COMMERCIAL VIABILITY OF BIOMASS DERIVED LIGNIN IN THE RESIN AND CARBON FIBER INDUSTRIES

by

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PROJECT SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF BUSINESS ADMINISTRATION

In the Masters of Technology Program
of the
Faculty
of
Business Administration

SIMON FRASER UNIVERSITY

Summer 2012

Approval

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Degree: **Master of Business Administration**

Title of Project: **Commercial viability of biomass derived Lignin in the Resin and Carbon Fiber industries**

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Abstract

Plant biomass is a sustainable energy source that can be used directly, or converted into other compounds like carbon fiber and resins. The full potential of plant biomass is difficult to exploit as up to 30% of the biomass consists of the complex compound lignin, which is difficult to degrade efficiently. Drs Eltis and Bugg have found that by manipulating the bacterium *Rhodococcus jostii* they are able to extract useful lignin-based polymers. To operate at an industrial level the technology must overcome scalability and efficiency issues; this should be achievable if enough resources are committed to developing the technology. Analysis of the technologies' commercial viability indicates that there are markets that can exploit the sustainability of technology in the resin and carbon fiber industries. Successful commercialization appears to be dependent on socio-political factors that drive the development and adoption of this sustainable technology.

Executive Summary

Plant biomass is an excellent source of energy and compounds. Raw materials in resin and carbon fiber based products can use these compounds; these industries have a combined global market of over USD $1 trillion. These markets rely heavily on raw materials produced from the petrochemical industry and are influenced heavily by the price of crude oil. In the wake of the recent global recession, the search for sustainable sources of raw materials has intensified. This report demonstrates the commercial viability of products generated by natural bacteria and enzymes to extract degraded lignin from biomass. Adoption and development of this extraction technology will require influence from external non-market (secondary) stakeholders to compete with the market incumbents.

Plant biomass has huge potential but as much as 30% of the biomass consists of the complex compound lignin that is difficult to degrade efficiently. There are no established methods for degrading biomass lignin; the current published methods are inefficient and inconsistent. Dr Lindsay Eltis' research group at the University of British Columbia investigates microbial enzymes and pathways involved in naturally degrading compounds. In collaboration with Dr Timothy Bugg's laboratory at the University of Warwick, they have genetically manipulated the bacterium *Rhodococcus jostii* to enhance the degradation of lignin to generate useful lignin-based polymers. The technology is still at an early experimental phase and requires assessment of its commercial viability and if there is a market audience.

Inconsistency, inefficiency and scalability problems plague the existing technologies, along with a lack of influence from secondary stakeholders. This report found that this newly discovered technology faces the same technical challenges. Furthermore, if these challenges can be overcome, there are diverse application markets for the technology. For example; the automobile manufacturing sector, which has a strong demand for both resin and carbon fiber, is worth in excess of USD $50 billion

globally. The technology, however, faces significant barriers to entry in all of the potential product markets. A large capital investment is required to establish facilities that will allow the organization to operate at an industrial scale. Raising capital to construct processing facilities in the current economic climate may be difficult, for this reason it would be prudent to seek an agreeable manufacturing partnership. Before entering into any partnership, the technology requires intellectual property protection. Protection through patents, copyrights and trademarks may not be enough to ensure the successful commercialization if economies cannot be achieved.

The TCOS framework was used to assess the commercial viability of the technology. A stakeholder in the project, Dr Jeremy Hall, proposed the TCOS framework. The TCOS framework is unique in that it takes into consideration the impact of social issues. Dr Hall argues that the technology has shown proof of principle and that adoption is dependent on the influence of secondary stakeholders. The sustainability of the technology makes it a strong alternative to crude oil derived compounds. Furthermore, car manufacturers can use carbon fiber products to develop in vehicles with increased fuel-efficiency. Sustainability and lowering the global carbon footprint are key political issues. Traditional business strategy frameworks, like Porter’s Five Forces, do not give the secondary stakeholders much credit in influencing the business strategy. Based on Porter’s Five Forces analysis; the market for this new technology would be considered unattractive due to the high capital intensity of the industry and the competitive strength of the incumbent players. The inclusion of social issues in the TCOS assessment, however, demonstrates the social advantages this technology has over the incumbents’ non-sustainable technology.

The technology, through proof of principle, has the ability to influence legislation and industry regulation to drive the development and adoption of the technology. With the appropriate resources dedicated to development, this technology has the potential to radically change industries and markets.

Dedication

To Andrea and Ollie.

Acknowledgements

Dr. Scott Patterson, a MOT MBA student at Simon Fraser University, was given the opportunity to collaborate with Dr. Jeremy Hall’s laboratory, to develop a business strategy for an innovative technology. Dr. Hall’s laboratory is a wonderful group of people who hope to help emerging technologies achieve their potential. The author of this dissertation wishes to express his sincere thanks to Dr. Pek-Hooi Soh, MOT MBA project supervisor.

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Glossary

Plant Biomass	Plant biomass is the energy that is stored in organic, biological materials.
Lignin	Lignin is a main component of vascular plants; it is the second most abundant natural compound, after polysaccharides.
Lignocellulosic biomass	Lignocellulosic biomass refers to plant biomass that is composed of cellulose, hemicellulose and lignin.
Biocatalyst	Is the use of natural catalysts to chemically transform or modify organic compounds
Resin	Resin is a natural or synthetic compound that is initially highly viscous but hardens with treatment. Trees naturally produce resin in the form of sap.
Carbon Fiber	The term carbon fiber refers to plastic that are reinforced by graphite textile. It consists of carbon atoms that are bonded together to form crystals which essentially align to form a fiber strand
Capital Intensity	A business process or an industry that requires large amounts of money and other financial resources to produce a good or service
Capital Intensity Ratio	A firm’s total assets divided by its sales, or the amount of assets needed to generate $1 in sales.
Piecemeal	Characterized by unsystematic partial measures taken over a period of time
TCOS Business Framework	Business strategy framework, which analyzes the technological, commercial, organization and social uncertainties to technology, needs to overcome to become a commercial success.
Polymer	A large molecule composed of repeating structural units; the term often refers to plastics.

1: Introduction

1.1 Background of the Project

The ability to utilise all components of plant biomass is a potentially powerful means of generating useful carbon based products, like carbon fiber and resins. However, the full potential of plant biomass is difficult to exploit as up to 30% of the biomass consists of the complex compound lignin that is difficult to degrade efficiently. Dr Lindsay Eltis' research group at the University of British Columbia have observed that by manipulating various forms of the bacterium *Rhodococcus jostii* RHA1 they are able to efficiently extract useful lignin-based polymers. Dr Eltis has formed a partnership with Dr Jeremy Hall, a professor at Beedie School of Business, and the TCOS lab to explore the commercial potential of this research, whereby they conduct a study to determine whether their extraction process is economically viable and efficient enough to pursue a commercial venture in resins and carbon fibers isolated from lignin.

1.2 The Stakeholders

The stakeholders of this project include the following experts, groups or organizations:

- Dr Jeremy Hall, Professor of Business at Simon Fraser University, is the principal investigator of the TCOS (Technological, Commercial Organisational, Social) lab. The lab has a proposed model for conceptualizing novel ideas into scientific experiments, or a series of testable conjectures, which are then translated into viable technologies, for certain markets.
- Dr Lindsay Eltis' laboratory at the University of British Columbia is the primary inventors of this 'version' of the technology. Dr Eltis' lab study how various enzymes from microorganisms degrade organic compounds. The lab investigates how the manipulation of these enzymes may be utilised for practical applications. By applying genetically engineered bacterium *Rhodococcus jostii*, Dr Eltis' scientific team hopes to identify a viable method for degrading lignin.
- Dr Timothy Bugg is a Professor of Biological Chemistry at the University of Warwick in the United Kingdom. Dr Bugg is a collaborator of Dr Eltis, working on the planning and design of experimental studies to demonstrate that the genetically engineered bacterium can transform lignin into specific aromatic compounds.
- Genome Canada provides funding for this research project. Genome Canada is a not-for-profit organisation set up by the Canadian Government for the purpose of development and implementation of large-scale genomic and proteomic research projects. Genome Canada funded a proposal jointly written by Dr Eltis and Dr Mohn to explore microorganisms that are found in soil ability to degrade biomass, with the objective of fully unlocking the potential of forest biomass.
- Dr. Scott Patterson, MOT MBA student at Simon Fraser University, together with Dr. Hall and his team in the TCOS laboratory, conduct industry and market research into the commercialisation potential of lignin–Resins and –Carbon fibers.

1.3 Objective

The objective of this report is to determine the commercial viability of a sustainable technology that uses properties of natural bacterial to liberate resin and carbon fiber compounds from biomass. The report will provide an overview of the technology and an analysis of the potential industries and markets the technology may look to enter. As the lignin extraction technique is potentially a disruptive technology, it is imperative to understand the existing lignin isolation and extraction processes for lignin-based products. An analysis of the resources required to isolate lignin and then convert lignin into a marketable product to gain a greater insight into the innovative strength of this novel technology. The report aims to assess the technology and identify the required actions for it to produce marketable products. It includes an analysis of the intellectual property, trade secrets and other proprietary features of the technology.

Analysis of the potential markets and products will follow to determine if there is an audience for the technology. The market analysis for resin and carbon fiber includes an overview of each industry's outlook, the competitive landscape of each industry, the basis of competition and barriers to entry. An analysis of the potential products is required to gauge the volatility of their individual markets and the factors technologies should consider before entering these markets. These factors include the level of capital investment required to begin producing the products, the regulatory factors involved with product production and the competitive landscape of the market for each product.

Sources of information include libraries, online, books and interviews. To determine the attractiveness of the technology to the markets, TCOS framework analysis was performed on each industry. The TCOS framework analyzes four dimensions of uncertainty (Technological, Commercial, Organizational and Social) that the technology/innovation has to overcome for it to become a 'successful commercialization'. TCOS analysis is believed to be more appropriate for technologies that are still in the early stages of development and face high uncertainty. For comparative purposes a Porter's five forces analysis has been included in the appendix.

This report is organized firstly into analysis of the technology; which includes an analysis of the lignin isolation methods, as this affects the quality of the lignin as well as the lignin degradation. The report then analyzes the potential market and products, these chapters identify potential issues would need to be addressed for the technology to become viable. Finally, analysis of the technology was performed using the TCOS framework to determine a business strategy for commercial success.

2: Overview of the Technology

This chapter aims to give an overview of the compound lignin. It firstly looks at why the compound's composition has impeded the development of commercially successful product and how it can be instead transformed into useful products. It introduces a new technology jointly discovered by Dr Eltis and Dr Bugg, and explains how they hope to harness the power of natural bacteria and enzymes to convert lignin into raw materials that can be used for commercial products. As the source of the lignin affects the consistency and quality, this chapter explains several processes of lignin isolation. This is followed by an explanation of the current processes that have been developed to degrade lignin and the limitations of these processes. Finally, this chapter looks at the products Resin and Carbon Fiber, how they are currently derived and why they are of commercial interest for this report.

2.1 Lignin as a Compound for Commercial Use

Lignin is a complex organic compound that fills and binds the cells, fibers and vessels which make up wood. After cellulose, it is the most abundant renewable carbon source in the world, making up approximately a third of the dry mass of wood. Lignin is one of three key components which make up the wood material of plants; these components combined are termed lignocellulose. Lignocellulose is made up primarily of cellulose, hemicellulose and lignin (Lignin, 2012). Cellulose and hemicellulose are polysaccharides which are easily broken down, and have been utilized to produce commercially viable products (e.g. paper and textiles). Unfortunately, lignin is made up of a heterogeneous complex aromatic polymer which protects it against degradation by microorganisms, but also hampers the breakdown of lignocellulose (Lebo, Gargulak, & McNally, 2001). This essentially results in lignin being primarily a waste byproduct which has an inconsistent quality and functionality. Products that are derived from plants, like paper, extract out the useful cellulose and generally discard the lignin as it is considered uneconomical to breakdown.

2.1.1 The Current Issue

There are over 40 million tons of lignin produced a year worldwide, the majority of which is simply non-commercialized waste (Gallezot, 2012). In nature lignin is degraded by various natural fungi and bacteria, numerous scientific groups have shown that the degradation of lignin can produce useful by-products like Vanillin, Resins, Carbon Fibers and Biofuels (Wahyudiono & Goto, 2008). Unfortunately, the commercial degradation of lignin is costly and inefficient. Given the abundance of lignin finding an economical way in which to extract it may provide a wide variety of potentially valuable products. The objective of the extraction process is to remove as much of the cellulose as possible with as little as possible hemicellulose and lignin.

2.1.2 An Innovative Solution

The degradation or transformation of biomass into useful products is not a new concept; biocatalysts as they are referred too, have been used for centuries for processes like brewing and dairy fermentation. More recently, biocatalysts have been explored as a way of liberating lignin from polysaccharides and modifying it into a functional by-product. In order to enhance the use of biocatalysts as a viable process, Dr Eltis and Dr Bugg have focused on the bacterium *Rhodococcus jostii* RHA1 as an alternative biocatalyst; they found that this bacterium degrades lignin using a novel peroxidase (Chen, et al., 2012) (Ahmad, et al., 2011). This finding was the first such characterization of a bacterial lignin-degrading enzyme. The bacterium *Rhodococcus jostii* RHA1 is considered the best-characterized lignin-degrading bacterium (Chen, et al., 2012) (Ahmad, et al., 2011), with the strain of bacterium having previous commercial success in the production of acrylamide. Using two novel assays developed by Dr Bugg, they were able to analyze the lignin degradation. They found that *Rhodococcus jostii* RHA1 degrades lignin using a dye-decolorizing peroxidase (DyP) (Ahmad, et al., 2011), a group of enzymes first identified in fungi. *Rhodococcus jostii* RHA1 has two DyPs, namely, *dypA* and *dypB*.

They found that the blockage of *dypB* but not *dypA* disrupts lignin degradation and that *dypB* catalysed lignin breakdown whereas *dypA* did not. It remains to be seen if *dypB* acts on lignin in the same manner in nature, though it is known that *Rhodococcus jostii* RHA1 requires an energy source to grow on lignin. By deriving the atomic structure they were able further investigate and engineer the lignin degrading properties of this *dypB*. The ongoing research has focused on the efficiency of the engineered *Rhodococcus jostii* RHA1 to isolate various compounds from lignin derived from various sources. Unpublished findings have found that lignin derived from kraft pulping is able to isolate up to 121mg/ml vanillin, with an efficiency of 2.5% weight/volume (25g lignin in 1 litre).

Gene disruption has been utilized to understand the various catabolic pathways and enzyme activity in *Rhodococcus jostii* RHA1. These methods have revealed how manipulation of the bacteria can improve degradation of lignin, producing commercially attractive aromatic compounds. The group currently has mapped the vanillin catabolic pathway and is currently pursuing options for resin and carbon. The question remains if the technology will work for these options, as they are more complex but potentially of greater commercial interest.

The group has established an impressive repertoire of techniques and tools that can be applied to any number of bacterium. This means that if *Rhodococcus jostii* RHA1 lignin degradation not a commercially viable bacterium, the group can apply their skills to other potentially interesting bacterium. To ensure that the group has a range of potential commercial options, they are investigating other bacterium, with the possibilities being almost limitless; for example in a single gram of soil there are over 5000 different types of bacteria. It stands to reason that harnessing nature’s potential for degrading lignin is simply a matter of time and resources.

2.2 Current Methods of Lignin Isolation

To generate products from lignin, the lignin must first be isolated from the lignocellulosic carbon sources. This step is important as it affects the purity and constancy of the lignin. Lignin can be isolated from lignocellulosic carbon sources by a variety of methods which involve various mechanical and chemical processes. These processes can be broadly defined by two major process types. The first process involves dissolution and removal of the soluble lignin, leaving the insoluble cellulose and hemicellulose residues. This process is outlined below as sulfite and kraft pulping. The second process, solubilizes cellulose and hemicellulose, leaving the insoluble lignin residue; these processes are outlined below as cellulosic ethanol production. These methods of lignin degradation are generated from a renewable lignocellulosic carbon source, and represent a sustainable industry.

2.2.1 Lignin Isolation

The isolation method plays a significant role in determining the nature and structure of the extracted lignin. For example, kraft lignin is relatively free from sulfur contamination, whilst sulfite lignin has considerable amounts of sulfonate group contamination. The contaminating factors significantly alter the chemical composition, changing the compounds molecular weight and complexity. The different compositions of lignin are able to be converted into various products; see the illustration of lignin conversion processes in Figure 1.

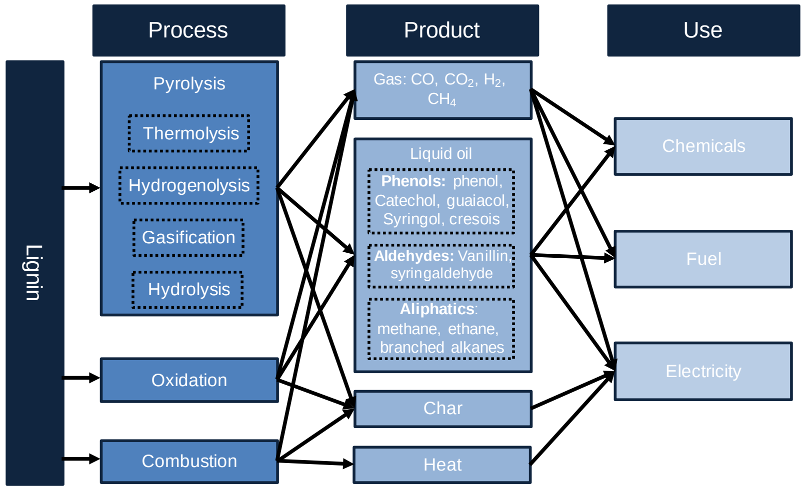

Figure 1: Lignin conversion processes and their potential products

Note: The above figure is created by the author, based on a model proposed by Pandey and Kim (2010) (Pandey & Chang, 2011).

2.2.2 Sulfite Pulping

Lignin is removed from wood pulp with sulfonates. Sulfite pulping is a complicated chemical process, which requires the combination of chemicals and heat to convert wood into pulp (Sulfite Process, 2012), (Pulp Production Processes, 2011). The process of Sulfite pulping was developed in the 1860s (The Sulfite Process, 2011), when sulfurous acid was used to treat wood primarily for the production of paper. The wood is cooked in a solution that contains calcium bisulfate and excess sulfur dioxide, with the process taking up to 14 hours at temperatures between 130^{o}C and 160^{o}C depending on the ratio of sulfurous acid and alkalines. This process splits the cellulose-lignin complex of wood using hydrolysis and the combination of the lignin with calcium bisulfate to form calcium lignosulfonate, which is soluble and easily washed away. During this hydrolytic reaction the hemi-cellulose dissolves and forms sugars, this leaves the usable cellulose in a relatively stable form. A drawback of this process is that it leaves the resins in the wood mostly unprocessed and insoluble; this means that this process is limited to less resinous woods. The type of wood also factors into the strength of the paper produced, this means that some woods are able to be processed but are not deemed suitable as their short fibers weaken paper strength. The end products of sulfite pulping are able to be easily bleached, as they have fewer colours, but are not as strong as other processes. For this reason, the use of Sulfite pulping has diminished and has evolved into kraft pulping, which is a similar process but uses a different combination of chemicals. In 2000, less than 2% of the chemical market pulp was sulfite produced (United States Department of Agriculture).

2.2.3 Kraft Pulping

Kraft pulping has effectively superseded Sulfite pulping; whilst the process is essentially the same, it is considered more effective (Pulping, 2009). Kraft pulping produces a variety of pulps that are used mainly for packaging, high-strength papers and writing papers. This is because kraft pulps are much stronger than pulps produced by other processes. The characteristic strength of kraft fibers is due to the digestive chemicals that are highly selective for wood constituents. Kraft pulping is considered more effective than sulfite pulping as the lignin removal is higher, which allows for bleaching without added pulp degradation. Kraft pulping has the added advantage over sulfite pulping of being able to process a wider range of woods, including very resinous types and even non-wood species like bamboo. Pulp mills are generally located close to large water sources due to the amount of water required during the pulping process; this unfortunately introduces the potential for pollution.

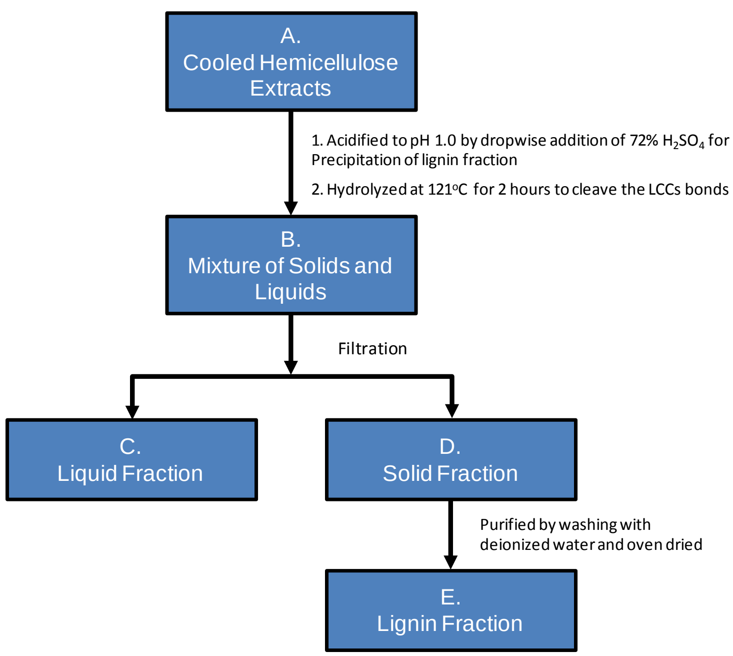

Figure 2: Protocol for Hydrolysis Lignin isolation method.

Note: The above figure is created by the author, based on a figure generated by Jie Luo 2010.

2.2.4 Cellulosic Ethanol Production

This is the production of a type of ethanol that can be used as a biofuel that is generated from cellulosic sources like wood chips and corn stover. The process removes the residual materials, like lignin, leaving sugars which are fermented to produce pure alcohol. In the United States this process is growing (Wall Street Journal, 2011) due to financial encouragement by the government to reduce the levels of biowaste produced each year (Kryzanowski, 2008). The efficiency of the process is dependent on the source, type of wood, etc. Moreover, there has always been an issue that the process has a poor economic efficiency costing over USD $0.55/litre to produce. However, with the ever increasing petrol prices (which costs now around USD $0.50/litre (Anderson & Kahya, 2011)), Cellulosic ethanol is becoming an increasingly viable financial option. This means there would be an ever increasing source of lignin, which if used to generate useful byproducts would reduce the amount of biowaste.

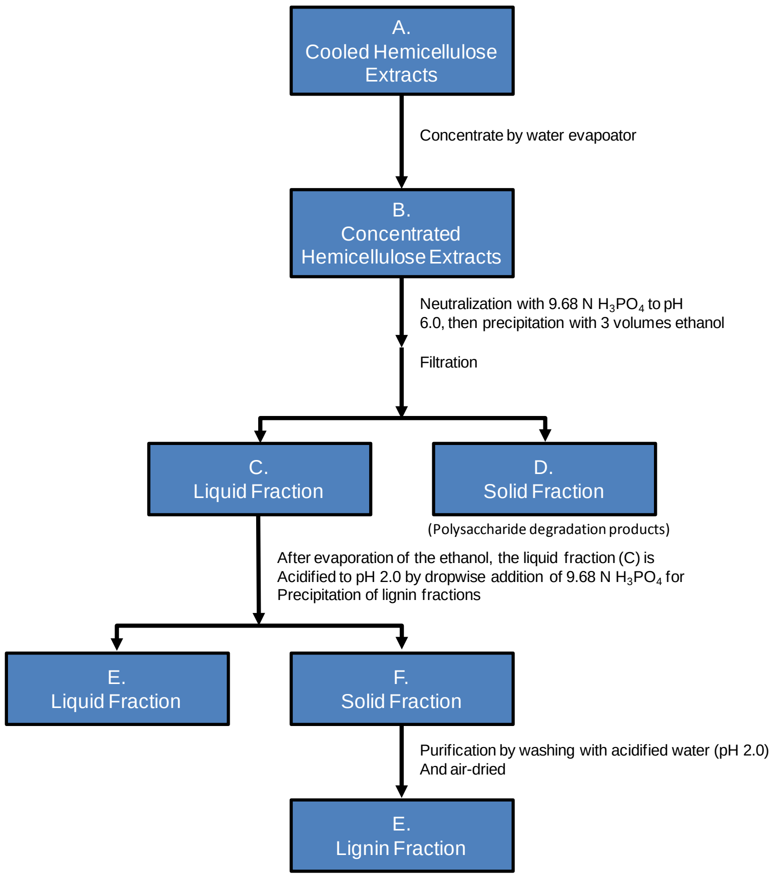

Figure 3: Protocol for Lignin isolation method using ethanol.

The above figure is created by the author based on a figure 5.1 generated by Jie Luo, 2010 (Luo, 2010).

2.3 Current Practices for Lignin Degradation

2.3.1 Hydrocracking

The process of "hydrocracking" is common in the fuel industry for depolymerising crude oil that is considered 'heavy' (Shell, 2011). This process involves placing the lignin in pressurised hydrogen gas and at high temperatures (>350^{o}C). This saturates the lignin with hydrocarbons that produce, depending on the reaction conditions, products ranging from petroleum gas (or propane) to complex hydrocarbon products that diesels use. This process of lignin degradation is too inefficient to pursue on a large scale. This resource intensive process works with pressurised potentially explosive gases. There are also safety concerns that go with the gas and vapour emissions (SET Laboratories, Inc., 2011).

2.3.2 Hydrogenation

Hydrogenation involves exposing lignin to hydrogen at high temperatures to saturate the complex lignin compound to generate compounds that have less complex chemical bonds. The resulting products range from alcohols to more dense resin like substances. Unfortunately, owing to the complex chemical nature of the process and variability of lignin, the resulting final compounds are not constant.

2.3.3 Hydrotreatment

Hydrotreatment is a catalytic chemical process, like hydrocracking, involves exposing the lignin to a hydrogen rich atmosphere. However, unlike the hydrocracking, the process uses with aromatic compounds. This means that the lignin has to be depolymerised in some manner prior to conducting this process. The process converts the aromatic compounds into oil-like products at relatively high yield (up 71% of lignin feedstock). The efficiency of the process is very dependent on the type/source of lignin (Oasmaa & Alen, 1993).

2.3.4 Alkaline and Acidic Oxidation

These processes involve the addition of alkaline or acidic oxygenising chemicals. Using conditions similar to those used in the hydrogen processes above, heat and pressure, the processes produce compounds that are less complex in nature. These processes have shown to be very inefficient, isolating only trace amounts of aromatic compounds in the resulting product. These processes have been proposed as an intermediary step in the lignin degradation (Xiang & Lee, 2000).

2.3.5 Base-Catalyzed Degradation (BCD)

Base-Catalyzed degradation (BCD) is the initial step in a three-step process for converting lignin into reformulated gasoline (Shabtai, Zmierczak, & Chornet, 1998). The process uses a combination of alkaline oxidation and alcohol at high temperatures and pressure, resulting in lignin compounds that are less complex. BCD simplifies lignin to produce a compound that has 50% less oxygen when compared to the initial lignin compounds. Hydrogenation follows BCD, which is then followed by a mild form of hydrocracking to finally produce precursors that can be used to make biofuel. This is an extremely intense process with numerous chemically critical stages where the degradation process may go wrong.

2.3.6 Technology Summary

Lignin utilization is not a new concept, Setua et al (2004) (Setua, Shukla, Singh, & Mathur, 2004) and Lora and Glasser (2002) (Lora & Glasser, 2002) conducted separate studies into the concept. The current technologies as outlined above are complicated processes that use potentially dangerous chemicals at high temperatures and pressure. In addition, the processes are not yet refined, with the products and the results being inconsistent and inefficient. Both the Setua and Lora groups independently concluded that the concept of lignin utilization is in principle sound, however, both groups also pointed out that these technologies have to improve as the process is currently to inefficient to produce pre-cursor materials that can be utilized for products like resin, carbon fiber and biofuels.

2.4 The Products

Lignin can be degrading into a number of compounds, of varying complexities. There are four product streams that lignin could be degraded into, they are (in order from least complex to most complex): (a) Vanillin; (b) Resin; (c) Carbon Fiber; (d) Biofuels. Resin and Carbon Fiber are billion dollar industries; the petrochemical industry is primary source of the raw materials. The technology aims to utilise its sustainable nature to gain access to these lucrative markets.

2.4.1 Resin

The term resin is simply what the industry refers to as unprocessed plastic. The compound resin is either naturally produced by plants or synthetically generated. Resin has the characteristic of begin as a highly viscous liquid substance that hardens with treatment. This characteristic of natural resins has been utilized for thousands of years in for example, adhesives and varnishes. Plants produce natural resin as a mechanism of self-defence and healing, as the resin when fresh, is sticky and soft, but hardens with time. The harvesting of natural resin dates back centuries', it is obtained by tapering the tree so that it forces the tree to continuously "bleed" resin as a result of the wound. China, Indonesia, Portugal and Brazil produce over 90% of the world's natural resin (Taxusbaccata, 2012). The hardened resin has many uses including paints, sealants, varnishes and adhesives. Resin is a colloid, which means it disperses evenly through another substance; this makes it a useful additive for solvents like turpentine that is extensively used around the world.

More recently, the majority of the polymers that incorporate resins use synthetic resins that are cheaper and easier to refine. Synthetic resins are predominately derived from petrochemical by-products and have the advantage of being more stable, predictable and consistent than natural resins. Synthetic resins are broadly grouped into two categories (Industry Canada, 2011): thermoplastic and thermosetting synthetic resins. Using heat and pressure, Thermoplastic resins can be softened and reshaped repeatedly; these resins make polyethylene, polypropylene and polyvinyl chlorine (PVC). Thermoplastic resins are widely used by packaging firms, for items like Tupperware containers. In addition, thermoplastic resins are widely used in the automotive industry. Thermosetting synthetic resins are generally softened during the shaping process and then set into their final shape, unlike thermoplastic resins, these resins cannot be reshaped. The most common type of product for this type of resin is polyester, which is widely used in the textile industry for the production of high-strength fiber. This resin is used in construction for high-strength bonding products like epoxy glues. The thermosetting resins are also used to make polyurethane, which is used in the production of tires and insulation materials.

2.4.2 Carbon Fiber

The term carbon fiber refers to plastic that is reinforced by graphite textile. It consists of carbon atoms that are bonded together to form crystals which essentially align to form a fiber strand, as illustrated in figure 4. The crystal structure of carbon fiber makes it extremely strong, light and tolerant of extreme conditions (Cantwell & Morton, 1991), with a strength-to-weight ratio which is almost unmatched by other compounds. The composition of carbon fiber dictates its distribution of strength, meaning that it can be extremely strong in one direction but have flexibility in another. Carbon fiber is used in high-quality products where strength and weight are a factor. Many vehicles utilize the benefits of the high strength to weight ratio; including boats, bikes, planes and cars. Carbon fiber is synthesized by spinning synthetic polymers, like rayon and polyacrylonitrile (PAN), into filaments to align the atoms. The filaments are then heated; this removes the remaining non-carbon atoms. The ability of carbon fiber to be shaped has allowed it be used in the textile industry, here the carbon fiber is spun into filament yarns which can be woven into cloth or fabrics.

Given the abundance of the raw materials that can make carbon fiber, it is surprising to learn that attempts to produce it in mass production have failed (wiseGEEK, 2012) due to inadequate demand and the customizable nature of carbon fiber. The high price of carbon fiber is the primary factor that prevents it from becoming a universally utilized material.

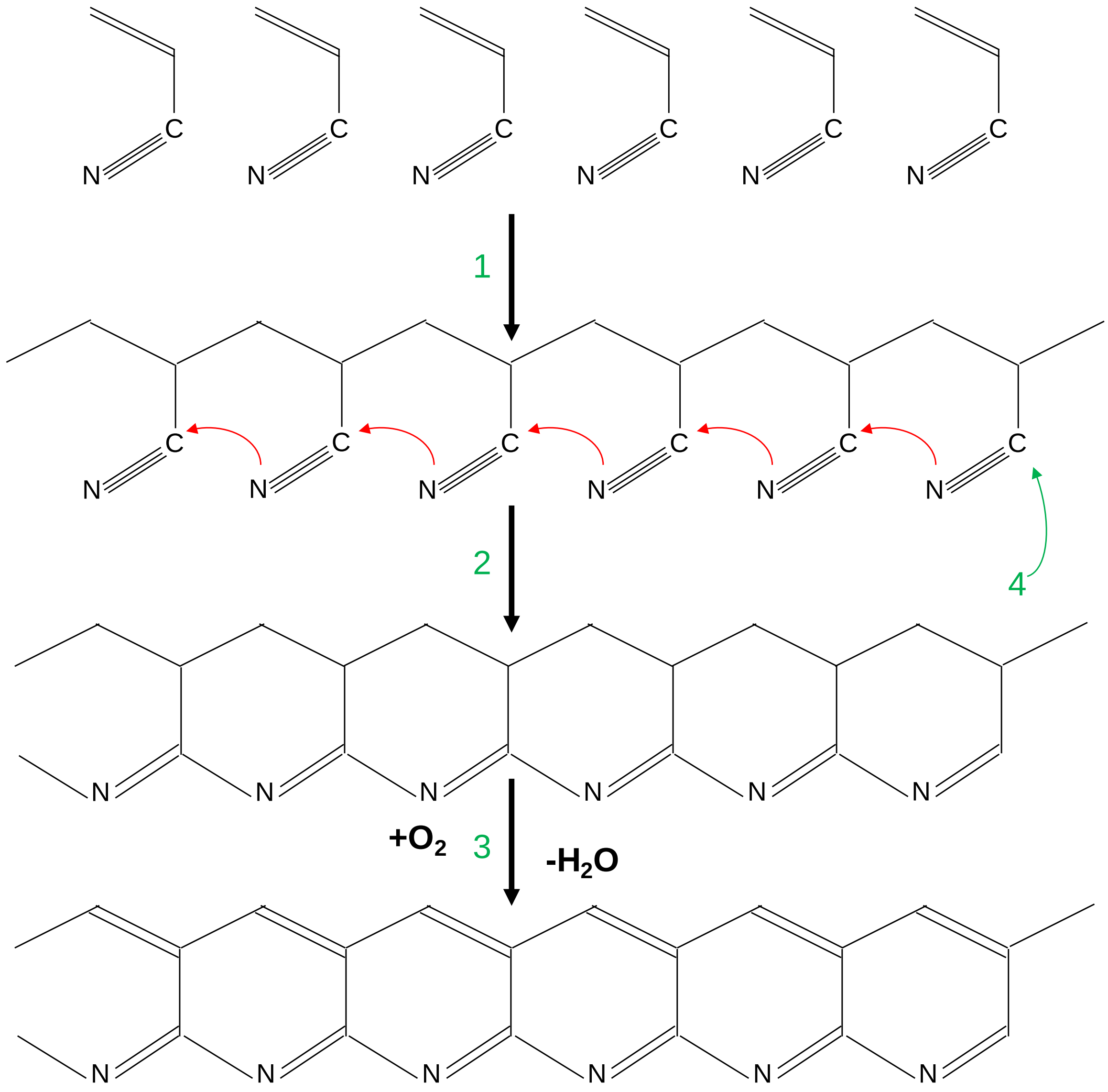

Figure 4: Synthesis of carbon fiber from Polyacrylonitrile.

(1) Polymerization of acrylonitrile to PAN. (2) Formation of carbon rings during low temperature process (3) High temperature oxidative treatment for the removal of hydrogen and enrichment of carbon. Finally, the nitrogen is removed and chains are joined into graphite planes.

The above figure is created by the author based on a information published by Cantwell and Mortons, 1991. (Cantwell & Morton, 1991)

3: Market Analysis

The following sections describe the existing and projected market place in which this technology will introduce its product. This chapter looks to analyze the markets with regard to the incumbent technologies using the information gathered on the technology and the incumbent products. The chapter looks at the entire industry, market volatility, the projected forecasts, the competitive nature of the industries and the barriers to entry.

3.1 Resins

Resins, and more specifically plastics, have become an integral part daily of life, with the industry surging forward with the advance of technology. The resin and plastics manufacturing industry had strong growth as the industry gradually replaced traditional materials like wood, leather and metal. As mentioned earlier, the industry relies on demand from several key industries, including textile, tire, and insulation materials; this means the strength of the industry is dependent on the stability of these industries. Between 2006 and 2010 global plastic resin consumption increased by almost 25% (figure 5, with legends starting from the largest share clockwise) with the continental proportions remaining relatively constant, this trend is continuing to increase.

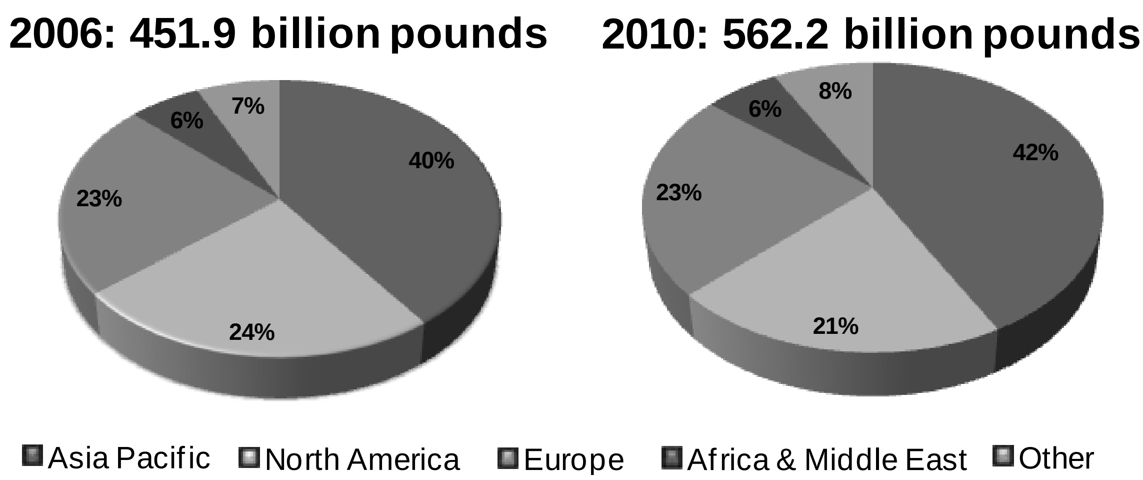

Figure 5: Global plastic resin consumption.

Source: The above figure is created by the author based on a figure generated by the plastic news 2009 (Materials, 2009).

Plastic resin is the primary component of plastic, with the majority of the raw materials originating from petrochemical compounds. In the past ten years, the price of crude oil has trended upwards, going from approximately $23 in July 2002, to as high as $132 in July 2008 before stabilising around $85 as illustrated in figure 6.

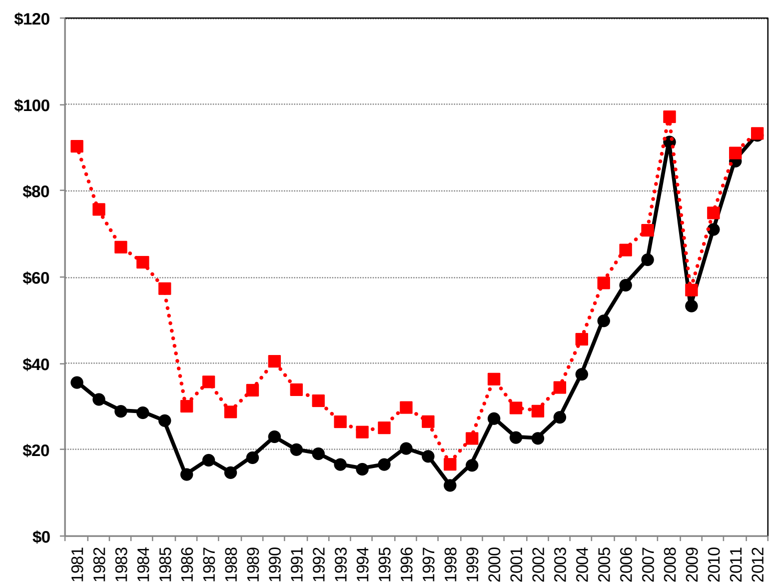

Figure 6: Historical crude oil average annual price.

Black line represents the nominal crude price. The red line represents the inflation adjusted crude oil price. The above figure is created by the author based on a figures obtained from InflationData.com, 2012 (Histroical Crude Oil Prices (Table), 2012).

The rising cost of crude oil had a direct flow on effect on the price of resin; for example, the price of crude oil rose over 35% in 2008 that resulted in the price of resin rising 11%. The majority of North American resin manufacturers rely heavily on natural gas as an energy source (National Public Radio, 2012), meaning the industry is also influenced by the price of natural gas; for example, in 2009 the price of natural gas in the United States dropped, as did the cost of resin. This caused an increase in resin exports to Asian and Latin American countries as they began their economic recovery. The North American petrochemical resin industry has found that the reduced production costs coupled with reduced prices resulted in smaller margins. The slow economic recovery has forced the industry to downsize; this means market consolidation has slowed as major players seek to improve their margins.

In Canada, the polymer/plastics industry employs over 100,000 workers and in 2010 had revenue of over $17 billion. The United States accounts for over 90% of the plastic exports from Canada, with China and the UK being the other major trading partners. Estimates indicate that Canada consumes enough resin to produce 2% of the world's plastic products. The Canadian government became the first G-20 country to eliminate tariffs on manufacturing inputs (Government of Canada, 2012), including among other things chemicals, tools, machinery and equipment. As the industry looks for alternatives sources of resin, the governmental incentives have allowed Canada to become a leader in research for producing plastic resins from biomass. The Canadian government has recognised the global reliance on plastics and is strategically positioning the domestic market to ensure that Canada becomes a global leader in the industry.

3.1.1 Industry Outlook

Globally the entire plastic resin industry is expected to strengthen in the next five years to 2017 (Mary Nanfelt, 2012). The strengthening construction industry will result in an increase in demand for resins and synthetic rubber. With the increased use of synthetic materials in housing construction, like pipes and flooring, forecasts indicate that demand for plastic resin will increase. The retail industry is another market segment that is projected to experience strong revenue and growth. As the economy recovers consumer spending will grow, which will create demand for plastic packaging materials. The automobile and aviation industries took a significant hit during the economic downturn; demand for plastics is expected to return to pre-2006 levels with the gradual rebuilding of the industry (Dale Schmidt, 2011). This anticipated market growth is based on projections that credit markets to loosen restrictions, allowing car manufacturers to regain strength and for vehicle sales to increase (Dale Schmidt, 2011). The industry expects to continue growing as the per capita disposable income rises; the market is anticipating that consumers will purchase more household products that contain plastic parts.

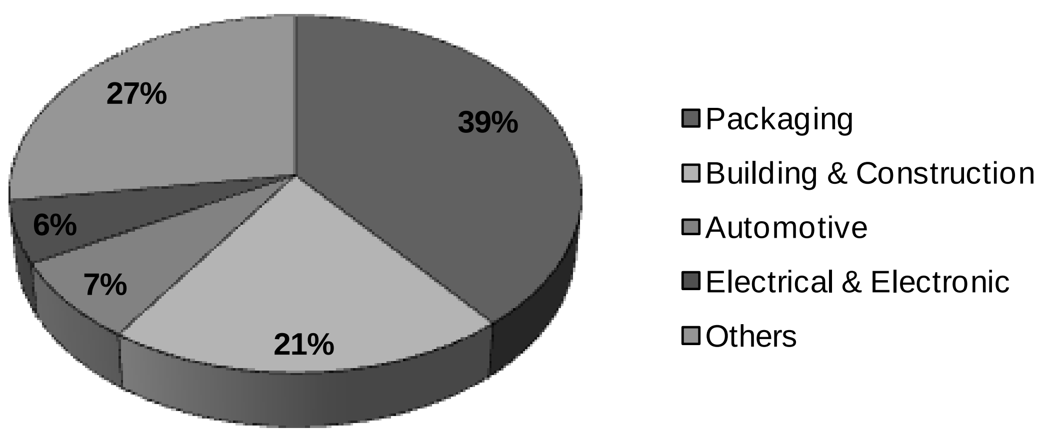

Figure 7: Plastic Resin Industry market segmentation for Europe in 2010.

The above figure is created by the author based on information published on the reportlinker.com, Plastic Industry: Market Research Reports, Statistics and Analysis, 2010 (European Plastics Manufacturers, 2011).

However, despite this positive outlook the volatile nature of the material costs will continue to assert pressure plastic resins industry profit margins. With resin-plastic being so dependent on the price of natural gas, it is important to forecast prices of natural gas. Like the price of crude oil, there is a volatile nature to the natural-gas market. In the United States, many manufacturers have pre-established purchasing contracts and so they will continue to purchase chemicals from their suppliers. Exporters of plastic products will see their profit margins decline if the price of natural-gas increases. As natural-gas prices increase, firms will likely look invest more in innovative technologies that do not rely on crude oil and natural gas, like bioplastic.

3.1.2 The Competitive Landscape

The industry has a low level of competitive concentration, which reflects the fragmented nature of the industry. The fragmented nature of the market means that no one player in the industry has a market share of greater than 8% (Dale Schmidt, 2011). There are varying levels of product segment focus; for example, during the economic recession and the period of industry consolidation, four polyethylene producers now account for approximately 80% of North Americas' capacity. In addition, seven manufacturers account for over 45% of the polyethylene capacity.

Raw materials are the largest cost for the industry and account for approximately 65% of total sales in the United States in 2012 (Dale Schmidt, 2011). The key materials include propylene, ethylene, phenol, acetone, chlorine and benzene; the majority of these materials originate from petroleum or natural gas. These materials will fluctuate in cost, which reflects the volatile nature of crude oil and natural gas industries; however, the anticipated cost structure must account for other expenses.. Companies that are not integrated into a refinery or petrochemical complexes have the added expense of transportation, depending on the materials that need to be transported, which can account for up to 85% of a product expenses (Dale Schmidt, 2011). General, administrative and selling expenses account for the second largest expense after raw materials. Wages follow then depreciation, which reflects the high-tech nature of the manufacturing plants. Finally, energy costs are the last significant contributor to the cost structure.

3.1.3 Basis of competition

Product price tends to be the main factor in determining competition; other factors may also influence the basis of competition. Despite the fact that plastic materials and resins are essentially global commodities, global crude oil prices influence their prices. Product quality and performance attributes including weight to strength ratios, installation costs and ability to recycle, influence the competitive nature of the industry. As technological innovation can influence the quality and demand for products, companies in the industry invest heavily in research and development to give them a competitive advantage. A company that is able to deliver a product that is consistent, reliable and on schedule may allow it to stand out from its competition. The competitive landscape is changing somewhat with the arrival of new competitors from non-traditional plastic and resin-manufacturing countries, a number of petroleum-rich countries have recently expanded their chemical industries.

3.1.4 Resin tariffs

On January 1st 1993, Canada and the United States assigned a free trade agreement; this resulted in the elimination of tariffs on resins used to make products including plastics, epoxy adhesives and varnishes. For this reason, the majority of the Canadian trade is done with the United States, which in 2010 totalled CAD$271 million in exports and CAD$990 million in imports. The recent recession significantly affected the resin industry, some countries found it cheaper to import rather than purchase locally; for example, in Mexico it was cheaper manufacturers to import resin from the United States rather than use domestically produced resin (Lemos, Coifman, & Martin, 2011). To encourage domestic production, countries like Argentina and Brazil apply strong tariffs on imports of resin to protect the local producers.

3.2 Carbon Fiber

Despite being over thirty years old, the carbon fiber market is a niche market and is still a long way from being commercialised. For the last 20 years the average growth rate of the industry is approximately 12% (marketsandmarkets.com, 2011), this increase in demand is due to its use in newer applications like wind energy and technological advances in industrial applications. The carbon fiber industry is cyclic, with periods of limited supply that results in higher prices alternating with periods of oversupply and lower prices. The potential markets for carbon fiber are extensive; carbon fiber can be substituted for any product that incorporates steel alloy.

The global economic situation significantly influences the carbon fiber market, purchase of luxury items like carbon fiber declines during periods of economic recession (marketsandmarkets.com, 2011). Like the resin-plastics industry, several external factors influence the demand for carbon fiber products; including the price of crude oil. The industries' reliance on raw material derived from crude oil means that the price of crude oil looms as a key factor in the current carbon fiber industry. Other industries influence the market, including the textile manufacturing industry that has a reliance on synthetic fibers, as well as the plastics industry. There is the additional influence applied on the industry by legislation with governments investing heavily in the automotive industries with the goal of producing transportation that is more ecologically sustainable (Ecological Society of America, 2007).

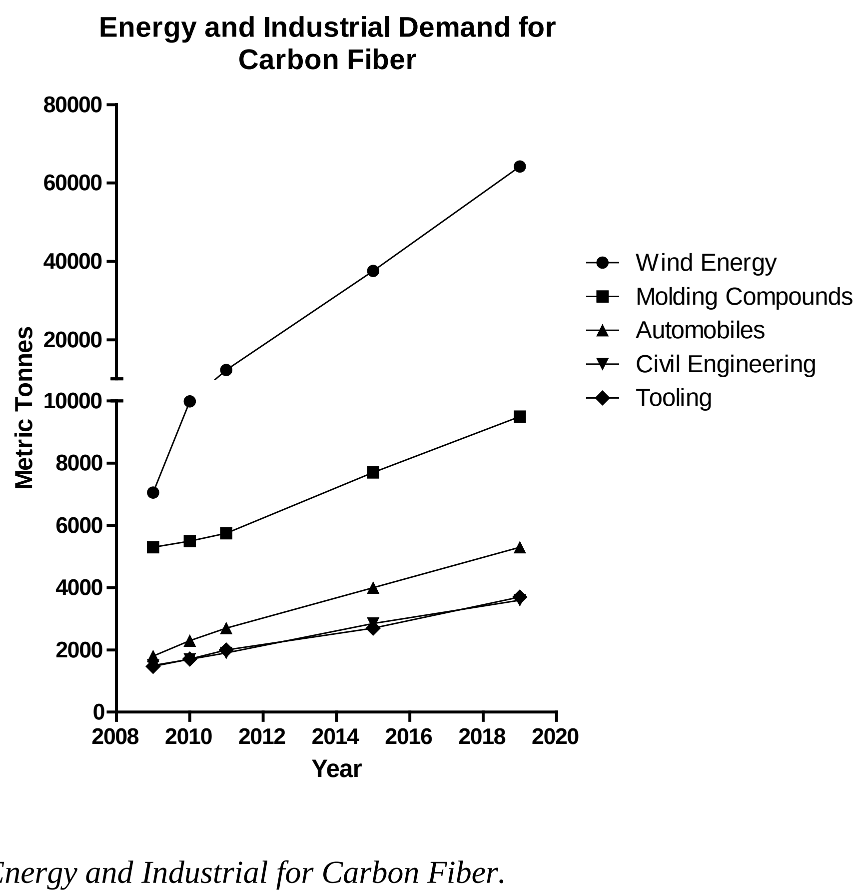

Figure 8: Energy and Industrial for Carbon Fiber.

The graph shows the growing demand for carbon fiber in selected industries.
The above figure is created by the author, based on information published by Jeff Sloan, 2011 (Sloan, 2011).

3.2.1 Energy Industries

The wind energy industry was the first industry to use large volumes of carbon fiber. This technology extensively uses carbon fiber for its high strength to weight ratio; for example, carbon fiber blades reduces the blade mass by 38% compared with similar fibreglass blades, allowing for quicker acceleration and improved efficiency (Griffin & Ashwill, 2003). Governments are encouraging energy suppliers to move away from fossil fuels and to find clean alternative energy sources there has been a shape rise in wind energy.

Electricity demand influences the industry, as demand grows, as does the need for energy sources. Demand directly linked with the price of electricity; electricity made from inexpensive renewable resources has a competitive advantage over non-renewable energy sources.

The 2008 recession affected the industry due to the capital-intensive nature of manufacturing turbines, with less credit available industry growth slowed (Molavi, 2012). To counter this, governments like the United States have established tax incentives to encourage investment in this technology. Government incentives help to drive the growth of this industry.

3.2.2 Automotive and aerospace industries

The automotive and aerospace industries have been hit hard by the recent economic recession. The high price of carbon fiber means that as a luxury item it is been used sparingly as vehicle manufacturers look to strength cash flow. ‘High-end’ cars, like Lamborghinis and Ferraris, are more likely to use luxury materials like carbon fiber; production of these types of cars recedes during economic recessions (Dale Schmidt, 2011). Automakers are almost solely reliant on parts manufactured by metal stamping suppliers, which operate in a high-through put manner stamping steal alloys into the appropriate shape. The automotive industry has relied on metal stamping since World War II and it has been the foundation of the lean, just-in-time processing that the industry has evolved into. The major players in the automotive industry are already capable of producing plastic body components. However, with the price of steel being approximately US$0.40/lb the technology needs significant improvements before carbon fiber is affordable enough to be used in mass automobile production (Steel Price Per Pound, 2012).

The aviation industry is starting to incorporate more carbon fiber into aircraft construction, an industry sector worth globally US$920.6 billion in 2009 (Clearwater corporate finance, 2011). Military aviation applications for carbon fiber have dated back to the development of fighter planes like the F-117, F-18 and F35 Stealth fighters (Global Military Aircraft & Aerospace Manufacturing, 2011), (MST, 2010). Carbon fiber allows the military to design aircrafts that are light, extremely manoeuvrable with long-range capabilities. The public sector of the aviation industry has been slower to adopt carbon composites due to the high manufacturing costs. Recently, the industry has come under pressure to reduce the global carbon footprint by improving aircraft fuel efficiency.

The leading companies Boeing and Airbus have begun moving towards aircrafts that are constructed primarily from carbon composites. In 2009, Boeing unveiled the 787 Dreamliner, a long-range jet airliner with 50% of its fuselage and wings made from carbon fiber (Boeing, 2009). Airbus aims to unveil in 2013 its own carbon fiber plane, the Airbus A350 that will be 53% carbon fiber. Whilst these planes have improved range due to better fuel efficiency they are significantly more expensive when compared to similar planes; for example the Boeing 737-600 costs USD$56.9 million (Boeing 737-600, 2012), whilst the Boeing 787 price starts at US$193.5 million (Boeing 787 Dreamliner, 2012). The additional cost is due to the added expense of using carbon fiber. Like the automotive industry, the economic recession has had a major bearing on the recent performance of the industry. The major airlines have all reported dropping revenues (Martin, 2012), which has meant that airlines have less money to spend on upgrading their fleets. For mass production of carbon fiber planes to become feasible, the cost of carbon fiber must decrease. Mass production of carbon fiber can be achieved by improving the manufacturing technologies.

3.2.3 The textile industry

The performance of synthetic fiber market in the textile industry has greatly affected by the economic recession. Owing to the high cost of raw materials and shrinking customer demand, prices are lowered in an attempt to increase demand; this has resulted in smaller margins. The textile industry has evolved to use just-in-time manufacturing, which has resulted in the industry size shrinking as textile manufacturers' aim to manufacture as demand requires. This has meant that the demand for synthetic materials has dwindled, resulting in the synthetic fiber manufacturing industry to shrink in net worth (Nanfelt, 2012). Consumer choice shapes the textile industry; many consider synthetic materials as non-eco-friendly fibers and this has resulted in a consumer shift back towards natural fiber products (natural fiber products makeup 35% of the market (Nanfelt, 2012)). Globally, the synthetic fiber manufacturing industry produced 46 million metric tons of manufactured fibers in 2007 (Nanfelt, 2012). With the low labour and production costs in the Asian countries, many manufacturers are shifting their manufacturing to these countries to offset the increasing raw materials expenses. In 2008, Asian countries accounted for nearly 70% of the World's fiber production (oerlikon, 2010). In terms of market segmentation, it can be broken up into two product groupings; non-cellulosic fibers are approximately 90% of the market, the remaining 10% is from 'natural' cellulosic fibers. Sustainability and the carbon footprint associated with the various types of fiber will become growing influences in the level of demand.

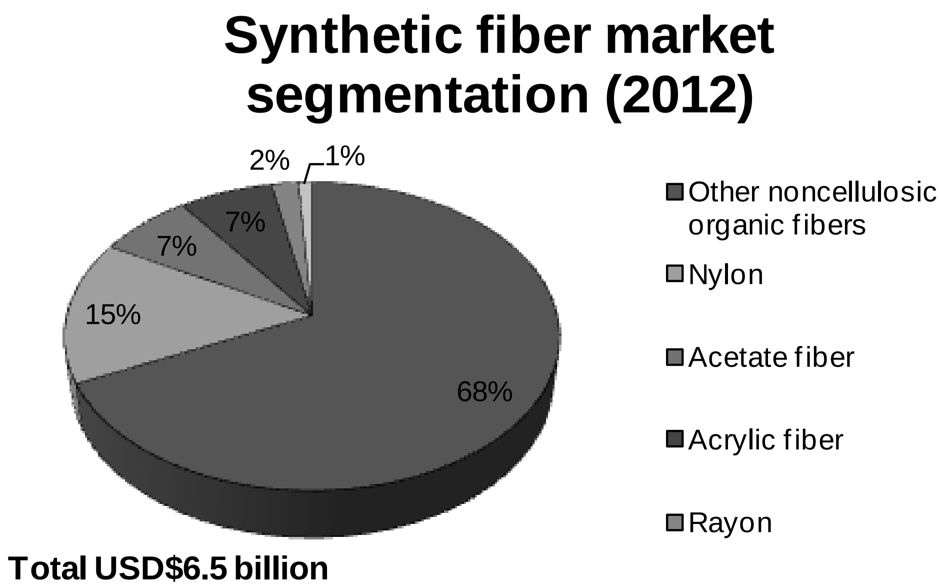

Figure 9: North American Synthetic fiber market segmentation.

The graph shows the diverse nature of synthetic fiber market. The above figure is created by the author based on figure in published by Nanfelt, 2012 (Nanfelt, 2012).

Historically, the structure of the synthetic fiber market has imposed a significant barrier to entry; however, this has changed with superior technology becoming more readily available. This has meant that competition between multinational chemical manufacturers has intensified. Environmental legislation and regulation has become an important legal barrier that new entrants to the industry must overcome in order to operate.

3.2.4 Other Carbon Fiber Industries

In the sporting world, equipment may give an individual an edge over their fellow competitors, more and more equipment in incorporating carbon fiber (McConnell, 2008). The strength, weight and durability that carbon composites can give equipment may be the difference between winning and losing. Like all carbon fiber markets, however, during the recession consumer spending dropped, which resulted in market growth slowing. Despite this, worldwide sales of sports equipment were valued at US$315 billion in 2010 (NPD Group, 2011). In 2010, the largest segments for sporting equipment sales were golf and fishing, two sports that have a significant investment in carbon fiber technology.

There are applications for carbon fiber in medical devices, prosthetic limbs, etc. where durability is very important and affects quality of life. The potential in the medical field is huge; in 2011, the global medical device market had revenue of US$300 billion, with this number expected to grow in the years to come with advancement in medical care (Kalorama Information, 2011).

The firearms industry is exploring the use of carbon fiber as a substitute to wood and metal, the reduced weight allows for greater comfort and durability. In 2011, the industry was worth over US$1.6 trillion and has grown steadily since 1998 (Global Issues, 2012). The current global political climate it suggests that the industry will continue to grow (Samadi, 2012), despite the Government policies and legislation heavily influencing the industry.

3.2.5 Overall Key Factors for Success in the Current Carbon Fiber Market

The carbon fiber market has huge potential, but entry into the market requires significant capital investment and ongoing research and development. As the market continues to consolidate in the wake of the recession, there are fewer players in the market. New market entrants should look to form partnerships to offset the capital investment required. For these partnerships to work, agreements must be reached with regard to intellectual property and trade secrets. New entrants should ensure that their intellectual property is well protected or they face losing their competitive advantage. To be competitive in the market the business must operate according to economies of scale; i.e. if the operator can produce at high capacity then this generally results in lower unit costs.

The market is affected by borrowing and interest rates, new entrants may find it difficult to raise capital if the borrowing rates are unfavourable. With high start up costs for carbon fiber technologies a significant level of capital is required to enter the market. New market entrants should look to form partnerships with corporate lenders to plan their entry strategy to overcome the barriers to entry. With the markets changing so quickly, businesses must invest significantly in research and development to ensure the continual process and product improvement. Businesses must be agile in their ability to allocate resources to products and services to meet consumer requirements as products evolve. With an ongoing capital investment, producers must be able to pass on the increased costs onto the end user, but still maximise returns.

4: Production Technologies

4.1 The Production of Resin

4.1.1 Resin plastics

To manufacture large volumes of resins producers must operate large-scale, capital-intensive, technically advanced facilities. A wide range of products of varying quality and value incorporate resin plastics; this means that the return on capital is very dependent on the quality of the product. Typically, the more stages in the manufacturing process, the higher the investment and equipment replacement costs. The industry is fortunate in that a minimum amount of skilled labour is required to manufacture plastic products, which means wages are not as high as industries requiring skilled labour (Mary Nanfelt, 2012). Facilities are often integrated directly with the primary raw material suppliers; For example, many oil refineries often have resin manufacturing facilities on site operating on a continuous basis. The technology in this industry has remained relatively inactive for the last ten years. Technological innovation has focused on increasing production efficiency, improving consistency and reliability of the final products. Due to the recent legislative push to produce sustainable products, some manufacturers have begun investigating the use of biomasses as a source of raw materials, with vegetable oil and cornstarch being the common sources. The move towards 'bioplastic' has been hampered by the fact that producing resin from biomasses is prohibitively expensive, costing anywhere from 20% to 100% more than petroleum-based plastic (Plastemart.com, 2008). For this reason, in an industry that is so capital intensive, the majority of the resin-plastic producers remain focused on the petroleum-based resins that are far more affordable.

The market volatility means long-term strategic decisions have potentially a huge bearing on the success of a firm. Poor investment decisions may result in underutilized capacity if demand suddenly falls, alternatively capacity constraints may occur if there is a rapid rise in demand. As technology evolves the dependence on various types of resin fluctuates, a company that manufactures only one product or sell to only one industry have revenue flow that is more volatile than a diversified company.

4.1.2 Epoxy Resin

Epoxy Resin manufacturing is capital intensive, requiring technically advanced plants and equipment for large-scale manufacturing (Amari, 2012). The industry, unlike resin plastic manufacturing, requires a skilled labour force to manufacture plastic products that are constantly evolving through innovation in technologies. Manufacturers are able to lower production costs by a one-time or periodical investment in equipment; this is dependent on the rate of change for the incumbent technology. The complex process involved in manufacturing epoxy resins means that there is not a universal epoxy adhesive, rather the final products are dependent on the mixture of raw materials. Many manufacturers have a proprietary formula that gives their brand of epoxy adhesives unique characteristics. In recent years, advances in technology have significantly improved the consistency and quality of the adhesives on the market. The industry is sensitive to changes in its primary markets; for example, the construction, automobile and aircraft markets felt the effects of the recession, this affect demand of epoxy resins.

4.1.3 Wood Varnish

Wood varnish manufacturing is an industry that requires a moderate amount of capital investment. This industry is considered to be one of the least capital intensive industries for those involved with resin; in the United States it has a capital intensity ratio of 0.21 (Panteva, 2012). As the industry uses processes that require heating and mixing of potentially hazardous substances, some aspects of production require modern automated equipment. The industry’s need to maintain staff in key areas such as research and development, process management and quality control limits the use of automation. In North America, the industry has become highly regulated; many safety precautions have been introduced to limit exposure to hazardous substances. Consequently, the industry will see the emergence of technologies that ensure greater safety for workers, though this will come with a significant capital investment.

The industry has invested significant capital developing products that contain little or no volatile organic compounds. Several countries have introduced legislative measures to ensure the use of sustainable materials in new product development. The significant focus on R&D has begun investigating nanotechnology and the potential to develop new products by manipulating raw materials at the molecular level. Nanotechnology is a capital-intensive technology is in early stages of development, but represents a potentially significant area of technical innovation in the industry.

To determine the attractiveness of different resin products, analysis of industry volatility against annualized growth was undertaken. The higher the level of revenue volatility, the greater the risk is for the industry. Revenue volatility can affect long-term strategic decisions, consequently placing greater importance on initial investment decisions. Overall, the volatility of the resin industry is medium to high; this reflects the reliance on their primary consumers and the nature of these markets. For example, resin plastic products are very sensitive to the fluctuations in the construction and automotive manufacturing industries. The recession significantly affected these industries, which in turn, increased the volatility in the resin plastic industries. In the United States, the resin plastics, epoxy resins and wood varnish products industries suffered to varying degrees during the recession. Figure 10 illustrates the revenue volatility against the annualized revenue growth of resin products, for the years 2008 to 2012. The markets all had negative annualized growth during the period graphed, this is predominately over the recession period and may not be a true reflection of the growth and attractiveness of the resin industry. However, based on the information available the wood varnish products are the most attractive. As the wood varnish industry is the least technically advanced, the production requires the lowest amount of capital investment and the least influenced by the economic stability of its consumers (compared to those analyzed in figure 10).

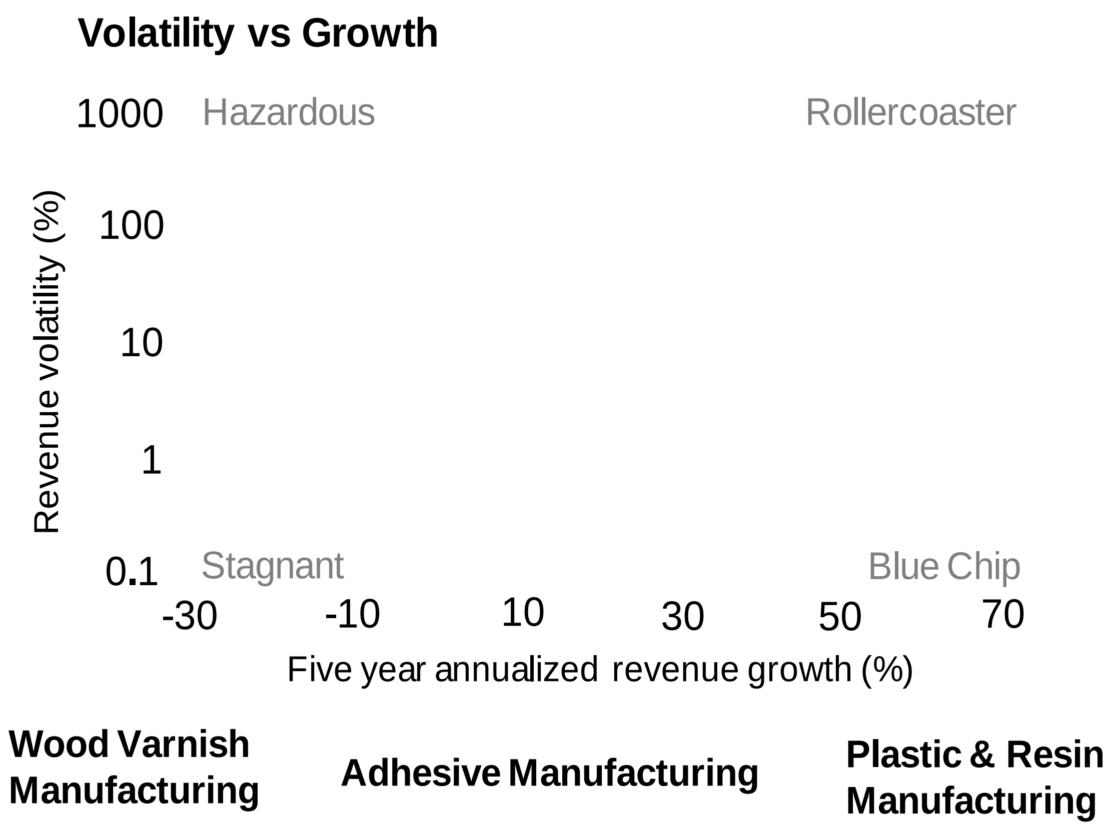

Figure 10: Resin industry volatility vs growth forecast.

This graph depicts the balance between volatility and forecasted growth relative to the type of economy each industry operates within.
The above figure is created by the author, based on figures generated in several 2012 IBIS World Industry reports (Mary Nanfelt, 2012), (Amari, 2012), (Panteva, 2012).

4.1.4 Resin manufacturing regulation

The industry is highly regulated (in developed countries), and heavy penalties are issued and imposed on manufacturers that do not comply with the regulations. In North America, strict regulations are in place to limit the use of volatile organic compounds in adhesives, plastics, varnishes and most products that include resin. Canada has strict protocols and policies to control environmental pollutants, with manufacturers made liable for any damage caused by pollutants (Architectual Coatings, 2012), (Canadian Synthetic Resins Industry, 2012). These policies also include health standards by which the industry must abide. Compliance with the regulations means that manufacturers must have appropriate equipment and maintain thorough records demonstrating compliance. Changing regulations also mean that manufacturers face the challenge of having to continuously altering their product formulations; this results in additional research and development costs. Early adopters of the changing regulations often stand to gain the greatest market share, whilst their competitors face the legislation repercussions. Violation of industry standards definitely exposes operators to expensive production disruptions as well as potential legal ramifications.

4.2 The Production of Carbon Fiber

4.2.1 Energy Industries

The energy generation by wind turbines is a capital-intensive process; the size of capital investment reflects the price of the energy generated. After the initial investment, the industry requires minimal labour input and the equipment has a long economic life. Operators' largest ongoing expenses are depreciation and maintenance. Location of the wind turbines is paramount, as turbines typically do not generate electricity in winds under 16 kilometres per hour or over 80 miles per hour (Williams, 2012). The limitations of the industry mean that the technology plays a key role in the process, as the easier turbines turn the greater the efficiency. The industry understands the benefits of carbon fiber, despite this; adoption has been gradual, with the limitation being the cost of the technology.

The industry is considered volatile even though the there has been relatively stable revenue growth and favourable government incentives. The volatility in the industry is due to the fluctuating prices of the other energy generating commodities; for example natural-gas, coal, hydro and nuclear (Molavi, 2012).The entire energy sector is highly influenced by government regulations; many governments around the world are pushing for the energy suppliers to increase the amounts of renewable energy that is produced. For example, in the State of Washington, clean energy initiatives require that energy providers to generate 15% of their power via renewable energy sources by 2020 (State of Washington Government, 2006).

4.2.2 Automotive and aerospace industries

The automotive industry is moderately capital intensive, with labour costs accounting for the majority of the operational expenses. Equipment is generally a one-time investment that requires only maintenance and modifications as technology evolves. Crude Oil prices strongly influence the automotive industry; the development of more fuel-efficient vehicles has reflected the consumers' sensitivity to high fuel prices. Automotive manufacturers constantly invest in research and development in order to create a competitive advantage. This constant product development has seen vehicles become lighter and more fuel-efficient without sacrificing passenger comfort or safety.

With the high labour costs of the industry, auto parts manufacturers are constantly seeking to improve productivity whilst maintaining and improving quality. The industry has seen a steady move towards automated production, particularly for larger parts and welding. Constant material innovation means that equipment requires regular investment to keep up with the evolving technology. Equipment upgrades costs the manufacturers' production time, which affects company revenue. The industry has tended to be slow to implement technological innovation on a large scale until the technology is cost effective to implement and has identified a consumer market.

The automotive industry has two primary forms of regulation; traffic safety and environmental. The traffic safety regulations ensure that the vehicles meet standards in crash avoidance, crash worthiness and post-crash standards. There is direct connection between the structural integrity and the traffic safety regulations. The environmental regulations set standards in levels of allowable emissions and fuel-efficiency. Governments are encouraging the automotive industry to become more ecologically responsible through legislation and tax incentives. The government in the United States updated the standards in March 2010 with an industry wide goal of each vehicle having a fuel efficiency of 34.1 miles per gallon (NHTSA & EPA, 2010).

The aviation industry has low capital-intensity, as the labour costs are far higher than the capital expenditure. The labour intensive nature of the industry is due to the size of the components and the skilled professionals that the technology requires. Suppliers and manufacturers work in close collaboration to ensure that new components fit aircraft specifications. These collaborations have been strengthened with technological innovation; this has lead to the development of new methodologies and equipment

The competitive nature of the aviation industry has meant that manufacturers, in their search for innovative success, have invested heavily in research and development. The fundamental objectives of the industry are to improve structural efficiencies and reduce manufacturing costs. The manufacturing processes and materials are unique from many other manufacturing industries by the stringency of the industry’s requirement for safety, reliability and operating efficiency. Manufactured components must comply with standards of greater accuracy and closer tolerances than many other industries. For this reason, the industry desires materials that are extremely strong and but low weight to maintain fuel-efficiency. For example, Boeing invested USD$3.9 billion in 2011 in a wide range of technologies including service initiatives; e.g. life cycle costing, safe and clean products (Barr Group Aerospace, 2012). Rising fuels costs has forced the industry to develop aircrafts that have greater fuel efficiency and smaller carbon footprints.

The two major players of the industry (Airbus and Boeing) are both operating at capacity with large order backlogs. These backlogs, coupled with the high price of the products create a calming effect on the industry; this reduces the level of volatility in the industry.

A highly regulated industry means that aircraft manufacturers have to comply with numerous regulations in regards to manufacturing and ongoing operations. National aviation authorities generally govern these regulations, with governments often heavily involved in the domestic airlines. Political support is often encourages economic stimulation by creating jobs, avoiding foreign dependency, stimulates technical and economic growth, as well as fostering national prestige.

4.2.3 The textile industry

The North American textile industry has a medium level of capital intensity; the average labour intensity ratio is approximately 6:1. The level of capital intensity varies greatly depending on the scale of the operation, with smaller operators being more capital intensive than larger operators are. The North American industry has been in decline in recent years, many manufacturers have relocated to Asia to increase their margins due to the lower wages (ICIS.com, 2009).

Applied research directed at particular objectives directs product innovation; for example; identifying new materials for products. Like all industries, there is a drive to reduce costs whilst maintaining quality; experimentation with synthetic fiber selection has become essential in improving product quality. The volatile nature of industry means that poor selection in technologies can drastically affect a firm's success.

North American operators in the synthetic fiber industry are required to comply with laws, regulations and legal requirements relating to the use, storage, handling, generation, transportation, emission, discharge, disposal and remediation of hazardous and nonhazardous substances and wastes. The North American industry struggles to compete with the cheaper Asian industry, as the margins are smaller and the industry has tighter regulations. To protect the North American synthetic fiber industry several countries (including China) have had anti-dumping tariffs placed on certain types of polyester fibers (Baijin Group, 2011). Despite the anti-dumping tariffs, there is little incentive for new producers to enter the industry as they struggle to compete with the large manufacturers with manufacturing operations in Asia.

4.2.4 Other Carbon Fiber Industries

4.2.4.1 Sports equipment

Sporting equipment, like many other North American industries, struggle with high labour costs, making it difficult to compete globally due to tight margins. Capital investment varies greatly between products; for example, cycle manufacturing requires technically advanced equipment, whereas football manufacturing depends primarily on labour. Product research and development is the industry's best survival factor, operators endeavour to produce better products to give themselves a competitive edge. Materials used in manufacturing are continually improving with the creation of lighter and increasingly durable compounds. Manufacturers are moderately regulated by environmental and health and safety laws and regulations for their plants.

4.2.4.2 Medical devices

The industry has medium capital intensity due to a high reliance on a labour force that manufactures unique products that automated machines cannot. The industry is extremely competitive, this means that products are constantly evolving with intellectual property and patents aggressively enforced to maintain their competitive advantages.

Advances in engineering have allowed the development of new products and reduced the costs of manufacturing through improved efficiency. The development of high-performance synthetic materials has opened up new possibilities for the industry; e.g. radiographic imaging table tops, mammography detection products, surgical tables, prosthetic limbs.

The economic environment does not affect the industry as much as other industries, so the volatility of the industry is only moderate. In addition, with companies protecting their proprietary technology with patents, trademarks, etc it enforces product innovation, which further drives demand and sales.

Bodies, like the Food and Drug Administration (FDA) and the Global Harmonization Task Force (GHTF), heavily regulate the industry. The regulatory bodies ensure that manufacturing of the products meet the appropriate standards to achieve premarket approval (PMA), Good Manufacturing Practices (GMP) and Quality Systems (QS) regulations. Further regulations are in place for tracking and trading once the device is in the hands of the vendor.

4.2.4.3 Firearms

The industry requires a significant initial capital investment in manufacturing plants and equipment; subsequent costs are primarily due to labour and maintenance. With the industry trending towards mechanization over the last five years, technological change in the industry has been slow. The technological advances have focused on reducing product weight whilst maintaining integrity. Demand is highly influenced by governmental policies and there is volatility introduced through the change in prices of materials. Regulation of the industry is required to protect the environment, health and safety.

To determine the attractiveness of the different carbon fiber products, an analysis of industry volatility against annualized growth was undertaken. Overall, the volatility of the carbon fiber industries varies greatly; the industry's reliance on their primary consumers affects the market stability. For example, aircraft manufacturing products are sensitive to the fluctuations of industry sales. Despite this, the industry operates primarily as a duopoly, the manufacturers operating with a large backlog of orders that serve to reduce volatility. The recession affected the individual industries differently; For example, the affect of the recession was more pronounced on luxury items, like those produced by the automotive industry. Conversely, medical devices are seen as necessity, so consumers continue to purchase these products when cash flow declines, sacrificing luxury items instead. Figure 11 illustrates the revenue volatility against the annualized revenue growth for the years 2008 to 2012. The annualized growth ranged greatly and was dependent on how the recession affected the product markets. The period graphed, is predominately during the recession and may not be a true representation of the growth and attractiveness of the carbon fiber products. However, based on the information available the medical device products are the most attractive. They are the least volatile and had an average annualized growth of approximately 15%. In terms of revenue growth, wind energy products have the largest revenue growth and there is legislative influence driving the growth of this industry. One could predict that as wind energy technology becomes more established, the industry volatility will diminish.

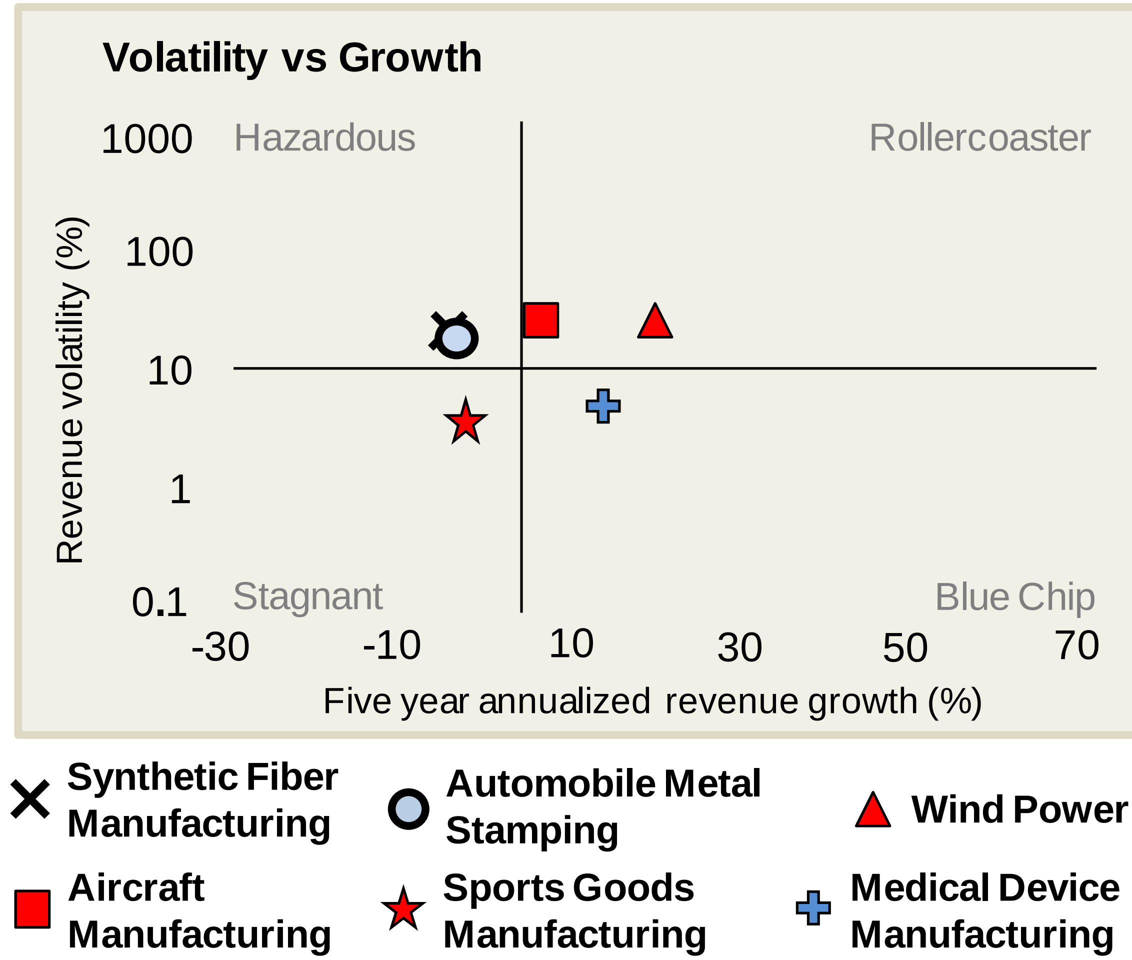

Figure 11: Carbon Fiber industry growth strategies for success.

This graph depicts the balance between capital intensity and labour intensity relative to the type of economy each industry operates within.

The above figure is created by the author based on figures generated in several 2012 IBISWorld Industry reports (Dale Schmidt, 2011), (Molavi, 2012), (Nanfelt, 2012), (Samadi, 2012), (McBee, 2012).

5: TCOS Framework Analysis

Many companies fail to convert innovative technologies into commercial success, as they are unable to overcome the innovative uncertainties. Hall et al. (2005) define "innovation" as the successful commercialization of an invention (Hall & Martin, 2005), (Hall, Matos, Silvestre, & Martin, 2011). Traditionally, frameworks designed to overcome the innovation discourse focused primarily on technological and commercial uncertainties, as depicted in figure 12. More recently, these frameworks have incorporated organizational uncertainties (Teece, 1986).

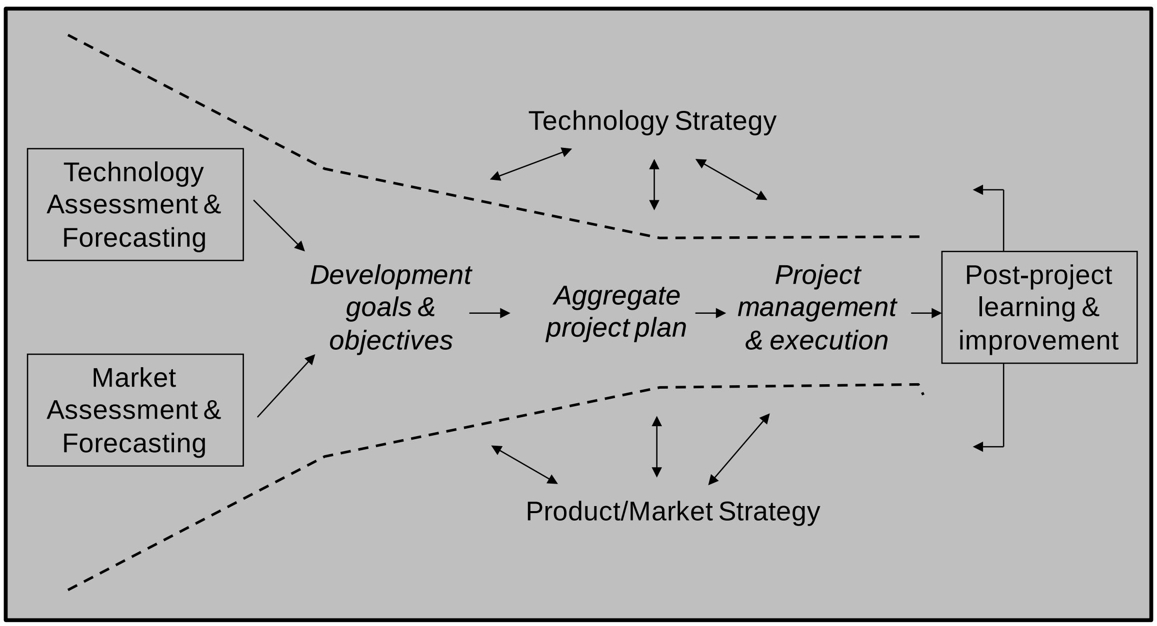

Figure 12: Traditional framework for exploring risks and uncertainties of an invention. Adapted from TCOS lab file (2012).

Hall and his colleagues argue that other business strategy frameworks neglect social uncertainties, which affect secondary stakeholders. The TCOS framework categorises the uncertainties into four dimensions, namely, Technical, Commercial, Organizational and Social (TCOS) uncertainties (Hall & Martin, 2005). For the technological uncertainty to be overcome the technology must be shown to be feasible based upon corporate scientific and technological competencies. To overcome the commercial uncertainties the technology must be able to compete in the current market. Organisational uncertainty requires the innovation to be consistent with the firm's strategy and capabilities, whilst protecting intellectual property and their complementary assets (Teece, 1986). Social uncertainty addresses the impact of the innovation on or from various secondary stakeholders. The social uncertainties are by far the most undefined and complex of the uncertainties proposed by Hall et al. (2005) due to the large number of variables.

Unlike the technological, commercial and organizational uncertainties, which are relatively well defined, the social uncertainties are socio-political in nature (Hall & Martin, 2005), (Hall, Matos, Silvestre, & Martin, 2011). The TCOS framework uses Karl Popper's "piecemeal social engineering" approach (Popper, 1959). This approach "recommends that politicians should attempt to correct generally accepted social ills in an ad hoc manner" (Hall & Martin, 2005). Hall et al (2005) believe that this approach is the most appropriate as it incorporates the complex nature and ambiguity of the social uncertainties. Popper's approach addresses secondary stakeholder's concerns on a case-by-case basis. Hall et al (2005) believe that social considerations may provide leverage for advancement of new innovations by providing legitimacy for the technology (Hall & Martin, 2005).

The summary of the theoretical foundation of the TCOS framework and the basis for the framework is illustrated in figure 13. As depicted in the figure, the technical, commercial, organizational and social issues are identified during the technologies' early stages of development. These issues are addressed throughout the development of the technology, so as new uncertainties arise they continually feedback into the development of the technology. Uncertainties tend to increase with ambiguity and complexity, with social uncertainties being the most complex and ambiguous (as depicted by the number of crosses in figure 13).

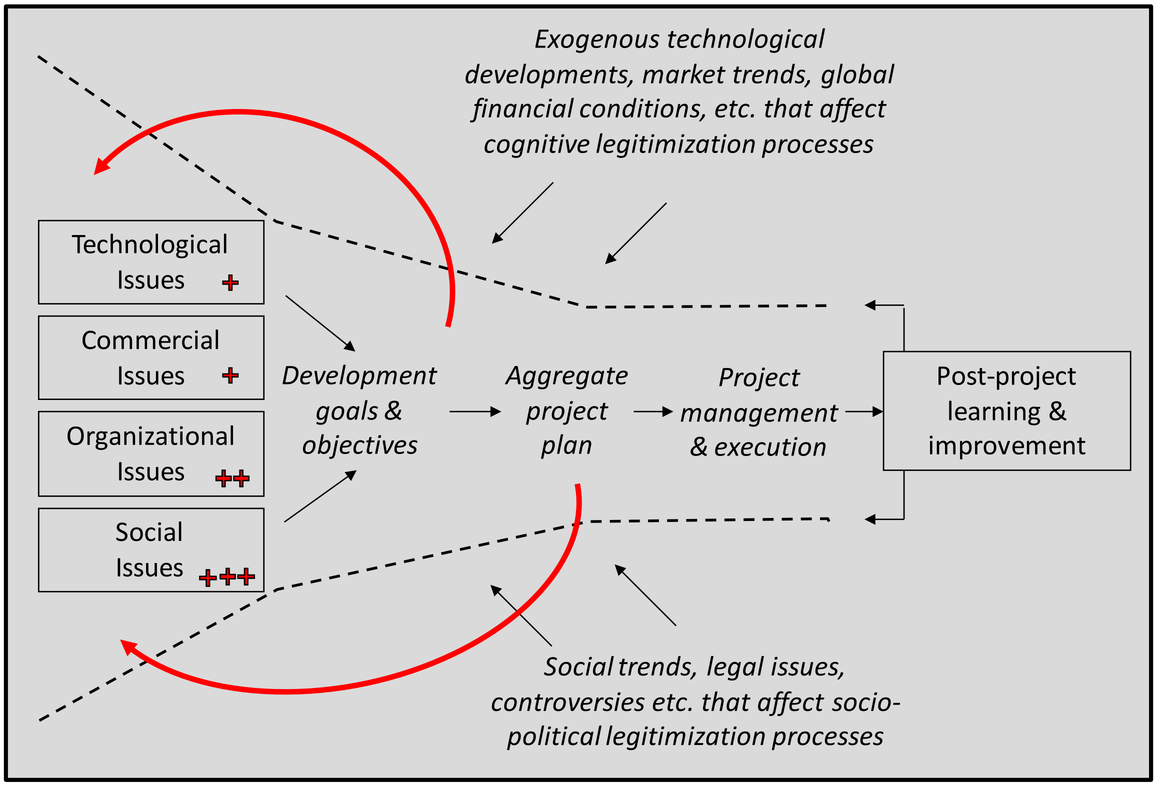

Figure 13: TCOS framework for exploring risks and uncertainties of an invention.

The level of complexity and uncertainty is represented by the number of crosses beside each issue.
Adapted from TCOS lab file (2012).

5.1 Technological Uncertainties

The technology is at a very early stage and is still being refined and optimized. Many issues are yet to be identified and addressed; for example, the best source of lignin has not yet been identified, which critically affects the final lignin products. The source of the lignin can affect the final lignin product in terms of consistency and durability. The main technical uncertainty that this technology faces is scalability of production, taking the discovery from a laboratory scale (millilitres and litres) to an industrial scale (tens of thousands of litres). To date, development of this technology has been performed in experimental sized batches, up to one-litre. To determine if this process can be used at an industrial scale, a 'pilot-scale' fermentation study is necessary (Junker, et al., 2003). A Pilot-scale fermentation study tests the feasibility of the fermentation process at industrial scales, investigating the scalability of the current degradation process. The technology will be required to operate at high a capacity to be competitive at an industrial level.

The technology still requires optimization of the engineered bacterium. Drs Eltis and Bugg selected *Rhodococcus jostii* as it has other proven commercial applications. It remains to be seen if other strains of bacteria possess better commercial properties; these studies are ongoing, with thousands of bacterial strains still to be screened. The limited resources of the laboratories and sheer number of bacterial strains still to be screened mean that optimization of the technology at the experimental level is still some way off. The research to date has focused on the isolation of vanillin, as mentioned in section 2.4, the least complex of the four product streams generated from degraded lignin. It may not be possible to isolate resin or carbon fiber from lignin using this technology or the process maybe to inefficient.

In addition, product consistency is paramount for the end users; inefficiency and product inconsistency has plagued other lignin extraction processes (Gallezot, 2012). These will issues will need to be overcome if the technology is going to realise its commercialization potential. This will require strict Standard Operating Procedures (SOPs) and Good Laboratory Practices (GLPs).

5.2 Commercial Uncertainties

There are a number of common uncertainties involved in the commercialization of either the resin or the carbon fiber products using this technology. Capital is required to scale the technology from the laboratory scale up to an industrial scale. In the current economy, lenders are hesitant to loan money to ‘risky’ start up ventures; the technology may find it difficult to raise capital. Any capital raised will have high interest rates to protect the lender; this increases the urgency for the technology to maximise returns on investment. Commercialization will require lead users, a company or service provider that is most likely to participate in an unproven innovation process. Potential lead users of this technology may be companies looking to break into a new market or for strategic market positioning. Entering an established market with a new technology would face barriers to entry due to lack of creditability and recognition.

The resin industry has incumbent technologies and established manufacturers. As a new entrant, the technology it would have to at least meet or surpass the industry standard in order to compete. To compete, the technology requires a large capital investment for the construction of large high-tech complexes that are able to manufacture high quality products. The ideal lead user would be an established manufacturer that is looking to diversify into other market segments or become an eco-friendly brand; for example, the company Glad specializes in trash bags and plastic food storage containers. Glad products are disposable and yet contain plastics that take years to degrade. Using this technology to produce ‘bioplastic’ could create a new image for Glad. In contrast, the carbon fiber market is a capital-intensive industry that is yet to realise its market potential. Unlike the established resin markets, there exist underserved areas for carbon fiber.

Entering either the carbon fiber or resin market raises the possibility of retaliation from the incumbent players, particularly the petrochemical resin and carbon fiber producers. The petrochemical industry producers have deep pockets and significant influence with governments, as all countries are heavily reliant on their products.

Economics of scale and the ability to operate at high capacity are necessary to operate in the both the resin and carbon fiber markets efficiently and to achieve low unit costs. Another significant barrier these markets face is the ongoing requirement for innovation, the evolution of technology drives product demand. This means new entrants must commit to invest a significant amount in research and development. A strategic partnership with a firm looking to break into a market may be beneficial for both parties; for example, the Canadian aeroplane manufacturer Bombardier is looking to break the Boeing and Airbus duopoly of the industry (Madslien, 2012). Using an innovative technology to produce energy efficient planes may be the competitive advantage Bombardier needs to break into this market. Any kind of partnership requires strict regulation to protect the innovators proprietary intellectual property. The organizational uncertainties section below outlines the boundaries of these types of agreements.

5.3 Organizational Uncertainties

The organization faces the dilemma of developing the technology in-house or out-licensing; each has their own set of uncertainties. Developing in-house is a significant undertaking with investments in human resources with the appropriate expertise and large capital investments in facilities and infrastructure. Drs Eltis and Bugg have yet to establish suitable protection of intellectual property using patents, trademarks and copyrights of the technologies. This is an extremely important as it holds the key for the organization if it establishes a foothold in a market. Protection of the technology may face uncertainty as the bacteria and enzymes are natural, so competitors may argue that the technology should be available to anyone. Chemical and petrochemical product innovations are difficult to protect; there are numerous examples of new products reaching the market but never generating economic returns because of imitation. For example, in the 1960s a large plastics producer, Dow, started producing rigid polyurethane foam, but in the absence of low cost manufacturing capabilities, smaller firms with lower overheads quickly imitated the technology (Teece, 1986).

The organizational uncertainties have some levels of overlap with the technological and commercialization uncertainties regarding the scalability of the technology. Unlike technological uncertainties where proof of principle is still required, here establishing manufacturing facilities for the larger scale operations is required. If the technology becomes commercially successful, then the organization may struggle to meet demand if the production capacity is not capable of ramping up. In-house development is limited to the capabilities of the organization, operating at an industrial scale may be prohibitively expensive for a small company. Contractual relationships may be required for the company to access the variety of complementary assets and competences for an operation of industrial size. Smaller firms are often eager to establish contractual agreements, as it adds credibility and generates a level of legitimacy for the technology. Contractual relationships may expose the innovators to a number of hazards and dependencies. Innovators may find it difficult to convince contractors to make costly irreversible commitments that are critical to the success of the innovation. In the current economic climate, many contractual suppliers are unwilling to take a risk on unproven technologies.

How does a company choose between developing a technology in-house and out-licensing? Gans and Stern (2003) argue that when intellectual property protection is strong and established firms hold key complementary assets, then start-up firms generate more economic rents if they out-license (Gans & Stern, 2003). Out-licensing secures access to complementary assets that are important for the innovation in question; start-up firms that are resource constrained need not incur costs and time to develop these assets. If protection of the intellectual property is poor and there are low barriers to entry then in-house development is an optimal strategy. The new technology currently lacks effective intellectual property protection, but the barriers to entry are relatively high due to the capital-intensity of the resin and carbon fiber industries. Under these circumstances, the Gans and Stern (2003) framework of technology commercialization indicates that the protection of the intellectual property must be in place if the technology is to be out-licensed (Gans & Stern, 2003); this avoids knowledge leakage that reduces the competitive advantage of the innovating firm. Without legal protection, start-up firms may seek out other mechanisms such as continuous improvements of the technology to limit the possibility of imitation by other firms.

If the organization decides to out-license the technology to an established manufacturer, the organization must address several issues. Firstly, an appropriate manufacturing partner must be found, and then both parties must reach an agreement. Due to the wide range of possible final products, strict limitations defining the products and industries the manufacturer can produce will be required. These limitations can include territories where the manufacturer may market and sell the technology. For example, in the case of Evian water bottles which use PET plastics, an agreement with Evian might restrict the distribution of bottles using PET bioplastic to Europe as such agreement infringes on competing contracts. The agreement will need a rate of royalty; several criteria affected the rate of royalty, as summarized in table 1. The agreed upon criteria of the partnership define the rate of royalty. As the innovators are the licensors they obviously determine who they license to and will have to consider the advantages a potential licensee has.

Criteria	Description
Exclusive or Non-exclusive	Exclusive idea will result in a higher royalty rate than non-exclusive licenses
Upfront Sum	The higher the up-front sum being paid to the licensee, the lower royalty rate the licensor will likely receive as it is an element of the overall compensation
Industry Standard Royalty Rates	Each industry tends to have an 'industry' royalty rate.
Company Standard Rates	Companies that have a good amount of experience in licensing ideas tend to have a standard package that they offer inventors
Intellectual Property Stage	The further along the intellectual property is to commercialization, the less risk the licensee will face, and the high the royalty will be paid to license.
Market Potential	The royalty rate will heavily depend upon the market potential of the idea you are looking to license.
Licensing to an infringer	If a company has been infringing on your idea, you may be entitled to damages, a percentage of past profits and typically command a higher royalty rate.
Related Intellectual Property Included	Packaged intellectual property can command higher royalty rates.
Testing/Certification	If your intellectual property requires testing or certification prior to being brought to market, having these milestones completed will increase the royalty rates.
Investment Required	All things being equal, the higher the investment required to get a product to market, the lower the royalty rate that will be paid.

Table 1: Royalty rates criteria and description.

The above figure is created by the author, based on figures generated in on a table on www.ideabuyer.com (Royalty Rates, 2011).

5.4 Social Uncertainties

The social uncertainties are ambiguous but potentially have greatest influence as to whether a technology successfully becomes a commercialized product. The sponsor, Dr Hall, argues that the technology has shown proof of principle and that limitation of the technology is that there is a lack of secondary stakeholders to drive the commercialization. Identification of the secondary stakeholders in required to determine the social uncertainties.

The beauty of this technology is that it uses lignin obtain from a sustainable resource, this means the technology can reduce global carbon emissions. In addition, as outlined in the industry organization analysis the products produced from the lignin can also reduce product carbon footprint. The G8 governments are working towards reducing the level of air pollutants globally; this has resulted in a global push toward production of ‘cleaner’, energy efficient products (Justin Gerdes, 2012). Lignin Carbon fiber fits the G8’s directive well; it is a sustainable resource, which increases vehicle fuel-efficiency. Legislative acceptance is a powerful tool that can drive the incorporation of the technology into common manufacturing practices. The objective the legislators may counteract the consumer desires. For example, the technology creates an interesting dilemma for the airlines that utilize the technology to manufacture carbon fiber aircrafts; flights could reach their destinations faster by using the same amount of fuel but have to spend more time with their planes on the ground. This would increase customer satisfaction but cost the airlines more in airport fees with planes spending longer on the ground, as well as not reducing carbon emissions. Alternatively, the airlines could use less fuel and arrive at the same time thus reducing the plane’s carbon emissions.

Automobile and aeroplane manufacturers are continuously looking to increase fuel efficiency. Ever since the properties of carbon fiber were defined, it has been considered an ideal material for these industries. Unfortunately, the nature of carbon fiber means that it cannot be mass-produced as easily as steel alloys and aluminium. Using carbon fiber significantly increases the end users price; for example, a Boeing 737-600 costs USD$56.9 million compared with a Boeing 787 Dreamliner (which is 50% carbon fiber) costing USD$193.5 million (Boeing 737-600, 2012), (Boeing 787 Dreamliner, 2012). For the end user, over the economic life of the plane, saving 20% fuel each flight through purchasing the Dreamliner may never reach savings made by simply buying the less expensive Boeing 737-600.

There are significant uncertainties surrounding the regulation of the Resin market; most products are manufactured using raw materials from petrochemical compounds that require a significant amount of processing. Strict standards are in place to regulate water, soil and air pollution. Ensuring the lignin bacterial degradation process meets the appropriate standards and regulations including and not limited to hazardous chemicals, air emissions and pollutants. Lignin resin manufacturers may argue that lignin resin has a lower carbon footprint when compared to petrochemical resin.

As the technology involves genetically engineering bacteria, questions may arise about the safety of the isolation process. Companies, like Monsanto, that have worked with genetically engineered products in the past have faced significant criticism. Unlike Monsanto, which was genetically engineering seeds for corn (Sewell, 2012), the final product is not intended for consumption. However, when companies are working with genetically engineered products there is often public concern about the repercussion if the bacteria escapes back into nature. Whilst the modification has safe guards (Chen, et al., 2012) to control survival of the bacteria, the public may not know or understand this concept.

In Canada, with its huge forestry industry, it makes sense to source the lignin from wood. The question is whether lignin from this source produces the most reliable and consistent compounds. Whilst is the group is the first to publish and show that bacteria can be used to depolymerise lignin to generate a product that could be commercialised, other groups are also investing in lignin exploration; for example corn feedstock in the United States or China. The companies, KL Energy and Mascoma have partnered with Energy suppliers Fair Energy and Chevron respectively to investigate possible usage of lignin derived from cellulosic ethanol (Lane, 2010).

With regard to the resin based products, they would be considered semi-synthetic because there are significant number of processes required to manufacture the end products like epoxy resin, plastic, etc. Environmentalists may argue that the benefits of using a sustainable, potential carbon neutral raw material may not outweigh the harm manufacturing the final product inflicts upon the environment.

5.5 Summary of TCOS Analysis

The manufacturing efficiency of the technology and its ability to meet commercial standards are the main uncertainties. Improvements in the consistency and durability are required for the technology to compete commercially. The commercial uncertainty negatively affects the potential to raise capital to compete and operate acceptable margins. The influence of the secondary stakeholders can mitigate the resistance of the incumbent market players.

Ongoing research performed by the academic laboratories that developed the technology mitigates the uncertainty surrounding the need for continual innovation to drive commercial success. As the innovators have little experience at operating commercial ventures, it appears that protection of the intellectual property is pivotal in determining the organizational uncertainty. For the technology to establish itself in either the resin or carbon fiber markets, it appears that the organization will have to collaborate with an incumbent market player. Before any partnership is entered into the intellectual property must be protected, otherwise the innovators risks losing their competitive advantage. If a partnership is established, an agreement for the rate and type of royalty is required; this will allow the technology to enter industries and markets where it believes it can have the greatest commercial viability.

The innovators have the option of commercializing the technology in-house, but this seems unlikely, as a large investment in facilities and equipment is required. The innovators would need to establish almost all organizational requirements (human resources, contractual agreements with distributors and suppliers, etc) to operate at an industrial level. The social uncertainty relates to the ‘buy-in’ by regulatory stakeholders; this technology aims to influence lawmakers via the sustainable nature of the technology. If this eco-friendly technology can gain favour with lawmakers, then the technology will establish a competitive advantage over existing sources of resin and carbon fiber.

There may be resistance by the end-users due to cost, but this is expected to be minimal as carbon fiber costs are still high for existing sources. Resin costs may meet higher resistance as the synthetic resins have low market value and so introducing resin that is more expensive may have a slow rate of change. Research into competing sustainable technologies is being performed, but is far from optimized; this report’s technology has an advantage, in that the entire process involves sustainable resources. However, with the publication of the technology in late 2011 (Ahmad, et al., 2011), the technology has now been revealed to potential competitors.

Table 2 summarizes the risk characteristics and their level of uncertainty; the numbers in brackets indicate the level of uncertainty (out of 5, the level of uncertainty increases with the number value). Overall the ‘uncertainty values’ reflect that the technological uncertainty has the greatest risk. The capital-intensity and economies of scale have the greatest commercial uncertainty. Due to the organizations circumstances, the intellectual property and royalties have high uncertainty.

The TCOS analysis suggests that the social uncertainties will be the factors that will drive the adoption of the technology, through legislation and regulatory influences. The environmental benefits of the technology its greatest asset. The technology is extremely reliant on these secondary stakeholders and this reliance will determine if the technology will become a commercially successful. Organizations like California Air Resources Board (CARB) are secondary stakeholders that promote the development of innovative technologies that promote compliance with air pollution rules and regulations. Without political buy-in, this technology will struggle to gain adoption as the incumbent technologies are deeply entrenched.

Uncertainties:	Technological	Commercial	Organizational	Social
Risk Characteristics	• Scalability (4.5) • Consistency (3.5) • Durability (3.5) • Inefficiency (4.5)	• Capital Intensity (4.5) • Incumbent players (3) • Economics of scale (4.5) • Ongoing innovation (2)	In-house: • Facilities (4.5) • Human resources (2.5) • Network (2.5) Out-license: • IP protection (4.5) • Rate and Type of Royalty (3.5)	• Reduced carbon footprint (4.5) • Air emissions, hazardous chemicals & pollutant regulations (4.5) • Entirely sustainable technology (4.5) • Genetically Engineered (2.5) • End-user cost (2) • Competing Emerging Technologies (3.5)

Table 2: Summary of the Risk Characteristics for Lignin Resin and Lignin Carbon Fiber.

6: Conclusion

Summary:

This report looks at the commercial viability of a sustainable technology that uses properties of natural bacterial to liberate resin and carbon fiber compounds from biomass. Analysis of the existing and competing technologies completed to understand why there are no commercially successful natural lignin derived products. These technologies use existing compound degrading processes, which are complex, inconsistent and inefficient. The beauty of this new technology is that it utilizes sustainable resources, which if developed appropriately could reduce the global reliance on compounds derived from fossil fuel. The sustainability of the technology will drive its development and adoption via the influence of secondary stakeholders.

Potential Markets:

Analysis of the potential resin and carbon fiber markets found that there is a growing reliance on synthetic compounds. The potential markets are huge, with synthetic compounds extensively used in construction, automobile manufacturing, clothing and many other industries. These markets are heavily dependent on compounds derived from the petrochemical industry. Demand for resin and carbon fiber products relates to the price of crude oil. The current political climate is attempting to reduce the global reliance on fossil fuels in order to reduce pollution; continued scientific research is pursuing sustainable technologies.

Demand for sustainable technologies has intensified and has begun to transform the competitive landscape (Nidumolu, Prahalad, & Rangaswami, 2009). The need for corporate social responsibility is influencing business objectives. Corporations are beginning to realize that the number of consumers wanting eco-friendly products is growing and that sustainable technologies are a potential competitive advantage. Legislative and corporate stakeholders are recognizing the global need for sustainable technologies. Governments are encouraging sustainable technologies as a means to reduce global pollution levels.

Ability to meet the market:

Drs Eltis and Bugg have identified a sustainable technology and shown proof of principle. Using genetically engineered natural bacteria, they are able to transform natural lignin derived from biomass into commercially viable compounds. However, uncertainty remains high concerning the scalability of technology, product quality, process efficiency and economies of scale. There are without doubt viable markets available for the technology in both the resin and carbon fiber industries, with both industries experiencing continued growth despite the recent economic recession. This technology aligns with both the corporate and legislative shift towards sustainable technologies. Despite the markets having incumbent resin and carbon fiber technologies, it appears that legislative and corporative policy changes will create space in the markets for the technology.

Business Strategy Analysis:

The TCOS analysis indicates that the socio-political influences will be the main factors that determine if this technology will become commercially successful. The technology is attempting to enter industries where the incumbent products are equally competent; a compelling value of the technology is its ability to utilize sustainable resources. This technology should take advantage of the various legislations and regulations introduced by governments to cut the global carbon footprint and pollution levels. Demonstrating that the technology is consistent and reliable would show governments that there does not have to be such a heavy reliance on petrochemical compounds. Secondary stakeholder influence will encourage investment in sustainable technologies. With enough research and capital, this technology can overcome the technological, commercial and organizational issues that have limited lignin commercialization.

The Porter's Five Forces analysis (see appendix) produced contrasting results. The analysis suggests that it would be difficult to recommend continuing the development of the technology, as the petrochemical industry dominates the markets. The economic recession has forced North American manufacturers to shrink margins to remain competitive with cheaper Asian manufacturers. The innovators face the daunting task of raising significant capital for a technology that still requires significant development. Finally, the technology must establish market share in industries that have strong incumbent suppliers. These hurdles would be too much to overcome for most small start-up technologies that lack significant financial backing.

The contrasting conclusions show the potential limitations of the Porter's Five Forces analysis and the benefit of the TCOS analysis. The Porter's Five Forces analysis negates the technologies' competitive advantage by omitting the social issues and concerns of secondary stakeholders. The potential influences of secondary stakeholders diminish many of the technological and commercial limitations of the technology.

Target Market:

The softest market to enter is the wood varnish industry, as the capital investment required is lower than the other markets analyzed. Furthermore, the volatility has remained low even during the economic recession, indicating that the level of influence by other industries is moderate. Unfortunately, using sustainable material in the wood varnish industry would not gain the same attention from secondary stakeholders compared to carbon fiber use in vehicles. Establishing commercial competency in the wood varnish industry may create a stepping stone for the technology to enter markets that are more lucrative. With appropriate intellectual property protection and strong contractual agreements, the technology could offer numerous products.

Course of Action:

The strategy for the innovators moving forward would be to focus primarily on optimizing the technology, to enhance the proof of principle for influential secondary stakeholders. If governmental secondary stakeholders have a sustainable alternative to petrochemical compounds, then adoption of the technology will be encouraged through legislation and tax incentives. Simultaneously, the intellectual property must be protected; this is the technologies' proprietary advantage for gaining entry and competing in the commercial sector. Drs Eltis and Bugg should look to enter a market with the least volatility and barriers to entry. Unfortunately, with the current economic climate some level of volatility exists in every market.

Due a lack of managerial expertise and financial capital, it would be prudent to out-license the technology to an incumbent firm that possesses the manufacturing and marketing capabilities. The decision to out-license is dependent on the securing of the technologies' intellectual property. The research group is currently the only group that utilizes natural bacteria for lignin degradation; this is a high priority as the sustainability of the technology is their competitive advantage. With access to more resources, this technology should overcome the technological and commercial issues that the inventors would struggle to conquer developing internally.

Appendix: Porter's Five Forces Analysis

For comparative purposes a Porter's Five Forces analysis follows; this framework differs from the TCOS framework in that it assesses overall industry profitability. In 1979, Michael Porter of the Harvard Business School developed this framework using five forces to determine the attractiveness of an industry by assessing its competitive intensity (Porter, 1979). Attractiveness refers to overall industry profitability; so an attractive/unattractive industry is when the five forces act to strengthen/weaken the overall profitability of firms operating in the industry. The five forces analysis places less strength on the social issues that can affect the business strategy of a technology. Definition of the five forces follows:

- Supplier Power – this refers to the market inputs. Suppliers of raw materials can exert influence on the producing industry. For example; if the suppliers are limited they can apply more force causing buyer to pay higher prices, conversely if there are many suppliers then they exert less force and prices will be lower.
- Threat of New Entrants – this refers to the barriers to entering the industry. This can be related to the cost of entry, legislative issues, and intellectual property, among others.
- Threat of Substitution – this is the existence of products outside the common product boundaries which increase the likelihood of customers switching to the alternatives.
- Buyer Power – the ability of customers to put the technology under pressure. For example; when there are multiple producers of the technology then the buyer has a greater ability to set the price. The same is true if the buyer purchases a significant amount of the product.
- Degree of Rivalry – this refers to the number and capability of the competitors in the industry. For example; if your technology is unique then there is little to no pressure; however if there are many competitors or your competitors have a greater competitive advantage then there will be significant pressure applied.

i. Porter's Five Forces Analysis – Lignin Resin

Supplier Power – High, over 90% of the world's lignin resin is synthetic in origin and produced from petrochemical production by-products. The suppliers are petrochemical companies, Wood Pulping companies and cellulosic ethanol companies. The petrochemical industry dominates the industry and drives the price of resin through the price of crude oil.

Threat of New Entrants –Low, though research and development is ongoing for "naturally" produced lignins (from wood and feedstock). A significant amount of capital and time would be required for a new entrant to enter the industry. The technology requires a significant level of economics of scale to become commercially viable and competitive.

Threat of Substitution – Low, currently the technologies are too inefficient and expensive to be considered a threat for the incumbents.

Degree of Rivalry – Moderate and growing; the industry has a low level of concentration, reflecting the fragmented nature of the industry. Customers can change between producers relatively easily with the industry prices being quite stable amongst suppliers. However, there are varying levels of product segment focus that the recession significantly affected. For example, four polyethylene producers now account for approximately 80% of North Americas' capacity. In addition, seven manufacturers account for over 45% of the polyethylene capacity. Manufacturing requires technologically advanced equipment; there can be a significant cost in exiting the industry as equipment depreciated quickly with the rapid evolution of technology.

Buyer Power – Average and decreasing; with the number of producers in the industry declining due to the recession buyers have less options, in addition no one buyer or single industry monopolizes a significant proportion of the technology meaning that buyers have little say over the final price. There are no competitive substitutes available.

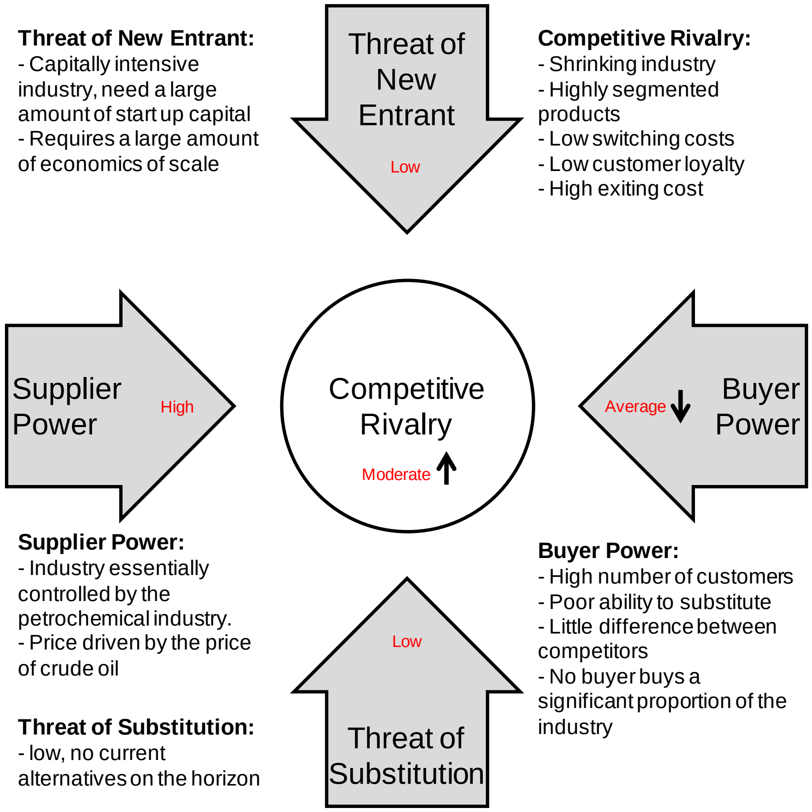

Figure 14: Summary of the Porter's Five Forces Analysis on Lignin Resin Industry.

Figure 14 illustrates the level of pressure demonstrated by each of Porter's five forces on the lignin resin industry. The suppliers apply the largest force; the petrochemical industry dominates the industry and controls the current market prices. The threat of new entrants and substitution are both low due to the industries capital intensity. The recession has caused the industry to shrink increasing competition and exiting cost, competitive rivalry is currently growing. No one buyer dominates the industry and buyers have little power, as competing products are essentially the same and there is a large number of customer base. Overall, it would be difficult to recommend continuing development of the technology; the petrochemical industry dominates the resin industry. A new entrant faces raising significant capital to compete in an industry with shrinking margins and increasing rivalry.

ii. Porter's Five Forces Analysis – Lignin Carbon Fiber

There are obvious similarities between the Lignin Resin and Lignin Carbon Fiber as the primary suppliers are the same.

Supplier Power – High, over 90% of the world's carbon fiber is synthetic in origin and produced from petrochemical production by-products. The suppliers are petrochemical companies, Wood Pulping companies and cellulosic ethanol companies. The petrochemical industry dominates the industry and drives the price of carbon fiber through the price of crude oil. If an alternative source of lignin emerged that was not reliant on the petrochemical industry, then the supplier pressure may lessen.

Threat of New Entrants – The risk of new entrants is low. New entrants face having to spend significant amount of capital and time in order to enter the industry. It requires a significant level of economics of scale, the ability to produce the amount of carbon fiber that could sustain an industry like the automobile or aircraft requires significant amounts of raw material. While a large amount research and development to produce composites that duplicate carbon fibers' properties, but these face the same issues of scalability and process efficiency.

Threat of Substitution – Low but increasing; with technology ever improving, a significant amount of research and development is being undertaken to develop compounds that could be used as substitutes to the current incumbent. To lower carbon emissions, the creation of laws and tax incentives are in place to encourage the investment in sustainable research and technologies.

Degree of Rivalry – Moderate and increasing; with the industry predicted to continue growing as the technology becomes widely adopted; it is easy to forecast that the level of rivalry will grow. Highly segmented final products mean that producers may operate in the same space. In addition, as the production process improves companies will compete more on price. With the manufacturing of products requiring technically advanced equipment, there can be a significant cost in exiting the industry as equipment depreciates quickly with the rapid evolution of technology. For customers there is a low switching cost, however with the industry currently concentrated in terms of producers there are not many options within the industry for the customer.

Buyer Power – Moderate; with the number of producers in the industry highly concentrated, it means that the buyers have less options, in addition no one buyer or industry monopolizes the technology. This means that buyers have little say over the final price. There are other competitive substitutes available, which means that customers can 'make do' with other products. Large industries, like automotive and aircraft manufacture, that may influence the industry have not yet stream lined their carbon fiber manufacturing processes to make it cost effective. When companies like Boeing can produce carbon aircrafts at a price similar to aircrafts using other composites then the buyer will be able to put more pressure on the industry. The industry an advantage over buyers as a wide range of products can utilise the technology, so there is still only moderate pressure to lower the price for the buyer.

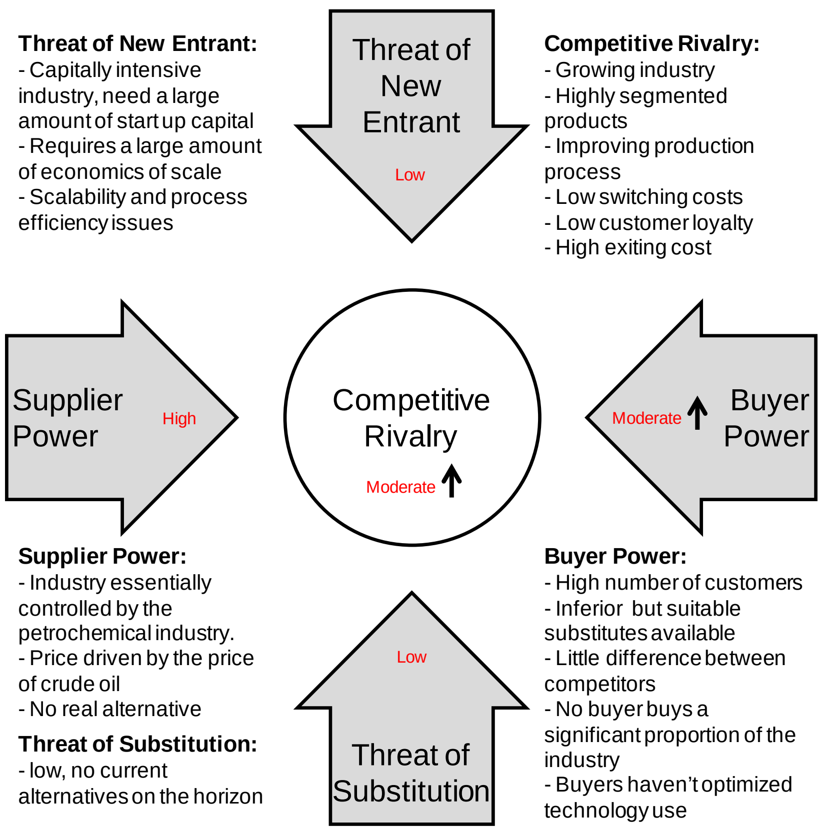

Figure 15: Summary of the Porter's Five Forces Analysis on Carbon Fiber Industry

Figure 15 illustrates the level of pressure exhorted by each of Porter's five forces on the lignin carbon fiber industry. The suppliers apply the largest force; the petrochemical industry dominates the industry and controls the current market prices. The threat of new entrants and substitution are both low due to the industries capital intensity. The recession has caused the industry to shrink increasing competition and exiting cost, the competitive rivalry is currently growing. Buyers are gradually applying pressure on the carbon fiber manufacturers, suitable substitute composites are available and so buyers are not complied to use the product. This means that manufacturers are developing processes to lower the production costs to entice customer adoption. Overall, it would be difficult to recommend continuing development of the technology as the petrochemical industry dominates the carbon fiber industry. A new entrant faces the task of raising significant capital to compete in a capital-intensive industry with shrinking margins and end-users that have suitable substitutes.

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