Evaluation of Tobacco Biomass for Bio-Plastics Production

CLIENT:

TYTON BioEnergy Systems

Prepared by:
Juan Jose Ocariz
Diana Rowe
Pablo Taccioli

2016 Candidates for the Duke University MEM/MBA degree

Adviser:
Dr. Timothy Johnson
Associate Professor of the Practice in Energy and the Environment
Nicholas School of the Environment, Duke University

Date Submitted:
April 25, 2016
Executive Summary

Evaluation of Tobacco Biomass for Bio-Plastics Production

By: Juan Jose Ocariz, Diana Rowe and Pablo Taccioli
April 25, 2016

Tobacco is a resilient plant that requires minimal water and fertilizer and can be grown on marginal lands, or those which are not suitable for food crops. Currently grown in 110 countries,¹ the plant has significant potential to serve as a feedstock for bio-based manufacturing as it has one of the highest concentrations of usable biomass of any plant.² In addition to its growing and harvesting benefits, tobacco has a complex chemical structure that comprises more than 3,000 compounds,³ making it ripe for biogenic and transgenic research.

Utilizing the complex molecular structure of tobacco, Tyton BioEnergy Systems (Tyton), a start-up headquartered in Danville, VA, has developed a unique strand of tobacco that contains three times the sugar content and two times the oil content of standard tobacco strands. In addition to the development of the company’s “energy tobacco,” Tyton has a patent-pending hydrothermal extractor that separates a pure sugar stream from the plant’s remaining components of oil, proteins, and various other chemicals that is known as biochar (a soil enhancer produced through pyrolysis).

Tyton’s current business model seeks to use tobacco-based sugars as a feedstock for ethanol production. However, due to the volatile nature of ethanol prices, the company is seeking alternate manufacturing applications for its “energy tobacco” as a means to diversify revenue and move toward high-value products. This project seeks to identify a short-term pathway for Tyton to enter the bio-chemicals market through its expertise in tobacco-based sugars as well as provide medium and long-term recommendations for how Tyton can capitalize on the oils, proteins, and complex genetic make-up of the plant.

Upon evaluation of bio-manufacturing trends within the chemicals industry, the team recommends that Tyton position itself to enter the bioplastics industry, which has a current US market value of $490 million.⁴ According to European Bioplastics, a trade association, global capacities for bioplastic production are projected to more than triple by 2018 from 2013 capacities of 1.62 million metric tons.⁵ Demand primarily stems from the US and European markets that seek more environmentally-sourced plastics and packaging; however, there is significant traction in Asia as well.

The team identified four major bioplastic compounds including polyhydroxyalkonoates (PHA), polybutylene succinate (PBS), bio-polyethylene (PE), and polylactic acid (PLA) and determined that the latter three use sugar-based manufacturing. Considering the complexity and long-term nature of international business, the team opted to focus on PLA since top global manufacturers of PLA are located in the US. PLA is made by converting a pure sugar stream into lactic acid through a fermentation process that eventually produces a lactide ring that then converts to a polymer chain. Through interviews with industry professionals, the team learned that the corn-based sugars represent a significant portion of the manufacturing cost.⁶

The team conducted a competitive analysis that revealed tobacco to be a viable substitute for corn in the production of PLA in the following areas:

- **Performance:** Based on discussions with industry professionals, the team determined that the purity of the sugar stream from tobacco (glucose) would have similar performance to that produced from corn (dextrose).

- **Environmental Impact:** The team performed a “cradle-to-gate” or “cradle-to-sugar” analysis that considered fertilizer, energy, and irrigation across the growing and harvesting as well as sugar extraction process for both corn and tobacco. The team used the functional unit environmental
impact per kilogram sugar produced to compare the two crops. The three impact assessment measures included global warming, acidification, and ecotoxicity.

The results found the growing and harvesting portion of tobacco to be nearly five times as energy-intensive as the growing and harvesting of corn. However, the result likely derives from Tyton’s use of greenhouses in order to increase the growing cycle of its tobacco. On the extracting side, tobacco was seven times more efficient than corn, which uses a wet mill process. This resulted in tobacco having an almost a 50 percent lower total energy usage and lower environmental impact in all three assessment categories.

Tyton’s tobacco fields are approximately 1,800 kilometers from the concentration of PLA manufacturing facilities. Therefore, the team added the additional factor of transportation, which eliminated all environmental benefit of tobacco. However, after speaking with Tyton about potential operation improvements, the team ran a sensitivity analysis on reductions in electricity and fertilizer. A 30 percent reduction in electricity usage and a 100 percent reduction in fertilizer use would bring the global warming impact of tobacco with transportation below that of corn.

- **Financial:** In addition to fertilizer, energy, and irrigation, the team also included labor & machinery, seeds, and overhead to the input categories for the financial analysis. Corn operating expenses totaled $0.27 per kilogram of sugar whereas tobacco had a sizable margin below this. Due to the confidentiality of Tyton’s production costs, an exact figure is not reported.

The team recommends that Tyton hire an external team to perform an in-depth engineering study to assess and confirm the feasibility of substituting corn with tobacco for PLA production. Recognizing the sensitivity of the “cradle-to-sugar” analysis, Tyton should approach a third-party institution to conduct a formal life-cycle analysis to endorse the findings and build credibility among industry players. Finally, Tyton should take initial steps to initiate partnerships with PLA manufacturers to begin introducing tobacco-derived sugars into the bioplastics industry.

For the medium-term, Tyton should select bio-based chemicals that could serve to replace animal and/or petroleum-based chemicals and acquire the necessary equipment or partner with a product manufacturer on research and development. Suggested market would be personal care & hygiene or homecare & cleaning as there is growing end-use consumer demand for bio-based products. For the long-term, Tyton should either develop the capabilities or partner with firms to express high-value chemicals and/or enzymes directly in the tobacco plant as this method could prove more economical than chemical production as it would bypass energy-intensive transformations.
# Table of Contents

Disclaimer .............................................................................................................................................. 6

Part I: Background and Project Scope .................................................................................................. 6
  Introduction ........................................................................................................................................... 6

Properties and Applications of Tobacco ............................................................................................... 7
  Plant Anatomy and Applications ......................................................................................................... 8
  Trends in the Cultivation of Tobacco .................................................................................................. 9

Tyon BioEnergy Systems ..................................................................................................................... 11
  Tyton Energy Tobacco ....................................................................................................................... 11
  Tyton Hydrothermal Extraction Process .......................................................................................... 12
  Tyton’s Business Model ..................................................................................................................... 13
  Tyton NC Biofuels and Ethanol Production ...................................................................................... 13

Part II: Objectives, Methods, and Preliminary Findings ...................................................................... 14
  Objective ............................................................................................................................................ 14

Research Methodology .......................................................................................................................... 14
  Phase 1: Exploration of Chemicals Industry ...................................................................................... 16
  Phase 2: Identifying Opportunity in Bioplastics ................................................................................. 17
  Phase 3: Competitive Analysis for the use of Tobacco in Bioplastics Manufacturing ...................... 20

Part III: Competitive Analysis of Tobacco vs. Corn Feedstock .......................................................... 21
  Environmental Analysis .................................................................................................................... 21
    Goal, Scope and System Boundaries ............................................................................................... 21
    Life Cycle Inventory and Environmental Analysis .......................................................................... 24
    Corn Growing & Harvesting Cycle Inventory ................................................................................. 24
    Tobacco Growing & Harvesting Life Cycle Inventory .................................................................. 26
    Corn Sugar Extracting Life Cycle Inventory ................................................................................. 28
    Tobacco Sugar Extracting Life Cycle Inventory ........................................................................... 29
    LCA Software Platform .................................................................................................................. 30
    Impact Assessment Measures ......................................................................................................... 30
    Model Assumptions and Inputs ........................................................................................................ 31

Results and Sensitivity Analysis .......................................................................................................... 32

Financial Analysis ................................................................................................................................. 34

Part IV: Recommendations & Next Steps ............................................................................................ 36
  Short-Term Recommendations for Entering the Bioplastics Industry .............................................. 36
  Long-Term Recommendations for Revenue Diversification .............................................................. 38
Transgenics for Production of High-Value Molecules ................................................................. 38
Capitalizing on Advanced Extraction Processes ................................................................. 40
Conclusion ............................................................................................................................... 40
Appendices ........................................................................................................................... 42
  Appendix A: Market Examples of Transitioning from Green Fuels to Chemicals ....... 42
  Appendix B: Industry Experts Consulted ................................................................. 45
  Appendix C: High Value Chemicals for Further Exploration .................................... 47
  Appendix D: Market Overviews on Demand for Bio-based Products .................. 51
  Appendix E: Corn Wet Milling (CWM) Process .......................................................... 56
References ............................................................................................................................. 58
Disclaimer

To execute this project, the team from the Nicholas School of the Environment signed a Non-Disclosure Agreement with Tyton BioEnergy Systems. To respect the company’s confidential and proprietary information, all sensitive information pertaining to Tyton’s financials and production costs are not included in this report. We have also opted to omit all specific recommendations for potential partners.

Part I: Background and Project Scope

Introduction

Tyton BioEnergy Systems (Tyton), a start-up headquartered in Danville, VA, is seeking alternate applications for its unique strand of “energy tobacco,” which it currently uses for the production of ethanol. Tyton’s energy tobacco contains three times the concentration of sugar and twice the concentration of oil as standard tobacco plants. In addition to the development of its energy tobacco, Tyton has a patent-pending hydrothermal extractor that allows the company to separate the sugar, oils, and proteins from the plant. This project seeks to identify a short-term pathway for Tyton to enter the bio-chemicals market through its expertise in tobacco-based sugars as well as provide medium and long-term recommendations for how Tyton can capitalize on the oils, proteins, and complex genetic make-up of the plant.

Part I of this paper provides background information on the unique properties of tobacco from both a harvesting and growing perspective as well as the cellular level. Next, the paper describes the ways in which Tyton has been able to utilize this benefits and develop expertise in the production of tobacco-based sugars. We discuss Tyton’s current business model as well as objectives for future diversification efforts.

Part II describes the team’s research methodology and preliminary findings. We divide our research into three distinct phases. Phase 1 includes an exploration of the chemicals industry to gain an understanding of the industry structure, product categories, markets served, and key players. Through these efforts, the team recognized the need to focus the scope of the project on the growing trend for bioplastics manufacturing for near-term market-entry opportunities. In Phase 2, the team identified four of the top bioplastic compounds and compared them on the basis of physical properties, market applications, manufacturing processes, and geographic locations of top manufacturers. Ultimately the team identified polylactic acid (PLA) as the preferred compound since it uses sugar-based manufacturing and has made considerable traction in market adoption. In the third phase of research, the team sought to explore potential performance, financial, and environmental benefits of using tobacco for PLA production.
Part III details the team’s analysis to measure both potential environmental and financial advantages of using tobacco in the front-end of PLA production. For the environmental component, the team uses a case study model that simulates a “cradle-to-gate” or “cradle-to-sugar” life cycle analysis (LCA) of using tobacco instead of corn measured by the functional unit of impact per kilogram of sugar produced. For the LCA, the team used the software OpenLCA and the database EcoInvent. The team measured impact in terms of global warming potential, acidification, and ecotoxicology using the Tool for the Reduction and Assessment of Chemical and other Environmental Impacts (TRACI) designed by the US Environmental Protection Agency. As part of our analysis, we ran sensitivity analyses to see potential gains if Tyton were able to make reductions in fertilizer and electricity usage. Finally, we find all corresponding financials to measure a final price of the cost savings for using tobacco as opposed to corn for sugar production.

This paper concludes in Part IV with near-term recommendations for Tyton to enter the bioplastics industry as well as more forward-looking recommendations for how Tyton can capture value from the oil and proteins in the tobacco plant as well as means to use tobacco for transgenics and advanced enzyme and chemical manufacturing. We also explore the possibility of Tyton finding additional commercial applications for its patent-pending hydrothermal extractor.

Properties and Applications of Tobacco

Cultivated tobacco, originally a native plant from the tropical Americas, is now grown in 110 countries with the potential to reach 120 countries. After the discovery of the Americas, European sailors took the plant back to Europe where it started to grow in popularity for chewing and smoking. However, it was not until the First World War when cigarette consumption increased significantly and, consequently, the land used to grow tobacco.
There are several advantages that tobacco offers from a growing and harvesting perspective. It is low in water intensity and fertilizer use. The plant has a fast growing cycle, allowing for more than one harvest per season, and farmers are able to process it fresh without the need for drying.

Mainstream culture typically associates tobacco with its use for cigarette manufacturing; however, the plant’s complex composition, including high amounts of sugars, proteins, and oil, can be used to make food products for animals and raw materials for various industries. Tobacco has a higher concentration of usable biomass than virtually any other agricultural crop, making it an efficient crop for bio-based manufacturing. Specifically for ethanol conversion, the plant’s biomass is attractive because it contains very low amounts of lignin, a woody material that can pose technical and economic challenges for producing a pure sugar stream. Use of tobacco for feedstock offers the advantage of utilizing a non-food crop that is well understood by farmers and yields high financial margins. An additional benefit is tobacco’s ability to be grown on marginal lands (poor soil or that which has little to no potential profit).

Plant Anatomy and Applications

The plant's chemical structure comprises more than 3,000 compounds, making it prime for advanced transgenic research because it can be easily manipulated. As an example, a wide range of biologically active compounds like alkaloids, steroids, polyphenolics, vitamins, and other chemicals have been developed inside the plant.
Tobacco contains three main components that can be used to produce various bio-products:

- **Sugars and Starches:** In addition to their use for food ingredients, simple and complex sugar chains can serve as building blocks to produce basic chemicals and polymers used in raw materials. In many cases, the sugars and starches from tobacco could serve as the feedstock to manufacture products that could replace petroleum-derived products. FOLIUM, a project aimed to produce chemicals and biofuels from tobacco, expects that cellulose produced from tobacco could be sold at the commodity price of $600 to $1000/ton.\(^\text{14}\)

- **Proteins and Enzymes:** Proteins within the tobacco plant, such as rubisco, are known to have good gelling and emulsifying properties. Enzymes, which serve to increase the rate of a chemical reaction for a number of industrial applications, can be naturally-occurring in tobacco or can be expressed through modifications in the plant’s DNA.

- **Oil and Specialty Compounds:** Given the high complexity of the plant and the number of compounds it contains, tobacco yields high-value chemicals that are used in many industries such as the pharmaceutical and personal care. For example, Solanesol, which is used in pharmaceutical and nutraceutical products, can produce coenzyme Q10 (a well-known potent antioxidant), and vitamin K2 (a coagulant and important vitamin for prevention of osteoporosis), which sell for $300 to $1000/kg.\(^\text{15}\)

Trends in the Cultivation of Tobacco

The trends in the cultivation of smoking tobacco are decreasing both in the US and worldwide, thus impacting certain local economies. Cigarette tobacco is a high-margin product; however, a decline in demand for cigarettes has forced farmers to grow less profitable and more commoditized crops. The peak of the era for tobacco cultivation was in 1985 when production reached 4.7 million hectares. Specifically in the US, the area dedicated to the cultivation of tobacco had a -2% compound annual growth rate (CAGR) reduction from 1961 to 2013.\(^\text{16}\)
As depicted in Figure 3, the decline in the production of tobacco is highly correlated with the consumption of cigarettes. Despite the 1 percent CAGR between 1960 and 1980, the years 1980 through 2011 saw a decline in cigarette consumption of 2 percent year-over-year. Relative speaking this decrease is the same as the decline in production of tobacco (Figure 2).

The top producer of tobacco in the US is North Carolina. The plant holds significant importance for the state’s economy and agricultural history. However, given the decline in cigarettes consumption, the overall production of tobacco in the state has decreased significantly (Figure 4). The use of tobacco for other
commercial applications would offer an opportunity to farmers with displaced land to continue using their expertise for growing tobacco.

Figure 4: Total Harvested Acres in North Carolina per year. 19

**Tyton BioEnergy Systems**

Tyton BioEnergy Systems (Tyton), headquartered in Danville, VA, has developed a unique strand of tobacco that can serve as an alternative feedstock for bio-based manufacturing. Tyton’s plant sciences expertise is based on proprietary technology developed under one of Tyton’s founders, Professor Hilary Koprowski (1916-2013), at the Biotechnology Foundation Laboratories of Thomas Jefferson University. Professor Koprowski was a world-famous immunologist known for his work in developing vaccines for polio and rabies as well as advancing cancer detection in blood tests. Research he directed in developing plants for pharmaceutical purposes led to the creation of Tyton’s genetically modified energy tobacco, which is similar to that of a dark fire-cured variety. Tyton’s unique plant characteristics combined with its patent-pending, hydrothermal extraction technology enables the company to sell sugars and oils at a more competitive price than corn, soy, and other cellulosic feedstock.

**Tyton Energy Tobacco** 20

Tyton’s “energy tobacco” has a concentration of glucose (C6 sugars) that is three times the amount of commercial varieties of tobacco for the smoking industry, as well as an oil content that is doubled. Tyton’s tobacco is naturally low in nicotine, and its growing method further minimize accumulation of nicotine so the plant can neither be smoked nor chewed.
The plant’s oil is contained in its large leaves as opposed to the seeds, allowing the Tyton to harvest the entire plant for ethanol conversion. Figure 5 provides an illustration of the components that Tyton is currently able to extract from its “energy tobacco.” In addition to its “energy tobacco” Tyton plants an additional strand of tobacco that was developed in Italy and resembles oriental tobacco. It is a high-seed one which grows more flower blooms than typical tobacco plants. Other strands developed by Tyton are in various stages of development.

Tyton’s tobacco varieties are spaced closer in the field in order to produce more plants per acre. Traditional tobacco varieties are grown at about 6,000 plants per acre. In comparison, the Tyton BioEnergy high-seed variety is grown at about 25,000 plants per acre. Its high-sugar and high-oil variety is grown at about 15,000 plants per acre.23

**Tyton Hydrothermal Extraction Process**

In 2015, Tyton installed its patent-pending, pilot-scale extractor at its Danville site and is now in the process of optimizing its operations. The pre-industrial-scaled extractor can process about 12 tons of biomass per day; however, industrial scale production could reach 10 times this amount. In its current state, the extractor is designed to produce the highest content of sugar; however, this technology could be calibrated to optimize extraction of other components of the plant, which could be useful for future applications.

The technology, which uses subcritical water to isolate a range of polymers from basic sugars and oils to complex chemicals, falls in-line with a global interest to develop subcritical and supercritical water systems as an alternative method for hydrolysis. Water has traditionally been viewed as inexpensive and readily available and its discharge has minimal environmental impact. By hydrolysis in subcritical or supercritical water, cellulose can be decomposed into glucose (C6 sugar) and galactose (C6 sugar), and hemi-cellulose into xylose (C5 sugar) and arabinose (C5 sugar).
The thermal conversion technology harnesses tobacco’s natural properties in a low-energy extraction process, which, according to Tyton, is fast, clean and economical. In the process, no harsh chemicals or expensive enzymes are utilized, and 100 percent of the tobacco plant is converted into saleable co-products, producing zero waste.

Tyton’s Business Model

Today, the company’s core business is producing sugars, oil, protein, and biochar from its “energy tobacco” that is grown by contracted farmers. Tyton then uses the tobacco plant to produce ethanol and sell the remaining processed biomass as a source of protein for animal feed.

The company has formed partnerships with major academic institutions that are conducting research using tobacco to expand their current business capabilities. For instance, the company has been conducting field trials on university research farms and at on-farm sites. Some university partners include North Carolina State University, Virginia Tech, and the University of Kentucky, amongst others.

In addition to its work with academic institutions, Tyton has formed partnerships with a number of firms from the private sector. In June 2015, Tyton announced that it was working with Smithfield Foods’ (Smithfield, VA) pork producers and nutritionists to use proteins in the company’s rations to feed pigs. Tyton and Smithfield also established field trials using manure as a more environmentally friendly fertilizer and one that could prove to be more economical as well. In September 2015, Tyton teamed up with Deinove, a French publicly-traded biotech company, to use Tyton’s tobacco sugars to help produce their renewable chemicals. Presently, Deinove uses sugar from sources such as corn, wheat and urban waste.

In October 2015, Tyton BioEnergy announced a collaboration with Italy-based Sunchem to combine apply Tyton’s research and commercial capabilities to Sunchem’s tobacco strand. Tyton and Sunchem are conducting research at Tyton’s Danville headquarters to increase yield of the Solaris tobacco and to optimize Tyton’s extractor.

Tyton NC Biofuels and Ethanol Production

Tyton NC Biofuels (Tyton Biofuels), a strategic partner of Tyton, is an ethanol bio-refinery located in Raeford, NC with the capacity to produce up to 55 million gallons per day. The objective of the refinery is to showcase the use of tobacco as a feedstock for ethanol production with minimal modification to a dry mill corn ethanol facility. Using Tyton’s tobacco, the company claims that it can produce up to three times the amount of ethanol per acre compared to corn and three times the amount of oil per acre compared to soy. The refinery is currently using corn as its feedstock with the intent to blend tobacco feedstock. Tyton
envisions ethanol producers across the US blending the current corn feedstock with up to 30 percent tobacco due to the cost competitiveness of the product.

Despite the economic and environmental benefits of using tobacco as a feedstock for ethanol production, Tyton and many other companies in the alternative energy space have faced challenges in attracting investment to take their technology to full commercial scale. The price of crude has hit historic lows and the selling price for ethanol is highly correlated with the price of crude. The correlation between ethanol prices (USDA)\textsuperscript{26} and oil prices (EIA)\textsuperscript{27} from 1997 to 2015 is 0.939, meaning that if oil prices decrease by $1, statistically speaking, ethanol prices should go down $0.93.

These market circumstances have prompted a shift in the company’s direction to explore opportunities in other bioproduct markets as a way to diversity operations from its current work in ethanol production. Tyton’s desire to seek other markets mirrors a number of early-stage companies that initially focused on biofuel production and later transitioned to the chemicals market for downstream applications in personal care & hygiene, bioplastics, and homecare products, among others. (See Appendix A for more information on biofuel start-ups.)

**Part II: Objectives, Methods, and Preliminary Findings**

**Objective**

The objective of this project is to identify alternate applications for Tyton’s “energy tobacco” as a means to diversify the company’s revenue streams. Ultimately, Tyton seeks to establish a product portfolio that includes high-value products that will withstand the volatility of the energy market and maintain their selling prices.

**Research Methodology**

The team developed a three-phase methodology to identify near, medium, and long-term opportunities for Tyton to use their current unique capabilities as well as provide recommendations to make an initial entry into a higher margin industry. The team conducted an analysis of Tyton’s capabilities and sought to understand the unique and combined potential uses for the sugar, oil, and protein in the tobacco plant and how these elements could be applied to the chemicals industry.

The complexity of tobacco’s cellular structure and the plant’s potential for transgenics adds to the potential range of applications. Recognizing the expertise that Tyton has developed in production of tobacco-based sugars, the team opted to focus on sugar applications as this would present a smaller hurdle for Tyton to
segue into the industry. Establishing near-term partnerships in the industry around sugar will serve to facilitate additional opportunities to collaborate on research and manufacturing opportunities that are currently outside the scope of Tyton’s expertise. Below is a brief summary of each phase of this project and how it ultimately led to the evolution of the next research phase:

**Phase 1: Exploration of the Chemicals Industry**

This initial phase of research sought to gain an understanding of the chemicals industry structure, product categories, markets served, and key players. Driving questions behind this exploratory research included:

- Which major product categories are manufactured from sugar, proteins, and oils?
- What products could be made using tobacco rather than petroleum?
- What are the major trends in the area of bio-based manufacturing?
- Who are the key players in the industry?

In addition to a literature review, the team interviewed six industry experts, both academic and industry professionals, (See Appendix B) to identify 55 high-value chemicals that have the potential to be manufactures from the sugars, oils, and specialty molecules obtained from tobacco (See Appendix C for a complete list).

To identify short-term opportunities, the team chose to focus on the existing demand and supply trends for bio-based chemicals. The team researched end-use markets, surveyed people in the industry (See Appendix B for examples) and determined the following six have the greatest demand for bio-based products: 1) homecare & cleaning; 2) building & construction; 3) automotive & transportation; 4) personal care & hygiene; 5) textiles; and 6) plastics & packaging (See Appendix D for market overviews on demand for bio-based products). Ultimately, the team selected bioplastics as the sub-market that would have the greatest opportunity for Tyton to make its initial entry into the chemicals industry.

**Phase 2: Identifying Opportunity in Bioplastics**

Having identified bioplastics as the sub-market for entry, the team worked to gain a better understanding of bioplastics and how this sub-market fits into the broader market of plastics & packaging. The team sought to answer the following questions:

- What are the major trends driving demand for bioplastics? Where is this demand concentrated?
- What are the top bioplastic compounds and could these be made from tobacco-based sugars?
- Who are the major manufacturers of bioplastics and could any be a potential partner for Tyton?
- What part of the manufacturing process could Tyton serve to add value?
Through an additional literature review and conversations with professionals from conventional and bioplastic industries, the team found an upward trend in the demand for bioplastics, primarily driven by end-user concern in the US and Europe around the environmental impact of conventional or petroleum-derived plastics. The team identified four of the top bioplastic compounds and compared them on the basis of their physical properties, market applications, manufacturing processes, and the geographic locations of top manufacturers.

The team selected polylactic acid (PLA) as the preferred compound since it uses sugar-based manufacturing and has made considerable traction in market adoption in the US.²⁸ The team saw potential for Tyton to add value to US-based manufacturers of PLA, by supplying tobacco for feedstock rather than corn, which is the main bio-source currently used.

**Phase 3: Competitive Analysis for the use of Tobacco in Bioplastics Manufacturing**

In the final phase of the project research, the team sought to identify potential benefits of using tobacco for the production of PLA instead of corn. The first area of focus was on performance since any sacrifice on the quality of the end-product would likely rule out the potential for adoption. Through conversations with industry professionals, the team determined that the end-product should not be impacted by the source of the sugar stream.

Next, the team evaluated whether tobacco could serve to minimize the environmental impact of the PLA manufacturing process. The team performed a “cradle-to-gate” or “cradle-to-sugar” analysis to assess the overall impact that the growing, harvesting, and extraction of sugars of tobacco versus corn. Recognizing the need for tobacco to offer a lower cost to PLA manufacturers than corn in order to incentivize a change in supply chains and offset switching costs, the team did a comparison of the unit cost for a kilogram of sugar produced by both corn and tobacco.

Below is additional information and key findings from each phase of the research:

**Phase 1: Exploration of Chemicals Industry**

The chemical industry is highly complex that is worth, in the US alone, $41 billion dollars in revenue²⁹ for chemical manufacturing and additional $43 billion for the inorganic chemical manufacturing.³⁰ The major players in the industry include companies such as BASF, DuPont, The Dow Chemical Company, Eastman, Exxon Mobil Chemicals, Lyondell Basel, and Olin Corporation, amongst many others.

Breaking down the complexity of the chemicals industry begins with a basic understanding of the industry value chain. Virtually all chemicals have their origins in petroleum. The value chain begins with crude oil
and natural gas inputs that are then passed through refining and manufacturing processes using catalytic cracking to separate certain elements and obtain petrochemical products. Further down the manufacturing line, basic chemicals are produced, which then are converted into polymers, specialty products, and active ingredients. As evident in Figure 6, different types of products are made in on each part of the value chain, all of which serve a multitude of end-use markets.

![Industry Value Chain](image)

**Figure 6: Value Chain and Product Categories in the Chemicals Industry**

After analyzing the industry and Tyton’s current capabilities, the team realized that Tyton should focus on using its expertise in sugars to produce polymers, the building blocks for plastics due to the following reasons:

- The conventional plastic industry is expected to reach $654 billion by 2020.\(^{31}\) This means that the global for plastics is going from 234 million tons in 2013 to 335 million tons in 2020 growing at a CAGR of 5.3 percent.
- Sugars are a key input in the production of bio-based plastics.
- End-use consumers are driving demand for bioplastics due to their desire for more environmentally-friendly packaging.
- The plastics & packaging industry touches upon a multitude of end-use markets that could serve to help Tyton segue into new end-use market applications.

**Phase 2: Identifying Opportunity in Bioplastics**

**Market Demand for Bioplastics**

The US bioplastic industry is currently worth $490 million.\(^{32}\) However, the growth is expected to increase due to the expectation that consumer demand for bio-based products will increase 19 percent by 2017, reaching 960 thousand metric tons of production. While this market is significant for a smaller company like
Tyton, it comprises less than 1 percent\textsuperscript{33} of the total plastics industry, which produces around 335 million tons of conventional plastic.\textsuperscript{34}

Bioplastics have not reached price and performance parity with the economies of scale in conventional manufacturing. Major manufacturers such as BASF, Dow, and DuPont, all of whom produce their sugars in-house, are offering bio-based alternatives, which makes it seem unlikely that Tyton's tobacco-derived sugars could become cost-competitive with the hydrogen-based, sugar manufacturing processes developed by the major chemical companies.

### Bio-Based Polymers

Bioplastic manufacturing can be achieved by three different methods: 1) using starch obtained from polysaccharides; 2) chemical synthesis; or 3) production from microorganisms.\textsuperscript{35} The majority of commercialized bioplastics utilize fermentation which allows for the use of renewable resources and can typically use less energy than chemical processes.

![Production of Biobased Polymers](image)

Currently, bioplastic companies are working to take market share from conventional plastics in the product categories of polymers and monomers. In these product categories, the performance of bioplastics is comparable to that of the petroleum based product.\textsuperscript{37} One of the major concerns with PLA, and other bioplastics, is the production costs, which can run significantly higher than petroleum-based plastics.\textsuperscript{38} Another barrier for it displacing conventional polymers is performance quality. The bioplastics that are currently have a significant penetration in the market are polyhydroxyalkanoates (PHA), polybutylene succinate (PBS), bio-polyethylene (PE) and polylactic acid (PLA). Below is an overview of each of the compounds:

---

Ocariz, Rowe, Taccioli | 18
• **Polyhydroxyalkanoates (PHA):** PHA can be produced by bacterial fermentation using oils and waste. Common market applications are in the medical industry for sutures and implant materials.  
Today, the largest producer of PHA is the Italian company Bio-On, who markets under the brand name Minerv. The company has a production capacity of 10 ktons/year and recently launched a line of children’s Legos made from PHA. US-based producers of PHA include Meridian and Metabolix (Mirel).

• **Polybutylene Succinate (PBS):** PBS is manufactured by condensing sugars, particularly succinic acid with butaneidol. The main industries using this product are the construction and packaging films industries. The main issue with PBS is the poor mechanical flexibility compared to petroleum-based PBS products. Top global producers of PBS include BASF (Germany), DuPont (US), and Hexing Chemical (China).

• **Bio-Polyethylene (PE):** Normally PE is produced by using catalytic cracking in heavy oils; however, when oil prices are high it can be produced by dehydrating ethanol produced from a variety of feedstocks. The market leader with a 52 percent share of global production is Braskem SA (Brazil) under its “I’m Green” marketing label. The company uses sugarcane for its feedstock.

• **Polylactic Acid (PLA):** PLA is a new plastic compound formed by producing lactic acid from fermentation of sugars and starches with bacteria. PLA has emerged as one of the most commonly-used filament types in 3D printing. Other industries using PLA include automotive, appliances, service ware, electronics, and textiles.

In seeking opportunities for Tyton to enter the bioplastics market, the team sought to identify strategic and marketing tools to promote its “energy tobacco” to bioplastic manufacturers and the benefits they offer compared to corn:

• Decrease costs by targeting potential competitors with manufacturing in the US. A domestic customer would minimize the complexity of doing business and thus accelerate deal formations as well as lowering potential transport costs.

• Serve to substitute a food crop in order to minimize negative publicity that a bioplastics company might be receiving.

• Target a market leader in terms of the specified bioplastic both in terms of scale of the company operations as well as quality of research and development that could lead to more advanced opportunities in the market.
With these value propositions in mind, the team evaluated each compound based on two key criteria to select which one Tyton could apply its current capabilities:

1. **Sugar-based manufacturing:** Since Tyton’s capabilities revolve around the production of cheap sugars, it was important that the bioplastic had sugar as a raw material.
2. **Geographic location of the major manufacturing sites:** Considering Tyton is a start-up looking for a near-term entry into the market, the team opted to find manufactures that were US-based in an effort to reduce the cost, complexity, and time required for business development efforts. Table 1 lists the top global manufacturers by geographic location.

Based on these decision criteria, the team chose PLA as the optimal compound given its sugar manufacturing requirements, its strong growth trend, and the US prominence of PLA manufacturing. (Details about PLA manufacturers have been omitted.)

**Phase 3: Competitive Analysis for the use of Tobacco in Bioplastics Manufacturing**

After the selection of PLA, the team sought to identify advantages that tobacco could offer in the supply chain and manufacturing process. The PLA production process involves adding microorganisms into the corn-based sugars to create dextrose through hydrolysis and then converting it to lactic acid and finally into pellets that can be formed through the polymer chain formed from the acid. The pellets are then sold downstream to customers to produce consumer goods in various industries.

Figure 8: PLA Manufacturing Process.

Bio-manufacturing companies currently using corn have desire to find alternate feedstocks as a means to minimize impact on the food supply chain as well as reduce production costs. However, the plastics and
chemicals industry is conservative in a way that companies are unwilling to make changes in the supply chain if it could impact overall product quality. Therefore, the use of tobacco as a feedstock would need to guarantee equal performance while also offering enough of a reduction in cost to offset any switching costs to the firm. After speaking with industry experts about performance characteristics of different sugars, the team determined that sugars with equal purity should produce the same end product. Next, the team next sought to determine if the use of tobacco as a feedstock would offer additional gain on price reductions for raw materials, or if it could minimize the overall environmental impact of the PLA manufacturing process.

**Part III: Competitive Analysis of Tobacco vs. Corn Feedstock**

Environmental Analysis

The team explored whether the use of sugars from tobacco to produce PLA would minimize the environmental impact of producing this bioplastic compared to its current manufacturing process of using corn as a feedstock. This evaluation is structured in the form of a case analysis that seeks to evaluate potential benefits if a company were to use a tobacco feedstock from Tyton rather than corn. The environmental analysis is performed using life cycle assessment (LCA) techniques and will include impact from fertilizer, energy, and irrigation usage. As discussed above, the push to compare the environmental impact is driven by consumer’s demand for chemical and plastic companies to produce cleaner, more environmentally friendly products. Once all of these inputs were gathered, they were put through a life cycle inventory assessment (LCIA) to determine the overall environmental impact of sugars from tobacco compared to those made from corn.

An LCA is a multi-step process comprising the following stages:  

1. Defining goal, scope, and system boundaries  
2. Collecting system inputs for the life cycle inventory (LCI)  
3. Selecting LCA software platform  
4. Selecting the appropriate environmental impact assessment measures  
5. Performing a life cycle inventory assessment (LCIA)  
6. Interpreting the results  

**Goal, Scope and System Boundaries**  
Our goal is to provide a clear understanding of the environmental impacts of tobacco versus corn production that will allow our client to demonstrate the advantage of using tobacco based sugars versus corn based
sugars for the production of PLA. In addition, this analysis should provide Tyton with information that can be used as a marketing and strategic tool. Given that Tyton is still in the process of scaling up its operations and understanding all of its inputs, our LCA results are intended to provide a first-level environmental analysis that can further be refined when more information is available.

Since a full “cradle-to-cradle” LCA would include many processes after the PLA production that would be identical regardless of what feedstock is used to produce the PLA, we chose a scope for this study that ended at the sugar production stage which we are calling “cradle-to-gate” or “cradle-to-sugar”. The term “cradle-to-gate” is used commonly among chemical companies and describes the process which starts at the extraction of the raw materials and ends when the product of interest is derived. The main points of differentiation between the two bio-feedstocks can be categorized into two phases: 1) growing and harvesting; and 2) extraction of sugars.

Figure 9 is a system boundary diagram which shows all of relevant inputs and processes that will be included in our assessment in black, and the excluded processes outside of the dotted line, labeled in red:

Figure 9: Scope of Environmental Analysis

There are several areas that were excluded due to their complexity and/or their similarity between the processes for both feedstocks. However, the team felt that they should be acknowledged because they can impact the overall results of the analysis:
• **Land Use:** The use of land, both direct and indirect, can have a significant impact on the overall outcome of the LCA, particularly if the land in question is being considered for food production. Direct land use includes the process of converting wetlands or grasslands to grow crops for sugar production, while indirect land use is the process of shifting existing crops such as wheat to other crops that will be used for sugar production. However, for the purpose of this analysis, the land impact is considered to be the same for both corn and tobacco and we recommend further work and analysis should be done in this regard. In reality, since tobacco can grow on more marginal land than corn, this is a conservative assumption.

• **Land Absorption:** The downstream effects of pesticides, fertilizer, and nutrient absorption were excluded from the model due to the difficulty of incorporating this into the analysis. We assumed that the nutrient absorption effects to grown tobacco would be similar to those to grown corn.

• **PLA Production:** Based on various discussions with industry experts, we are assuming that all PLA plastic production will be the same for any feedstock after it is converted into the desired sugar.

• **Post-Gate/End-of-Life (EOL):** We recognize that there are various extrusion facilities across the country and that customer disposal behavior is unpredictable. Given the uncertainty in these two factors, we opted to exclude disposal from this report. In addition, any energy recovery opportunity was ignored given the complexity to measure it. Furthermore, the complexities and specificities of tracking the impact at the end of life would require us to select a specific product that is outside of the scope of this project since we are targeting opportunities for Tyton to enter the supply chain upstream.

**Functional Unit:** As noted previously, we concluded that the PLA production processes would be identical once the desirable sugar was attained from a given feedstock. Therefore, we decided that our product of interest and the functional unit that we would use to compare tobacco to corn would be in terms of sugar. Given our final product, the end results will be presented in terms of an *environmental impact per kilogram of sugar*. For the sake of this analysis and after talking to industry professionals, the team assumed that a kilogram of dextrose (sugar produced from corn) and a kilogram of mostly glucose (sugar produced from tobacco) would behave similarly in the overall manufacturing process. We acknowledge that this assumption will need to be tested and confirmed, but without access to test how enzymes used in lactic acid production react to tobacco sugars, the team felt this was a reasonable assumption.
Life Cycle Inventory and Environmental Analysis

As discussed above, the scope of the environmental analysis begins with the growing of the crop and ends once the sugar is extracted. The section below will discuss the differences between the process of growing and harvesting and of sugar extraction between tobacco and corn. Figure 10 illustrates the differences between the processes to attain sugar from tobacco compared to corn:

<table>
<thead>
<tr>
<th>Growing &amp; Harvesting</th>
<th>Extracting</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Corn</strong></td>
<td><strong>Step 1-3 Corn Wet Mill Process</strong></td>
</tr>
<tr>
<td>Step 1: Field Growth</td>
<td><em>SHELLED CORN</em> → <em>STARCH</em> → <em>ACID or ENZYMES</em> → <em>SUGAR</em></td>
</tr>
<tr>
<td>Step 2: Field Growth</td>
<td></td>
</tr>
<tr>
<td><strong>Tobacco</strong></td>
<td><strong>Step 1: Extractor</strong></td>
</tr>
</tbody>
</table>
| Step 1: Greenhouse   | *

Figure 10: Tobacco vs Corn Sugar Production Processes

While corn is only grown in the field, Tyton’s tobacco requires an additional pre-growing stage in order to harvest the crop twice a year. Tyton first plants the seed in a greenhouse environment and allows the seedlings to grow indoors from February until later April or early May. Once the seedlings have matured, they are transplanted into the field. Although the growing and harvesting process for tobacco is slightly more complicated than that for corn, Tyton’s extraction process is much simpler and requires fewer inputs. For corn, the kernels first need to be separated from the cob and then shelled. The shelled corn is then put through the corn wet milling (CWM) process which converts the corn into starch and then with the help of acids or enzymes, is converted to dextrose sugar.49 (See Appendix E for detailed information on the CWM process.) As discussed in the previous sections, Tyton’s extractor is able to intake the tobacco stem and leaf and covert the plant to a high purity sugar stream with the addition of water, and energy for heat and cooling.

Corn Growing & Harvesting Cycle Inventory

When considering the inputs for growing corn, we used data from USDA Economic Research Service50 to determine the average fertilizer, energy, and irrigation required per acre. We acknowledge that growing...
practices will vary from state to state; however, we felt that the data we acquired was robust and the best way to approximate inputs. As such, we did not consider the effects of rotating crops like alfalfa which would absorb nitrogen and require lower amounts of fertilizer for future crops. The energy portion required to grow corn included the diesel used during tillage and the electricity consumed to run various pieces of farm equipment, including irrigation units. The upstream energy inputs required to make fertilizer are not directly included in this section, but will be captured in the LCIA.

To convert our inputs to the functional unit of one kg of sugar, we performed a simple two-line conversion. We multiplied the bushels per acre gathered from the USDA’s 2015 report (168.4 bushels/acre) by the amount of sugar per bushel from the 2003 LBNL report (15 kg sugar/bushel):

$$\frac{168.4 \text{ Bushel}}{\text{acre}} \times \frac{15 \text{ kg Sugar}}{\text{Bushel}} = \frac{2,526 \text{ kg Sugar}}{\text{acre}}$$

The table below presents key conversions in our analysis. For instance, the amount of diesel use was first converted from a volume to British thermal units (Btu) and then into usage per kg of dextrose sugar:

$$\frac{5 \text{ liters diesel}}{\text{acre}} \times \frac{1 \text{ gallon}}{3.785 \text{ liters}} \times \frac{139,000 \text{ btu}}{1 \text{ gallon diesel}} \times \frac{\text{acre}}{2,526 \text{ kg Sugar}} = \frac{73.5 \text{ btu}}{\text{kg Sugar}}$$

<table>
<thead>
<tr>
<th><strong>Corn Growth</strong></th>
<th><strong>Quantity</strong></th>
<th><strong>Metric</strong></th>
<th><strong>Per kg Sugar</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen (N)⁵⁵</td>
<td>60.4</td>
<td>kg/planted acre</td>
<td>0.024 kg</td>
</tr>
<tr>
<td>Phosphate (P₂O₅)⁵⁶</td>
<td>24.1</td>
<td>kg/planted acre</td>
<td>0.010 kg</td>
</tr>
<tr>
<td>Potash (K₂O)⁵⁷</td>
<td>28.6</td>
<td>kg/planted acre</td>
<td>0.011 kg</td>
</tr>
<tr>
<td>Irrigation⁵⁸</td>
<td>20.30</td>
<td>L/acre</td>
<td>0.008 L</td>
</tr>
<tr>
<td>Diesel⁵⁹</td>
<td>5.0</td>
<td>L/acre</td>
<td>74 Btu</td>
</tr>
<tr>
<td>Electricity⁶⁰</td>
<td>364.25</td>
<td>kWh/acre</td>
<td>491 Btu</td>
</tr>
<tr>
<td><strong>Total Energy</strong></td>
<td></td>
<td></td>
<td><strong>565 Btu</strong></td>
</tr>
</tbody>
</table>

Table 1: Growing and Harvesting Corn Inputs per kg of Sweetener

Given that fertilizer usage makes up a significant amount of the environmental impact of growing a crop, the team looked at how fertilizer usage varies across the US. The USDA has produced an annual report that measures the amount of nitrogen (N), phosphate (P₂O₅), and potash (K₂O) used in corn production. Based on similar calculations as above, the team converted these number from the report to attain the
quantity for each fertilizer in terms of our environmental unit: kilograms fertilizer per kilogram of sugar which is summarized in Table 2:

<table>
<thead>
<tr>
<th>State</th>
<th>Year</th>
<th>Nitrogen (N)</th>
<th>Phosphate (P₂O₅)</th>
<th>Potash (K₂O)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colorado</td>
<td>2010</td>
<td>0.023</td>
<td>0.005</td>
<td>0.003</td>
<td>0.031</td>
</tr>
<tr>
<td>Georgia</td>
<td>2010</td>
<td>0.032</td>
<td>0.012</td>
<td>0.018</td>
<td>0.062</td>
</tr>
<tr>
<td>Illinois</td>
<td>2010</td>
<td>0.030</td>
<td>0.017</td>
<td>0.019</td>
<td>0.066</td>
</tr>
<tr>
<td>Indiana</td>
<td>2010</td>
<td>0.032</td>
<td>0.012</td>
<td>0.021</td>
<td>0.066</td>
</tr>
<tr>
<td>Iowa</td>
<td>2010</td>
<td>0.026</td>
<td>0.012</td>
<td>0.014</td>
<td>0.052</td>
</tr>
<tr>
<td>Kansas</td>
<td>2010</td>
<td>0.024</td>
<td>0.007</td>
<td>0.007</td>
<td>0.037</td>
</tr>
<tr>
<td>Kentucky</td>
<td>2010</td>
<td>0.030</td>
<td>0.018</td>
<td>0.019</td>
<td>0.066</td>
</tr>
<tr>
<td>Michigan</td>
<td>2010</td>
<td>0.022</td>
<td>0.006</td>
<td>0.017</td>
<td>0.045</td>
</tr>
<tr>
<td>Minnesota</td>
<td>2010</td>
<td>0.022</td>
<td>0.009</td>
<td>0.011</td>
<td>0.043</td>
</tr>
<tr>
<td>Missouri</td>
<td>2010</td>
<td>0.023</td>
<td>0.011</td>
<td>0.010</td>
<td>0.044</td>
</tr>
<tr>
<td>Nebraska</td>
<td>2010</td>
<td>0.025</td>
<td>0.007</td>
<td>0.005</td>
<td>0.037</td>
</tr>
<tr>
<td>New York</td>
<td>2010</td>
<td>0.011</td>
<td>0.006</td>
<td>0.007</td>
<td>0.024</td>
</tr>
<tr>
<td>North Carolina</td>
<td>2010</td>
<td>0.023</td>
<td>0.007</td>
<td>0.014</td>
<td>0.044</td>
</tr>
<tr>
<td>North Dakota</td>
<td>2010</td>
<td>0.029</td>
<td>0.008</td>
<td>0.006</td>
<td>0.043</td>
</tr>
<tr>
<td>Ohio</td>
<td>2010</td>
<td>0.025</td>
<td>0.012</td>
<td>0.016</td>
<td>0.053</td>
</tr>
<tr>
<td>Pennsylvania</td>
<td>2010</td>
<td>0.016</td>
<td>0.008</td>
<td>0.009</td>
<td>0.033</td>
</tr>
<tr>
<td>South Dakota</td>
<td>2010</td>
<td>0.023</td>
<td>0.009</td>
<td>0.005</td>
<td>0.038</td>
</tr>
<tr>
<td>Texas</td>
<td>2010</td>
<td>0.023</td>
<td>0.006</td>
<td>0.003</td>
<td>0.033</td>
</tr>
<tr>
<td>Wisconsin</td>
<td>2010</td>
<td>0.017</td>
<td>0.008</td>
<td>0.010</td>
<td>0.034</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>2010</strong></td>
<td><strong>0.024</strong></td>
<td><strong>0.010</strong></td>
<td><strong>0.011</strong></td>
<td><strong>0.045</strong></td>
</tr>
</tbody>
</table>

Table 2: Fertilizer Usage in Corn Production (kg Fertilizer / kg Dextrose)

Table 2 highlights that Kentucky, where tobacco is prevalent, requires the highest level of fertilizer for corn. Given that tobacco can be grown on more marginal land than other crops including corn, the growing and harvesting environmental impact difference between corn and tobacco is most likely greatest in Kentucky.

**Tobacco Growing & Harvesting Life Cycle Inventory**

As discussed above, growing and harvesting Tyton’s tobacco involves a two-step process where the seedling is first grown in the greenhouse before being transplanted to the field. The information used to develop the LCA study for tobacco is particular to the growing and harvesting process used by Tyton for its
tobacco fields located in North Carolina and Virginia. Growing tobacco should be similar among US farms; however, some inputs might differ given the type of tobacco being used, as well as the growing processes.

We used a similar process as for corn to calculate Tyton’s tobacco sugar content per acre. We multiplied Tyton’s total mass of tobacco per acre (80 metric tons) by the dry mass quantity (15 percent dry mass) that is put into the extractor and by the sugar content of the plant (60 percent):

\[
\frac{80 \text{ metric tons}}{\text{acre}} \times (15 \text{ percent Dry Mass}) \times (60 \text{ percent Sugar Content})
\]

\[
= \frac{7.2 \text{ metric tons sugar}}{\text{acre}} = \frac{7,200 \text{ kg Sugar}}{\text{acre}}
\]

**Sugar Content**: Tyton is optimizing its extracting capabilities to capture all of the 7,200 kg sugar/acre from the sugar stream. We assume that Tyton would be able to capture all of the sugar in the plant in our calculations.

**Water Use**: With regard to water use, Tyton’s Field Operations Lead reported that the company has needed to use irrigation only once in the past few years.\(^6\) We make the assumption that there are no serious future drought trends.

The team was also asked to project fertilizer usage across various states. The team we calculated the ratio of fertilizer used for corn for each state to the fertilizer used in North Carolina (base case). For example, the ratio of nitrogen fertilizer used for corn in Georgia versus North Carolina is 0.023/0.032 = 1.38. We then multiplied the nitrogen fertilizer used for tobacco in North Carolina (0.0050 kg) by the 1.38 factor to predict the fertilizer required in Georgia to grow tobacco: 1.38 x 0.0050 kg = 0.0069 kilograms of N per kg of sugar.
Corn Sugar Extracting Life Cycle Inventory

The environmental impact of the extraction process, which serves to separate a pure sugar stream from the bio-product, differs depending on the type of facility in use. For the purposes of this evaluation, we compared wet milling for corn against Tyton’s proprietary hydrothermal extractor. As discussed above, corn is put through a wet milling process to convert the corn to sugar. The objective of corn wet milling is to separate the four main components in corn, namely starch, germ, fiber, and protein and then transform the components into downstream products. The most comprehensive analysis on the energy intensity of wet milling is a 2003 report by Berkeley National Laboratory.\(^\text{64}\) Although this report is dated, we believe it remains a good proxy for wet mills in the US. A more in depth description of the wet milling process can be found in Appendix E.

Based on the results of the 2003 Berkeley National Laboratory study, we found that a total of 6,230 Btu are needed to produce one kg of sugar. This figure accounts for steam, fuel use for drying, and electricity use (including distribution losses).\(^\text{65}\) A conversion factor of 3.08, based on average heat rates of US power plants was used to convert final energy to primary. A 100,000 bushel (240,500 kilogram) facility operating 24 hours per day was used as the basis for conversion. The highest point of energy intensity in the wet mill is driven by the multiple phases that require drying. We were unable to find data on the water used in the process; however, literature suggests that the water that is originally used to steep the corn is not wasted, but rather recycled throughout the wet milling process.\(^\text{66}\)
Tyton installed a pilot, sub-critical hydrothermal extractor to separate the sugars from the protein, fats, and oils in the tobacco plant. The pilot currently processes 12 dry tons per day. In its current state, the extractor is designed to produce the highest content of sugar; however, this technology could be calibrated to optimize extraction of other components of the plant, which could be useful for future applications. Actual input numbers from the extracting operation are kept confidential in this report for proprietary reasons.

Aggregating the life cycle inventory for both corn and tobacco allows us to better understand the total inputs. Overall, more than twice as much energy is required to produce 1 kilogram of sugar from corn compared to tobacco. However, it is important to note that since the total energy for each crop is made up of various inputs that have different environmental impacts, corn does not necessarily have twice the environmental impact as tobacco. For example, 100 Btu of liquid propane has a different environmental impact than 100 Btu of electricity generation produced from natural gas.

Table 4: Corn Wet Milling Energy Input

<table>
<thead>
<tr>
<th>Process</th>
<th>Electricity kWh/kg</th>
<th>Steam Btu/kg</th>
<th>Fuel Btu/kg</th>
<th>Total Btu/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steeping</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corn receiving</td>
<td>0.008</td>
<td>28</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Steeping</td>
<td>0.004</td>
<td>14</td>
<td>210</td>
<td>-</td>
</tr>
<tr>
<td>Steepwater evaporation</td>
<td>0.010</td>
<td>35</td>
<td>1,304</td>
<td>-</td>
</tr>
<tr>
<td>Degermination</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Germ recovery (1st grind)</td>
<td>0.013</td>
<td>45</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Germ recovery (2nd grind)</td>
<td>0.007</td>
<td>23</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Germ recovery (grain washing)</td>
<td>0.000</td>
<td>2</td>
<td>229</td>
<td>224</td>
</tr>
<tr>
<td>Germ dewatering and drying</td>
<td>0.009</td>
<td>29</td>
<td>1,304</td>
<td>-</td>
</tr>
<tr>
<td>Grinding &amp; Screening</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fiber recovery</td>
<td>0.042</td>
<td>144</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Fiber dewatering</td>
<td>0.007</td>
<td>25</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Starch-Gluten Separation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Protein (gluten) recovery</td>
<td>0.020</td>
<td>67</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Gluten thickening and drying</td>
<td>0.010</td>
<td>34</td>
<td>-</td>
<td>238</td>
</tr>
<tr>
<td>Starch washing</td>
<td>0.009</td>
<td>32</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Starch dewatering and drying</td>
<td>0.052</td>
<td>179</td>
<td>-</td>
<td>1,804</td>
</tr>
<tr>
<td>Gluten feed dryer</td>
<td>0.019</td>
<td>65</td>
<td>-</td>
<td>1,498</td>
</tr>
<tr>
<td>Total</td>
<td>0.212</td>
<td>724</td>
<td>1,743</td>
<td>3,763</td>
</tr>
</tbody>
</table>
Evaluation of Tobacco Biomass for Bioplastics Production

LCA Software Platform

Selecting a software to run the analysis and provide assessment reports is the first step in performing a Life Cycle Inventory Assessment (LCIA). There are various types of software available including SimaPro, GaBi, Umberto, and OpenLCA that can be used to perform an LCIA. The software is only an interface that requires it to be paired with a database in order to access flows, processes, impact assessment methods, and product systems. Some companies like GaBi offer both the software and the database, while other software companies like OpenLCA require access to an external database. The OpenLCA software is an open-source platform that is widely used across industries. Since it offers modular options, it can for instance, be paired with plugins for the construction industry that follow the EN 15804 (European Environmental Standards). After speaking with faculty at Duke University, the team was encouraged to use the OpenLCA software and pair it with the Ecoinvent database. Ecoinvent is one of the leading database companies and a partner of the Sustainable Recycling Industries project since 2014.

Impact Assessment Measures

Environmental impact measures work in combination with databases to aggregate all of the upstream process inputs into a meaningful metric. For example, natural gas, ammonia, ammonium nitrate, and other inputs are required upstream to produce a fertilizer. Impact measures aggregate these inputs into metrics such as global warming, ozone depletion, ecotoxicity, and eutrophication, which are well understood by the environmental community. After doing research and speaking to industry professionals, the team opted to use the Tool for Reduction and Assessment of Chemicals and Other Environmental Impacts (TRACI) impact assessment measure, which was created by the U.S. Environmental Protection Agency (EPA) and is widely used in life cycle assessments. After running several scenarios, we concluded that global warming, acidification, and ecotoxicity were the three metrics that were most sensitive to our inputs, so we focused on these.
our results on these. Global Warming refers to the increase in the global temperatures that result from greenhouse gas emissions.\textsuperscript{77} Ecotoxicity is the ecological risk based on the presence of chemicals in the environment that could affect birds, fish and wildlife.\textsuperscript{78} Acidification refers to the process in which the pH in the atmosphere is reduced, producing acid rain when chemicals like sulfur dioxide are released into the environment.\textsuperscript{79}

\textbf{Model Assumptions and Inputs}

Although Ecoinvent is a very powerful and popular database to gather upstream inputs, it does have its limitations. The database is more widely used in the European Union and China, which limits the US-based parameter options. Below, is a discussion of our assumptions and comments on how the parameters were selected:

\textbf{Electricity:} The “Electricity, Low Voltage, at Grid - US” parameter was chosen for all electricity applications. Ecoinvent is not able to differentiate between the supply-mix within various regions in the US. Therefore, Ecoinvent recommends to use the US low voltage grid options for agricultural applications.\textsuperscript{80}

\textbf{Tracker Diesel Usage:} The transportation options available in Ecoinvent required an input of mass multiplied by distance. However, since we had the diesel usage in terms of liters for both corn and tobacco, we chose “Diesel Burned in Building Machine”. In order to determine if this assumption was appropriate, we compared our results for the same diesel input using the US Department of Energy’s GREET Excel document that calculates global warming potential.\textsuperscript{81} For the same diesel input, the GREET calculator for an “Off-road Grader/Maintainer” estimated a global warming impact of 700 kg CO\textsubscript{2} compared to Ecoinvent’s 570 kg CO\textsubscript{2}. We felt that given these two estimates were within 80 percent of one another, that our Ecoinvent parameter selection for diesel usage was reasonable.

\textbf{Fertilizers:} We used the following parameters for specific fertilizers based on what was available in Ecoinvent: Potash (K\textsubscript{2}O): “Potassium Chloride, K\textsubscript{2}O; Nitrogen (N)”: “Ammonium Nitrate, N”; Phosphate (P\textsubscript{2}O\textsubscript{5}): “Phosphoric Acid, Fertilizer Grade, 70 percent H\textsubscript{2}O.”

\textbf{Liquid Propane Fuel:} We selected the “Propone/Butane, at Refinery” parameter to capture the liquid propane used to grow tobacco in a greenhouse. The value was converted from liters to kilograms using a volume to weight energy calculator.\textsuperscript{82}

\textbf{Steam/Fuel Energy:} CWM facilities typically use coal-fired steam turbines as they require a significant amount of heat and steam.\textsuperscript{83} We tried to incorporate coal as an input to our model, but the results were extremely high and did not align with other studies. As such, we modeled the total steam and fuel required
for drying using the “Heat, Natural Gas, at Industrial Furnace” parameter which we came up with by calibrating it to a study from NatureWorks. Based on the NatureWorks Ingeo LCA study, the total global warming impact of the corn and dextrose production is 0.54 kilograms CO₂ equivalent. Backing out the sugar content from the study and knowing that 1 kilogram of PLA requires 1.57 kilograms of sugar, we calculated that 0.344 kg CO₂ equivalent is required to produce 1 kilogram of dextrose sugar. Our analyses below shows that the total global warming impact for growing, harvesting, and producing corn dextrose is 0.522 kg CO₂ equivalent. Although these two results are not identical, it suggests that our preliminary model is reasonable.

**Results and Sensitivity Analysis**

Although the total life cycle inventory comparison between tobacco and corn showed that corn had a larger energy and fertilizer footprint, we needed to run the assessment and aggregate the output to compare the two crops using TRACI environmental metrics. The figure below outlines the environmental differences between the two crops under three different scenarios:

1) **Total Corn**: Growing & Harvesting + Sugar Extraction
2) **Total Tobacco**: Growing & Harvesting + Sugar Extraction
3) **Total Tobacco + Transport**: Growing & Harvesting + Sugar Extraction + Transport

The first two scenarios are simply the total impact for each crop based on the life cycle inventory inputs that were previously discussed. The third scenario includes the total tobacco impact with the addition of 1,800 kilometers of transportation, assuming a 32-ton truck. The transportation figure assumes that Tyton produces the sugar in Virginia and then transports it to PLA manufacturing facilities.
Figure 8: TRACI Environmental Impact Assessment: Corn vs Tobacco

Not including the transportation scenario, tobacco outperforms corn in the three most important TRACI categories. However, we imagine that in the short term, Tyton might want to consider the option of shipping the sugar from Virginia rather than establishing a facility close to its customers.

Tyton believes that in some regions, it could reduce its fertilizer usage by 50 percent or potentially even by 100 percent. In addition, Tyton has estimated that by scaling up its extractor, electricity usage could be reduced by at least 5 percent. Therefore, we wanted to investigate how changing these parameters might improve the scenario where tobacco sugar is extracted in Virginia and shipped. Table 6 outlines a few scenarios that would make the global warming impact of tobacco with transport lower than corn that required no transportation. If Tyton were able to eliminate using fertilizer and reduce its electricity usage by 30 percent, its estimated global warming impact would drop to 0.503 kg CO₂ equivalent per kg of sugar, lower than corn’s 0.522 kilograms CO₂ equivalent per kilogram of sugar.
Financial Analysis

The overall lower environmental impact of tobacco over corn offers a compelling marketing benefit to PLA producers. However, adoption is unlikely to occur if there is not a significant cost benefit to switching feedstocks.

Interviewing people in both the upstream and downstream segments of the plastic industry, including Robert Green from NatureWorks and Edgar Jaber from Duna, a plastic manufacturer in Mexico, the team determined that the margin on each product sold was a matter of cents. In order for our client to be competitive in the bioplastics market, particularly in selling PLA, Tyton will need to meet the following criteria:

1. Sugars from tobacco should provide the same performance as those from corn.
2. Switching to a tobacco feedstock should not require additional capital expenditures or require changes in the company’s current manufacturing process.
3. The offer should be at least $0.07/kg to $0.09/kg cheaper than the current market options. This range incorporates switching costs and possible relationship damages with previous feedstock suppliers.

Understanding the importance of cost competitiveness, the team calculated the estimated production price per kilogram of sugar from both corn and tobacco. Table 7 provides a breakdown of the total price, which we determined to be $0.27 per kilogram of sugar produced from corn. The team used cost figures reported by USDA.

Table 6: Electricity and Fertilizer Reduction Sensitivity Analysis

<table>
<thead>
<tr>
<th>Electricity Reduction</th>
<th>Fertilizer Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0%</td>
</tr>
<tr>
<td>0%</td>
<td>0.616</td>
</tr>
<tr>
<td>15%</td>
<td>0.584</td>
</tr>
<tr>
<td>30%</td>
<td>0.551</td>
</tr>
</tbody>
</table>
### Table 7: Corn Operation Expenses (OPEX) in 2014

<table>
<thead>
<tr>
<th>Cost Category</th>
<th>Dollars per planted acre</th>
<th>Cost per Kg Sugar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land Preparation and incl. seeds</td>
<td>$101.04</td>
<td>$0.04</td>
</tr>
<tr>
<td>Fertilizer and Pesticides</td>
<td>$149.23</td>
<td>$0.06</td>
</tr>
<tr>
<td>Chemicals</td>
<td>$29.20</td>
<td>$0.01</td>
</tr>
<tr>
<td>Custom operations</td>
<td>$18.24</td>
<td>$0.01</td>
</tr>
<tr>
<td>Fuel, lube, transport and electricity</td>
<td>$32.80</td>
<td>$0.01</td>
</tr>
<tr>
<td>Repairs</td>
<td>$26.17</td>
<td>$0.01</td>
</tr>
<tr>
<td>Purchased irrigation water</td>
<td>$0.12</td>
<td>$0.00</td>
</tr>
<tr>
<td>Allocated Overhead</td>
<td>$332.88</td>
<td>$0.13</td>
</tr>
<tr>
<td>Interest on operating capital</td>
<td>$0.12</td>
<td>$0.00</td>
</tr>
<tr>
<td><strong>Total OPEX</strong></td>
<td><strong>$689.80</strong></td>
<td><strong>$0.27</strong></td>
</tr>
</tbody>
</table>

The team then compared this figure to the costs reported by Tyton on sugar production from tobacco, and found that tobacco-derived sugars offered a sizable discount compared to corn-based sugars. Specific financial figures are not included in this report.

It is important to note that any financial costs relating to transportation of the crop and/or sugars was not considered. Switching to tobacco-based sugars includes several options for PLA manufacturers: 1) transport a pure sugar stream to the PLA plant site; 2) transporting whole tobacco and install a hydrothermal extractor on site; or 3) using local fields to grow tobacco and install a hydrothermal extractor on site to avoid transportation all together. Tyton will need to explore these options in more depth and analyze how they will impact the company’s price advantage.

**Long term price competitiveness**

Since corn and tobacco are considered commodity products, the market can have a significant impact on the price advantage our client has in comparison to corn. In order to understand the price fluctuation of corn and tobacco, the team did a correlation study comparing prices for natural gas, crude oil, corn ($/bushel), tobacco ($/pound), and percentage GDP growth in the US from 1997 to 2014. A summary from the analysis is represented in the Table 8:
The correlation study reveals that both corn and tobacco prices fluctuate with oil prices, meaning that the competitive advantage that Tyton has may decrease if the price for oil continues on a downward trend. Even though tobacco has a correlation of -0.287 compared with natural gas, the correlation with oil is 0.520, meaning that macroeconomic changes might affect the price of tobacco in the market. However, corn, which in this case is being considered its closest competitor, has a correlation with oil of 0.853, indicating that price fluctuations have a higher impact on the price per bushel. Something that was surprising from the analysis is that both tobacco and corn have an inverse correlation with GDP. The economic benefit of the production of tobacco compared to corn, in addition to the lower correlation to oil pricing, can give a strategic competitive analysis.

### Part IV: Recommendations & Next Steps

Our analysis demonstrates that the use of tobacco instead of corn could offer both environmental and financial benefit to manufacturers of PLA. From a financial standpoint, tobacco-based sugar represents a sizable reduction in cost, not including any transportation costs. The potential cost reduction should be significant enough to overcome switching costs that manufacturers may incur. Furthermore, the analysis concluded that the use of tobacco would reduce total environmental impact of PLA manufacturing by up to 50 percent with respect to global warming, acidification, and ecotoxicology. End-user concern around environmental impact of plastics is a driving force behind the demand for bioplastics. Additional gains in minimizing environmental impacts offer valuable marketing opportunities to PLA manufacturers to further themselves from competitors. The use of a non-food crop adds to the overall credibility of these companies’ claims of producing environmentally-friendly products.

### Short-Term Recommendations for Entering the Bioplastics Industry

The team identified a strong contenders for which Tyton should partner; however, these companies will not be named in this report. Tyton should move forward with initiating discussions with these companies about sourcing economic and environmentally-friendly sugars to the company’s manufacturing site. Discussions
with industry professionals (Appendix B) indicated that much education is needed about the potential benefits that tobacco could offer as a feedstock; most had not considered tobacco as an option. Therefore, Tyton will need to be proactive about communicating these benefits to industry players.

Tyton should partner with a third-party industry association, such as PlasticsEurope, Biotechnology Innovation Organization (BIO), or the American Chemistry Council, to conduct a formal LCA on the benefits of using tobacco versus other biomass sources. This will serve to validate the conclusions presented in this paper and serve to gain credibility among industry players. As evident in the Part III discussion on the environmental analysis, LCAs are sensitive to the inputs; therefore, having an objective third-party will be key to gaining acceptance in the overall findings. Commissioning independent industry associations and consultants is common practice in the chemicals industry.

Tyton will need to conduct an in-depth feasibility study to confirm and understand all ramifications for displacing corn (or other biomass) with tobacco for PLA manufacturing. Interviews with industry professionals indicated that there should be no difference in performance once a sugar stream is produced; however, confirmation is needed as to whether the enzymes used for conversion of sugar to lactic acid will be as efficient with tobacco-based sugars as with corn-based sugars. Additional information is needed on whether there will be capital expenditures to enable switching feedstocks. Furthermore, Tyton will need to better understand the logistics and costs around potential transportation. The environmental analysis considered a potential 1,800-kilometer distance between Tyton’s tobacco fields and potential manufacturing facilities; however, these costs were not factored into the financial analysis for the price per kilogram of sugar. Switching to tobacco-based sugars includes several options for PLA manufacturers: 1) transport a pure sugar stream to the PLA plant site; 2) transporting whole tobacco and install a hydrothermal extractor on site; or 3) using local fields to grow tobacco and install a hydrothermal extractor on site to avoid transportation all together.

In the event that PLA manufacturers are not interested in switching feedstocks, Tyton has other new business development opportunities in bioplastics. Adoption of bio-based polyethylene terephthalate (PET) is gaining momentum. The Coca-Cola Company launched the Plant PET Technology Collaborative (PTC) to work toward the development of a 100 percent bio-based soda bottle. CocaCola is currently working with Virent, Inc., a biochemical firm based in Madison, Wisconsin. Virent uses beet sugars to produce paraxylene, a raw material that is used in the manufacturing of purified terephthalic acid (PTA) and dimethyl terephthalate (DMT), which comprises nearly 70 percent of bottle-grade PET. Tyton could do additional analysis to see if tobacco offers added benefit for other bioplastic compounds.

In the event that PLA manufacturers are not interested in switching feedstocks, Tyton has other new business development opportunities in bioplastics. Adoption of bio-based polyethylene terephthalate (PET) is gaining momentum. The Coca-Cola Company launched the Plant PET Technology Collaborative (PTC) to work toward the development of a 100 percent bio-based soda bottle. CocaCola is currently working with Virent, Inc., a biochemical firm based in Madison, Wisconsin. Virent uses beet sugars to produce paraxylene, a raw material that is used in the manufacturing of purified terephthalic acid (PTA) and dimethyl terephthalate (DMT), which comprises nearly 70 percent of bottle-grade PET. Tyton could do additional analysis to see if tobacco offers added benefit for other bioplastic compounds.

In the event that PLA manufacturers are not interested in switching feedstocks, Tyton has other new business development opportunities in bioplastics. Adoption of bio-based polyethylene terephthalate (PET) is gaining momentum. The Coca-Cola Company launched the Plant PET Technology Collaborative (PTC) to work toward the development of a 100 percent bio-based soda bottle. CocaCola is currently working with Virent, Inc., a biochemical firm based in Madison, Wisconsin. Virent uses beet sugars to produce paraxylene, a raw material that is used in the manufacturing of purified terephthalic acid (PTA) and dimethyl terephthalate (DMT), which comprises nearly 70 percent of bottle-grade PET. Tyton could do additional analysis to see if tobacco offers added benefit for other bioplastic compounds.

The team sought potential US-based partners to decrease the complexity, time, and cost of initiating new business partnerships. However, if Tyton is not able to secure a deal in the US, there is opportunity abroad.
In fact, China and greater Asia are attracting a large share of new investment in bioplastics due to feedstock availability and favorable political frameworks. Ideally, initial relationships with bioplastic manufacturers could serve as the base for building additional partnerships in the industry that would move the company toward the production of higher value chemicals.

**Long-Term Recommendations for Revenue Diversification**

Tyton has done well to build expertise in the production and extraction of tobacco-based sugars; however, the company has an opportunity to capitalize on the other components and benefits of the plant. For the medium-term, Tyton should select bio-based chemicals that could serve to replace animal and/or petroleum-based chemicals and acquire the necessary equipment or partner with a product manufacturer on research and development. Suggested markets on which to focus include personal care & hygiene or homecare & cleaning as there is growing end-use consumer demand for bio-based products. (See Appendix D for additional detail on these markets.) Through the team’s Phase 1 exploration of the chemicals market, we were able to identify 55 chemicals that have the potential to be produced from tobacco, many of which use the oil and proteins in the plant. (See Appendix C).

**Transgenics for Production of High-Value Molecules**

For the long-term, Tyton should either develop the capabilities or partner with firms to express high-value chemicals and/or enzymes directly in the tobacco plant as this method could prove more economical than chemical production as it would bypass energy-intensive transformations.

Many of the advancements in the field of tissue culture, plant cells, and molecular biology have originated from the experimentation with tobacco plants due to the plant’s ease of manipulation, among other properties. For example, tobacco and potato plants were used in the 1990 discovery of human serum albumin, the first recombinant plant-derived pharmaceutical protein. Tyton should explore joint research opportunities with industry players currently exploring transgenics as a means to produce high-value molecules.

The two industries that appear to be investing most heavily in transgenics for biomolecule production include pharmaceuticals and manufacturing of other industrial enzymes. The cost of producing biomolecules from plants is relatively economical since plants are able to synthesize proteins and metabolite through solar energy. Conversely, biomolecules from animal and microbial cell structures need equipment, a substrate, and electricity. For example, the cost to produce immunoglobulin A from transgenic plants is less than 1 percent of what it costs using mammalian cell cultures and under 5 percent of the cost from transgenic goats.
Industrial Enzymes, which are used to accelerate the speed of chemical reactions, are typically produced in fermenters, a process that can be labor, time, and capital-intensive. Margins for industrial enzymes can be low, thus requiring high expression at a low cost in order to be economical. Plants are seen as a viable production mechanism as they are able to be scaled easily and have low production costs. Additional advantages include the following: 1) natural storage in the seeds and other parts of the plant; 2) direct usage of the plant for food supplements; 3) eukaryotic post-translational modifications (PTM) (critical for certain enzymes); 4) ability to compartmentalize inside the cell; and 5) absence of human pathogens that might contaminate a purified enzyme.96

Initial studies at Pacific Northwest Laboratory (PNL) found plants to be less technical and more economical “bioreactors” for growing enzymes. Typical costs for fermentation range from $50 to $250 per gram of raw product; however, PNL estimated that growing the same enzymes in plants could cost less than $0.01 per gram of finished cellulose product.97 The largest market share for enzymes is detergent followed by starch and textiles.

Pharmaceuticals and Vaccine Production

Transgenic plant work is a popular research focus in pharmaceuticals since it minimizes health hazards that could stem from other sources of tissue culture. For instance, PNL conducted studies in gene splicing for transplanting human genes into tobacco plants to express factors for blood clotting.98 Significant work in biomolecular production has focused on vaccine harvesting. A study conducted in 2013 by the Hotung Molecular Immunology Unit at London’s St George’s University was able to get tobacco plants to produce rabies antibodies through genetic modification.99 The plant was used as a platform to carry a modified antibody found in rodents that is resistant to rabies. In addition to cost benefits, the production of recombinant vaccines in plants could serve to make distribution and overall effectiveness more feasible in developing countries. Studies have demonstrated that plant-derived vaccines do not have the same refrigeration requirements or injection requirements.100

Japan has seen significant activity in transgenics for molecule production. The Japanese Ministry of Economy, Trade and Industry (METI) conducted two phases of research aimed at developing technology to produce bioactive compounds in plants. The first, which ran from 2002-2009, was conducted by 10 industries and 17 academic institutions, including those based in China and Indonesia. End-product goals included amino acids, rubber, steroids, hyaluronic acid, carotenoid, pulp, and glycyrrhizin. The second project ran from 2006-2010 and focused on production of raw materials, enzymes, and reagents to develop vaccines for several ailments including Alzheimer’s (soybean), avian influenza virus (potato), porcine edema (lettuce), miraculin (tomato), human thioredoxin (lettuce), and sesamin (forsythia).101
Capitalizing on Advanced Extraction Processes

Tyton has a potential opportunity to use its proprietary extraction technology to advance the biomass extractor industry by providing efficiency increases and production cost reductions during the extraction phase in plant production and sourcing. This could be an interesting avenue to pursue if Tyton feels its extraction techniques could be applied to plants other than tobacco.

Extracting oil from bio-based products is typically achieved using plant seeds with one of three main techniques: 1) cold pressing; 2) expeller pressing; 3) or solvent extraction. The first two methods use mechanical techniques whereas the latter is a chemical operation. Market research suggests that innovation in the extraction process of plant materials could offer strong value to the market and serve as an alternate path for Tyton to explore.

Many plant leaves contain added health benefits that can be exploited. For example, olive leaf extract houses key bio-actives for hydroxytyrosol/tyrosol and oleuropein/ligstroside that can help protect LDL cholesterol from oxidation. Other plants such as aloe vera leaf extracts have health benefits that are projected to grow demand for the extracts among end-users. Tyton could seek to position itself as an equipment manufacturer to these niche industries in order to help them utilize biomass more efficiently.

Conclusion

This project initiated from the need for Tyton to identify alternate applications for its “energy tobacco” as a means to diversify the company’s revenue streams and move toward a portfolio of high-value products. The team set the objective of identifying a short-term pathway for Tyton to enter the bio-chemicals market through its expertise in tobacco-based sugars as well as provide medium and long-term recommendations for how Tyton can capitalize on the oils, proteins, and complex genetic make-up of the plant.

After a top-level analysis of the chemicals industry and bio-manufacturing trends within end-use markets, the team identified bioplastics as a strong industry for which to enter due to the ubiquity of plastics in end-use markets and the upward growth trends in bio-based feedstocks. The team felt it was important to focus on a bioplastic compound that had a strong US-based manufacturing presence as a means to ease the complexity, cost, and challenges of entering the supply chain. After evaluating the dominant compounds in the bioplastics industry, the team selected PLA as an optimal compound for Tyton to pursue.

The team ran a comprehensive competitive analysis that considered performance, cost, and environmental impact when evaluating the benefits that PLA producers could gain by switching to a tobacco feedstock from corn. The results were positive as a “cradle-to-gate” LCA demonstrated that the use of tobacco could result in a 50 percent reduction in environmental impact, an advantageous marketing message for a
company that seeks to gain market share from environmentally-conscious consumers. Most significant was the sizable cost advantage in the cost per kilogram of sugar produced from tobacco over corn-based sugar.

Tyton’s next steps should include commissioning an industry trade association or other third-party to conduct a formal LCA analysis on the benefits of using tobacco for bio-based manufacturing as this will serve to verify this project’s results and earn credibility within the industry. Additionally, Tyton will need to run a detailed feasibility study to identify complications or capital investment requirements for switching to a tobacco feedstock. This would include identifying any impact on how tobacco-based sugars might respond to the enzymes used for lactic acid production, a key step in the manufacturing of PLA.

There is significant potential to unlock additional value from Tyton’s “energy tobacco” by utilizing the plant’s oil and protein contents to produce high-value chemicals. Even more promising is the plant’s potential to provide an alternate means for manufacturing specialty compounds through transgenics. These options are longer-term transitions that will require Tyton to either make heavy capital investments or initiate research and development partnerships with some of the larger players in the industry. Our intent is to have near-term partnerships in bioplastics serve to establish Tyton’s reputation in the chemicals industry and build the foundation for more complex initiatives that will lead Tyton on a path to more high-value product offerings that will withstand the volatility of energy markets.
Appendices

Appendix A: Market Examples of Transitioning from Green Fuels to Chemicals

Mounting concern over environmental impacts of petroleum-based fuels has prompted significant research and commercialization efforts for bio-based and alternative fuels. Despite the need, long-term growth in the alternative fuels market is constrained by the market price for crude oil and conventional gasoline. The cyclical nature of these commodities and its impact on growth has promoted many of the start-ups that were initially involved in green fuels to transition to a “hybrid” business model where the companies place a greater emphasis on developing opportunities in the specialty chemicals market where products are sold on the basis of performance or function, rather than composition.

<table>
<thead>
<tr>
<th>Company</th>
<th>HQ Location</th>
<th>Products/Markets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solazyme</td>
<td>San Francisco, CA</td>
<td>Uses microalgae to produce high-performance products in the food, homecare, and personal care industries. Unilever is one of Solazyme’s top customers. Initially used algae toward the production of bio-jet fuel.</td>
</tr>
<tr>
<td>Sweetwater Energy</td>
<td>Rochester, NY</td>
<td>Patent to produce low-cost sugars and clean lignin fiber from non-food plant materials for bio-chemicals, bioplastics, and biofuels.</td>
</tr>
<tr>
<td>Gen2 Energy</td>
<td>Ames, IA</td>
<td>Uses coffee and cocoa mucilage, manure and dry waste, and agave waste to produce biofuels, fertilizers, pharmaceuticals, bioplastics, fuel pellets, and personal care chemicals.</td>
</tr>
<tr>
<td>BioDimensions</td>
<td>Memphis, TN</td>
<td>Harvests winter oilseed crops and sells identity-preserved, specialty plant oils as a feedstock for green chemicals and advanced biofuels.</td>
</tr>
<tr>
<td>Renewable Oils*</td>
<td>State University, AR</td>
<td>Genetic technology used to produce cellulose enzymes in the germ of corn seeds.</td>
</tr>
<tr>
<td>Infinite Enzymes*</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Delta BioRenewables*

Memphis, TN

Specializes in sorghum juice and syrup as well as bagasse fiber products. Services include custom services for processing other bio feedstocks.

Cobalt Technologies

Mountain View, CA

Manufactures bio n-butanol from sugars through its own extraction and manufacturing process.

*Wholly-owned subsidiaries under BioDimensions.

Table 10: Companies Adopting Hybrid Business Model in Fuels and Chemicals

In addition to the companies mentioned above, there are many other companies currently pursuing the production of bio-based chemicals from plant sources:

<table>
<thead>
<tr>
<th>Company</th>
<th>HQ Location</th>
<th>Products/Markets</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Agriculture</td>
<td>MD</td>
<td>Plans to produce renewable energy, chemicals and high-value food products from plant biomass with emphasis on vertical integration for proteins.</td>
</tr>
<tr>
<td>Soliance</td>
<td></td>
<td>Develops ingredients derived from vegetable sources, microorganisms and microalgae to international clients in the cosmetic industry. Recently acquired by Givaudan.</td>
</tr>
<tr>
<td>Algenol</td>
<td>Fort Meyers, FL</td>
<td>Currently uses algae to produce fuels with intention to enter bioplastics market.</td>
</tr>
<tr>
<td>Avantium</td>
<td>The Netherlands</td>
<td>Produces polyethylene-furanoate for PET derived from plant-based sugars. Clients include Coca-Cola, Danone, and Alfa.</td>
</tr>
<tr>
<td>Blue Marble</td>
<td>Seattle, WA</td>
<td>Originally founded to produce bio-jet fuel from algae, the company partnered with Bionavitas in 2009 to produce esters for the food, fragrances, resins, and adhesives markets.</td>
</tr>
</tbody>
</table>

Table 11: Companies Involved in Bio-Chemicals
Appendix B: Industry Experts Consulted

The following individuals were consulted throughout the scope of this project:

**William Faulkner**, Entrepreneur with more than 10 years of experience in the industry. Former VP of Draths, a biobased chemical startup in Minneapolis. Currently the CEO of Ascenix, a startup focused on a bioroute to MMA

**Fernando Gabarain**, Former Regional Technical Manager of Engineering Polymers Plant, DuPont

**Robert Green**, Global Business Leader Ingeo fibers and Nonwoven at Natureworks LLC

**Brandon Morrison**, Duke University, PhD Student – Research: Bioeconomy, trying to delineate the amount of agricultural crops that go into biofuels, bioplastics, biochemicals, etc. More recently, research focused on the renewable energy realm, specifically on wood pellets


**Chantel Reid**, Duke University, Assistant Professor of the Practice of Biology. Studies environmental stresses on leaf gas exchange and plant carbon allocation control carbon gain, plant growth and reproduction

**Rich Helling**, Director of Sustainable Chemistry, The Dow Chemical Company

In researching the potential to introduce tobacco-based products into the personal care & hygiene industry, the following individuals and companies were consulted:

**Sharima Rasanayagam**, Director of Science, Breast Cancer Fund. Discussed the “Red List” of chemicals that should not be used in cosmetics (http://www.safecosmetics.org/take-action/businesses-and-retailers/become-a-certified-safer-products-retailer/)

**Lorraine Dalimeier**, Director of Formula Botanica, the online Organic Cosmetic Science School - Discussed various oils in personal care products.
Emailed and surveyed the following: Most were concern with traces of nicotine in the tobacco oil:

**Natural Personal Care Companies:** Aubrey Organics, Inc., Burt’s Bees, Beauty without cruelty, Druide, Erbaviva, Giovanni Cosmetics, Juara, Lavera, MOP Hair, Weleda, Dr. Hauschka, The Organic Make-up Company, Method

**Distributors:** Formulator Samples Shop, Oregon Trail Soapers Supply

### Appendix C: High Value Chemicals for Further Exploration

The following list contains chemicals that can potentially be derived from Tobacco and Other Plant-Based Materials.

<table>
<thead>
<tr>
<th>Name</th>
<th>Composition</th>
<th>Current Feedstock</th>
<th>Market</th>
<th>Active Players</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sebacic Acid and 11-aminoundecanoic acid</td>
<td>Oil</td>
<td>Castor Oil</td>
<td>Bioplastics</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oleic Acid</td>
<td>Oil</td>
<td>Rapseed</td>
<td>Biolubricants</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alkyd Resins, linoleum and epoxidized oils</td>
<td>Oil</td>
<td>Soybean, sunflower and linseed Oil</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fatty Acids</td>
<td>Oil</td>
<td>Coconout, Palm and Palm Kernel Oil</td>
<td>Soaps, detergents and personal care</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Microcystin-LR (MC-LR)</td>
<td>Tobacco Strain</td>
<td>Tobacco</td>
<td>Water</td>
<td></td>
<td>Helps temper the damaging effects of toxic pond scum</td>
</tr>
<tr>
<td>Sorbitol (Glucitol)</td>
<td>Sugar</td>
<td>Corn syrup, apples, peaches, pears</td>
<td>Food ingredient and Personal care like toothpaste</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Butanol</td>
<td>Sugars</td>
<td>Biomass</td>
<td>Solvents, Paints, Butyl, rubber, Fuels</td>
<td>Gevo, Butamax, Cathay, Metex</td>
<td></td>
</tr>
<tr>
<td>Adipic Acid</td>
<td></td>
<td>Nylons, resins, Polyurethanes</td>
<td></td>
<td>Verdenzyne, Rennova, BioAmber</td>
<td></td>
</tr>
<tr>
<td>Succinic Acid</td>
<td>Sugars</td>
<td>c4 molecules, PBS, PBT,</td>
<td></td>
<td>Bioamber, Myriant</td>
<td></td>
</tr>
<tr>
<td>Solvents dehydration</td>
<td>Butanediol (BDO)</td>
<td>C4 molecules, PBS, PBT</td>
<td>DSM/Roquette, BASF/Purac</td>
<td></td>
<td></td>
</tr>
<tr>
<td>----------------------</td>
<td>------------------</td>
<td>------------------------</td>
<td>--------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Butadiene</td>
<td></td>
<td>Rubber</td>
<td>Genomatica, LanzaTEch, Bioamber</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Isoprene</td>
<td></td>
<td>Fibers, Cosmetics, Polyurethanes</td>
<td>GlycosBio, AE Biofuels/Zymetics</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Propanediol (PDO)</td>
<td></td>
<td>Coatings, adhesives, plastics</td>
<td>DuPont, GlycosBio, Itaconix</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acrylic Acid</td>
<td></td>
<td>Polysters, polyurethans</td>
<td>OPX Biotechnologies, Novomer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Furans</td>
<td></td>
<td>PET, Plasticizers</td>
<td>Avantium, Pennakem</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teraphtalic Acid</td>
<td></td>
<td></td>
<td>Draths, Aventium, Gevo</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Methyl Ether Sulfonate (MES) Surfactants</td>
<td>Sucrose or Glucose</td>
<td>Coconut Oil, Palm Kernel Oil</td>
<td>Paint, Cosmetic, Textile, Agricultural</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N-Butanol</td>
<td></td>
<td>Corn</td>
<td>Paints</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Isobutanol</td>
<td>Starch</td>
<td>Corn</td>
<td>Cathay Industrial Biotech</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glycol</td>
<td></td>
<td></td>
<td>$5 billion</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bioplasticizers</td>
<td>Oil/fatty acids</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bio toners</td>
<td>Oil/fatty acids</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Product</td>
<td>Source</td>
<td>Example Products</td>
<td>Company</td>
<td>Cost</td>
<td></td>
</tr>
<tr>
<td>--------------------------</td>
<td>-------------------------</td>
<td>-----------------------------------</td>
<td>----------------------</td>
<td>-----------------------------</td>
<td></td>
</tr>
<tr>
<td>2-pyrrolidone</td>
<td>Sugar</td>
<td>Plastics, fibers, coatings</td>
<td>Genomatica, BASF</td>
<td>5.5 million pounds by 2017</td>
<td></td>
</tr>
<tr>
<td>1,4 butane diol</td>
<td>Sugar</td>
<td>Genomatica, BASF</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tetrahydrofuran</td>
<td>Sugar</td>
<td>Car bumpers, Spandex, Pants</td>
<td>Genomatica, BASF</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2,3 butanediol</td>
<td>Sugars, cellulosic</td>
<td>Rubbers, plastics, synthetic fibers</td>
<td>BASF, LanzaTech, Geniomatica</td>
<td>$2,000/ton, $7.5B by 2017</td>
<td></td>
</tr>
<tr>
<td>Isopropanol</td>
<td></td>
<td>Rubbers, plastics, synthetic fibers</td>
<td>LanzaTech</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mono-Ethylene glycol</td>
<td></td>
<td>Plastic bottles</td>
<td>Gevo</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polyhydroxy alkanates</td>
<td></td>
<td>Gevo</td>
<td>Gevo</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solanesol</td>
<td>Tobacco</td>
<td>Pharmaceutica and Nutraceutical products</td>
<td>300-$1000/kg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alkaloids</td>
<td>Tobacco</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steroids</td>
<td>Tobacco</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phenolics</td>
<td>Tobacco</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vitamins</td>
<td>Tobacco</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Levulinic acid</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gluacaric acid</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydroxymethylfur fural</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2,5-Furan dicarboxulic acid</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P-Xylene</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Organic Acids (Lactic Acid)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Succininc acid</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chemical</td>
<td>Application</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---------------------------</td>
<td>----------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Itanoic Acid</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adipic Acid</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 hydroxy propionic acid/</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>aldehyde</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Isoprene/ farnesene</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glutamic Acid</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aspartic Acid</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mecalithe</td>
<td>Construction</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Keratin Protein</td>
<td>Computer Chips</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polylactic Acid starch</td>
<td>Corn</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polylatic Acid Starch</td>
<td>Corn</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biodegradable Plastics</td>
<td>Microorganism converts cornstarch into resin</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ecoflex Polyster</td>
<td>Biodegradable Plastics</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acrilic Alkyd Oil</td>
<td>Soy</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sefose Sucrose Paint</td>
<td>Paint</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chempol Resins</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sentricon Pesticide</td>
<td>Dow</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 15: High-Value Chemicals Potentially Derived from Tobacco and Other Plant-Based Materials
Appendix D: Market Overviews on Demand for Bio-based Products

*Due to consumer concerns that might arise from tobacco-derived ingredients, markets that included human ingestion were not considered.*

![Figure 19: Major Product Categories for Global Bio-Based Manufacturing](image)

**Automotive & Transportation**

With more than 68 million cars and 22 million trucks produced globally in 2014, the automotive industry is heavily reliant on plastics and other petrochemical products. However, the Center for Automotive Research released a report showing that there is a movement towards bio-based products in the industry, largely prompted by government regulations, preferences from consumers, and in some instances, financials benefits. These bio-based materials include crops, grasses, wood, as well as wastes and residues and to replace conventional adhesives, fabrics, polymers, and reinforcement fibers, polymers.

A number of obstacles must be addressed before the industry sees large adoption of bio-based products. The largest barrier is the market price of the polymer that the bio-based alternative would displace. In addition, the bio-based materials lack some of the mechanical properties of traditional fiberglass materials, which limits their use. In some instances, the lack of performance quality is more of a perception than a reality. For example, 22 percent of the new Peugeot 308’s plastic is made from bio-based materials (19 percent natural materials and 2 percent biopolymers) which helps the car shed 20 percent of the weight;
however, there is no mention of this in the marketing material because of the public perception that bio-based products are lower in quality.¹⁰⁹

Many of the advancements in the industry have focused on mixing PE fibers with natural fibers in higher-end vehicles to improve performance. Polymers specializing in absorbing sound vibration can also be used in bumpers and lights.¹¹⁰ Advancements in the industry include Mitsubishi Chemicals Corporation’s DURABIO, which is a plant-derived plastic that has excellent optical properties and high resistance to heat and humidity.¹¹¹ PSA and Soprema, a world leading company in sealing and insulation, have partnered to produce polyurethanes from bio-based feedstocks. Another bio-based product, Polyamide 11, developed by Arkema from ricin oil, is considered a substitute for PA 12 that is derived from hydrocarbons.¹¹² The Polyamide 11 offers exceptional properties and can be used in various applications including fuel tubes, hydraulic tubes, and connectors.¹¹³

**Building & Construction**

The sustainable building material manufacturing industry is currently worth $36.1 billion in revenue and $1.6 billion in net profits. It had a CAGR of 21.4 percent from 2010-2015 and is expected to grow 10.6 percent annually from 2015-2020.¹¹⁴ The industry is adopting green chemicals and sustainable construction because there are important tax subsidies, cost reduction and an increase in the certification of buildings under the Leadership in Energy and Environmental Design (LEED) standards. According figures published by Transparency Market Research (TMR), the world market for construction chemicals reached a $21.1 billion market value in 2012; with an 8.7 percent compound annual growth rate (CAGR) from 2013 to 2019. TMR projects the market to reach $37.7 billion by 2020.¹¹⁵

Structural building materials represent that largest segment of the industry at approximately 44 percent and includes products from concrete to recycled metals and plastics. Concrete admixtures represent 50 percent of the revenue coming from the chemicals used for construction and it is likely to grow 7.8 percent between 2014 and 2020¹¹⁶. An example of a biomaterial is Houston wood concreate out of The Netherlands that with the addition of Mecalithe, a powder additive that increases the strength of cement by 30 percent, can contain 30-90 percent wood.

Other opportunities for bio-based solutions in the construction industry include adhesives and sealants as well as paints, tar, and resin materials. The paint industry is under pressure from consumer and regulatory agencies to reduce its environmental impact¹¹⁷. Major chemicals used to produce paints include: 1) N-butanol, currently a $5 billion market that is forecasted to grow at an annual rate of approximately 4 percent, or 120,000 metric tonnes, per year;¹¹⁸ 2) acetone; and 3) ethanoic acid. The industry is starting to use natural oils in protective coatings. There is also an opportunity to see improvements in insulation materials such as Styrofoam and polystyrene.
Homecare & Cleaning

The US cleaning products market is $30 billion.\textsuperscript{119} According to the American Cleaning Institute, materials, including the safety of chemical ingredients, raw material sourcing, and scarcity, is the issue of top concern for both company and stakeholder concerns. There has been considerable movement among end-users in terms of demanding “green” cleaning solutions, or those that are less harmful than standard products in the market. Seventh Generation began selling a laundry detergent containing a surfactant that is 98 percent bio-derived with USDA certification.\textsuperscript{120} Seventh Generation has partnered with the chemical firm Rhodia (France) to develop a surfactant called Laureth-6 alcohols derived from palm oil. A major manufacturing of homecare and cleaning products, P&G, has partnered with US-based chemical companies LS9, Zeachem, and Amyris. Both P&G and Seventh Generation seek to use surfactants made from sugar feedstock as well.

**Surfactants** decrease surface tension in liquids, which allows chemicals to mix more easily. Household cleaning detergents is the largest market for surfactants.\textsuperscript{121} They can be made from bio-based sources, referred to as oleochemical, and/or petroleum-derived raw materials. The most common feedstocks for plant based surfactants are plant oils, like those from palms or coconuts, or from plant sugars. Animal fats are also another base for oleochemicals; however, animal fats are not as widely used as plant oils are becoming more prevalent in the industry.\textsuperscript{122}

The key drivers that impact the market for surfactants are price, product safety, and performance. Biosurfactants offer benefits in terms of biodegradability and low toxicity in raw materials. However, production costs tend to be higher than petrochemical-derived surfactants; therefore current oil prices undermine market expansion. (Surfactants made from mineral oil tend to be less expensive than plant-derived surfactants.)\textsuperscript{123} The EU is the largest market\textsuperscript{124} for bio-based surfactants with consumption totaling 1.52 million metric tons in 2008. The potential growth is estimated to be an annual 3.5 percent with the potential to reach 2.3 million metric tons of consumption by 2020.\textsuperscript{125} Top manufacturers include Houston-based Huish Detergents Inc., which manufactures methyl ester sulphonate from renewable resources. The capacity of the company’s plant is approximately 70,000 metric tons.\textsuperscript{126}

**Solvents** are used as degreasing agents for textile detergents. Bio-solvents can range from 100 percent plant based to lower concentrations blended with conventional feedstocks. Examples of bio-solvents include actate esters (fermentation derived lactic acid reacted with methanol or ethanol), soy methyl ester (soy oil esterified with methanol), and D-Limonene (extracted from citrus rinds). A key benefits of using bio-derived solvents is that most do not emit volatile organic compounds (VOC), which are hazardous to human health and also an ozone precursor. Consumption of bio-solvents in the EU totaled 0.63 million metric tons in 2008, with expects to have an annual growth of 4.8 percent to reach 1.1 million metric tons in 2020.\textsuperscript{127}
Bio-solvent manufacturing costs are not competitive with conventional solvent production. However, research in this area has made progress as there have been successful demonstration of bio-based halogenated solvents (those which contain halogen, chlorine, bromine, or iodine) in various forms.  

**Personal Care & Hygiene**

The total beauty and personal care industry realized $454 billion in global revenue in 2013, of which 29 percent was represented by Asia Pacific. Skin care and hair care top the list of 2014 retail sales at $110 billion and $78 billion, respectively, while the fastest growth segments will be coming from the other-facial Make-up and Men’s Skin Care at an expected CAGR of 11 percent and 8 percent, respectively, over 2013-2018.

While the global market continues to sustain growth of 5 percent per year, natural and sustainable cosmetics are expected to grow at 15 percent per year, carving out a $14 billion personal care ingredients market. These trends in the natural beauty market are more pronounced in Asia and in South America, yet there has been a 7 percent growth in the US and a 6 percent growth in Europe. In addition, Kline Natural Personal Care Reports classifies the natural care industry as “extremely fragmented,” with only six companies having 3 percent or higher market share, opening the door for new entrants.

At the high-end of the personal care industry spectrum lies skin care creams that can fetch up to $739 per ounce. These products contain various compounds such as angiotensin-converting (ACE) enzyme that can be expressed in tobacco and hyaluronic acid (HA) that can be made from bio-based feedstocks. HA, which has traditionally been extracted from rooster combs, can also be synthesized through bacterial fermentation of sugars with an added benefit of eliminated cross-contamination or transmission of endotoxins. In addition to HA’s use in facial creams, HA is a key player in the facial aesthetics segment. This market segment grew by 21 percent in 2013, with the number of HA filler procedures growing by 31 percent in 2013. Squalene is another important compound traditionally extracted from shark liver oil can now be produced through sugar fermentation using a common strain of yeast called Saccharomyces cerevisiae.

Other high-value products that could be produced via plants as opposed to conventional methods include quercetin and ursolic acid. Bio-based compounds have a promising future in terms of displacing high-value petrochemical and animal-based products.

**Textiles & Apparel Manufacturing**

In textiles and apparel manufacturing, synthetic fabrics have become more widely-used than traditional, natural fabrics. Synthetics continue to grow in popularity due to their hand feel, application, and the ability
to print on them. Within the industry, there has been competition to produce bio-based polyester through polytrimethylene terephthalate (PTT) pods. DuPont has commercialized Sorona, a biopolymer used in apparel, carpets, mats and carpets for the automotive industry. Sorone contains 37 percent renewable plant-based components. However, the blended nature of the fabric prevents it from being recycled.

One of the more notable success stories for bio-based synthetic fabrics is the launch of Yulex wetsuits by Patagonia. The company discovered that the guayule plant, a desert shrub found in the Southwestern US, produced a rubber that could minimize the use of traditional neoprene made from petroleum or limestone. Turkey-based Flokser Group, a top producer of leather, suede, and fabrics, recently launched a bio-based leather fabric under its SERTEX brand utilizing bio-based succinic acid made by BiAmber Bio-SA and bio-based 1.3-propanediol produced by DuPont Tate & Lyle Bio Products.

Progress has been made for bio-based polyamide 6,6 (PA66), more commonly known as nylon. PA66 is a high-end textile fiber due to its strength, wear resistance, moisture absorbance, comfort, dye-ability, and anti-static and flame-retardant properties. Rennovia (US) launch a 100 percent bio-based nylon 6,6 polymer under the company’s RENNLON brand with its renewable monomers, adipic acid (AA) and hexamethylenediamine (HDM). Additionally, Cathay Industrial Biotech (China) launched Terryl, a bio-based polyamide that is the first of its kind to be produced from plant sugars for the PA66 market.

One of DuPont’s most valuable products is the Nylon P 66, manufactured from HDM and AA. A former scientist at the company revealed that there are only a few producers of the two inputs, making DuPont subject to high prices. The company attempted to internally produce HDM but abandoned the efforts due to cost. There could be potential opportunity for Tyton if tobacco could be used to produce HDM more economically.
Appendix E: Corn Wet Milling (CWM) Process

Wet Milling consists of five general steps:142

1. Steeping: Corn that has been removed from the cob and cleared from any other debris enters a steeping stage that soaks the kernels in mildly acidic water at 120-degree F 20 to 36 hours. This loosens the gluten bonds and releases the starch. Next, to release the germ from the kernel, the corn is coarsely ground. The steepwater that was used to soak the corn contains much of the soluble components, including most of the proteins and sugars.

2. Degermination/separation: The slurry from the coarse grinding next goes through a “degermination” phase that separates the germ, which contains the majority of oil in the kernel. Oil is typically separated using hydrocyclone separators. After which, the germ goes through a series of screens to remove loose gluten and starch and is then washed multiple times to recover and return the starch to the process stream. A screw press is used to detwater the germ. Once dried, corn oil is extracted through a series of chemical and mechanical processes.

3. Grinding and screening: The slurry goes through fine grinding and screening to extract any remaining starch and protein from the fiber. The fiber then becomes the key element in animal feed and is combined with corn steep liquor. Typically, feed is dried and shipped; however, it can be sold as wet distiller’s grains if local farms are present. Post fiber wash, the solution is separated and dewatered to recover gluten and starch.

4. Starch-gluten separation: The starch-gluten mixture undergoes separation via a centrifuge. Corn gluten meal, a byproduct of gluten, typically serves to make animal feed. The remaining starch solution is diluted and spun to produce a high-purity starch, typically greater than a 99.5 percent purity.

5. Saccharification/starch conversion: Acid and/or enzymes are applied to the remaining starch solution to transform the starch into various types of sugars such as dextrose or maltose. According to the 2003 Berkeley National Laboratory report, a typical yield from one bushel of corn (24.5 kilograms) is 33 pounds of sugar or approximately 2-3 gallons of ethanol.
Figure 20: Corn Starch Conversion Process
References

1 Food and Agriculture Organization of the United Nations (statistics Division) Available at: http://faostat3.fao.org


6 Interview with Robert Green, Global Business Leader Ingeo fibers and Nonwoven at Natureworks LLC (2016)

7 Ibid. Food and Agriculture Organization of the United Nations (statistics Division)

8 Ibid. Food and Agriculture Organization of the United Nations (statistics Division)


11 Ibid. New Agriculture Inc. (no date).


16 Ibid. Food and Agriculture Organization of the United Nations (statistics Division)


North Carolina Department of Agricultural and Consumer Services (no date) North Carolina flue-cured crops 1919-2014 Available at: http://www.ncagr.gov/markets/commodity/horticultural/tobacco/tobaccocrops.htm

Interviews with Peter Majeranowski, co-Founder and President; Iulian Bobe, co-Founder and CTO; Conor Hartman, Vice President of Business Development Dr. Sean Su, Senior Scientist (2015)


Image source: http://www.tobaccomachinery.eu/

Interview with Iulian Bobe, CTO of Tyton, (2015)


Tyton NC Biofuels (no date). Tyton NC Biofuels - Home. Available at http://www.tytonbiofuels.com/


Ibid. The Society of the Plastics Industry Bioplastics Council (2012)


Evaluation of Tobacco Biomass for Bioplastics Production


45 How Ingeo is made. NatureWorks, LLC. Available at www.natureworksllc.com


54 Energy content in common energy sources (no date) Available at: http://www.engineeringtoolbox.com/energy-content-d_868.html

56 Ibid.

57 Ibid.

58 United States Department of Agriculture Economic Research Service - ARMS Oct 2015


61 Ibid. USDA *Fertilizer use and price*

62 Ibid. USDA *Fertilizer use and price*

63 Interview with Jennifer Atkins, Field Operations lead for Tyton (2016) and Dr. Florin Barla, Processing Lead for Tyton


65 Ibid. *Energy Efficiency Improvement*

66 Tate & Lyle (No date). *Corn Wet Milling*. Available at: http://www.tateandlyle.com/aboutus/ourindustry/pages/cornwetmilling.aspx


68 Software for SimaPro available at: http://www.simapro.co.uk/

69 Software for GaBi available at: http://www.gabi-software.com/international/index/


71 Software for OpenLCA available at: http://www.openlca.org/

72 OpenLCA News (No date). *OpenLCA News*. Available at: http://www.openlca.org/news

73 Access to EcoInvent database available at: http://www.ecoinvent.org

74 Ecoinvent (No date). *SRI Project*. Available at:
http://www.ecoinvent.org/about/projects/sri-project/sri-project.html

76 Chen, Xun (2013). Key Inputs and Processes of Nitrogenous Fertilizer Production. Available at: http://marketrealist.com/2013/10/key-inputs-processes-nitrogenous-fertilizer-production/


79 U.S. Environmental Protection Agency (No Dat). Sulfur Dioxide. Available at: https://www3.epa.gov/airquality/sulfurdioxide/


82 Aqua-Calc (No date). Volume to Weight Conversion. Available at: http://www.aqua-calc.com/calculate/volume-to-weight/substance/propane


87 US Energy Information Administration (EIA) (2016) Europe Brent spot price FOB (dollars per barrel). Available at: https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=pet&s=rbrte&f=m

88 University of Illinois - Farmdoc (no date) Management - US average farm price history. Available at: http://www.farmdoc.illinois.edu/manage/uspricehistory/us_price_history.html


90 World Bank. Available at www.worldbank.org


94 Note that the majority of available research on biomolecule production seems to pre-date 2010. This calls into question the current viability and market potential. Further research and interviews are needed.


103 Examine.com (no date) Olive leaf extract - scientific review on usage, dosage, side effects. Available at: http://examine.com/supplements/olive-leaf-extract/


Surfactants are usually organic compounds that are amphiphilic, meaning they contain both hydrophobic groups (their tails) and hydrophilic groups (their heads). Bio-surfactants are surfactants in which at least one of the two groups (hydrophilic or hydrophobic) is obtained from plants: they are therefore not necessarily 100 percent plant-derived.
Evaluation of Tobacco Biomass for Bioplastics Production


124 Much of the movement toward “green” or bio-based chemicals has been promoted by the Registration, Evaluation, Authorization, and Restriction of Chemicals (REACH) regulations in the EU that were passed in December 2006.


126 Ibid. ECO- Innovation Biochem (2010)

127 Ibid. ECO- Innovation Biochem (2010)

128 Ibid. Ibid. ECO- Innovation Biochem (2010)


132 Schuler, C. (2013) 9 most expensive skin care creams. Available at: http://www.totalbeauty.com/content/gallery/most-expensive-creams

133 Medical Protein Engineering Edited by Yury E. Khudyakov, Page. 460


138 Schuler, C. (2013) 9 most expensive skin care creams. Available at: http://www.totalbeauty.com/content/gallery/most-expensive-creams

139 Patagonia (no date) Yulex. Available at: http://www.patagonia.com/us/patagonia.go?assetid=93864
