in line with their true interests.

(7) **Develop learning scenarios.** Once the scenario themes have been constructed and checked for consistency, logic, and plausibility, the remaining uncertainties and trends can be organized around them. It is important to remember that one and the same trend can have a different significance in each scenario. Another vital part of this step is to give the scenarios a name. Scenarios tell a story and compelling stories need to be named. These learning scenarios, serve as directive for further research and study.

(8) **Identify research needs.** In this step the knowledge about the trends and uncertainties should be enhanced. The very nature of scenarios implies that many influences for the trends and uncertainties come from outside the usual business domain of a company. Therefore it is essential to identify and study the blind spots that most likely still exist among stakeholders and/or new developments in any given field of research.

(9) **Develop quantitative models.** Quantitative formalized models, that describe dependencies between certain variables, should be utilized. These add an additional layer of plausibility as they prevent scenarios form going too far and therefore resulting in numbers that are impossible. They also support the interpretation of scenarios, since they provide straightforward numbers to work with and compare.

(10) **Evolve toward decision scenarios.** This final step leads to the scenarios that can eventually be brought into play when testing strategies and generating ideas. The last step should also lead to and facilitate the rethinking of the previous steps. If the resulting scenarios do not conform to the questions and issues at hand, adjustments in the preceding steps may be necessary. Scenario planning is an iterative approach and it

builds on science as well as creativity and imagination.[57]. If reassessment is finalized, scenario construction is completed and they can for example be published by means of a presentation and/or corporate document. The resulting scenarios can now serve as a basis for future oriented decision making.

4.2.4 How to Bring Scenarios into Play

After the scenarios have been constructed, the question arises as how to best make use of these. Scenarios need not be constructed by the managers that actually use them. They can also be provided by other management teams or external consultants. Schoemaker (1995) came to the conclusion that scenarios have the same impact when developed by the decision maker himself as when developed by third parties.[58]

Scenarios can also be used to test existing strategies by running through the scenario with every plausible strategy. The result of testing will conclude that the given strategy corresponds well in a scenario and further testing may eventually present additional insights how to improve the strategy if it doesn't. Scenario planning can serve as a tool to create strategies as well as be useful in performing risk analyses.

The ultimate goal of scenario planning is to create strategies to enable companies survive in an environment of multiple outcomes and prosper in at least a few of them.

4.3 Real Options Approach and Analysis

In contrast to scenario planning, which is a very qualitative and top-down approach, we will now discuss the real options approach, which is very quantitative and bottom-up in its nature. The term real option is used to refer to options whose underlying assets are not financial. Still, real options are similar to financial options. For example an investment in a R&D project to explore the opportunities of a new technology is comparable to a financial call option. It provides the right, for a specific cost, to engage in an emerging technology and it creates the opportunity, but not the commitment, to make further financial investment in the future.[59]

[57] refer to Schoemaker, P.J.H. (1995), p. 30
[58] refer to Schoemaker, P.J.H. (1995), pp. 37/38
[59] refer to Hamilton, W.F. (2000), p. 274

Applying real options for investment decisions is not just a matter of applying new models and formulas; it is a new way of framing and structuring decisions.[60]

4.3.1 The Benefits of Real Options

By their very nature, emerging technologies and their markets are very uncertain. This in mind, it is clear that different approaches towards evaluating investment decisions are necessary. Traditional approaches like DCF often undervalue investments in emerging technologies.

Merton (1998) explains why real options and emerging technologies fit so well together. “The future is uncertain (if it were not, there would be no need to create options because we know now what we will do later) and in an uncertain environment, having the flexibility to decide what to do after some of that uncertainty is resolved definitely has value.”[61]

To leverage the power of real options, solely recognizing the option alone will not suffice. Hamilton (2000) suggests thinking of the options approach as a continuous cycle. This cycle is depicted in Figure 12.

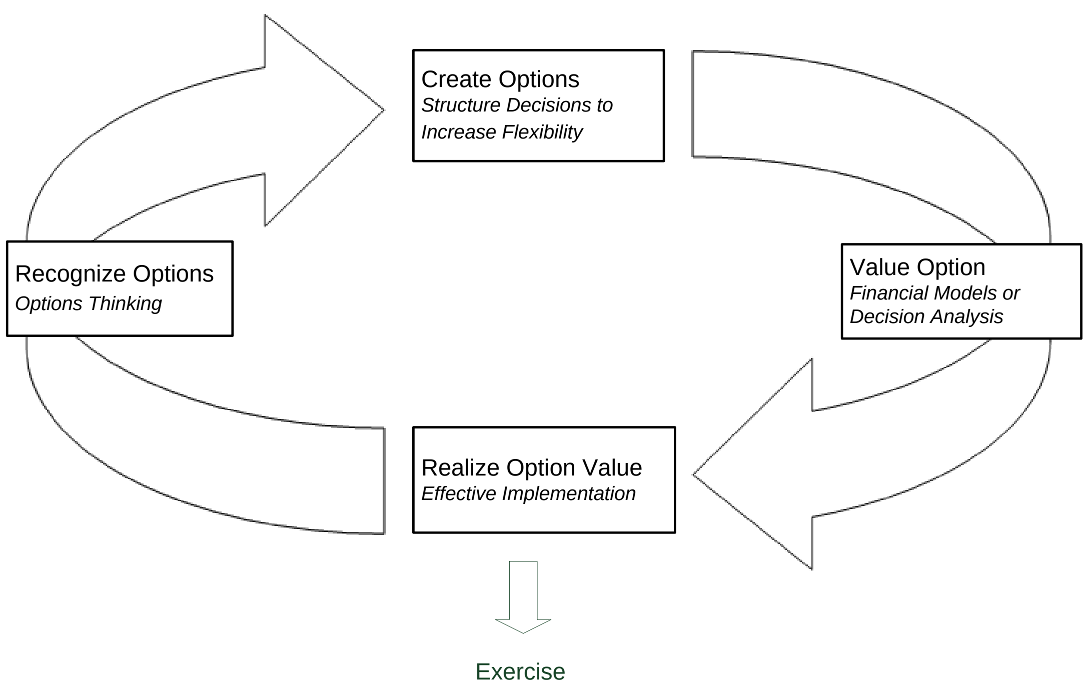

Figure 12: Dynamic Real options Framework
Source: Depiction according to Hamilton, W.F. (2000), p. 277, Figure 12.1

[60] refer to Amram, M., Kulatilaka, N. (1999). p. 96
[61] Merton, R.C. (1998), p. 339

Once an options perspective has been adopted these can be recognized. In the next step, further options have to be created and as a final point all options need to be valued. Built into the decision making process the option value can then be realized and then exercised. The different types of options, the creation of new options and the valuation of these will be further discussed in the following sections of this chapter.

4.3.2 Real Options vs. Traditional Valuation Approaches

Engagements in new technologies usually encompass strategic investment decisions. The traditional and most widely used approach to value investment decisions are DCF methods. Although DCF methods are well understood and employed by many managers, they lack certain qualities that critical when dealing with emerging technologies. DCF methods are based on mathematical models. These models in turn are based on assumptions which to a certain degree can either be met or not. In the case of emerging technologies the latter is often the case.

The real options approach can identify important sources of value that would have been missed by using DCF methods. DCFs even treat some of the value creating characteristics of emerging technologies as negatives[62].

[62] refer to Hamilton, W.F. (2000), p. 275

Table 1 illustrates the disparities between the DCF and the real options approach.

Traditional DCF Perspective	Real Options Perspective
Views uncertainty as a risk that reduces investment value	Views uncertainty as an opportunity that increases value
Assigns limited value to future information	Values future information highly
Recognizes only tangible revenues and costs. Unknown, intangible, or immeasurable factors are valued at zero	Recognizes the value of flexibility and other intangibles as well as qualitative strategic positions
Assumes clearly defined decision paths	Recognizes paths determined by future information and managerial discretion
Future free cash flow streams are all highly predictable and deterministic	Future cash flows are difficult to estimate as they are usually stochastic and risky
Decisions are made now	Not all decisions are made today, as some may be deferred to the future, when uncertainty becomes resolved

Table 1: Traditional Financial vs. Options Perspective
Source: Hamilton, W.F. (2000), p. 278, Table 12.1 and Mun, J. (2002), p. 59, table 2.1

DCF is still a very useful valuation approach which works quick and easy and offers many benefits. But traditional DCF does not cope well with investment decisions that have high levels of uncertainty and flexibility. As we will learn later in this chapter, DCF can be applied in real options valuation once it’s enhanced with an options perspective.

4.3.3 Creating Real Options

While some options may arise naturally and present themselves, others may have to be created. By shifting the managerial mindset towards thinking in an options perspective, numerous options will become apparent. To implement an options approach, it is not enough to just recognize existing options. Decision paths have to be reorganized and restructured in order to create new options or make existing ones clearly visible. As pointed out, in contrast to the DCF approach where multi-year investments are valued in order to make a one-time decision, the real options approach breaks the decision path down into many smaller fractions. Every option adds value by adding viable alternative decision paths.

Almost every investment decision encompasses several options which may be highly individualized to the problem at hand. Nevertheless there are a few common types of options that can be found in many investment decision paths.[63]

Timing Options are common in almost every decision making process. Postponing a decision until further information about markets or the viability of a technology can be obtained definitively has value.

Growth Options. Investments in production facilities and sales forces for example need not only serve a current expansion. More than that they may open new options and enable further growth, providing additional value.

Staging Options surface upon dividing investment processes into phases. The outcome of each phase and the knowledge acquired therein, provide a basis for gradually steering the process, adding value.

Exit Options increase the value of a project, reducing the size of the investment at risk by providing an exit possibility at different stages.

Flexibility Options. Centralization and consolidation of production facilities for instance may realize cost savings. On the other hand the value of options gained by being flexible through splitting production among many plants may outweigh the benefit of cost savings.

Learning Options. By releasing a new product in a small but representative market, value adding lessons can be learned prior to its final release.

Scouting Options are exceptionally valuable if the technology itself is relatively certain but the market is not. Launching the new technology in small markets presents a great way to learn more about the markets themselves. Even if the investment is lost, it was not worthless. Similar

[63] Amram, M., Kulatilaka, N. (1999), pp. 96-98

to the military metaphor; even if the scout does not return, you then at least know where the enemy is.[64]

The above mentioned options may appear obvious, but in most cases they have to be created. Hamilton W.F. (2000) recommends two approaches to create and structure options.[65]

(1) **Look for opportunities to unbundle decisions.** Investment decisions are usually comprised of many incremental decisions. Unbundling them to multiple smaller decisions allows structuring investments into multistage decisions. As with projects, the decision path is broke up to segments with milestones, representing decision points and acting as connectors. These milestones facilitate a change of scale, scope and direction throughout an investment project. Decision trees are a practical tool to visualize a decision path. An example of a decision tree will follow later in this chapter.

(2) **Expand consideration of additional possibilities for future action.** Considerations of complementary and competitive possibilities such contracting partnership agreements, acquisitions or technology licensing can add value through creating new options.

This process should enable a company to come up with an option portfolio. Creating too many options is counterproductive, as a multitude of these can increase uncertainty and complexity.

4.3.4 Valuing Real Options

Once possible options have been identified, they have to be valued in order to serve as a basis for decision making. Although real options bear similarities to financial call options their valuation or quantification can be difficult and in some cases even impossible.

4.3.4.1 The Black-Scholes Formula

In certain circumstances real options can be quantified in the same manner as a financial call option. Derived from the options pricing theory, the Black-Scholes formula can be adapted to value real options. Nonetheless option valuation for emerging technology investments with the Black-Scholes formula is only feasible under certain conditions. Another downside of this

[64] refer to Day, G. S., Schoemaker, P. J. H., (2007), p. 110
[65] refer to Hamilton, W.F. (2000), pp.279/280

valuation approach are the underlying assumptions that are necessary to fit an emerging technology investment decision into this model, and the estimations necessary due to the lack of comparable investments. It therefore shall not be discussed further in this thesis.[66]

4.3.4.2 The Decision (Tree) Analysis Approach

A better way to value real options for new technologies is the decision analysis approach. This approach also creates transparency through visually structuring the investment decision, by means of a decision tree. The decision analysis approach builds on subjective risk and value assessments of the decision maker in contrast to the objectivity of the mathematic Black-Scholes model.

A decision tree is comprised of branches and nodes. There are three different kinds of nodes. (1) Decision nodes which are symbolized by a square, divide the tree into several branches, with so called partial cash-flows affiliated to each branch. (2) Chance nodes, symbolized by a circle, also divide the tree into several branches. However in this case with a probability of occurrence assigned to each branch. (3) The last type of node, symbolized by a triangle, is the terminal node and represents the end of a certain branch. Using branches and nodes, all possible paths of an investment decision can be visualized. Nevertheless, complicated and nested tree structures should be avoided.

Once the decision tree is laid out, the expected value can be calculated. Conventional decision trees are calculated by a method called “folding back”, which sums up all the cash flows of the branches following a chance node, multiplied by the probability of their occurrence. The decision path is the mapped through the decision node connecting the decisions with the highest cash flow. The goal of a decision tree is to find the best decision path. In the option valuation approach, the objective is to value the option of engaging in an investment.

The superiority of the options approach over the DCF approach is illustrated in the following example.[67]

A company proposes a R&D project do develop a new pictorial-quality color printer. It is an emerging market with uncertain financial returns which are dependent on the

[66] For an example of real option valuation with the Black-Scholes formula refer to Leslie, K.J., Michaels, M.P. (1997)
[67] refer to Faulkner, T.W. (1996), pp. 51/52

cost/performance characteristics of the product. These in turn depend on the R&D outcome which is uncertain. To engage in the new technology an initial investment of $6 million is required. Independent of the research outcome, further $15 million are necessary to commercialize the technology. The discount rate is 12 percent. All the costs, uncertainties and returns are shown in the decision tree in figure 13.

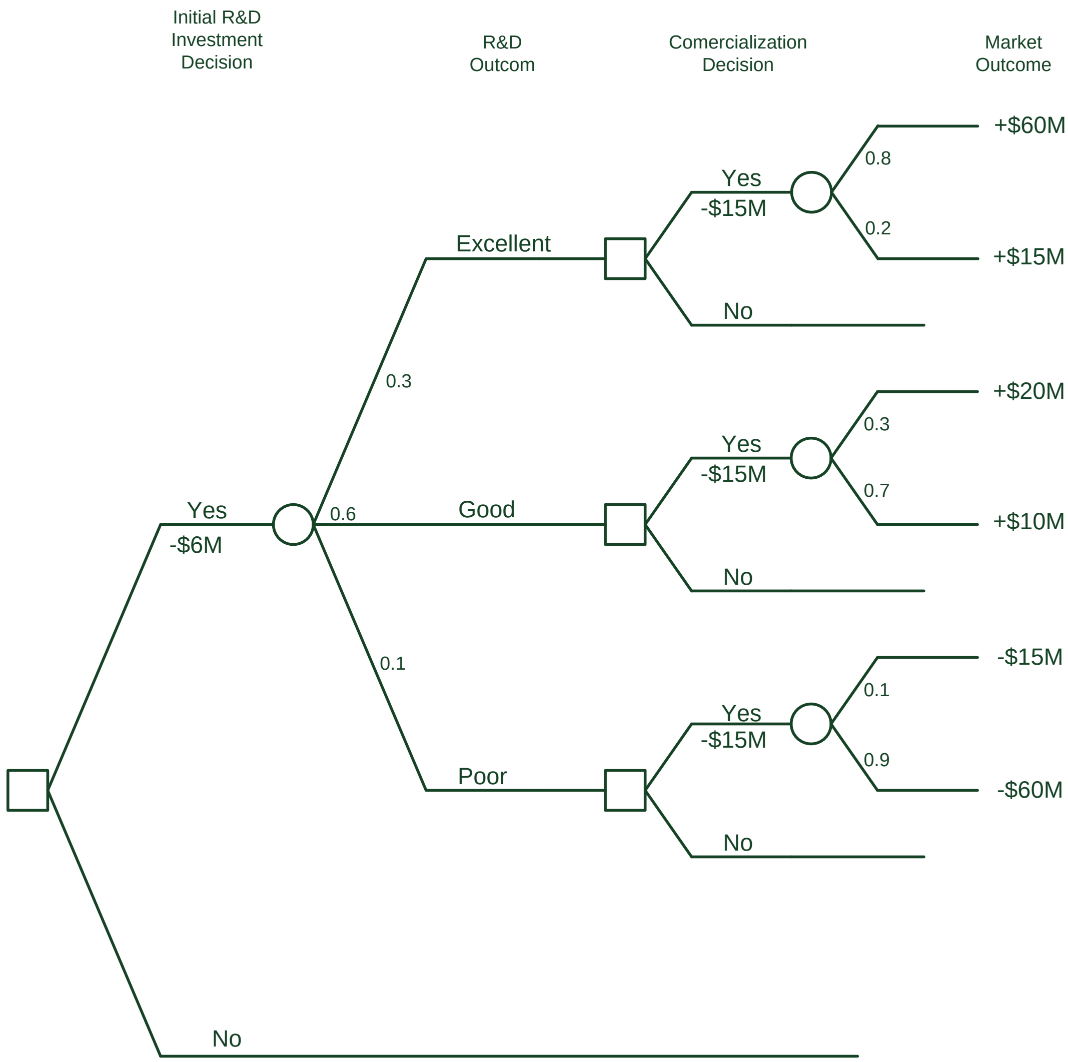

Figure 13: Decision Tree for option valuation
Source: Faulkner, T.W. (1996), p. 52

As illustrated the investment decision is structured in an options thinking perspective. We can now apply the DCF calculation method. Table 2 shows a comparison of DCF valuation with and without an options perspective. Hence the option valuation builds on an adapted form of DCF calculation.

Valuation Method		NPV	Year 0	Year 1	Year 2
DCF 1:	Use most likely values	**- $11.4**	- 6 -	$\left(\frac{15}{1.12}\right)+$	$\left(\frac{10}{1.12^2}\right)$
DCF 2	Consider market uncertainty	**- $9.0**	- 6 -	$\left(\frac{15}{1.12}\right)+$	$\left(\frac{(0.3)\,(20)+(0.7)\,(10)}{1.12^2}\right)$
DCF 3	Plan to introduce considering all uncertainties	**- $5.4**	- 6 -	$\left(\frac{15}{1.12}\right)+$	$\frac{(0.3)\,[(0.8)\,(60)+(0.2)\,(15)] + (0.6)\,[(0.3)\,(20)+(0.7)\,(10)] + (0.1)\,[(0.1)\,(-15)+(0.9)\,(-60)]}{1.12^2}$
Options Valuation:		**+ $2.2**	- 6 -	$(0.3)\left(\frac{15}{1.12}\right)+$	$(0.3)\left(\frac{(0.8)\,(60)+(0.2)\,(15)}{1.12^2}\right)$

Table 2: Options value calculation - decision tree
Source: Faulkner, T.W. (1996), p. 52<

DCF 1 calculates the NPV with the most probable outcome. DCF 2 takes into consideration market uncertainty and DCF 3 encompasses all possible uncertainties. All three variations of the DCF calculation result in a negative NPV and would therefore lead to a dismissal of the investment. The options valuation method on the other hand yields a positive NPV. The above calculation illustrates that the options valuation calculates the NPV on a best case basis. This can be justified, since the options approach is based on postponing the decision until more information is available. So unless the R&D outcome is not excellent, the project will be cancelled.

We have seen in this chapter that the option approach recognizes the value of learning. This is especially important when dealing with emerging technologies, because strategic decisions to engage in new technologies and to invest in R&D are typically not one time events. Consequently an approach that considers the options that arise is better suited to valuate investment decisions in regard to emerging technologies.

5 Organizational Structures for Emerging Technologies

5.1 New Organizational Forms

Companies that deal with emerging technologies need a flexible and responsive organizational environment to operate in. In other words, innovative companies need innovative organizational structures.

The diverse needs of organizational forms of emerging technologies expand over all six elements of an organization.

These six elements are:[68]

(1) Organizational goals
(2) Strategies
(3) Authority Relations
(4) Technologies
(5) Markets
(6) Processes

Among these six elements, companies that engage in emerging technologies and innovation have considerably different requirements. Whereas the organizational goal for a mature technology is to protect its market share, a new technology's goal is to create a market and gain market share respectively. Authority relations are more about speed and flexibility than about control. Processes are rather dynamic than standardized. This fact presents a challenge especially for large corporations which have to balance the organizational needs of their established core businesses together with their innovation activities. To facilitate this, they often disconnect their innovation efforts into separate business units, utilizing the benefits of other organizational forms. The following section presents organizational forms that react well to the demands of fast changing environments and high uncertainties.

5.1.1 The Virtual Organization

Due to the increasing availability of communication technologies since the turn of the century, traditional bureaucratic-hierarchical organizations are continuously transforming towards

[68] refer to Herber, J., V. Singh, J., Useem, M. (2000), pp. 378/379

virtual organizations, where virtual teams interact with each other regardless of their physical location. Lipnack and Stamps (1999) define a virtual team as "teams with a common purpose that use technology to cross time zones, distance and the boundaries of organization."[69]

Virtual organizations minimize asset commitments resulting in greater flexibility paired with lower costs. Despite all those benefits, virtual organizations bring about a new set of challenges. For instance the supervisor in a virtual organization does not stand in the middle anymore, and the flat hierarchical structure may lead to the bypassing of critical information.[70]

5.1.2 The Network Organization

A network organization is a set of autonomous or semi-autonomous business units working together to deliver a complete product or service. They are connected by relationships and can be either external or internal. In external network organizations companies concentrate on their core business, relying on external companies like suppliers and distributors to complete the value chain.[71] In internal network organizations the same principal is applied inside a company among a set of business units.

5.1.3 The Spin-Out Organization

A spin-out organization emerges when a company establishes a fresh entity inside the company and then releases it at least partially on its own. To facilitate this process, large corporations often form corporate venture capital groups. These corporate VC groups will be discussed in detail in chapter 6.5.4. These entities usually spin-out of the parent company due to the fact that their technology does not fit with the company's strategic set goals and/or the parent company cannot provide the necessary environment for the entity to thrive and grow.

5.1.4 The Ambidextrous Organization

Contrary to the spin-out organization, the ambidextrous[72] organization does not spin-out the new business entity; instead it integrates it into the company. However, to create the proper

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[69] Lipnack, J., Stamps, J. (1999), p. 92

[70] refer to Herber, J., V. Singh, J., Useem, M. (2000), pp. 380/381

[71] refer to Herber, J., V. Singh, J., Useem, M. (2000), pp. 382/383

[72] The term ambidextrous is derived from the Latin words ambi and dexter, meaning both and right. It refers to people who are two-handed, meaning they are equally adept to perform tasks with each hand.

innovative environment, the new entity is separated to a certain degree. "The ambidextrous organizational form creates an environment in which both established and emerging businesses flourish side by side."[73] Companies are constantly forced to increase the performance of their existing product line through continuous incremental innovation. At the same time they must purse product innovation efforts in order to deliver new products and stay ahead of the game. This process is a combination of exploiting and exploring.[74] The Ambidextrous organization overcomes the issue that many companies face and which Christensen (2002) calls the "Innovators Dilemma".

5.2 Strategic Alliances

A strategic alliance is a cooperative relationship between two or more organizations, for the purpose of achieving a common goal. The term organization is used in this context instead of company or firm because the participants of a strategic alliance encompass firms as well as universities and governmental agencies.[75]

Dyer and Singh (2000) point out the importance of complementarities in alliances. In order for collaborative efforts to work, every partner has to contribute something distinctive, be it basic research, development skills, production capacity or sales channels. According to Hagedoorn's (1993) research, high-tech companies predominantly form alliances for complementary reasons. One reason was discussed in chapter 2. The increasing convergence of technologies encourages complementary cooperation, in which the different fields of technology of each partner create value by being combined. Another reason is the limited access of resources and capabilities. If a specific product relies on the resources and capabilities of more than one organization, and these cannot be acquired elsewhere, then an alliance is the only option to produce this product. For example Apple's first Powerbook was an alliance between Apple Computers and Sony. It was built upon Sony's capability of miniaturization and Apple's capability of designing ease-to-

[73] refer to Herber, J., V. Singh, J., Useem, M. (2000), pp. 387
[74] refer to O'Reilley, C., Tushman, M.L. (2004), p. 76
[75] refer to Dyer, J.H., Singh, H. (2000), p. 360

use. Neither of the companies alone could have built the Powerbook. This form of cooperation is a symbiotic relationship.[76]

5.2.1 Types of Inter-Organization Technology Cooperation and Alliances

There are countless forms of strategic alliances. The domains of inter-organization relationships can either be vertical or horizontal and in perspective of time, sort-term or long-term.[77] A vertical alliance for instance could be a research-cooperation between a company and one of its suppliers with the company financially supporting the research of its supplier. In turn the supplier may grant exclusive rights to the sponsoring company. The co-development of an engine by two car manufacturers is an example of a horizontal alliance. Alliances can also be either equity based or not. Equity-based alliances generally exist in the form of joint-ventures, realizing a separate organizational structure apart from their parent organizations. Non equity-based alliances are governed by contracts that defining each party's roles and responsibilities in the partnership.[78]

[76] refer to Dyer, J.H., Singh, H. (2000), p. 369
[77] refer to Hagedoorn (1993), p. 371
[78] refer to Dyer, J.H., Singh, H. (2000), p. 360

Figure 14 shows a list of different organizational types of interfirm cooperation in respect to the level of interdependence and internalization.

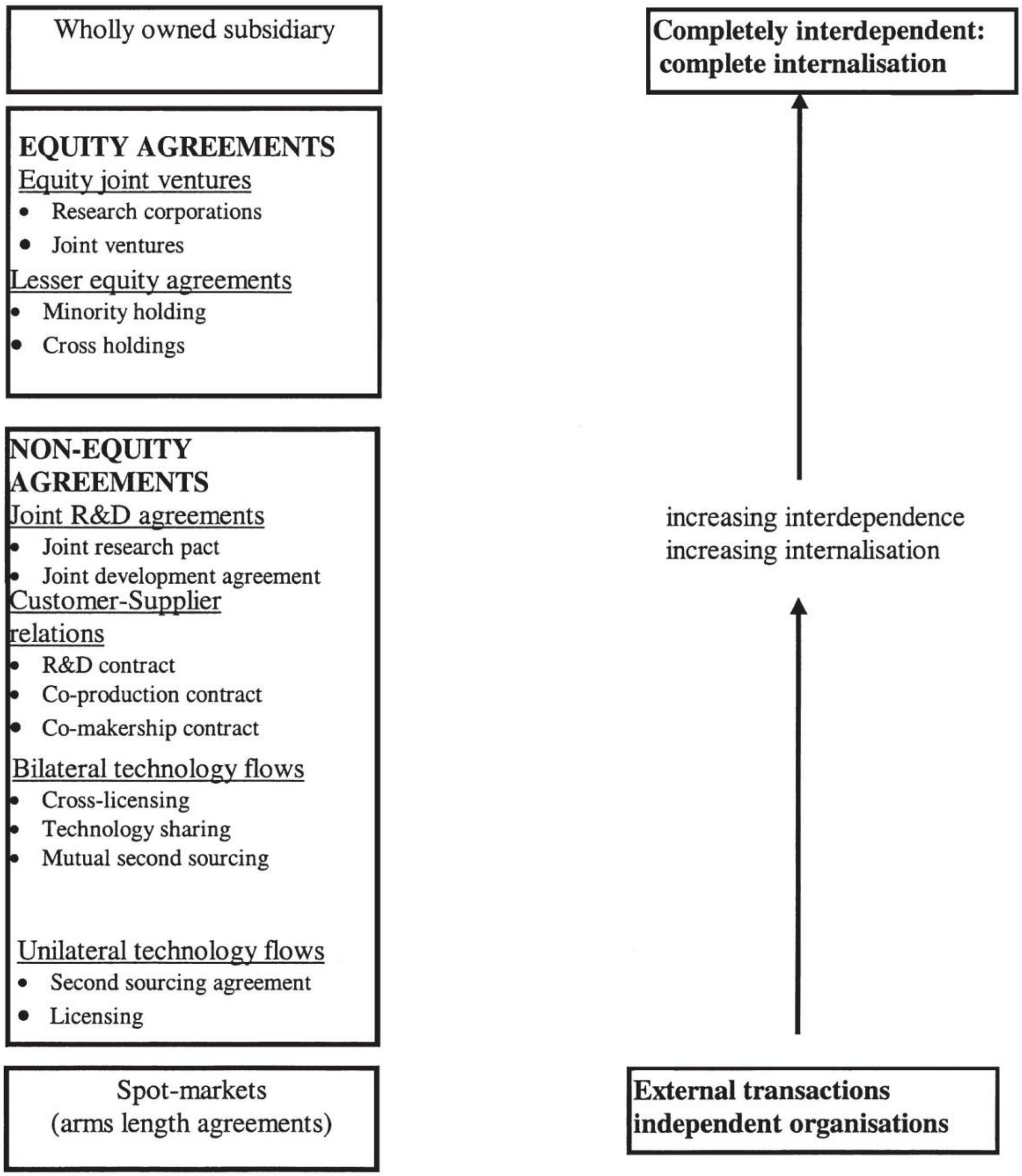

Figure 14: Forms of Cooperation and extent of internalization and independence
Source: Narula, R., Hagedoorn,J. (1999), p. 290, Fig. 4

Figure 14 highlights the broad spectrum of possible forms of alliances. We will now illustrate the motives to form these alliances.

5.2.2 Motives for Inter-Organization Technology Cooperation and Alliances

The motives for technology cooperation can be numerous. Hagedoorn (1993) distinguishes between three basic fields of motivation for technology cooperation.

(1) Motives related to basic and applied research and some general characteristic of technological development:

- Increased complexity and intersectoral nature of new technologies, cross-fertilization of scientific disciplines and fields of technology, monitoring of evolution of technologies, technological synergies, access to scientific knowledge or to complementary technology
- Reduction, minimizing and sharing of uncertainty in R&D
- Reduction and sharing of costs in R&D

(2) Motives related to concrete innovation processes:

- Capturing of partner’s tacit knowledge of technology, technology transfer, technological leapfrogging
- Shortening of product life cycle, reducing the period between invention and market introduction

(3) Motives related to market access and search for opportunities:

- Monitoring of environmental changes and opportunities
- Internationalization, globalization and entry to foreign markets
- New products and markets, market entry, expansion of product range

Table 3: Motives for technology cooperation
Source: Hagedoorn, J. (1993), p. 373, Table 1.

In his study on 4000 strategic technology alliances he concludes that in the more mature industries such as food and beverages industry for example, the central motives for forming alliances are market access and the influencing of the market structure. High-tech industries on the contrary value the benefits of technological complementarities and reduction of the innovation time span and cost.[79]

5.3 Knowledge Networks

Formalized strategic alliances are not the only means of technological knowledge exchange. In fact quite a lot of information can be obtained from knowledge networks without the need for signing any form of partnership agreement.

Knowledge networks play a vital role in emerging technologies. Rosenkopf (2000) states that “Emerging technologies are not developed and commercialized by individuals or single firms.

[79] refer to Hagedoorn (1993), p. 378

They are developed in networks." In the early stages of a new technology many different technological solutions are proposed. We mentioned in chapter 3.2.3 that the selection environment filters a dominant design out of these proposals. But even before that market selection takes place, the knowledge community around a new technology may do the same by imposing standards on this new technology. These networks often have serious impact on the evolutionary path of a technology. It is therefore essential for companies to participate and play an active role in these knowledge networks.[80]

[80] refer to Rosenkopf, L. (2000), p. 341

6 Strategies for Financing Emerging Technologies

6.1 Introduction

The financing of emerging technology ventures faces several challenges. Due to their early stage of development they are generally unable to create continuous streams of cash flows, if any at all. It may take years of R&D before the first cash flows can be attained. Furthermore the assets created by research are usually intangible. And then they suffer from the problem of information asymmetry. Despite all these hurdles there are still several financial options to fund emerging technologies.

Larger companies and corporations generally are able to finance their R&D and commercialization efforts of new technologies internally. In this case it is rather a question of the investment decision to engage in a new technology than anything else. Investment decisions and their valuation were covered in chapter 4 in depth. Hence this chapter primarily focuses on the funding of new ventures in a more entrepreneurial environment.

6.2 Challenges of Financing Emerging Technologies

6.2.1 Assets are Intangible

A few decades ago company value mainly derived from physical assets and not intangibles such as knowledge. Today, a growing share of the value of companies is presently not being created by people managing the tangible assets, but by for example the hordes of programmers trying to find new algorithms, writing lines of code and searching for better ways to do things as in the example of Microsoft.[81] These assets are intangible and the valuation hereof difficult, especially in the initial stages of a new technology where uncertainty is high. This in turn leads to a higher level of perceived risk and raises the cost of capital. In case of a bankruptcy, losses are greatest with intangible assets such as technology and human capital. Due to this fact, debt-ratios are low in high-tech industries where value depends on continued success in R&D (thus intangible).

[81] refer to Allen, F. Percival, J. (2000), p. 292

What's more, Intangible assets cannot easily serve as collateral for debt financing; consequently companies with risky intangible assets rely primarily on equity financing[82].

6.2.2 Information is Asymmetric

Another problem source of external financing is from asymmetric information. Akerlof described the problem of asymmetric information in the used car market (Market for Lemons)[83] and received the Nobel Prize in Economics in 2001 jointly with Spencer and Stiglitz for their research related to the asymmetry of information.

The borrowers of funds, in this case the company or entrepreneur that needs funding to develop a new technology, knows more about prospects, values and risks than the lender. Investors also fear that borrowers may take risks that are undesirable, because they receive the upside potential while the investors bear the downside risk. Rising interest rates on loans due to the higher risk inflicted by the asymmetry of information lead to a reduction of the quality of borrowers. Clearly, the ones that care less about high interest rates are the ones that anticipate the highest probability of default.[84] Therefore banks address this issue by restricting the amount of lending rather than raising interest rates.

This notion is called "adverse selection". Adverse selection also concerns Venture Capitalists, because the high costs of capital caused by the expected rate of return may drive the most profitable ventures away to other means of financing. These issues are hard to resolve, and therefore dealing with asymmetric information continues to be a balancing act for investors.

6.3 Methods of Financing Emerging Technologies

The Funding of R&D of new technologies can be acquired from several sources. However, the optimal financing strategy is heavily dependent on the company deciding to engage in a new technology. In many cases a company doesn't even exist and an entrepreneur or a team of entrepreneurs are committed to start their own venture. This case would practically rule out

[82] refer to Brealey, R.A., Meyers, S.C. (2003). pp. 508/509

[83] Akerlof conducted a study about asymmetric information the used car market - "The Market for 'Lemons'": Quality Uncertainty and the Market Mechanism," *Quarterly Journal of Economics* (August 1970)

[84] Allen, F. Percival, J. (2000), pp. 299/300

internal funding, at least in the early stages of the company. Basically there are two ways to fund new technologies. They can either be funded internally or externally.

6.3.1 Internal Funds

Internal funds are generated within the company; e.g. profits, sale of assets, reduction in working capital, extended payment terms, account receivables. Large companies generally fund their R&D effort with these internal funds. Also outside equity investors do not expect any payback in the early stages of a venture and let the companies use them to invest in further growth.[85] If this kind of financial backing does not exist, which is usually the case in start-up ventures, funds need to be obtained from external sources.

6.3.2 External Funds

External sources of funds to the venture are; funds provided by the entrepreneur himself, his family and friends, commercial banks, angel investors, venture capital and governmental loan programs and grants.

6.4 Debt vs. Equity

If external funds have to be acquired, the next main question that remains is weather the venture should be finance by means of debt or equity. And then again it's not only a question of what the best approach is, but often, what the most viable financing approach is. As discussed earlier, the problem of information asymmetry and the absence of collateral, leads to the fact that innovative ventures are usually financed by equity. Debt financing becomes a viable option in the later stages of a venture once major uncertainties are resolved, sufficient collateral and continuous cash flow streams are available.

Another difference is that stockholders and lenders differ in their cash flow and control rights. Stockholders are entitled to the remaining cash flows after security holders are paid off and they have control over how the company spends its money. In practice these cash flow and control rights are negotiated with the VC who will ensure they have a saying in the company.[86]

[85] refer to Hisrich, R.D., Peters, M.P., Shepherd, D.A. (2006), p. 346
[86] refer to Brealey, R.A., Meyers, S.C. (2003), p. 403

As a result an entrepreneur may be willing to finance the venture through debt in order to retain the ownership rights.

If the company needs financing for further growth or acquisitions and the required funds can neither be provided by equity nor debt financing, a hybrid instrument like mezzanine financing can be utilized. This combines the characteristics of debt and equity financing. Owing to its debt attributes, mezzanine capital requires unconditional repayment of debt and interest. Like equity it is subordinated to senior debt and it entails little or no collateral. The thereby elevated risk is compensated by higher interests rates or the right to convert to an ownership in the company, e.g. stock options.[87] Due to the debt like repayment, continuous cash flows are necessary ruling this type of financing out for the early stage of an investment.

6.5 The Role of Venture Capital

Wright, M., Robbie, K. (1998) define Venture Capital as follows: “Venture capital is typically defined as the investment by professional investors of long-term, unquoted, risk equity finance in new firms where the primary reward is an eventual capital gain, supplemented by dividend yield.”[88] Venture Capital plays an important role in financing R&D projects. Besides providing funds, VCs provide knowledge, consulting services, access to their networks, et cetera.

6.5.1 Venture Capital Industry Overview

The Venture Capital Industry grew rapidly in the US in the 1990’s fueled by the dot.com bubble peaking in 2000. Table 4 shows the development of the investment amount, the number of deals and the investment amount per deal in the US from 1995 to 2006.

[87] refer to Stadler, W. (2004), pp. 224/224 with ideas form www.investopedia.com
[88] Wright, M., Robbie, K. (1998), p. 521

Year	Investment Amount in Mio. USD	# of Deals	Average Investment Amount/Deal
1995	8,118	1,844	4.40
1996	11,271	2,573	4.38
1997	14,890	3,156	4.72
1998	21,117	3,647	5.79
1999	54,132	5,507	9.83
2000	105,249	7,911	13.30
2001	40,700	4,481	9.08
2002	21,943	3,091	7.10
2003	19,769	2,914	6.78
2004	22,501	3,069	7.33
2005	23,091	3,127	7.38
2006	26,346	3,553	7.42

Table 4: Amount of Investment / # of Deals - Venture Capital – US
Source: Money Tree^{TM} Report (2007)

After the crash in 2000, the number of deals and the amount of money invested declined sharply. The investment amount per deal of an average of 7 million has been stable for the last 5 consecutive years.

Table 5 shows the percentages of the investment stages: startup-seed stage, early stage, expansion stage and later stage.

Year	Investment Amount			
	Startup - Seed Stage	Early Stage	Expansion Stage	Later Stage
1995	16%	22%	47%	15%
1996	11%	25%	48%	15%
1997	9%	24%	52%	15%
1998	8%	26%	50%	15%
1999	6%	22%	56%	16%
2000	3%	24%	57%	16%
2001	2%	21%	57%	20%
2002	1%	18%	56%	24%
2003	2%	18%	51%	29%
2004	2%	18%	41%	39%
2005	4%	16%	38%	42%
2006	4%	15%	44%	37%

Table 5: Investment amount per stage
Source: Money Tree TM Report (2007)

The classifications of the stages in the Money Tree TM Report (2007) are defined as follows:

- Startup-Seed Stage: This is the initial stage of a new venture. Concept and prototypes are still under development. Existence usually less than 18 months.
- Early Stage: The Product or service is in testing or pilot production. The Product may be available commercially and may be creating revenues. In business less than three years.
- Expansion Stage: The Product or service is in production and commercially available. The Company shows revenue growth, may be making profits and is in business for a period greater than three years
- Later Stage: Product widely available, the company is generating ongoing revenues, most likely generating positive cash flows and making profits.

Table 5 illustrates that early stage investments, startup-seed stage, have decreased by three quarters whereas the later stage investments rose significantly (more than doubled). This leads to the conclusion, that VC investors became increasingly risk averse, because the earlier the stage of investment, the higher the inflicted risked due to high levels of uncertainty. Hisrich et al. (2006) derives this development from the pressure applied to VCs by their investors (limited partners) that constantly urge them to make safer investments with higher rates of return. Later stage investments, besides lower risk, deliver faster returns and need less managerial assistance[89].

6.5.2 The Venture Capital Investing Process

6.5.2.1 Screening and Valuation

The investing process of a VC starts with a screening process of the entrepreneur's or company's investment proposal, generally in form of a business plan. The VCs select carefully among them, resulting in an acceptance rate of approximately only one percent. VCs usually screen business plans in stages, evaluating each proposal deeper in the subsequent stages. The preliminary screening usually looks for industry and location fit. Only the executive summaries of the business plans will be read at this stage. In later stages thorough investigation of the business proposals and the technology in question will be thoroughly evaluated.[90] Detailed reports with risk assessments, market and industry research will be composed and potential customers, suppliers and the management will be evaluated. VCs invest great efforts to understand the risks involved to close the information asymmetry gap.

6.5.2.2 Contracting

After a positive screening process through the VC, negotiation on a partnership agreement and structuring can begin. The contract spans issues about the ownership and oversight rights, as well as defines the deliverables for subsequent funding stages.

VCs generally provide funds in stages. Every stage includes a specific deliverable and upon achievement the next stage of funds will be released. This course of action serves several purposes. Providing funds in stages basically is a monitoring mechanism to ensure that the venture stays on track and information is passed on to the investors. A very important aspect of staging is, that through providing funds in phases and under the condition that each achieves the set goals, the option value is maximized.[91] We explored the option valuation approach in

[89] refer to Hisrich, R.D., Peters, M.P., Shepherd, D.A. (2006), p. 384
[90] Refer to Fenn, G.W, et al. (1995), p. 30
[91] Refer to Allen, F. Percival, J. (2000), p. 301

detail in chapter 4.3 and learned that the majority share of value for emerging technologies lies in their option value. Staging for that matter ensures an exit option for the investor at every phase and allows the investor to exert control over the venture.

The partnership ownership stakes are usually determined by the expected returns of the investment. They range from 25 to 50 percent per year depending on the investment stage, with higher returns affiliated to earlier stage investments. By projecting the company's value at some future date and the expected rate of return, the percent of ownership, in respect to the money invested, can be calculated. This return can only be realized if the partnership is a success and is therefore a conditional expected return.[92] Allen and Percival (2000) point out that the form of security that is usually used is convertible preferred stock. The difference between convertible preferred stock and common stock, which is usually held by the management of the venture, is that holders of preferred stock have to be paid first in case of a bankruptcy. In addition to that, the convertibility feature enables the VC to turn the security into equity at a predetermined ratio, should the venture be successful. VCs invest a great amount of time to draw up contracts that include incentives for the managers of the venture to act in the VC best interest.

6.5.2.3 Monitoring

Venture capitalists rarely play an active role in the management of the companies they invest in. They however consult the company and support the management in numerous ways. Monitoring is important, but held to a minimum due to the time constraints of VC portfolio managers. They are represented on the board of directors; they exert their voting rights according to the contract and ultimately decide on further financing.[93]

6.5.2.4 Exiting the Venture

Even though VC investments are long term, they are temporary. VCs intend to realize the value gained through exiting the investment after a period of three to seven years.[94] This cash-out can be realized by means of an IPO, an acquisition by another firm or a management buyout. The

[92] refer to Fenn, G.W, et al. (1995), p. 31
[93] refer to Fenn, G., Liang,N., Prowse, S. (1995), pp. 32/33
[94] refer to NVCA (2007)

IPO is a very common exiting option in the US. 30 percent of the VC firms exited by means of an IPO followed by 23 percent through private sales. In Europe only 10 percent exited through an IPO and 41 percent through the sale of the company.[95]

6.5.3 What VCs Look for

Hisrich et al. (2006, pp. 385) names three distinctive criteria every VC expects from a company. (1) The company must have a strong management team with solid experience and backgrounds. The VC would rather invest in a second-rate product and a first-rate management team than vice versa. (2) The product and/or market opportunity must be unique and have a differential advantage in a growing market. A secured unique market niche allows growth during the investment period. Protections through patents and the like are supportive. (3) The business opportunity must have significant capital appreciation.[96] The expected returns of the investment range from 25 to 50 percent depending on the type of investment and the investment stage.

6.5.4 Corporate Venture Capital

Corporate venturing groups are divisions of corporations that invest in ideas and opportunities, inside as well as outside of their company. Most of these technologies are created inside the company's proprietary research lab and, while being promising applications, they sometimes don't fit within the company's strategic direction. An example is the New Ventures Group (NVG) established by Lucent Technologies. The NVG was an approach to correct false negatives in the commercialization decisions of new technologies. False negatives are decisions that initially judge a project to lack promise, which later delivers value.[97] Tapping into external sources of knowledge is another incentive to establish a corporate VC division. This strategy was pursued by the Intel Corporation. The VC group was called Intel Capital and invested in new technologies that offer enhancing and complementary technological benefits.[98]

[95] refer to Allen, F. Percival, J. (2000), p. 305

[96] refer to Hisrich, R.D., Peters, M.P., Shepherd, D.A. (2006), p. 386

[97] refer to Chesbrough, H. (2003), pp. 146/147

[98] refer to Chesbrough, H. (2003), pp. 126/127

Other benefits of corporate venturing groups are the additional created growth opportunities which up to that point resided latent in the company and the entrepreneurial surrounding that can be created inside the company.[99] Despite all these upside potentials of corporate VC, the implementation hereof faces many challenges. According to Chesbrough (2000) there are conflicts between strategic objectives and financial objectives of the sponsoring firm as well as issues about compensation and resource allocation, if the new venture succeeds. To resolve these conflicts he suggests that the business model of corporate VCs should closely follow the example of private VCs.

6.6 Angel Investing

Since neither debt nor VC and mezzanine capital are always accessible for seed and early stage investments, money has to be acquired from savings, family and friends or angel investors.

The angel capital market is considered to be enormous. An estimated $ 10 billion have been invested in over 30,000 small firms in the US each year. Because angel investors are not institutionalized it is nearly impossible to obtain reliable data about them.[100]

Angels, owing to their entrepreneurial backgrounds, primarily invest in the seed and startup stage of new ventures. Angel investments range anywhere from $ 50,000 up to $ 1 million, but their amounts are considerably smaller than VC investments. Freear et al. (2002) define a typical angel as a “predominantly affluent, self-made men in their forties and older, with graduate degrees, who tend to invest in the industry in which they made their money.” Although return on invested capital is one motive, they also invest for the fun and excitement of being involved in the early stage growth of a business. They expect to be actively involved in the venture, as informal consultants or board members.[101] What's more, their support is not limited to financial backing but they help raise further funds, assist in the hiring employees, et cetera. The criteria angels value the most when searching for new investment options is the trust to the entrepreneur. Business plans and proposals are, while still important, secondary to this trust

[99] refer to Chesbrough, H. (2000), p. 41
[100] refer to Fenn, G., Liang,N., Prowse, S. (1997), p. 5
[101] refer to Freear, J., Sohl, J.F., Wetzel, W. (2002), p. 280

issue.[102] Similar to VC, angels prefer convertible preferred stock over common stock. This reduces the risk for the investor and provides another incentive for the managers of the venture who themselves own common stock.

6.7 Governmental Funding

We already explored the role of the government in regard to emerging technologies in several parts of this thesis. Their role in the funding of emerging technologies is a very substantial one.

OECD (2002) highlights that taxes are the most potent policy influence for governments. They can however adversely affect economic growth by discouraging investment and entrepreneurial incentives. Thus, virtually all OECD governments use tax measures such as tax exemptions and deductions to raise the level of entrepreneurship.[103]

Aside from tax exemptions governments offer a wide range of funding opportunities for new startups as well as for established companies. These range from VC groups set up and funded by the government over research grants to the provision of equity and sureties.

[102] refer to Prowse, S. (1998), p. 789

[103] refer to ORCD (2002), p. 42

7 Case Study

7.1 Introduction

This case study is built on two main pillars

(1) The development of aluminum foam technology.

This pillar contains a historical reconstruction of the subsequent invention and development stages, production processes, potential applications and so forth. The objective of this section, aside from providing a basic understanding of the technology itself, is to identify how and under which circumstances the technology emerged. The contents of this originate primarily from research publications, conference proceedings and patents. Albeit some technological definitions are necessary to describe the underlying characteristics and economics of the aluminum foam technology, they are however only presented as far as necessary for the purpose of understanding. This case study does not, nor is it intended to extent deep into the fields of material science and physics.

(2) The aluminum foam industry.

The objective of this section is to draft a picture of the aluminum foam industry today and its development up until now. As the core information resides in the companies themselves due to the early stage of this emerging market, the major share of information collection has been obtained through interviews with the respective principles. To support these views, further information has been gathered through company as well as relevant publications.

The information presented in the above sections is then followed up and concluded in the final section of this case study.

7.2 Development of the Aluminum Foam Technology

7.2.1 Introduction

"When nature builds large load-bearing structures,
she generally uses cellular materials: wood,
bone, coral. There must be good reasons for it."

M. F. Ashby

We all know and use porous or cellular materials in our everyday life. The most widely known material is polystyrene, often referred to as Styrofoam©.[104] It is mainly used for packaging, insulated cups and insulation of buildings.

With foamed metals we enter a completely new domain of cellular materials. Foamed metals are strong enough to bear loads and thus enable the construction of a wide variety of structures. While aluminum foam (AF) does not offer a single property any other material wouldn't, it offers a distinctive and singular combination of properties that cannot be achieved by any other material itself. Nevertheless other materials can be engineered and designed to mimic these properties.

AF is mostly referred to as "foam" even though there are other processes to realize cellular structures in metals without actually foaming them. In its original sense the term foam actually refers to a gas dispersed in a liquid. When speaking of "aluminum foam" one generally means a solid foam.[105] The name foam refers to a step in the production process where the liquid melt is actually foamed.

[104] Styrofoam is a registered trademark name for polystyrene thermal insulation, which was invented by the Dow Chemical Company in the early 1940's

[105] refer to Banhart, J. (2001), pp. 562/563

7.2.2 Brief History of the Aluminum Foam Development

The first attempts to foam aluminum ware made by Benjamin Sosnick in 1943 in San Francisco, California. He claimed to be able to make a metal with disclosed voids which he designated "sponge metal".[106] He achieved this by adding mercury to aluminum which in turn created pores in the structure going through a thermal process. The downside of his approach was the toxicity of the mercury. In the late 1950's J. C. Elliot and W.S. Fiedler, working at the Bjorksten Research Laboratories (BRL), circumvented this problem and replaced mercury by other foaming agents that generate gas by thermal decomposition.[107] Then in 1959 B. C. Allen invented a powder compact foaming method for producing AF.[108] Those three inventions laid the basis for AF production techniques and processes.

In the late 1950s, development of an aluminum foaming process for the US Navy began at the BRL. BRL entered an agreement with the LOR Corp. to commercialize AF. The project, later sold to the Ethyl corp., produced fairly high qualities and even fiber reinforced AF.[109] They also supplied the Ford Motor Company with samples for evaluation in 1972. As passenger safety and lightweightness were not much of an issue in that era, the material was dismissed and the excitement for foamed metals and R&D activities declined after 1975. By the end of the 1980's however, the interest in foamed aluminum reappeared and several companies embarked on further development. In 1985 the Japanese company Shinko- Wire Co was the first to develop a process for producing relatively uniform AF called Alporas. Alporas is primarily used for insulation and sound dampening applications in Japan. Norwegian Norsk Hydro and the Alcan Corp. in Canada independently and simultaneously developed a foaming process to produce stabilized aluminum foam (SAF). Today Cymat, a spin-off company from Alcan which was founded in 1995, holds the exclusive license to sell SAF in North America under patents held by Alcan. Additionally they acquired the patents from Norsk Hydro to sell SAF outside of North America as well.

[106] refer to Sosnick, B., (1943)
[107] refer to Elliot, J., C., (1956) and Fiedler, W.S. (1965)
[108] refer to Allen, B., C., et al (1963)
[109] refer to Niebyliski, L.M. (1976)

In 1990 the German Physicist Joachim Baumeister from the Fraunhofer Laboratory in Bremen took on of B.C. Allen's powder compact foaming method. He refined the process and brought it to a level of sophistication that allowed the manufacturing of AF in satisfactory quality. [110] The specific production methods will be detailed later in this chapter.

7.2.3 Characterization of AF

A cellular metal like AF is a heterogeneous material consisting of aluminum or an aluminum alloy and a gas.

Kriszt (2002) characterizes cellular metals in a three level hierarchy: the "macro", "meso" and "micro" level[111]. At the macro level cellular metals can be characterized by their relative density which expresses the ratio of metal and gas. Cellular metals have a relative density which is lower than 0.3. Materials with densities above 0.3 are referred to as porous metals. At the meso level the distribution of the local density is the characterization criteria. Varying densities as a consequence of different pore sizes, numbers and shapes can either be a desired condition due to constructive requirements or can be an unwanted side effect due to production techniques. Observing the meso level is, amongst other factors, important to rule out quality issues in the production process. The microstructure is the third hierarchical level and is characterized by the grains and their boundaries, precipitates, dislocations and the like. The effect of this microstructure on the mechanical properties of metallic foams makes their understanding so important.

7.2.4 Production Methods

Currently a few production techniques to obtain foamed aluminum exist. Figure 15 shows the different processing techniques according to the state of the metal.

[110] refer to Banhart,J., Weaire, D. (2002), p. 38 and Banhart, J. (2001), p. 574
[111] refer to Degischer H.P., Kriszt, B., (2002), pp. 127/128

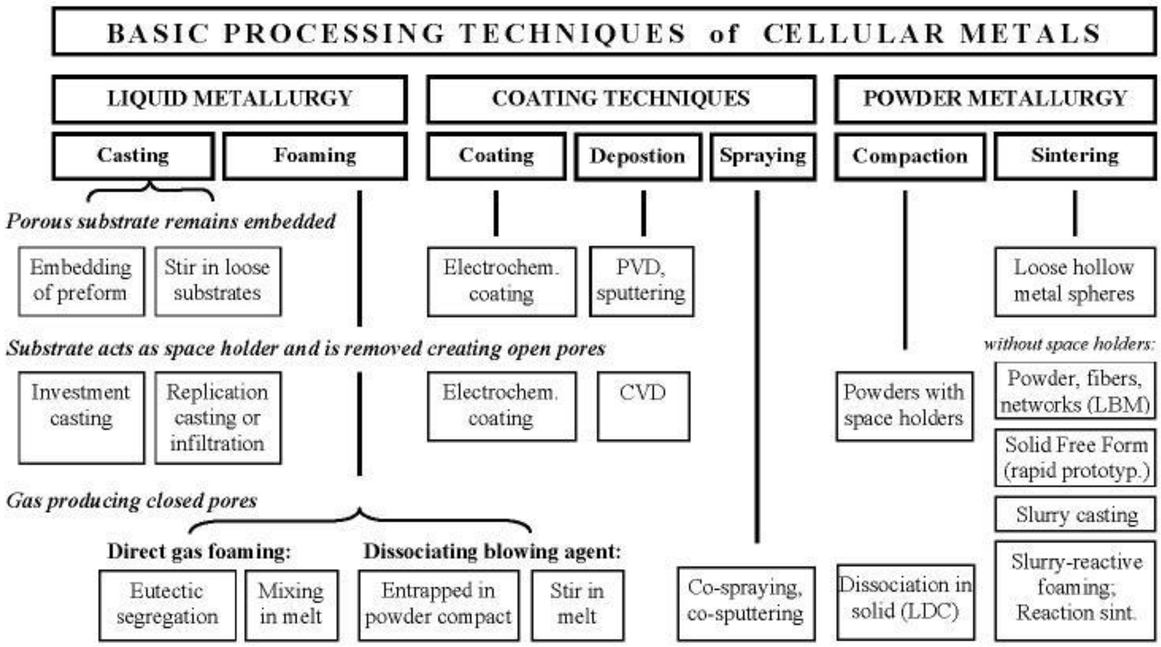

Figure 15: Processing techniques for cellular metals
Source: Degischer H.P (2002 - I), p. 5, figure 2-1

As a result of the diverse production techniques, wide arrays of different cellular metals with varying properties are achievable. After the invention of the basic methods and ideas of production in the 1940's and 50's, a few companies refined those techniques towards commercialization. These R&D efforts led to different and dissimilar processes to obtain cellular aluminum structures. Basically however, there are two ways to foam aluminum; either by injecting gas into the liquid metal from an external source or though in-situ gas formation in the liquid metal by adding gas-releasing blowing agents.[112]

7.2.4.1 Foaming by Gas Injection

This melt-foaming process with continuous gas-injection was developed simultaneously but independently by Alcan and Norsk Hydro in the 1980's and 1990's. [113] Alcan's patent is now exclusively licensed to the Cymat Aluminum Corporation, a spin-off company from the Alcan Corp. In addition to that Cymat acquired the patents from Norsk Hydro in 2001, which basically consolidated all intellectual rights on stabilized aluminum foam (SAF) to Cymat.

[112] refer to Banhart, J. (2001), p. 564
[113] refer to Degischer H.P., Kriszt, B., (2002), p. 8

In this process gas is injected via small nozzles that are part of a rotating impeller, into a molten aluminum matrix. The dispersed gas bubbles are trapped by ceramic particles serving as a stabilizer. The ceramic particles additionally increase the viscosity of the melt and thus stall the escaping of bubbles in the melt. The resulting, still liquid AF ascends to the surface, where it is transported off by means of a conveyor belt on which it eventually cools down and solidifies. Figure 16 shows a schematic depiction of the gas injection process.

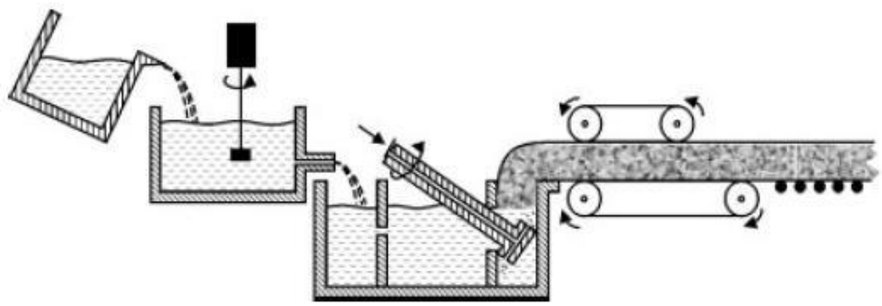

Figure 16: Gas-injection Production Process
Source: Körner, C., Singer, R.F. (2002), pp. 8/9, p. 8, figure 2.1-1

This process produces SAF with densities ranging from 2 – 20% and allows the casting of continuous panels with a width of up to 1.5 meters.[114]

7.2.4.2 In-situ Gas Generation

There are two different processes that utilize this type of production technique - the Shinko-Wire and the FORMGRIP[115] process.

The Shinko-Wire process is a batch casting process patented by Shinko-Wire Company Ltd, Japan. The resulting AF product is called Alporas. The first step in this process is the thickening of aluminum melt by adding 1.5% Ca and stirring. The resulting aluminum melt is poured into a cuboid casting mold where it then expands after adding TiH_2 and stirring. The TiH_2 acts as foaming agent by dissociating H_2 bubbles. After cooling the mold releases an Alporas block which is then sliced into plates.

[114] refer to Körner, C., Singer, R.F. (2002), pp. 8/9 and Banhart, J. (2001), pp. 564 - 567
[115] Foaming of Reinforced Metals by Gas Release in Precursors

Figure 17 illustrates the process steps for producing Alporas. It is employed since 1986 by Shinko Wire, Amagasaki, Japan.[116]

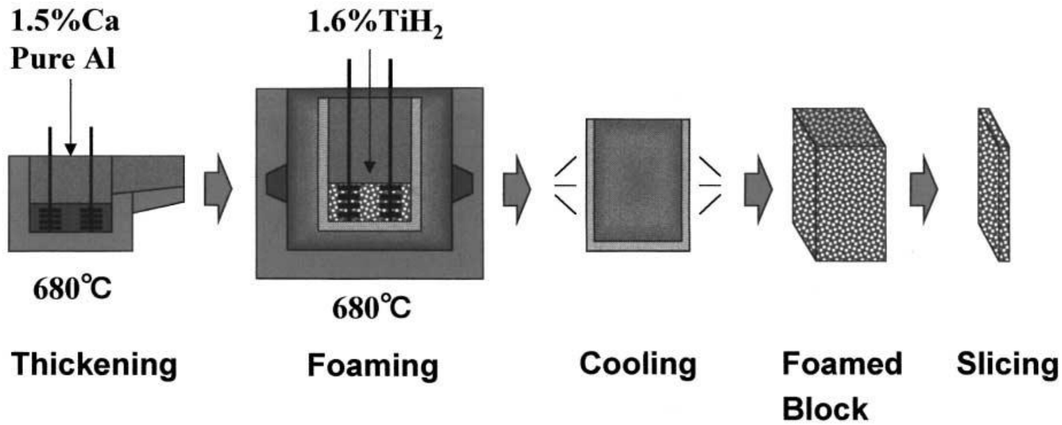

Figure 17: Shinko-Wire process – Alporas
Source: Banhart, J. (2001), p. 570, Fig. 7

Alporas AF delivers high qualities and reliable results due to its uniform cell size.

7.2.4.3 Powder Compact Foaming (PCF)

Opposed to the two preceding production methods, PCF is a different production approach. Although it is a powder metallurgical process, the actual foaming takes place in a liquid state. This manufacturing process allows the use of a wide range of aluminum alloys and even the successful foaming of other metals. The realization of complex shaped 3D parts is possible, the item size however is limited to smaller scales.

The first step in this process is the mixing of the metal powder with a foaming agent. The yielding of a homogenous mixture is of upmost importance to achieve high-quality results. Subsequently the densification process to obtain a foamable precursor material follows. These precursors cannot be foamed instantly. The still remaining porosity would lead to a massive loss of bubbles. Instead they are preheated and for example extruded as rods. The extruded material can then be transformed into almost any desired shape. The final stage is the actual foaming of the extruded rods in a mold by means of a heat treatment process. In this stage the foaming agent releases bubbles thereby expanding the matrix. This process enables a wide variety of complex shapes.

[116] refer to Körner, C., Singer, R.F. (2002), pp. 10/11 and Banhart, J. (2001), p. 570

Figure 18 shows the process steps of the PCF method.

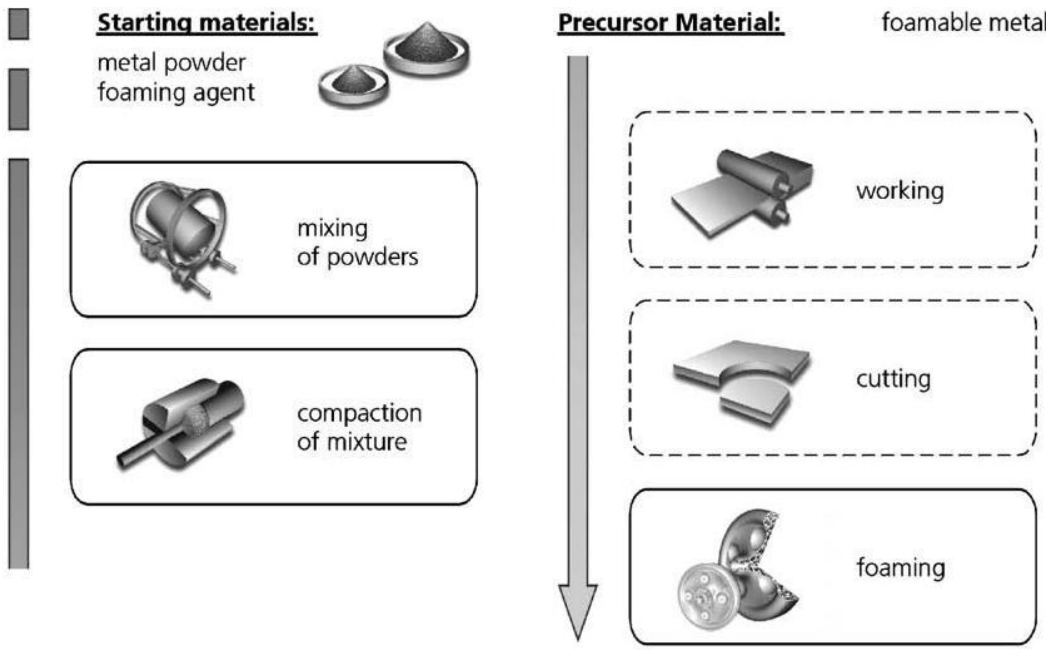

Figure 18: PCF Method
Source: Depiction according to Banhart, J. (2001), p. 575, Fig. 11

The three described methods represent the basic industrialized production processes. They have however been modified, improved and enhanced by the companies that apply these processes today. Nevertheless they illustrate the basic ideas behind AF production. The outstanding innovations achieved by the companies surveyed will be detailed in section two of the study.

7.2.5 Properties of AF

As stated earlier, the single properties of AF are not remarkable by themselves; it is rather the unique combination of these properties that make AF so singular. AF offers high stiffness at low density, high impact energy absorption capacity at low stresses, and good damping properties. Several properties are superior to polymeric foams; they are stiffer by an order of magnitude, resistant to fire, stable at high temperatures, do not evolve toxic fumes in a fire, and are fully recyclable.[117] These set of properties combined with the right economies can formulate a strong USP for AFs.

Absorption of High Impact Energies

Almost every material absorbs energy to a certain degree. AFs have superior energy absorption capacities and efficiencies due to their unique stress – strain response[118]. The impact energy transformation is caused by plastic deformation of the cell walls. Unlike other crash absorbing materials or structures, its isotropic properties provide equal crash response regardless of the impact angle.

Very lightweight

Since the relative densities of AF are usually below 0.3, the material is very lightweight; it even floats on water. While it is very light, AF is comparably very stiff.

Sound Absorption

Cellular metals absorb sound waves to a higher degree than solid metals. The sound absorption performance of AF can be even improved by, for instance opening the materials surface with drilled holes.

Structural Dampening

The dampening ability of cellular metals significantly reduces the transmission and the emergence of noise induced via vibrations. The vibrational energy is converted through tiny plastic deformations in the cell walls and friction between the surfaces of cracks in the cell walls into heat.

Heat Resistant

Unlike other materials that show crash absorbing or dampening properties such as polymeric foams, AF is heat resistant and practically inflammable. Through the gas inclusions, thermal conductivity is significantly reduced.

Recyclable

[117] refer to Simancik, F. (2001), p. 823
[118] refer to Degischer H.P., Kriszt, B., (2002), p. 190

AF is practically 100% recyclable. There are however issues with reinforced AF, which are controllable. Altogether AFs enable ecologically sustainable product life cycles.[119]

7.2.6 Applications and Markets

The specific properties of AF make it suitable for multiple applications. The fact that it is far lighter than bulk aluminum and simultaneously providing a high level of stiffness makes it the perfect material for aviation and aerospace. The recent trend towards more fuel efficient automobiles paired with the crash absorbing properties of AF present ideal application possibilities in transportation, especially in the automotive sector. The crash absorbing properties could also provide solutions for blast mitigation and amour in security and military applications.

As a consequence, there are numerous prospective markets that are being envisioned by AF developers. Some of them are already being followed; other applications are being tested for their feasibility. In the context of this study we will differentiate between AF and cellular metal structures in general. Cellular metals with open pore structures and metals other than aluminum enable a wide range of applications such as in batteries or filters. As this study covers closed cell AF only, we will leave the other applications and potential markets aside.

Later in this chapter the potential applications should then be circumstantiated by the empirical data gathered in the survey.

7.2.6.1 Automotive industry

The increasing development towards enhancing passive and active vehicle safety led to a considerable increase of vehicle weight. On the other side auto manufacturers are called upon to make vehicles lighter in order to improve fuel efficiency and comply with emission regulations.[120] Moreover in Europe and Japan cars with reduced length are desired. At the same time crashworthiness and passenger space must not be diminished. Reducing the length of a car also poses the problem of heat dissipation by the closely packed aggregate.[121]

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[119] refer to Degischer H.P (2002 - II), p. 28
[120] refer to Baumeister, J., Banhart, J., Weber, M. (1997), p. 217
[121] refer to Banhart, J. (2001), p. 610

These growing demands in car design formulate a strong proposition for AF as it delivers light weight due to its low density while still being stiff enough to bear loads. This high stiffness-to mass ratio would allow the light-weight construction of a car's chassis without compromising the stiffness of the car-body framework. AF can also improve crashworthiness because of its unique crash absorbing capabilities. It also shows favorable attributes in terms of noise dampening and insulation.

Feasibility studies for the deployment of AF in car bodies have been conducted and show promising results.[122] Because of all these performance attributes, many AF manufacturers pursue automotive applications, as we will see later in this study. There is, however, a catch. Cars today are highly commoditized. Therefore cost is a serious issue and a price-performance threshold must be first overcome. Another critical point is quality. Industry quality standards in the automotive industry allow only very few ppm of faulty parts.

The pressing need for more fuel efficient and safe automobiles presents a great opportunity for AF, if the hurdles of cost and quality can be overcome.

7.2.6.2 Building and Architectural Industry

AF panels can be used in diverse building and architectural applications. For one, they look aesthetically pleasing due to their singular structure and surface. Also in architectural applications the unique characteristics of AF can play out their strengths. AF panels are good insulators and are practically inflammable. Hence they can be employed for fire protection in buildings by affixing them to walls or for making fire proof doors. They are noise dampening, making them ideal for interior use in floors and walls or on ceilings as well.

7.2.6.3 Machine Construction

There are several interesting applications in the field of machine construction. Foam filled structures could reduce mass without compromising stiffness. This can be very essential for usage in moving parts due to the thereby reduced inertia. AF also provides superior dampening

[122] refer to Bingham L., J., (2002)

and electromagnetic properties. These attributes make it furthermore suitable for machine housings.[123]

7.2.6.4 Aerospace Industry

In the aerospace industry lightweightness is a central issue. Up until now only honeycomb materials have been used. Honeycombs panels are very expensive and generally flat. AF plates can be produced comparably cheap and in curvatures or any other three dimensional shape. The sandwich plates are metallurgically connected without the use of adhesives. There are even potential applications in turbines, where the turbine blades cut into the cellular metal during the first run to realize a gas-tight seal. Also space technological applications have been tested in the function of structural parts in satellites and crash absorbers for landing probes.[124]

7.2.6.5 Ship Building

In recent years, lightweight construction has also gained importance in the shipbuilding industry. Passenger ships can now be entirely built out of aluminum. AF is very suitable for this application. In fact, due to its low density, AF is lighter than water and therefore stays afloat. To be applicable in this domain however, effective methods for jointing sandwich panels must first be devised.

7.2.6.6 Military and Defense Industry

AF can absorb high impact energies. This makes it an interesting material for armoring and blast mitigation applications. Structural building parts such as pillars could be protected from bomb blasts if they are encased with AF panels. In case of an explosion they would more likely stay intact and protected the structural integrity of buildings. Other security sensitive areas such as airport building, embassies et cetera could be protected by AF panels as well.

7.2.6.7 Sporting equipment

Sporting equipment has always been a good testing ground for new materials owing to the low price sensitivity of buyers in this sector. Golf clubs have always been a testing ground for high

[123] refer to Banhart, J. (2001), p. 617
[124] refer to Banhart, J. (2001), p. 615

end materials. AF could be applied in the protective gear of ice-hockey and football players for instance.[125] A prototype of a bicycle has already been developed using AFS plates.[126]

7.3 The Aluminum Foam Industry

7.3.1 Introduction

The second section of this case study focuses on the AF industry today. The aim of this section is to give an overview of the companies that engage in the AF technology. Upon the information provided, a comprehensive profile of the companies engaging in this technology has been compiled.

Finally, the insights and information gained on the AF technology and industry are then consolidated in the conclusion of this thesis. The center of our attention was to understanding the diffusion process in detail. All subsequent steps that took place in the diffusion process will be revealed and their implications evaluated. Financing issues, the competitive environment, co-operations, commercialization attempts and so forth will be elaborated.

7.3.2 Data Collection and Methodology

The key insights for this section of the case study were gained by the interviews conducted. Company publications, research publications and company homepages provided additional information for this study.

The following persons were interviewed:

- Dr. Wayne Maddever
  CTO - Cymat Technologies Ltd., Ontario, Canada
- Dr. J. Daniel Bryant,
  Project leader/AF development - Alcoa Inc. USA
- Dr. Hans-Wolfgang Seeliger,
  Founder and CEO - ALM-GmbH, Saarbrücken, Germany
- DI. Thomas Höpler,
  Impact Division - Neuman Aluminium, Marktl Austria

[125] refer to refer to Banhart, J. (2001), p. 617
[126] refer to http://www.alm-gmbh.de/html_engl/prod_bike.html; 10.10.2007

The interviews were conducted either personally, over the phone, or in writing.

7.3.3 Interview Guideline

The following interview guideline lists the questions asked in the conducted survey. The concept and intention behind the questions is given below. The questionnaire severed both goals of this section of the case study. First, it should allow compiling a comprehensive evaluation of the company pertaining to AF and the technology used. Second, patterns should be synthesized to allow the conclusion of this study.

(1) Can you give me a brief history of your company?

This question was aimed at attaining a deeper knowledge about the company's structures, the persons mainly responsible for and promoters of this technology, and the venture itself. Of special interest was the acquiring of information about the organizational structure of the perspective company.

(2) Why and under what circumstances has the venture been undertaken?

New ventures can start out for different reasons. If AF development started in an existing company, it was to learn how the idea of foaming aluminum was conceived. In the case of a start-up business we wanted to know why the entrepreneur undertook the venture.

(3) What is the organizational structure of your company? How does your business unit (AF) fit into the organizational structure?

The basic conditions in the field of emerging technologies, such as high levels of uncertainty, require different organizational strategies to ensure the right level of flexibility along with appropriate risk management. We were looking to learn more about the organizational structure of the company and who the main investors and equity holders are.

(4) From where came the idea to foam aluminum in your company?

Chapter 3.4 illustrates various approaches towards identification of new promising technologies and markets. This question should highlight how the interviewed company identified AF as a prospective technology to follow.

(5) What needs are satisfied or problems solved by your product(s) (AF)?

Successful products need to solve a problem, satisfy a need or give a potential user advantage of cost. This question should provide the answer to one or more of the above qualities.

(6) How is, in your opinion, AF superior to any of its substitutes – if there are any?

AF shows some remarkable properties and is suitable for many applications. The advantages must not necessarily be primarily the metallurgical properties, instead economical factors or other effects such as environmental friendliness may be the issue.

(7) Which segments and applications are the most attractive and have the greatest potential today? Market niche or mass production?

There are several potential applications of AF – starting from structural automotive parts and reaching all the way to interior design applications. Which applications have been picked out and in which sequence the roll out took place could provide answers to how the challenges of creating a new market were met by the company. The answer to this question may imply how the diffusion process took place.

(8) What developments and opportunities do you see in the AF industry?

This question was aimed at gaining a firsthand view of the prospective of the AF industry, and the future envisioned by the companies themselves. Furthermore the due consideration of future developments and opportunities seen by the interviewee gave an impression of options thinking and scenario planning within the company.

(9) What production methods do you employ to make AF?

There are different production processes to make foamed or cellular metals. The different processing techniques offer varying benefits but are able to produce comparable products for similar applications. It is not sure which processing technique will prevail as the dominant design or if more of them can exist in parallel. The chosen production technique might also provide useful information about market adoption, diffusion and assessment of promising market segments.

(10) What are your company's strengths in the development and commercialization of AF?

The commercialization strategies are manifold and play a critical role in the diffusion and adoption process. The strategies devised by the companies can then be put into perspective with the selection forces of the market

(11) What were the milestones in your research towards commercialization?

Set milestones illustrate the innovation process on the one hand. On the other hand, the staging of the project by predetermined milestones refers to project oversight and financing issues. These are a sign that options are being exercised.

(12) Why do you think others failed or exited?

This question is a counterfactual approach towards finding the success factors in AF development and commercialization.

(13) Is there an AF knowledge community?

Especially in the field of emerging technologies knowledge communities play a leading role. For this study it was of interest to learn what sources of knowledge exist, which ones the company in question tapped in on, and how they participated.

(14) What role do these communities play in your company?

Knowledge communities and networks can play a wide set of roles. They can be the source of the idea, the incubator for the business proposal and they can provide useful knowledge for R&D, target markets and potential customers**.** Conferences also serve as a platform for Research institutes, AF manufacturers and potential customers and partners

(15) What industries do your serve, who are your major customers and how do you convince your customers about the advantages of your product?

This question is aimed at gaining a deeper understanding of the commercialization strategies employed by the company. Especially how prospective target markets and segments have been identified and evaluated. The number or spectrum of markets targeted is of special interest.

(16) Did one of your targeted industries or customers particularly influence your R&D and venture?

The role that launching customers and industries play is of major significance, particularly for the understanding of the evolutionary path of the technology itself, the development progress and innovation efforts. Moreover, the effect of this influence may contain facts about the diffusion and adoption process.

(17) How do and did you finance your R&D efforts and your venture respectively?

R&D and Ventures can be funded by several means. The different possibilities have been explored in detail in chapter 6. Depending on specifics of the company in question, the portfolio of funding used may differ significantly. Though the exact figures may not be obtainable due to disclosure issues, the type of funding involved alone serves of interest for this study.

(18) Who actually provides these funds and what rights regarding controlling, oversight and control do they own?

This question follows up on the previous one. How and by whom oversight rights are exercised leads to insight if investment decisions were staged and if, how.

(19) Do you measure your research success and if how?

There are several metrics that can be applied to measure R&D success like return-on-investment or return-on-equity. Aside from these financial metrics, there numerous ways to measure research success, such as tracking the compliance with predetermined deliverables and goals.

(20) How do you make sure to appropriate the gains of your R&D efforts? Patents? Lead-time?

Patents are only one way to assure the appropriation of gains. Another would be choosing the right lead time. It was of interest to learn if the interviewees considered patenting a sufficient protection of their IP.

(21) Are you concerned about competition and what do you do to stay ahead of your competition?

This question was aimed at exploring the competitive environment of the company in question, and the strategies that the company follows to stay ahead. Furthermore it was of interest to learn how the company defines the boundaries of its competitive environment. An emerging technology like AF strives to replace existing solutions by offering a viable substitute.

(22) Do you engage in any co-developments, joint-ventures or any other form of cooperation?

When dealing with emerging technologies, partnerships with other companies, institutions or universities are fairly common. Due to the knowledge networks that form around new technologies and the necessity to tap into these sources of knowledge, companies often need to form partnerships in form of strategic alliances or co-developments.

(23) How did/do demands for your product(s) arise and how do you evaluate market and customer demands?

Similar to question (16) the objective of this question was to obtain knowledge about the company's approach towards commercialization. In chapter 3.4 several methods of identifying and evaluating prospective markets and customer demands have been revealed.

(24) How did your technological objectives change over time?

The uncertainty inflicted through emerging technologies like AF calls for flexible planning and development. To enable the exercise of learning options, a steady adjustment of the technological objectives is a must.

(25) Did/do you have a business plan?

It is not self-evident that the development of a new technology be accompanied by a business plan. Above all, many AF developments materialized in the research labs of established corporations with no need for external financing. But even these should use a business plan, for the sake internal use and project oversight.

7.3.4 Company Evaluation

The companies, namely Alcoa, Cymat, ALM GmbH and Neuman Aluminium, kindly participated in this survey. Metcomb and Alulight International GmbH are only briefly profiled. Their influence in the development of the AF industry was derived solely through research and their company publications.

7.3.4.1 Alcoa

Company History and Profile

Alcoa Inc. is producer of primary aluminum, fabricated aluminum and alumina. It was founded in 1886, under the name “Pittsburgh Reduction Company” by Charles Martin Hall who invented the first economically viable method to smelt aluminum. Up until the mid 1880’s aluminum was a semi-precious metal even scarcer than silver. In the following years the price for a pound of aluminum had been reduced from $ 4.86 in 1888 to $ 0.78 in 1893 and down to $ 0.20 in the late 1930’s. In 1907 the company’s name was changed to – Aluminum Company of America (Alcoa). In the following years Alcoa grew steadily, keeping its position as the world’s leading aluminum company. By the end of Year 2006 the company created sales of $30 Billion with 123,000 employees operating in 44 countries all over the globe. Alcoa is a leading producer in its field. It covers all major aspects of its industry; technology, mining, refining, smelting, fabricating and recycling.[127] Operations consist of six business segments: Alumina, Primary Metals, Flat-Rolled Products, Extruded and End Products, Engineered Solutions, as well as Packaging and Consumer.[128] Alcoa’s aluminum products are used in automobiles, aircraft, buildings, beverage cans among many more. In addition to that, Alcoa is engaged in related business such as precision casting, vinyl siding, closures, packaging machinery et cetera, and consumer brands such as Alcoa wheels or Reynolds Wrap® aluminum foil.

Innovation at Alcoa

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[127] refer to Alcoa Inc. (2002)

[128] refer to http://online.wsj.com/quotes/key_facts.html?mod=2_0470&symbol=AA&news-symbol=AA; 30.09.2007

Alcoa employs an open innovation approach as suggested by Chesbrough (2003). They acknowledge that a globalized market demands a collaborative approach towards innovation. Through collaboration Alcoa can deliver solutions to the market faster and more efficiently. Partnerships with Alcoa's proprietary research labs spanning across the globe cooperate with world-renown universities, national labs and industry leaders.[129] Their Innovation capabilities stretch across three partially intersecting innovations domains, namely; development, research and applied engineering. Figure 19 depicts the innovation strategy and capabilities of Alcoa.

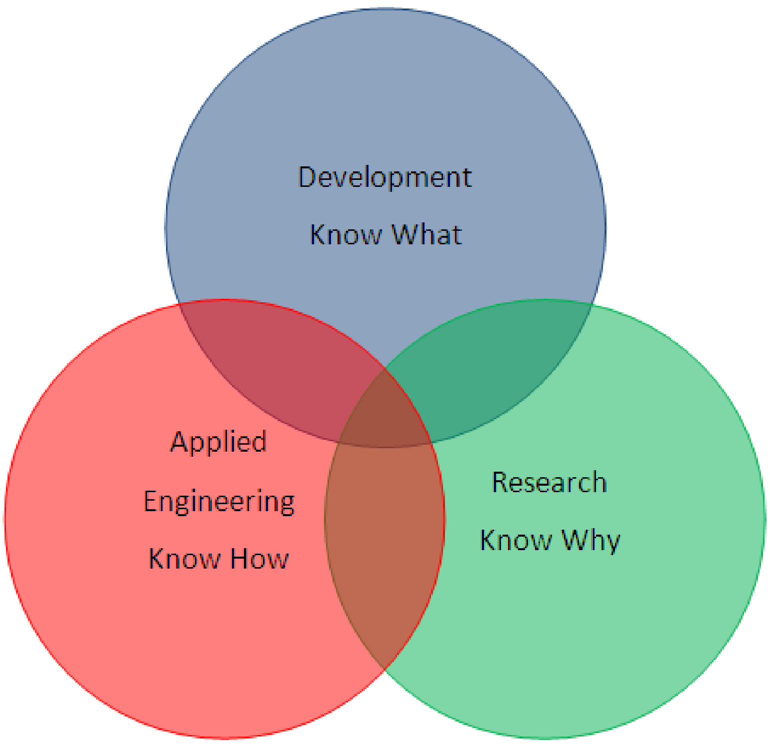

Figure 19: Alcoa's Technological Innovation Capabilities
Source: depiction according to http://www.alcoa.com/global/en/innovation/info_page/capabilities.asp

Alcoa is organized into business units that are largely based on markets. Additionally, there is a central corporate entity including the Alcoa Technical Center (ATC), located in Pennsylvania. The ATC is financed by the business units as well as by corporate and is the world's largest light-metal research laboratory.

At Alcoa the development of a new product is split into 6 Stages: (1) Idea Search, (2) Develop Concept, (3) Evaluate Concept, (4) Prototype, (5) Product-Process Validation and (6) Production

[129] refer to http://www.alcoa.com/global/en/innovation/info_page/open_innovation.asp; 01.10.2007

AF Development

The interview upon which most of the insights of this section are based was held with the Inventor of the production process and project leader for the AF Project, Dr. Daniel Bryant. He is a metallurgist, working at the Reynolds Metal Company where he first conceived the idea of AF. The Reynolds Metal Company was acquired by Alcoa in 2000 at which time AF transformed from a small laboratory interest to a major development program of the ATC.

Alcoa developed a proprietary continuous casting process to produce flat panel products. It employs low cost chemical foaming agents and scrap aluminum[130]. The process yields a uniform small cell size with uniform properties throughout the panel. In addition, it is a green process, meaning that the resulting AF is 100% recyclable. The major milestones in their development was the creation of AF without the use of extrinsic ceramic stabilizers, thereby lowering the product cost and creating a sustainable material flow path. The next major milestone was the development of a continuous casting technique to create low density foam panels. And the final milestone was the scaling up of this continuous casting process to an industrial scale with the capability of producing millions of pounds of the product on a single production line.

Alcoa places a great deal of emphasis on owning the intellectual property (IP) created and has therefore filed several patents on this technology to secure the gains of their R&D. Since they have developed and secured their IP, they now intend to work more closely with the Metallic Foam community. Before, they preferred to stand by observe the work of the knowledge community, gaining insights that were relevant for their development.

In line with our findings in chapter 6.3.1, abundant internal research funds allowed the project to be financed internally. Alcoa had a total budget of $213 million for all R&D projects in 2006. Because the AF technology was not targeted at any single business unit, this so called “white space” idea was to be funded through corporate funds. Project oversight is provided by Alcoa corporate technology. Metrics to measure the research success (such as equipment development, output rates, product characteristics) are in place and are being reviewed on a monthly basis. In addition to that, a detailed business plan was written.

[130] Aluminum is one of the most sustainable metals. In fact 75% of all aluminum that has ever been made is currently out in the field. The remaining 25% are often too polluted to be reclaimed. The process employed by Alcoa to foam aluminum utilizes this scrap aluminum.

Alcoa is pursuing a stratified market approach. They see the largest portion of the available market in building and construction products. This focus is substantiated by the fact that the developed production process is tailored to producing flat AF panels. Alcoa is entering a joint venture in this area. At the same time Alcoa is pursuing selected niches, letting these provide short-term revenue until the larger market materializes.

Conclusion

Alcoa's move into the AF market is an ideal example of the sense and follow strategy we explored in chapter 3.4.1.5. In comparison to the pioneers like Cymat, Shinko Wire or Alulight they entered production comparably late. Yet Alcoa is quite predestinated to follow such a strategy. As a very vertically integrated company with strong financials and a long history of innovativeness, Alcoa has the resources and capabilities at its disposal to be a fast follower. In fact Dr. Bryant pointed out that "Alcoa's core expertise in large scale industrial production of commodity materials will be essential in the successful manufacturing of AF. As a vertically integrated company, Alcoa is uniquely positioned as to supply the raw material used to create AF (mixed scrap metal), develop the technology to produce the material (metal processing expertise) and commercialize the product (Alcoa Building and Construction Products, for example)."

7.3.4.2 Cymat

Company History and Profile

The Cymat Corp was established in 1995 as successor of the 1990 founded Cymat Technologies Inc., a subsidiary of Alcan. On July 31, 1995 Cymat entered two agreements with Alcan International Inc. granting licenses to make, use and sell SAF in the North American market. Norsk Hydro additionally granted a license to sell SAF outside of North America. In 1997 the Technology Partnerships of Canada announced a funding approval for $3.4 million for the development of AF. "Technology Partnerships Canada (TPC) is a special operating agency of Industry Canada, with a mandate to provide funding support for strategic research and development, and demonstration projects that will produce economic, social and environmental benefits to Canadians."[131] All TCP investments are conditionally repayable, although a repayment in the R&D stage where the technology does not yield any cash flows is not expected.[132] In 1998 Cymat raised $ 2.5 million in an IPO and by September 1999 completed the first production run of AF panels using a newly installed, custom, state-of-the-art manufacturing system.[133] Following this successful up-scaling, Alcan extended the previous North American license to the rest of the world by the end of 2000.[134] In 2001 Cymat acquired $17.25 million in a second public offering and is now listed on Canada's senior stock exchange, the Toronto Stock Exchange.[135] In the same year Cymat acquired the IP rights from Norsk Hydro in an all-stock transaction making Norsk Hydro a significant shareholder.[136]

AF Development

Since 1995 Cymat focuses solely on developing, making and selling SAF. Even though the basic IP has been obtained externally by means of in-licensing and acquisition (the process has been detailed in previous sections of the case study), considerable amounts of funds have been invested into further development resulting in new and improved processing techniques and patents. One such innovation is the Low Pressure Foam Casting which permits the injection of SAF into molds without compromising the unique cell structure.

Cymat is targeting several markets with its technology. The focus lies on automotive applications where several joint-development programs, feasibility studies and field tests have been undertaken. Cymat SAF is being tested by the Wilhelm Karmann GmbH, Valeo and quite recently a commercial scale pilot production system has been set up with Georg Fischer Automotive, a major European automotive supplier. Cymat entered a licensing agreement with Georg Fischer Automotive for its Low Pressure Foam Casting technology, providing exclusive global rights for royalty payments on a component by component basis. Cymat is also partnering with MIT's Impact and Crashworthiness Consortium (including members like Ford,

[131] http://tpc-ptc.ic.gc.ca/epic/site/tpc-ptc.nsf/en/h_hb00001e.html; 03.10.2007
[132] refer to http://tpc-ptc.ic.gc.ca/epic/site/tpc-ptc.nsf/en/h_hb00018e.html; 03.10.2007
[133] refer to Cymat Corp. (1999) pp. 1/2
[134] refer to Cymat Corp. (2000 - I)
[135] refer to http://www.cymat.com/history.html; 03.10.2007
[136] refer to Cymat Corp. (2001 - I)

Honda, GM, Volvo and BMW).[137] Crash absorbers have been successfully used in NASCAR race cars since 2001. According to Dr. Maddever, this automotive focus, more precisely the focus on automotive crash management and automotive noise vibration harshness, shaped the trajectory of development to some extent. He also mentioned that in the automotive sector evaluating market estimates and demands is quite easy. Aside from this focus, Cymat has identified three shorter term transactional markets: rail, truck and defense applications. These have a shorter term revenue potential resulting from shorter design and testing cycles.[138] For instance, Cymat supplies the US Army Corps of Engineers with SAF in an effort to develop blast protection Systems in Federal and other security sensitive buildings.[139] Cymat also established a new division, which sells SAF for building and architectural applications under the trademark name Allusion™.

Conclusion

Due to Cymat's rather mature state of development, compared to Alcoa or ALM, the company actively engages in commercialization attempts. This can be clearly seen by the rather large number of customer contracts already signed and co-operations underway. Strategic commitment according to chapter 3.4.1.5 is definitively geared towards "believe and lead". The company is built around SAF technology; it has accumulated considerable resources and is aggressively en route for commercialization. According to Dr. Maddever, their technological objectives changed over time, specifically to meet market demands by offering better price/performance ratios.

Another very apparent notion is the high degree of diversification in the commercialization strategy. This is a strong sign of options thinking. The production process and plant are designed to satisfy the needs of multiple markets. Even in the set automotive focus numerous applications are envisioned and being pursued.

[137] refer to Cymat Corp. (2000 – II)
[138] refer to Cymat Corp. (2001 - III)
[139] refer to Cymat Corp. (2001 - II)

7.3.4.3 ALM GmbH

The company was founded by Dr. Seeliger. He has ten years of experience in the AF technology. Dr. Seeliger acquired the knowledge of foaming aluminum from his previous employer, the Wilhelm Karmann GmbH, where he developed several AF applications for the automotive industry. Four years ago Dr. Seeliger undertook this venture and founded the ALM (Applied Lightweight Materials) GmbH, which developed a proprietary process for producing AF Sandwich (AFS) panels.

In a start-up competition in Germany, the company made it into the top ten out of 500 participants.[140] The Venture was funded by means of the founder's capital, VC, debt and governmental funding. VC's funds played a critical role in the initial R&D process. The Saarländische Wagnisfinanzierungsgesellschaft mbH (SWG) is the VC group funding ALM. Among the limited partners that fund this VC group is the ministry of economy and labor. The mission of the SWG is funding technology start-up companies and companies developing new innovative products in the Saarland area. Owing to the structure of the limited partners the VC has at least to some extent, governmental funding aspects.

AF Development

ALM invented and developed a proprietary process based on the powder metallurgical route and patented it. The innovation in the method applied by ALM is the densification of the precursor by milling. Furthermore they developed a continuous process which is able to produce large flat panels. According to Dr. Seeliger, the critical breakthrough necessary for AF to succeed, which they have already achieved, is to upscale the production process from a lab application to a robust industrial process. The resulting product is an AF sandwich (AFS), which is basically an AF core with aluminum cover sheets on the outside, bound without using adhesives. Dr. Seeliger states that this specific feature, namely the absence of adhesives, is critical, because customers want a material they can weld or drill into. To manufacture complex structures, the precompacted sandwich sheet can be shaped as any sheet metal. As soon as the desired shape has been achieved, the inner layer is foamed.[141] The compacting and the foaming

[140] refer to ALM (2004)

[141] refer to IFAM (2006)

steps are fairly complicated to control. Mastering both of them was the biggest challenge in the development of this technology. The development progress occurred incrementally, increasing the size of the manufactured AFS panels step by step. In the development of a new technology which progresses this way, it is essential to find the right customers at the right time. The early stages of development are better suited for small scale and less price sensitive applications. The farther the technology gears towards mass production the more likely the technology can break the price-performance threshold for mass applications.

In addition to their technological capabilities, ALM developed a set of value adding services. They identified that the major obstacles in the adoption of a new material are the understanding of the material's characteristics as well as the required changes in design. AF is often considered as a surrogate material. However, without changing the construction and design concepts in AFS applications, the real potential of AFS cannot unfold. ALM offers a comprehensive solution by supporting their customers at integrating AFS into their products.[142]

Conclusion

ALM is a very innovative start-up company. They have successfully developed the technology to produce large AFS panels. According to Dr. Seeliger, AFS is the most viable use of AF. In his opinion AF is more of a functional filling material for a sandwich structure than a useful structure of its own. Therefore, the company directed its research focus on developing AF in sandwich structures. In his view the most promising applications are machine construction, sporting equipment and automotive applications in sports cars. ALM has already developed several applications for its technology. For instance they have developed a very lightweight load bearing lift arm carrier and a bicycle.[143] A potential application in the Ariane rocket V booster is being tested.[144] ALM has the capability to provide its customers with a comprehensive in-house solution starting with defining of the technical requirements and ending in the final product.[145]

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[142] refer to http://www.alm-gmbh.de/html_engl/services.html; 5.10.2007
[143] refer to http://www.alm-gmbh.de/html_engl/prod_arm.html; 5.10.2007
[144] refer to IFAM (2006)
[145] refer to ALM (2007)

7.3.4.4 Neuman Aluminium

Neuman Aluminium is an Austrian Company which produces a wide range of aluminum items such as extrusion parts, chassis parts and aluminum profiles. In 1998 they began to develop AF for automotive applications only to discontinue the development in 2001. The interview was held with D.I. Höpler, who was engaged in this R&D program at the time.

AF development

The idea to foam aluminum was conceived by an employee of the company who worked on a new production process based on the powder metallurgical route. They developed a process in collaboration with Dr. Simancik from the Slovak Academy of Sciences that utilizes a prechamber in the foaming process. Dr. Simancik is highly engaged in the development of AF. He has published multiple research papers and filed several patents relating to AF. The development efforts were scaled up when a major German auto manufacturer ordered an AF part to reinforce the doors to improve crashworthiness. The company invested heavily in this new technology for which a new production facility was built. A new business unit was founded as a separate GmbH[146], controlled by the holding company of Neuman Aluminium. The project was funded by means of internal funds, governmental research grants and funding through the German auto manufacturer participating in the R&D efforts.

Conclusion

The company unsuccessfully attempted to create a uniform pore structure. Because of the non uniform structure, the resulting AF was not definable in its characteristics. They worked on the problem but ended up running out of time. Their customer found a workaround for its problem and consequently cancelled the order. They entered talks with several other auto manufacturers but finally dismissed the program.

7.3.4.5 Metcomb

Metcomb, an Austrian company, developed a new process based on the liquid route that delivers uniform, consistent and controllable cell sizes. The fact that they are able to exactly define the pore size and distribution enables Metcomb AF do deliver highly customizable

[146] A „GmbH" is he Austrian the term for a limited company according to Austrian corporate law

outputs with predictable performance attributes. To achieve this, the company leverages a nanotechnological process. This integrated nanostructure control process, which is protected by 5 patents, allows for different, yet, homogeneous cell sizes.[147] Also complex shaped three-dimensional structures with a closed outer skin can be obtained, by casting the foam into moulds.

This extent of process control, if achievable in mass production at reasonable costs, would formulate a strong selling proposition. Today Metcomb is at the verge of commercialization. Letters of intent to cooperate with the University of applied sciences in Ingolstadt have been signed for several projects involving the use of Metcomb AF for automotive and defense applications.[148] The focal point of Metcomb is geared towards automotive applications. Other segments such as defense, aerospace, mechanical engineering et cetera are envisioned as well.

7.3.4.6 Alulight

Alulight international GmbH, based in upper Austria, was founded in 1999 as a joint venture of the "Schwäbische Hüttenwerke" and "Ecka Granules". In 2002 Alulight emerged as a 100% subsidiary of Ecka Granules, the global leader in the manufacturing of non ferrous metal powders. These powders are a main ingredient in AF produced with the powder metallurgical route. In 2004 "Alulight of America" was established to introduce Alulight AF to the North American market.[149]

In the densification step Alulight uses a conform system to extrude a continuous thread like precursor. This precursor can then be cut into pieces and laid out to be then foamed into multiple different shapes. Alulight offers its customers a wider variety of AF products. They produce AFS panels much like ALM, reinforced ASF panels, crash absorbers, structural parts et cetera. Alulight cooperates intensely with Dr. Simancik from the Slovak Academy of Sciences.

Since 2006 Alulight successfully up-scaled its production through an in-house developed, fully automated AF production facility, marking the beginning of mass production. With an output of 100,000 parts per year they are now producing a serial part, which is a crash absorber for the

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[147] refer to http://www.metcomb.com/faq.html; 5.10.2007
[148] refer to Metcomb (2006)
[149] refer to http://www.alulight.com/en/about-us; 5.10.2007

separation net in the Audi Q7. The AF crash absorbers ensure that the net separates the passenger area from the baggage compartment in case of a collision.[150] The crash absorber is a joint-development of Alulight and REUM, a German automotive supplier. Aside from automotive applications Alulight sees the ship, railway and engine building industry as well as architectural and design applications, as potential markets.

7.4 Findings and Synthesis

7.4.1 Technology Evolution and Diffusion

From the invention up until today, the diffusion and technology evolution process has come in three phases. These phases follow each other consecutively and represent a specific time frame in the development of AF.

7.4.1.1 Phase 1 – Invention

Phase 1, the invention phase, begins in 1943 with the first patent relating to the AF development being filed by Benjamin Sosnick and lasts into the early 1980's. In these first patents by Sosnick and J.C. Elliot, little was disclosed about potential applications. The vision what kinds of applications this invention would churn out was quite blurry. The main reason being the undeveloped state of the technology itself. The processes developed then, and described in these first patents emanate from lab experiments. They were nowhere near a level of sophistication to serve as a robust industrial process. It is also fair to assume that the quality achievable and predictable was rather poor. How the idea to foam aluminum or metals in general was originally conceived, is not known. It can be assumed that the invention of Styrofoam in the 1940's nurtured this idea. On the other hand, it is possible that foaming of metal was discovered by accident. The lack of a special application leads to the conclusion that the invention of AF was not triggered by the notion to solve a specific problem. Sosnick however mentioned applications for insulation and sound dampening.[151]

[150] refer to Ecka (2006)
[151] refer to Sosnick, B., (1943)

Almost 20 years later, B.C. Allen, who invented the PCF method, was more conclusive in regard to the potential applications of his technology. He specifically mentioned that AF could replace expensive honeycombs in the air frame and missile field.[152]

In the last two decades of the first phase, development continued in the research laboratories. But AF could not make its way into any industrial application. Product innovations clearly dominated this phase, although there were a few process innovation attempts, they were negligible.

7.4.1.2 Phase 2 – Industrialization Attempts

Phase 2 spanned from the early 1980's into the mid 1990's. In that era, and for the first time, the large Aluminum corporations Alcan, Norsk Hydro, Pechiney and Aluswiss indulged into AF development. Alcan stumbled upon this technology more or less by accident. They foamed aluminum while they were trying to purify it.[153] The Japanese company Shinko-Wire invented the Alporas process and was the first to enter the market in 1986 with an industrial process capable of 1000 Kilograms AF output per day.[154] Alporas was mainly used for insulating and sound dampening fly-over highways and as a crash absorbing element in railway trains operating in the Asiatic region.

The goal of the research groups was to develop a reliable industrial process. They were working independently, employing different processes and techniques. By the beginning of the 1990's the renowned Fraunhofer Institute continued with the work from B.C. Allen. Except for Shinko-Wire none of the companies upscaled their developed processes for mass production. Alcan licensed and Norsk Hydro sold their technology to Cymat. Pechiney and Aluswiss dismissed the project.[155] The reasons for this were numerous. Despite the initial high expectations, it slowly materialized that the effort necessary to commercialize AF was higher than anticipated. In addition to that, the potential fields of application were still somewhat blurry since they still depended heavily on the outcome of ongoing research. It also was not clear if AFs could ever

[152] refer to Allen, B., C., et al (1963)
[153] This information was provided in an interview by O.Univ.Prof. Dipl.-Ing. Dr.techn Degischer from the University of Technology Vienna
[154] refer to Banhart, J. (2001), p. 567
[155] This information has been provided in an interview by O.Univ.Prof. Dipl.-Ing. Dr.techn Degischer from the University of Technology Vienna

find a mass market leaving market niches as an undesirable option for the big corporations. These facts paired with a rather moderate level of commitment led to the problem that the companies remained stuck at the beginning of the learning curve.

Although in this era process innovations to some extent occurred, development was mainly driven by product innovations. AF once again did not develop into marketable applications despite the fact that significant advancements had been made.

7.4.1.3 Phase 3 – Commercialization

Phase 3 initiated around the mid 1990’s and is still underway today. Smaller companies that specialize on AF only dominate this Phase. Furthermore the number of AF manufacturers has increased.

Cymat followed up on the work from Alcan and Norsk Hydro. In Austria the companies Alulight, Neuman Aluminium and Metcomb have begun developing and manufacturing AF. In Germany ALM GmbH, Schunk Sintermetalle, Gleich GmbH (which is essentially distributing Alporas) have entered production. American Alcoa is currently also entering AF production and development.

In this third phase much has changed. Even though the companies still invest great efforts in further R&D, the focus has primarily shifted towards commercialization and therefore on process innovations. The basic ideas behind the different foaming concepts have not changed and all of them are being applied. On the one hand there has been enhancement and perfection allowing mass produsction, and on the other hand processes have been individualized and adapted to enable a broader spectrum of specialized applications. The number of field tests, co-operations and joint-ventures has risen significantly. Small scale commercializations have been successfully launched and mass production has already started by Alulight and Shinko-Wire.

With the start of the commercialization, market selection as well as adoption forces become apparent. Due to the availability of substitutes such as polymeric foams and honeycombs for certain applications, the penetration of a certain price/performance threshold is necessary. The interviewees of the survey unanimously confirmed that the price issue is critical. Although qualities have improved, AFs are still far from being precisely predictable in their quality. AF products are now also entering the phase of standardization. This is a critical stage for any technology and could present the final step towards wide spread adoption.

The formation of knowledge networks and knowledge clusters became evident in this phase as well. One of them is the IFAM Fraunhofer Institute in Bremen, Germany, which is hosting the CELLMET conference and is publishing CELLMET news. In Austria the LKR Ranshofen, a subsidiary of the Austrian Research Centers also engages in AF research. The Metfoam conference was held for the 5th time in September 2007.

It is not foreseeable when the next phase of diffusion will be entered. If technological development is successful, more and more manufacturers will enter the market. The diversity of solutions offered to the customer will increase. Market selection forces and competition will become fiercer. With increasing maturity the next step will probably be marked by consolidation. Up until today no one dominant design has excelled. And it is far from certain that all production processes and applications will prevail.

7.4.1.4 Conclusion

Following the diffusion process from its beginning until now, one notion becomes very apparent. In the first phase the technological objectives regarding the applicability of the invention were very blurry. With decades passing, incremental improvements and innovations led to superior production processes, which allowed for a boarder spectrum of specific applications. Therefore it can be safely assumed that the level of fitness of a technology plays a critical role in the definition of the potential markets. This fact is even more substantiated once the applications of AF are observed. The first commercially available AF, namely Alporas, was used for sound dampening and insulation applications only. In these applications the technological requirements concerning quality are much lower. Back in the beginning of the 1990's there was still a long way to go for large scale high quality structural applications. Today's level of product sophistication already allows applications in the automotive and aerospace industry.

In Chapter 3.2.1 we explored that technologies diffuse into markets at different paces. With AF the diffusion happened quite slowly. Actually, AF is still at the beginning of its diffusion process. The basic ideas, production concepts and patents had already been introduced in the 1950's. But adoption of this new material lagged throughout the last 50 years. The reasons for this will now be put in the context of the four notions accompanying the adoption process we identified;

perceived advantage, perceived risk, barriers to adoption, and opportunities to learn and try. Although AFs offer some remarkable features and potential benefits, it is just now that they are starting to overcome adoption obstacles. Price was one critical issue. The other one was the technological uncertainty. Solutions have to be proven to the potential customer. Today numerous field tests have been completed or are underway to instill trust in potential customers. The now started standardization process also contributes to this effort.

Both concepts – the alternation of product and process innovation as well as the technology S-curve – could be observed very clearly in the diffusion. First, the initial innovation time span was considerably long in perspective to the performance improvements achieved. The technology is continuously moving faster forward towards the inflection point of the S-curve. However, it cannot be concluded that it has been reached. It is more likely that the pace of technological performance will grow faster in the immediate future. Second, the innovation focus shifted distinctly towards process innovation in the third phase after 50 years of sole product innovations.

Lineage development thought shifts in the domain of applications could also be observed. They became most apparent in the case of open cell metal foams. The Canadian company Inco produces open cell nickel foam structures for applications in batteries, fuel cells, filters and catalysts. Other applications in biomedicine (mainly implants) and nanofoams for sensors are now under development.[156]

Table 6 summarizes the findings on diffusion and technology evolution and figure 20 shows a depiction of a section of the technology S-curve in perspective of the three development phases.

[156] refer to Metfoam (2007)

Phase		
Phase 1	**Innovators:**	Research Labs
	Innovations:	Foaming by in-situ gas generation Powder compact foaming
	Innovation Focus:	Product
	Applications:	Insulation Dampening
Phase 2	**Innovators:**	Large Aluminum Corporations Some research institutes
	Innovations:	Alcan/Norsk Hydro Process Alporas Process
	Innovation Focus:	Product and Process (to some extent)
	Application:	Insulation Dampening Simple Crash Absorber
Phase 3	**Innovators:**	Smaller AF only producing companies Larger number of research institutes
	Innovations:	Fully automated production lines Successfully economic process upscalings Low pressure foam casting Precursor rolling Reinforced AF Nanostructures Et cetera
	Innovation Focus:	Mainly Process
	Applications:	Insulation Dampening Architecture and Building Sandwich panels Automotive crash management Mechanical engineering Ship building Aerospace Et cetera

Table 6: Diffusion and Technology Evolution

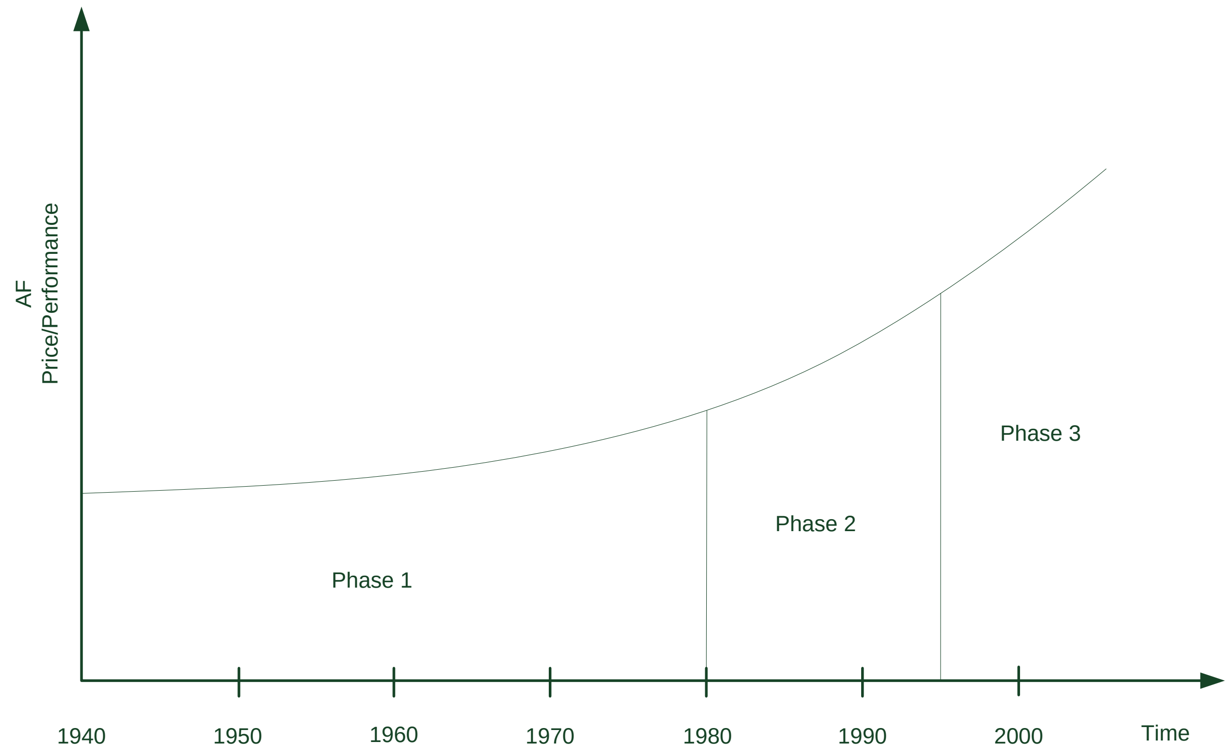

Figure 20: Technology S-curve & Development Phases

7.4.2 Financing

Cash flows created by AF today are still practically negligible compared to the development cost accumulated over the years. Therefore internal financing was only an option for companies like Alcoa, Alulight or Neuman Aluminium where other product lines or holding companies are able to finance the development efforts. In cases where these were available, they have been abundantly used.

Debt financing was used, but only for financing assets such machinery or buildings. The remaining sources of funding were VC and governmental funds. VC funds have been acquired by ALM GmbH. Cymat, Neuman Aluminium, and ALM GmbH have received governmental funds of some sort. The last sources of funds were research partners and customers. In the case of Neuman Aluminium the customer paid for a significant share of the research efforts. Cymat is publicly held and funded the majority of their research through two public offerings.

A strategy to generate cash flows early in the development stage was employed by all of the surveyed companies. They staged their commercialization attempts in a way that, aside from following a core market they established small, supplementary niches they could serve early in their development process. These were for instance less price sensitive markets such as defense and the military, or markets that had lower expectations in terms of quality. These could therefore be served earlier in the development process. We will scrutinize this staging strategy in the following section.

7.4.3 Commercialization Strategies

We learned in the interview with Dr. Seeliger that finding the right customer at the right time is critical. Not only ALM but also Cymat, Alcan and Alulight focused on supplementary applications of their AF products, that especially in the early stages of development help generate cash flows. More than just that, they also serve as testing ground upon which the development can then be directed. This is a typical staging option, which incrementally adds value in terms of sales on the one hand and knowledge gained on the other.

A second evident notion is the focus on flexible production systems and the diversified product portfolios. Almost all manufactures offer solutions for more than one market. They however have concentrated on one core market while considering the others as supplementary market niches. Even if this flexibility comes at a cost, the thereby gained flexibility options may out weight the cost, especially in respect to the uncertainty still inflicted with this technology.

7.4.4 Competitive Environment

All interviewees were not concerned about competing AF producing companies to any extent. On the contrary, they would embrace more competition. Any success from competing manufacturers would serve to generate more of a market for AF. Therefore any manufacturer would benefit directly from their competitors success. One Interviewee however noted that companies that overpromise and under-deliver can seriously hinder the success of AF. However there is competition. But it comes from other materials like honeycombs, polymer panels etc. Basically these are substitutes to AF. Actually, as AF is the emerging technology, it tries to substitute these materials. As we have learned in chapter 3.2.1, the adoption of a new innovation depends on notions like perceived advantage, risk and barriers to adoption. Unless AFs can offer an improvement in the price-performance ratio or live up to its expectations in terms of delivering an economically viable and technically reliable solution, adoption and market diffusion will stall. A greater number of manufacturers lead to more field testing applications and studies, which in turn support the maturing of the technology and the instilling of trust into potential customers.

7.4.5 Cooperation

A rich variety of partnerships have been formed by the companies surveyed. Many of them have formed joint ventures and joint research programs. They are intensely co-operating with their customers, complementary partners and research institutes. Alulight for example attained the first serial part contract by partnering with another automotive supplier. Cymat already reached licensing agreements and is testing their AF in race cars. As essentially all partnerships were formed in the third, the commercialization phase, it is safe to assume that co-operations play a vital role in the commercialization of emerging technologies. Especially the companies that solely manufacture AF like ALM and Cymat are very horizontal integrated. Alulight can procure the raw materials from its holding company Ecka Granules and tap into their sales force. Alcoa is very vertically integrated. Nevertheless both of the later mentioned, also engage heavily in co-operations. Consequently there must be a second reason for forming these partnerships. The second reason to commit to partnerships is the adoption barriers we mentioned earlier. It takes a certain amount of momentum and commitment for a new technology to overcome these barriers and partnerships present a way to achieve this.

7.5 Summary

We have evaluated the diffusion process in depth and distinct between three consecutive diffusion phases. It also became apparent that although options thinking is omnipresent and vital, it is not executed to the high degree it could be. Options are mainly considered to enhance flexibility and allow a stratified commercialization approach. As well, we have affirmed that co-operations are necessary and widely used. New technologies need proving grounds to learn and co-operations provide these opportunities for learning.

Equity financing is key and many sources of equity, from VC to going public, have been exploited. We further learned that a wide spectrum of governmental funding was extensively used. Finally, we discovered that competition does not primarily come from other AF manufacturers, rather it comes from potential substitutes such as honeycombs and polymeric foams.

The technology has faced numerous setbacks during the first 50 years of its development. There are still major uncertainties left that need to be resolved. Even if the first serial parts are now in production there is still a long way to go before widespread application of AFs come about. The cost issue is still critical and more process innovations will be necessary to improve the fitness of the production processes and to solve the economic equation. Further developments are expected to increase the price performance ratio, and a growing number of successful field tests and applications will eventually instill the trust into the potential customers. Today it seems that AFs are increasingly finding favor and may eventually be successful in gaining enough momentum to overcome adoption barriers and be commercialized on a wide basis.

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