Developing Strategies to Capture Value from Emerging Technologies

By

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Abstract

The development of fundamentally new technology requires companies to carefully consider how they intend to profit from the commercialization of their ideas. Because companies pursuing disruptive innovations require new organizational capabilities and are often pushing into new markets with unproven technology, they must become masters in dealing with uncertainty. This thesis attempts to provide a holistic and rigorous process to systematically develop and evaluate options for profiting from the commercialization of disruptive technologies that are currently in the limited application stage of development.

This thesis reviews the basic elements of technology commercialization, existing approaches to the value capture phase of technology strategy, the fundamental stages of the product development process, and the role of real options theory in addressing uncertainty.

The author's experiences with the hydrogen industry provided further insight into the key difficulties in developing strategic options to capture value from the commercialization of disruptive technology. These difficulties include market and technical uncertainty, the infancy of the value chain, capabilities development, the development and valuation of specific strategic options, and the role of established processes, structure and culture of existing companies.

This thesis describes a two part process to addressing these difficulties. The macro level process guides the company's strategy development process by emphasizing emergent strategy, the transition to complementary assets, and a focus on navigating the limited application phase of technology commercialization. The product specific strategy provides a rigorous process for exploring the value chain, identifying sources of uncertainty, and developing specific options for capturing value from the disruptive innovation while emphasizing sound product development practices and requirements.

This thesis builds upon the author's experiences at ChevronTexaco to illustrate the application of these concepts. In one case study, the product specific process is applied to the development of a stationary engine emissions control device. The application of this process revealed or verified significant product development risks while emphasizing that the target segment of the value chain was unlikely to be highly profitable. In another case study, a real options analysis is performed to examine the value of ChevronTexaco developing a near term limited manufacturing capability that would provide future strategic flexibility. The analysis demonstrated how an internal manufacturing capability might improve the probability of profiting from the commercialization of hydrogen fuel processing technology.

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I dedicate this thesis to my wife, Janelle, and my daughter, Calleigh. Their encouragement and enduring support meant everything to me.

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Chapter 1

Introduction

1.0 The Challenge to Be Solved

Companies, academic institutions, and individuals are producing fundamental advances in technology at increasing rates. Businesses are continually searching for innovations in technology or business processes that will enable them to maintain the tremendous growth rates demanded from today's companies.

These companies must determine how to effectively translate the technological advances of yesterday and today into the innovative products customers will clamor for tomorrow. Sustaining innovations may be incremental or breakthrough and are rooted in the existing capabilities of the company. In contrast, disruptive innovations are based on a different capability set and often lead to the development of new markets[1].

Because companies pursuing disruptive innovations are based on a new capability set and are often pushing into new markets with unproven technology, they must become masters in dealing with uncertainty. Even if the company is successful in developing the technology, there is no guarantee that they will make any money from their innovation.

In order to visualize various methods of profiting from innovation, it is useful to examine a basic definition of technology commercialization.

> "The process of acquiring ideas, augmenting them with complementary knowledge, developing and manufacturing saleable goods, and selling the goods in a market."[2]

This definition suggests that the idea must typically lead to saleable goods in order for any meaningful profit to be made. Many companies have the ideas, but lack a well thought out approach to developing complementary knowledge and bringing the products to market.

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[1] Christensen, C. and Raynor, M, The Innovator's Solution, Harvard Business School Press, Boston, Massachusetts, 2003, p. 43.

[2] Mitchell W, Singh K., Survival of Businesses Using Collaborative Relationships to Commercialize Complex Goods. *Strategic Management Journal*, 1996; 17(3): 169 – 195.

Currently, the road to technology commercialization branches into three primary paths that companies take to capture value from their innovation[3]:

1. Establish a business to create products that are sold into the market
2. License the technology to other companies who may or may not commercialize it.
3. Sell the technology outright.

The selection of the value capture path is clearly linked to the company's overall business strategy and specific product development strategies. Whether it is a new or existing company, it is clear that early decisions to determine a value capture path can have profound long term affects on the boundary of the company and the development of capabilities the company will use to differentiate itself in the long run. Developing sound strategies to capture value at both the business strategy level and the product specific level can ultimately drive the success or failure of the entire company.

Unfortunately, the tremendous amount of uncertainty associated with disruptive innovations in the initial stages of technology commercialization makes it extremely difficult to select the appropriate path to capture value. Upon crafting a deliberate strategy, the business environment must be carefully monitored for signs of a new, emergent strategy that might be more effective.

The challenge faced by companies seems to be how to construct and review macro and detailed strategies that enable the company to navigate the uncertainty and position itself for a variety of outcomes. However, a company cannot position itself for every eventuality so it must somehow value the merit of various strategies so that only the strategies with the highest potential value are accommodated.

The goal of this thesis is to create a holistic and rigorous process to systematically develop and evaluate options for profiting from the commercialization of disruptive technology. The critical attributes of the process are identified through understanding the key difficulties in developing strategies to capture value from innovation. The author's experiences in the hydrogen industry and the previous work of technology strategy experts are used to identify the key difficulties and

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[3] Allen, Kathleen R., Bringing New Technology to Market, Pearson Education, Upper Saddle River, New Jersey, 2003, p. 16.

develop the processes. Finally, the application of the process is demonstrated in two case studies involving hydrogen related projects at ChevronTexaco.

1.1 Fuel Cells and Hydrogen

One emerging technology poised to disrupt a number of companies is fuel cells. Fuel cells are electro-chemical power plants that convert hydrogen fuels into electricity and heat with water as the most common by-product. Theoretically, fuel cells can achieve much higher electrical generation efficiencies than thermally based processes since they are governed by the kinetics of chemical reactions. Utilizing pure hydrogen as a fuel source, fuel cells produce no harmful emissions.

While the basic technology to produce a functional fuel cell has been around for decades, their use has been primarily limited to niche applications such as spacecraft where cost is less important than performance. In space applications, fuel cells are utilized to provide power, heat, and clean drinking water to astronauts.

In the 1990's there was substantial research and development funding to commercialize fuel cell technology for various applications including distributed power generation and automotive power trains. For both markets, fuel cells are discontinuous innovations that are also disruptive. Fuel cells are disruptive to the power generation market from the standpoint that while they are currently more expensive and less reliable than other alternatives such as stationary internal combustion engines but they can compete on another dimension that customers value—low emissions. Fuel cells have also opened up some new markets such as utilizing waste natural gas generated by sewage treatment facilities and landfills to generate electricity and heat. For the automotive market, cars with fuel cell power trains are similarly positioned with generally poorer performance but no harmful exhaust emissions. Companies competing in the power generation and automotive markets would have to develop radically new capability sets to compete with this emerging technology.

Since fuel cells require hydrogen instead of petroleum, coal, or natural gas, they also represent a disruptive innovation to many of the major energy companies focused on providing power or petroleum products. Most power companies produce power from centralized locations utilizing coal or natural gas as feed stocks and rely on complex transmission systems to distribute the power. Power generated by fuel cells would likely be accomplished in a distributed fashion in which small power plants are located close to sites of power consumption. Hydrogen fuel would initially be obtained by reforming methane into hydrogen. These fuel cell power plants could be owned and operated by end user companies, thus eliminating the need for a centralized power provider for many applications.

Automotive fuel cell applications are particularly threatening to big oil companies since hydrogen is most economically obtained by reforming methane. This process does cancel out some of the emissions savings of fuel cell applications since almost the same amount of CO_2 is produced from reforming methane into hydrogen as generated by gasoline internal combustion engines. An alternative method of creating hydrogen is electrolysis and basically involves running a fuel cell backwards. In essence, a substantial amount of electricity is used to convert water into hydrogen and oxygen. Utilizing renewable power sources such as solar or wind would lead to an emissions free energy pathway. In either case, a hydrogen infrastructure would likely involve positioning hydrogen generation equipment throughout the country. Existing energy companies would need to develop radically new capability sets to accomplish this task.

Companies developing fuel processing technology include energy giants such as ChevronTexaco, diversified manufacturers like United Technologies and GE, dedicated fuel cell companies such as Nuvera and small niche fuel processing companies like H_2Gen. Each of these companies has widely differing capability sets, financial strength, expectations for growth and cultures. Consequently, these companies have different strategies to profit from the many innovative technologies needed to push fuel cell applications into commercialization.

The last key factor that makes this example particularly relevant is the tremendous uncertainty involved with the markets and technology development. Factors affecting the development of the distributed power generation market include the pressure of government regulations, the public perception of power security, and the ability to decrease capital costs and improve reliability. The automotive market is also heavily influenced by government emissions regulation, a desire for energy security, the development of alternative high efficiency power trains, the availability of low cost petroleum, and the availability of economical fuel cell systems and hydrogen fuel.

Both examples highlight a dependence on technology development to make fuel cell power systems less expensive to acquire, operate, and maintain while providing nearly equivalent performance to existing technologies. To emphasize the uncertainty in developing this technology, there was a widely held belief in the early to middle 1990's that fuel cell power systems would be entering commercialization by the end of the decade. This belief was evidenced by the run – up of pure play fuel cell stocks such as Ballard Power and Plug Power. Their stunning crash and continued dismal performance demonstrates that commercialization is still quite distant. The fuel cell industry has continued to evolve through a multitude of mergers, acquisitions and strategic relationships. Many of these changes to the industry have been solely focused on betting strategically on different technology options. Neither the fuel cell nor fuel processing industries have yet to put forward dominant architectures that clearly indicate required paths of future technology development.

1.2 Organization

Companies operating in the fuel cell/fuel processing space face a number of significant decisions that will potentially affect their ability to effectively compete when the markets become attractive. This thesis is organized as follows to examine this problem in more detail.

Chapter 2—Review emerging technology research and existing theories for capturing value.
Chapter 3—Identify key difficulties associated with developing strategies to capture value.
Chapter 4—Develop a process to address key difficulties.
Chapter 5—Describe the new strategy development process.
Chapter 6—Examine a case study of applying the product specific value capture process to a niche market for hydrogen generation technology.
Chapter 7—Examine a case study that uses real options analysis to value a strategic option.
Chapter 8—Conclusions

The analysis in chapters 3 to 5 is based primarily on the author's experiences during an internship with ChevronTexaco. The internship focused on the development of a hydrogen based product and broadened into an examination of how ChevronTexaco might exploit the uncertainty currently surrounding hydrogen and fuel cells. The details of this work are presented as case studies located in chapters 6 and 7.

1.3 Scope

Many of the concepts, tools and processes described in this thesis can be applied to a broad set of disruptive innovations being developed by new and existing companies. However, the primary objective is to examine existing companies developing discrete, engineered, physical products based on disruptive technologies. The approach is particularly helpful to companies who have developed an idea on how to make money with their invention and are in the early stages of limited commercialization.

Chapter 2

Emerging Technology and Existing Theories for Capturing Value

2.0 Chapter Overview

This thesis builds upon the work of a number of experts in the fields of technology commercialization, technology strategy, innovation, product development, and real options. Each of these areas contains many concepts that are important to solving the challenge. This chapter examines the foundational elements of each of these areas and describes the following critical points:

- Technology commercialization involves obtaining a new idea or technology, designing products based on the idea or technology, manufacturing the products and selling the products. Each of these stages must be executed by someone in order for there to be an opportunity for recurring profits.
- The transition from limited application to widespread application is the most difficult aspect of commercializing a new technology.
- Realizing that the technology will eventually mature and building complementary assets in advance is critical to maintaining competitive advantage and profiting from the innovation.
- The technology supply chain, the product development chain, and the fulfillment chain all interact to support and define the company's strategy. For each chain the company must decide which pieces will be outsourced, who the chain partner will be, and the type of contractual relationship that will be formed. Integrating along axes that maximize performance that is considered important to the customer is critical.
- Possessing a well integrated, internal manufacturing capability can have a positive effect on critical technology commercialization success factors including:
    - Number of new product introductions
    - Product innovativeness
    - Technology commercialization speed
    - Number of patents
- Companies commercializing disruptive technology often become anchored to a deliberate strategy long before the ideal strategy can be determined
- Understanding the key attributes of an effective product development process is fundamental to developing and evaluating options to capture value from technology.
- Companies that invest in a real option today are acquiring the ability to take a particular action in the future that otherwise might not have been available or would be much more expensive.

These points are used to better understand the key difficulties identified in Chapter 3 and to develop the critical process attributes described in Chapter 4.

2.1 Innovation Defined

In 1995, Clay Christensen[4] popularized the notion that emerging technologies fall into two categories—sustaining and disruptive.

- Sustaining: Technologies that simply sustain the current manufacturing practices and technological capabilities required by an industry.
- Disruptive: Technologies that disrupt the current capability set required by a given industry.

Other authors had previously discussed similar concepts such as discontinuous innovation and paradigm shifts. Chapter 2.1 further defines disruptive innovation, discontinuous innovation and examines one possible relationship between the two concepts. Finally, a working definition of disruptive innovation is defined that will be used throughout this thesis.

2.1.1 Disruptive Innovation

Christensen's original work identified three critical elements of disruption (See Figure 1). First, in every market there is a certain amount of performance that customers can utilize. Second, in every market there is also a certain trajectory of technological improvement. Often, this path of technological improvement is steeper than the performance that can be utilized by customers.

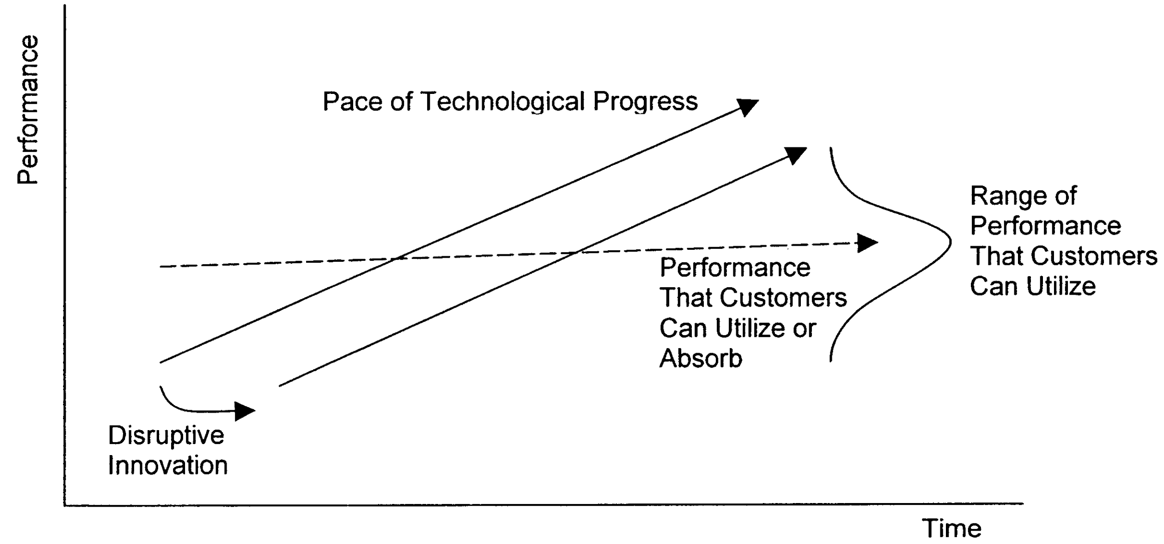

Figure 1: The Disruptive Innovation Model[5]

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[4] Christensen C. and Bower J, Disruptive Technologies: Catching the Wave, *Harvard Business Review*, 1995; Jan. – Feb., 43 – 53.

[5] Christensen, C. and Raynor, M, The Innovator's Solution, Harvard Business School Press, Boston, Massachusetts, 2003, p. 33.

At some point, these two paths cross resulting in products that cost too much for the performance those customers require. Christensen states that the third critical element is a more precise distinction between sustaining innovations and disruptive innovations. Sustaining innovations continue to focus on existing, demanding customers. These innovations deliver improved performance through incremental changes to the product or breakthrough advances. In contrast, disruptive innovations focus on introducing products that may not be as good when compared along traditional attributes. Instead, they appeal to other customer needs that often include simplicity, convenience and low cost. Christensen found that existing companies almost always win battles of sustaining innovation while new companies have a distinct advantage when competing with disruptive innovations.

Christensen's[6] most recent work has outlined two different types of disruptive innovation. New market disruptions describe a situation in which the technology serves a previously unmet customer need. Two examples of this disruption include Sony's first battery powered pocket radio and desktop photocopiers. Low-end disruptions are those that seek out the worst customers in existing markets and compete on new product attributes. Steel mini-mills and discount retailing are two excellent examples of disruptive innovations that attacked the existing competitors with poorer products but much lower costs.

Another important concept presented in the Innovator's Solution is that disruption is a relative term. An idea that is disruptive to one business may simply be a sustaining innovation to another. A current example of this is the emergence of Radio Frequency Identification (RFID) tags. These tags may represent a sustaining innovation to retailers like Wal-Mart but could be considered a disruptive innovation by the manufacturers of optical scanning equipment[7].

Data indicates that new companies are much better off entering with a disruptive innovation. Only 6% of new companies competing with a sustaining strategy succeeded while 33% of companies utilizing a disruptive strategy were successful.[8]

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[6] Christensen C. and Raynor M, The Innovator's Solution, Harvard Business School Press, Boston, Massachusetts, 2003, p. 43.

[7] Unattributed quote from Operations Strategy Lecture, MIT, March 2004.

[8] Christensen C. and Raynor M, The Innovator's Solution, Harvard Business School Press, Boston, Massachusetts, 2003, p. 43.

Christensen's examination of disruptive innovation demonstrates that companies competing with disruptive innovations require fundamentally different capability sets, often with new technology that has yet to mature. Additionally, these companies are often targeting new markets that are relatively uncertain. Both of these points are fundamentally important to the challenge at hand.

2.1.2 Discontinuous Innovation

Other experts in the field of innovation describe innovations as being continuous or discontinuous. Rice et. al.[9] describe many of the improvement philosophies focused on cost reduction and quality as continuous innovations. These include quality function deployment, concurrent engineering, reduced cycle time, just in time inventory management and stage gate decision systems. However, they describe discontinuous innovation as transforming the relationship between customers and suppliers, restructuring marketplace economics, displacing current products, and creating entirely new product categories (See Figure 2).

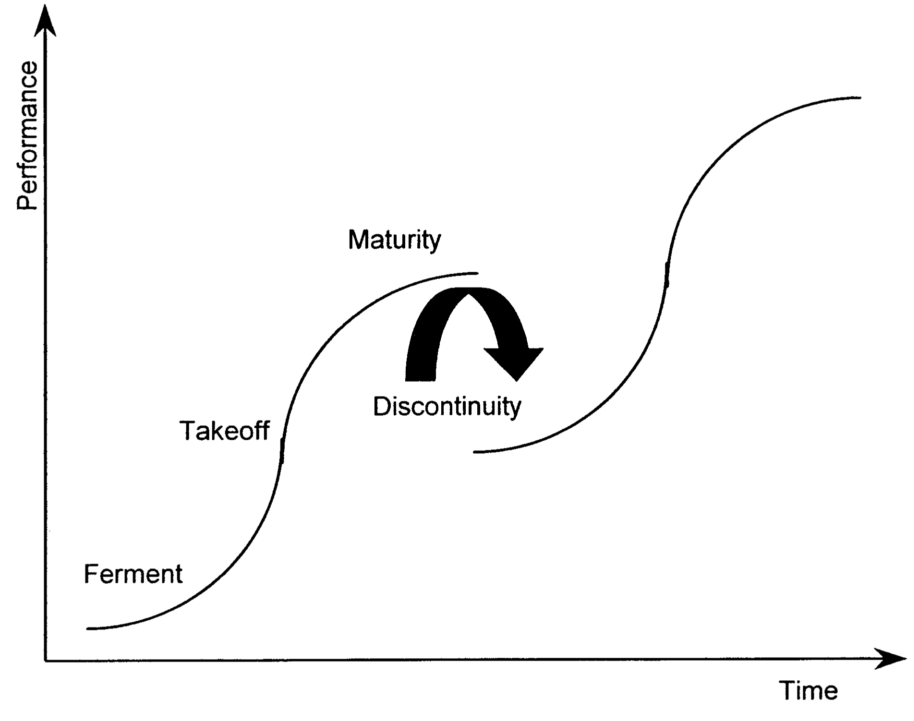

Figure 2: S – Curve for Discontinuous Innovation

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[9] Rice M, Leifer R, and O'Connor G, Commercializing Discontinuous Innovations: Bridging the Gap From Discontinuous Innovation Project to Operations, *IEEE Transactions on Engineering Management*, 2002; 49(4): 330 – 340.

Rice et. al. detail several types of uncertainty associated with discontinuous innovation. In addition to technical and market uncertainty, they discuss organizational and resource uncertainty in existing companies attempting to commercialize discontinuous innovations. Organizational and resource uncertainties are generated from the conflict between the core business unit and the unit engaged in disruptive innovation.

DeTienne and Koberg[10] draw comparisons to Thomas Kuhn's "paradigm shifts" when describing discontinuous innovations.

> "They permit entire industries and markets to emerge, transform, or disappear, providing a firm a significant competitive advantage. They are often described as technological breakthroughs that help companies rewrite industry rules or create entire new industries."

2.1.3 Relationship Between Disruptive and Discontinuous Innovation

Linton[11] draws a distinction between discontinuous and disruptive innovation. He describes disruptive innovations as being based on a new technology base that renders existing technical competencies meaningless. Discontinuous innovations, on the other hand, involve shifting from one technological s-curve to another curve to obtain major gains in the selected performance parameter. However, these shifts are sometimes made without adversely impacting the technological core of the company. Using these definitions, Linton suggests that disruptive innovations are a subset of all discontinuous innovations (See Figure 3).

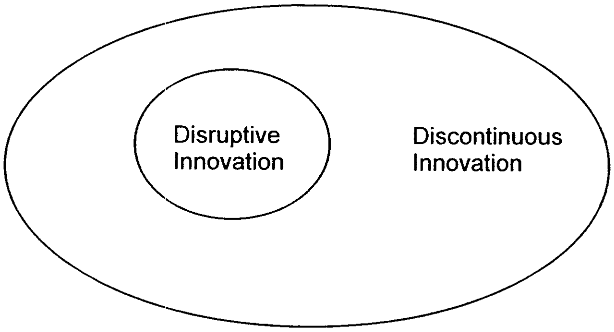

Figure 3: Venn Diagram of Discontinuous Innovation

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[10] DeTienne D, Koberg C, The Impact of Environmental and Organizational Facotrs on Discontinuous Innovation Within High-Technology Industries, *IEEE Transactions on Engineering Management*, 2002; 49(4): 352 - 364.

[11] Linton, J, Forecasting the Market Diffusion of Disruptive and Discontinuous Innovation, *IEEE Transactions on Engineering Management*, 2002; 49(4): 365 - 374.

Finally, Schumpeter[12] proposes that innovation means the commercialization of invention. This definition clarifies how the commercialization of disruptive technologies or inventions results in disruptive innovations.

As a working definition, this thesis will utilize the term disruptive innovation to describe discontinuous innovations that require companies to develop new capability sets and include substantial uncertainty in market and technological development.

2.2 Technology Commercialization

Technology commercialization is both a process with well defined process steps and an evolutionary pathway marked by distinct stages of technology maturation. Examining technology commercialization first as a process highlights the important components.

> Technology commercialization is "the process of acquiring ideas, augmenting them with complementary knowledge, developing and manufacturing saleable goods, and selling the goods in a market".[13]

The fundamental components of technology commercialization appear to include:

- Obtain a new idea or technology
- Design products based on the idea or technology
- Manufacture the products
- Sell the products

Each component must be executed by someone in order for the technology to be commercialized. Therefore all elements are needed for anyone to make a profit from the development of a new idea or technology. The only exception to this rule is the one time outright sale of the technology to another party. However, without the significant probability of successful technology commercialization, this sale will result in relatively small profits. Similarly, since technology licensing revenues are largely dependent on licensing royalties based on actual product sales, this path will only result in significant profits if the products are actually

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[12] Schumpeter J., Capitalism, Socialism, and Democracy, New York: Harper and Row, 1942
[13] Mitchell W, Singh K., Survival of Businesses Using Collaborative Relationships to Commercialize Complex Goods. *Strategic Management Journal*, 1996; 17(3): 169 – 195.

brought to market[14]. In summary, someone must execute all four fundamental components of technology commercialization for there to be a potential of reoccurring profits.

Technology commercialization also includes three basic chronological stages of maturation: proof of concept, limited application and widespread application.[15]

In the proof of concept stage, the inventor has demonstrated that the technology or idea will in fact work. Targeted research and development funding supports technology development. In this stage, it is likely that no commercial market has been identified.

In the limited application stage, the technology may be established as the only practical solution for a niche market. The limited revenue generated in this stage helps expand supporting product development capabilities and justifies additional investment. There is often a significant time delay between the development of the technology and its limited application. Often this delay is caused by defensive innovations of existing technologies.

> "And it ought to be remembered that there is nothing more difficult to take in hand, more perilous to conduct, or more uncertain in its success, than to take the lead in the introduction of a new order of things. Because the innovator has enemies consisting of all those who have done well under the old conditions, and lukewarm defenders in those who may do well under the new." Machiavelli—16th century

Myers et. al. observed that technologies typically reach stage 2 because they offer a unique solution to an important problem. This finding supports Christensen's theories on disruptive innovation.

> "Look closely at the products emerging from disruptive technologies...They were breakthroughs because they met the latent requirements of the customer before the customer become aware of the need."[16]

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[14] Allen, Kathleen R., Bringing New Technology to Market, Pearson Education, Upper Saddle River, New Jersey, 2003, p. 134.

[15] Myers D, Sumpter C, Walsh S, Kirchoff B, A Practioner's View: Evolutionary Stages of Disruptive Technologies, *IEEE Transactions on Engineering Management*, 2002; 49(4): 322 – 327.

[16] Mello S. Customer-Centric Product Definition, AMACOM, *American Management Association.*, 2002, p. 57.

The transition from stage 2 to stage 3, widespread application, is the most difficult transition. In stage 3, the technology has become the preferred solution for multiple applications. Selection of the next application after stage 2 is critical to the ultimate success of the technology. In stage 3, a strong product development infrastructure has been developed.

This thesis focuses on disruptive technologies that are at or near stage 2. It will explore how existing companies develop strategies to extract profit from the development of a new idea or technology.

2.3 Technology Strategy

Henderson[17] proposes that there are there are three primary elements to technology strategy: creating value, capturing value and delivering value.

Creating value involves obtaining an idea and developing a product that the customer is willing to pay for. Specifically, the products benefit perceived by the customer must exceed the cost of acquiring and using the product.

Capturing values focuses on developing competitive strategies that allow the company to make a profit from the value they have created. Throughout the technology lifecycle, companies rely on different mechanisms to stay ahead of the competition. Fundamentally, strategies for capturing value are aimed at developing a lasting competitive advantage and may evolve over time.

Delivering value looks at how the company is organized to execute its strategies for creating and capturing value. These supportive strategies enable the company to capitalize on the competitive advantages it has developed.

2.3.1 Uniqueness and Complementary Assets

This thesis assumes that a company has acquired a new idea or technology and is poised to create value for customers and moves directly into examining how companies develop

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[17] Henderson, Rebecca, Technology Strategy Lecture Notes, MIT.

strategies to capture value. Companies primarily compete based on the uniqueness of their products or technology, or on the existence of complementary assets that provide other competitive advantages[18].

Competing on uniqueness involves controlling the knowledge generated by the innovation. Companies can build positions of uniqueness through intellectual property, secrecy, or speed of development and execution. Early in the technology lifecycle, particularly at the beginning of a disruptive innovation, companies are typically heavily dependent on uniqueness for survival. They often try to protect their intellectual property through patents or copyrights. In situations where the technology or process innovation is difficult to protect, they may decide to hold the technology proprietary. Other companies may simply rely on staying one step ahead by executing more rapidly than their competitors.

Relying on uniqueness for competitive advantage does have some drawbacks. Intellectual property can be difficult and costly to defend. Some patents are more easily invented around than others. Even if the intellectual property position is solid and defensible, the company may still have to invest a significant amount of money to seek out patent infringements and prosecute them. Secrecy can simply be difficult to maintain and other companies may be able to erode a unique position based on speed by also executing rapidly.

Complementary assets allow a company to make money even if their innovation isn't unique. The best complementary assets are tightly controlled by the company and are not easily imitated. Complementary assets commonly include process based activities such as product design, manufacturing, supply chain coordination or sales and service expertise. Complementary assets also include things that the company owns such as brands, customer relationships, and distribution channels. Possessing strong complementary assets is particularly critical as the disruptive innovation becomes widely accepted as the standard and sources of uniqueness begin to erode (See Figure 4). Realizing that the technology will eventually mature and building complementary assets in advance is critical to maintaining competitive advantage and profiting from the innovation.

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[18] Ibid.

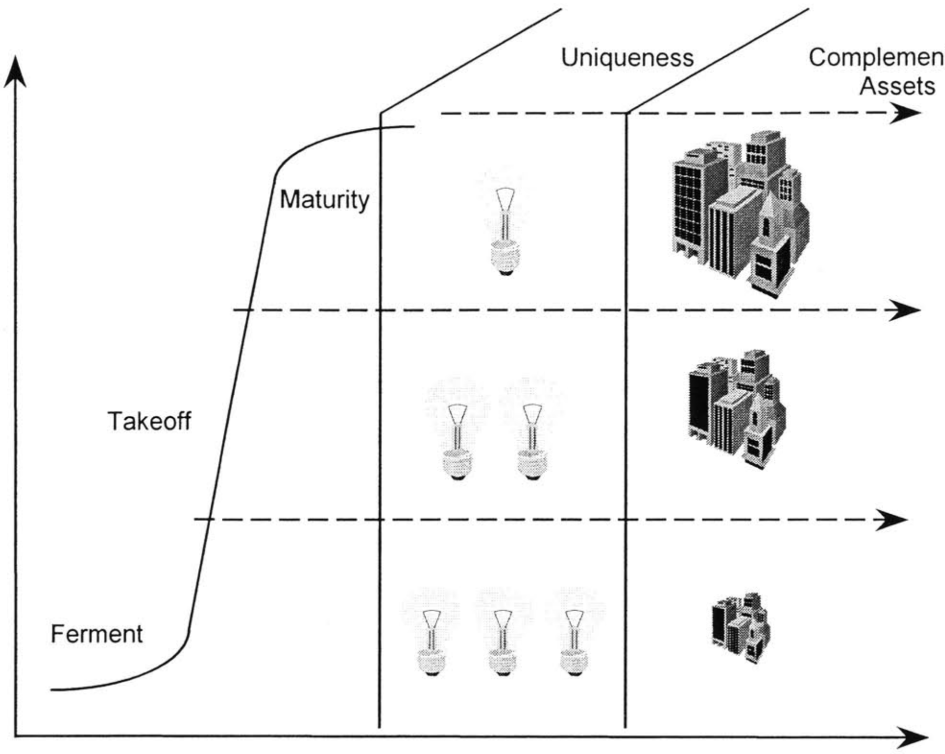

Figure 4: Dynamic Relationship of Uniqueness and Complementary Assets[19]

Other authors describe the development of complementary assets as a relationship between capabilities (the things you do) and resources (the things you have). The Resource Based View (RBV) of the company was popularized by Barney[20] in the early 1990's and argued that a company's resources and capabilities served as the basis for strategy and ultimately the company's profitability. Grant[21] argues that the resource-based approach to strategy comprises three key elements.

- Developing a strategy that exploits existing resources and capabilities
- Ensuring maximum utilization of resources.
- Continuing to build the companies resources and capabilities.

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[19] Ibid.

[20] Barney J.B., Firm Resources and Sustained Competitive Advantage, *Journal of Management*, 1991; 17, 99 – 120.

[21] Grant R, Contemporary Strategy Analysis: Concepts, Techniques, Applications, Blackwell, Cambridge, Massachusetts, 1995.

Stalk et. al.[22] provide some additional insights on the dynamic nature of competing on capabilities. They point out that as the rate of technology development increases and product lifecycles become shorter, the capability to rapidly create new products and exploit new markets will become increasingly important. From studying companies such as Wal-Mart, Honda, Canon, The Limited or Banc One, they have developed four basic principals of capabilities based competition.

- The building blocks of corporate strategy are not products and markets but businesses processes.
- Competitive success depends on transforming a company's key processes into strategic capabilities that consistently provide superior value to the customer.
- Companies create these capabilities by making strategic investments in a support infrastructure that links traditional business units and functions.
- Because capabilities necessarily cross functions, the champion of a capabilities-based strategy is the CEO.

Many companies have developed some type of process to compare their current strategic plan, the resources and capabilities needed to execute it with the current set of resources and capabilities. Itami[23] introduced the concept of dynamic resource fit that also focuses on creating new capabilities based on experiences in executing the current strategy.

Unfortunately, core capabilities can also become core rigidities for existing companies trying to create new capabilities often needed to commercialize disruptive innovations.[24] The specific elements underlying capabilities that make capabilities powerful as a complementary asset are the very same attributes that make them so rigid and difficult to change. These elements include employee knowledge and skill, technical processes, managerial processes and values and norms. Companies that clearly recognize this conflict can take steps to adjust the organization in order to provide fertile ground for the new capabilities to develop.

2.3.2 Capturing Value—The Value Chain

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[22] Stalk G, Evans P, Shulman L, Competing on Capabilities: The New Rules of Corporate Strategy, *Harvard Business Review*, March-April 1992, 57 – 69.

[23] Grant R, Contemporary Strategy Analysis: Concepts, Techniques, Applications, Blackwell, Cambridge, Massachusetts, 1995.

[24] Leonard-Barton, D, Core Capabilities and Core Rigidities: A Paradox in Managing New Product Development, *Strategic Management Journal*, 1992, 13(5): 111 – 126.

Porter[25] demonstrated the importance of thoroughly analyzing the external forces at work in shaping an industry. A careful analysis of the rivalry between companies and the threat of new companies entering the industry is important when examining which resources and capabilities may be required to compete. The relationship of the company to suppliers and buyers is also critical in understanding the value chain. Porter also looks at the threat of product substitutes and other external factors such as the regulatory environment when examining the attractiveness of a particular industry. This static view of the company provides insights regarding the structure of an existing industry and how it might change if various external forces were modified or new products or business models were introduced.

Viewing the value chain dynamically is even more valuable in this era of globalization and rapid change. Fine[26] has described a dynamic view of technology strategy that emphasizes the "Clockspeed" of a given industry. Through examination of various industries including automotive, aerospace, computers, and semi-conductor tool manufactures, Fine observed that the structure of these industries changes at different rates. Industries also move through a somewhat predictable process of moving between vertical integration and modularity (See Figure 5).

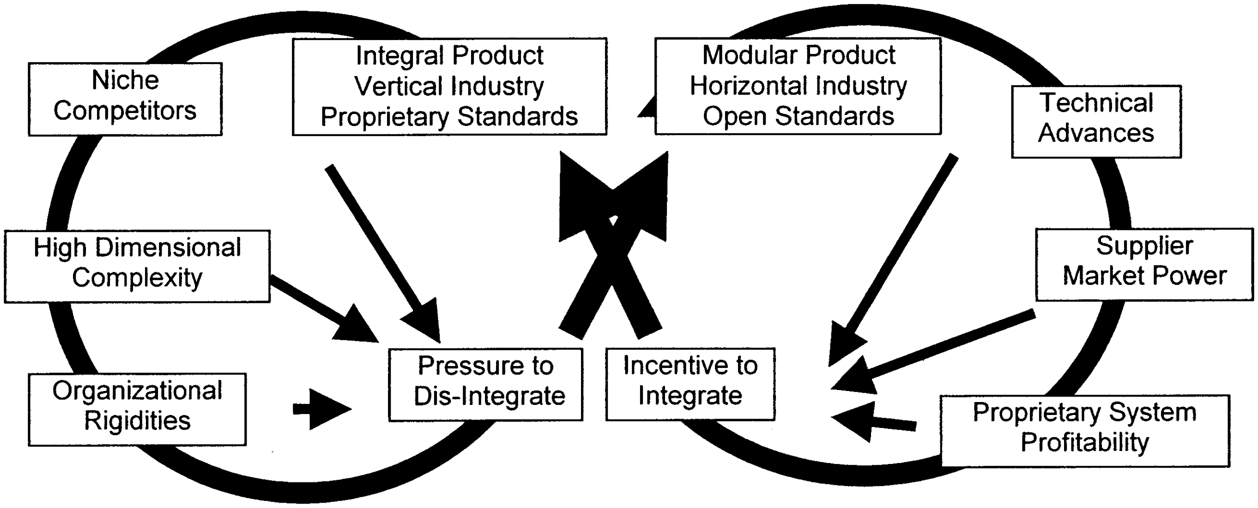

Figure 5: Dynamics of Product System Architecture and Value Chain Structure[27]

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[25] Porter M, <u>Competitive Strategy: Techniques for Analyzing Industries and Competitors</u>, The Free Press, New York, 1980, p. 5.

[26] Fine, C., <u>Clockspeed: Winning Industry Control in the Age of Temporary Advantage</u>, Perseus Books, Reading, Massachusetts, 1998.

[27] Ibid, p. 49.

Using a rigorous process to map the value chains can also yield important insights about the chain structure and areas of opportunity. Specifically, the value chain should be mapped from each the organizational, technological, capabilities perspectives.

Understanding the exogenous dynamics that act to shape the value chain is critical to developing a strategy to extract value from the chain. These dynamics include customer preferences, technology, regulatory policy, business cycles, corporate strategy and capital markets.

Combining the value chain map and an understanding of important dynamics will support the design of the value chain. Fine highlights three chains that are critical to designing the enterprise (see figure 6). The technology supply chain, the product development chain, and the fulfillment chain all interact to support and define the company's strategy. For each chain the company must decide which pieces will be outsourced, who the chain partner will be, and the type of contractual relationship that will be formed. Fine asserts that companies who master this ability to strategically craft their value chain from a dynamic perspective may posses the ultimate core competence.

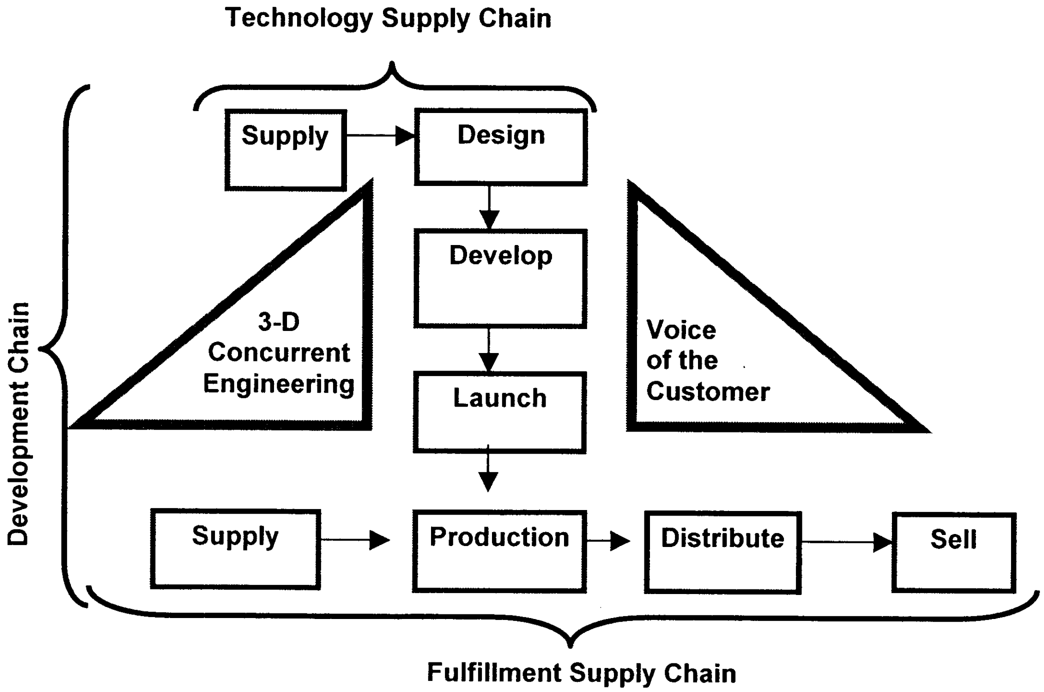

Figure 6: Three Chains of Enterprise Design[28]

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[28] Fine, Charles H., Operations Strategy Course Material, MIT.

2.3.3 Disruptive Innovation and the Boundary of the Company

Christensen[29] examines the problem of capabilities development and outsourcing from the perspective of disruptive innovation. For existing companies developing disruptive technologies, it may not be enough to make strategic decisions based on current capabilities.

> "Instead, managers should ask what do we need to master today, and what will we need to master in the future, in order to excel on the trajectory of the improvement that customers will define as important?"

Many products based on disruptive innovation are "not good enough" in certain areas that customers find important. In order to maximize performance in these systems, designers are typically forced to develop integrated product architectures. Assuming that the developed product is composed of multiple systems working together, designers optimize product performance by designing the subsystems together. This usually results in proprietary architectures. Once a product matures in performance, functionality exceeds customer expectation and the design might become more modular to satisfy new customer needs such as cost. One example of this progression is the evolution of the PC industry that has moved from an integral architecture to a modular one.

Christensen argues that companies competing in a "not good enough" world must be integrated along axes that maximize performance that is considered important to the customer. While the company may not actually manufacture every component in this chain, they must be structured to maintain control over key interface design and manufacture. Coordination issues are also extremely important since intense communication is required when designing multiple sub-systems together. Christensen provides three conditions that must be met in order for a company to modularize part or all of the product:

- Suppliers and customers need to know which attributes of the component are crucial to the operation of the product system
- Suppliers and customers must be able to measures those attributes to determine if the specifications have been met
- There cannot be any poorly understood or unpredictable interdependencies across customer-supplier interfaces.

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[29] Christensen C. and Raynor M, The Innovator's Solution, Harvard Business School Press, Boston, Massachusetts, 2003, p. 125.

Christensen also emphasizes that in a "not good enough" world, providing one piece of an interdependent system does not solve the customer's problem. This is particularly significant observation since many existing companies pursuing disruptive innovation find it more appealing to provide a system component. This approach requires less investment and allows the company to focus on what it believe is most important. Companies are tempted to develop partnerships or outsource heavily to fill out their value chains. However, Christensen's research demonstrates that these gains are often unrealized and the new growth companies fail. Modularity is often not feasible early in the product lifecycle of a disruptive innovation.

> "People cannot efficiently resolve interdependent problems while working at arm's length across an organizational boundary."[30]

A study performed by Zahra and Nielsen[31] specifically demonstrated a positive correlation between internal manufacturing capabilities and technology commercialization. The study followed 97 companies from 1996 to 1999 and examined how company decisions regarding manufacturing capability development affected four key factors associated with technology commercialization. The following four factors were examined:

- Number of new product introductions
- Product innovativeness
- Technology commercialization speed
- Number of patents

The study looked specifically at the human resources and technology components of manufacturing capability development. The integration of these manufacturing resources was also considered. The study concluded that investments in developing internal human resources and technical manufacturing sources should be a priority. External human resources, such as outsourcing and alliances can facilitate new product introductions and speed technology commercialization. However, utilizing external sources may require tradeoffs in product innovativeness and patents. Relying on external sources can reduce tacit knowledge accumulation. Companies that relied on formal integration had more benefit from internal sources of human resources and technology than those relying on informal integration.

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[30] Ibid, p. 138.

[31] Zahra S, Nielsen A, Sources of Capabilities, Integration, and Technology Commercialization, *Strategic Management Journal,* 2002; 23, 377 – 398.

> "Integration is the process by which the firm coordinates and deploys its different manufacturing sources to achieve successful TC. It includes the approaches, systems, and processes management uses to involve the firm's manufacturing staff in the TC process."[32]

The study concluded that integration is important to translating manufacturing capabilities in to successful technology commercialization and the development of new capabilities. Early integration of manufacturing sources into technology commercialization is critical since a large percentage of the products long term costs, quality and features are determined in design.[33]

The authors felt that the dynamics of the learning cycle was an important mechanism in promoting successful technology commercialization. Integration improves the transition from design to manufacturing, leading to reduced costs and shortened development times. Integration also encourages joint problem-solving, ownership, and learning and builds the company's tacit knowledge base. Ultimately, the authors suggest that managers making integration decisions should keep in mind that technology commercialization is a knowledge-intensive process and that relationships must be chosen based on their potential to add to the company's knowledge base.

2.3.4 Disruptive Innovation and Deliberate vs. Emergent Strategy

Mintzberg and Waters[34] articulate two separate approaches to strategy development. Deliberate strategy involves the careful consideration of factors listed previously in this thesis such as industry structure, dynamic value chain analysis, and resources and capabilities to develop a comprehensive business strategy. Emergent strategy recognizes that great strategies often emerge from the daily decisions made be middle management in response to various forces (See Figure 7).

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[32] Zahra S, Nielsen A, Sources of Capabilities, Integration, and Technology Commercialization, *Strategic Management Journal,* 2002; 23, 377 – 398.

[33] Whitney D, Manufacturing by Design, *Harvard Business Review,* 1988, 66(4): 83 – 91.

[34] Mintzberg H and Waters J, Of Strategies, Deliberate and Emergent, *Strategic Management Journal*, 1985, 6, 257.

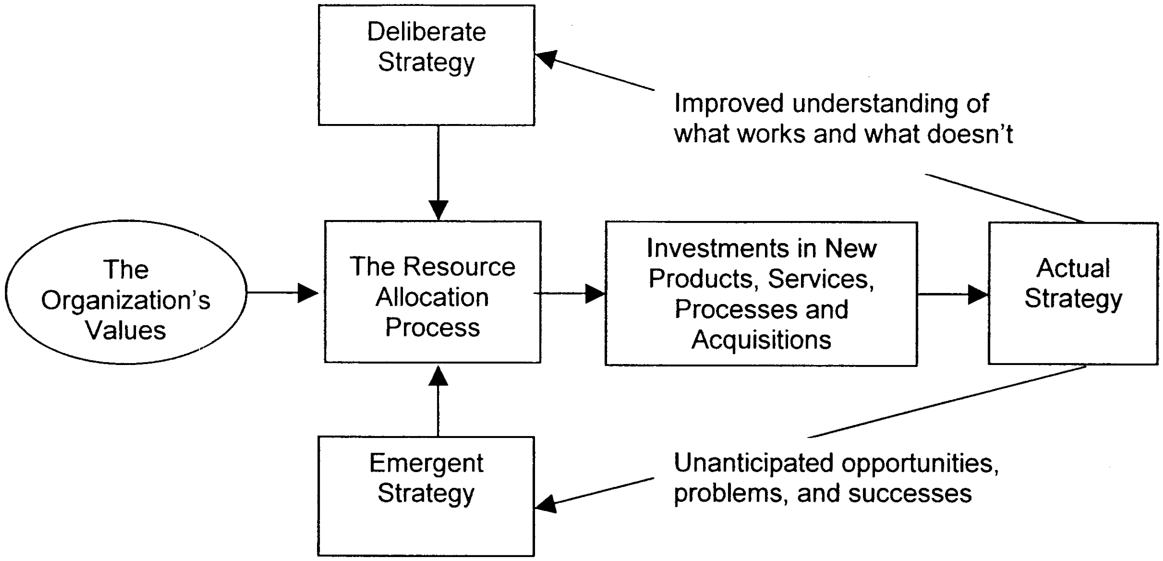

Figure 7: Relationship between Deliberate and Emergent Strategy[35]

Christensen's research indicates that in over 90% of new, successful businesses, the strategy the founder's originally pursued was not the one that lead them to success. This data indicates that companies should use an emergent approach to strategy development when the future is uncertain. Christensen also noticed that when multiple companies are competing in a disruptive space, the losers tend to fail for two primary reasons. First, the companies become anchored to a deliberate strategy long before the ideal strategy can be determined. Next they squander precious resources following this strategy. The second failure occurs after much of the market and technology uncertainty has been resolved. Companies who have successfully navigated the early stage with an emergent strategy may end up failing if they cannot rapidly switch to an effective deliberate strategy and focus all investments appropriately.

Christensen has built upon the work of several in this field in proposing a process for managing the emergent strategy process. The key element of this process involves transitioning from a deliberate planning process to a discovery-driven planning process that focuses on pattern recognition. The four key steps of a discovery-driven planning process include:

- Make the targeted financial projections.
- Determine what assumptions must prove true in order for the projections to materialize.
- Implement a plan to learn more about the critical assumptions and test their reasonableness.
- Invest to implement the strategy.

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[35] Christensen C. and Raynor M, The Innovator's Solution, Harvard Business School Press, Boston, Massachusetts, 2003, p. 215.

2.4 Product Development

The term product development is widely applied to a variety of processes used to bring a product to market. This thesis will rely primarily on a product development process proposed by Ulrich and Eppinger[36] for engineered, discrete, physical products. This scope seems appropriate since the majority of disruptive innovations result in these types of products. The process itself views product development as a sequence of interrelated activities to conceive, design and commercialize a product.

Understanding the key attributes of an effective product development process is fundamental to developing and evaluating options to capture value from technology. While there is a substantial amount of information regarding effective product development practices, this thesis seeks to understand the ideal process flow, the critical steps, and the relationship of different functional organizations.

Ulrich and Eppinger outline a generic product development process composed of the following phases: planning, concept development, system-level design, detail design, testing and refinement and production ramp-up (See Figure 8). Complex development projects may require several iterations of the detailed design and testing phase.

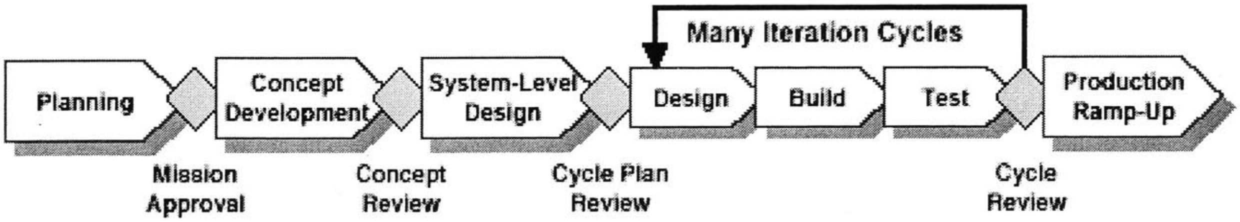

Figure 8: Product Development Process for Complex, Engineered, Discrete, Physical Products[37]

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[36] Ulrich K, and Eppinger S, <u>Product Design and Development</u>, McGraw-Hill, Boston, Massachusetts, 2000, p. 9.
[37] Ibid.

Planning--Begins with corporate strategy and includes an evaluation of technology and markets.

Output: Project mission statement, the target market, business goals, key assumptions and constraints.

Concept Development—Customer needs are refined, product concepts are generated and evaluated.

Output: Detailed understanding of customer needs, target product specifications, final selection of product concept.

System-level Design—Alternative product architectures are evaluated and the design is decomposed into subsystems and components.

Output: Geometric lay-out of the product, functional specification of subsystems, and a preliminary final assembly process.

Detail Design—The complete specification of the geometry, materials, and tolerances of all unique parts and the identification of standard parts to be purchased from suppliers.

Output: Drawings of production parts and related tooling, manufacturing assembly plans, and specifications for purchased parts.

Testing and Refinement—Multiple production representative prototypes are manufactured and tested.

Output: Performance, reliability, and manufacturability data.

Production Ramp-Up—Product is produced with the intended production process.

The process proposed in Chapter 5 focuses primarily on the first three phases of the generic product development process. The role of marketing, design, manufacturing, research and finance is described in Table 1. Each of these functions has deliverables at every phase that often require coordination with the other functions. The organization's research function is heavily involved in the early development of a disruptive product. Careful cross-functional alignment of the product development team is often critical to an effective product development process.

The benefits of an effective product development process include improved product quality (fitness for use and reliability), decreased product cost, shortened development times, decreased development costs, and an overall increase in product development capability.[38]

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[38] Ibid, p. 2.

Planning	Concept Development	System-Level Design
Marketing • Articulate market opportunity • Define market segments	• Collect customer needs • Identify lead users • Identify competitive products	• Develop plan for product options and extended product family
Design • Consider product platform and architecture • Assess new technologies	• Investigate feasibility of product concepts • Develop industrial design concepts • Build and test experimental prototypes	• Generate alternative product architectures • Define major sub-systems and interfaces • Refine industrial design
Manufacturing • Identify production constraints • Set supply chain strategy	• Estimate manufacturing cost • Assess production feasibility	• Identify suppliers for key components • Perform make-buy analysis • Define final assembly scheme
Finance • Provide planning goals	• Facilitate economic analysis	• Facilitate make-buy analysis
Research • Demonstrate Available Technologies	**Legal** • Investigate patent issues	

Table 1: Tasks and Responsibilities for the First Three Product Development Phases[39]

2.5 Real Options and Uncertainty

Real options theory involves trying to value the flexibility inherent in many projects. Meyers[40] describes the tendency of companies to treat projects as black boxes that involve one time decisions to move forward or stop. However, many projects have subsequent decision points that depend on actions taken today. Using a discounted cash flow analysis to evaluate the merits of a project does not factor in the ability of managers to adjust the project based on outcomes. Meyers argues that this decision flexibility becomes more valuable as projects

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[39] Ibid, p. 16.

[40] Myers B and Brealey R, Principles of Corporate Finance, McGraw-Hill, Boston, Massachusetts, 2003, p. 255.

become more uncertain. These "real options" to modify projects can be evaluated utilizing many of the same tools that are used to value financial options such as a call or put.

Companies that invest in a real option today are acquiring the ability to take a particular action in the future that otherwise might not have been available or would be much more expensive. The objective of these options is to mitigate downside risk while maximizing upside potential.[41] Most real options are strategic in nature and involve decisions such as expansion, contraction or abandonment of the business. Other real options focus on the timing of projects such as postponing the implementation of a new project.

Much of the recent interest in real options is being driven by start up companies seeking to prove the long term value of their investments to wall street.[42]

Professor Michael Brennan and Eduardo Schwartz[43] provide a simple example that illustrates the basic concepts of real options. A mining company acquires the mineral rights to a piece of property believed to contain gold. The mineral rights provide the company the right, but not the obligation to mine the gold. This right also provides the company flexibility in determining when they want to mine the gold, such as when prices are high. The cost to mine the gold is X. The expected value of the mined gold is S and is described as the underlying asset. The pay off schedule for the option is:

$$\begin{array}{lll} S - X & \text{if and only if} & S > X \\ 0 & \text{if and only if} & S \leq X \end{array}$$

This payoff is identical to a call option on the underlying asset. The mining company will only begin operations if $S \geq X$. If $S < X$, then the option will expire worthless.

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[41] Billington C, Johnson B and Triantis A, A Real Options Perspective On Supply Chain Management in Technology, *Journal of Applied Corporate Finance*, 2003; 15(2), 32 – 43.
[42] Triantis A, University of Maryland Roundtable on Real Options and Corporate Practice, *Journal of Applied Corporate Finance*, 2003; 15(2), 8 – 23.
[43] Mun J, <u>Real Options Analysis: Tools and Techniques for Valuing Strategic Investments and Decisions</u>, Hoboken, N.J., 2002, p. 77.

Chapter 3

Key Difficulties in Developing Strategic Options to Capture Value

3.0 Chapter Overview

This chapter describes the key difficulties in developing strategic options to capture value from the commercialization of disruptive technology. The author's experiences with the emissions abatement product development effort described in chapter 6 lead to the identification of several key difficulties.

- Presence of market and technical uncertainty
- Infancy of the existing value chain
- Need to develop new capabilities
- Lack of a holistic process to develop and value product specific value capture options
- Constraints of existing company processes, structure and culture

Several related points, such as the presence of market and technical uncertainty, competing on capabilities, mapping the value chain, and understanding the company's core rigidities were described in chapter 2.

Market uncertainty clouds the capital investment process and makes it difficult to justify projects based strictly on a Net Present Value (NPV) analysis. Market uncertainty also complicates technology licensing and partnering negotiations. Uncertainty regarding technology uniqueness also complicates the capital investment process as many early stage companies rely on intellectual property to establish and early competitive advantage. Questions about technology effectiveness may require partnering with other companies who are less invested in the success of the product.

Companies moving into new markets may also encounter undeveloped value chains. This complicates determining the most profitable location in the value chain and hinders the development of deliberate strategy.

Developing capabilities to build complementary assets is simply not an early objective for companies competing with disruptive technology. Knowing which capabilities to build internally, which to outsource, and which existing capabilities might become core rigidities is a critical hurdle to long term competitiveness.

Companies may lack a holistic process that develops and values product specific value capture options. This may be due to capabilities gaps in certain areas or inexperience working with high levels of market and technology uncertainty.

Finally, many companies attempt to undertake disruptive innovations with a pre-existing set of organizational constraints. Attributes of existing companies such as high growth requirements, large existing cost structures and a reliance on deliberate strategy can all decrease the probability of commercializing a disruptive technology.

3.1 Market and Technical Uncertainty

By nature, disruptive innovations are characterized by a high degree of technical and market uncertainty. This relationship has been noted by several authors and is a well known challenge to developing products based on disruptive technology (See Figure 9).

Technical Uncertainty	Low	High
High		Disruptive Innovation
Low	Incremental Innovation	

Market Uncertainty

Figure 9: Relationship of Technical and Market Uncertainty to Innovation[44]

Market uncertainty is a function of several components. The absolute size of the market can be quite difficult to determine for a disruptive innovation. This is particularly true for disruptive

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[44] Rice M, Leifer R, O'Connor G, Commercializing Discontinuous Innovations: Bridging the Gap From Discontinuous Innovation Project to Operations, *IEEE Transactions on Engineering Management*, 2002; 49(4): 330 – 340.

innovations targeting a latent customer need. The timing of the market is impacted by several factors. Some markets are constrained by the adequacy of the developing technology while other markets may be more heavily influenced by exogenous factors such as industry structure or government regulation. The adoption rate of the technology might also vary substantially. Recent high technology consumer products such as camera phones appear to be penetrating markets much more rapidly than older innovations such as television.

This market uncertainty presents several specific problems to identifying and valuing options to capture value. For development intensive projects, companies must carefully balance their cash burn with a need to continue advancing their technology. The ability to acquire new investment usually involves questions regarding when a return will be realized. A related problem[45] involves large companies trying to determine if a particular project is worth their time. Market size uncertainty can create a lack of focus and commitment if the project is anywhere near the "is this project worth it" boundary. Market uncertainty also clouds estimates of potential capital investment projections and the suitability of existing capabilities to execute the project. A company with solid capabilities producing hundreds or thousands of units per year may be stretched to efficiently manufacture millions of units. Similarly, market size and timing uncertainty clouds the revenue projections from technology licensing. Uncertainty in the market also makes it much more difficult to enlist risk sharing partners. Many partners may be unwilling to share development costs for a product that has an uncertain payoff, particularly if that partnership also moves them outside of their core business.

Technology uncertainty includes questions about effectiveness, time to readiness, and uniqueness. The early discussion on the stages of technology commercialization clearly indicates that there can be a substantial gap between technology acceptance and its early application. Disruptive technologies are again, by default, highly uncertain advances often being undertaken by companies with little prior experience in developing a product with a related technology. While the company may have a fundamental scientific understanding of the technology, understanding its application in a new product may be entirely different. Companies may also be uncertain of the uniqueness of their technology since early in the development process, details of recent patent claims are unavailable or the technology may be proprietary.

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[45] Christensen C. and Raynor M, The Innovator's Solution, Harvard Business School Press, Boston, Massachusetts, 2003.

Technology uncertainty also presents several problems. A general lack of confidence in the uniqueness of the existing technology can be a difficult hurdle to clear since many companies rely on a strong intellectual property position to help capture early profits. This makes it difficult for the company to present a convincing business case that is needed to attract new investment. Uncertainty regarding technology effectiveness may lead the company to seek development partners. However, partnerships also have risks and dilute any profits made from the innovation. The lack of a dominant architecture also makes potential licensing profits highly uncertain. The company may also be uncertain as to which technology attributes are critical to customer satisfaction. This uncertainty could lead to poorly received products or extended product development cycles.

3.2 Infancy of Existing Value Chain

Companies poised to change paradigms and create new industries are tasked with analyzing and even establishing new value chains. Disruptive innovations may create relationships between companies or industries that were previously not considered. Obtaining a clear picture of the competitors and their intentions is extremely difficult since the only visible effort of their strategy may be patents. The competitive landscape is often cluttered with integrated and specialized competitors that are all seeking to determine the optimum business strategy. However, most of these companies are unknowingly constrained by their own paradigms and fail to understand what the value chain could be or where the profits will fall.

Companies are particularly burdened with determining who they should partner with and when they should do it. Partnering early is advantageous since the partnering options are less constrained. Waiting to partner might lead to fewer choices, but include less uncertainty regarding technology development and the required partner capabilities.

External dynamic factors play a big role in the early shaping of the value chain.[46] Companies may believe they have the appropriate deliberate strategy and the proper relationships in place only to have their entire plan thrown into chaos because of merger, acquisition, or divestiture activities in the chain.

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[46] Fine, C., Clockspeed: Winning Industry Control in the Age of Temporary Advantage, Perseus Books, Reading, Massachusetts, 1998

3.3 Capabilities Development

Companies engaged in disruptive innovation are commonly faced with developing new capabilities. These capabilities may include technological know how, process focused capabilities such as product development, marketing in the absence of a known market, working with unfamiliar partners, technology in and out licensing, and many others. While many organizations have a general sense of what they are good at and areas where they need to learn, it is unclear how many organizations have a systematic and detailed process to assess existing capabilities, compare them with the business strategy, and determine specific capabilities that need to be developed. Most commonly these evaluations are done to examine the strength of the organization along pre-determined attributes that are known to be of value to the company. Gap based capabilities evaluations are likely to be functionally oriented as opposed to process oriented. However, a process focused capabilities assessment is critical if a company is new or has little experience in commercializing disruptive technologies.

Capabilities development from the standpoint of developing complementary assets is simply not an early objective of an organization developing a disruptive technology. The organization knows that it absolutely must acquire the right skills to make the technology viable to move to limited application and likely has few resources to spend on such a long range problem as developing complementary assets. One key difficulty is therefore related to the issue of deliberate vs. emergent strategy. Organizations must determine when to focus more of their resources on developing complementary assets that will sustain the company long term and what capabilities should the focus on.

Another challenge associated with capabilities development involves the desire by many companies to outsource wherever possible to reduce capital expenditures and development costs. There are significant advantages to maintaining a low cost structure early in the development of a disruptive innovation.[47] Given that some outsourcing will be required, are there ways companies can extract the most value from the relationships such that in the long run, there are other advantages besides reduced costs? Companies entering into joint development agreements or establishing joint ventures seem single mindedly focused on obtaining the output of the relationship. For a joint development agreement, it might be a piece

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[47] Christensen C. and Raynor M, The Innovator's Solution, Harvard Business School Press, Boston, Massachusetts, 2003 p. 225.

of technology or a prototype. For a joint venture, it may simply be a revenue stream or the opportunity for a large one time payout when the joint venture position is cashed out. However, there are many less tangible resources and capabilities that could be extracted from these situations if the partners approached the relationship from a capabilities perspective.

Another difficulty that affects value capture strategies is determining which new capabilities need to be developed or acquired, which existing capabilities need to be maintained, and which existing capabilities have become "core rigidities" and need to be eliminated.[48] Identifying capabilities for development is not a trivial exercise when developing a disruptive innovation. If most companies who successfully commercialize disruptive technology end up using an emergent strategy, they are likely employing different capabilities as well.

Assuming the company has been successful in identifying target capabilities for development, they must next decide how they will develop those capabilities. Depending on the nature of the disruptive innovation, companies may be able to select from a variety of different projects to build capabilities. However most projects are sorted based on estimated cash flows and capabilities development is often not a significant criteria.

3.4 Developing and Valuing Specific Value Capture Options

Companies who have a disruptive technology approaching limited application are confronted with trying to determine specific approaches to capturing value. The highest level decision involves deciding to sell the technology, license it to other companies, or commercialize it with partners or independently. While the company may have already established a deliberate strategy for this phase of the development, reevaluating the decision may be a prudent step.[49] Unfortunately, the merits of each approach likely depend on the details of their implementation. This requires a rigorous process to fully examine the details of each approach.

Since disruptive innovation is surrounded by extreme amounts of uncertainty, comparing options through discounted cash flow analysis alone seems risky. Companies need to determine which criteria are most important to evaluating options. For example, a company that

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[48] Leonard-Barton, D, Core Capabilities and Core Rigidities: A Paradox in Managing New Product Development, *Strategic Management Journal*, 1992, 13(5): 111 – 126

[49] Christensen C. and Raynor M, The Innovator's Solution, Harvard Business School Press, Boston, Massachusetts, 2003, p. 221.

has little or no product development experience may not fully appreciate how various architecture choices can affect the supply chain strategy.

3.5 Established Processes, Structure, and Culture of Existing Companies

There are several key factors that inhibit existing companies from pursuing disruptive innovations. The culture of the existing organization may be poorly suited to requirements of a disruptive environment. Processes and values that are critical to executing sustaining improvements may be hindrances to executing disruptive innovations. Large companies tend to bypass the smaller initial returns of disruptive projects because they are simply too small to meet the current growth demands. Existing companies tend to execute "big". They are typically not focused on maintaining an ultra-low cost structure that will allow them to compete in low end disruptive markets. Large companies tend to rely on rigorous financial analysis of projects that was appropriate for sustaining environment. In depth market research often focuses on existing markets and less on understanding the latent needs of new customers. Rigorous financial analysis focused on estimating future cash flows fails to account for the tremendous uncertainty involved with the project. Existing companies are more likely to draft a deliberate strategy and stick with it than smaller, more nimble competitors. Existing companies are also more likely to view problems from the perspective of existing capability sets rather than determining the ideal location in the value chain and developing the required capabilities. All of these factors contribute to clouding the best alternatives to capture value.

Chapter 4

Developing a Process to Address Key Difficulties

4.0 Developing a Process that Addresses Key Difficulties

A process to develop value capture options must address the fundamental difficulties described in chapter 3. Considering the challenges as an integrated problem and incorporating many fundamental principles from chapter 2 makes it easier to determine the key attributes of a new process.

The first central theme that must be addressed by the process is uncertainty. Disruptive innovation will always be characterized by significant market, technology, and strategic uncertainty. One method to deal with uncertainty is establishing which areas of uncertainty are critical to the project and which are simply annoying. Diagnosing the key areas of uncertainty requires communication between the key participants early in the product development cycle—marketing and R&D. This leads to the first critical process attribute.

> **The process must explore and map areas of uncertainty from a functionally integrated perspective.**

The second technique in dealing with uncertainty is maintaining flexibility. Emergent strategy has played a substantial role in the development of several substantial corporations such as Intel, Wal-Mart, and Honda.

> “Openness to emergent strategy enables management to act before everything is fully understood—to respond to an evolving reality rather than having to focus on a stable fantasy…Emergent strategy itself implies learning what works—taking one action at a time in a search for that viable pattern or consistency.”[50]

This emphasis on flexibility and emergent strategy leads to the second critical process attribute.

> **The process must value flexibility and provide a mechanism to detect and craft emergent strategies.**

The third approach to dealing with uncertainty involves having choices. If the future of a particular technology or market path is uncertain but the team feels that there are only a few potential outcomes, then the group should be adequately prepared to rapidly respond to any of the outcomes. The team must be able to rapidly execute the new deliberate strategy once it has become evident.[51] This approach can be effective at various levels of the strategy development process and provides the third critical process attribute.

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[50] Ibid, p. 232.
[51] Ibid, p. 216.

The process must create and evaluate a significant number of strategic options to cover key areas of uncertainty.

Early in the development of a disruptive innovation, companies may place a tremendous emphasis on technology development and intellectual property. There may even be a strong belief that a solid IP portfolio will provide a lasting source of uniqueness that will ensure long term profits. While this approach may be an effective approach to a short term company flip, it is unlikely to provide an enduring competitive advantage. In the resource based view of the company, companies need to develop core competencies that will sustain growth long after the initial technological edge has dulled. This focus on complementary assets provides the fourth critical process attribute.

The process must emphasize complementary assets and identify capabilities for further development or acquisition.

Companies undertaking disruptive innovations are diverse in size, culture, structure, and capabilities. Existing companies embracing disruptive innovation face additional uncertainty in the relationship with the mainstream organization.[52] This uncertainty is demonstrated in how the disruptive organization is structured and funded. Because the mainstream organization may not be entirely converted to "believers", there is often a wavering level of support that distresses the new organization. Understanding these differences is critical to understanding which value capture strategies may be effective and which may not.

The process must recognize existing company culture, structure and core rigidities.

Finally, the product development process itself is critical to successfully commercializing a disruptive technology. Sound product development practices influence customer perception of the product, time to market and product cost.[53] The identification of value capture options must therefore consider best practices in product development and manufacturing.

The process must promote sound product development and manufacturing practices.

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[52] Rice M, Leifer R, O'Connor G, Commercializing Discontinuous Innovations: Bridging the Gap From Discontinuous Innovation Project to Operations, *IEEE Transactions on Engineering Management*, 2002; 49(4): 330 – 340.

[53] Allen, Kathleen R., Bringing New Technology to Market, Pearson Education, Upper Saddle River, New Jersey, 2003, p. 153.

Chapter 5

Describing the New Strategy Development Process

5.0 Chapter Overview

This chapter develops a macro strategy and a product specific process for improving the chance a company will profit from their idea. The emphasis on developing a PROCESS to create strategies for capturing value encourages stakeholders to methodically explore their own situation and develop a plan of action. The process provides general strategic recommendations based on commonly respected best practices and then provides a mechanism to carefully explore the current situation. The result of this process includes specific recommendations at the product level and the surfacing of important factors that could affect the macro strategy. It also recognizes the importance of flexibility and values it through the use of real options.

The macro strategy for capturing value encourages the development of an emergent strategy development process such as the one described in Chapter 2. Companies need to develop a culture and management structure that values flexibility.

The macro strategy also emphasizes the risks associated with relying too heavily on intellectual property as a source of uniqueness. Companies need a disciplined process for examining the capabilities required to develop complementary assets. Factors such as the defensibility of intellectual property, the time required to build capabilities and the clockspeed of the target or related industry all influence when a company should actively begin developing complementary assets.

The last element of the macro strategy involves recognizing the dynamics of the limited application phase of technology development. Examining the characteristics of this phase leads to the theory that organizational speed and again, flexibility, will be important competitive attributes. Additionally, many companies struggle with commercializing disruptive technology because they do not have much experience doing it. This thesis proposes that larger companies should consider a centralized team focused on moving products from limited application to the widespread application.

The product specific strategy for capturing value provides a strategic and functionally integrated approach to crafting technology, design, and fulfillment supply chains. This process is designed to methodically map the competitive landscape, closely examine key areas of uncertainty, and integrate with the product development process. The process is executed in parallel with the traditional product development process and includes the phases of Value Chain Baseline, Value Capture Development, and Value Capture Pre-selection.

Value Chain Baseline focuses on integrating early knowledge of the customer, technology readiness, and the competitive environment. Outputs of this phase include value chain maps, a capabilities assessment, a 5 forces analysis of the industry, and a description of how customer needs relate the market and technology readiness.

Value Capture Development integrates more developed product concepts and preliminary product architecture information to develop options for the product development, technology, and fulfillment chains. Integration options include potential partners/key suppliers, proposed value chains, and critical areas of uncertainty.

Value Capture Pre-Selection incorporates updated product development information and incorporates feedback from potential partners. Options are evaluated based on potential for capabilities development, financial measures, predicted effectiveness based on complexity, and organizational alignment between key organizations. Real options are developed to accommodate key areas of uncertainty.

5.1 Macro Strategy for Capturing Value

The macro level view of the problem suggests the adoption of emergent strategy, development of complementary assets, creation of a culture based on flexibility and speed, and the development of a new organization to help companies successfully navigate the treacherous limited application phase of technology commercialization.

5.1.1 Emergent Strategy

The macro strategy must explore areas of uncertainty and adapt to changing conditions. Having a strategy development process that emphasizes emergent strategy is critical to rapidly exploiting changing conditions. This requires executives who are experienced in operating in a highly uncertain environment.[54] These leaders must foster a culture where people are encouraged to constructively challenge the current strategy and foundational assumptions. It is also important for executives to inspire people in periods of doubt, confusion, and perhaps even chaos.[55] Put simply, creating a culture of flexibility and the acceptance of rapid change is fundamental to executing emergent strategy.

5.1.2 Transitioning to Complementary Assets

Understanding the relationship between uniqueness and complementary asset development is critical to companies launching disruptive innovations. Some companies have retained dominant positions through technology development and an impenetrable barrier of patents. However, many companies rely too heavily on patents and fail to use the time to build complementary assets. Understanding the limitations of uniqueness and developing a plan to build complementary assets must be part of the macro strategy.

Uniqueness created by intellectual property is a valuable resource early in the commercialization of disruptive technologies. The ability of the company to leverage their position of uniqueness to appropriate the vast majority of the value they have created is significant. The ability to appropriate this value is commonly driven by the nature of the technology and the effectiveness of the legal system.

> "It has long been known that patents do not work in practice as they do in theory. Rarely, if ever, do patents confer perfect appropriability although they do afford considerable protection on new chemical products and rather simple mechanical inventions. Many patents can be 'invented around' at modest costs."[56]

The recent trend of the United States Patent Office to grant what many believe an increasing number of overlapping patents to separate parties appears to degrade the effectiveness of protecting IP through the legal system. At the very least, it results in increased costs to companies seeking to defend their patents in court. Perhaps a more effective approach for some technologies is to hold the underlying technology as a trade secret. This may be

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[54] Christensen C. and Raynor M, The Innovator's Solution, Harvard Business School Press, Boston, Massachusetts, 2003, p. 181.

[55] McDermott C and O'Connor G, Managing Radical Innovation: An Overview of Emergent Strategy Issues, *Journal of Product Innovation Management*, 2002; 19, 424 – 438.

[56] Ibid, p. 189.

particularly useful to companies developing products where the technology can be protected until after the products are available to the public.

While some situations may enable strong intellectual property positions to capture value for an extended period of time, it appears that a more common benefit is to provide a period of time early in the commercialization process to create complementary assets that will sustain the company.

> "In almost all cases, the successful commercialization of an innovation requires that the know-how in question be utilized in conjunction with other capabilities or assets. Services such as marketing, competitive manufacturing, and after-sales support are almost always needed."[57]

Assuming that complementary assets are vital to the company's long term success, the company must make capabilities development criteria by which management decisions are evaluated. However, given that the correct deliberate strategy is not usually implemented directly by companies pursuing disruptive innovations, the company must have a process to generate and evaluate capabilities development options.

Existing companies need a capabilities development process that recognizes the current capabilities of the company and compares them to what is need.

- Understand Existing Capabilities: Knowledge and skills, technical skills, managerial systems, and values and norms.
- Predict Needed Capabilities: Evaluate what types of complementary assets will provide strategic advantage. Focus on integrating across what isn't good enough.
- Compare existing and predicted to determine potential core rigidities (Leonard-Barton)
- Determine how new capabilities will be obtained
    - Competency stretching from existing capabilities
    - Purchase of new capabilities
    - Outsourcing with aim to acquire capabilities through the relationship.

Organizations must determine when to switch more resources from technology development to capabilities development. The upper boundary of this transition point is likely marked by the emergence of a dominant design. Companies that have not developed complementary assets by this time will be at a competitive disadvantage. Tight or weak appropriability regimes can also affect the probability of the innovator maintaining its competitive advantage.[58] Companies

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[57] Ibid, p. 191.
[58] Ibid, p. 193.

with tight appropriability solidly protect their IP through patents or trade secrets and may have designs that are difficult to imitate. Companies with tight appropriability will have more time to identify an optimum design and develop complementary assets. The nature of the complementary asset and how closely it is related to existing capabilities will also play a role. Some assets, such as manufacturing capability, will take longer to develop than other assets. Additionally, competencies that can be stretched from existing capabilities will also take less time to develop. Finally, companies can examine the "clockspeed" of the related industry and the buying patterns of the customers. For example, products entering into markets significantly affected by regulation will be slower to evolve, allowing more time to develop capabilities.

5.1.3 Navigating the Limited Application Phase

The values of speed and flexibility seem to augment many of the complementary assets potentially developed by companies launching disruptive innovations. In a rapidly changing, uncertain environment, companies must value and maintain flexibility in nearly all aspects of their business. Additionally, the company also benefits from being able to rapidly implement selected decisions.

> "The degree to which a company can execute its R&D and commercialization processes more rapidly than its competitors will determine its ultimate success. The challenge is to develop superior products faster and at less cost. This need for speed has resulted in more strategic alliances and more in-licensing of noncore technology."[59]

Speed and flexibility have been emphasized as critical attributes for companies competing in a dynamic environment.

> "The prize will be companies that combine scale and flexibility to outperform the competition along five dimensions:
> - **Speed: The ability to respond quickly to customer or market demands and to incorporate new ideas and technologies quickly into products.**
> - Consistency: The ability to produce a product that unfailingly satisfies customers' expectations.
> - Acuity: The ability to see the competitive environment clearly and thus to anticipate and respond to customer's evolving needs and wants.
> - **Agility: The ability to adapt simultaneously to many different business environments.**
> - Innovativeness: The ability to generate new ideas and to combine existing elements to create new sources of value."[60]

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[59] Allen, Kathleen R., Bringing New Technology to Market, Pearson Education, Upper Saddle River, New Jersey, 2003, p. 154.

[60] Stalk G, Evans P, Shulman L, Competing on Capabilities: The New Rules of Corporate Strategy, *Harvard Business Review*, March-April 1992, 57 – 69.

Technology commercialization speed is recognized as one of the key factors of successful technology commercialization.

> "This allows the firm to flank or attack its competitors, reduce costs, improve quality, absorb new technologies, expedite learning from customers, and improve new market performance."[61]

One problem with these values is that their importance changes somewhat over the life-span of a disruptive technology. The proof of concept stage may last several years before a technology is ready for limited commercialization. However, even towards the end of this stage, flexibility becomes increasingly important as different applications are considered for the technology. As the product moves towards widespread application, the need for flexibility diminishes as key uncertainties also begin to subside (See Figure 10). While technology development must proceed at an adequate rate during the proof of concept, organizational speed becomes even more critical as the project moves into limited application and then levels out or diminishes somewhat during the widespread application phase.

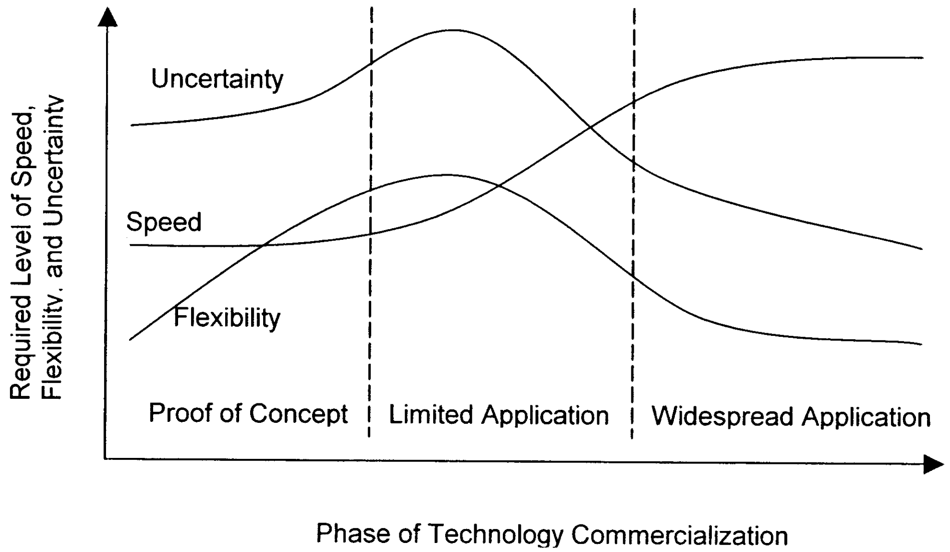

Figure 10: Trends in Speed and Flexibility as Uncertainty Changes Over Time

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[61] Zahra S, Nielsen A, Sources of Capabilities, Integration, and Technology Commercialization, *Strategic Management Journal,* 2002; 23, 377 – 398.

The phase with the least amount of stability appears to be the limited application phase which has the following key attributes:

- Substantial market and technological uncertainty (new markets)
- Dominant designs have not emerged
- Project is still typically owned by R&D
- Product development process is being exercised to at least the prototype or pre-production stage
- Supporting pieces of value chain relatively undeveloped or uncoordinated
- Partnerships and alliances are beginning to emerge
- Initial value capture strategy developed, but still uncertain
- Organization and resource uncertainty
- Product is sold into niche applications

In fact, successfully navigating the limited application stage is the most difficult part of technology commercialization.[62] Many authors have described the problems existing companies have with transitioning the project from the innovating organization to the organization who will own the product during widespread application.[63] One framework recommends autonomous organizations when companies are pursuing disruptive innovations that have a poor fit with the company's existing processes and values.[64] However, setting up an autonomous organization for each disruptive innovation does not address the problem that most existing companies simply do not have enough experience executing disruptive projects.[65]

An alternative approach would be to create a centralized Center of Technology Commercialization whose primary function would be to help disruptive projects navigate through the limited application stage into widespread application. In essence, this would be an independent group focused on the process of moving creative research ideas from the limited application phased into the beginning of the widespread application phase. The transition to operation might include moving the product to an existing business unit, establishing a new

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[62] Myers D, Sumpter C, Walsh S, Kirchoff B, A Practioner's View: Evolutionary Stages of Disruptive Technologies, *IEEE Transactions on Engineering Management*, 2002; 49(4): 322 – 327.

[63] Rice M, Leifer R, and O'Connor G, Commercializing Discontinuous Innovations: Bridging the Gap From Discontinuous Innovation Project to Operations, *IEEE Transactions on Engineering Management*, 2002; 49(4): 330 – 340.

[64] Christensen C. and Raynor M, The Innovator's Solution, Harvard Business School Press, Boston, Massachusetts, 2003, p. 191.

[65] Rice M, Leifer R, and O'Connor G, Commercializing Discontinuous Innovations: Bridging the Gap From Discontinuous Innovation Project to Operations, *IEEE Transactions on Engineering Management*, 2002; 49(4): 330 – 340.

business unit, or spinning out the business. The center would need to clearly establish a core set of team members that generally stayed with the center of disruption.

Mission

- Transfer disruptive products from stage 2 to stage 3

Strategies

- Execute a highly integrated approach to product development (marketing, research, design engineering, manufacturing)
- Build strong relationships with research organizations
- Accumulate tacit knowledge of the innovative product development process
- Develop the strategies to capture value and shape the value chain
- Provide low volume production with non-automated equipment suitable for volumes in the limited application, early widespread application phase.
- Focus on disruptive innovations for new markets
- Develop a core team of experts that transfer knowledge to people passing through the center

Values

- Draw upon entrepreneurial talent with an attitude for new product development and ability to cope with change and uncertainty
- Encourage a culture of flexibility, speed and creativity in all aspects of the organization

5.2 Developing Product Specific Strategies for Capturing Value

Because existing companies rarely undertake disruptive projects, they are a faced with fundamental strategic questions for every project. The basic choices involve selling the technology, licensing it someone else, or commercializing the product themselves. While companies can capture recurring revenues from technology licensing, the uncertainty involved with commercializing disruptive technology makes this a risky proposition. The lack of a dominant architecture, weak appropriability, and the difficulty in functioning as a specialized supplier in a market that requires an integrated solution make this option less attractive. Consequently, this process focuses on the company commercializing the product themselves.

Companies commercializing technology themselves are faced with another tier of choices. Strategic decisions must be made regarding supply chains for technology, design, and fulfillment. Options range from completely outsourcing a particular component to retaining complete control in house. These decisions are complex and there are plenty of advocates for every approach. Many companies favor reducing financial risk and speeding product development through partnering or in-licensing technology. However, some research indicates that capabilities based competition, including the commercialization of disruptive technology, may favor companies that are more integrated.

> "At a time when cost pressures are pushing many companies to outsource more and more activities, capabilities-based competitors are integrating vertically to ensure that they, not a supplier or distributor, control the performance of key business processes."[66]

Similarly, evidence suggests that developing internal manufacturing capabilities based on human resource skills and technology and integrating them formally with the product development process can positively affect all critical attributes of technology commercialization.[67] However, external human resources obtained through partnerships, universities, and consultants and external manufacturing technology obtained through outsourcing and alliance can have a positive affect on the number of new products introduced and technology commercialization speed. Outsourcing does negatively impact the radicalness of new products and the acquisition of intellectual property. The accumulation of tacit knowledge is generally reduced as well. However, there are likely some situations where outsourcing is advantageous or even a necessity. This process is designed to methodically develop a map of the competitive landscape, closely examine key areas of uncertainty, and coordinate with the product development process to develop options for capturing value from the project.

5.2.1 Describing the Process and the Team

The basic approach consists of two parallel processes that interact at various points early in the product development process. The first process is the generalized product development process described earlier. The relevant phases include planning, concept development and system level architecture. The second process will be called the Value Capture process and consists of three major components shown in figure 11.

- Value Chain Baseline—Strategic snapshot focused externally on the competitive landscape and internally on the strategy and capabilities of the company.
- Value Capture Development—Detailed integration of the value chain baseline with more specific product development concepts.
- Value Capture Pre-Selection—Comparison of value capture options based on strategic criteria and more detailed input from the product development team.

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[66] Stalk G, Evans P, Shulman L, Competing on Capabilities: The New Rules of Corporate Strategy, *Harvard Business Review*, March-April 1992, 57 – 69.

[67] Zahra S, Nielsen A, Sources of Capabilities, Integration, and Technology Commercialization, *Strategic Management Journal,* 2002; 23, 377 – 398.

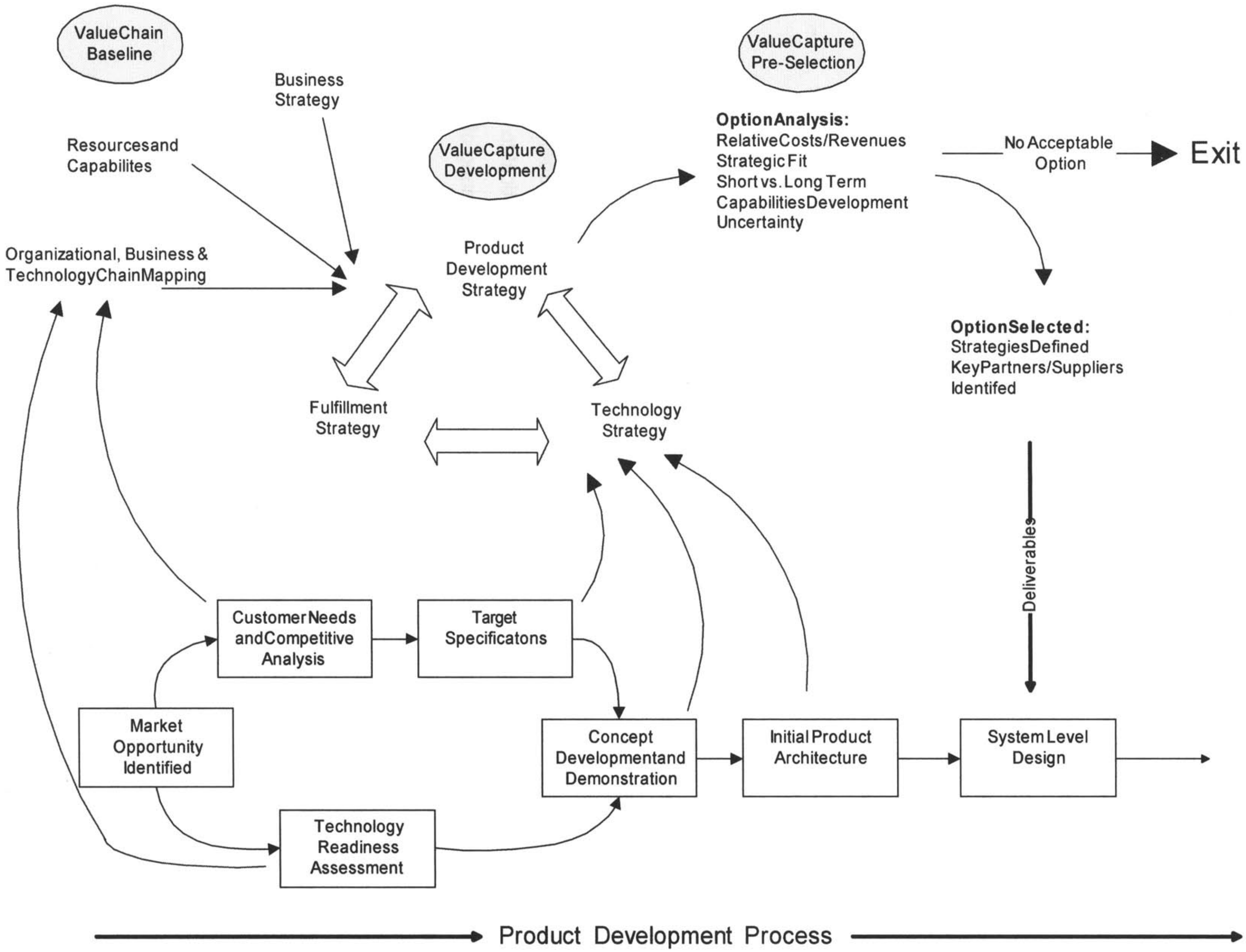

Figure 11: Product Specific Process to Develop Value Capture Strategies

The approach is defined as two parallel processes in order to highlight some key organizational issues. While companies clearly expend resources tackling market and technology uncertainty, it is not obvious how the two realms are integrated to develop a comprehensive strategic approach to the project. There is a tendency for the project leader to be either from marketing or technology development. In this situation, it is difficult to understand and carefully balance the uncertainties faced by both groups and develop an optimized solution for the whole. Additionally, it is unlikely that an individual chosen from either of these disciplines has the requisite knowledge of product development, particularly operations strategy to develop a strategic plan that develops complementary assets needed for the long term. The other approach companies take to solving the problem is bringing input from the marketing development and engineering teams together at a much higher level. In essence, the project is functionally oriented with the functional organizations reporting together at the director level or higher. This individual rarely has the time for detailed involvement.

What is needed is a project leader that is primarily focused on reconciling various sources of uncertainty and developing long term options to capture value from the innovation. This leader is supported by marketing and engineering team members and preferably has a solid product development background and experience crafting emergent strategy. The leader will also likely need an experienced operations strategy team member who will provide input on how various options to capture value affect the fulfillment chain. If the project is large, team leaders may be needed for the marketing and technology development teams. However, it is critical to maintain a flat structure to maximize integration between the functions and reduce the filtering of information needed by the team leader to execute the Value Capture Process.

5.2.1.1 Value Chain Baseline

The first phase of the process focuses on integrating early knowledge of the customer, the technology readiness, and the competitive environment. The process has the following inputs, activities, and outputs.

Inputs

- Technology readiness assessment
- Market opportunity description
- General description of customers needs (what does the product need to accomplish)
- Basic information on competitors, competitive products, and the structure of the value chain
- Existing elements of the business strategy

Activities:

- Value Chain Mapping—organizational, technology, capabilities, and functions/systems
- Internal resources and capabilities mapping
    - Identification of potential core rigidities
    - Preliminary identification of required capabilities

Outputs:

- Value chain maps
- Capabilities assessment
- 5 forces analysis of Industry
- Description of customer needs and relationship to market and technology readiness

5.2.1.2 Value Capture Development

The second phased utilizes more detailed product concepts and preliminary product architecture information to develop options for shaping the product development, technology, and fulfillment chains. This phase begins to identify critical areas of uncertainty. Phase 2 has the following inputs, activities and outputs.

Inputs

- Value chain/industry analysis
- Capabilities assessment
- Product target specifications
- Product concepts
- Preliminary functional results of concept demonstration*
- Preliminary assessment of product architecture options*

*Dependent on technology readiness and product complexity. More technically complex projects will likely need this information in order to proceed farther with the process.

Activities:

- Relate existing value chain to customer needs
    - "Integrate along what isn't good enough"
- Estimate long-term, high profit value chain locations
- Develop initial strategic options
    - Technology development/acquisition
    - Product design/development
    - Manufacturing supply chain (fulfillment)
- Identify areas of uncertainty and project risks

Outputs:

- General strategy for integration
    - Macro future value chain
- More detailed integration options
    - Potential partners/key suppliers
    - Proposed value chains
    - Technology development pathways
- Key areas of uncertainty

5.2.1.3 Value Capture Pre-Selection

Phase 3 involves incorporating updated information to develop specific recommendations to capture value. Potential partners are approached and the phase is iterated depending on the response of key partners/suppliers. The phase ends with several recommendations that are implemented if the project is selected to move forward. The inputs, activities, and outputs of phase 3 are shown below.

Inputs

- General integration strategy
- Detailed integration options
- Key areas of uncertainty
- Preliminary financial model and required financial performance
- Capabilities development targets from larger organization
- Updated information on technology/market uncertainties
- Updated information on systems architecture concepts

Activities:

- Update detailed integration options
- Utilize real options analysis to explore key areas of uncertainty and develop "real options" for selected elements of strategy
- Identify preferred integration option based on:
    - Fit with core values—flexibility and speed
    - Capabilities development
    - Estimated financial projections
    - Cultural and communications compatibility
    - Fit with known effective product development best practices
    - Fit with existing businesses
- Approach potential key partners/suppliers for preferred integration option
- Update uncertainties, risks and value chain assessments
- Iterate step 3 as needed based on feedback from key partners/suppliers

Outputs:

- Strategy describing approach and key suppliers/partners to
    - Develop technology
    - Design/develop the product
    - Manufacture the product (fulfillment)
- Estimated impact to key project assessment criteria
    - Financial model
    - Capabilities development
- Scenarios for how the value chain could develop
- Description of future "real options" to accommodate value chain, market, and technical uncertainty
- Finalized proposal delivered to decision makers for approval

5.2.2 Relating Product Specific Strategy Development and Product Development

A major emphasis of this approach is to drive an early, concurrent development of value chain development with product development. Most projects will have three fundamental supply chains that need to be explored and developed early in the technology commercialization process (See Figure 6):

- Technology Supply Chain
- Product Development Chain
- Fulfillment Chain

The technology supply chain is particularly important to the commercialization of complex products requiring multiple enabling technologies. The company may decide to in-license technology, enter into joint technology development agreements, purchase technology, or purchase complete sub-systems with the technology embedded.

The product development chain is critical to most projects since early in the process it involves technology assessment, concept development, prototype design and construction, and system level design.[68] Early in the process the team must understand existing capabilities and those required to develop the product. Decisions are made early to acquire capabilities or develop them internally. In order to integrate along attributes customers find most important, the design team coordinates early with the marketing group.

The fulfillment supply chain focuses on how the product will be manufactured and distributed to customers. All project teams will have to decide how much of the product will be manufactured internally and what will be purchased from suppliers. Careful consideration of the value chain is again critical to ensure that the company retains elements of the value chain that will be profitable in the future. The best outsourcing situation occurs when sub-system is modular and the company has the required knowledge but lacks the capacity to produce it. In these situations, there are often multiple suppliers with the required capacity and supplier power is diminished. Conversely, the worst outsourcing situation occurs when the sub-system has an integral architecture and the company is dependent for knowledge and capacity.[69]

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[68] Ulrich K, and Eppinger S, Product Design and Development, McGraw-Hill, Boston, Massachusetts, 2000, p. 16.

[69] Fine, C., Clockspeed: Winning Industry Control in the Age of Temporary Advantage, Perseus Books, Reading, Massachusetts, 1998, p. 169.

This process requires an early and frequent interaction between marketing, design, manufacturing, and business strategy experts to develop strategies to capture value. It is important that this is led by the strategic team in order to balance all of the functional uncertainties. This process enhances communication of uncertainties and encourages a cross-functional team approach to mitigate or resolve them. The early integration of R&D with Marketing and R&D directly with the customer are effective methods of improving the product development process.[70]

The identification of key areas of uncertainty is an important aspect of this process. The development of the three supply chains is much more difficult for a product based on disruptive technology. The process is dependent on recognizing key areas of uncertainty and developing real options to provide project flexibility. Because flexibility is critical, it must be valued as part of the process to compare value capture options. The most desirable approach from a static perspective based on a discounted cash flow analysis may be much less valuable than a project that requires more investment up front but builds in choices that can be exercised later to deal with areas of uncertainty. This process essentially facilitates a structured approach to emergent strategy that is critical early in the technology commercialization process.[71]

5.2.3 Evaluating the Options

The options generated by the value capture strategy development process should be evaluated based on financial targets, capabilities development, predicted effectiveness, flexibility, organizational alignment, and future value chain profitability.

The financial evaluation will likely be based on a discounted cash flow model. Uncertainty should be explored and valued through the use of real options. Overall levels of risk should be estimated.

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[70] Souder W, Sherman, D, Davies-Cooper R, Environmental Uncertainty, Organizational Integration, and New Product Development Effectiveness: A Test of Contingency Theory, *Journal of Product Innovation Management*, 1998; 15, 520 – 533.

[71] Triantis A, University of Maryland Roundtable on Real Options and Corporate Practice, *Journal of Applied Corporate Finance*, 2003; 15(2), 8 – 23.

Capabilities development includes ranking the projects based on their ability to improve the capabilities of the organization in key areas.

Predicted effectiveness involves a relative comparison of complexity of the various options to determine which ones are more likely to be executed effectively. Effectiveness can include time to market, product development cost, innovativeness, and intellectual property accumulation. Complex arrangements are more likely to result in coordination issues that drive increased costs and product development delays. Significant outsourcing may decrease intellectual property accumulation.

Evaluating the options on flexibility looks at the actual options that project has built in. While not all options are provided for, key areas of uncertainty should be addressed by options to modify the project at a later date. Most of the options will likely involve making small investments today sp that a strategic option is available tomorrow. Additionally, many options may be structured to increase the abandonment value of a project.

Organizational alignment focuses strictly on ensuring structural fit between the innovating group, the parent organization, and key partners. This is a particularly critical consideration for joint development agreements, joint ventures, acquisitions, mergers, and spin-outs.

Value chain profitability addresses positioning the company for dynamic forces that will affect the value chain in the future. Each dynamic force should be evaluated.[72]

5.3 Relationship between the Macro and Product Specific Approaches

The relationship between the two approaches is straight forward. The macro strategy provides direction and focus to the product specific strategy. The focus on capabilities development guides option development. Establishing core values such as flexibility and speed helps generate new ideas and evaluate them. Understanding the stages of technology commercialization reveals organizational insights critical to developing detailed options for specific projects. An emphasis on understanding uncertainty helps reveal trends or develop new ideas that are important to crafting emergent strategy.

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[72] Fine, C., Clockspeed: Winning Industry Control in the Age of Temporary Advantage, Perseus Books, Reading, Massachusetts, 1998, p. 30.

Chapter 6

Applying the Product Specific Process at ChevronTexaco

6.0 Chapter Overview

This chapter describes a product development project undertaken by Analytic Energy Systems, LLC (AES), a former subsidiary of ChevronTexaco Technology Ventures, LLC (CTTV), formerly known as Texaco Energy Systems Inc. The author arrived at AES approximately two months after the project idea was surfaced. For a period of three months, the author executed several steps of the Value Capture process while working with the product development team. The case study is meant to illustrate more concretely how the product specific value capture process enhanced the product development process. The process was not executed in its entirety so in several areas the author suggests hypothetical ways the approach could have been used and what the results may have been.

The project team consisted of the team leader, an AES marketing leader located in NY, two engineers from AES located in Boston, a technical advisor located in Houston, and the author also located in Boston. Each of the team members had a variety of other responsibilities.

The result of the analysis was that CTTV decided not to proceed with the emissions abatement project. The team concluded that CTTV would have no direct NO_x adsorber intellectual property or other technical advantages needed to take advantage of the most profitable location in the value chain as a catalyst provider or integrated system provider with catalyst capability. Additionally, the team identified several factors that all reduce the probability of CTTV or other companies profiting in this market.

- Catalytica Energy Systems had recently filed for patents in the area of NO_x traps but their scope was unknown
- Current regulations that promote emissions abatement for stationary engines are limited to non-attainment areas. Regulations are an external force that strongly influences market size and timing.
- Catalytica Energy Systems, a potential NO_x trap competitor, has already tested a prototype unit for mobile applications and is examining stationary applications.
- NO_x traps are still one of several promising methods of reducing emissions from stationary gas reciprocating engines. Engine manufacturers are actively pursuing solutions that attempt to eliminate the need for costly catalytic solutions.

The analysis approach was effective in systematically analyzing the value chain, industry structure, competitor positioning, and internal resources and capabilities. This information was loosely linked with preliminary product development efforts to better understand key areas of technological uncertainty. The process also facilitated a general discussion of the macro business strategy. However, since the entire product specific value capture process could not be completed, the overall effectiveness of the process could not be determined.

6.1 Emissions Abatement Overview

Emissions abatement is broadly defined as the reduction or elimination of harmful airborne emissions produced by combustion or other chemical processes. The Clean Air Act established in 1990 drove the creation of the National Ambient Air Quality Standards (NAAQS). These standards established safe thresholds for six toxic airborne pollutants. Areas of the country exceeding these limits are designated non-attainment areas and are required by law to develop plans to reduce pollution levels. Nitrogen Oxide (NO_2, NO or NO_x) has been receiving more attention as a precursor to the formation of Ozone, one of the six toxic pollutants regulated by NAAQS. Approximately 92 million people in the United States live in Serious to Extreme Ozone non-attainment areas. A wide variety of combustion sources are now facing new or tightened regulations for NO_x emissions.

6.2 Emissions Abatement Project Conception

From approximately 2001 to 2003, CTTV has engaged in research and development activities to create a device capable of producing fuel cell quality hydrogen by reforming natural gas. This device was sized to provide enough hydrogen for an approximately 5KW fuel cell. These activities led to the development of several proof of concept and more advanced prototype units that were originally intended to have commercialization potential. This unit was called the HALIAS™ and has been externally marketed at various trade shows, conferences, and on the CVX website.

For various reasons, there has been little demand for the HALIAS™ unit. The business development group at CTTV has continued to search for the earliest potential market opportunities for a hydrogen producing device. In the spring of 2003, market research indicated that a new type of pollution control technology, NOx traps, might be an early application for a hydrogen producing device.

Initial calculations suggested that a HALIAS™ sized unit would be appropriately sized for a NO_x trap system designed for an approximately 1 MWe emissions source. Since HALIAS™ reforms natural gas, it seemed appropriate to first examine opportunities for 1 MW sized natural gas engines, commonly used for distributed power generation.

6.3 Emissions Abatement Value Chain Baseline and Value Capture Development

This chapter provides an overview of the various activities that were conducted to establish a baseline understanding of the emissions abatement value chain for large (>500kw) stationary, natural gas reciprocating engines. Key activities included technology, market and regulatory reviews. Existing competitors and the current structure of the value chain were also researched. Information was collected regarding CTTV capabilities and business strategy.

6.3.1 NO_x Abatement Technology

The abatement of NO_x produced by internal combustion engines is primarily accomplished by Non-Selective Catalytic Reduction (NSCR or Three-way) for rich-burn engines and Selective Catalytic Reduction (SCR) for lean-burn engines. Three-way catalysts, commonly found in automobiles with gasoline engines, use catalysts to simultaneously reduce emissions of NO_x, carbon monoxide (CO), and volatile organic compounds (VOCs).[73]

> Three-way catalyst promotes the chemical reduction of NO_x in the presence of CO and VOC to produce oxygen and nitrogen. The three-way catalyst also contains materials that promote the oxidation of VOC and CO to carbon dioxide and water vapor. The standard catalyst typically achieves 90 percent reduction in NO_x 50 percent reduction in VOC, and 80 percent reduction in CO.

Electronic control systems are required to maintain the proper fuel/air ratio for maximum effectiveness. Three-way catalysts also operate in a narrow temperature range. Rich burn natural gas engines with three-way catalysts installed are capable of achieving emissions rates of .15 g/bhp-hr.

Natural gas fired reciprocating engines have historically operated in rich-burn conditions but are now transitioning to lean-burn technology. The increased air flow rate associated with lean burn conditions offers two primary advantages. First, increased oxygen saturation promotes a more complete combustion of the fuel, resulting in less fuel being wasted in the exhaust. Second, the

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[73] Appendix B of Best Available Control Technologies Regulations for California

lower operating temperature of lean-burn engines leads to improved durability and decreased maintenance costs. Efficiency advantages are especially noticeable for large engines where the increased controls complexity and cost is offset more rapidly by lower operating costs. The efficiency advantage is diminished for engines operating in combined heat and power (CHP) applications since much of the waste heat from a rich burn engine can be recycled.

The excess oxygen in lean burn applications prohibits the use of three-way catalysts and requires an alternative treatment method. SCRs rely on reactions between ammonia or urea and NO_x at high temperatures to abate NO_x emissions (See figure 12).[74]

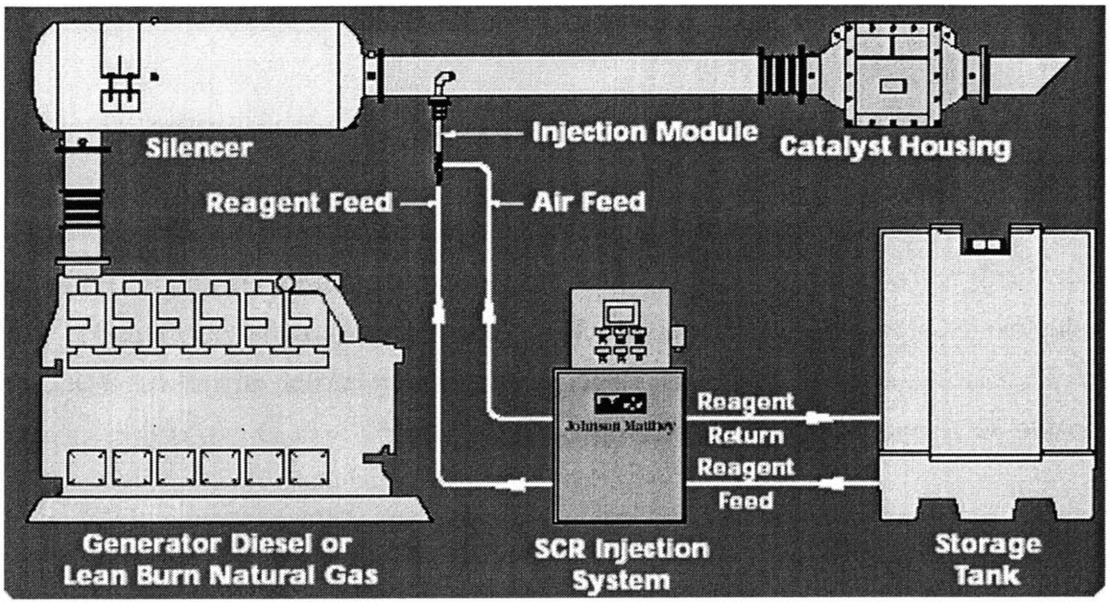

Figure 12: Selective Catalytic Reduction System[75]

These systems rely on complex control systems to sense the amount of NO_x in the exhaust stream and inject a precisely measure amount of ammonia. This mixture then reacts over the catalyst and the NO_x is reduced to Nitrogen.

$$6NO + 4\ NH_3 \rightarrow 5N_2 + 6H_2O$$
$$2NO + 4\ NH_3 + 2O_2 \rightarrow 3N_2 + 6H_2O$$
$$6NO_2 + 8\ NH_3 \rightarrow 7N_2 + 12H_2O$$

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[74] Bradford M, Grover R, Paul P, Controlling NOx Emissions Part 2, *CEP Magazine,* 2002, April, 38 – 42

[75] Johnson-Matthey, www.jmscd.com.

The reaction dynamics must be carefully controlled to minimize the amount of unreacted ammonia that emerges from the catalyst. SCR systems are quite effective at removing NO_x and are able to achieve emissions rates of .07 g/bhp-hr. However, many system costs do not scale with size. This typically makes the system prohibitively expensive for engines smaller than 1 MW. Additionally, the system has relatively high operating costs and requires the storage and handling of a hazardous substance.

NO_x adsorbers or NO_x traps rely on the chemical bonding of NO_x to the catalyst during lean operating conditions and the subsequent release of N_2 during the rich regeneration cycle. The reactions in the oxidation/adsorption cycle are as follows:[76]

$$CO + \tfrac{1}{2} O_2 \rightarrow CO_2$$
$$NO + \tfrac{1}{2} O_2 \rightarrow NO_2$$
$$4NO_2 + 2BaCO_3 \rightarrow 2CO_2 + Ba(NO_3)_2 + Ba(NO_2)_2$$

When the surface of the Barium catalyst becomes saturated with N_2, the system enters the regeneration phase where a dilute stream of H_2 is passed across the surface of the catalyst in the absence of oxygen.[77]

$$Ba(NO_3)_2 + Ba(NO_2)_2\ 4NO_2 + 6H_2 + 2CO \rightarrow\ 2BaCO_3 + +6H_2O + 2N_2$$

NO_x trapping technology has been successfully demonstrated. The two primary technology barriers to commercialization are sulfur tolerance and catalyst durability. The small amount of sulfur present in natural gas essentially poisons the catalyst and disrupts the reaction kinetics. Catalyst durability is a factor since the high temperatures required for the regeneration reaction in the presence of sulfur can lead to catalyst sintering. The catalyst would experience the regeneration process roughly once every ten minutes, dependent on the volume of catalyst used.

A NO_x trapping system would require a hydrogen source, control systems to monitor the catalyst loading, dual catalyst adsorbers for switching, and some method of cooling the exhaust gas temperature (around 550deg C) down to the trapping temperature of 300 deg C.

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[76] Majewski A, NOx Adsorbers, www.dieselnet.com, 2002, Sep
[77] Ibid.

NO_x traps have several advantages over three-way catalysts and SCR systems. NO_x traps can be used in lean conditions, including on-board trapping of NO_x from mobile diesel engines. NO_x traps eliminate ammonia handling and storage issues and secondary ammonia emissions. NO_x emissions would be competitive or better than emissions from SCR systems. Assuming catalyst durability issues could be resolved, operational expenses would be less than SCR systems. It was also estimated that initial systems costs would be somewhat less.

NO_x traps are a disruptive to the SCR business since they provide equivalent NO_x reduction performance while offering other attributes that customers value such as no ammonia handling and lower operating costs. Commercializing the technology requires different capabilities in catalysts and new capabilities in processing a hydrocarbon fuel into the H_2 needed for regeneration. NO_x traps also have the opportunity to open new markets involving mobile diesel engines.

Sources of technology uncertainty include sulfur tolerance and durability issues. However, the team also discovered over 100 patents regarding NO_x trap technology. Most of these patents were for mobile applications even though some claims seemed to be reaching towards stationary applications as well. Catalytica had recently filed for two new patents in this specific area, but their exact content will not be known until May 2004. EmeraChem is also utilizing similar technology for gas turbine applications but has chosen to keep their process proprietary.

6.3.2 Market and Regulatory Environment

The market for emissions abatement technology is also quite uncertain. The market is driven by Federal regulations, but each state, county or city may establish their own requirements. New regulations, typically stricter, are always being proposed, but their timing is uncertain and subject to political forces.

The team's original charter focused on stationary natural-gas internal combustion engines. Current regulations that promote emissions abatement for stationary engines are limited primarily to non-attainment areas in California, Houston, and the North East (particularly Massachusetts). In 2002, total sales of SCR systems for stationary engines exceeded 500 units, or approximately $100 million.

The team received early executive management pressure to think about larger markets in order to provide the necessary return on capital needed to develop the technology. Several estimates of larger markets were made with one estimate of worldwide purchases of NO_x control equipment averaging $2 billion/year over the next five years.[78] While these large generalized estimates were placed in project proposals, they were never anchored to specific regulatory requirements. In order to address a manageable scope, the author focused on stationary gas reciprocating engines in non-attainment areas with existing strict regulatory requirements. In Southern California, the south coast air district limited NO_x emissions to .15 g/bhp – hr for engines smaller than 2064 hp. The limit in Massachusetts is .2 g/bhp-hr for engines larger than approximately 325 kwe.

6.3.3 Competitive Analysis

The initial stage of the competitive analysis involved collecting information that was freely obtainable from public sources. Analysis focused on companies supplying SCR systems and companies known to be developing NO_x traps.

The primary competitors in the SCR market include Miratech, Johnson Matthey, and Englehard. Miratech is a small, privately held company focused on providing emissions solutions for stationary internal combustion engines. Annual revenue is estimated to be less than $5 million. Miratech is partnered with HUG engineering for SCR catalyst technology. Miratech is the U.S. distribution channel for HUG and sells a complete system. Miratech is the most recognized SCR brand in the United States.

Johnson Matthey is a large, vertically integrated specialty chemicals company with an emphasis on catalysts and precious metals trading. Revenues not derived from metals trading were $1.9 billion in 2003. In 2003, Johnson Matthey launched three new SCR systems targeted at stationary power applications, including reciprocating engines and turbines. Johnson Matthey is a leading provider of three-way catalysts for automotive applications.

Englehard is a large, diversified surface and materials science company. Revenues in 2002 were $3.8 billion. Englehard is a major supplier of catalysts used in stationary and mobile applications. Englehard is working to develop NO_x adsorber catalysts for the mobile diesel engine market. They are currently providing NO_x trap catalysts on a sample basis.

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[78] See www.mcilvainecompany.com

Catalytica Energy Systems (CES) and Emerachem are the leading competitors for NO_x trap development. CES is a small, public company focused on the application of catalysts to combustion systems and next generation fuel processing applications to reduce emissions of power generation and transportation systems. The company has primarily been focused on the commercialization of their Xonon cool combustion technology and in 2002 had a net loss of $18 million. In 2001, CES was awarded a $12 million cost-shared contract by the DOE to develop a compact fuel processor capable of operating in mobile applications.

Emerachem is a small, privately held company with annual sales of approximately $40 million. Emerachem has developed a NO_x adsorber system that is currently targeted at gas-fired turbine power plants. The Emerachem system is marketed to be capable of lower NO_x levels than SCR while being price competitive.

6.3.4 Industry Analysis

Porter's five forces analysis approach was used to evaluate the industry (See Figure 13). The industry was defined as pollution control for large (>500kw) stationary, gas reciprocating engines. Current products for post combustion treatment include 3 way catalysts for rich burn engines and SCR systems for lean burn engines. The strength of each external force is determined by evaluating the industry with several detailed criteria. A detailed analysis of the first force, barriers to entry, is shown in figure 13.

Barriers to entry describe various industry forces that would make it difficult for new competitors to enter the industry. As an industry incumbent, high barriers to entry are extremely attractive. The first barrier to entry, economies of scale, examines whether industry incumbents enjoy increasing operating efficiencies as the scale of their business grows. Rapidly increasing economies of scale make it difficult for new entrants to compete on cost since existing companies benefit from a lower cost structure. The emissions abatement product is an engineered, discrete system whose manufacture would likely involve some economies of scale. However, the most significant economies of scale probably involve the product of the catalyst. Examining the remaining elements of barriers to entry yields a composite evaluation of moderately high barriers to entry which are moderately attractive to incumbent competitors. The remaining elements of barriers to entry and the rest of the five forces are described in detail in Appendix A.

Industry Definition: Pollution control for large (>500kw) stationary, gas reciprocating engines. Current products for post combustion treatment include 3 way catalysts for rich burn engines and SCR systems for lean burn engines.

Attractiveness of Barriers to Entry for Incumbents

BARRIERS TO ENTRY		HIGHLY UNATTRACTIVE	MILDLY UNATTRACTIVE	NEUTRAL	MILDLY ATTRACTIVE	HIGHLY ATTRACTIVE	
Economies of scale	Small				X		Large
Product differentiation	Little				X		Big
Brand identification	Low			X			High
Switching cost	Low				X		High
Access to distribution channels	Ample			X			Restricted
Capital requirements	Low			X			High
Access to latest technology	Ample				X		Restricted
Access to raw material	Ample				X		Restricted
Government protection	Nonexistent	X					High
Experience effect	Unimportant				X		Very important

Increasing Barriers to Entry →

Figure 13: Analysis of Barriers to Entry

A composite score for each of the five forces is shown in figure 14. Barriers to entry, rivalry among competitors, and availability of substitutes are all mildly attractive to industry incumbents. Assuming industry incumbents do not have their own catalyst capability, catalyst supplier power is high making the industry highly unattractive.

OVERALL ASSESSMENT	HIGHLY UNATTRACTIVE	MILDLY UNATTRACTIVE	NEUTRAL	MILDLY ATTRACTIVE	HIGHLY ATTRACTIVE
Barriers to entry				X	
Rivalry among competitors				X	
Power of buyers			X		
Power of suppliers	X				
Availability of substitutes				X	

Figure 14: Composite Five Forces Analysis of the Pollution Control for Large (>500kw) Stationary, Gas Reciprocating Engines

Clearly this industry segment is driven by regulations which are visible signals of market opportunities. However, the regulatory complexity and their capacity to change require careful consideration and do somewhat decrease the attractiveness of the market.

There are several barriers to entry that make this market attractive for incumbents. Perhaps the most significant and still unknown barrier is existence of intellectual property. However, once the market is penetrated, the industry is mildly attractive, particularly if you have your own source of catalyst.

The catalyst suppliers appear to be capturing the largest value from this industry. Emissions performance is becoming an increasingly important point of engine differentiation and catalyst performance is critical to the emissions abatement product. Few catalyst suppliers provide catalysts for stationary gas reciprocating applications. Additionally, few catalyst suppliers provide an integrated emissions abatement solution.

Rivalry is more intense in other segments such as gas turbines and diesel engines.

6.3.5 Analysis of CTTV Resources and Capabilities

Information was gathered from conversations with various CTTV employees in the fuel cells and fuel processing organization to obtain a general overview of organizational resources and capabilities. The resource analysis examined tangible, intangible, and human resources. The assessment of organizational capabilities focused on capabilities in marketing, technology development, product development, support processes and business processes. An estimate of CTTV resources and capabilities is shown in Appendix B. The information in this thesis should not be construed as a complete description of CTTV resources and capabilities.

The resources and capabilities were compared to 5 criteria to determine which competencies are distinctive.[79] Because of confidentiality, this information is not included.

Scarcity: Availability of resource/capability
Relevance: Linkage to key industry success factors.
Durability: Ability of resource/capability to endure over time
Transferability: The ability of resources/capabilities to move between companies
Replicability: Ease to replicate a given resource/capability

These capabilities can also be viewed as potential core rigidities to commercializing the emissions abatement technology. One potential core rigidity was the organization's strong linkage to the ChevronTexaco business processes. ChevronTexaco is quite proficient at performing complex cash flow analysis of various market opportunities. However, in this situation of market and technology uncertainty, the value is less certain and may have distracted from other more important activities. A second potential core rigidity was high overhead costs that are related to how the organization was formed and the structure and culture of the parent unit.

6.3.6 Value Chain Analysis

Information gathered on the existing structure of the SCR and NO_x adsorber value chains is shown in Figures 15 and 16. The diagrams illustrate the key value elements of the chain and the integration level of the competitors. The required capabilities for each stage of the chain are shown along with key technologies that influence overall system performance.

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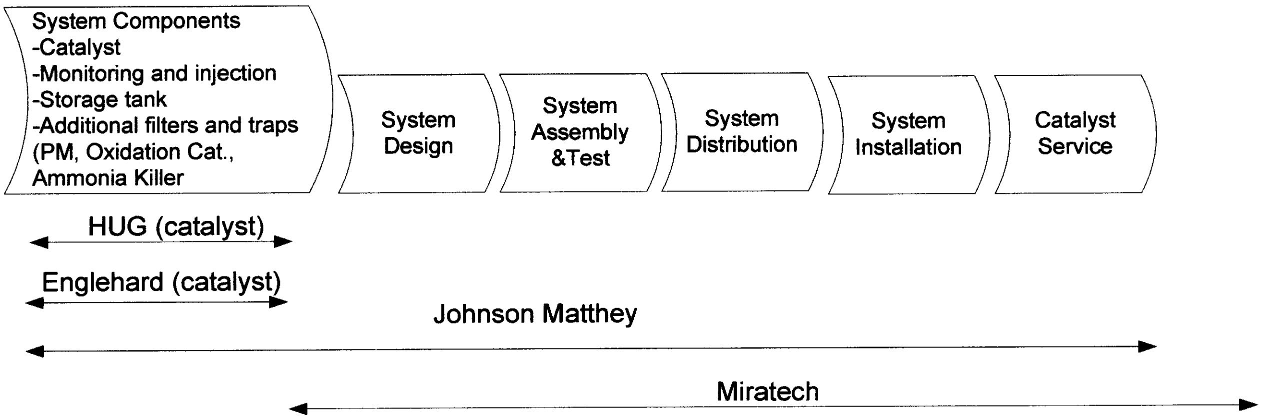
[79] Grant R, <u>Contemporary Strategy Analysis: Concepts, Techniques, Applications</u>, Blackwell, Cambridge, Massachusetts, 1995, p. 128.

Exhaust Treatment Value Chain
Stationary Sources--SCR

Selective Catalytic Reduction System with Ammonia or Urea



System Components
-Catalyst
-Monitoring and injection
-Storage tank
-Additional filters and traps (PM, Oxidation Cat., Ammonia Killer

System Design

System Assembly &Test

System Distribution

System Installation

Catalyst Service

HUG (catalyst)

Englehard (catalyst)

Johnson Matthey

Miratech

Capabilities Chain

–Product development skills –Detailed customer knowledge –System optimization skills –Design for assembly –Functional engineering skills	–Manufacturing system –Supplier management –Assembly capability –Configuration control –Process engineering –Testing capability	Packaging and Logistics	Product Service Network	--Chemical processing –Regulatory

Technologies Chain

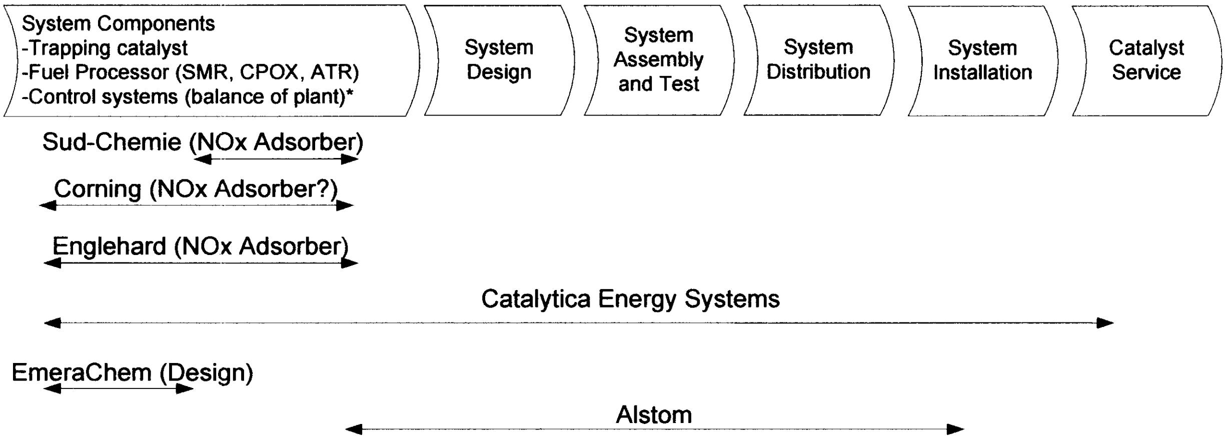
Key technologies driving SCR system performance or manufacturing

–Catalyst temp. range
–Reactive controls that automatically adjust inject rate
–Ammonia/air mixing to obtain proper mist for reaction on catalyst

Figure 15: Exhaust Treatment Value Chain for SCR

Exhaust Treatment Value Chain
NOx Adsorber

NOx trap with H2 regeneration



Capabilities Chain

--Product development skills
--Detailed customer knowledge
--System optimization skills
--Design for assembly
--Functional engineering skills
--Regulatory knowledge

--Manufacturing system
 --Supplier management
 --Assembly capability
 --Configuration control
 --Process engineering
--Reliability analysis and testing capability

Packaging and Logistics

Product Service Network

--Chemical processing
--Regulatory

Technologies Chain

Key technologies driving NOx trapping system performance
--Sulfur trapping and sulfur tolerance
--Catalyst peformance degradation after regeneration
--NOx trapping temperature range

* Balance of Plant
--Control systems--electronics
--Blower
--Sensors: thermocouples, mass flow controllers
--Valves and fittings

Figure 16: Exhaust Treatment Value Chain for NO_x Adsorber

6.3.7 CTTV Existing Business Strategy

During this project, the overall business strategy was in flux. Much of the uncertainty was driven by the timing of the commercialization of fuel cells. CTTV has primarily positioned itself as a fuel processing technology provider. CTTV is researching new technology to economically and effectively convert hydrocarbon fuels into hydrogen. The primary markets for this type of distributed hydrogen production include fuel cell based automobiles and fuel cell based distributed power generation. Because these markets are still perceived to be quite distant, CTTV has also been researching other applications for its hydrogen generation technology. These applications would provide an early, if small revenue stream to support continued development until larger markets matured. CTTV has been successful in obtaining DOE funding for a next generation technology for processing natural gas into high purity hydrogen (>98%).[80]

CTTV has focused on basic research and product development that extends through early prototyping. CTTV sub-contracted the manufacturing of advanced HALIAS™ to a supplier of test equipment for the fuel cell industry. CTTV is still considering the merits of having their own manufacturing capability. As a non-manufacturing oriented company, this type of operation is outside of their existing capability set.

6.3.8 Target Specifications and Product Concepts

While the team did have some understanding of general customer needs obtained from popular literature, a detailed analysis of customer needs was not performed. That is, a set of target customers was not identified and interviewed by the team before the project ended. The team primarily relied on the team leader's previous experiences in the power industry for customer knowledge.

Identified customer needs included NO_x reduction performance exceeding regulatory requirements, the ability of the system to accommodate high-temperature exhaust gases, a

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[80] Department of Energy, DE-SC02-03CH11137.

need to avoid wasting heat that could be used for CHP applications, and a general desire that the system be durable and require low maintenance.

The team developed several preliminary product concepts based on the high level understanding of customer needs. The team did not have an opportunity to test or evaluate any of the product concepts.

6.3.9 Summary of Value Chain Baseline and Value Capture Development

The value chain and industry analysis indicate that the most profitable location in the value chain is as a catalyst provider or integrated system provider with catalyst capability. Technological hurdles to NO_x adsorber commercialization are dominated by catalyst issues. Catalyst performance is the "not good enough" factor and will require the continued development of catalysts and systems that optimize catalyst performance.

Stationary markets for SCR and NO_x adsorber catalysts are relatively small markets compared to the mobile catalyst markets and companies without catalyst intellectual property will encounter a substantial amount of catalyst supplier power.

The value chain baseline analysis uncovered the following significant factors that all reduce the probability of CTTV profiting in this market.

Technological

- CTTV has no direct NOx adsorber intellectual property or technological advantages in the catalyst component.
- It is unclear, if and when NOx adsorber technology will be effective enough for the emissions abatement market opportunity.
- Catalytica Energy Systems has recently filed for patents. It is assumed that they involve NOx trap system technology but the scope of their claims is unknown.

Market

- Current regulations that promote emissions abatement for stationary engines are limited to non-attainment areas. Future regulations may become more encompassing, but the timing is unknown. In 2002, total sales of SCR systems for stationary engines exceeded 500 units. This market is much smaller that originally anticipated and would likely be fiercely defended by companies like Miratech, especially for engines larger than 1 MW. Rich burn engines with three-way catalysts are still common options for engines < 1 MW.

Competition

- Catalytica Energy Systems has already partnered with 2 diesel engine manufactures and has tested a prototype emissions abatement unit for the mobile market. In 2001, they received a DOE contract for $11 million to develop multi-fuel processing technology. They state their technology could also be applied to stationary applications.
- Cummins has announced new engine technology that maintains generator set efficiency at 37.8% while achieving emissions of (.096 g/hp hr). This process combines exhaust gas recirculation with a 3 way catalyst.
- The major catalyst suppliers are actively pursuing the mobile emissions market.

Capabilities

- While CTTV's existing capabilities in system integration and catalyst selection and optimization would be important for this product, it is unclear how much of a competitive advantage they would provide.

Partnering

- The gas reciprocating engine manufacturers are already partnered with multiple groups as part of the Advanced Reciprocating Engine program to improve engine efficiency and reduce emissions.
- In developing a NO_x abatement product, CTTV's existing fuel processing partners with catalyst capabilities would likely benefit more from working directly with a catalyst supplier such as Catalytica Energy Systems than with CTTV.

6.4 Emissions Abatement Value Capture Pre-Selection

Most of the tasks from stage 1 and stage 2 of the Value Capture process were completed for the Emissions Abatement product. A project review was held at which the results of the previous actions were examined. At the review, Professor's Fine and Hardt both recognized that this project had little potential to be successful. CTTV management also participated in the conversation and concurred with the assessment. After the meeting, the emissions abatement project was effectively canceled and team members were redirected.

While it is difficult to develop detailed recommendations for a hypothetical situation, it is somewhat useful to examine potential issues had the outcome been different. Assuming that CTTV did have significant NO_x adsorber catalyst intellectual property that was clearly differentiated from competitors and a potential market that justified the capital expenditure, CTTV would have had to address the following strategic issues:

- CTTV could potentially license the technology to Catalytica or Englehard, but it is difficult to determine how valuable this license would be without knowing the uniqueness of their approach, the size of the developing market, and how much leverage they would have with partners. Additionally, integration issues would likely be substantial since key pieces of the NO_x adsorber system are not yet modularized.

- Commercializing the technology themselves would have likely required integration along the axis of optimizing system performance to support catalyst durability.
- Determining which pieces of the system to outsource would also be driven by existing capabilities deficiencies. Since this is essentially an entry niche market to support development for larger markets, a capabilities alignment analysis would need to be performed. For example, gaining experience in manufacturing some system components and assembling them may build capabilities that could be used to manufacture and assemble fuel processors.

CTTV would need a mechanism to value the advantages of developing a manufacturing capability. Developing this capability was not part of the current long-term business strategy. However, with substantial uncertainty in the fuel cell value chain, would a future manufacturing capability be a valuable asset?

This question lead to the next phase of the project which examined utilizing the real options framework to support strategy development in a highly uncertain environment.

Chapter 7

Uncertainty and the Real Options Framework

7.0 Chapter Overview

CTTV is currently operating in an extremely uncertain environment. All the classical uncertainties that face disruptive technologies are present in the fuel cell and hydrogen industry. Ten years ago, many "believers" predicted technology commercialization by 2000. Now it is 2004 and the technology is still squarely hunkered down in the limited application phase where it continues to rely on investment from equity markets, venture capital, internal R&D and government funding to sustain further research and development. The value chain is still in flux as companies continually reassess which technologies will emerge as the dominant standard. Given the uncertainty regarding where future profits will fall in the value chain, a strong argument can be made for developing real options that better position the company for several outcomes.

One potential scenario involves examining who will manufacture the fuel processing equipment that will produce hydrogen. The fuel processing competitors are faced by a significant challenge in that no company has ever mass produced what is essentially a small chemical plant. Full commercialization of fuel cells for automotive or distributed power applications could require annual production quantities in the thousands. However, traditional energy companies developing technology in fuel processing have little or no previous capability developing and manufacturing discrete, engineered products on this scale.

This scenario can be made even more realistic by examining how the profits have been distributed in the DRAM industry.[81] While a substantial amount of revenue has flowed to DRAM manufactures like Micron and Samsung, most of the profit kept flowing to the manufacturing equipment suppliers like Applied Materials. In this situation, Micron and Samsung were providing relatively undifferentiated products that become commodities. In order to remain marginally profitable, the DRAM manufacturers relied on sophisticated equipment from Applied Materials to continually improve yields and reduce costs. In this example, the "not good enough" axis was manufacturing equipment performance and Applied Materials profited

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[81] Fine, C., Clockspeed: Winning Industry Control in the Age of Temporary Advantage, Perseus Books, Reading, Massachusetts, 1998, p.79.

immensely by selling integrated equipment that was differentiated along an axis that the customer valued.[82]

For CTTV, the big question is what part of the value chain will become a commodity and what part will remain differentiated? For purposes of examining the value of real options in developing strategy, this chapter will explore how real options are used to demonstrate the value of CTTV building its own manufacturing capability. While the numbers in the case have been disguised, the original analysis was conducted using actual financial models and market projections.

> "Remember, though, that real options are not just about 'getting a number'. The rigour of thinking about strategic decisions as real options can help you make better decisions."[83]

Incorporating modest perturbations to market share, gross margin and manufacturing costs in the financial model revealed that reduced manufacturing costs contributed the least to variance of the project's NPV. Projected linkages between internal manufacturing capability and technology commercialization success manifested as increased market share and gross margin were the primary drivers in improving the projects probability of profitability from 60% to 81%. The process of valuing this underlying asset revealed that the extreme level of uncertainty associated with fuel cell development renders the actual cost of follow on investments required to create a manufacturing capability almost insignificant in determining the option's value since these costs will only be encountered if the hydrogen market is highly profitable. The option analysis financially justifies a limited short term investment in manufacturing capability that could be expanded in the future given the appropriate conditions. While not modeled, this investment would also have some abandonment value if the right conditions for internal commercialization did not develop.

The most significant value of this process involved exploring the indirect linkages between manufacturing capability and technology commercialization. Applying the real options analytic framework provided a more tangible way of framing the role of manufacturing in the hydrogen fuel processing industry. Hopefully the analysis will stimulate further conversation regarding the adequacy and flexibility of the existing strategy and the role equipment manufacturers might play in the future value chain.

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[82] Christensen C. and Raynor M, The Innovator's Solution, Harvard Business School Press, Boston, Massachusetts, 2003, p.155.
[83] Walters C and Giles, T, London Economics Company

7.1 Developing the Baseline Financial Model

Performing a real options analysis requires a baseline net present value financial model. The model includes estimates of sales revenue, cost of goods sold, and overhead costs required for product development. The model estimates the annual net income generated by the fuel processor product over a period of 20 years. The NPV of the project is determined from these cash flows. CTTV provided the baseline financial model that was used in this analysis. The value of several variables is described with a normal distribution based on range estimates provided by the CTTV business development group. These original estimates of variable distributions are used throughout the analysis unless specifically noted.[84]

Describing many of the key variables with distributions facilitated a Monte Carlo simulation of the baseline financial model. CTTV had previously performed simulations in order to determine the distribution of the project's NPV. The author's simulation confirmed the unsurprising result that market size, market share, and gross margin have the highest percent contribution to variance in the project's NPV.

7.2 Calculating the Value of a "Manufacturing Option"

The process of valuing a manufacturing option involves determining the value of the underlying asset, estimating its volatility, developing the structure of the option, and finally calculating the value of the option. This section of chapter 7 applies the real option analysis method introduced in chapter 2.5. Readers can find additional information on performing real options analysis in Jonathan Mun's book "Real Options Analysis: Tools and Techniques for Valuing Strategic Investments and Decisions". The example analysis provided by Shockley, et. al. in their article titled "The Option Value of an Early-Stage Biotechnology Investment" was particularly helpful in performing this analysis.

7.2.1 Determining the Value of the Underlying Asset

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[84] Details of all the variables and their distributions are not available because of confidentiality.

The underlying asset is what you receive if you exercise the option.[85] The underlying asset for the manufacturing option is the incremental increase in the expected project NPV. This assumes that developing manufacturing capabilities will result in increased product development effectiveness and efficiency and therefore a higher NPV.

The complex nature of companies competing to make a profit makes it quite difficult to estimate the impact of any particular capability on the bottom line. While existing research does not quantify the results of developing a manufacturing capability, it does describe various mechanisms through which companies possessing a manufacturing capability can improve their performance. These mechanisms are illustrated with a system dynamics diagram based on the research of how an internal manufacturing capability can affect technology commercialization success.[86] Specifically, this model assumes that developing an internal manufacturing capability can positively affect technology commercialization (TC) speed, the number of new products introduced, product innovativeness, and the generation of patents (See Figure 17). The model is a graphical representation of the proposed causal relationship between these variables and sales margin and market penetration, the most significant variables in the baseline NPV analysis. For simplicity, the model did not incorporate balancing causal loops which would prevent ever increasing market penetration and sales margin. However, the model is complete enough to describe how developing an internal manufacturing capability could positively affect key measures of technology commercialization success and eventually lead to increased profits.

The following example is helpful in understanding the nomenclature of the model.

- An increased number of patents discourages new competitors and decreases competitive forces on the company.
- Decreased competition and increased product attractiveness result in increased sales prices.
- Increased sales prices, decreased unit costs, and an increased sales rate all result in a higher profit rate.
- A higher profit rate results in an increasing accumulation of retained earnings that are drained over time by investments in new capabilities.

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[85] Shockley R, Curtis S, Jafari J, Tibbs K, The Option Value of an Early-Stage Biotechnology Investment, *Journal of Applied Corporate Finance,* 2003; 15(2), 44 – 52.

[86] Zahra S, Nielsen A, Sources of Capabilities, Integration, and Technology Commercialization, *Strategic Management Journal,* 2002; 23, 377 – 398.

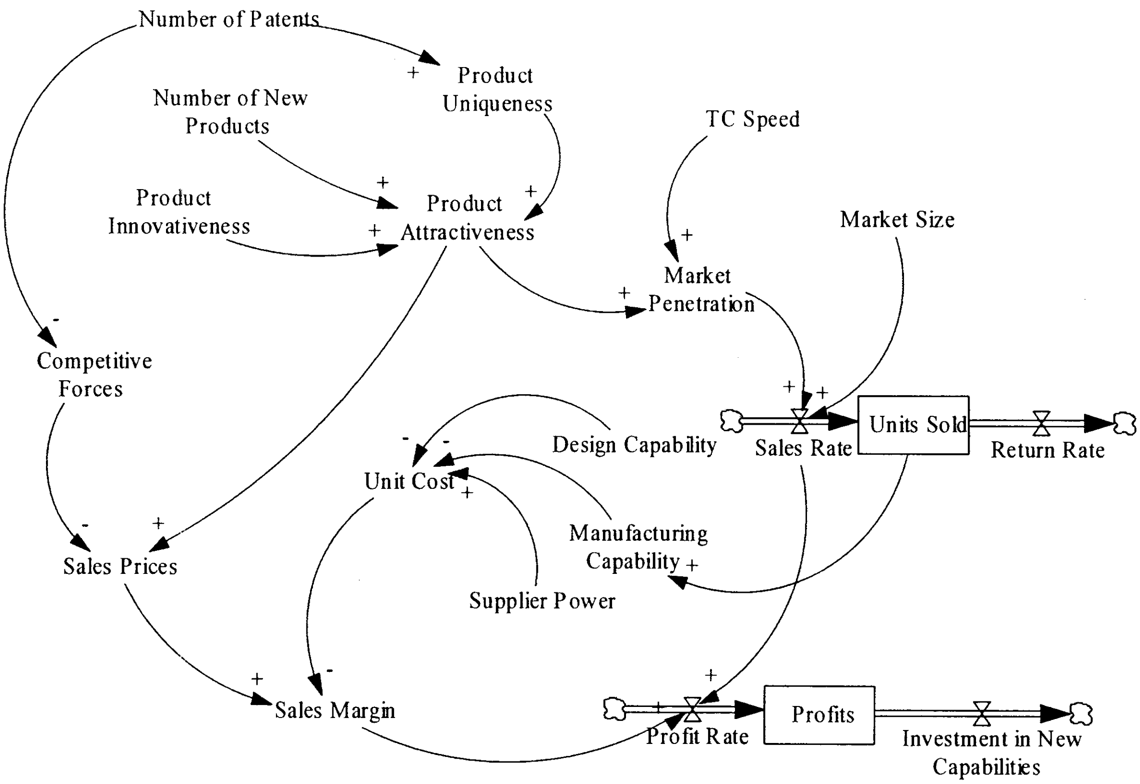

Figure 17: Dynamic Model of How Internal Manufacturing Capability Affects Key Variables

The next step in the real options analysis involved modifying the financial model to account for the benefits of possessing manufacturing capability. Modifications to the model primarily focused on changing variables with the most contribution to variance in the NPV. The above causal loop diagram indicates that manufacturing capability would have an affect on margins and market penetration. These variables were modified as follows:

- Primary market share—mean value increased by 20%. Standard deviation of the normal distribution held constant. For example, a mean value of 10% market share was increased to 12%.
- Secondary market share—mean value increased by 33%. Standard deviation of the normal distribution held constant. For example, a mean value of 9% market share was increased to 12%.
- Average gross margins—mean value increased by 10%. Standard deviation of the distribution was reduced by 50% to account for decreased uncertainty in operations. For example, a mean value of 20% gross margin was increased to 22% while a standard deviation of 10% was reduced to 5%.

The determination of these increases was somewhat arbitrary in that they are not based on any quantitative research. Rather, adjustments were made that appeared significant, but not unreasonable.

While manufacturing costs did not substantially contributed to the project's NPV during the baseline Monte Carlo simulation, further modeling of the variable was performed to further examine the proposed relationship between manufacturing capability and unit costs. Substantial changes were made to mean assembly costs in order to detect the variable's effect on project NPV.

- Average assembly costs were decreased by 45% to account for improved manufacturing efficiency. The distribution was narrowed by 50% to account for decreased manufacturing uncertainty.

Before performing another Monte Carlo simulation to compare the distribution of the baseline model's NPV with the NPV of the modified model, it is important to understand the interrelationship of key variables. When running the simulation, the model must account for correlations between variables. For example, in this model it is likely that a company's activities that lead to increased primary market penetration will also lead to increased secondary market penetration. This correlation was modeled by arbitrarily setting the correlation coefficient between the variables to .8. Similarly, primary market penetration and gross margins are both influenced by product attractiveness (see figure 17). The correlation coefficient between primary market penetration and gross margins was set to .55. The relationship between these variables is somewhat weaker since unit costs could also heavily influence gross margins.

With the correlations in place, another sensitivity analysis was performed for the baseline and the modified models (see figures 18 and 19). In the baseline model, gross margin, primary market penetration and secondary market penetration accounted for 81% of the variance in the project's NPV. These same variables accounted for 65% of the NPV variance in the modified. With the exception of manufacturing cost, variables in the modified model had a more balanced contribution to variance of the dependent variable, NPV. The primary explanation for this change is that increased market penetration in the modified model increased the relative importance of primary market size and secondary market growth rate.

Another significant aspect of the sensitivity comparisons is the minor effect manufacturing cost variability had on the overall variability of the model, despite its significant adjustment in the manufacturing option. For the modified model, manufacturing cost contributed to less than .1% of the variance in NPV. This further reinforces the point that developing a manufacturing capability is not necessarily done to solely reduce manufacturing cost.

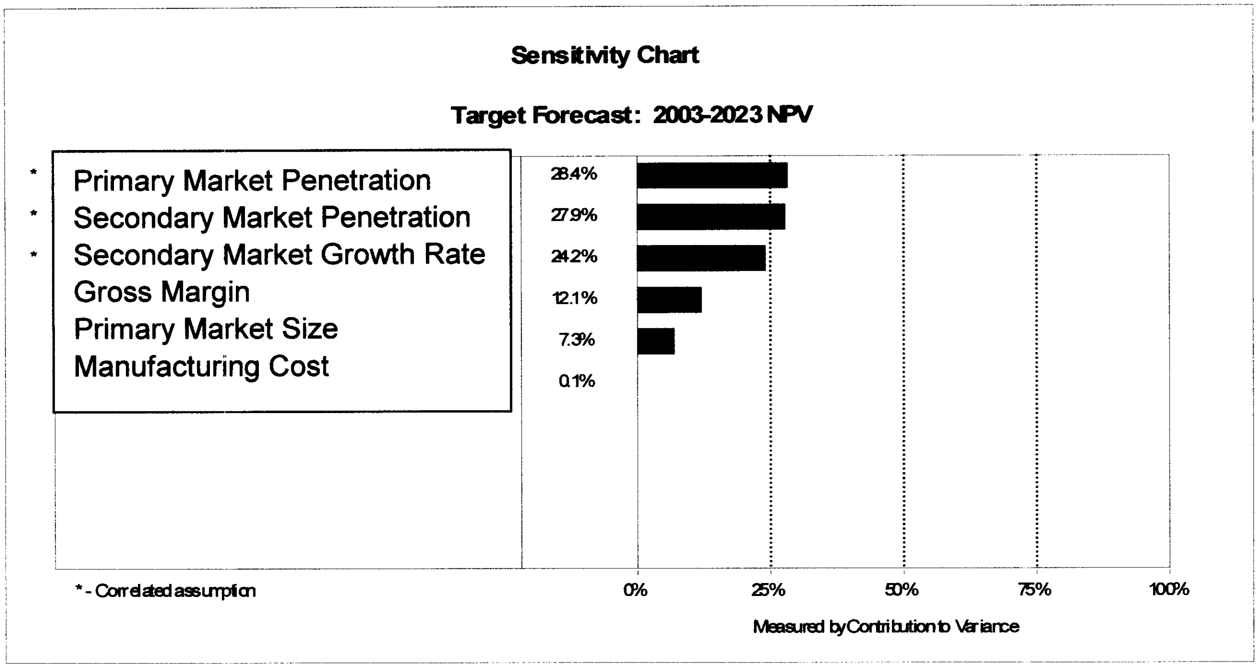

Figure 18: Contribution to Variance for Baseline Model

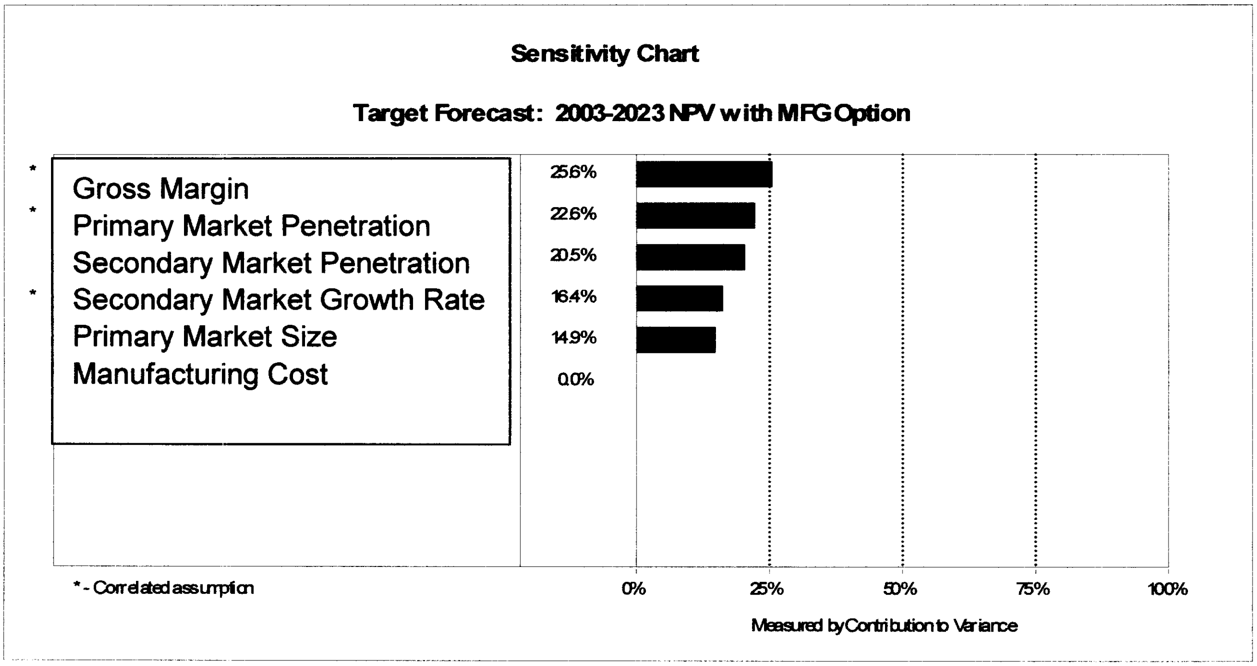

Figure 19: Contribution to Variance for Model with Manufacturing Capability

A final Monte Carlo simulation was performed for the baseline model and the revised model in compare the distributions of the dependent variable, the project's NPV. (Actual numbers have been disguised).

Baseline Model	**Revised Model with Manufacturing Capability**
Mean = $100	Mean = $200
Median = $50	Median = $150
STDEV = $200	STDEV = $200
Probability of Profitability = 60%	Probability of Profitability = 81%

While the NPV standard deviation for both models was similar, the financial model incorporating the manufacturing capability yielded a higher mean value for the project's NPV. This translated into the project having a higher probability of a NPV greater than zero. Specifically, the probability of profitability was determined by examining what fraction of the NPV distribution was greater than zero.

In this analysis, the value of the underlying asset for the manufacturing option is the incremental increase in the expected project NPV. This provides an underlying asset value of $100 ($200 - $100).

7.2.2 Estimating Volatility

The next step in determining the option's value is estimating the volatility of the underlying asset. For stocks, volatility is the standard deviation of the stock's annual return. Individual stocks commonly have a volatility of 35 to 40%.[87] For real options, volatility is a measure of the uncertainty in the value of the underlying asset.[88] Projects with high uncertainty regarding future cash flows have high levels of volatility.

In this situation, the value of the underlying asset varies with the NPV of the baseline model. This point is illustrated with the following example. Assuming a profit margin of 20%, $50 in sales generates $10 in profits. Similarly, $100 in sales generates $20 in profits. Increasing the profit margin by 10% provides $11 and $22 in profits based on sales of $50 and $100

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[87] Vayanos, D., Finance Theory I Lecture Notes, MIT.

[88] Shockley R, Curtis S, Jafari J, Tibbs K, The Option Value of an Early-Stage Biotechnology Investment, *Journal of Applied Corporate Finance,* 2003; 15(2), 44 – 52.

profit margin by 10% provides \$11 and \$22 in profits based on sales of \$50 and \$100 respectively. The increase in profit is \$1 or \$2 depending on the sales level. In this model, the value of the underlying asset is correlated with the variability of the project's NPV in the baseline analysis.

A technique described by Copeland and Antikarov can be used to determine the volatility associated with the baseline NPV model.[89] The technique involves discounting all the cash flows back to time 0 with independent variables set at their expected values. The sum of these cash flows is A and is a static value. Variable B is the sum of all the cash flows, excluding time 0, discounted back to time 1. Variable B is a dynamic variable obtained from each trial of the model. Using Monte Carlo simulation, a distribution X is generated where $X = \ln (B/A)$. Volatility is estimated as the standard deviation of X. This process was used to obtain an estimated volatility of 120% or 1.2. This volatility was somewhat conservative since only non-negative values of B could be used in this approach. This volatility is consistent with other highly uncertain research and development projects. Shockley uses a volatility of 100% in estimating the uncertainty involved with an early stage bio-technology investment.

7.2.3 Developing the Option Structure

Developing the option structure involves examining the strategic ways the option could be implemented. In the case of developing manufacturing capability, implementing the option seemed likely to involve a series of investments (See Figure 20) The option would be acquired now and, if exercised, would require additional investments five and ten years from now in order to develop a credible manufacturing capability. This is called a sequential compound option where investing now buys the option to invest later in another option. While acquiring the option has some cost now, the majority of the investment is not made until favorable project conditions are more certain.

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[89] Copeland T and Antikarov V, Real Options: A Practitioner's Guide, Texere, New York, 2001.

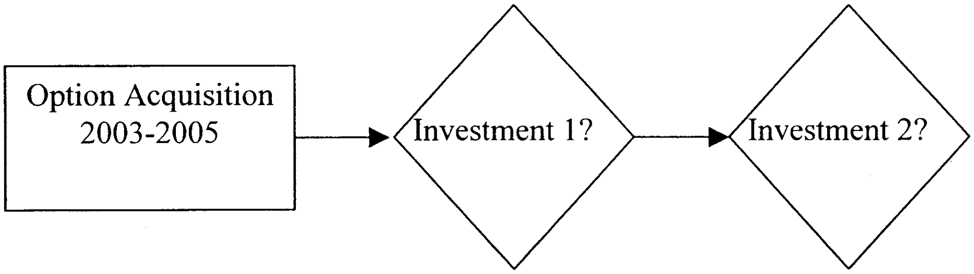

Figure 20: Structure of Sequential Compound Option

First and second minimum implementation costs of \$30 and \$60 were assumed as a starting point. A Weibull distribution with a long tail was used to characterize the uncertainty in the investments that might be required (Appendix C).

7.2.4 Analyzing the Option With the Binomial Lattice Approach

The binomial lattice approach was used to value the sequential compound option.[90] First, the lattice of the underlying values was created for the time period 2003 to 2015 utilizing 1 year time increments. The following equations are necessary to compute the value of the lattice.

$$u = \text{up probability} = e^{\rho}$$
$$d = \text{down probability} = 1/u$$
$$rnp = \text{risk neutral probability} = (e^{rf} - d)/(u - d)$$
$$dr = \text{discount rate} = 1/e^{rf}$$

where ρ = volatility and rf is the risk free rate

The binomial lattice of the underlying asset is constructed by starting with the expected value of the underlying and then multiplying by the up and down probabilities to calculate the two values to the right. Details of the calculations are shown in Appendix D.

The lattice of the option value is constructed from right to left based on the lattice of the underlying asset. The mechanics of constructing this lattice are also shown in Appendix D.

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[90] Shockley R, Curtis S, Jafari J, Tibbs K, The Option Value of an Early-Stage Biotechnology Investment, *Journal of Applied Corporate Finance,* 2003; 15(2), 44 – 52.

Monte Carlo simulation of both binomial lattices was performed to better understand how the variance of the option value was impacted by changes in the value of the underlying asset, the volatility and the two implementation costs. The simulation was first performed with the expected values and distributions shown in Appendix C. The analysis revealed that the value of the underlying asset contributed to 88.9% of the variance in the option's value (see figure 21). Correspondingly, actual implementation costs had little effect on the option value. This result occurs because the option is only exercised when the potential NPV of the project is high.

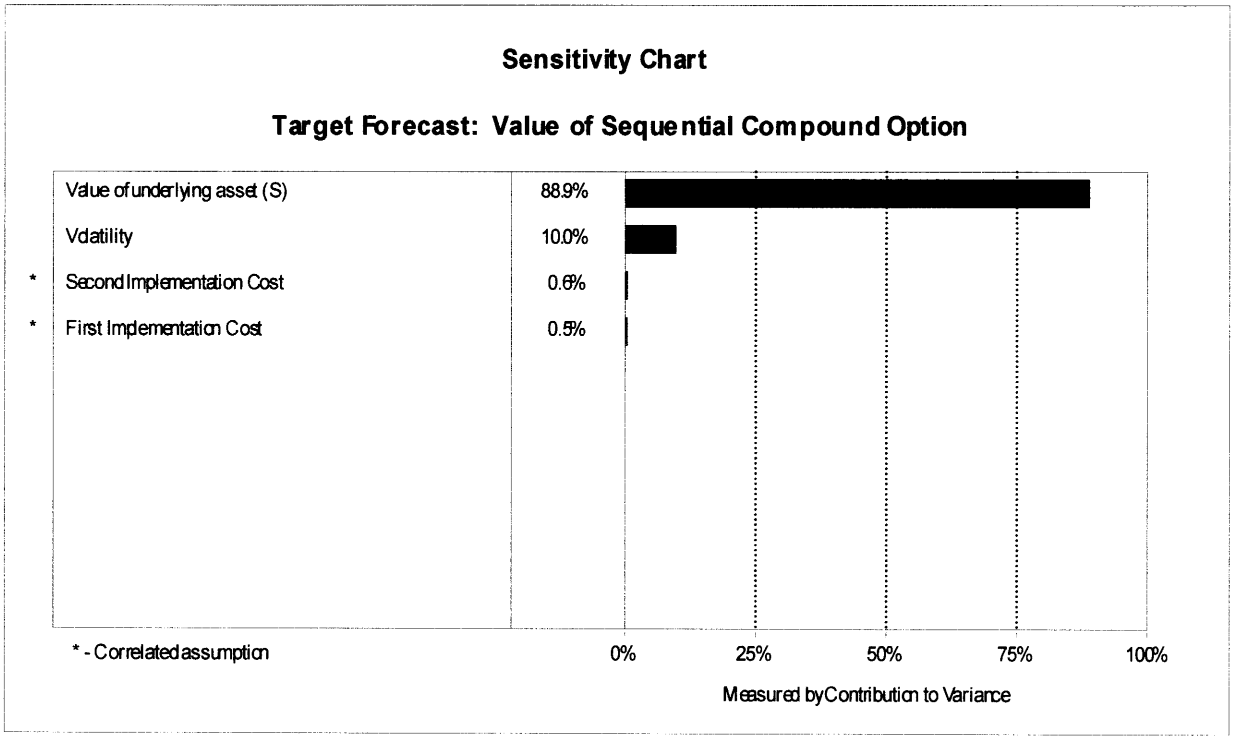

Figure 21: Contribution to Variance for Volatility Range .7 to 1.2.

For the volatility range .7 to 1.2, the Monte Carlo simulation returns an expected option value of $84.2, close to the underlying asset value of $100. The standard deviation of the option value is $18.6.

Since high volatility generally yields option values approaching the value of the underlying asset[91], a volatility range of .2 to .7 was used to explore the affects of lower volatility. Another simulation and sensitivity analysis was performed with the new volatility range (see figure 22).

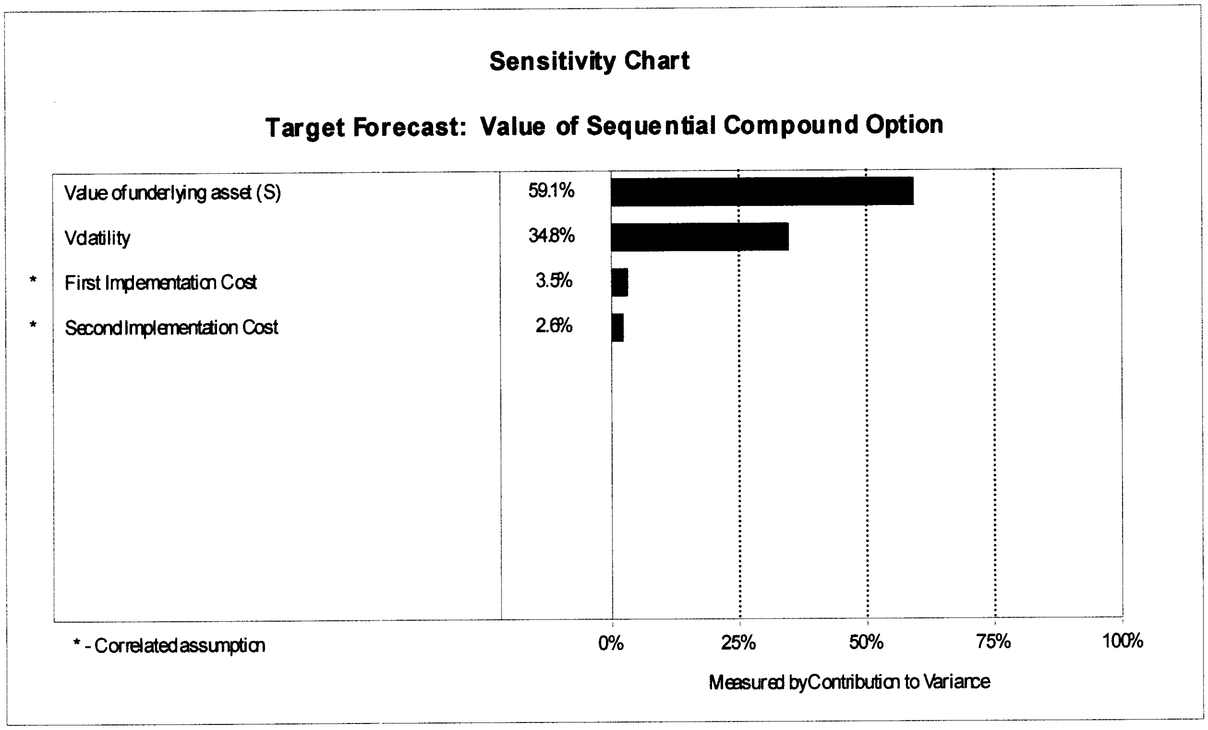

Figure 22: Contribution to Variance for Volatility Range .2 to .7.

This simulation indicates that the actual volatility level now has a substantial impact on the option value. Since the calculation of the underlying lattice is based on compounded growth utilizing volatility as the growth rate, the value of the underlying asset is heavily influenced by the volatility level. Implementation costs still have a minor affect but are becoming more significant. The simulation predicts an expected option value of $53.3 with a standard deviation of 20.5.

7.2.5 Interpreting the Results

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[91] Ibid.

The analysis demonstrates the importance of trying to determine the value of the underlying asset since the value of the option can never exceed the value of the underlying asset.

Assuming the project is operating in the high volatility range, the value of acquiring the right to develop a manufacturing capability is $84.2. For this option, acquiring the right to develop a manufacturing capability involves making some investment in people and capital. CTTV should be willing to spend less than $84.2 over the next 5 years to acquire the right to further develop a manufacturing capability. This approaches delays substantial investment until some uncertainty is resolved while providing CTTV a strategic alternative that can be expanded in the future.

7.3 Assessing the Value of the Real Options Approach

While the real options framework does develop an actual value to developing a manufacturing capability, the real power of the tool lies elsewhere. When CTTV was presented with this analysis, one of the most interesting comments was provided by a senior technology manager. He stated that he never thought about manufacturing like this before and the analysis was quite useful. The tool may provide some justification of expenditures to develop this strategic option. In the end, its most significant role was to stimulate further conversation regarding the adequacy and flexibility of the existing strategy and the role equipment manufacturers might play in the future value chain.

Chapter 8

Conclusions

8.0 Conclusions

This thesis has presented a two pronged approach that enables the development of strategies for capturing value from disruptive technologies.

The macro level strategy guides the company's strategy development process by emphasizing emergent strategy, the transition to complementary assets, and a focus on navigating the limited application phase of technology commercialization. Applying this process to the development of hydrogen fuel processing equipment encouraged a deeper understanding of the role manufacturing might have as a complementary asset in the development of this industry. Additionally, utilizing the real options framework provided a systematic method of assessing the specific ways a manufacturing capability might improve a company's technology commercialization success rate. The real options analysis also estimated the financial value of developing this strategic option to accommodate market, technology, and value chain uncertainty in the hydrogen industry. .

The product specific strategy provides a rigorous process for exploring the value chain, identifying sources of uncertainty, and developing specific options for capturing value from commercializing disruptive technology. The application of this process to the emissions abatement project enabled a comprehensive examination of external factors such as market uncertainty, competitive forces and the structure of the value chain. The process also considered internal factors such as technology maturity, existing resources and capabilities and existing business strategy. This integrated approach lead to the conclusion that the project's risk significantly outweighed its reward and the project was abandoned. In this sense, the framework may have demonstrated additional value as a process for determining which projects should proceed and which should be stopped.

The intertwining of the two processes creates a system that encourages the exchange of information between teams developing the macro strategy and groups engaged in product development. This feedback process is critical to detecting and crafting emergent strategy and guiding capabilities development. The execution of both processes provides a holistic and rigorous approach to capturing long term profits from the commercialization of disruptive technologies.

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Appendix A: Five Forces Analysis

Industry Definition: Pollution control for large (>500kw) stationary, gas reciprocating engines. Current products for post combustion treatment include 3 way catalysts for rich burn engines and SCR systems for lean burn engines.

Attractiveness of Barriers to Entry for Incumbents

BARRIERS TO ENTRY		HIGHLY UNATTRACTIVE	MILDLY UNATTRACTIVE	NEUTRAL	MILDLY ATTRACTIVE	HIGHLY ATTRACTIVE	
Economies of scale	Small			X			Large
Product differentiation	Little				X		Big
Brand identification	Low			X			High
Switching cost	Low				X		High
Access to distribution channels	Ample			X			Restricted
Capital requirements	Low			X			High
Access to latest technology	Ample				X		Restricted
Access to raw material	Ample				X		Restricted
Government protection	Nonexistent	X					High
Experience effect	Unimportant				X		Very important

Increasing Barriers to Entry →

Economies of scale—As engineered, discrete systems, there are economies of scale that would tend to protect incumbents from new entries. However, the most substantial economies of scale are probably related to the production of catalyst.

Product differentiation—Most products do seem to be differentiated based on performance. 3 way catalysts might be closer to becoming a commodity. SCR systems are complex enough that competition is based on other factors—performance, support, ease of use, etc.

Brand identification—There does seem some element of brand identification. Miratech, Hug and Johnson Matthey were really the only 3 companies mentioned for SCR.

Switching cost—Switching costs do appear to be a factor—at least for an SCR type system. Some training is required depending on the amount of user intervention and maintenance.

Access to distribution channels—For potential retrofit products, access is good, thus decreasing the entry barrier. However the current market is really driven by regulations for new products. The distribution channels for new engines are more restricted. New entrants could either could go through the engine manufacturers (preferred) or work with an existing after treatment provider that may not have a competitive product.

Capital requirements—For manufacturing low volumes (thousands or lower—15 minute takt time), capital requirements might not be too bad for assembly and integration. This work could be performed manually in manufacturing cells.

Access to latest technology—This is uncertain. There could be substantial blocking IP that creates a large barrier to entry.

Access to raw material—If raw material is considered catalyst, this could be restrictive. There are a limited number of catalyst suppliers.

Government protection—The govt. is basically encouraging new entrants by continually tightening the regulations and increasing the market size.

Experience effect—Catalyst is again key. It is really not known how difficult it will be to develop a good catalyst and integrate it into an efficient system. Catalyst experience could be significant.

SUMMARY—The threat of entry is moderately low (mildly attractive barriers). Which is good if you're an incumbent. Most all of the categories discourage new participants. The biggest wildcard is the access to technology. Emerachem and Catalytica, while not currently providers of commercial products for this segment, could both have IP positions that prevent a NOx adsorber entrant.

Attractiveness of Rivalry Among Competitors for Incumbents

RIVALRY AMONG COMPETITORS		HIGHLY UNATTRACTIVE	MILDLY UNATTRACTIVE	NEUTRAL	MILDLY ATTRACTIVE	HIGHLY ATTRACTIVE	
Number of equally balanced competitors	Large				X		Small
Relative industry growth	Slow				X		Fast
Fixed or storage cost	High			X			Low
Product features	Commodity				X		Specialty
Capacity increases	Large increments			X			Small increments
Strategic stakes	High			X			Low

Decreasing Rivalry Among Competitors →

Number of equally balanced competitors—The competitors appear to be unbalanced. Miratech is a small private company while Johnson Matthey is a large vertically integrated corporation. This tends to decrease rivalry.

Relative industry growth—Industry growth is moderate and will likely continue to grow globally.

Product features—SCR systems are not commodity products. There is an opportunity to customize the product to specific customer needs.

Capacity increases—It depends upon the structure of the entrant, but capacity increases could be in small to medium increments.

Strategic stakes—Small, niche companies have high strategic stakes. Larger companies have small stakes.

SUMMARY—Rivalry appears to be moderately low (mildly attractive). The industry is growing and the competitors are unbalanced. These are not commodity products. The industry of providing emissions reduction solutions for diesel engines and turbines is another story—lots of competitors that may be more evenly balanced.

Attractiveness of Power of Buyers for Incumbents

POWER OF BUYERS		HIGHLY UNATTRACTIVE	MILDLY UNATTRACTIVE	NEUTRAL	MILDLY ATTRACTIVE	HIGHLY ATTRACTIVE	
Number of important buyers	Few		X				Many
Availability of substitutes for industry products	Many				X		Few
Buyer switching cost	Low			X			High
Buyers' threat of backward integration	High			X			Low
Industry threat of forward integration	Low	X					High
Contribution to quality or service to buyers' products	Small				X		Large
Total buyers' cost contributed by the industry	Large fraction		X				Small fraction
Buyers' profitability	Low			X			High

Decreasing Buyer Power

→

Number of important buyers—If buyers are considered to be engine OEMs, there are few important buyers. It appears that dealers may be able work with different after market providers.

Availability of substitutes for industry products—There are not a lot of substitutes available to buyers when low NOx is required.

Buyer switching cost—Switching costs are average.

Buyers' threat of backward integration—Some of the engine providers could potentially backward integrate.

Industry threat of forward integration—Threat of forward integration is very low.

Contribution to quality or service to buyers' products—NOx performance will become an increasing large part of an engine manufacturers performance.

Total buyers' cost contributed by the industry—For SCR applications, the cost is a significant cost of the package. Could be 20 to 40% of engine price.

Buyers' profitability—The engine manufacturers are moderately profitable. This is a competitive market but not "cutthroat".

Buyer Power Summary—Buyer power moderate. Number of buyers, threat of backward integration, no threat of forward integration and total buyers cost contributed by industry all increase buyer power. Availability of substitutes, increasing contribution to quality, and to some extent switching costs—decrease buyer power.

Attractiveness of Power of Suppliers for Incumbents

POWER OF SUPPLIERS		HIGHLY UNATTRACTIVE	MILDLY UNATTRACTIVE	NEUTRAL	MILDLY ATTRACTIVE	HIGHLY ATTRACTIVE	
Number of important suppliers	Few			X			Many
Availability of substitutes for the suppliers' products	Low	X					High
Differentiation or switching cost of suppliers' products	High		X				Low
Suppliers' threats of forward integration	High		X				Low
Industry threat of backward integration	Low		X				High
Suppliers' contribution to quality or service	High	X					Small
Total industry cost contributed by suppliers	Large fraction	X					Small fraction
Importance of the industry to suppliers' profit	Small		X				Large

Decreasing Supplier Power →

Number of important suppliers—There are several major catalyst suppliers including: Sud Chemie, Johnson Matthey, Corning, and Englehard. There are a variety of smaller catalyst players. For some of the smaller private companies, it is difficult to determine from where they obtain their catalyst.

Availability of substitutes for the suppliers' products—Basically no substitutes.

Differentiation or switching cost of suppliers' products—Switching might be difficult if system was optimized for a particular supplier's unique catalyst.

Suppliers' threats of forward integration—For catalyst supplier, the threat is real. Not all catalyst suppliers are interested in providing integrating systems, but the threat is significant.

Industry threat of backward integration—There is some threat of backward integration, but it is probably quite small since it is fairly difficult to develop expertise in catalyst technology and manufacturing.

Suppliers' contribution to quality or service—Catalyst performance will be critical to the performance of the system. It is not expected that hydrogen production will have a significant impact on system performance.

Total industry cost contributed by suppliers—Catalyst cost is substantial. Followed next by H2 generator.

Importance of the industry to suppliers' profit—The currently targeted market would be a fairly small fraction of the catalyst suppliers overall profit. However, it could grow as the technology is spread to other applications.

Supplier Power Summary—Catalyst supplier power is moderately high to high which is highly unattractive for incumbents that do not have their own catalyst.. Hydrogen producer power is moderately low.

Attractiveness of Availability of Substitutes

AVAILABILITY OF SUBSTITUTES		HIGHLY UNATTRACTIVE	MILDLY UNATTRACTIVE	NEUTRAL	MILDLY ATTRACTIVE	HIGHLY ATTRACTIVE	
Availability of close substitutes	Large				X		Small
User's switching costs	Low				X		High
Substitute producer's profitability and aggressiveness	High			X			Low
Substitute price/value	High				X		Low

Decreasing Substitute Availability →

Availability of close substitutes—Substitutes could be considered alternatives to distributed power that burn clean. For California, they have specifically mandated gaseous fuels. This may include small gas turbines equipped with SCR, low NOx burners, XONON catalytic combustion and/or flue gas recirculation. However small turbines (< 5 MW) have electrical efficiencies in the high twenty's and would only be competitive in a CoGen applications. Microturbines might be another distributed power substitute but they are not very efficient. Fuel cells are currently too expensive.

User's switching costs—Adding new types of distributed generation does add to the training and maintenance costs of a facility.

Substitute producer's profitability and aggressiveness—Most of the substitute providers are not terribly profitable.

Substitute price/value—All of the competing substitutes have lower efficiencies or prohibitive costs. Diesel engines are the least expensive but have higher emissions.

Substitute Summary—The threat of substitutes is currently moderately low for gas recip engines. Currently the largest obstacle for gas. Recips. is grid power. If the unit is not used in a CHP application, the economics may not be attractive since an increasingly large % of grid power is now produced from gas turbines. That is, gas recips. will be susceptible to the same natural gas price fluctuations as the utilities and may not be economic to operate. This reasoning does not take into account the other advantages of DG.

Regulatory

Regulations are fragmented but becoming increasing tighter across the world. Regulations based on BACT support the development of higher performing systems—especially if they treat all the hazardous substances and GHGs without introducing new chemicals such as urea. Regulations that become more output based and take into account efficiency will further drive the importance of after treatment systems that don't affect CHP applications. Regulatory consulting could also be a lucrative side business as almost all installations call in a consultant.

Summary of Industry Attractiveness for Incumbents

OVERALL ASSESSMENT	HIGHLY UNATTRACTIVE	MILDLY UNATTRACTIVE	NEUTRAL	MILDLY ATTRACTIVE	HIGHLY ATTRACTIVE
Barriers to entry				X	
Rivalry among competitors				X	
Power of buyers			X		
Power of suppliers	X				
Availability of substitutes				X	

Summary

Clearly this industry segment is regulation driven. Regulations are visible signals of market opportunities. However, the regulatory complexity and their capacity to change require careful consideration and do somewhat decrease the attractiveness of the market.

There are several barriers to entry that make this market attractive for incumbents. Perhaps the most significant and still unknown barrier is existence of intellectual property. However, once the market was penetrated, the industry is mildly attractive, particularly if you have your own source of catalyst.

It appears that the catalyst suppliers are capturing the largest value from this industry. Emissions performance is becoming an increasingly important point of engine differentiation and catalyst performance is key to the emissions abatement product. There are not many catalyst suppliers that provide catalysts for stationary gas recip. applications. Additionally, not many catalyst suppliers provide and integrated emissions abatement solution.

Rivalry does appear to be more intense in other segments such as gas turbines and diesel engines.

Appendix B: Assessment of CTTV Resources and Capabilities

Resources

Tangible
- Access to ChevronTexaco capital
- Petroleum refining and distribution infrastructure
- Fuel processor testing facilities
- Catalyst test lab
- Reactor test lab
- Equity stake in several joint ventures (Batteries, hydrogen storage, solar)

Intangible
- ChevronTexaco brand name
- Intellectual property around novel fuel processing technology

Human
- Access to ChevronTexaco resources in catalysts and metallurgy
- Highly educated and trained technical work force

Organizational Capabilities (or competencies)

Marketing

- New business opportunity identification
- Marketing capabilities both market pull and technology push

Technical

- Catalyst selection and optimization
- Catalyst packaging (e.g. loading the catalyst material in a reactor)
- Balance of plant development for a 5 kw fuel processor
    - Controls—software, hardware
    - Pump and motor selection
- System integration
- Prototype reliability testing
- Liquid fuels knowledge

Product Development Process

- Experience from concept development to alpha prototype

Support Processes
- Change management
- Environmental, Health and Safety

Business Processes

- Partnering with external companies
- Licensing/IP process
- Process is focused on capital stewardship

Appendix C: Distribution of Key Variables Used for Valuing the Manufacturing Option

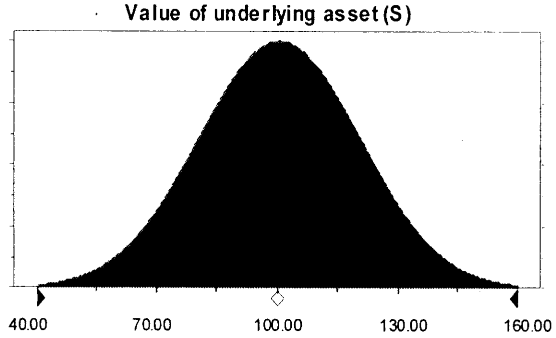
Assumptions

Assumption: Value of underlying asset (S)

Normal distribution with parameters:

Mean	100.00
Standard Dev.	20.00

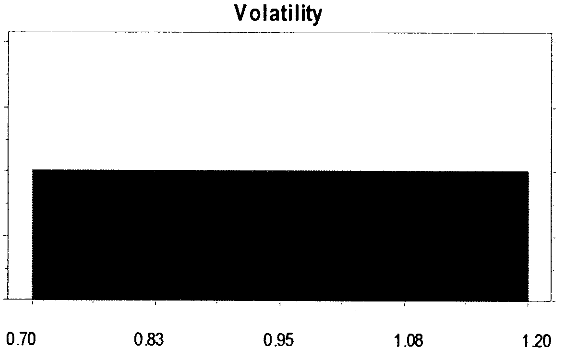
Selected range is from -Infinity to +Infinity



Assumption: Volatility

Uniform distribution with parameters:

Minimum	0.70
Maximum	1.20

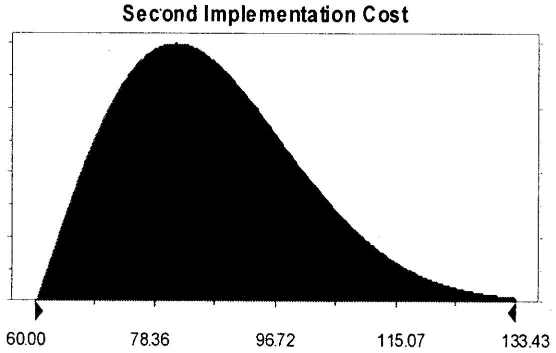


Assumption: Second Implementation Cost

Weibull distribution with parameters:

Location	60.00
Scale	30.00
Shape	2

Selected range is from 60.00 to +Infinity



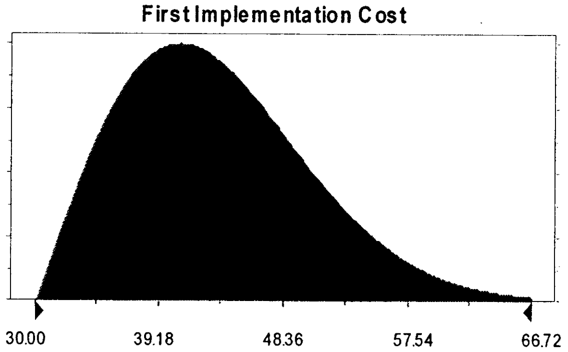
Correlated with:
First Implementation Cost .75

Assumption: First Implementation Cost

Weibull distribution with parameters:

Location	30.00
Scale	15.00
Shape	2

Selected range is from 30.00 to +Infinity



Appendix D: Calculating the Binomial Lattice

Lattice of the Underlying Asset

Value of underlying asset (S)	100
Volatility	0.95
Risk free rate	0.05
Second Implementation Cost	60
First Implementation Cost	30

u = 2.58571
d = 0.386741
rnp = 0.302201
Discount rate= 0.951229

Scenario assumes two investments in manufacturing capabilities. The first investment in 2010 and the second investment in 2015.

2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
100.0	258.6	668.6	1,728.8	4,470.1	11,558.4	29,886.7	77,278.4	199,819.6	516,675.4	1,335,972.7	3,454,437.5	8,932,172.3
	38.7	100.0	258.6	668.6	1,728.8	4,470.1	11,558.4	29,886.7	77,278.4	199,819.6	516,675.4	1,335,972.7
		15.0	38.7	100.0	258.6	668.6	1,728.8	4,470.1	11,558.4	29,886.7	77,278.4	199,819.6
			5.8	15.0	38.7	100.0	258.6	668.6	1,728.8	4,470.1	11,558.4	29,886.7
				2.2	5.8	15.0	38.7	100.0	258.6	668.6	1,728.8	4,470.1
					0.9	2.2	5.8	15.0	38.7	100.0	258.6	668.6
						0.3	0.9	2.2	5.8	15.0	38.7	100.0
							0.1	0.3	0.9	2.2	5.8	15.0
								0.1	0.1	0.3	0.9	2.2
									0.0	0.1	0.1	0.3
										0.0	0.0	0.1
											0.0	0.0
												0.0

Example Calculation for 2004:

258.6 = 100 * u = 100 * 2.58

38.7 = 100 * d = 100 * .386

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Lattice of the Option Value

2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
86.8	236.2	634.0	1,681.3	4,412.1	11,491.6	29,813.8	77,201.7	199,770.5	516,623.8	1,335,918.4	3,454,380.4	8,932,112.3
	28.5	81.2	227.1	622.2	1,670.4	4,401.0	11,481.7	29,837.6	77,226.8	199,765.3	516,618.4	1,335,912.7
		7.8	24.1	72.6	214.0	610.6	1,657.9	4,421.0	11,506.8	29,832.4	77,221.4	199,759.6
			1.4	4.8	16.7	58.0	201.9	628.2	1,677.1	4,415.8	11,501.4	29,826.7
				0.0	0.0	0.0	0.0	77.2	220.1	614.3	1,671.7	4,410.1
					0.0	0.0	0.0	6.7	21.0	65.6	201.5	608.6
						0.0	0.0	0.3	1.0	3.3	11.5	40.0
							0.0	0.0	0.0	0.0	0.0	0.0
								0.0	0.0	0.0	0.0	0.0
									0.0	0.0	0.0	0.0
										0.0	0.0	0.0
											0.0	0.0
												0.0

Example Calculation for 2015:
608.6 = Max (668.6 – 60, 0) (Decision to incur second implementation cost)

Example Calculation for 2014
1,671 = Max of ((4,410 * rnp + 608.6 * (1-rnp)) * discount rate) and 0

Example Calculation for 2010
201.9 = Max of ((628.2 * rnp + 77.2 * (1-rnp)) * discount rate - 30) and 0
(Decision to incur first implementation cost)