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STRATEGIES FOR THE SCALE-UP OF THE U.S. CELLULOSIC BIOFUELS INDUSTRY: INTEGRATED BIOREFINERY & BUYER-SUPPLIER RELATIONSHIPS

A Dissertation in

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by

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The world’s growing population is demanding increasing energy and materials, currently dominated by non-renewable fossil fuels. The U.S. biofuels industry development is responding to consumer demand for environmentally-friendly products. A thorough review reveals that in the United States, corn-grain ethanol and biodiesel have served as the major alternatives for petroleum-based gasoline and diesel over the past few decades. However, first generation biofuels are often criticized on their implications on food price and land use change. Second generation (cellulosic) biofuels avoid the food-fuel controversy, but have yet to become widely commercialized. As a result, existing literature has signaled that the integrated production of cellulosic biofuel and bio-based chemicals is a potential strategy to provide financial incentives and competitive advantage to cellulosic biofuel biorefineries (BRs). Another strategy for cellulosic biofuel BRs to consider is to form relationships with downstream customers which may solidify the supply chain and bring stability to commercialization plans.

However, no existing literature was found to quantitatively evaluate potential factors confronting the commercialization of the U.S. cellulosic biofuels industry and integrated cellulosic BRs/integrated production of both cellulosic biofuels and biochemicals. Also, less is known about the relationships between biofuel suppliers and their downstream customers. The present study was designed to bridge the gap in the literature to provide empirical evidence of 1) quantifying (rating and ranking) the importance/degree of drivers and barriers to the commercialization of the U.S. cellulosic biofuels industry and integrated cellulosic BRs and 2) examining the types of biofuel customers, identifying variables characterizing biofuel buyer-supplier relationships, and exploring strategies strengthening the relationships.

This study’s online and paper-based surveys resulted in 228 or 34 percent of the 678 experts from seven USDA-National Institute of Food and Agriculture (NIFA) Agriculture and Food Research Initiative (AFRI) Coordinated Agricultural Projects (CAPs) and two industrial conferences between July and November 2015 to address the first objective. Also, this study conducted in-depth personal interviews with three corn-grain and cellulosic ethanol producers from two industrial conferences between October and November 2015 to address the second objective.
Some key research findings are highlighted as follows:

1. **Government policies** were rated as the most important factor for the commercialization of cellulosic biofuels, followed by **added value from non-fuel co-products** and **carbon emission reduction**. Also, **competition vs. petro-fuels, high production costs**, and **policy uncertainty** were ranked as the top three barriers to the scale-up of cellulosic biofuels.

2. **Competition vs. petro-chemicals, high production costs**, and **policy uncertainty** represented the top three barriers to the integrated production of cellulosic biofuels and bio-based chemicals.

3. Results also showed that the integrated production of cellulosic biofuels and bio-based chemicals requires **consistent government funding & incentives, new technology development, and education of end-use consumer.**

4. The rated likelihood of success results suggested that participants were more optimistic about the future of integrated cellulosic BR than that of cellulosic BR (excluding biochemicals and biomaterials).

5. Refiners and blenders of gasoline were the primary customers of corn-grain ethanol with fuel marketing companies as secondary intermediaries. Ethanol supplier-customer relationships are mostly non-contractual but sometimes they do form informal contracts.

6. **Trust, shared values, communication, and commitment** between participating parties are identified as important attributes characterizing “best” biofuel customers based on three personal interviews. Also, companies trying to strengthen buyer-supplier relationship may benefit by assuring product quality, on-time delivery, and customer education regarding the environmental benefits of biofuels over petroleum-based counterparts.
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PREFACE

This dissertation begins with a brief introduction of the U.S. biofuels industry and issues and concerns surrounding the sustainable growth of the cellulosic biofuels industry, which directs to the research objectives of this study (Chapter 1). A relevant literature review is provided regarding the concept of biorefinery, the categories of biofuels, integrated cellulosic biorefineries, the profile of the U.S. biochemical industry, factors confronting the scale-up of cellulosic biofuels and integrated cellulosic biorefineries, variables characterizing buyer-supplier relationships, and supply management strategies (Chapter 2). The purpose of this chapter is to provide the readers with a deeper understanding of the concepts used in this study. Readers will use this chapter as a reference if further background information is needed. It should be admitted that each of the remaining articles are stand alone, and the most relevant material cited in Chapter 2 is also seen within the subsequent chapters.

Chapter 3 is provided to discuss the implemented methodology of the remaining chapters. Again, this chapter is presented as a reference for readers who wish to better understand the methodological techniques used in this study.

Chapter 4 through 7 provides results from the empirical data collected for this study. Since each chapter is written as a stand-alone manuscript, the reader will notice substantial redundancy between chapters – particularly in the introduction and methodology sections. Chapter 4, the first article, provides a historical perspective for the development of the U.S. biofuels industry and to examine barriers to the scale-up of second and third generation versions with future development considerations. Chapter 5, the second article, discusses and quantifies the drivers for and barriers to the commercialization of the U.S. cellulosic biofuels industry based on the perceptions of experts throughout the supply chain. This chapter also evaluates the perceptual differences among expert respondents and projects the likelihood of success for the production of cellulosic biofuels (excluding biochemical and biomaterials) and the integrated production of both cellulosic biofuels and biochemicals by the year 2020. Chapter 6 develops a list of potential barriers to the commercial development of the U.S. integrated cellulosic BRs by qualitative e-Survey and quantitatively assesses the degree of these identified barriers by paper-based surveys and e-Surveys. Finally, Chapter 7 explores the customer types of corn-grain ethanol and cellulosic ethanol and identifies variables characterizing and activities strengthening the buyer-supplier relationships across the value chain of the U.S. biofuels industry.
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CHAPTER 1

INTRODUCTION

This chapter was written to provide an overview of the problem statement and research objectives.
**Problem Statement**

Population growth and attendant demand for energy and environmentally-friendly products are straining conventional non-renewable resources. The world’s dependency on fossil fuels, much of which are imported from unstable sources, is under scrutiny. Bio-based economy, instead, addresses both supply and demand issues, and offers the promise of various benefits related to energy security, environmental benefits, and economics (Hoekman, 2009).

Currently, the U.S. bio-based economy is dominated by first generation biofuels, corn-grain ethanol and biodiesel, which account for over 90 percent of the total renewable biofuels within the United States (Environmental Protection Agency, 2015). The U.S. corn-grain ethanol industry has reshaped corn farming by reducing government support for cropping subsidies while raising farmers’ incomes (Renewable Fuels Association, 2014). Meanwhile, corn ethanol blends in gasoline (typically, up to 10%) improve the octane number and add oxygen content to meet the U.S. Clean Air Act (CAA) (Urbanchuk, 2010). Similarly, the U.S. biodiesel industry has also contributed to the U.S. CAA with 52 percent lower GHG emissions compared to petroleum-based diesel (Energy Efficiency & Renewable Energy, 2015).

Driven by the increased pressure from the “food-versus-fuel” debate and the ethanol “blend wall”, research interests have transited from first generation biofuels to second generation and third generation biofuels recovered from lignocellulosic biomass and algae (Brown & Brown, 2013; Mohr & Raman, 2013; Solomon, Barnes, & Halvorsen, 2007). Compared to first generation biofuels, cellulosic and algae biofuels avoid the food-fuel controversy while benefiting from lower lifecycle GHG emissions (Balan, Chiaramonti, & Kumar, 2013; FitzPatrick, Champagne, Cunningham, & Whitney, 2010). However, second generation cellulosic biofuels have yet to become widely commercialized in the US due to a variety of underlying issues (Balan et al., 2013; FitzPatrick et al., 2010). For instance, cellulosic ethanol faces the same ethanol “blend wall” issue, plus intense price competition from existing corn-grain ethanol players. Additional barriers to the scale-up (commercialization) of the cellulosic biofuels industry are well documented and include feedstock costs and availability, high production costs, high capital requirements, policy uncertainty, and various technical, environmental and social issues (Balan et al., 2013; Brown & Brown, 2013; Chen, Smith, & Wolcott, 2016; Cheng & Timilsina, 2010; Cheng & Timilsina, 2011; Oltra, 2011; Pimentel & Patzek, 2005; Temesgen, Affleck, Poudel, Gray, & Sessions, 2015). A complete knowledge of the dynamics underpinning the U.S. biofuels
industry is missing but necessary for decision-makers reconciling economic, energy, and environmental objectives.

Existing literature have also signaled that integrated production of cellulosic biofuels and non-fuel co-products (e.g. bio-based chemicals/biochemicals) is a potential strategy to provide financial incentives and competitive advantage to cellulosic biofuels industry (Batidzirai, Smeets, & Faaij, 2012; Bozell & Petersen, 2010; Golden & Handfield, 2014). Many scientists have analyzed the economic value of bio-based chemicals recovered from renewable feedstock. For example, a recent USDA report projected that the added value of bio-based chemicals would increase from $775 million by 2017 to $3 billion by 2022. Despite the importance of the integrated production scenario, there has been little research conducted to examine and evaluate potential factors affecting the integrated production of cellulosic biofuels and bio-based chemicals.

Additionally, relationships are growing in importance as a viable strategy to form purchase agreements and to sustain competitive advantage for both suppliers and customers (Dyer, 1996). For example, Alaska Airlines will buy 1,000 gallons of Gevo’s alcohol-based jet fuel for commercial flights in 2016. On January 2016, AltAir prepared 1.34 million gallons of F-76 types Naval Distillate Fuel for the U.S. Navy’s Great Green Fleet. AltAir is leveraging purchase agreements with United for up to 15 million gallons of sustainable aviation biofuel over a three-year period (Lane, 2016). The significant benefits of buyer-supplier relationship have raised interests about what factors contribute to its formation.

A review of the literature indicates that many scholars have attempted to characterize the relationship. Variables, such as commitment, trust, cooperation, and dependence have been well documented (Anderson & Narus, 1990; De Ruyter, Moorman, & Lemmink, 2001; Fontenot & Wilson, 1997; Morgan & Hunt, 1994). Existing literature also suggests that future research should examine the relationships between ethanol producers and their downstream customers.

**Project Objectives**

Given the previous problem statement, this project has the following objectives:
- Present a roadmap for the U.S. biofuels industry; in particular, provide a historical perspective for the development of the U.S. biofuels industry and examine barriers to the scale-up of second and third versions with future development considerations.

- Explore and evaluate the factors affecting the scale-up (commercialization) of second generation (cellulosic) biofuels and the successfully integrated production of both cellulosic biofuels and biochemicals by surveying academic and industrial experts from USDA-NIFA AFRI CAPs and industrial conferences.

- Examine the type of existing relationships between biofuel supplier and customer by interviewing select players within the U.S. biofuels industry.

- Identify key factors characterizing and activities strengthening relationships between biofuel suppliers and their downstream customers.

**Significance and Importance of Research**

Given the applied focus of this research, significant attention will be given to the managerial implications pertaining to the use of this collected information. First, U.S. cellulosic biofuel BRs managers will be able to use the information (such as factors affecting the commercialization of cellulosic biofuels and successfully integrated production of cellulosic biofuels and bio-based chemicals) to better allocate resources for different bio-based products and manage product portfolios. Second, research findings may provide directions of future scientific research for academic researchers, and may provide evidence to policy makers to support the U.S. cellulosic biofuels and bio-based chemicals industries. Third, knowledge about buyer-supplier relationships can help existing and potential biofuel producers promote sustainable operations and maintain a competitive advantage. Four, this research also contributes to academic literature. A significant theoretical contribution of this research includes examining key variables characterizing relationships between biofuel suppliers and customers. The proposed research is unique in that the knowledge about buyer-supplier relationships will be extended to the U.S. biofuels industry.
References


CHAPTER 2

LITERATURE REVIEW

This chapter was written to provide the readers with broad background knowledge regarding the concept of biorefinery, the categories of biofuels, integrated cellulosic biorefineries, the profile of the U.S. bio-based chemicals industry, factors confronting the commercialization of cellulosic biofuels and integrated cellulosic biorefineries, variables characterizing buyer-supplier relationships, and supply management strategies.
Introduction to Biorefineries

Biorefineries are production facilities that sustainably convert renewable resources (biomass) to marketable chemicals, energy, and fuels (Cherubini, 2010; Liu, Abrahamson, & Scott, 2012). Biorefineries could also be defined as an alternative method of using carbon from environmentally-friendly resources to produce fuels and chemicals instead of fossil fuels (petroleum, coal, natural gas, etc.), which contribute significantly to the degradation of the environment and the fluctuation of the economy (Amidon et al., 2008).

Feedstock for biorefineries

Feedstock which is mainly named as biomass refers to the raw materials used in biorefineries. Biomass is renewable and different from fossil resources, in that biomass is synthesized via a photosynthetic process that converts carbon dioxide and water from the environment to chemicals with energy from sunlight (Cherubini, 2010). Biomass derived from wood, agricultural/forest residues, grasses, plants and crops are versatile (Naik, Goud, Rout, & Dalai, 2010) and are vital to the sustainable production of biofuels and non-fuel co-products from biorefineries. Meanwhile, renewable biomass can be divided into three broad categories (Cherubini, 2010; Naik et al., 2010; You, Tao, Graziano, & Snyder, 2012):

1. Agricultural plants
   - Starch/sugar crops (grain such as rice, wheat, and barley, sugarcane and sugar beets, potatoes, corn)
   - Oil seeds (soybean, oil palm, sunflower oil, canola, camelina, jatropha)

2. Lignocellulosic feedstocks
   - Crop residues (corn stover, wheat straw, rice straw)
   - Grasses (switchgrass, miscanthus, rye)
   - Wood and paper wastes
   - Short rotation woody crops (willow, poplar)

3. Aquatic plants (macroalgae, microalgae, and cyanobacteria)
Conversion process of biorefineries

Biorefineries use a multi-step production process, and several conversion processes should be jointly applied. The goal of biotechnological processes in biorefineries is to depolymerize and transform the biomass into energy and valuable co-products. The technological processes can be categorized into four major groups: thermochemical, biochemical, chemical, and mechanical/physical processes (Cheng & Timilsina, 2010; Cherubini, 2010).

1. Thermochemical conversion:
   There are four primary thermochemical processes to produce energy and chemical products from renewable biomass. Gasification heats the biomass at high temperature (>700 °C) with low oxygen content to generate syngas, a mixture of hydrogen, carbon monoxide, carbon dioxide and methane. Syngas can be converted to fuels (dimethyl ether, ethanol, isobutene, etc.) through the Fischer-Tropsch (FT) process and/or via chemical transformation process (alcohols, organic acids, ammonia, methanol, etc.) (Cheng & Timilsina, 2010). Pyrolysis uses intermediate temperatures (300 to 600 °C) without oxygen to convert feedstock into bio-oil (also known as liquid oil), solid charcoal and gases similar to syngas. Liquefaction refers to the process of generating heavy oil (Naik et al., 2010). Combustion is the sequence of exothermic chemical reactions for the conversion of heat and steam.

2. Biochemical conversion
   Compared with thermochemical processes, biochemical conversion takes place at a lower temperature with a slower reaction speed. The two most common types of biochemical processes are anaerobic digestion and fermentation. Anaerobic digestion includes the bacterial breakdown of biomass into methane and other biogas (such as carbon dioxide and other gas wastes) without oxygen and at temperatures ranging from 30 °C to 60 °C (Cherubini, 2010). Fermentation uses microorganisms and enzymes to convert biomass into alcohols (methanol, ethanol, butanol, etc.) and other chemical compounds or biopolymers (e.g. hydrogen, succinic acid).

3. Chemical conversion
   Chemical conversion mainly refers to changing of the chemical structure of molecule of biomass by reaction with other chemical substances. The most commonly used chemical reactions of biorefineries are hydrolysis and trans-esterification. Hydrolysis is one of the most important processes for the conversion of lignocellulosic feedstock into ethanol and chemicals. Hydrolysis is the breaking down of complex molecules (cellulose) into simpler molecules (glucose) using water together with a catalyst. The catalyst can either be chemicals (e.g. sulfuric
acid) or biological enzymes (FitzPatrick, Champagne, Cunningham, & Whitney, 2010). Trans-esterification is most commonly used to produce biodiesel, through which vegetable oils can be converted to methyl or ethyl esters of fatty acids (Cherubini, 2010).

(4) Mechanical/physical conversion

Mechanical conversions are processes that maintain the chemical composition of biomass, but only alter the original structure of biomass or separate some components from the raw material. Pretreatment of lignocellulosic feedstock (Cherubini, 2010) is one of the most important steps to remove lignin from cellulose and hemicellulose so that the catalyst used in the hydrolysis process can have easier access to the sugars.

Categories of biorefineries

With technology advancement and more feedstock availability, the U.S. biofuel biorefineries (BRs) are evolving into different categories. Till now, this study’s researcher has identified 414 biofuel BRs within the United States through secondary research. Categorized by feedstock input, these identified biofuel BRs can be classified into four major groups, including Corn-Grain Ethanol Biorefineries (n=208), Biodiesel Biorefineries (n=162), Cellulosic Biofuel Biorefineries (n=40), and Algae Biofuel Biorefineries (n=4) (Figure 2-1).

Because of mature commercial market, corn-grain ethanol is a major player in the U.S. biofuels industry. In 2014, 208 corn-grain ethanol BRs produced over 14 billion gallons of ethanol in the United States. Due to similar performance and lower lifecycle GHG emissions compared to petro-based diesel, biodiesel production totaled approximately 1.27 billion gallons with the United States in 2014 (EIA, 2015). Driven by increased pressure from the “food-versus-fuel” debate, cellulosic biofuels and algae biofuels, have gained momentum to enter the U.S. biofuels industry (Schnepf, 2010). For cellulosic biofuels, forty BRs are under construction or in progress by the end of 2015. For algae biofuels, four BRs have been identified through secondary source.

Compared to corn ethanol, cellulosic biofuels have several advantages in terms of the use of non-food based feedstocks and lower lifecycle greenhouse gas (GHG) emissions (Balan, Chiaramonti, & Kumar, 2013; FitzPatrick et al., 2010). However, cellulosic BRs industry has yet to become widely commercialized (Coyle, 2010; Pacini, Sanches-Pereira, Durleva, Kane, & Bhutani, 2014). By the end of 2015, five cellulosic biofuel BRs have achieved commercial-scale

**Integrated cellulosic biorefineries**

Integrated BRs, defined by Department of Energy, Office of Energy Efficiency & Renewable Energy, are facilities employing various sorts of feedstock and conversion technologies to produce a variety of products. Potential value stream outputs from the U.S. integrated cellulosic BRs include biofuels and bio-based products, such as cellulosic sugars and/or bio-based chemicals (Figure 2-2).

Cellulosic biofuels include cellulosic ethanol, butanol, synthetic diesel, bio-Dimethyl Ether (DME), bio-Synthetic Natural Gas (SNG), and other hydrocarbon-based biofuels (Balan et al., 2013; Naik et al., 2010).

Cellulosic sugar is an important intermediate from cellulosic BRs. Pretreatment and hydrolysis processes are used to separate cellulose and hemicellulose from lignin, and these carbohydrates are further converted into an intermediate sugar stream with the introduction of enzyme (Yue, You, & Snyder, 2014). In Sept. 2011, Biofuelsdigest.com mentioned that some companies, including Proterro, Renmatix, Comet Biorefining, and Virdia (originally known as HCL Cleantech), provided low-cost cellulosic sugars to companies (e.g. Amyris, Solazyme, LS9 and others) for the production of advanced biofuels and chemicals (Lane, 2011). In January 2015, Edeniq (a biorefining and cellulosic technology company) secures $16 million in funding for cellulosic sugar production. As stated by Brian Thome, President and CEO of Edeniq, “Edeniq is committed to delivering low capital, highly operable solutions to biofuel and biochemical producers. Low cost sugars are a key enabler for next generation biofuel and biochemical producers in need of affordable feedstock”.

Bio-based chemicals are also potential products from cellulosic biorefineries. Bio-based chemicals were defined as “platform and intermediate chemicals derived from biomass feedstock and used to produce other chemicals” (de Jong, 2012). High value, lower volume bio-based chemicals can provide incentive to commercialize cellulosic biofuels (Bozell & Petersen, 2010).
Introduction to Bio-based Chemicals

Around 7-8% of oil imports in the U.S. are converted to petrochemicals (Bozell & Petersen, 2010). However, rising concerns over depleting fossil fuel reserves and increasing consumer demand for environmentally friendly products are collectively driving society towards bio-based chemicals converted from renewable carbon sources (Energy Information Administration, 2014; ICIS, 2013; Welle, 2012). Meanwhile, the boost in natural gas production in the U.S. has reduced the supply of three-carbon and four-carbon molecule platform chemicals (e.g. propylene and butylene), which were originally produced from naphtha cracking (De Guzman, 2016; Welle, 2012).

Bio-based chemicals represented around 4% of U.S. chemical production in 2014 (Jay S Golden, Handfield, Daystar, & McConnell, 2015) and is forecasted to account for at least 45 percent of all U.S. chemicals by 2025 (Bardhan, Gupta, Gorman, & Haider, 2015). According to a 2014 USDA report, the U.S. production of bio-based chemicals could generate $775 million in added value by 2017, and $3 billion per year by 2022 (Nexant, 2014). The emerging biochemical industry may also contribute to the U.S. rural economy by providing 3,500 jobs in 2017 and 19,000 in 2022 (Nexant, 2014).

The growth of this industry is partially due to government supports. For example, EPA has enacted a Green Chemistry Program to reduce toxicity and to cut greenhouse gas emissions (Environmental Protection Agency, 2016). The 2014 Farm Bill allowed companies that produce polymers, plastics or other chemical substances from renewable biomass to qualify loan guarantees under the Biorefinery Assistance Program (Erickson, 2014; USDA, 2014). Also, the Biobased Markets Program is another indicator of the governmental preference for the procurement of biobased products (Schweiker, 2014). Supported by these U.S. government incentives and policies, financing for renewable chemicals companies has been US-focused; as of 2014, the Americas accounted for 87% of the global venture capital funding for bio-based chemicals (De Guzman, 2016).

Previous research

Because of the economic and societal benefits, bio-based chemicals from the first generation and second generation feedstocks are experiencing greater research and development
interests (Maity, 2015). The first generation feedstock mainly includes corn, wheat, soybeans, sugarcane, as well as sugar beet, and the second generation feedstock refers to forest biomass, agricultural residues, perennial grasses, short rotation woody crops, and municipal solid waste (MSW). In 2004, the U.S. Department of Energy (DOE) identified a list of twelve chemicals from renewable carbohydrates based on two criteria: potential markets as building blocks and technical complexity of synthetic pathways (Maity, 2015; Werpy et al., 2004). The development of bio-based chemicals and products progressed significantly since 2004 (Maity, 2015). Based on similar criteria used in the 2004 report and recent trends of bio-based chemicals, Bozell and Petersen (2010) provided an updated group of “Top 10+4” platform chemicals. Figure 2-3 summarizes the production process of these identified top platform chemicals.

**Current projects in the U.S. bio-based chemicals industry**

Evaluation of recent technology and projections for future growth are relatively easy; however, development and production of the platform chemicals from renewable biomass on a commercial scale are much harder (Bozell & Petersen, 2010). An attempt was thus made in the present article to identify existing and proposed projects in the U.S. bio-based chemicals industry. As of August 2016, this study identified thirty-five companies producing twenty bio-based chemicals, which are organized by their carbon number, i.e. C3 to Cn (Table 2-1). These thirty-five firms can be categorized into three major groups, including “Chemical Giants”, “Biochemical Start-Ups”, and “Agricultural Giants” (Table 2-1).

**A Summary of Factors Affecting the Scale-up of Cellulosic Biofuels and Integrated Cellulosic Biorefineries**

The effort to investigate factors affecting cellulosic biofuels commercialization is justified by the importance and relevance of the limitation on fossil fuels, greenhouse gas emissions, and the “food-vs.-fuel” debate. By reviewing existing literature related to bio-based economy, bioenergy, advanced biofuels, and biofuel biorefineries, we developed a list of theoretical drivers for and barriers to the commercialization of cellulosic biofuels (Table 2-2).
A Summary of Buyer-Supplier Relationships

Buyer-supplier relationships have been significantly emphasized by existing literature. Wilson (1995) indicated that strengthened relationship with suppliers could provide buyers with increased quality, reduced inventory and decreased time to market. Meanwhile, information sharing can speed up flows and lower tied-up capital (Zineldin & Jonsson, 2000).

Within the biofuels industry, several companies are co-located to have access to feedstock supply (Solecki, Dougherty, & Epstein, 2013). For example, BioProcess Algae is co-located with a Green Plains’ ethanol plant in Shenandoah in order to have access to resources (e.g. CO₂ and waste heat) (Bioprocessalgae, 2014). Also, biofuel suppliers are forming purchase agreements with downstream customers. Cellana and Neste Oil signed a multi-year, commercial-scale off-take agreement for algae oil feedstock for biofuels (Cellana, 2014). Alaska Airlines will buy 1,000 gallons of Gevo’s alcohol-based jet fuel for commercial flights in 2016. On January 2016, AltAir prepared 1.34 million gallons of F-76 types Naval Distillate Fuel for the U.S. Navy’s Great Green Fleet. AltAir is leveraging purchase agreements with United for up to 15 million gallons of sustainable aviation biofuel over a three-year period (Lane, 2016).

In the following section, this study’s researcher will review three major aspects related to supplier-customer relationships: 1) the types of supplier-customer relationships, 2) key variables characterizing relationships, and 3) supply management strategies. This overview will provide researchers with a theoretical lens to investigate and explore buyer-supplier relationships within the U.S. biofuels industry (Dyer & Singh, 1998; Wagner, Eggert, & Lindemann, 2010).

The types of buyer-supplier relationships

Webster Jr (1992) provided researchers with a distinction among types of relationships and outlined the range of marketing relationships as a continuum from discrete transactions to vertical integrations (Figure 2-4).

At the beginning of the continuum of business relationships, discrete transactions are monetary exchanges, and both seller and buyer attempt to achieve maximum profitability. Each exchange is independent of all other events, since price, established by the marketplace, is the only factor guiding transaction (Fontenot & Wilson, 1997). In this context, a simple transaction is
a one-time exchange of value with no prior or anticipated future interaction between seller and buyer. In addition, there is no brand name, no brand preferences, or product differentiation (Webster Jr, 1992). In reality, pure discrete transactions are rare; instead, most business transactions exhibit more relational activities, such as advertising and sales promotion. The goal of these relational activities is to gain customer’s preference and loyalty for repeated purchase over time, thus gaining higher prices and greater profits (Webster Jr, 1992).

As marketing relationship evolves to a long-term relationship, prices are negotiated by sellers and buyers and are determined by the marketplace, quality, delivery, and technical support (Webster Jr, 1992). As a result, long-term buyer-seller relationship is characterized by mutual dependence and trust (Ganesan, 1994). However, long-term relationships probably involve some adversarial behavior as both parties attempt to achieve best economic position and are dependent on market control (Fontenot & Wilson, 1997). When firms form buyer-seller partnerships, firms show strong mutual dependence and experienced mutual benefits, such as cost savings and production efficiencies (Fontenot & Wilson, 1997). As the marketing relationship continues to evolve, firms will form strategic alliance, when “two or more independent firms pursue a mutually beneficial goal or shared vision that would be difficult to achieve alone” (Spekman, Isabella, MacAvoy, & Forbes, 1996). Consequently, strategic alliance, different from previous forms of inter-organizational cooperation, is characterized by shared objectives and commitment of resources by both parties (Webster Jr, 1992). A network organization is a complex and multifaceted organizational structure, which is a combination of strategic alliances, divisions, subsidiaries, and value-added re-sellers (Webster Jr, 1992). And the ultimate marketing relationship is vertical integration (Webster Jr, 1992).

Long-term vs. Short-term

Business relationships have been moving from short-term transactional relationships toward long-term collaborative relationships because strengthened relationships make it possible to share information and cooperate in the process of value creation (Lostakova & Pecinova, 2014; Webster Jr, 1992). Revolutionary technologically innovative products are associated with short-term opportunistic relationships, whereas evolutionary technologically innovative products should provide the impetus for long-term relationships instead of short-term opportunistic relationship (Low, 1996). Aase (2013) interviewed 14 managers of wood industry and indicated
that wood industry buyer-chemical supplier relationships are long term because supplier changes often cause high transaction costs.

**Contractual vs. Non-contractual**

As indicated by several researchers, another commonly applied classification of the type of relationships is contractual versus non-contractual (Macaulay, 1963). Contractual, defined by Macaulay (1963), is 1) “relational planning of the transaction with careful provision for as many as future contingencies as can be foreseen”, and 2) “the existence or use of actual or potential legal sanctions to induce performance of the exchange or to compensate for non-performance.”

The use of contract is beneficial to creating exchange relations and settling the dispute. Also, formal contractual relationships can reduce the changes of uncertainty and opportunism by both parties (Carson, Madhok, & Wu, 2006). Cannon & Perreault (1999) sampled more than 400 buyer-seller relationships from a wide array of industries and market situations and developed a classification of different types of business relationships. Among eight types of business relationships, the contractual transaction is formalized by a legal contract and characterized by minimal cooperation, interaction, and linkage (Cannon & Perreault Jr, 1999). On the other hand, by interviewing 68 businessmen and lawyers in manufacturing industry, former researcher found that in most situations contract is not needed, and often its functions are served by other devices, such as a standardized product with description or specification (Macaulay, 1963). More recently, Aase (2013) found that relationships in the U.S. and Europe wood industry are commonly based on trust and handshake agreement; formal contracts do exist in the U.S. market, but they are often short term.

**Variables characterizing buyer-supplier relationships**

Variable characterizing buyer-supplier relationships are well documented and include commitment/propensity to leave, trust, cooperation, dependence/power, communication, functional conflict, relationship-specific investment/nonretrievable investments, shared values/mutual goals, relationship termination costs, opportunistic behavior, and adaption (Anderson & Narus, 1990; De Ruyter, Moorman, & Lemmink, 2001; Fontenot & Wilson, 1997;
In the following section, these fifteen variables will be briefly discussed.

**Commitment** is an important variable in determining successful relationships (De Ruyter et al., 2001; Wilson, 1995). According to Fontenot & Wilson (1997), commitment is the motivation to stay with a valuable supplier or customer, and the willingness to invest time, effort and resources to the relationship. Meanwhile, commitment is negatively related to **propensity to leave**, which indicates one’s expectation that they may soon exit the relationship (Fontenot & Wilson, 1997). The higher the motivation to maintain the relationship, the larger the probability that the quality of the relationship will increase (Parsons, 2002). Morgan & Hunt (1994) explored the nature of relationship marketing and concluded that commitment lead directly to effective cooperation that is conducive to relationship marketing success.

**Trust** is central and fundamental to relationship model and refers to the confidence in relationship partners’ reliability and integrity. Specifically, trust is the belief that their counterpart in the relationship will perform expected actions that will result in positive outcomes (Anderson & Narus, 1990; Morgan & Hunt, 1994). Trust is a multidimensional construct and plays a significant role in long-term partnership (Anderson & Narus, 1990; Ganesan, 1994; Ganesan & Hess, 1997; Mohr & Spekman, 1994). Two dimensions of trust, including credibility and benevolence, have been included in several studies (Ganesan, 1994; Mayer, Davis, & Schoorman, 1995).

**Cooperation** is defined as coordinated, joint efforts taken by firms in interdependent relationships to achieve mutual goals or singular goals with expected reciprocation over time (Anderson & Narus, 1990). Anderson and Narus (1990) implied that cooperation is an antecedent rather than a consequence of trust. On the other hand, Morgan & Hunt (1994) proposed that cooperation arises directly from commitment and trust.

**Dependence** is an important variable. Dependence occurs when one partner cannot obtain the same resources and outcomes from the alternative relationship (De Ruyter et al., 2001). In the relationship marketing literature, researchers showed that the more dependent one party is on the other, the larger desire that party will develop a strong, collaborative long-term relationship with its counterpart (De Ruyter et al., 2001). Dependence is highly correlated with **power**, which is the ability to influence the decisions or actions of the others (Fontenot & Wilson, 1997). Scholars have indicated that mutual dependence or interdependence would result in collaborative relationships while power/dependence imbalance would lead to competitive relationships (Rinehart et al., 2004).
Communication can be “defined broadly as the formal as well as informal sharing of meaningful and timely information between firms” (Anderson & Narus, 1990). Communication captures the efficacy of the information exchanged (Mohr & Spekman, 1994). Past communication is the antecedent of trust while the accumulated trust leads to meaningful future communication (Morgan & Hunt, 1994). Communication in a buyer-seller relationship, therefore, focuses on communication quality (such as accuracy, timeliness, and credibility), the extent of proprietary information sharing between partners and joint planning (Mohr & Spekman, 1994).

Functional conflict is beneficial to the establishment and maintenance of long-term relationships (Claycomb & Frankwick, 2010). Functional conflict refers to relationship partners’ conflict resolution mechanisms, which may result in “productive discussion”, mutually satisfactory solution and, thus, successful partnership (Anderson & Narus, 1990; Claycomb & Frankwick, 2010; Mohr & Spekman, 1994). Former researchers indicated that firms that have developed strong trust in a relationship are more likely to develop amicable conflict resolution techniques (Anderson & Narus, 1990; Dwyer, Schurr, & Oh, 1987). These productive conflict resolution mechanisms include joint problem solving, persuasion and smoothing (Mohr & Spekman, 1994). Other researchers also indicate that resolving conflicts may strengthen inter-organizational relationships and lead to greater trust and commitment (De Ruyter et al., 2001; Gundlach, Achrol, & Mentzer, 1995).

Relationship-specific investments/nonretrievable investments are resources committed to the dyadic relationships, such as time, money, facilities, training, and equipment (Rinehart et al., 2004; Wilson, 1995). These resources are often referred to as “asset specific resources” (Dyer, 1996), and are difficult to switch to another relationship (Morgan & Hunt, 1994). Several researchers have demonstrated a positive correlation between relation-specific investments and increased commitment and trust, which lead to long-term relationships (De Ruyter et al., 2001; Dyer, 1996; Ganesan, 1994; Rinehart et al., 2004).

Shared values are the extent to which partners have beliefs in common about the importance, appropriateness of certain behaviors, goals, and policies (Fontenot & Wilson, 1997; Morgan & Hunt, 1994). Morgan & Hunt (1994) posited that shared values among exchange partners would lead to greater commitment to the relationship. This idea is further confirmed by later researchers, such as Wilson (1995) and Fontenot & Wilson (1997). Wilson (1995) also defined a similar but narrower concept, mutual goals as “the degree to which partners share goals that can only be accomplished through joint action and the maintenance of the relationship.”
**Relationship termination cost** is a common term in the relationship marketing literature and is generated when a terminated party seeks an alternative relationship (Morgan & Hunt, 1994). Relationship termination cost is investments that are difficult to switch to another relationship and switching costs will lead to dependence. Buyers anticipating high switching costs are more likely to remain in current relationship (Fontenot & Wilson, 1997). Also, termination costs are all expected losses from termination and result from the perceived lack of comparable potential alternative partners (Morgan & Hunt, 1994).

**Opportunistic behaviors** are negatively related with trust and commitment (Fontenot & Wilson, 1997). When a party believes that a partner engages in opportunistic behavior, such perceptions will lead to decreased trust.

**Adaption** happens when one party in a relationship alters its processes or the product exchanged to accommodate the other party (Wilson, 1995). Adaption behavior will vary over the continuum of the relationship. In the early stages adaption will help develop trust, and in the mature stage it will expand and solidify the relationship (Wilson, 1995).

**Relationship Management**

Relationship management is critical to meeting an organization’s ultimate goals of financial performance and competitive advantage (Carr & Pearson, 1999; J. R. Carter, 2006). Carter (2006) suggested that relationship management is an integrated set of business activities. Fontenot and Wilson (1997) summarized a list of eleven relationship activities which were empirically tested by Wilson and Vlosky (1997). These relationship activities including new product development programs, pricing, logistics, dealer promotion, advertising, salesforce activities, marketing planning, performance reviews, manufacturing, communication, and information exchange. More recently, existing literature has found that activities to better understand buyer’s need and generate a good performance will help the supplier gain buyer’s trust and loyalty (Monczka, Handfield, Giunipero, & Patterson, 2015).

Overall, regardless the broad range of research on buyer-supplier relationships, limited research has been identified to focus on attributes characterizing and strategies strengthening the relationships within the U.S. biofuels industry.
(i) U.S. corn-grain ethanol biorefineries (N=208)

(ii) U.S. biodiesel biorefineries (N=162)

(iii) U.S. cellulosic biofuel biorefineries (N=40)

(iv) U.S. algae biofuel biorefineries (N=4)

Figure 2-1. Maps of the U.S. biofuels biorefineries.
Figure 2-2. Value chains of integrated cellulosic biorefineries.
Figure 2-3. Process flow of bio-based chemicals from renewable carbon sources.

(Bozell & Petersen, 2010; Jay S Golden et al., 2015; Werpy et al., 2004)
Figure 2-4. The range of marketing relationships.

(Webster Jr, 1992)
<table>
<thead>
<tr>
<th>Bio-based Chemicals</th>
<th>Companies (n=35)</th>
<th>Headquarters</th>
<th>Company Type</th>
<th>Conversion Technique</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acrylic acid</td>
<td>Blue Marble Biomaterials</td>
<td>Missoula, MT</td>
<td>Biochemical start-up</td>
<td>Polyculture fermentation system</td>
</tr>
<tr>
<td></td>
<td>Cargill, Incorporated</td>
<td>Wayzata, MN</td>
<td>Agricultural giant</td>
<td>Acquired OPXBio’s EDGE™ bioengineering technology</td>
</tr>
<tr>
<td></td>
<td>SGA Polymers, LLC</td>
<td>South Charleston, WV</td>
<td>Biochemical start-up</td>
<td>Converts lactic acid from carbohydrates into acrylic acid</td>
</tr>
<tr>
<td></td>
<td>Blue Marble Biomaterials</td>
<td>Missoula, MT</td>
<td>Biochemical start-up</td>
<td>Polyculture fermentation system</td>
</tr>
<tr>
<td></td>
<td>DuPont Industrial Biosciences</td>
<td>Itasca, IL</td>
<td>Chemical giant</td>
<td>DuPont™ GENECOR® fermentation system</td>
</tr>
<tr>
<td></td>
<td>GlycosBio Biotechnologies Inc.</td>
<td>Houston, TX</td>
<td>Biochemical start-up</td>
<td>Metabolic engineering and fermentation</td>
</tr>
<tr>
<td></td>
<td>Myriant Corporation</td>
<td>Woburn, MA</td>
<td>Chemical giant</td>
<td>Single step, anaerobic fermentation with engineered microorganisms and catalytic upgrading</td>
</tr>
<tr>
<td></td>
<td>DuPont Tate &amp; Lyle Bio Products Company, LLC</td>
<td>Loudon, TN</td>
<td>Chemical giant</td>
<td>Convert corn glucose to Bio-PDO™ via fermentation</td>
</tr>
<tr>
<td></td>
<td>Butamax Advanced Biofuels LLC</td>
<td>Wilmington, DE</td>
<td>Biochemical start-up</td>
<td>Butamax™ technology is designed to convert the sugars from various biomass feedstocks, including</td>
</tr>
<tr>
<td></td>
<td>Company Name</td>
<td>Location</td>
<td>Process Description</td>
<td></td>
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<td></td>
<td>Gevo Inc.</td>
<td>Englewood, CO</td>
<td>Biochemical start-up</td>
<td></td>
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<td></td>
<td>Working Bugs, LLC</td>
<td>East Lansing, MI</td>
<td>Biochemical start-up</td>
<td></td>
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<tr>
<td></td>
<td>BioAmber Inc.</td>
<td>Plymouth, MN</td>
<td>Biochemical start-up</td>
<td></td>
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<tr>
<td></td>
<td>Genomatica, Inc.</td>
<td>San Diego, CA</td>
<td>Biochemical start-up</td>
<td></td>
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<tr>
<td></td>
<td>Myriant Corporation</td>
<td>Woburn, MA</td>
<td>Chemical giant</td>
<td></td>
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<td></td>
<td>Furans</td>
<td>West Sacramento, CA</td>
<td>Biochemical start-up</td>
<td></td>
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<tr>
<td></td>
<td>Micromidas Inc.</td>
<td>West Sacramento, CA</td>
<td>Biochemical start-up</td>
<td></td>
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<tr>
<td></td>
<td>GlycosBio Biotechnologies Inc.</td>
<td>Houston, TX</td>
<td>Biochemical start-up</td>
<td></td>
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<tr>
<td></td>
<td>Yulex Corporation</td>
<td>Chandler, AZ</td>
<td>Biochemical start-up</td>
<td></td>
</tr>
</tbody>
</table>

- **Corn and Sugarcane**: Production of biobutanol using existing biofuel production facilities.
- **Isobutanol**: Production of isobutanol by using an integrated strategy of biological and chemical processes.
- **Succinic acid & 1,4-butanediol (BDO)**: Industrial biotechnology and chemical catalysis.
- **Integrated biotechnology platform**: Single step, anaerobic fermentation with engineered microorganisms and catalytic upgrading.
- **Single step, anaerobic fermentation with engineered microorganisms and catalytic upgrading**: Use a non-fermentation, non-gasification, chemical-only process.
- **C5 Isoprene**: Metabolic engineering and fermentation.
- **Purifying process to remove over 99.9% of natural rubber harmful impurities**:
<table>
<thead>
<tr>
<th>Cn</th>
<th>Cellulose &amp; Cellulose acetate (CA)</th>
<th>Cellulose acetate is derived from cellulose by deconstructing wood pulp into a purified fluffy white cellulose</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,6-hexanediol (1,6-HDO)</td>
<td>Rennovia Inc.</td>
<td>Biochemical start-up</td>
</tr>
<tr>
<td></td>
<td>Santa Clara, CA</td>
<td>Chemical catalytic process technology</td>
</tr>
<tr>
<td>Adipic acid</td>
<td>Rennovia Inc.</td>
<td>Biochemical start-up</td>
</tr>
<tr>
<td></td>
<td>Santa Clara, CA</td>
<td>Chemical catalytic process technology</td>
</tr>
<tr>
<td></td>
<td>Verdezyne Inc.</td>
<td>Biochemical start-up</td>
</tr>
<tr>
<td></td>
<td>Carlsbad, CA</td>
<td>Fermentation</td>
</tr>
<tr>
<td>Glucaric acid</td>
<td>Rennovia Inc.</td>
<td>Biochemical start-up</td>
</tr>
<tr>
<td></td>
<td>Santa Clara, CA</td>
<td>Chemical catalytic process technology</td>
</tr>
<tr>
<td></td>
<td>Rivertop Renewables, Inc.</td>
<td>Biochemical start-up</td>
</tr>
<tr>
<td></td>
<td>Missoula, MT</td>
<td>Novel Chemistry™ approach produces glucaric acid and other chemicals for consumer and industrial applications</td>
</tr>
<tr>
<td>Hexamethylenediamine (HMD)</td>
<td>Rennovia Inc.</td>
<td>Biochemical start-up</td>
</tr>
<tr>
<td></td>
<td>Santa Clara, CA</td>
<td>Chemical catalytic process technology</td>
</tr>
<tr>
<td>Benzene</td>
<td>Anellotech Inc.</td>
<td>Biochemical start-up</td>
</tr>
<tr>
<td></td>
<td>Pearl River, NY</td>
<td>Thermo Catalytic Biomass Conversion (Bio-TCAT™) to produce a mixture of benzene, toluene, and xylenes (bio-BTX)</td>
</tr>
<tr>
<td>Cn</td>
<td>Cellulose acetate LLC</td>
<td>Biochemical start-up</td>
</tr>
<tr>
<td></td>
<td>Dallas, TX</td>
<td>Chemical giant</td>
</tr>
<tr>
<td>Eastman Chemical Company</td>
<td>Kingsport, TN</td>
<td>Chemical giant</td>
</tr>
<tr>
<td>Innovia Films</td>
<td>Atlanta, GA</td>
<td>Chemical giant</td>
</tr>
<tr>
<td>Rotuba Extruders</td>
<td>Linden, NJ</td>
<td>Biochemical start-up</td>
</tr>
<tr>
<td>Product Type</td>
<td>Company/Group</td>
<td>Location</td>
</tr>
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<td>------------------------------</td>
<td>----------------------------------------------------</td>
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</tr>
<tr>
<td>Polyamides (PA)</td>
<td>Arizona Chemical Company, LLC</td>
<td>Jacksonville, FL</td>
</tr>
<tr>
<td></td>
<td>Arkema</td>
<td>King of Prussia, PA</td>
</tr>
<tr>
<td>Polyethylene terephthalate (PET)</td>
<td>Toray Plastic (America), Inc.</td>
<td>North Kingstown, RI</td>
</tr>
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<td></td>
<td>Arkema</td>
<td>King of Prussia, PA</td>
</tr>
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<td>Polyhydroxyalkanoates (PHAs)</td>
<td>Meredian Holdings Groups (MHG)</td>
<td>Bainbridge, GA</td>
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<td></td>
<td>Metabolix Inc.</td>
<td>Lowell, MA</td>
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<td></td>
<td>Newlight Technologies LLC</td>
<td>Costa Mesa, CA</td>
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<td>Polylactic acid (PLA)</td>
<td>Corbion</td>
<td>Lenexa, KS</td>
</tr>
<tr>
<td></td>
<td>NatureWorks LLC</td>
<td>Minnetonka, MN</td>
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<td></td>
<td>PolyOne Corporation</td>
<td>Avon Lake, OH</td>
</tr>
<tr>
<td>Starch blends</td>
<td>StarchTech Inc.</td>
<td>Minneapolis, MN</td>
</tr>
<tr>
<td></td>
<td>Teknor Apex</td>
<td>Pawtucket, RI</td>
</tr>
<tr>
<td></td>
<td>Trellis Bioplastics</td>
<td>Seymour, IN</td>
</tr>
</tbody>
</table>
Table 2-2. Drivers for and barriers to the commercialization of cellulosic biofuels from existing literature.

<table>
<thead>
<tr>
<th>Drivers (n=8)</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>5. Rural economic development</td>
<td>(Cherubini, 2010) (Dale et al., 2014) (Ebadian et al., 2013)</td>
</tr>
<tr>
<td>7. Energy security</td>
<td>(Dale et al., 2014) (Ebadian et al., 2013) (Hughes, Moser, &amp; Gibbons, 2014)</td>
</tr>
<tr>
<td>8. Added value from non-fuel co-products</td>
<td>(Bozell &amp; Petersen, 2010) (de Jong, 2012) (Yue et al., 2014)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Barriers (n=9)</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Feedstock costs</td>
<td>(Adams et al., 2011) (Yue et al., 2014) (Zhao et al., 2015)</td>
</tr>
<tr>
<td>3. Technology availability</td>
<td>(Cherubini &amp; Strømman, 2011) (Dale et al., 2014) (Pacini et al., 2014) (Sharma et al., 2013)</td>
</tr>
<tr>
<td>4. Competition vs. corn-grain ethanol</td>
<td>(Babcock, Marette, &amp; Tréguer, 2011) (Sims, Taylor, Saddler, &amp; Mabee, 2008)</td>
</tr>
<tr>
<td>5. Competition vs. petro-fuels</td>
<td>(Dale et al., 2014) (Sims et al., 2008)</td>
</tr>
<tr>
<td>6. Policy uncertainty</td>
<td>(Adams et al., 2011) (You et al., 2012) (Zhao et al., 2015)</td>
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<tr>
<td></td>
<td>Reason for Industry Lower Productivity</td>
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<tr>
<td>7.</td>
<td>High production costs</td>
</tr>
<tr>
<td></td>
<td>(Carole, Pellegrino, &amp; Paster, 2004)</td>
</tr>
<tr>
<td></td>
<td>(Cherubini, 2010)</td>
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<td></td>
<td>(Coyle, 2010)</td>
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<td></td>
<td>(Yue et al., 2014)</td>
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<td>8.</td>
<td>Capital availability</td>
</tr>
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<td></td>
<td>(Adams et al., 2011)</td>
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<td></td>
<td>(de Jong, 2012)</td>
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<td></td>
<td>(FitzPatrick et al., 2010)</td>
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<td></td>
<td>(Pacini et al., 2014)</td>
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<td></td>
<td>(Welle, 2012)</td>
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<td>9.</td>
<td>Cellulosic biofuel logistics</td>
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<td></td>
<td>(S. Kim &amp; Dale, 2015)</td>
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References


CHAPTER 3

RESEARCH METHODOLOGY

This chapter was written to provide a better understanding of the data collection and analysis methodology used in this study.


**Research Design**

Figure 3-1 depicts the research plan of this proposed study, which consists of three major phases. Phase I included identification of population and key issues via literature review. Phase II – Integrated Cellulosic Biorefinery is a mixed methods design (Creswell & Clark, 2011). This study’s researcher first conducted a pilot qualitative study (online survey) to develop constructs for the follow-up quantitative data collection instrument. As a result, the quantitative paper- and online-based surveys build on the qualitative one. Phase III – Buyer-Supplier Relationships is an explanatory design, which involves in-depth personal interviews with select industrial experts. Personal interview gives the participant the feelings of being the focus of attention, and interviewers can probe at length to reveal feelings and motivations that underlie statements of respondent (McDaniel & Gates, 2004).

**Phase I – Population identification**

A wide variety of secondary information sources regarding bioenergy, biofuel, and biorefinery have been selected and critically assessed. Those information sources included government organizations, industrial associations, magazines, and academic and trade journals as listed in Table 3-1.

**Phase II – Integrated cellulosic biorefinery**

**Pilot qualitative study**

**The pool of experts.** Nonprobability purposive sampling method was employed to reach a targeted sample quickly and to ensure the assembling of a sample with known or demonstrable experience and expertise in the U.S. bioenergy, biofuel, and bio-based products areas (Trochim, 2000). Eighteen experts from universities, national labs, and the industrial sector were identified through exploratory documentary analysis and internet searches.
University and industrial experts were identified by searching recent publications (2010 to 2015) via google scholar with the following four key words: advanced biofuels, cellulosic biofuels, second generation biofuels, and integrated biorefinery. The ten most cited articles for each key word were used to identify “experts”. Overall, the forty selected articles were published in the following peer-reviewed journals, including AIChE Journal, Biofuels, Bioprocessing and Biorefining (Biofpr), Biomass & Bioenergy, Bioresource Technology, Biotechnology and Bioengineering, Chemical Engineering Journal, Chemical Engineering Research and Design, Energy Policy, Energy & Environmental Science, Environmental Science & Technology, Fuel, Green Chemistry, Renewable Energy, and Renewable & Sustainable Energy Reviews. Of the forty articles, only the corresponding authors were included in our sample frame resulting in forty identified experts who received our qualitative e-Survey. Ten university experts and five industrial experts participated in this pilot study, resulting in a response rate of 37.5 percent (15/40).

Government experts were identified from the four U.S. national labs devoted to research and development of renewable liquid transportation fuels: (1) the Forest Products Laboratory in Madison, WI; (2) the National Renewable Energy Laboratory in Golden, CO; (3) the Oak Ridge National Laboratory in Oak Ridge, TN; and (4) the Pacific Northwest National Laboratory in Richland, WA. Experts from three of the four (75%) national labs participated in the pilot study.

**Construct measurement and data collection.** The data for this pilot study was obtained from an online survey (e-Survey) from June to July 2015 via SurveyMonkey® to decrease time and costs and to provide access to geographically dispersed subjects (Burns, 2010; James, 2007). A three-email strategy was applied for online data collection. The first email included an embedded URL link to a SurveyMonkey® website (Appendix A), followed by two reminder emails at one-week intervals (Dillman, Smith, & Christian, 2014). The e-Survey instrument consisted of several open-ended questions designed to address the following topics: 1) barriers to the integrated production of bio-based chemicals and cellulosic biofuels; and 2) potential solutions to those identified barriers (Appendix B).

**Thematic analysis.** Thematic analysis is a process for encoding qualitative information (Boyatzis, 1998). The coding of a text’s meaning into categories made it possible to quantify how often specific themes were addressed in a text, and the frequency of themes could then be compared and correlated with other measures (Kvale, 2007). By categorization, the meaning of long statements is reduced to a few simple categories. This method simplifies understanding of the phenomena under study and also signals the most significant dimensions which respondents
touched-upon (García-Maroto, Muñoz-Leiva, & Rey-Pino, 2014). The categories can be developed in advance or they can arise ad hoc during the analysis. Specifically, theory driven, prior data or prior research driven, and inductive (i.e., from the raw data) or data driven are three different ways to develop categories or thematic codes (Boyatzis, 1998). In this particular case, inductive or data driven was adopted to develop categories or thematic codes. A condensation and clustering of the main themes was drawn up. This allowed this study’s researcher to take a quantitative approach to the main points of interest, based on the frequency of the clustered themes.

**Quantitative paper- and online-based surveys**

**Study population.** The data was collected from July to November 2015. The sample population was obtained from the registration lists of the 2015 annual meetings of seven USDA) National Institute of Food and Agriculture (NIFA) Coordinated Agricultural Projects (CAPs) (Table 3-2 & Figure 3-2) (National Institute of Food and Agriculture (NIFA), 2015). “NIFA has invested $156 million in seven five-year projects across the U.S. to assist with research and development for regionally-based advanced biofuel and bioproduct industries” (National Institute of Food and Agriculture (NIFA), 2015). To balance industrial expert group representation, attendees to the following two industrial conferences were added to our population; the 2015 National Advanced Biofuel Conference & Expo (NABC&E) and the 12th Advanced Bioeconomy Leadership Conference (ABLC) (Table 3-2 & Figure 3-2). NABC&E provides a vertically integrated venue for “industry professionals engaged in producing, developing and deploying advanced biofuels, cellulosic biofuels, biobased platform chemicals, and biopolymers” (http://www.advancedbiofuelsconference.com/ema/DisplayPage.aspx?pageId=The_Conference__Expo). The ABLC provides a venue to gather senior leadership in the advanced bioeconomy focusing on advanced low carbon fuels, chemicals, and materials, plus advanced policies and financing strategies (http://advancedbiofuelssummit.com/). In this sense, the samples analyzed in the paper are non-probability convenience samples. Overall, these seven CAP programs and two industrial conferences represent a unique set of knowledge and experience on all aspects of the biorefinery supply chains (Figure 3-3).

**Construct measurement and data collection.** The semi-structured survey instrument consisted of RATING questions designed to 1) examine the importance/degree of the eight
drivers and nine barriers identified from literature to the commercialization of cellulosic biofuels; and 2) to evaluate the degree of the eight barriers identified from pilot qualitative study to the integrated production of both cellulosic biofuels and biochemical (Appendix C). Follow-up RANKING questions delineated the top three barriers in a meaningful and interpretable way (Dillman et al., 2014) (Appendix C). The RANKING questions were designed to force differences which may not have been produced in the RATING questions.

Administration of the quantitative surveys included paper-based surveys and online surveys (e-Surveys) following each AFRI CAP annual meeting and industrial conference to increase responses. A three-email strategy was also deployed for the online surveys (Dillman et al., 2014). Data collection efforts resulted in 228 respondents, and the overall response rate was approximately 34% (228/678) (Table 3-2).

Nonresponse bias. To assess non-response bias, those who responded to the initial onsite paper-based surveys (early respondents; n=147) were compared to those who responded after follow-up steps were taken (e-Survey) (late respondents; n=89) across a number of survey questions with analysis of variance (ANOVA). The late respondents were generally to behave more like non-respondents so late responders can be used as a proxy for non-respondents (Armstrong & Overton, 1977; Miller & Smith, 1983; TRC, 2009; Welch & Barlau, 2013). The variables used for this comparison are years of experience, the importance of government policies as a driver for the scale-up of cellulosic biofuels, the degree of competition vs. petro-fuels as a barrier to the scale-up of cellulosic biofuels, the degree of competition vs. petro-chemicals as a barrier to the integrated production of cellulosic biofuels and biochemicals, and the likelihood of success for the scale-up of cellulosic biofuels by 2020. The ANOVA indicated that with 95% confidence interval, no significant differences were found between early and late respondents on their mean years of experience, perceptions of the importance/degree of drivers and barriers, and likelihood of success for cellulosic biofuels. Therefore, concerns of non-response bias may be set aside.

Analysis techniques. The collected quantitative data was analyzed using descriptive statistics, sub-group analysis, analysis of variance (ANOVA), and pair-wise t-test. ANOVA and pair-wise t-test were conducted to examine the difference of perceived drivers and barriers between participant groups (i.e., Feedstock specialists, Processing scientists, Economics/Business experts, and Sustainability analysts).
Phase III – Buyer-supplier relationships

Sample population. The present study adopted a non-probability purposeful sampling technique; three cellulosic ethanol producers at commercial scale participated in this study (response rate = 3 of 5 [60%]) (Table 3-3). The participants were accessed at two industrial conferences: the 5th National Advanced Biofuel Conference & Expo (NABC&E) and the 12th Advanced Bioeconomy Leadership Conference (ABLC).

Data collection procedure. Primary data was collected through semi-structured personal interviews from October to November 2015. Each was audiotape-recorded and transcribed for a more thorough analysis. Interviews ranged from 20 to 45 minutes.

Construction of interview. As standardized questions are a good means of obtaining the same kind of information, interviews were based on a data collection guide with a list of five questions in the same order and with the same wording for all the subjects interviewed (García-Maroto et al., 2014; Kvale, 2007). The interview instrument was designed to address the following three topics: 1) customer types for corn-grain ethanol and cellulosic ethanol; 2) attributes characterizing “best” customers; and 3) strategies to strengthen buyer-supplier relationships (Appendix D).

Thematic analysis was also adopted for analyzing qualitative interview scripts.
Figure 3-1. The research plan of data collection.
Figure 3-2. Locations of the seven USDA-NIFA AFRI CAPs and two industrial conferences.
Figure 3-3. Cellulosic biorefinery supply chain from field/forest to wheel/wing.
Source: (An, Wilhelm, & Searcy, 2011; Hoekman, 2009; Yue, You, & Snyder, 2014)
Table 3-1. Secondary information sources for Phase I – population identification.

<p>| | |</p>
<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Government organizations</td>
<td>U.S. <em>Department of Agriculture</em> (USDA) Forest Products Laboratory; U.S. <em>Department of Energy</em> (DOE) National Renewable Energy Laboratory (NREL) and Bioenergy Technologies Office (BTO); and U.S. <em>Energy Information Administration</em> (EIA)</td>
</tr>
<tr>
<td>Industrial organizations</td>
<td><em>Renewable Fuels Association</em> (RFA) and <em>National Biodiesel Board</em> (NBB)</td>
</tr>
<tr>
<td>Journals &amp; Magazines</td>
<td><em>Ethanol Producer Magazine, Biofuels, Bioproducts and Biorefining</em> (Biofpr), and <em>Biofuelsdigest.com</em></td>
</tr>
</tbody>
</table>
Table 3-2. The profile of the seven USDA coordinated agricultural projects (CAPs) and two industrial conferences for Phase II – quantitative surveys.

<table>
<thead>
<tr>
<th>Regional CAP</th>
<th>Lead University</th>
<th>2015 Annual Meeting Date &amp; Location</th>
<th>Academic researchers (&amp; participants)</th>
<th>Industrial experts (&amp; participants)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advanced Hardwood Biofuels Northwest (AHB)</td>
<td>U of Washington</td>
<td>Sept. 10, Seattle, WA</td>
<td>82 (n=24)</td>
<td>14 (n=5)</td>
</tr>
<tr>
<td>Bioenergy Alliance Network of the Rockies (BANR)</td>
<td>Colorado State U</td>
<td>Oct. 14, Missoula, MT</td>
<td>63 (n=7)</td>
<td>6 (n=1)</td>
</tr>
<tr>
<td>CenUSA Bioenergy</td>
<td>Iowa State U</td>
<td>July 28-29, Madison, WI</td>
<td>57 (n=13)</td>
<td>8 (n=6)</td>
</tr>
<tr>
<td>Southeast Partnership for Integrated Biomass Supply Systems (IBSS)</td>
<td>U of Tennessee</td>
<td>Aug. 10, Auburn, AL</td>
<td>74 (n=26)</td>
<td>6 (n=3)</td>
</tr>
<tr>
<td>Northwest Advanced Renewable Alliance (NARA)</td>
<td>Washington State U</td>
<td>Sept. 15, Spokane, WA</td>
<td>98 (n=47)</td>
<td>22 (n=5)</td>
</tr>
<tr>
<td>The Northeast Woody/Warm-season Biomass Consortium (NEWBio)</td>
<td>Pennsylvania State U</td>
<td>Aug. 3-5, Morgantown, WV</td>
<td>83 (n=52)</td>
<td>6 (n=5)</td>
</tr>
<tr>
<td>Sustainable Bioproduct Initiative (SUBI)</td>
<td>Louisiana State U</td>
<td>Oct. 21, Baton Rouge, LA</td>
<td>54 (n=9)</td>
<td>5 (n=1)</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td></td>
<td></td>
<td><strong>511 (n=178)</strong></td>
<td><strong>67 (n=26)</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Industrial Conference</th>
<th>Organizer</th>
<th>Dates &amp; Location</th>
<th>Academic researchers (&amp; participants)</th>
<th>Industrial experts (&amp; participants)</th>
</tr>
</thead>
<tbody>
<tr>
<td>National Advanced Biofuel Conference &amp; Expo (NABC&amp;E)</td>
<td>BBI International</td>
<td>Oct. 26-28, Omaha, NE</td>
<td>-</td>
<td>40 (n=14)</td>
</tr>
<tr>
<td>The 12th Advanced Bioeconomy Leadership Conference (ABLC)</td>
<td>Biofuels Digest</td>
<td>Nov. 2-5, San Francisco, CA</td>
<td>-</td>
<td>60 (n=10)</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>100 (n=24)</strong></td>
</tr>
</tbody>
</table>
Table 3-3. Profile of three respondents from the U.S. cellulosic biofuel producing companies for Phase III – strategic relationships.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Title</th>
<th>Years of experience</th>
<th>Years of production</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>CEO of corn-grain and cellulosic ethanol company</td>
<td>5</td>
<td>13</td>
</tr>
<tr>
<td>B</td>
<td>CTO of corn-grain and cellulosic ethanol company</td>
<td>9</td>
<td>20</td>
</tr>
<tr>
<td>C</td>
<td>CEO of corn-grain and cellulosic ethanol company</td>
<td>13</td>
<td>30</td>
</tr>
</tbody>
</table>
Reference


CHAPTER 4

U.S. BIOFUELS INDUSTRY: A CRITICAL REVIEW OF OPPORTUNITIES AND CHALLENGES

This paper, by Min Chen, Paul M. Smith, and Michael P. Wolcott, has been published in BioProducts Business Vol. 1, No.4, 2016: 42-59.
Abstract

Due to climate change concerns, governments and consumers are demanding higher environmental accountability for transportation fuels, particularly as related to carbon emissions. Additionally, the U.S. policymakers are seeking renewable alternatives to enhance energy security, reduce oil price volatility and increase rural economic development opportunities. Such factors present an emerging market opportunity for lignocellulosic materials to be used as biofuels. But this opportunity also has a number of associated challenges, particularly in terms of scaling up. This paper offers a comprehensive review of the emerging biofuels sector in the U.S. It begins with first generation corn-grain ethanol and biodiesel, today's most widely available biofuels within the U.S. The paper argues that further growth of these biofuels may be limited by the “blend wall”, the “food-versus-fuel” debate, and land use change issues. As a result, industrial, governmental and academic research interests have shifted to second and third generation biofuels produced from lignocellulosic biomass and algae to address GHG emissions, land use change, and the food-fuel issue. We outline that there are several limitations in scaling-up these hydrocarbon drop-in biofuels which include feedstock costs and availability, high production and capital costs, policy uncertainty, and various technical, environmental and social issues. Overall, this paper synthesizes the extant literature and draws on secondary sources to present a comprehensive and current inventory of existing U.S. biofuel players and a thorough review of the U.S. biofuels industry.

Introduction

Over the past century, the success of personal transportation in the form of automobiles powered by internal combustion engines has driven the worldwide success of oil (Brancheau, Wharton, & Kamalov, n.d.). In turn, the historical growth of the petroleum industry has led to these hydrocarbons supplying not only a bulk of the world’s energy needs but also a vast majority of the building blocks for chemicals and materials. But according to the Energy Information Administration’s (EIA) 2014 International Energy Outlook and Annual Energy Outlook 2015, liquid fuel supplies are uncertain beyond the year 2040 due to a variety of “above-ground” geo-
political issues leading to average oil price volatility of 30 percent per year over the past two decades (Energy Information Administration, 2014, 2015).

These supply and demand issues are exacerbated by the emission of greenhouse gases (GHGs) from the combustion of fossil fuels and the associated climate change effects. Fossil fuel recovery and use also introduces an array of other environmental issues, such as air and water pollution. To combat climate change, in March 2015, the U.S. submitted an Intended Nationally Determined Contribution (INDC) to the United Nations Framework Convention on Climate Change to cut net GHG emissions by 26-28 percent below 2005 levels by 2025 (The White House, 2015b). At the subsequent Paris climate conference (COP21) in November and December 2015, approximately 200 countries adopted the universal global climate deal to avoid dangerous climate change by limiting global warming to well below 2°C (European Commission, 2015). According to the 2016 Federal Activities Report on the Bioeconomy released on February 2016, the Biomass R&D Technical Advisory Committee has recommended “targeting a potential 30% penetration of biomass carbon into the U.S. transportation market by 2030” (The Biomass Research and Development (R&D) Board, 2016). And, in January 2016, the White House and Environmental Protection Agency (EPA) released the final Clean Power Plan to reduce carbon dioxide emissions by 32 percent from 2005 levels by 2030 (The White House, 2015a). Additional mechanisms to curb U.S. fossil fuel emissions include the 1970 Clean Air Act (CAA), Corporate Average Fuel Economy (CAFÉ) and the Renewable Fuel Standard (RFS).

In response to an increasing consumer awareness (Charles, Ryan, Ryan, & Oloruntoba, 2007), governments are demanding that renewable liquid fuels deliver economic benefits while mitigating several key negatives associated with petroleum products, including unreliable global supply, price volatility, and GHG emissions (Gegg, Budd, & Ison, 2014; The Biomass Research and Development (R&D) Board, 2016). To economically migrate to bio-renewable feedstocks for liquid fuels and chemicals, some have envisioned what is termed, the bioeconomy. Golden & Handfield (2014) have defined the bioeconomy as:

“...the global industrial transition of sustainably utilizing renewable aquatic and terrestrial resources in energy, intermediate, and final products for economic, environmental, social, and national security benefits.” (p. 7)

The global bio-based economy has been initially based on first generation biofuels produced primarily from food crops, such as, grains, sugar cane, and vegetable oils (Mohr & Raman, 2013). In the United States, corn-grain ethanol and biodiesel have served as the major substitute fuels for petroleum-based gasoline and diesel over the past few decades. Today, these
two first generation biofuels account for over 90 percent of the total renewable biofuels within the United States (Environmental Protection Agency, 2015a). The U.S. corn-grain ethanol industry, with the production volume growth at an annual rate of 67 percent from 1991 to 2015 (Renewable Fuels Association, 2016), has also reshaped corn farming by reducing government support for cropping subsidies while raising farmers’ incomes (Renewable Fuels Association, 2014). Meanwhile, corn ethanol blends in gasoline (typically, up to 10%) improve the octane number and add oxygen content to meet the U.S. Clean Air Act (CAA) (Urbanchuk, 2010). Similarly, the U.S. biodiesel industry has aided in the development of the rural economy by providing over 60,000 jobs nationwide (National Biodiesel Board, 2015c). Biodiesel also contributes to the U.S. CAA with 52 percent lower GHG emissions compared to petroleum-based diesel (Energy Efficiency & Renewable Energy, 2015b).

Despite the benefits of first generation corn-grain ethanol, the “food-versus-fuel” and ethanol “blend wall” arguments continue to constrain the industry. The “food-versus-fuel” debate has lasted for more than a decade and includes controversy over food security (Carter & Miller, 2012; Ziegler, 2008) and food price inflation (Ahmed, 2008; Ajanovic, 2011; Bardhan, Gupta, Gorman, & Haider, 2015; Cuesta, 2014). The ethanol “blend wall” also constrains the growth of the U.S. corn ethanol industry due to the E10 (10%) blend limit, the infrastructure requirements for higher blend options, and consumer acceptance for higher biofuel blends (Energy Information Administration, 2011). In addition to the food-fuel issue, biodiesel fuels also face challenges related to environmental, economic and social impacts, for example, NOx emission, distribution and infrastructure modifications, and land use change (Bomb, 2005; Castanheira, Grisoli, Freire, Pecora, & Coelho, 2014; Rabago, 2008). As a result, interest in developing new biofuels from non-food based lignocellulosic feedstocks has grown (Brown & Brown, 2013; Mohr & Raman, 2013; Solomon, Barnes, & Halvorsen, 2007).

Compared to first generation biofuels, second generation cellulosic alcohols (ethanol and butanol) avoid the food-fuel controversy while benefiting from lower lifecycle GHG emissions (Balan, Chiaramonti, & Kumar, 2013; FitzPatrick, Champagne, Cunningham, & Whitney, 2010). However, second generation cellulosic biofuels have yet to become widely commercialized in the US due to a variety of underlying issues (Balan et al., 2013; FitzPatrick et al., 2010). For instance, cellulosic alcohols face the same ethanol “blend wall” issue, plus strong price competition from existing corn-grain ethanol players. Additional barriers to the scale-up (commercialization) of the cellulosic biofuels industry are well documented and include feedstock costs and availability, high production costs, high capital requirements, policy uncertainty, and various technical,
environmental and social issues (Balan et al., 2013; Brown & Brown, 2013; Cheng & Timilsina, 2011; Oltra, 2011; Pimentel & Patzek, 2005; Temesgen, Affleck, Poudel, Gray, & Sessions, 2015). Going forward, government, academic, and industrial biofuel research efforts will include hydrocarbon biofuels recovered from lignocellulosic biomass and algae (Gegg et al., 2014; Regalbuto, 2009).

The overall goal of this paper is to present a comprehensive review of the U.S. biofuels industry. The specific objectives are to provide a historical perspective for the development of the U.S. biofuels industry and to examine barriers to the scale-up of second and third generation versions with future development considerations. This paper contributes to extant debates on the transition from first generation biofuels to cellulosic alcohols and drop-in advanced biofuels.

Historical Perspective of the U.S. First Generation Biofuels

Corn-grain ethanol

As shown in Figure 4-1, ethanol production dates back nearly 9,000 years to alcoholic beverages consumed in China; later, first century AD Greeks distilled ethanol, allowing higher alcohol concentrations ("Ethanol history", 2010). Between 1824 and 1826, Samuel Morey invented the world’s first internal combustion engine running on ethanol and turpentine ("Ethanol history", 2010). In 1896, Henry Ford built the first automobile to run on pure ethanol; however, the prohibition era in the U.S. (1919-1933) marked the end of ethanol and the rise of gasoline as an automobile fuel ("Ethanol history", 2010; Gustafson, 2010). The 1973 energy crises once again made ethanol fuel more interesting and the U.S. began exploring ways to encourage its corn-grain ethanol industry (Hoffman & Baker, 2010; Stephen R. Hughes, Gibbons, & Kohl, 2009; Nixon, 1973). Later, the U.S. corn-grain ethanol industry’s growth was supported by the 1990 Clean Air Act (CAA) and the 1992 Energy Policy Act (EPAC). Using ethanol as an oxygenate helped control carbon monoxide emissions (Environmental Protection Agency, 2014), and the 1992 EPAC created a biofuels tax credit for the U.S. corn-grain ethanol industry (Lave, Burke, & Tyner, 2011). From 2003-2007, methyl tertiary butyl ether (MTBE) was phased out as a U.S. gasoline oxygenate (Lave et al., 2011; Lidderdale, 2000) and early in the 21st Century, the 2005 Energy Policy Act established the first Renewable Fuel Standard (RFS1) to further spur the
biofuels industry while addressing oil price volatility, greenhouse gas (GHG) emissions, energy security, and rural economic development (Golden & Handfield, 2014; Schnepf & Yacobucci, 2013). In 2007, the Energy Independence and Security Act (EISA) expanded the reach of RFS1 (to RFS2) by mandating 36 billion gallons of biofuels to be blended into the U.S. fuel supply by 2022 (Schnepf & Yacobucci, 2013). The U.S. corn-grain ethanol industry’s production grew from approximately 830 million gallons in 1991 to nearly 14.8 billion gallons in 2015, representing about 60 percent of the world’s ethanol production (Figure 4-2) (Renewable Fuels Association, 2015, 2016).

Biodiesel

The use of biofuels recovered from vegetable oils in diesel engines originated with the demonstration of the diesel engine by the German inventor Rudolph Diesel, at the World Exhibition in Paris in 1911 (Yusuf, Kamarudin, & Yaakub, 2011). Diesel envisioned widespread use of vegetable oils, such as hemp and peanut oil, for diesel engines; however, modern biodiesel, recovered by converting vegetable oils into fatty acid methyl esters, was not established in Europe until the late 1980s (Pacific Biodiesel, 2015). In the U.S., biodiesel was first manufactured in 1991 in Kansas City, Missouri (National Biodiesel Board, 2015a). Later, by 2002, biodiesel legislation in Minnesota required the inclusion of 2 percent soybean biodiesel into the majority of Minnesota’s diesel pool (National Biodiesel Board, 2015a). Figure 4-3 depicts the growth of the U.S. biodiesel industry from approximately 10 million gallons of 100% biodiesel (B100) in 2002 to 1.26 billion gallons in 2015 (Energy Information Administration, 2016a).

Current Status of the First Generation Biofuels in the U.S.

Corn-grain ethanol

Over 90% of U.S. ethanol biorefineries use corn grain as feedstock; the remaining use sorghum, cheese whey or waste beer (O’Brien, 2010; Renewable Fuels Association, 2015). Figure 4-4 illustrates the 208 U.S. corn-grain ethanol biorefineries in 2015 with the heaviest concentrations in the Midwestern corn-belt of Iowa (n=40), Nebraska (n=25), Minnesota (n=21),
South Dakota (n=15), and Illinois (n=14). The largest ethanol producers in 2015 were Archer Daniels Midland (ADM), POET, Valero Renewable Fuels, Green Plains Renewable Energy, and Flint Hill Resources (Table 4-1).

**Conversion Technologies & Co-products.** Corn-grain ethanol in the United States is produced in both wet and dry mills (Naik, Goud, Rout, & Dalai, 2010). Wet mills separate each component of the corn kernel into different fractions via steeping, de-germinating and separation (Figure 4-5). A variety of products can be recovered in wet mills, including starch, gluten meal, gluten feed and oil. The starch derived from wet mills may be further processed into sweeteners (high-fructose corn syrup, HFCS) or ethanol (AMG, 2013). This diversified product portfolio allows producers to quickly adapt to changes in market conditions (Hoffman & Baker, 2010).

Compared to wet mills, dry mills are typically smaller, less expensive to build and produce a narrower product mix (Figure 4-6). The primary co-products of dry mill are distillers’ dried grains with solubles (DDGS) and/or corn oil (Figure 4-6). Roughly one-third of every 56-pound bushel of grain that enters the ethanol process is converted to distillers’ grains and corn oil, with approximately one-quarter of dry mill’s gross revenue from the sale of these two co-products in 2013 (Renewable Fuels Association, 2014). As a result, the market share of ethanol dry mills increased from 30 to 89 percent from 1991 to 2009/10 (Hoffman & Baker, 2010; Urbanchuk, 2010).

**Biodiesel**

Biodiesel is defined under the standard of ASTM D6751 as “a fuel comprised of mono-alkyl esters of long-chain fatty acids”, and can be produced from vegetable oilseeds (such as rapeseed, sunflower, olive, and soybean), animal fats (such as poultry, tallow, and white grease) or recycled restaurant grease (e.g. yellow grease) (Alternative Fuels Data Center, 2014; Energy Information Administration, 2016a; Lai, 2014). Among all biodiesel feedstocks, vegetable oilseeds were the major biodiesel feedstock, accounting for approximately 71 percent of the U.S. total in 2015 (Energy Information Administration, 2016a). That year, soybean oil was the largest feedstock accounting for 52 percent of the total, followed by recycled grease (14.3%), animal fats (13.4%), corn oil (11%), canola oil (8%), and other (1.3%) (Energy Information Administration, 2016a). Figure 4-7 shows the locations of the identified 162 U.S. biodiesel biorefineries in 2015 (Biodiesel Magazine, 2015; Lane, 2013a; National Biodiesel Board, 2015b).
Conversion Technologies & Co-products. Trans-esterification is the most widely used technology in biodiesel production (Fig. 8) (Moser, 2011). This trans-esterification reaction involves a triacylglycerol (TAG) reacting with short-chain monohydric alcohol with the presence of alkaline catalysts (such as NaOH, KOH, or related alkoxides) to form fatty acid alkyl esters (biodiesel) and glycerol (Figure 4-8). The price of biodiesel depends largely on conversion technologies. In order to be cost-competitive against petro-diesel, research interests have been focused on the development of heterogeneous catalyst systems to increase conversion yields and to standardize biodiesel to enhance its marketability (Hanna, Isom, & Campbell, 2005; Santacesaria, Vicente, Di Serio, & Tesser, 2012).

Glycerol, a co-product from biodiesel production, has a wide range of applications including personal care, pharmaceuticals, foods, and beverages (Hanna et al., 2005; Sheela, 2014). According to (Transparency Market Research, 2013), the global demand for glycerol was around 2,000 kilotons in 2011 and is expected to reach 3,000 kilotons by 2018, with an estimated worth of $2.1 billion (Sheela, 2014).

Challenges Confronting First Generation Biofuels

Ethanol “blend wall”

Corn-grain ethanol in the U.S. is blended with gasoline, primarily as E10 (up to 10% ethanol blended with 90% unleaded gasoline). A key benefit of E10 is that it is compatible with existing vehicles and infrastructure, including fuel tanks and retail pumps (Schnepf & Yacobucci, 2013). Since 2010, the ethanol production volume has surpassed the capacity that can be blended with conventional motor gasoline at the 10% blend rate, commonly referred to as the ethanol “blend wall” (Figure 4-9).

To address this demand dilemma, the EPA approved the sale of E15 (up to 15% ethanol blended with 85% unleaded gasoline) in 2010 for 2001 and newer vehicles, with the potential to increase the annual amount of ethanol sold by 50% (Renewable Fuels Association, 2013). In addition, the U.S. ethanol industry anticipates significant progress through the USDA’s Biofuels Infrastructure Partnership program (October 2015), which will result in 4,880 pumps and 515 tanks installed throughout the U.S. over the next year in 1,486 stations to offer consumers E15
and higher blends (Buis, 2016). However, the adoption of higher blends is not a panacea as a lack of compatible fueling infrastructure and poor automaker and consumer acceptance of E15 or E85 for flex fuel vehicles (FFVs) remain (Antoni, Zverlov, & Schwarz, 2007; Energy Information Administration, 2011; Martin, 2013; NACS, 2013).

“Food-versus-fuel” debate

The “food-versus-fuel” debate unfolded during the food crisis of 2007 and 2008 because most feedstocks currently used for first generation biofuels are directly or indirectly used for food production (Ajanovic, 2011; Babcock, 2012; Srinivasan, 2009). As a result, serious concerns remain regarding the preservation of the food security of the planet and increasing feedstock prices (Carter & Miller, 2012; Srinivasan, 2009; Ziegler, 2008). However, others contend that oil prices and export demand may be the driving influences of feedstock and food price inflation and that the impact of biofuels production on food security and price inflation are exaggerated (Schill, 2016). The Renewable Fuels Association (RFA) contends that corn ethanol production uses only the grain’s starch component and returned an estimated 39 million metric tons of protein, minerals, fat, and fiber to the animal feed market in 2014 (Renewable Fuels Association, 2014).

At the Global Forum for Food and Agriculture (January 2015), Jose Graziano de Silva, director of the United Nations Food and Agriculture Organization (FAO), stated:

“*We need to move from the ’food versus fuel’ debate to a ’food and fuel’ debate. There is no question: food comes first. But biofuels should not be simply seen as a threat or a magical solution. Like anything else, they can do good or bad.*” (Food and Agriculture Organization, 2015)

Biodiesel challenges

In addition to the food-fuel issue, biodiesel fuels also face challenges related to environmental, economic, and social impacts (Castanheira et al., 2014). In the case of crop-based feedstock, representing approximately 71% of U.S. biodiesel production in 2015, specific issues include seasonal crop availability and similar land use change concerns associated with corn-grain ethanol production (Bomb, 2005; Castanheira et al., 2014; Gnansounou, Panichelli, Dauriat,
Including animal fat and restaurant grease-based biodiesel, overall challenges to biodiesel include potential infrastructure modifications to move fuel from production facilities to personal vehicles, storage shelf life and related distribution and infrastructure modifications, NOx emissions, low-temperature operability, and reduced energy content than petro-diesel (Bomb, 2005; Castanheira et al., 2014; Howell & Weber, 1995; Rabago, 2008; Yoon, 2011).

**Transition to Cellulosic Alcohols**

A wide variety of agricultural biomass can be used as raw materials to produce cellulosic alcohols including short rotation forestry crops (poplar, willow), perennial grasses (miscanthus, switchgrass), agricultural, forest and mill residues, and municipal solid waste (MSW) (Pacini, Sanches-Pereira, Durleva, Kane, & Bhutani, 2014; Sims, Taylor, Saddler, & Mabee, 2008). Due to concerns over “food-versus-fuel”, land-use change and GHG emissions, non-edible cellulosic alcohols, primarily ethanol and butanol, are gaining momentum in U.S. road transportation fuel markets (Mohr & Raman, 2013; Schnepf, 2010). Compared to petroleum-based fuels and corn-grain ethanol, cellulosic alcohols benefit from their reliance on non-food based feedstocks, less competition on land use, and lower lifecycle GHG emissions (Balan et al., 2013; FitzPatrick et al., 2010; Pacini et al., 2014). Researchers from the University of California at Berkeley, Stanford University, and Argonne National Lab estimated that, on a life-cycle basis, cellulosic ethanol could lower GHG emissions by around 90 percent relative to petroleum-based gasoline (Energy Efficiency & Renewable Energy, 2014b; Farrell et al., 2006; Schmer, Vogel, Mitchell, & Perrin, 2008).

**Cellulosic alcohol biorefineries**

Cellulosic alcohols may be produced in either “bolt-on” and “stand-alone” biorefineries. “Bolt-on” facilities are added to or co-located with existing corn-grain ethanol biorefineries to leverage existing corn-grain ethanol facilities. These “bolt-on” cellulosic biorefineries can share feedstock and distribution supply chains and lower capital costs to reduce investment risk (Fulton, Morrision, Parker, Witcover, & Sperling, 2014; Lane, 2014). Currently, eleven U.S. “bolt on”
cellulosic biofuel refineries are in start-up mode (Table 4-2) with two having launched commercial-scale production: POET-DSM “Project Liberty” (Sept. 3, 2014) and Quad County Corn Processors (July 1, 2014) ("Four commercial", 2014).

In addition, sixteen U.S. “stand-alone” cellulosic alcohol refineries have been identified with three having successfully launched commercial scale production: Abengoa Bioenergy 25 MGY in Hugoton, KS (Oct. 19, 2014); DuPont 30 MGY in Nevada, IA (Oct. 30, 2015); and INEOS Bio 8 MGY in Vero Beach, FL (July 31, 2013) ("Four commercial", 2014; DuPont, 2015b; INEOS, 2013). Fifteen refineries produce cellulosic ethanol as the major product; Butamax focuses on the production of n-butanol (Table 4-3).

**Conversion Technologies.** Enzymatic/dilute acid hydrolysis and fermentation are the leading conversion technologies deployed in the U.S. to produce cellulosic alcohols (Balan et al., 2013; Brown & Brown, 2013; Coyle, 2010). Due to the recalcitrance of lignocellulose, a composite of cellulose, hemicellulose, and lignin, pretreatment is required to separate the lignin and improve enzymatic and microbial breakdown of biomass into sugars (Himmel et al., 2007). Various pretreatments are available, such as wet oxidation, dilute acid, steam explosion, ammonia fiber expansion (AFEX), mechanical extrusion, liquid hot water, lime, organosolv, and ionic liquid (Balan et al., 2013; FitzPatrick et al., 2010). After separating from lignin, cellulase enzymes or acid is used to depolymerize cellulose into glucose, which is then fermented to ethanol (Figure 4-10).

Consolidated bioprocessing (CBP) combines enzyme production, enzymatic hydrolysis, and fermentation into the same reactor and has been adopted by Aemetis and Mascoma to produce cellulosic alcohols (Brown & Brown, 2013). CBP is purported to reduce capital and operating costs as compared to separate enzymatic/dilute hydrolysis & fermentation (Brown & Brown, 2013; Olson, McBride, Shaw, & Lynd, 2012) (Figure 4-11).

**Growth of Cellulosic- and Algae-Based Hydrocarbon Biofuels**

**Hydrocarbon biofuels refineries**

The U.S. biofuels industry has also witnessed considerable progress of the non-food based hydrocarbon biofuels, which are drop-in replacements for gasoline, diesel, and jet fuel
Drop-in hydrocarbon biofuels are chemically similar to petroleum-based fuels and, therefore, are fully compatible with existing infrastructure, i.e., no need for engine modifications and drop-in biofuels may use existing petroleum distribution systems (Alternative Fuels Data Center, 2016). As of January 2016, seventeen companies are currently or proposing to use second generation (lignocellulsoic) and third generation (algal) feedstock for the production of various end products (Table 4-4).

**Conversion Technologies.** Lignocellulosic biomass and algae can be converted to renewable hydrocarbon biofuels by thermochemical and hybrid (combined thermochemical and biochemical) technologies (Yue, You, & Snyder, 2014). Three specific processes for the conversion are: 1) gasification of biomass to syngas (carbon monoxide and hydrogen) and further conversion of syngas to liquid fuels via Methanol-to-Gasoline (MTG) or Fischer-Tropsch (FT) syntheses; 2) fast pyrolysis or liquefaction of biomass to produce bio-oils followed by upgrading to liquid hydrocarbon biofuels via hydroprocessing; and 3) biochemical conversion of biomass to ethanol followed by catalysis or bioforming to hydrocarbon biofuels (Figure 4-12).

**Challenges Confronting the U.S. Cellulosic- and Algae-Based Biofuels Industries**

**Challenges of cellulosic biofuels**

Compared to petro-based gasoline and diesel, cellulosic biofuels enjoy improved sustainability, energy security, and lower GHG emissions. However, cellulosic biofuels are confronting high entry barriers that inhibit their entrance to the U.S. transportation fuel markets. These barriers include feedstock costs and availability, high production costs, and policy uncertainty (Cheng & Timilsina, 2010; Cheng & Timilsina, 2011; Oltra, 2011; Pimentel & Patzek, 2005).

**Feedstock Costs and Availability.** Long-term investments in research, demonstration, and deployment are ongoing to develop and fully scale cost-effective and time-sensitive supply chains for cellulosic biofuel biorefineries (Richard, 2010; Yue et al., 2014). In contrast to corn-grain and oilseeds, lignocellulosic feedstocks are generally less expensive; however, lower bulk density and higher moisture content results in significant logistical challenges (Balan, 2014; Coyle, 2010; Richard, 2010). Feedstock costs, estimated at 35-50 percent of total cellulosic ethanol production.
costs, consist of both the raw materials and the logistics costs, including harvesting, collecting, storing, preprocessing, and transporting biomass to biorefineries (Coyle, 2010). Feedstock availability issues related to environmental and social considerations represent another challenge. For agricultural residues and wastes, harvesting may be restricted by sustainability criteria and soil quality maintenance which can impact the steady year-round supply of biomass to the biorefinery (Coyle, 2010; Wilhelm, Johnson, Karlen, & Lightle, 2007). For example, corn stover represents three-fourths of all available biomass, yet 30% of it must remain on the fields after harvest to mitigate water and wind erosion (Energy Efficiency & Renewable Energy, 2011; Ertl, 2013; Gallagher et al., 2003; Graham, Nelson, Sheehan, Perlack, & Wright, 2007). For forestry residues, there is no clear consensus on the minimum amount of organic material required to remain on site to maintain ecosystem services (Daioglou, Stehfest, Wicke, Faaij, & Vuuren, 2015); however, research is currently addressing forest biomass inventories in response to changing land uses and climatic conditions (Hollinger, 2008; Temesgen et al., 2015).

**High Production Costs.** Compared to the relatively mature fermentation process for corn-grain ethanol and trans-esterification for biodiesel, cellulosic biofuels are still at their early stages of development with most of these technologies at pilot or demonstration scale (Balan et al., 2013). The main technical obstacle of producing cellulosic biofuels is the tough, complex structure of lignocellulosic biomass cell walls and the need to separate lignin (Hahn-Hägerdal, Galbe, Gorwa-Grauslund, Lidén, & Zacchi, 2006; Houghton, Weatherwax, & Ferrell, 2005; Zhu et al., 2015). As a result, relatively immature and untested technologies for large-scale production challenge the economic-competitiveness of U.S. cellulosic alcohols and cellulosic hydrocarbon biofuels (Coyle, 2010). For example, on January 2016, U.S. Department of Energy (DOE) researchers reported achieving a cellulosic ethanol production cost of $2.15 per gallon (National Renewable Energy Laboratory, 2016). At this cost, cellulosic ethanol is not competitive with petroleum-based gasoline when oil prices are below $50 per barrel (Center for Climate and Energy Solutions, 2009).

**Policy Uncertainty.** Stable and consistent policies enabled first generation U.S. corn-grain ethanol biofuels to grow dramatically to approximately 15 billion gallons by 2015 (Dahmann, Fowler, & Smith, 2016). Second generation biofuels, however, have struggled to reach commercial scale production due, in part, to policy uncertainty (Dahmann et al., 2016; Dinneen, 2016). This uncertainty is reflected in the fluctuating Renewable Volume Obligations (RVOs) under RFS set by the U.S. Environmental Protection Agency (EPA) (Lane, 2015). RVOs are the obligated quantities of biofuels for companies that supply gasoline or diesel transportation
fuel for the retail market (Schnepf & Yacobucci, 2013). The U.S. EPA has been tasked with the implementation of the RFS by calculating and establishing RVOs based on RFS2 volume requirements and U.S. Energy Information Association (EIA) projections of gasoline and diesel production for the coming year (Environmental Protection Agency, 2015b; Schnepf & Yacobucci, 2013). EPA then issues an annual notice of proposed rulemaking and a final rule by November 30 of each year to set the RFS for each ensuing year (Schnepf & Yacobucci, 2013). However, in light of recent and dramatic oil price drops, biofuel exports and retired Renewable Identification Numbers (RINs)\(^1\), current U.S. law and policy for cellulosic and other advanced biofuels have neither provided adequate stimulus nor a clear a direction to foster stable and predictable development and commercialization (Dahmann et al., 2016).

As an alternative approach, California has taken a leadership role in developing and implementing a Low Carbon Fuel Standard (LCFS) with the goal of establishing:

“…average carbon intensity values for various fuels such as gasoline, diesel, biofuels, natural gas, and electricity. Carbon intensity values are calculated using a life-cycle analysis, which accounts for all greenhouse gas emissions associated with a fuel’s production, distribution and use — as opposed to a simple measure of carbon emissions when a fuel is burned” (Dahmann et al., 2016; Langston et al., 2011; Yeh et al., 2012).

In addition to California, a LCFS is being explored elsewhere, including Oregon, Washington and in the eastern U.S. where 11 states signed a 2009 Memorandum of Understanding to adopt a “Clean Fuels Standard” (Dahmann et al., 2016; Yeh et al., 2012). This type of carbon-based policy tool could greatly impact the future direction of the U.S. biofuels industry in terms of feedstock use, plant siting, and technology deployment.

**Challenges of algae-based hydrocarbon biofuels**

Algal feedstocks enjoy high growth rates and tolerance to varying environmental conditions, which allows them to survive and reproduce in low quality high saline water unsuitable for agriculture (Energy Efficiency & Renewable Energy, 2014a; Naik et al., 2010). Similar to lignocellulosic hydrocarbon biofuels, drop-in algae-based hydrocarbon biofuels also benefit from existing fuel distribution networks and lower GHG emissions. However, feedstock

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\(^1\) RIN refers to a serial number (a unique 38-character) to a batch of biofuel for the purpose of tracking its production, use and trading as required by Renewable Fuels Standard (RFS) (Schnepf & Yacobucci, 2013).

Discussion

Corn-grain ethanol and biodiesel are relatively mature U.S. first generation biofuels due in part to stable and supportive policies, established conversion technologies, and synergy with existing U.S. food production systems. In 2015, 208 U.S. corn-grain ethanol biorefineries produced approximately 15 billion gallons of ethanol. However, first generation corn-grain ethanol biofuels are facing challenges to further growth in term of the ethanol “blend wall”, the “food-versus-fuel” debate, and consumer acceptance related to engine wear and reduced energy content (Table 4-5).

Biodiesel is a renewable substitute for diesel fuel (up to 100%) with favorable lubricity properties which may extend the life of diesel engines (Energy Efficiency & Renewable Energy, 2015a; Pacific Biodiesel, 2016). In 2015, 162 biodiesel refineries produced about 1.26 billion gallons of pure biodiesel (B100), of which 71 percent of the production used vegetable oil seeds with the balance derived from animal fat and restaurant grease. The crop-based biodiesel faces similar food-fuel and land use change issues and all biodiesel fuels face infrastructure, shelf life, energy content, NOx emission, and low-temperature operability issues (Table 4-5).

Driven by the “food-versus-fuel” debate and concerns over GHG emissions, second generation cellulosic alcohols (e.g. cellulosic ethanol and butanol) are gaining interest from researchers, policymakers, and investors. By using non-food based feedstocks, cellulosic alcohols offer an opportunity to reduce impacts on food supply and price, impose less competition on land use, and further reduce GHG emissions by around 90 percent relative to petroleum-based gasoline (Table 4-5). As of January 2016, eleven “bolt-on” and sixteen “stand-alone” U.S. cellulosic alcohol biorefineries have been established in the U.S.

Second generation non-food based drop-in cellulosic and third generation algae-based hydrocarbon biofuels eliminate the food-fuel issue and infrastructure/engine compatibility concerns (Table 4-5). Cellulosic alcohols and cellulosic hydrocarbon biofuels face several potential challenges associated with feedstock costs and availability, high production and capital
costs, policy uncertainty, and various technical, environmental, and societal constraints. As of January 2016, seventeen U.S. companies were producing or proposing to produce hydrocarbon-based “green” gasoline, renewable diesel and/or biojet. Early success of these pioneering projects is critical to attract capital investment and create demand (Brown & Brown, 2013).

In spite of high potential yield and the ability to grow algae in locations unsuitable for agriculture, algae-based hydrocarbon biofuels are challenged by feedstock cultivation, processing, and logistics issues, technology (large volume requirement of water, nitrogen and phosphorus), and economic barriers (high production costs and high energy requirements) that need to be addressed in the coming years (Energy Efficiency & Renewable Energy, 2014a; Stephen R. Hughes et al., 2013; Lee, 2013; Oltra, 2011; Sheehan et al., 1998).

**Conclusions**

Future biofuel conversion technologies and resultant final products are difficult to predict; however, a fully drop-in, sustainable, and energy dense biomass-based liquid fuel at price parity with petro-based fuels is the ultimate goal to address societal needs around climate change and energy security (Babcock, Marette, & Tréguer, 2011). In particular, specific biofuel pathways will be driven by a favorable value proposition vis-à-vis petro-fuels in terms of overall economics and proven environmental benefits without perceived negative impacts on performance. And, the lessons learned from corn/grain ethanol suggest that specific and stable policies addressing feedstock infrastructure/logistics, capital formation, and environmental issues may more rapidly and effectively advance the adoption and diffusion of next generation renewable liquid fuels. Additionally, researchers have recognized that innovative technology underpins a strong bioeconomy (The Biomass Research and Development (R&D) Board, 2016). Therefore, further research and development on technological advances should be encouraged and supported to help lignocellulosic liquid biofuels achieve economic-competitiveness. This paper provides an up-to-date critical review for researchers and policymakers to better understand the structure of existing U.S. biorefineries and to benchmark future opportunities for the U.S. bioeconomy.
Figure 4-1. History of ethanol.
Figure 4-2. Growth of the U.S. corn-grain ethanol industry (# of biorefineries and production) from 1991 – 2015.

Source: (Renewable Fuels Association, 2015, 2016)
The production volume of 2015 is predicted by the first 11 months of 2015.

Figure 4-3. Growth of the U.S. biodiesel industry (# of biorefineries and capacity) from 2001 to 2015.

Source: (Energy Information Administration, 2016a)
Figure 4-4. U.S. corn-grain ethanol biorefineries (n=208) by location in 2015.
Adapted from (Renewable Fuels Association, 2015)
Figure 4-5. Schematic of wet milling process of corn-grain ethanol.
Source: (AMG, 2013; Naik et al., 2010)
Figure 4-6. Schematic of dry milling process of corn-grain ethanol.
Source: (Naik et al., 2010; O’Brien, 2010)
Figure 4-7. U.S. biodiesel biorefineries (n=162) by location in 2015.
Adapted from (Biodiesel Magazine, 2015; Lane, 2013a; National Biodiesel Board, 2015b)
Figure 4-8. Production of fatty acid alkyl esters (biodiesel) via trans-esterification.

Source: (Moser, 2011)
Figure 4-9. Annual U.S. ethanol production volumes from 2006 to 2015 and their corresponding percentage of the conventional motor gasoline consumption.

Source: (Energy Information Administration, 2016b, 2016c)
Figure 4-10. Cellulosic ethanol via enzymatic/dilute acid hydrolysis.
Modified from (Balan et al., 2013)
Figure 4-11. Cellulosic ethanol via consolidated bioprocessing (CBP).
Modified from (Brown & Brown, 2013)
Figure 4-12. Simplified conversion processes for cellulosic- and algae-based hydrocarbon biofuels.

Modified from (Balan et al., 2013; Brennan & Owende, 2010; Brown & Brown, 2013; Naik et al., 2010; Yue et al., 2014)
Table 4-1. The U.S. leading corn-grain ethanol producers by capacity (million gallons per year – MGY) in 2015.

Source: (Renewable Fuels Association, 2015)

<table>
<thead>
<tr>
<th>Company</th>
<th>States</th>
<th>2015 Capacity (MGY)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Archer Daniels Midland (ADM)</td>
<td>IA, IL, MN, NE</td>
<td>1,762</td>
</tr>
<tr>
<td>POET LLC</td>
<td>IN, IA, MN, MI, MO, SD, OH</td>
<td>1,666</td>
</tr>
<tr>
<td>Valero Renewable Fuels</td>
<td>IA, IN, MN, NE, OH, SD, WI</td>
<td>1,300</td>
</tr>
<tr>
<td>Green Plains Renewable Energy</td>
<td>IA, IN, MI, MN, NE, TN, TX, VA</td>
<td>1,220</td>
</tr>
<tr>
<td>Flint Hills Resources LP</td>
<td>IA, NE</td>
<td>820</td>
</tr>
<tr>
<td>Cargill, Inc.</td>
<td>IA, NE</td>
<td>345</td>
</tr>
<tr>
<td>The Andersons Ethanol LLC</td>
<td>IA, IN, MI, OH</td>
<td>330</td>
</tr>
<tr>
<td>Abengoa Bioenergía Corp.</td>
<td>IL, IN, KS, NE, NM</td>
<td>323</td>
</tr>
</tbody>
</table>
### Table 4-2. “Bolt-on” cellulosic alcohol biorefineries in U.S. as of January 2016 (n=11).

<table>
<thead>
<tr>
<th>Companies</th>
<th>Location</th>
<th>Product</th>
<th>Capacity (gallons/year)</th>
<th>Citations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abengoa</td>
<td>York, NE</td>
<td>Ethanol</td>
<td>20,000</td>
<td>(Piersol, 2011)</td>
</tr>
<tr>
<td>ACE ethanol</td>
<td>Stanley, WI</td>
<td>Ethanol</td>
<td>Up to 3.6 million</td>
<td>(Lane, 2013b)</td>
</tr>
<tr>
<td>ADM</td>
<td>Decatur, IL</td>
<td>Ethanol</td>
<td>25,800</td>
<td>(Lane, 2013a)</td>
</tr>
<tr>
<td>Aemetis</td>
<td>Keyes, CA</td>
<td>Ethanol</td>
<td>NA</td>
<td>(Aemetis, 2012)</td>
</tr>
<tr>
<td>Flint Hills</td>
<td>Fairbank, IA</td>
<td>Ethanol</td>
<td>NA</td>
<td>(Business Wire, 2012)</td>
</tr>
<tr>
<td>Front Range</td>
<td>Windsor, CO</td>
<td>Ethanol</td>
<td>Up to 3.6 million</td>
<td>(Sweetwater Energy, 2013)</td>
</tr>
<tr>
<td>Gevo</td>
<td>Luverne, MN</td>
<td>Iso-butanol</td>
<td>0.6~1.2 million</td>
<td>(Gevo, 2015)</td>
</tr>
<tr>
<td>ICM</td>
<td>St. Joseph, MO</td>
<td>Ethanol</td>
<td>NA</td>
<td>(ICM, 2012)</td>
</tr>
<tr>
<td>Pacific Ethanol</td>
<td>Boardman, OR</td>
<td>Ethanol</td>
<td>Up to 3.6 million</td>
<td>(Pacific Ethanol, 2013)</td>
</tr>
<tr>
<td>POET-DSM</td>
<td>Emmetsburg, IA</td>
<td>Ethanol</td>
<td>25 million</td>
<td>(POET-DSM, 2014)</td>
</tr>
<tr>
<td>Quad-County Corn Processors</td>
<td>Galva, IA</td>
<td>Ethanol</td>
<td>2 million</td>
<td>(Advanced Ethanol Council, 2015; Quad County, 2015)</td>
</tr>
<tr>
<td>Company</td>
<td>Location</td>
<td>Feedstock</td>
<td>Products</td>
<td>Capacity (MGY)</td>
</tr>
<tr>
<td>-------------------------</td>
<td>---------------------</td>
<td>-----------------------------------------------------</td>
<td>-----------------------------------</td>
<td>----------------</td>
</tr>
<tr>
<td>Abengoa</td>
<td>Hugoton, KS</td>
<td>Corn stover, switchgrass</td>
<td>Ethanol</td>
<td>25</td>
</tr>
<tr>
<td>American Process</td>
<td>Alpena, MI</td>
<td>Sugarcane bagasse</td>
<td>Ethanol, acetic acid</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>Thomaston, GA</td>
<td>Non-food based biomass, woodchips</td>
<td>Ethanol, succinic acid, BDO</td>
<td>Up to 0.3</td>
</tr>
<tr>
<td>Beta Renewables</td>
<td>Clinton, NC</td>
<td>Energy grasses</td>
<td>Ethanol, lignin</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bluefire Renewable</td>
<td>Fulton, MS</td>
<td>Municipal solid waste (MSW)</td>
<td>Ethanol</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>Anaheim, CA</td>
<td></td>
<td></td>
<td>200 lbs/day</td>
</tr>
<tr>
<td>Butamax</td>
<td>Wilmington, DE</td>
<td>Woody Biomass</td>
<td>n-butanol</td>
<td>NA</td>
</tr>
<tr>
<td>Canergy</td>
<td>Imperial Valley, CA</td>
<td>Energy cane</td>
<td>Ethanol</td>
<td>25</td>
</tr>
<tr>
<td>Coskata</td>
<td>Madison, PA</td>
<td>Woody chips, MSW</td>
<td>Ethanol, ethylene</td>
<td>NA</td>
</tr>
<tr>
<td>DuPont Biofuel Solutions</td>
<td>Nevada, IA</td>
<td>Corn cob</td>
<td>Ethanol</td>
<td>30</td>
</tr>
<tr>
<td>Enerkem</td>
<td>Pontotoc, MS</td>
<td>MSW</td>
<td>Ethanol and methanol</td>
<td>10</td>
</tr>
<tr>
<td>Fiberight</td>
<td>Blairstown, IA</td>
<td>MSW</td>
<td>Ethanol</td>
<td>6</td>
</tr>
<tr>
<td></td>
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</tr>
<tr>
<td>INEOS</td>
<td>Vero Beach, FL</td>
<td>Vegetative and wood waste</td>
<td>Ethanol</td>
<td>8</td>
</tr>
<tr>
<td>Mascoma</td>
<td>Kinross, MI</td>
<td>Hardwood</td>
<td>Ethanol &amp; biochemicals</td>
<td>20</td>
</tr>
<tr>
<td>Mendota Bioenergy</td>
<td>Five Points, CA</td>
<td>Energy beets</td>
<td>Ethanol</td>
<td>15</td>
</tr>
<tr>
<td>ZeaChem</td>
<td>Boardman, OR</td>
<td>Energy woods</td>
<td>Ethanol &amp; biochemicals</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>25</td>
</tr>
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<td></td>
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</table>
Table 4-4. Drop-in hydrocarbon biofuels start-ups as of January 2016 (n=17).

<table>
<thead>
<tr>
<th>Company</th>
<th>Location</th>
<th>Products</th>
<th>Citations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lignocellulosic biomass</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amyris</td>
<td>Emeryville, CA</td>
<td>Renewable diesel from farnesene</td>
<td>(Amyris, 2016)</td>
</tr>
<tr>
<td>Cool Planet</td>
<td>Alexandria, LA</td>
<td>Renewable jet fuels &amp; gasoline</td>
<td>(CoolPlanet, 2015)</td>
</tr>
<tr>
<td>Emerald Biofuels</td>
<td>Chicago, IL</td>
<td>Renewable diesel</td>
<td>(Emerald, 2015)</td>
</tr>
<tr>
<td>Envergent (UOP &amp; Ensyn)</td>
<td>Kapolei, HI</td>
<td>Green diesel &amp; jet fuel</td>
<td>(Envergent, 2015)</td>
</tr>
<tr>
<td>Fulcrum BioEnergy</td>
<td>Storey County, NV</td>
<td>SPK jet fuel or renewable diesel</td>
<td>(Fulcrum, 2015)</td>
</tr>
<tr>
<td>Haldor Topsoe Inc.</td>
<td>Pasadena, TX</td>
<td>Dimethyl ether, renewable gasoline</td>
<td>(Topsoe, 2015)</td>
</tr>
<tr>
<td>LanzaTech</td>
<td>Soperton, GA</td>
<td>Drop-in jet fuel via Alcohol-to-Jet (ATJ)</td>
<td>(LanzaTech, 2015)</td>
</tr>
<tr>
<td>Maverick Synfuels</td>
<td>Brooksville, FL</td>
<td>Renewable diesel/jet fuel via Methanol-to-Olefins (MTO)</td>
<td>(Maverick, 2015)</td>
</tr>
<tr>
<td>Red Rock Biofuels</td>
<td>Fort Collins, CO</td>
<td>Drop-in jet, diesel, and naphtha fuels</td>
<td>(RedRock, 2015)</td>
</tr>
<tr>
<td>Sundrop Fuels</td>
<td>Longmont, CO</td>
<td>Green gasoline</td>
<td>(Sundropfuels, 2015)</td>
</tr>
<tr>
<td>SynTerra Energy</td>
<td>CA &amp; OH</td>
<td>Synthetic diesel fuel</td>
<td>(SynTerra, 2012)</td>
</tr>
<tr>
<td>Terrabon, Inc.</td>
<td>Bryan, TX</td>
<td>Renewable gasoline &amp; chemicals</td>
<td>(Terrabon, 2008)</td>
</tr>
<tr>
<td>Virent</td>
<td>Madison, WI</td>
<td>Renewable diesel, jet fuel &amp; gasoline</td>
<td>(Virent, 2015)</td>
</tr>
<tr>
<td><strong>Algae</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Algenol</td>
<td>Fort Myers, FL</td>
<td>Renewable diesel, gasoline, and jet fuel</td>
<td>(Algenol, 2016)</td>
</tr>
<tr>
<td>Joule Unlimited</td>
<td>Hobbs, NM</td>
<td>Sunflow-D (diesel)</td>
<td>(Jouleunlimited, 2014)</td>
</tr>
<tr>
<td>Sapphire Energy</td>
<td>Columbus, NM</td>
<td>Gasoline from omega oils</td>
<td>(Bardhan et al., 2015; Sapphire, 2014)</td>
</tr>
<tr>
<td>Solazyme</td>
<td>Peoria, IL</td>
<td>Soladiesel, Solajet</td>
<td>(Bardhan et al., 2015; Solazyme, 2014)</td>
</tr>
</tbody>
</table>
Table 4-5. Summary of the opportunities and challenges confronting U.S. biofuels.

<table>
<thead>
<tr>
<th>Fuels</th>
<th>Opportunities</th>
<th>Challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fossil fuels</td>
<td>Meets current energy needs</td>
<td>Price volatility</td>
</tr>
<tr>
<td></td>
<td></td>
<td>GHG emissions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Energy insecurity</td>
</tr>
<tr>
<td>Corn-grain ethanol</td>
<td>Renewable substitute Oxygenate</td>
<td>“Food-fuel”</td>
</tr>
<tr>
<td></td>
<td>About 10% of US gasoline consumption</td>
<td>Ethanol “blend wall”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Consumer acceptance</td>
</tr>
<tr>
<td>Biodiesel</td>
<td>Renewable substitute</td>
<td>“Food-fuel”</td>
</tr>
<tr>
<td></td>
<td>Up to 100% blends</td>
<td>Land use change</td>
</tr>
<tr>
<td></td>
<td>Increased lubricity</td>
<td>Infrastructure</td>
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<td></td>
<td></td>
<td>Energy content</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Shelf life</td>
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<td></td>
<td></td>
<td>NOx emissions</td>
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<td></td>
<td></td>
<td>Low-temperature operability</td>
</tr>
<tr>
<td>Cellulosic alcohols</td>
<td>Renewable substitute</td>
<td>Feedstock costs/availability</td>
</tr>
<tr>
<td></td>
<td>“Food-fuel”</td>
<td>Production/capital costs</td>
</tr>
<tr>
<td></td>
<td>Lower lifecycle GHG emissions</td>
<td>Policy uncertainty</td>
</tr>
<tr>
<td>Cellulosic hydrocarbons</td>
<td>Renewable substitute</td>
<td>Technical, environmental, and societal constraints</td>
</tr>
<tr>
<td></td>
<td>“Food-fuel”</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lower lifecycle GHG emissions</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Drop-in</td>
<td></td>
</tr>
<tr>
<td>Algae-based hydrocarbons</td>
<td>Renewable substitute</td>
<td>Feedstock cultivation/processing/logistics</td>
</tr>
<tr>
<td></td>
<td>“Food-fuel”</td>
<td>Production costs</td>
</tr>
<tr>
<td></td>
<td>Lower lifecycle GHG emissions</td>
<td>Energy/water/nitrogen/phosphorus requirements</td>
</tr>
<tr>
<td></td>
<td>Drop-in</td>
<td></td>
</tr>
<tr>
<td></td>
<td>High potential yields</td>
<td></td>
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<tr>
<td></td>
<td>Flexible feedstock siting</td>
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CHAPTER 5

THE U.S. CELLULOSIC BIOFUELS INDUSTRY: EXPERT VIEWS ON COMMERCIALIZATION DRIVERS AND BARRIERS

This paper, by Min Chen and Paul M. Smith, has been submitted to Biomass and Bioenergy and is in review.
Abstract

The continued growth of U.S. first generation biofuels, mostly corn-grain ethanol, is facing increased pressure from the “food-vs.-fuel” and ethanol “blend wall” debates. Second generation (cellulosic) biofuels avoid the uncertainties about impact on food security and land competition and typically benefit from lower lifecycle greenhouse gas (GHG) emissions, but have yet to become widely commercialized. Existing literature has suggested that the development of biofuels from renewable carbon sources supports national energy security, improves rural economic development, and slows global climate change. However, no study was found to quantify the relative importance of factors driving or constraining the commercialization of the U.S. cellulosic biofuels industry. Respondents to this study’s online and paper-based surveys, administered between July and November, 2015, included 228 experts throughout the biorefinery supply chain from seven USDA National Institute of Food and Agriculture (NIFA) Coordinated Agricultural Projects (CAPs) and two industrial conferences. Government policies were rated as the most important driver for the commercialization of cellulosic biofuels. The second most importance driver was added value from non-fuel co-productions, followed by carbon emission reduction and volatile oil prices. High production costs, policy uncertainty, and competition vs. petro-fuels were identified as the top three barriers to the commercialization of cellulosic biofuels by the study’s expert participants. This paper also identified significant differences in the rating of drivers and barriers among four self-described expert groups (feedstock specialists, processing scientists, economic/business experts, and sustainability analysts), thus underscoring the importance of examining issues from multiple perspectives and highlighting the value of the USDA NIFA CAPs. Finally, participants were significantly more optimistic about the success of the integrated production of both cellulosic biofuels and biochemicals by the year 2020 vs. cellulosic biofuels alone (at the p=.001 level), underscoring the perceived advantages of the integrated biorefinery model.

Introduction

Fossil fuels (petroleum, coal, and natural gas) have long been the predominant source of liquid fuels, chemicals, and energy (Amidon et al., 2008; Naik, Goud, Rout, & Dalai, 2010). However, fossil fuel reserves are not infinite or sustainable from an economic and environmental
point of view (Kamm, Kamm, Gruber, & Kromus, 2005). Concerns regarding global climate change, volatile oil prices, and resource depletion have collectively motivated research into sustainable and renewable alternatives (Fernando, Adhikari, Chandrapal, & Murali, 2006; Zaimes, Vora, Chopra, Landis, & Khanna, 2015). Liquid biofuels from renewable carbon sources are at the forefront of these developments as they contribute to maintaining national energy security, improving rural economic development, and reducing carbon emissions (Balan, Chiaramonti, & Kumar, 2013; Cherubini, 2010; Gegg, Budd, & Ison, 2014).

In the United States, research and development on first generation biofuels, mainly corn-grain ethanol, has grown significantly due in part to stable and supportive policies, mature conversion technologies, and synergy with existing U.S. food production systems (M. Chen, Smith, & Wolcott, 2016). In 2015, 208 corn-grain ethanol biorefineries produced approximately 14.8 billion gallons of ethanol, accounting for approximately 88% of all the renewable biofuels in the U.S. (Renewable Fuels Association, 2016). The corn-grain ethanol industry has reshaped corn farming by reducing government support while raising farmers’ incomes (Renewable Fuels Association, 2014). Meanwhile, corn ethanol blends (typically, up to 10%) improve the octane number and add oxygen content to meet the U.S. Clean Air Act (CAA) (Urbanchuk, 2010).

Despite these benefits, two fundamental challenges continue to constrain the corn-grain ethanol industry. First, the decade-long “food-vs.-fuel” debate, focused on food security, considers the usage of farmland or crops for food vs. biofuels production (Carter & Miller, 2012; Ziegler, 2008) and food price inflation (Ahmed, 2008; Cuesta, 2014). And second, the ethanol “blend wall” is also limiting the growth of the U.S. corn-grain ethanol industry (Energy Information Administration, 2011). The 10 percent maximum ethanol blend rate, defined as E10, is partially caused by a lack of retail gasoline pump infrastructure and consumer acceptance of higher biofuel blends (NACS, 2013). Accordingly, research interests are transiting to second generation biofuels to avoid these first generation biofuel limitations while benefiting from lower lifecycle greenhouse gas (GHG) emissions (Brown & Brown, 2013; Mohr & Raman, 2013).

A wide variety of non-edible agricultural biomass can be used to produce second generation biofuels. These lignocellulosic feedstocks mainly include short rotation forestry crops (poplar, willow), perennial grasses (miscanthus, switchgrass), forest and mill residues, and municipal solid waste (MSW) (Bardhan, Gupta, Gorman, & Haider, 2015; Pacini, Sanches-Pereira, Durleva, Kane, & Bhutani, 2014; Sims, Taylor, Saddler, & Mabee, 2008). As of January 2016, twenty-seven cellulosic alcohol (ethanol or butanol) biorefineries and thirteen cellulosic hydrocarbons (drop-in replacements for gasoline, diesel, and jet fuel) biorefineries were identified.
in the U.S. (M. Chen et al., 2016). Most of these cellulosic biorefineries are at an early stage of development; whereas the following five have launched commercial scale production: Abengoa Bioenergy 25 MGY in Hugoton, KS (Oct. 19, 2014); DuPont Advanced Biofuels 30 MGY in Nevada, IA (Oct. 30, 2015); INEOS Bio 8 MGY in Vero Beach, FL (July 31, 2013); POET-DSM “Project Liberty” (Sept. 3, 2014); and Quad County Corn Processors (July 1, 2014).

In recent years, the U.S. government has supported the growth of cellulosic biofuels through various policy mechanisms. For example, on January 1, 2009, the Food, Conservation, and Energy Act of 2008 established a credit for the production of cellulosic biofuels whereby cellulosic biofuel producers could claim $1.01 per gallon tax credit through 2016 (Yacobucci, 2012). The U.S. Department of Agriculture’s Biorefinery Assistance Program (BAP) provides loan guarantees and grants for the construction and retrofitting of biorefineries to produce advanced biofuels (Yacobucci, 2012). And, the Department of Energy Loan Guarantee Program provides loan guarantees for energy projects that reduce air pollution and greenhouse gas emissions (Yacobucci, 2012). However, cellulosic biofuels have yet to become widely commercialized (FitzPatrick, Champagne, Cunningham, & Whitney, 2010). Meanwhile, KiOR’s November 2014 bankruptcy and Cobalt’s June 2015 asset auction signal the challenges faced by cellulosic biofuel startups seeking scaled production.

While several studies have shed light on opportunities and challenges for the U.S. cellulosic biofuels industry, this is the first study to quantitatively evaluate the relative importance of these factors. Accordingly, the overall objective of this paper is to examine, understand, and quantify the drivers for and barriers to the commercialization of the U.S. cellulosic biofuels industry based on the perceptions of experts throughout the biorefinery supply chain. Also, this study asked participants to provide their best estimate of the likelihood that the production of cellulosic biofuels (excluding biochemical and biomaterials) and the integrated production of cellulosic biofuels and biochemicals will achieve success by the year 2020. The results will better inform the cellulosic biofuels industry regarding key scale-up issues.

**Factors Affecting Cellulosic Biofuels Commercialization**

From previous literature, eight potential drivers and nine barriers confronting the commercialization of cellulosic biofuels were identified (Table 5-1). Of these studies, only Adams et al. (2011), somewhat related to biofuels, quantified the relative importance of the
drivers and barriers of bioenergy in terms of renewable heat and electricity; all others mentioned factors confronting renewable biofuels without specific ordering. In the Adams et al. (2011) research of United Kingdom bioenergy projects, developers/owners rated the three most important drivers as availability of financial reward/support mechanisms, market opportunity, and possible reduction in carbon emissions; and the three most important barriers to the development of bioenergy projects as technology, development and operational costs, and legislative issues.

Methodology

Study population

To better understand the issues confronting the sustainable development and commercialization of the U.S. cellulosic biofuels industry, expert opinions throughout the biorefinery supply chain were sought. Data were collected via quantitative surveys between July and November 2015. The sample population for this study was obtained from the registration lists of the 2015 annual meetings of seven U.S. Department of Agriculture (USDA) National Institute of Food and Agriculture (NIFA) Coordinated Agricultural Projects (CAPs) (Table 5-2 & Figure 5-1) (National Institute of Food and Agriculture (NIFA), 2015). “NIFA has invested $156 million in seven five-year projects across the U.S. to assist with research and development for regionally-based advanced biofuel and bioproduct industries” (National Institute of Food and Agriculture (NIFA), 2015). Accordingly, these CAPs contain significant science-based expertise in feedstock logistics, conversion processes, economic/business, and sustainability analysis, as well as expertise gained from collaboration with key stakeholders and industrial partners (National Institute of Food and Agriculture (NIFA), 2015). As a result, these seven programs represent a unique set of knowledge and experience on the U.S. biorefinery supply chain from field/forest to wheel/wing (Figure 5-2). To supplement and balance industrial expert group representation, attendees to the following two industrial conferences were added to our population: the 2015 National Advanced Biofuel Conference & Expo (NABC&E) and the 12th Advanced Bioeconomy Leadership Conference (ABLC) (Table 5-2 & Figure 5-1). NABC&E provides a vertically integrated venue for “industry professionals engaged in producing, developing, and deploying advanced biofuels including cellulosic ethanol, biobased platform chemicals, polymers and other
“renewable molecules”
(http://www.advancedbiofuelsconference.com/ema/DisplayPage.aspx?pageId=The_Conference__ _Expo). The ABLC provides a venue to gather senior leadership in the advanced bioeconomy focusing on advanced low carbon fuels, chemicals, and materials, plus advanced policies and financing strategies (http://advancedbiofuelssummit.com/). Together, these two conferences represent considerable industrial knowledge on the production, development, and deployment of biofuels. In this sense, the samples analyzed in the paper are non-probability convenience samples which, arguably, possess an optimal array of biorefinery supply chain expertise across all U.S. geographic regions (Figure 5-1).

**Construct measurement & data collection**

The semi-structured survey instrument consisted of RATING questions designed to examine the relative importance/degree of the identified eight drivers and nine barriers to the commercialization of the U.S. cellulosic biofuels industry. Also, this study deployed a RANKING question to delineate the top three barriers in a meaningful and interpretable way (Dillman, Smith, & Christian, 2014). The RANKING questions were designed to force differences which may not have been produced in the RATING questions.

Administration of the quantitative surveys included paper-based surveys and online surveys following each AFRI CAP annual meeting and industrial conference to increase responses. A three-email strategy was deployed for the online surveys (Dillman et al., 2014). The first email included an embedded URL link to a SurveyMonkey® website, followed by two reminder emails at one-week intervals sent to all non-respondents.

**Respondent profile**

Data collection efforts resulted in 228 respondents, with an overall response rate of 34 percent (228/678) (Table 5-2). Respondents were categorized into four groups based on their research focus/expertise with two fifths focused on feedstock research in terms of breeding, genetics, agronomy, planting, and harvesting; one third were process development experts; 17 percent were experts analyzing economics and/or business applications; and the remaining 12
percent were sustainability analysts, such as life cycle/environmental impact analysis. Among the four groups, Economics/Business experts had the highest level of research experience (mean=8.6 years), whereas sustainability analysts had the lowest (mean=5.0 years of experience) (Figure 5-3).

Nonresponse bias

To assess non-response bias, those who responded to the initial onsite paper-based surveys (early respondents; n=147) were compared to those who responded after follow-up steps were taken (e-Survey) (late respondents; n=89) across a number of survey questions with analysis of variance (ANOVA). The late respondents were generally to behave more like non-respondents so late responders can be used as a proxy for non-respondents (Armstrong & Overton, 1977; Miller & Smith, 1983; TRC, 2009; Welch & Barlau, 2013). The variables used for this comparison are years of experience, the importance of government policies as a driver for the scale-up of cellulosic biofuels, the degree of competition vs. petro-fuels as a barrier to the scale-up of cellulosic biofuels, the degree of competition vs. petro-chemicals as a barrier to the integrated production of cellulosic biofuels and biochemicals, and the likelihood of success for the scale-up of cellulosic biofuels by 2020. The ANOVA indicated that with 95% confidence interval, no significant differences were found between early and late respondents on their mean years of experience, perceptions of the importance/degree of drivers and barriers, and likelihood of success for cellulosic biofuels. Therefore, concerns of non-response bias may be set aside.

Results and Discussion

Drivers for the commercialization of the U.S. cellulosic biofuels industry

Not surprisingly, this study’s expert participants rated all eight drivers as somewhat to very important with the food-vs.-fuel debate rated as the least important driver to scale-up of the U.S. cellulosic biofuels industry (mean = 3.18) (Table 5-3). This issue may be perceived as somewhat irrelevant to second generation (cellulosic) biofuels, particularly by the 71 processing
experts and 39 economic/business experts who rated this driver as neither important nor unimportant (mean ratings of 3.09 and 3.10, respectively) (Table 5-3).

**Government policies** were rated as significantly more important than any other cellulosic biofuel scale-up driver, with an overall mean value of 4.63 (Table 5-3). This is highlighted by other studies which have suggested that incentives and supporting policies are critical to the development of nascent industries, such as biofuels, due to high initial costs of production and requisite infrastructure development (Su, Zhang, & Su, 2015; Yue, You, & Snyder, 2014). Also, supportive policies and regulations have been shown to be essential for energy market penetration (Dale et al., 2014).

**Added value from non-fuel co-products**, the second most important scale-up driver (mean rating of 4.23), is supported by several studies indicating the importance of co-products for additional profit to make cellulosic biofuels more economically competitive with petroleum-based fuels (Joseph J. Bozell & Petersen, 2010; Fiorese, Catenacci, Verdolini, & Bosetti, 2013).

**Carbon emission reduction** (mean rating of 4.12) has been a consistent scale-up driver in the literature; when compared to petroleum-based fuels, cellulosic biofuels provide lower GHG emissions (Cherubini & Strømman, 2011b; Farrell et al., 2006). The importance of carbon emissions, particularly viewed by sustainability analysts (mean = 4.5), may be due to political and public conversations concerning environmental impacts related to climate change.

In the year leading up to this study’s survey, U.S. oil prices fluctuated between $100 per barrel in September 2014 to $45 per barrel in September 2015 (Energy Information Administration, 2016), which may help explain the fourth highest rated scale-up driver – **volatile oil prices** (4.09). It has been suggested that biofuels offer a potential solution to the petroleum industry’s unstable prices (Fiorese et al., 2013; Welle, 2012). Additional “somewhat important” drivers to the scale-up of the U.S. biofuels industry included **dependence on fossil fuels** and **energy security** with many scholars advocating for the research and development on renewable biofuels as alternatives to petroleum-based fuels to cut demand for fossil fuels and to increase national security (Balan, 2014; FitzPatrick et al., 2010). Interestingly, **rural economic development** was rated as the sixth most important factor motivating the scale-up of the U.S. cellulosic biofuels industry, with a mean score of 3.88. The economic benefits of renewable biofuels have been reaffirmed by several previous studies (Balan et al., 2013; Ebadian, Sowlati, Sokhansanj, Townley-Smith, & Stumborg, 2013).

Significant differences between group mean values were found at the p=0.10 significance level for two out of the eight drivers identified in this study (Table 5-3). Experts on Feedstock
(G1-F) and Sustainability (G4-S) rated dependence on fossil fuels as a significantly more important driver for cellulosic biofuel scale-up vs. Economics/Business experts (G3-E/B) (Table 5-3). Sustainability researchers (G4-S) viewed carbon emission reduction as a significantly more important driver compared to the other three expert groups.

Barriers to the commercialization of cellulosic biofuels

This study’s expert participants rated high production costs, policy uncertainty, and competition vs. petro-fuels as the top three barriers to the commercialization of cellulosic biofuels with overall mean values of 4.22, 4.17, and 4.17, respectively (Table 5-4). The higher production costs, including pretreatment costs, for cellulosic biofuels compared to petroleum-based fuels or first generation biofuels have been underscored by several studies (Coyle, 2010; Hahn-Hägerdal, Galbe, Gorwa-Grauslund, Lidén, & Zacchi, 2006; Houghton, Weatherwax, & Ferrell, 2005; Isola, 2013). As shown in recent estimates of biofuel production costs, cellulosic ethanol is considerably more expensive than gasoline on an energy equivalent basis (Balan, 2014; Carriquiry, Du, & Timilsina, 2011; Energy Information Administration, 2016; van der Hoeven, 2016). Policy uncertainty was the second highest rated barrier overall but the #1 barrier for our 39 Economics/Business respondents (mean = 4.26) (Table 5-4). This highlights the controversial nature of current U.S. biofuel policies to the business community and their questionable impact on the industrial scale-up of the cellulosic biofuels industry (Carriquiry et al., 2011; Golden & Handfield, 2014; Lave, Burke, & Tyner, 2011). In particular, the debate over the RFS program is hindering investment in the U.S. biofuel industry (Dale et al., 2014).

About one-third of biofuel production costs are associated with feedstocks (Balan, 2014), which underscores the fourth highest scale-up barrier - feedstock costs (mean rating of 3.89). Existing literature has also suggested that feedstock delivery and storage costs, two significant components of the total biofuels costs, are critical to achieving competitiveness with petro-based fuels (Sims, Mabee, Saddler, & Taylor, 2010).

Additional cellulosic biofuel commercialization barriers include capital availability (3.78), technology availability (3.57), cellulosic biofuels logistics (3.50), and consistent

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1 Based on the statistics of 2015 annual gasoline retail price ($1.726 per gallon) (Energy Information Administration, 2016), projected cellulosic ethanol prices ranging from $2.17 per gallon (Raizen – Brazil) to $4.55 per gallon (Abengoa – US) (van der Hoeven, 2016), and the assumed energy content of ethanol =21.1 mj/lt and gasoline = 32 mj/lt (Carriquiry et al., 2011).
feedstock supply (3.29) (Table 5-4). Lignocelluloses are complex matrix comprised of cellulose, hemicellulose, lignin, and other minor components (Balan, 2014). The biological process for converting the lignocelluloses to ethanol requires delignification to separate cellulose and hemicellulose from lignin and de-polymerization of carbohydrate polymers to produce sugars for ethanol production (Borron, McManus, & Hammond, 2012; Houghton et al., 2005). Also, effective technologies to densify, handle, and store lignocellulosic biomass must be available in order for this industry to achieve large scale production (Balan, 2014; Dale et al., 2014). Finally, the availability of capital for these immature technologies, growing concerns regarding fluctuations in crop yield, area harvested, and logistical challenges are documented in the literature (Joseph J Bozell, 2008; Cherubini & Strømman, 2011a; Isola, 2013; S. Kim & Dale, 2015).

**Competition vs. corn-grain ethanol,** with an overall mean value of 3.01, was rated as a “moderate” barrier to the scale up of cellulosic biofuels industry and was rated significantly lower vs. the other eight potential barriers (Table 5-4).

Comparing the four respondent groups, Processing scientists (G2-P) largely viewed potential cellulosic industry scale-up barriers differently vs. the other three groups (Table 5-4). Processing experts (G2-P) generally viewed technology availability as a higher obstacle than Economics/Business (G3-E/B) and Sustainability experts (G4-S) at the p=0.10 level of significance. Feedstock (G1-F) and Processing (G2-P) experts rated cellulosic biofuels logistics as a significantly higher impeding factor to the scale-up of cellulosic biofuels compared to Sustainability participants (G4-S). These findings underscore the importance of examining issues from multiple perspectives.

**The TOP three barriers to the commercialization of cellulosic biofuels**

A follow-up RANKING question was designed to better explain the RATING scale responses regarding potential barriers to the scale-up of the U.S. cellulosic biofuels industry. Participants were asked to RANK the top three barriers by using a pull-down menu of the 9 BARRIERS listed in the previous RATING question. Responses were given a value weighting of 3 points for the “#1 RANKED commercialization barrier”, 2 points for the “#2 RANKED commercialization barrier” and 1 point for the “#3 RANKED commercialization barrier”.


The three highest RATED barriers to the commercialization of cellulosic biofuels (Table 5-4) were also identified as the highest RANKED barriers in Figure 5-4, providing a measure of construct validity. However, the RANKING results showed that competition vs. petro-fuels was the #1 commercialization barrier with an overall score of 228 when participants were forced into a rank-ordering. The #2 ranked commercialization barrier was high production costs (208), followed by policy uncertainty (206). For Feedstock, Processing, and Sustainability experts, competition vs. petro-fuels accounted for the largest percent (21%, 22%, and 25% respectively) of their group scores; thus confirming the RATING scale results. For Economics/Business experts, the #1 RANKED barrier, policy uncertainty, was also confirmed and accounted for 23 percent of the group score.

Likelihood of success for the production of cellulosic biofuels by 2020

Finally, the quantitative survey asked participants to indicate the likelihood that the production of cellulosic biofuels (excluding biochemicals and biomaterials) [Cellulosic BR] and the integrated production of both cellulosic biofuels and biochemicals [Integrated Cellulosic BR] will achieve success in the next five years (by 2020).

Participants rated the likelihood of success for cellulosic BR (excluding biochemicals and biomaterials) by 2020 (overall mean=4.77 on a 10-point scale) significantly lower than that for integrated cellulosic BR (overall mean=6.55) at the p=0.001 significance level (Figure 5-5). For both scenarios, Economics/Business experts were the least optimistic among the four expert groups with group means of 4.67 and 5.73, respectively (Figure 5-5).

The wide dispersion of responses is reflected in Figure 5-5 by the very large error bars. All four groups provided widely differing opinions regarding the future of cellulosic BR and integrated cellulosic BR. Interestingly, the averages were near the midpoint, illustrating that some respondents are relatively pessimistic or optimistic; and some simply do not know and rate the likelihood near the midpoint (Figure 5-5). These findings underscore and highlight the serious challenges that remain to the sustainable development and commercialization of this industry.
Conclusions

Second generation (cellulosic) biofuels represent a promising solution to avoid the food-fuel controversy, reduce dependence on fossil-fuels in the U.S. liquid transportation fuel sector, ease economic and geopolitical concerns, and lower lifecycle greenhouse gas (GHG) emissions. Significant progress has been made in recent years with respect to research and technical improvements; however, cellulosic biofuels have yet to become widely commercialized.

Earlier studies have provided potential factors affecting the scale up of the U.S. cellulosic biofuels industry in list form. This study specifically quantifies the major drivers and barriers confronting the U.S. cellulosic biofuels industry via paper-based and online surveys, administered between July and November, 2015. Respondents to the surveys included 228 experts from seven USDA National Institute of Food and Agriculture (NIFA) Coordinated Agricultural Projects (CAPs) and two industrial conferences. In this sense, the samples analyzed in the paper are non-probability convenience samples which, arguably, possess an optimal array of biorefinery supply chain expertise across all U.S. geographic regions. While the results do not represent the views of the entire U.S. biofuel community, the work presented in this paper highlights critical issues for decision-makers when considering industry entry options and potential incentives for the U.S. cellulosic biofuel industry.

The semi-structured survey instrument consisted of RATING and RANKING questions designed to examine the relative importance/degree of the identified eight drivers and nine barriers to the scale-up (commercialization) of the U.S. cellulosic biofuels industry. Results showed that government policies were rated as significantly more important than any other cellulosic biofuel scale-up driver. The second most importance driver was added value from non-fuel co-productions, followed by carbon emission reduction and volatile oil prices. Also, high production costs, policy uncertainty, and competition vs. petro-fuels were identified as the top three barriers to the commercialization of cellulosic biofuels by this study’s expert participants.

Policy uncertainty was found to be the second highest rated barrier overall but the #1 barrier for our 39 Economics/Business respondents. This highlights the controversial nature of current U.S. biofuel policies to the business community and their questionable impact on the industrial scale-up of the cellulosic biofuels industry.

This study’s results also highlighted the differences among participant groups. In particular, Economics/Business experts rated dependence on fossil fuels and carbon emission reduction as significantly less important drivers for cellulosic biofuels scale-up compared to
Feedstock specialists and Sustainability analysts. Also, Economic/Business experts viewed technology availability as a lower obstacle to the commercialization of cellulosic biofuels than Processing scientists. Feedstock and Processing experts rated cellulosic biofuels logistics as a significantly higher factor impeding the scale-up of cellulosic biofuels compared to Sustainability analysts. Meanwhile, Processing experts viewed high production costs as a significantly higher barrier vs. Feedstock specialists. The perceptional differences among participants regarding the factors confronting the U.S. cellulosic biofuels industry may not be surprising since different expert groups have their own research focus. These findings also underscore the importance of examining issues from multiple perspectives and highlight the value of the integrated USDA NIFA CAP program.

When assessing the likelihood that cellulosic biofuel biorefineries (excluding biochemicals and biomaterials) and integrated cellulosic biorefineries will achieve success in the next five years (by 2020), the mean for cellulosic BR’s falls near the midpoint (mean=4.77 on a 10-point scale); however, for integrated cellulosic BR’s, the perception is significantly more optimistic (mean=6.55). For both scenarios, Economics/Business experts were the least optimistic among the four expert groups, perhaps due to their views regarding the impact of volatile oil prices and policy uncertainty on this industry.

Expert perceptions regarding cellulosic biofuels scale-up (commercialization) can better inform and focus scientists and funding agencies to ameliorate feedstock delivery and storage issues and address cost-effective conversion technologies for the large-scale production of cellulosic biofuels. Policymakers may also consider the long-term impacts of national and regional biofuel policies/incentives on capital formation and economic development to address cellulosic biorefinery scale-up barriers.
Figure 5-1. Locations of the seven USDA-NIFA AFRI CAPs and two industrial conferences.
Figure 5-2. Cellulosic biorefinery supply chain from field/forest to wheel/wing.
Source: (An, Wilhelm, & Searcy, 2011; Hoekman, 2009; Yue et al., 2014)
Figure 5-3. Profile of four participant expertise groups in quantitative surveys: Feedstock, Processing, Economics/Business, and Sustainability [n=228].
Responses to the RANKING question were given a value weighting of 3 points for the “#1 RANKED commercialization barrier”, 2 points for the “#2 RANKED commercialization barrier”, and 1 point for the “#3 RANKED commercialization barrier”.

The downward sloping line shows the total score for each of the nine barriers and the vertical bars represent the percentage breakdown by participant groups (Feedstock specialists, Processing scientists, Economics/Business experts, and Sustainability analysts).

Figure 5-4. Cumulative score for the nine RANKED barriers and the percentage breakdown by four self-described participant background/expertise groups [n=219].
Likelihood of success was measured using a 10-point Likert scale, from 1=very low chance of success to 10=very high chance of success.

Cellulosic BR < Integrated cellulosic BR at the 0.001 significance level based on pair-wise comparisons, overall and among participant groups.

Error bars represent standard deviation.

Figure 5-5. Comparison of the likelihood of Success between Cellulosic Biorefinery (BR) and Integrated Cellulosic BR in the next 5 years (by 2020), by four self-described participant background/expertise groups.
Table 5-1. Drivers and barriers confronting the commercialization of cellulosic biofuels from existing literature.

<table>
<thead>
<tr>
<th>Drivers (n=8)</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Government policies</td>
<td>(Bardhan et al., 2015) (Golden &amp; Handfield, 2014) (Su et al., 2015) (Zhao, Brown, &amp; Tyner, 2015)</td>
</tr>
<tr>
<td>5. Rural economic development</td>
<td>(Cherubini, 2010) (Dale et al., 2014) (Ebadian et al., 2013)</td>
</tr>
<tr>
<td>7. Energy security</td>
<td>(Dale et al., 2014) (Ebadian et al., 2013) (Hughes, Moser, &amp; Gibbons, 2014)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Barriers (n=9)</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Feedstock costs</td>
<td>(Adams et al., 2011) (Yue et al., 2014) (Zhao et al., 2015) (Sharma, Ingalls, Jones, &amp; Khanchi, 2013)</td>
</tr>
<tr>
<td>3. Technology availability</td>
<td>(Cherubini &amp; Strømman, 2011a) (Dale et al., 2014) (Pacini et al., 2014) (Sharma et al., 2013)</td>
</tr>
<tr>
<td>4. Competition vs. corn-grain ethanol</td>
<td>(Babcock, Marette, &amp; Tréguer, 2011) (Sims et al., 2008)</td>
</tr>
<tr>
<td>5. Competition vs. petro-fuels</td>
<td>(Dale et al., 2014) (Sims et al., 2008)</td>
</tr>
<tr>
<td>6. Policy uncertainty</td>
<td>(Adams et al., 2011) (You et al., 2012) (Zhao et al., 2015)</td>
</tr>
<tr>
<td>---</td>
<td>------------------------</td>
</tr>
</tbody>
</table>
Table 5-2. Profile of the seven USDA Coordinated Agricultural Projects (CAPs) and two industrial conferences.

<table>
<thead>
<tr>
<th>Regional CAP</th>
<th>Lead University</th>
<th>2015 Annual Meeting Date &amp; Location</th>
<th>Academic researchers (&amp; participants)</th>
<th>Industrial experts (&amp; participants)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advanced Hardwood Biofuels Northwest (AHB)</td>
<td>U of Washington</td>
<td>Sept. 10, Seattle, WA</td>
<td>82 (n=24)</td>
<td>14 (n=5)</td>
</tr>
<tr>
<td>Bioenergy Alliance Network of the Rockies (BANR)</td>
<td>Colorado State U</td>
<td>Oct. 14, Missoula, MT</td>
<td>63 (n=7)</td>
<td>6 (n=1)</td>
</tr>
<tr>
<td>CenUSA Bioenergy</td>
<td>Iowa State U</td>
<td>July 28-29, Madison, WI</td>
<td>57 (n=13)</td>
<td>8 (n=6)</td>
</tr>
<tr>
<td>Southeast Partnership for Integrated Biomass Supply Systems (IBSS)</td>
<td>U of Tennessee</td>
<td>Aug. 10, Auburn, AL</td>
<td>74 (n=26)</td>
<td>6 (n=3)</td>
</tr>
<tr>
<td>Northwest Advanced Renewable Alliance (NARA)</td>
<td>Washington State U</td>
<td>Sept. 15, Spokane, WA</td>
<td>98 (n=47)</td>
<td>22 (n=5)</td>
</tr>
<tr>
<td>The Northeast Woody/Warm-season Biomass Consortium (NEWBio)</td>
<td>Pennsylvania State U</td>
<td>Aug. 3-5, Morgan-town, WV</td>
<td>83 (n=52)</td>
<td>6 (n=5)</td>
</tr>
<tr>
<td>Sustainable Bioproduct Initiative (SUBI)</td>
<td>Louisiana State U</td>
<td>Oct. 21, Baton Rouge, LA</td>
<td>54 (n=9)</td>
<td>5 (n=1)</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td></td>
<td></td>
<td><strong>511 (n=178)</strong></td>
<td><strong>67 (n=26)</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Industrial Conference</th>
<th>Organizer</th>
<th>Dates &amp; Location</th>
<th>Academic researchers (&amp; participants)</th>
<th>Industrial experts (&amp; participants)</th>
</tr>
</thead>
<tbody>
<tr>
<td>National Advanced Biofuel Conference &amp; Expo (NABC&amp;E)</td>
<td>BBI International</td>
<td>Oct. 26-28, Omaha, NE</td>
<td>-</td>
<td>40 (n=14)</td>
</tr>
<tr>
<td>The 12th Advanced Bioeconomy Leadership Conference (ABLC)</td>
<td>Biofuels Digest</td>
<td>Nov. 2-5, San Francisco, CA</td>
<td>-</td>
<td>60 (n=10)</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>100 (n=24)</strong></td>
</tr>
</tbody>
</table>
Table 5-3. The mean RATING\(^1\) of the eight drivers for the scale-up (commercialization) of the U.S. second generation (cellulosic) biofuels industry and significant differences of perceived drivers among four participant categories: Feedstock (G1-F), Processing (G2-P), Economics/Business (G3-E/B), and Sustainability (G4-S).

<table>
<thead>
<tr>
<th>Scale-up DRIVERS</th>
<th>Overall (n=226(^2))</th>
<th>G1-F (n=88)</th>
<th>G2-P (n=71)</th>
<th>G3-E/B (n=39)</th>
<th>G4-S (n=28)</th>
<th>Sig(^3)</th>
<th>Pairwise Comparisons(^4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Government policies</td>
<td>4.63</td>
<td>4.70</td>
<td>4.54</td>
<td>4.69</td>
<td>4.57</td>
<td>0.284</td>
<td>G4-S&gt;G3-E/B, G2-P, G1-F</td>
</tr>
<tr>
<td>2. Added value from non-fuel co-products</td>
<td>4.23</td>
<td>4.19</td>
<td>4.35</td>
<td>4.18</td>
<td>4.14</td>
<td>0.594</td>
<td></td>
</tr>
<tr>
<td>3. Carbon emission reduction</td>
<td>4.12</td>
<td>4.13</td>
<td>4.07</td>
<td>3.92</td>
<td>4.5</td>
<td>0.101</td>
<td></td>
</tr>
<tr>
<td>4. Volatile oil prices</td>
<td>4.09</td>
<td>4.07</td>
<td>4.15</td>
<td>4.05</td>
<td>4.04</td>
<td>0.890</td>
<td></td>
</tr>
<tr>
<td>5. Dependence on fossil fuels</td>
<td>3.94</td>
<td>4.09</td>
<td>3.96</td>
<td>3.51</td>
<td>4.0</td>
<td>0.027</td>
<td>G1-F, G4-S&gt;G3-E/B</td>
</tr>
<tr>
<td>6. Rural economic development</td>
<td>3.88</td>
<td>3.82</td>
<td>3.96</td>
<td>3.95</td>
<td>3.75</td>
<td>0.633</td>
<td></td>
</tr>
<tr>
<td>7. Energy security</td>
<td>3.85</td>
<td>3.93</td>
<td>3.86</td>
<td>3.79</td>
<td>3.62</td>
<td>0.382</td>
<td></td>
</tr>
<tr>
<td>8. Food-vs.-fuel debate</td>
<td>3.18</td>
<td>3.26</td>
<td>3.09</td>
<td>3.10</td>
<td>3.25</td>
<td>0.759</td>
<td></td>
</tr>
<tr>
<td><strong>Pairwise Comparisons(^4)</strong></td>
<td><strong>1&gt;2-8;</strong></td>
<td><strong>1&gt;2-8;</strong></td>
<td><strong>1&gt;4-8;</strong></td>
<td><strong>1&gt;3-8;</strong></td>
<td><strong>1&gt;6-8;</strong></td>
<td><strong>1&gt;3-8;</strong></td>
<td><strong>1&gt;6-8;</strong></td>
</tr>
</tbody>
</table>

\(^1\) RATING was measured using a 5-point Likert-scale, from 1=not important at all to 2=somewhat unimportant to 3=neither important nor unimportant to 4=somewhat important to 5=very important.

\(^2\) Two incomplete responses were deleted, resulting in 226 responses entering the final analysis.

\(^3\) Based on parametric analysis of variance (ANOVA) test, bold = significant at the 0.1 level.

\(^4\) Based on two-sample t-test at the 0.1 significance level.
Table 5-4. The mean RATING\(^1\) of the nine barriers to the scale-up (commercialization) of the U.S. second generation (cellulosic) biofuels industry and significant differences of perceived barriers among four participant categories: Feedstock (G1-F), Processing (G2-P), Economics/Business (G3-E/B), and Sustainability (G4-S).

<table>
<thead>
<tr>
<th>Scale-up BARRIERS</th>
<th>Overall (n=227(^2))</th>
<th>G1-F (n=89)</th>
<th>G2-P (n=71)</th>
<th>G3-E/B (n=39)</th>
<th>G4-S (n=28)</th>
<th>Sig.(^3)</th>
<th>Pairwise Comparisons(^4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. High production costs</td>
<td>4.22</td>
<td>4.11</td>
<td>4.37</td>
<td>4.18</td>
<td>4.22</td>
<td>0.267</td>
<td>G2-P&gt;G4-S, G3-E/B</td>
</tr>
<tr>
<td>2. Policy uncertainty</td>
<td>4.17</td>
<td>4.17</td>
<td>4.11</td>
<td>4.26</td>
<td>4.17</td>
<td>0.885</td>
<td>G1-F, G2-P&gt;G4-S</td>
</tr>
<tr>
<td>3. Competition vs. petro-fuels</td>
<td>4.17</td>
<td>4.19</td>
<td>4.25</td>
<td>3.92</td>
<td>4.29</td>
<td>0.333</td>
<td></td>
</tr>
<tr>
<td>4. Feedstock costs</td>
<td>3.89</td>
<td>3.94</td>
<td>3.94</td>
<td>3.84</td>
<td>3.67</td>
<td>0.528</td>
<td></td>
</tr>
<tr>
<td>5. Capital availability</td>
<td>3.78</td>
<td>3.74</td>
<td>3.81</td>
<td>3.92</td>
<td>3.64</td>
<td>0.701</td>
<td></td>
</tr>
<tr>
<td>6. Technology availability</td>
<td>3.57</td>
<td>3.62</td>
<td>3.73</td>
<td>3.36</td>
<td>3.30</td>
<td>0.083</td>
<td>G1-F, G2-P&gt;G4-S</td>
</tr>
<tr>
<td>7. Cellulosic biofuels logistics</td>
<td>3.50</td>
<td>3.60</td>
<td>3.53</td>
<td>3.49</td>
<td>3.14</td>
<td>0.103</td>
<td></td>
</tr>
<tr>
<td>8. Consistent feedstock supply</td>
<td>3.29</td>
<td>3.33</td>
<td>3.23</td>
<td>3.41</td>
<td>3.18</td>
<td>0.731</td>
<td></td>
</tr>
<tr>
<td>9. Competition vs. corn-grain ethanol</td>
<td>3.01</td>
<td>3.07</td>
<td>3.02</td>
<td>2.97</td>
<td>2.87</td>
<td>0.850</td>
<td></td>
</tr>
<tr>
<td><strong>Pairwise Comparisons</strong>(^4)</td>
<td>1-3&gt;4-9; 1&gt;8&gt;9; 1-7&gt;9</td>
<td>1-3&gt;4-9; 1&gt;8&gt;9; 1-7&gt;9</td>
<td>1-5&gt;9; 1&gt;7&gt;9</td>
<td>2&gt;3-9; 1-3&gt;4-9</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

\(^1\) RATING was measured using a 5-point Likert-scale, from 1=not a barrier to 2=low barrier to 3=moderate barrier to 4=high barrier to 5=very high barrier.

\(^2\) One incomplete response was deleted, resulting in 227 responses entering the final analysis.

\(^3\) Based on parametric analysis of variance (ANOVA) test, bold = significant at the 0.1 level.

\(^4\) Based on two-sample t-test at the 0.1 significance level.
References


CHAPTER 6

BARRIERS TO THE SCALE-UP OF THE U.S. INTEGRATED CELLULOSIC BIOREFINERIES: A MIXED METHODS RESEARCH

This paper, by Min Chen and Paul M. Smith, was written for submission to Fuel or Biomass and Bioenergy.
Abstract

Second generation (cellulosic) biofuels provide an attractive solution to reduce the dependence on fossil fuels, to meet climate change policy targets, and to address concerns about competition with food crops and land use change confronting the U.S. first generation biofuels. However, the production of cellulosic biofuels has not yet proven to be cost-effective and has yet to become widely commercialized. The integrated production of cellulosic biofuels and biochemcials/integrated cellulosic biorefinery (BR) offers an opprotunity to effectively utilize feedstock fractions, diversify value stream outputs, improve financial performance, and mitigate political and market risks. A dearth of literature exists addressing potential barriers to the scale-up of this industry; thus, this study deployed a mixed methods approach to address this issue. In phase I, a qualitative e-Survey with eighteen academic and industrial experts collated a list of eight barriers. In phase II, quantitative paper- and online-based surv eys were responded by 228 or 34 percent of the 678 expert participants recruited from seven USDA National Institute of Food and Agriculture (NIFA) Coordinated Agricultural Projects (CAPs) and two industrial conferences to examine these barriers. RATING and RANKING results both show that competition vs. petrochemicals, high production costs, and policy uncertainty represent the top three barriers to the U.S. integrated cellulosic BRs. Our eighteen Phase I experts indicated that, to address these key barriers to the commercial development of the U.S. integrated cellulosic BR industry, consistent government funding & incentives and, to a lesser extent, new technology development and education of end-use consumer will be required.

Introduction

Due to increasing concerns over greenhouse gas (GHG) emissions from the combustion of fossil fuels and the associated climate change impacts, the U.S. submitted an Intended Nationally Determined Contribution (INDC) to the United Nations Framework Convention on Climate Change (UNFCCC) to cut net GHG emissions by 26-28 percent below 2005 levels by 2025 (The White House, 2015b). On August 3, 2015, President Obama announced the final Clean Power Plan to reduce carbon dioxide emissions by 32 percent from 2005 levels by 2030 (The White House, 2015a). At the G20 Summit held on September 4, 2016, U.S. formally commited to Paris Climate Accord which sets a long-term goal of keeping the increase in global average
temperature to well below 2°C above pre-industrial level (Chemnick, 2016; European Commission, 2016). Supported by these government policies, the quest for environmentally benign sources of energy for our needs has become urgent in recent years. A variety of renewable energy sources are being studied in U.S., including solar, wind, hydro, nuclear, and biomass. Renewable biofuels recovered from biomass are at the forefront of these developments as they show great potential to promote rural economic development while mitigating several key negatives associated with petroleum products, including unreliable global supply, price volatility, and carbon emissions (Gegg, Budd, & Ison, 2014).

The U.S. biofuels industry is currently dominated by first generation biofuels, corn-grain ethanol and biodiesel, which account for over 90% of the total renewable biofuels within U.S. (Environmental Protection Agency, 2015). However, the first generation biofuels seem to create some skepticism to scientists and policymakers. Concerns exist about the sourcing of feedstocks, including the impact of edible feedstock on biodiversity, land use change, and competition with food (Chen, Smith, & Wolcott, 2016; Naik, Goud, Rout, & Dalai, 2010). As a result, many industrial, governmental, and research interests are transiting to second generation (cellulosic) biofuels (Brown & Brown, 2013; Mohr & Raman, 2013). Compared to first generation biofuels, cellulosic biofuels provide an attractive solution in avoiding the food-fuel controversy while meeting the stringent targets of GHG emissions reduction. However, the U.S. cellulosic biofuels have yet to become widely commercialized due to a variety of issues, including high production costs, policy uncertainty, and strong competition from petroleum-based counterparts (Balan, Chiaramonti, & Kumar, 2013; Chen et al., 2016; FitzPatrick, Champagne, Cunningham, & Whitney, 2010).

Facing these issues, several researchers have suggested a short-to-medium term strategy for the sustainable development of the U.S. cellulosic biofuels industry; that is, to integrate the production of biochemicals with cellulosic biofuels (Joseph J Bozell, 2008; Joseph J. Bozell & Petersen, 2010; Cherubini, 2010; Cherubini & Strømman, 2011; FitzPatrick et al., 2010). Biochemicals represented around 4% of U.S. chemical production in 2014 (Golden, Handfield, Daystar, & McConnell, 2015) and are forecasted to account for at least 45 percent of all U.S. chemicals by 2025 (Bardhan, Gupta, Gorman, & Haider, 2015). According to a 2014 USDA report, the U.S. production of bio-based chemicals could generate $775 million in added value by 2017 and $3 billion per year by 2022 (Nexant, 2014). The emerging biochemicals industry may also contribute to the U.S. rural economy by providing 3,500 jobs in 2017 and 19,000 in 2022 (Nexant, 2014). More recently, according to a new BIO report, the renewable chemical is
estimated to make up 11 percent of the $3,401 billion global chemical market by 2020 (de Guzman, 2016). As a result, this integrated cellulosic biorefinery (BR) scenario can contribute to the effective utilization of feedstock fractions, to a diversified value stream outputs, to the improvement of financial performance, and to the mitigation of potential market and political fluctuations (Joseph J Bozell, 2008; Joseph J. Bozell & Petersen, 2010; Fernando, Adhikari, Chandrapal, & Murali, 2006; FitzPatrick et al., 2010).

To date, research works on integrated cellulosic biorefineries (BRs) have been largely conducted to improve and optimize the performance of individual conversion processes with techno-economic studies (Andiappan et al., 2015; Dang, Hu, Rover, Brown, & Wright, 2016; Jensen et al., 2016; Ng, Hassim, & Ng, 2013). However, apart from technology development, a variety of issues should be taken into account to commercialize integrated cellulosic BRs, such as political, environmental, and market issues. A dearth of literature exists addressing potential barriers to the scale-up of the U.S. integrated cellulosic BRs industry. The overall goal of this paper is to develop a list of major barriers and potential solutions to the scale-up of U.S. integrated cellulosic biorefineries and to quantitatively assess the degree of these identified barriers via a mixed methods research.

**Research Design**

This research deployed a mixed methods exploratory sequential design for primary data collection (Creswell & Clark, 2011) (Figure 6-1). Phase I conducted a pilot study with “select” academic and industrial experts to develop a list of barriers to the scale-up of the U.S. integrated cellulosic biorefineries and to explore potential solutions to these identified barriers. Phase II implemented quantitative surveys with academic and industrial experts to evaluate the degree of these identified barriers.
Phase I: Qualitative e-Survey (pilot study)

The pool of experts

Nonprobability purposive sampling method was employed to reach a targeted sample quickly and to ensure the assembling of a sample with known or demonstrable experience and expertise in the U.S. bioenergy, biofuel and bio-based products areas (Trochim, 2000). Eighteen experts from universities, national labs, and the industrial sector were identified through exploratory documentary analysis and internet searches (Table 6-1).

University and industrial experts were identified by searching recent publications (2010 to 2015) via google scholar with the following four key words: advanced biofuels, cellulosic biofuels, second generation biofuels, and integrated biorefinery. The ten most cited articles for each key word were used to identify “experts”. Overall, the forty selected articles were published in the following peer-reviewed journals, including AlChE Journal, Biofuels, Bioprocessing and Biorefining (Biofpr), Biomass & Bioenergy, Bioresource Technology, Biotechnology and Bioengineering, Chemical Engineering Journal, Chemical Engineering Research and Design, Energy Policy, Energy & Environmental Science, Environmental Science & Technology, Fuel, Green Chemistry, Renewable Energy, and Renewable & Sustainable Energy Reviews. Of the forty articles, only the corresponding authors were included in our sample frame resulting in forty identified experts who received our qualitative e-Survey. Ten university experts and five industrial experts participated in this pilot study, resulting in a response rate of 37.5 percent (15/40).

Government experts were identified from the four U.S. national labs devoted to research and development of renewable liquid transportation fuels: (1) the Forest Products Laboratory in Madison, WI; (2) the National Renewable Energy Laboratory in Golden, CO; (3) the Oak Ridge National Laboratory in Oak Ridge, TN; and (4) the Pacific Northwest National Laboratory in Richland, WA. Experts from three of the four (75%) national labs participated in the pilot study.

Construct measurement and data collection

The data for this pilot study was obtained from an online survey (e-Survey) from June to July, 2015 via SurveyMonkey® to decrease time and costs and to provide access to
geographically dispersed subjects (Burns, 2010; James, 2007). A three-email strategy was applied for the data collection. The first email included an embedded URL link to a SurveyMonkey® website, followed by two reminder emails at one-week intervals (Dillman, Smith, & Christian, 2014). The e-Survey instrument consisted of two open-ended questions designed to address the following topics: 1) barriers to the integrated production of biochemicals and cellulosic biofuels; and 2) potential solutions to those identified barriers.

**Phase II: Quantitative paper- and online-based surveys**

**Study population**

The data used for analysis in phase II was collected via quantitative paper-based surveys and e-Surveys from July to November 2015. The sample population for this study was obtained from the registration lists of the 2015 annual meetings of seven U.S. Department of Agriculture (USDA) National Institute of Food and Agriculture (NIFA) Coordinated Agricultural Projects (CAPs) (Table 6-2 & Figure 6-2) (National Institute of Food and Agriculture (NIFA), 2015). “NIFA has invested $156 million in seven five-year projects across the U.S. to assist with research and development for regionally-based advanced biofuel and bioproduct industries” (National Institute of Food and Agriculture (NIFA), 2015). Accordingly, these CAPs contain significant science-based expertise in feedstock logistics, conversion processes, economic/business and sustainability analysis, as well as expertise gained from collaboration with key stakeholders and industrial partners (National Institute of Food and Agriculture (NIFA), 2015). To supplement and balance industrial expert group representation, attendees to the following two industrial conferences were added to our population: the 2015 National Advanced Biofuel Conference & Expo (NABC&E) and the 12th Advanced Bioeconomy Leadership Conference (ABLC) (Table 6-2 & Figure 6-2). NABC&E provides a vertically integrated venue for “industry professionals engaged in producing, developing and deploying advanced biofuels including cellulosic ethanol, biobased platform chemicals, polymers and other renewable molecules” (http://www.advancedbiofuelsconference.com/ema/DisplayPage.aspx?pageId=The_Conference__Expo). The ABLC provides a venue to gather senior leadership in the advanced bioeconomy
focusing on advanced low carbon fuels, chemicals, and materials, plus advanced policies and financing strategies (http://advancedbiofuelssummit.com/). Together, these two conferences represent considerable industrial knowledge on the production, development and deployment of biofuels. In this sense, the samples analyzed in the paper are non-probability convenience samples which arguably, represent a unique set of knowledge and experience on the U.S. biorefinery supply chain from field/forest to wheel/wing across all U.S. geographic regions (Figure 6-3).

**Construct measurement and data collection**

The semi-structured survey instrument for phase II consisted of RATING questions designed to examine the degree of the phase I identified barriers to the successful integrated production of cellulosic biofuels and biochemicals. A follow-up RANKING question delineated the top three barriers in a meaningful and interpretable way and to ensure construct validity (Dillman et al., 2014). The RANKING questions were designed to force differences which may not have been produced in the RATING questions.

Administration of the quantitative surveys included both onsite paper-based surveys and e-Surveys following each AFRI CAP annual meeting and industrial conference to increase responses. A three-email strategy was also deployed for the data collection (Dillman et al., 2014).

**Respondent profile for phase II**

Data collection efforts resulted in 228 respondents, with an overall response rate of 34 percent (228/678) (Table 6-2). Respondents were categorized into four groups based on their research focus/expertise with two fifths focused on feedstock research in terms of breeding, genetics, agronomy, planting, and harvesting; one third were process development experts; 17 percent were experts analyzing economics and/or business applications; and the remaining 12 percent were sustainability analysts, such as life cycle/environmental impact analysis. Among the four groups, Economics/Business experts had the highest level of research experience (mean=8.6 years), whereas Sustainability analysts had the lowest (mean=5.0 years of experience) (Figure 6-4).
Nonresponse bias

To assess non-response bias, those who responded to the initial onsite paper-based surveys (early respondents; n=147) were compared to those who responded after follow-up steps were taken (e-Survey) (late respondents; n=89) across a number of survey questions with analysis of variance (ANOVA). The late respondents were generally to behave more like non-respondents so late responders can be used as a proxy for non-respondents (Armstrong & Overton, 1977; Miller & Smith, 1983; TRC, 2009; Welch & Barlau, 2013). The variables used for this comparison are years of experience, the importance of government policies as a driver for the scale-up of cellulosic biofuels, the degree of competition vs. petro-fuels as a barrier to the scale-up of cellulosic biofuels, the degree of competition vs. petro-chemicals as a barrier to the integrated production of cellulosic biofuels and biochemicals, and the likelihood of success for the scale-up of integrated cellulosic biorefinery by 2020. The ANOVA indicated that with 95% confidence interval, no significant differences were found between early and late respondents on their mean years of experience, perceptions of the importance/degree of drivers and barriers, and likelihood of success for the scale-up of integrated cellulosic biorefinery by 2020. Thus, no evidence of significant nonresponse bias exists for this sample.

Results and Discussion

Barriers to integrated cellulosic biorefineries from pilot e-Survey

Question: In your opinion, what is the highest BARRIER to the integrated production of cellulosic biofuels and biochemicals?

This open-ended question collected information regarding significant barriers to the integrated production of cellulosic biofuels and biochemicals. This study’s eighteen experts suggested eight common barriers, including new technology availability, capital availability, policy uncertainty, high production cost, process complexity, competition vs. petro-chemicals, product/market expertise, and compatibility with existing infrastructure (Table 6-3).
New technology availability

Four or 22 percent of the eighteen expert participants indicated new technology availability as the highest integrated production barrier (Table 6-3). The integrated production of both cellulosic biofuels and biochemicals requires additional process to convert lignocellulosic biomass to renewable biochemicals. Also, half of the participants mentioned that the technology development is still at bench scale.

“Adding coproduct production potentially involves more ‘new’ steps that will require time/effort to learn how to operate well.” (Participant A)

“The availability of broad based technology to carry out production of chemicals, and the technology still has to be proven at large scale – struggling to get beyond pilot stage still – needs clear independent evidence of performance.” (Participant L)

Capital availability

Another four or 22 percent of the respondents acknowledged that integrated cellulosic BR faced the challenge of capital availability. Of these, three respondents believed that unproven new technology is one of the main factors hindering the level of investment or funding.

“Adding another production process increases biorefinery capital cost – imposes a bigger financing hurdle to overcome.” (Participant C)

“From an industry perspective, capital availability will be the major barrier to the integrated manufacturing of bioproduct and biofuel, and investors are hesitant to invest in technologies that have not been set-up for commercial manufacture yet.” (Participant R)
Policy uncertainty

Policy uncertainty was acknowledged by three participants (17%) as the highest barrier to the integrated production scenario. Also, policy uncertainty was viewed to have a negative impact on attracting investment.

“Stable and consistent policy will attract long-term investment, which is critical to drive forward biofuel technology as well as biochemical sector.” (Participant G)

High production cost

Another three of the eighteen expert participants viewed high production costs as the highest barrier to integrated cellulosic BRs.

“...The cost of biofuels and bio-based chemicals derived from integrated cellulosic biorefineries given current technologies will be higher than that of petrochemically-derived materials or non-cellulosic biobased chemicals.” (Respondents H)

Additional barriers

Additional barriers to the scale-up of integrated cellulosic biorefineries included process complexity, competition vs. petro-chemicals, product/market expertise, and compatibility with existing infrastructure. Product/market expertise was indicated by participant F as “market introduction of several compounds and chemical industry expertise”.

Rating of integrated production barriers from quantitative surveys

In Phase II – quantitative paper-based surveys and e-Surveys, expert participants were asked to RATE the relative “degree” of the eight barriers by the following question:
**Question:** Please indicate the degree to which you consider the following 8 factors as BARRIERS to the integrated production of biochemical and cellulosic biofuels. [Note: The degree of these eight barriers were measured using a 5-point Likert-scale, from 1=not a barrier to 2=low barrier to 3=moderate barrier to 4=high barrier to 5=very high barrier].

This study’s 221 participants, as a whole, rated the eight barriers as moderate to high, which underscores the validity of those constructs identified from former pilot study. Overall, *competition vs. petro-chemicals*, *high production costs*, *policy uncertainty*, and *capital availability* were rated as significantly higher barriers than any other factor with overall mean values of 3.97, 3.89, 3.86, and 3.75 (Table 6-4). The high cost of cellulosic biofuel and biochemical production is underscored by cost competitiveness analysis in a recent USDA report (Nexant, 2014). With higher production costs, cellulosic biofuels and biochemicals are less likely to be economically competitive with traditional petroleum-based alternatives (Joseph J Bozell, 2008). *Policy uncertainty*, the third highest barrier, is supported by several studies indicating the adverse impact of unreliable policies on the large-scale production of bio-based chemicals (Carus, Carrez, Kaeb, Ravenstijn, & Venus, 2011; Carus & Dammer, 2013). *Capital availability* was rated as the fourth highest barrier overall but the #1 barrier for our 39 Economics/Business experts (Table 6-4). This highlights the difficulty for the business community to attract capital investment with nascent technology and uncertain political environment (Maity, 2015).

Additional barriers to the scale-up of integrated cellulosic BR systems included *process complexity* (3.48), *new technology availability* (3.40), *compatibility with existing infrastructure* (3.39), and *product/market expertise* (3.32) (Table 6-4). These results are in line with existing literature which have suggested that the availability of new conversion process for biochemicals and its compatibility with existing infrastructure are critical to the commercial development of integrated cellulosic biorefineries (Joseph J. Bozell & Petersen, 2010; de Jong, Higson, Walsh, & Wellisch, 2012; Richard, 2010). Also, organic renewable chemicals are different from liquid transportation biofuels in terms of applications and markets. As a result, the integrated production of cellulosic biofuels and biochemical requires the producers to have knowledge about both products and have access to both markets.

Significant differences between group mean values were found at the p=0.1 significance level for three out of the eight drivers identified in this study (Table 6-4). In particular, Economics/Business experts (G3-E/B) largely viewed potential integrated cellulosic biorefineries industry scale-up barriers differently vs. the other three groups. Economics/Business participants...
(G3-E/B) viewed *product/market expertise* as relatively higher impeding factors compared to the other three expert groups. On the other hand, Economics/Business (G3-E/B) and Sustainability (G4-S) experts rated *competition vs. petro-chemicals* as a lower obstacle to the integrated cellulosic BR than Feedstock specialists (G1-F) and Processing scientists (G2-P). Meanwhile, Processing scientists (G2-P) rated *process complexity* as significantly higher barriers to the commercialization of integrated cellulosic BR than the other experts. These findings underline the significance of examining issues from multiple perspectives.

**The TOP three integrated production barriers**

A follow-up RANKING question was designed better to explain the RATING scale responses regarding potential barriers to the scale-up of the U.S. integrated cellulosic BR.

**Question:** Please indicate the TOP 3 highest barriers to integrate the production of biochemical into a second generation (cellulosic) plant, by using the pull-down menu of the 8 BARRIERS listed in former rating question.

All responses were given a value weighting of 3 points for the “#1 RANKED commercialization barrier”, 2 points for the “#2 RANKED commercialization barrier” and 1 point for the “#3 RANKED commercialization barrier”. Interestingly, the three highest RATED barriers to integrated cellulosic biorefinery (Table 6-4) were also identified as the highest RANKED barriers in Figure 6-5, providing a measure of construct validity. *Competition vs. petro-chemicals* was the #1 ranked “highest barrier” by 56 expert participants and with a cumulative score of 239 when participants were forced into a rank-ordering. The #2 ranked commercialization barrier was *high production costs* (#1=34 and cumulative score=177), followed by *policy uncertainty* (#1=32 and cumulative score=159).
Potential solutions to the integrated production scenario

Finally, in phase I – pilot study, after collecting information regarding the highest barriers to the integrated cellulosic BR, an open-ended, follow-up question asked participants to suggest potential solution to overcome their suggested highest barrier, as follows.

**Question:** Can this highest barrier be overcome? How so or why not?

According to the responses from eighteen expert participants, three common solutions were identified, including **consistent government funding & incentives**, **new technology development**, and **education of end-use consumer** (Table 6-3).

**Consistent government funding & incentives**

Eleven or sixty-one percent of our eighteen participants indicated the importance and necessity of **consistent government funding & incentives** for a successful integrated cellulosic BR scenario (Table 6-4). Most participants suggested that policy stability was critical to attract long-term investment.

“Probably, but only through better funding support. I note that DOE is holding a ‘Chemical from Biomass’ workshop in mid-July this year [2015]. Part of which is to identify top chemical candidates for research and investment.” (Participant A mentioned the barrier of new technology availability)

“Yes. Political commitment can drive investment and support for technology development through necessary loan guarantee or other forms of support.” (Participant L mentioned the barrier of new technology availability)

“Yes. Need consistent and long-term government policies that level playing field of biofuels and bioproducts production. Consistent policy can help in access to capital. Costs can be reduced given research and development funding”. (Participant M mentioned the barrier of high production cost)
“Yes. The government needs to encourage investors to invest in these integrated bioproduct/biofuel technologies just as it has encouraged them to invest in traditional corn ethanol biorefineries. Additional boost in investment in research on developing/improving integrated bioproduct/biofuel processes is required. (Participant R mentioned the barrier of capital availability)

Also, government plays an important role – through the taxation of carbon – in contributing to economic competitiveness of integrated cellulosic BRs.

“Yes. If there is economic incentive to do so, e.g., by implementation of policies that incentivize such production, e.g., imposition of attributes of carbon tax. Foremost, much greater policy certainty is needed, certainty that the improved sustainability attributes of cellulosic biofuels and biochemical technology will be valued such that their higher costs of production compared to current (fossil fuel-based) technologies can be justified.”

(Participant J mentioned the barrier of high production cost)

New technology development

New technology development was the second most frequently mentioned solution to the successful integrated production of cellulosic biofuels and bio-based chemicals. Over twenty percent of the participants (22%) stated that new technology development, such as R&D in enzymes, conversion yields, and microbial technology, will underwrite the scale up of integrated cellulosic biorefineries (Table 6-4). Meanwhile, the cooperation between industry and academic sectors were suggested by participant B as a promising solution to the technological barrier confronting the integrated production of cellulosic biofuels and biochemical.

“Yes. It’s all microbial technology, new strains that can do this, pull the C5, C6 sugars out of stover or other feedstocks for the production of biofuels and/or biochemical, much more efficiently and as a consequence, lower cost.” (Participant I mentioned new technology availability)
“Yes, the scale up needs new technology development, which could be achieved via cooperation and engagement between industry and academia.” (Participant B mentioned the barrier of process complexity)

**Education of end-use consumer**

One participant mentioned about lack of customer preference in terms of price premium when comparing bio-based chemicals with petroleum-based alternatives and emphasized the importance of *education of end-use consumer* about the environmental benefits of bio-based products.

“I guess education of final customers – about the desirability of bio-based as a route to climate change mitigation – is the most realistic long-term strategy to compete with petro-products, which ripples back to manufacturers. Since I have not seen, in many conversion pathways and bio-products proposed over the last 8 years, realistic promise of breakthrough production cost reductions, the economic improvement, must come from selling price premium – assured over the 20 to 30 year project life.” (Participant D mentioned the barrier of competition vs. petro-chemical)

**Conclusions**

Cellulosic biofuels represent a promising solution to reduce the dependence on fossil fuels, to meet climate change policy target while addressing food-vs.-fuel debate confronting the U.S. corn-grain ethanol industry. Significant progress has been made in the last decade with respect to research and development. However, the U.S. cellulosic biofuels industry has yet to become widely commercialized due to a variety of reasons, such as high production costs, policy uncertainty, and strong competition from petroleum-based fuels. The integrated cellulosic biorefinery scenario provides many practical benefits including effective use of feedstock fractions, diversified value stream outputs, improved financial performance, and risk mitigation.
However, a dearth of literature exists addressing potential barriers to the scale-up of integrated cellulosic BRs. This study sheds light on this issue via an exploratory sequential design, one of the mixed methods research, as follows:

- (Phase I) **Qualitative e-Survey** to derive a list of barriers to the integrated cellulosic biorefinery scenario as well as potential solutions to these identified barriers; and
- (Phase II) **Quantitative surveys** to examine the relative degree of the Phase I barriers.

In phase I, qualitative e-Survey with eighteen “select” experts identified a list of eight barriers confronting the commercial development of U.S. integrated cellulosic biorefineries. In phase II, the 228 academic researchers and industrial experts from seven USDA CAPs and two industrial conferences rated these identified eight barriers as moderate to high. Results from the rating and ranking questions revealed that the top three barriers to the successful integrated production of cellulosic biofuels and bio-based chemicals were *competition vs. petro-chemicals*, followed by *high productions costs* and *policy uncertainty*.

This study’s results also highlighted the differences among participant groups. In particular, Economics/Business experts rated *product/market expertise* as relatively higher impeding factors compared to the other three expert groups, and viewed *competition vs. petro-chemicals* as a significantly lower obstacle to the integrated cellulosic BR than Feedstock specialists (G1-F) and Processing scientists (G2-P). Meanwhile, Processing scientists (G2-P) rated *process complexity* as significantly higher barriers to the commercialization of integrated cellulosic BR than the other experts. The perceptional differences among participants regarding the factors confronting the U.S. cellulosic biofuels industry are understandable since each expert group has their own research focus and interests. These findings also highlight the significance of examining issues from multiple perspectives and underscore the value of the integrated USDA NIFA CAP program.

This paper highlights a number of implications for existing players, newcomers, and policymakers. In order for integrated cellulosic biorefinery scenario to be successful, industrial players need supportive and *consistent government funding & incentives*. Liquid transportation biofuels were described as being supported by a plethora of incentives and legislative support schemes, such as subsidies of feedstock and mandates of biofuel blending (Gegg et al., 2014). On the contrary, several researchers have highlighted concerns regarding unparalleled political support for biochemicals (Carus et al., 2011; Carus & Dammer, 2013). As discussed in this study,
the successful integrated production calls for leveling playing field of policy support for both biofuels and biochemicals. Among the government policies and incentives, carbon tax should be strictly enforced in order to help renewable biofuels and biochemical achieve cost-competitiveness with petroleum-based counterparts. Additionally, competition with petroleum-based alternatives requires new technology development to reduce overall production costs and more importantly needs the education of end-use consumer regarding climate impact and environmental benefits of renewable bio-based products. The collected information from this study contributes to extant debates on the future commercial development of integrated cellulosic biorefineries.

Acknowledgement

This work, as part of the Northwest Advanced Renewables Alliance (NARA), was funded by the Agriculture and Food Research Initiative Competitive Grant no. 2011-68005-30146 from the USDA National Institute of Food and Agriculture.
**Problem:**
Barriers to the Commercialization of Integrated Cellulosic Biorefineries (BRs)/Integrated Production of Cellulosic Biofuels and Biochemicals

<table>
<thead>
<tr>
<th>Phase I:</th>
<th>Phase II:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qualitative e-Survey (Pilot Study)</td>
<td>Quantitative Paper- and Online-based Surveys</td>
</tr>
</tbody>
</table>

**Objective:**
- **Phase I:**
  Develop a list of barriers confronting the commercialization of the U.S. integrated cellulosic biorefinery industry, & explore potential solutions to these identified barriers.
- **Phase II:**
  Quantitatively evaluate barriers to commercialization.

**Implications:**
- The results highlight issues to existing players and new comers when designing and managing an integrated cellulosic biorefinery system;
- The findings can be used by government researchers to better inform policies aimed at encouraging this industry.

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*Figure 6-1. Mixed methods design for research on barriers to integrated cellulosic biorefineries commercialization.*
Figure 6-2. Locations and relative sizes of the seven USDA-NIFA AFRI CAPs and two industrial conferences.
Figure 6-3. Cellulosic biorefinery supply chain from field/forest to wheel/wing.
Source: (An, Wilhelm, & Searcy, 2011; Hoekman, 2009; Yue, You, & Snyder, 2014)
* Forty-six incomplete responses were excluded for this analysis.

**Figure 6-4. Profile of four participant expertise groups: Feedstock specialists, Processing scientists, Economics/Business experts, and Sustainability analysts [n=228].**
Responses to the RANKING question were given a value weighting of 3 points for the “#1 RANKED commercialization barrier”, 2 points for the “#2 RANKED commercialization barrier”, and 1 point for the “#3 RANKED commercialization barrier”.

Figure 6-5. Number of “#1 RANKED commercialization barrier” and cumulative score for the eight barriers by four self-described participant background/expertise groups [n=204].

1 Responses to the RANKING question were given a value weighting of 3 points for the “#1 RANKED commercialization barrier”, 2 points for the “#2 RANKED commercialization barrier”, and 1 point for the “#3 RANKED commercialization barrier”. 
## Table 6-1. List of participants for phase I – pilot e-Survey.

<table>
<thead>
<tr>
<th>Participant</th>
<th>Sector</th>
<th>Expertise/Job Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>University</td>
<td>Technology of bio-based chemicals &amp; products</td>
</tr>
<tr>
<td>B</td>
<td>University</td>
<td>Technology of integrated cellulosic biorefineries</td>
</tr>
<tr>
<td>C</td>
<td>University</td>
<td>Technology of cellulosic biofuels</td>
</tr>
<tr>
<td>D</td>
<td>University</td>
<td>Energy systems and policy of cellulosic biofuels &amp; biorefineries</td>
</tr>
<tr>
<td>E</td>
<td>University</td>
<td>Technology of cellulosic biofuels &amp; biorefineries</td>
</tr>
<tr>
<td>F</td>
<td>University</td>
<td>Economics of bio-based products</td>
</tr>
<tr>
<td>G</td>
<td>University</td>
<td>Policy and energy systems of cellulosic biofuels</td>
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<tr>
<td>H</td>
<td>University</td>
<td>Technology of bio-based chemicals</td>
</tr>
<tr>
<td>I</td>
<td>University</td>
<td>Policy and energy systems of bio-based products</td>
</tr>
<tr>
<td>J</td>
<td>University</td>
<td>Policy of cellulosic biofuels</td>
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<tr>
<td>K</td>
<td>National lab</td>
<td>Technology of cellulosic biofuels &amp; bio-based chemicals</td>
</tr>
<tr>
<td>L</td>
<td>National lab</td>
<td>Environmental science of biofuels &amp; bioproducts</td>
</tr>
<tr>
<td>M</td>
<td>National lab</td>
<td>Technology of cellulosic biofuels &amp; biorefining</td>
</tr>
<tr>
<td>N</td>
<td>Industrial consultant</td>
<td>Technology and policy of biofuels &amp; biochemical</td>
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<tr>
<td>O</td>
<td>Industrial consultant</td>
<td>Energy systems of biofuels</td>
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<tr>
<td>P</td>
<td>Industrial consultant</td>
<td>Energy systems of biofuels</td>
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<tr>
<td>Q</td>
<td>Industrial consultant</td>
<td>Technology of biofuels &amp; biochemical</td>
</tr>
<tr>
<td>R</td>
<td>Industrial producer</td>
<td>CEO of bio-based chemicals &amp; products plant</td>
</tr>
</tbody>
</table>
Table 6-2. The Seven USDA Coordinated Agricultural Projects (CAPs) and two industrial conferences.

<table>
<thead>
<tr>
<th>Regional CAP</th>
<th>Lead University</th>
<th>Date &amp; Location</th>
<th>Experts (&amp; participants)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advanced Hardwood Biofuels Northwest (AHB)</td>
<td>U of Washington</td>
<td>Sept. 10, Seattle, WA</td>
<td>96 (n=29)</td>
</tr>
<tr>
<td>Bioenergy Alliance Network of the Rockies (BANR)</td>
<td>Colorado State U</td>
<td>Oct. 14, Missoula, MT</td>
<td>69 (n=8)</td>
</tr>
<tr>
<td>CenUSA Bioenergy</td>
<td>Iowa State U</td>
<td>July 28-29, Madison, WI</td>
<td>65 (n=19)</td>
</tr>
<tr>
<td>Southeast Partnership for Integrated Biomass Supply Systems (IBSS)</td>
<td>U of Tennessee</td>
<td>Aug. 10, Auburn, AL</td>
<td>80 (n=29)</td>
</tr>
<tr>
<td>Northwest Advanced Renewable Alliance (NARA)</td>
<td>Washington State U</td>
<td>Sept. 15, Spokane, WA</td>
<td>120 (n=52)</td>
</tr>
<tr>
<td>The Northeast Woody/Warm-season Biomass Consortium (NEWBio)</td>
<td>Pennsylvania State U</td>
<td>Aug. 3-5, Morgantown, WV</td>
<td>89 (n=57)</td>
</tr>
<tr>
<td>Sustainable Bioproduct Initiative (SUBI)</td>
<td>Louisiana State U</td>
<td>Oct. 21, Baton Rouge, LA</td>
<td>59 (n=10)</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td></td>
<td></td>
<td><strong>578 (n=204)</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Industrial Conference</th>
<th>Organizer</th>
<th>Dates &amp; Location</th>
<th>Experts (&amp; participants)</th>
</tr>
</thead>
<tbody>
<tr>
<td>National Advanced Biofuel Conference &amp; Expo (NABC&amp;E)</td>
<td>BBI International</td>
<td>Oct. 26-28, Omaha, NE</td>
<td>40 (n=14)</td>
</tr>
<tr>
<td>The 12th Advanced Bioeconomy Leadership Conference (ABLC)</td>
<td>Biofuels Digest</td>
<td>Nov. 2-5, San Francisco, CA</td>
<td>60 (n=10)</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td></td>
<td></td>
<td><strong>100 (n=24)</strong></td>
</tr>
</tbody>
</table>
Table 6-3. Perceived barriers to the integrated production of cellulosic biofuels & biochemicals by experts [n=18] from the qualitative pilot study and potential solutions to these identified barriers.

<table>
<thead>
<tr>
<th>Perceived Highest Scale-up Barriers</th>
<th>Potential Solutions to the Highest Barrier</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. New technology availability (n=4)</td>
<td></td>
</tr>
<tr>
<td>a) University ----------------------</td>
<td>Consistent government funding &amp; incentives</td>
</tr>
<tr>
<td>b) University ----------------------</td>
<td>New technology development</td>
</tr>
<tr>
<td>c) National Lab ---------------------</td>
<td>Consistent government funding &amp; incentives</td>
</tr>
<tr>
<td>d) Industry -------------------------</td>
<td>New technology development</td>
</tr>
<tr>
<td>2. Capital availability (n=4)</td>
<td></td>
</tr>
<tr>
<td>a) University ----------------------</td>
<td>Consistent government funding &amp; incentives</td>
</tr>
<tr>
<td>b) University ----------------------</td>
<td>-</td>
</tr>
<tr>
<td>c) National Lab ---------------------</td>
<td>-</td>
</tr>
<tr>
<td>d) Industry -------------------------</td>
<td>Consistent government funding &amp; incentives</td>
</tr>
<tr>
<td>3. Policy uncertainty (n=3)</td>
<td></td>
</tr>
<tr>
<td>a) University ----------------------</td>
<td>Consistent government funding &amp; incentives</td>
</tr>
<tr>
<td>b) Industry -------------------------</td>
<td>Consistent government funding &amp; incentives</td>
</tr>
<tr>
<td>c) Industry -------------------------</td>
<td>Consistent government funding &amp; incentives</td>
</tr>
<tr>
<td>4. High production costs (n=3)</td>
<td></td>
</tr>
<tr>
<td>a) University ----------------------</td>
<td>Consistent government funding &amp; incentives</td>
</tr>
<tr>
<td>b) University ----------------------</td>
<td>Consistent government funding &amp; incentives</td>
</tr>
<tr>
<td>c) National Lab ---------------------</td>
<td>Consistent government funding &amp; incentives</td>
</tr>
<tr>
<td>5. Process complexity (n=1)</td>
<td></td>
</tr>
<tr>
<td>a) University ----------------------</td>
<td>New technology development</td>
</tr>
<tr>
<td>6. Competition vs. petro-chemicals (n=1)</td>
<td></td>
</tr>
<tr>
<td>a) University ----------------------</td>
<td>Education of end-use consumer</td>
</tr>
<tr>
<td>7. Process/market expertise (n=1)</td>
<td></td>
</tr>
<tr>
<td>a) University ----------------------</td>
<td>Consistent government funding &amp; incentives</td>
</tr>
<tr>
<td>8. Compatibility with existing infrastructure (n=1)</td>
<td></td>
</tr>
<tr>
<td>a) Industry -------------------------</td>
<td>New technology development</td>
</tr>
</tbody>
</table>
Table 6-4. The mean value of the RATING\(^1\) of the eight barriers to the integrated production of biochemical and cellulosic biofuels and significant differences of perceived barriers among four participant categories: Feedstock (G1-F), Processing (G2-P), Economics/Business (G3-E/B), and Sustainability (G4-S).

<table>
<thead>
<tr>
<th>Scale-up BARRIERS</th>
<th>Overall (n=221(^2))</th>
<th>G1-F (n=85)</th>
<th>G2-P (n=71)</th>
<th>G3-E/B (n=39)</th>
<th>G4-S (n=26)</th>
<th>Sig.(^3)</th>
<th>Pairwise Comparisons(^4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Competition vs. petro-chemicals</td>
<td>3.97</td>
<td>4.08</td>
<td>4.10</td>
<td>3.68</td>
<td>3.65</td>
<td><strong>0.031</strong></td>
<td>G2-P, G1-F &gt; G3-E/B, G4-S</td>
</tr>
<tr>
<td>2. High production costs</td>
<td>3.89</td>
<td>4.01</td>
<td>3.80</td>
<td>3.82</td>
<td>3.88</td>
<td>0.393</td>
<td>G2-P &gt; G1-F, G4-S, G3-E/B</td>
</tr>
<tr>
<td>3. Policy uncertainty</td>
<td>3.86</td>
<td>3.87</td>
<td>3.86</td>
<td>3.81</td>
<td>3.88</td>
<td>0.992</td>
<td></td>
</tr>
<tr>
<td>4. Capital availability</td>
<td>3.75</td>
<td>3.71</td>
<td>3.79</td>
<td>3.84</td>
<td>3.60</td>
<td>0.730</td>
<td></td>
</tr>
<tr>
<td>5. Process complexity</td>
<td>3.48</td>
<td>3.36</td>
<td>3.69</td>
<td>3.42</td>
<td>3.38</td>
<td><strong>0.071</strong></td>
<td>G2-P &gt; G1-F, G4-S, G3-E/B</td>
</tr>
<tr>
<td>6. New technology availability</td>
<td>3.40</td>
<td>3.33</td>
<td>3.59</td>
<td>3.26</td>
<td>3.35</td>
<td>0.172</td>
<td></td>
</tr>
<tr>
<td>7. Compatibility with existing infrastructure</td>
<td>3.39</td>
<td>3.44</td>
<td>3.39</td>
<td>3.37</td>
<td>3.30</td>
<td>0.866</td>
<td></td>
</tr>
<tr>
<td>8. Product/market expertise</td>
<td>3.32</td>
<td>3.32</td>
<td>3.29</td>
<td>3.55</td>
<td>3.04</td>
<td><strong>0.074</strong></td>
<td>G3-E/B &gt; G4-S</td>
</tr>
<tr>
<td><strong>Pairwise Comparisons</strong>(^4)</td>
<td>1&gt;4&gt;5&gt;8</td>
<td>1&gt;2&gt;3&gt;8; 1&gt;5&gt;8;</td>
<td>2&gt;3&gt;8; 1&gt;3&gt;4&gt;8</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

\(^1\) Rating was measured using a 5-point Likert-scale, from 1=not a barrier to 2=low barrier to 3=moderate barrier to 4=high barrier to 5=very high barrier.

\(^2\) Seven incomplete responses were deleted, resulting in 221 responses entering the final analysis.

\(^3\) Based on parametric analysis of variance (ANOVA) test, bold = significant at the 0.1 level.

\(^4\) Based on two-sample t-test at the 0.1 significance level.
References


CHAPTER 7

QUALITATIVE INSIGHTS INTO BUYER-SUPPLIER RELATIONSHIPS ACROSS THE VALUE CHAIN OF THE U.S. BIOFUELS INDUSTRY

This paper, by Min Chen and Paul M. Smith, was written for submission to Industrial Marketing Management or Renewable Energy Focus.
Abstract

The United State biofuels industry has experienced significant growth since its inception in the early 1990s due to concerns regarding climate change, energy security, and oil price volatility. Corn-grain ethanol has served as an alternative to petroleum-based gasoline over the past few decades and currently accounts for nearly 90 percent of total U.S. renewable biofuels. In recent years, research interests have transited to biofuels recovered from lignocellulosic biomass primarily due to the food-fuel controversy and the “ethanol blend” wall issue. However, the sustainable development and scale up of the U.S. lignocellulosic biofuels industry is now facing a variety of challenges. Literature suggests that relationship management between biofuels producers and their customers has the potential to solidify the supply chain and bring stability to commercialization plans. This study conducted semi-structured interviews with three lignocellulosic biofuel producers to explore relationships with their ethanol customers. Results show that refiners and blenders of gasoline were the primary customers of corn-grain ethanol with fuel marketing companies as secondary intermediaries. Ethanol supplier-customer relationships are mostly non-contractual (transactional) but sometimes they do form informal contracts. Meanwhile, variables such as trust, shared values, communication, and commitment between participating parties are identified as important relationship attributes. This study concludes that companies trying to strengthen buyer-supplier relationship may benefit by assuring product quality, on-time delivery, and customer education regarding the environmental benefits of biofuels over petroleum-based counterparts. This research may also provide business-to-business marketers of biofuels with a better understanding of relationship management.

Introduction

New carbon emission legislation, environmental concerns resulting from the combustion of fossil fuels (such as climate change, air and water pollution, and acid rain), and supply and demand issues have collectively motivated research to develop commercially viable alternatives to traditional fossil-based liquid fuels for the U.S. transportation sector (Energy Information Administration, 2015; Gegg, Budd, & Ison, 2014; The White House, 2015). The U.S. biofuels industry is currently dominated by first generation biofuel – corn-grain ethanol, which accounted for around 87.4% of the total U.S. renewable biofuels in 2015 (Environmental
Protection Agency, 2015). Corn-grain ethanol represents a mature biofuel due in part to stable and supportive policies, established conversion technologies, and synergy with existing U.S. food production systems (Chen, Smith, & Wolcott, 2016). In 2015, the number of corn-grain ethanol production plants achieved 217 with an overall production volume of around 14.8 billion gallons (Chen et al., 2016). As a result, the U.S. corn-grain ethanol industry has reshaped corn farming by reducing government support for cropping subsidies while raising farmers’ incomes (Renewable Fuels Association, 2014). Meanwhile, ethanol blends in gasoline (typically, up to 10%) improve the octane number and add oxygen content to meet the U.S. Clean Air Act (CAA) (Urbanchuk, 2010).

Despite the benefits of first generation corn-grain ethanol, the “food-versus-fuel” and ethanol “blend wall” arguments continue to constrain the industry. The “food-versus-fuel” debate has lasted for more than a decade and includes controversy over food security (C. A. Carter & Miller, 2012; EuBP, 2013; Ziegler, 2008) and food price inflation (Ahmed, 2008; Ajanovic, 2011; Bardhan, Gupta, Gorman, & Haider, 2015; Cuesta, 2014). The ethanol “blend wall” also constrains the growth of the U.S. corn-grain ethanol industry due to the E10 (10%) blend limit, the infrastructure requirements for higher blend options, and consumer acceptance for higher biofuel blends (Energy Information Administration, 2011). Therefore, industrial, governmental, and academic research interests are shifting to second generation biofuels produced from lignocellulosic biomass to avoid the negative impacts associated with first generation biofuels.

A wide variety of agricultural biomass can be used as raw materials to produce second generation biofuels including short rotation forestry crops (poplar, willow), perennial grasses (miscanthus, switchgrass), agricultural, forest, and mill residues, and municipal solid waste (MSW) (Pacini, Sanches-Pereira, Durleva, Kane, & Bhutani, 2014; Sims, Taylor, Saddler, & Mabee, 2008). Compared to first generation biofuels, second generation biofuels avoid the food-fuel controversy while benefiting from lower lifecycle GHG emissions (Balan, Chiaramonti, & Kumar, 2013; FitzPatrick, Champagne, Cunningham, & Whitney, 2010). Chen et al. (2016) have identified twenty-five companies focusing on the production of lignocellulosic ethanol, of which, five have launched commercial scale production (Table 7-1).

The other twenty, however, remain “under development” due to a variety of underlying issues (Balan et al., 2013; FitzPatrick et al., 2010). For instance, lignocellulosic ethanol faces the same ethanol “blend wall” issue, plus strong price competition from existing corn-grain ethanol players (Chen et al., 2016). Additional barriers to the commercialization of the lignocellulosic ethanol industry are documented throughout the supply chain from field/forest to wheel/wing
These barriers include feedstock costs and availability, high production and capital costs, policy uncertainty, and various technical, environmental, social, and market issues (Balan et al., 2013; Brown & Brown, 2013; Chen et al., 2016; Cheng & Timilsina, 2010; Cheng & Timilsina, 2011; Oltra, 2011; Pimentel & Patzek, 2005; Temesgen, Affleck, Poudel, Gray, & Sessions, 2015).

Relationship management has been emphasized as a crucial strategy to address potential risks and improve value between suppliers and their customers (Solecki, Dougherty, & Epstein, 2013; Zineldin & Jonsson, 2000). Scholars related relationship benefits to sustained competitive advantage by mutual strategy development (Dyer, 1996). Wilson indicated that strengthened relationship with suppliers can provide buyers with increased quality, reduced inventory, and decreased time to market (Wilson, 1995). Information sharing can speed up flows and decrease tied-up capital (Zineldin & Jonsson, 2000). Within the U.S. biofuels industry, relationship management has been suggested to solidify the supply chain and bring stability to commercialization plans (Solecki et al., 2013). Companies, like AltAir Fuels, are leveraging purchase agreements with United Airlines and U.S. Navy to receive better debt financing terms (Solecki et al., 2013). Existing literature, therefore, suggests that future research may benefit from a focus on the relationship management between ethanol producers and their customers (Russell, Ruamsook, & Thomchick, 2009). Also, with technology advancement and increasing sustainability concerns, the relationship management of advanced (lignocellulosic) ethanol is of key interests to current researchers (Russell et al., 2009). As a result, the major objectives of this study are to: 1) explore the customer types of corn-grain ethanol and lignocellulosic ethanol; 2) identify variables characterizing buyer-supplier relationships within the U.S. renewable ethanol industry; and 3) explore relationship management activities across the value chain of this industry.

Contractual vs. Non-contractual Relationships

As indicated by several researchers, one commonly applied classification of the type of relationships is contractual versus non-contractual (Macaulay, 1963). Contractual, defined by Macaulay (1963), is: 1) “relational planning of the transaction with careful provision for as many as future contingencies as can be foreseen”; and 2) “the existence or use of actual or potential legal sanctions to induce performance of the exchange or to compensate for non-performance”.

(Figure 7-1). These barriers include feedstock costs and availability, high production and capital costs, policy uncertainty, and various technical, environmental, social, and market issues (Balan et al., 2013; Brown & Brown, 2013; Chen et al., 2016; Cheng & Timilsina, 2010; Cheng & Timilsina, 2011; Oltra, 2011; Pimentel & Patzek, 2005; Temesgen, Affleck, Poudel, Gray, & Sessions, 2015).
The use of contracts is beneficial to creating exchange relations and settling disputes (Macaulay, 1963). In addition, formal contractual relationships can reduce uncertainty and opportunism by both parties (Carson, Madhok, & Wu, 2006). Cannon & Perreault (1999) sampled more than 400 buyer-seller relationships from a wide array of industries and market situations and found that contractual transactions are formalized by legal contracts and characterized by minimal cooperation, interaction, and linkage (Cannon & Perreault Jr, 1999). By interviewing 68 businessmen and lawyers in manufacturing industry, Macaulay (1963) found that in most situations contracts are not needed, and often its functions are served by other devices, such as a standardized product with a description or specification. More recently, other researcher found that relationships in the U.S. and European wood industry are commonly based on trust and handshake agreements and formal contracts are often short term (Aase, 2013).

A Summary of Variables Characterizing Buyer-Supplier Relationships

Variable characterizing buyer-supplier relationships are well documented and include commitment/propensity to leave, trust, cooperation, dependence/power, communication, functional conflict, relationship-specific investment/nonretrievable investments, shared values/mutual goals, relationship termination costs, opportunistic behavior, adaption, and shared technology (Anderson & Narus, 1990; De Ruyter, Moorman, & Lemmink, 2001; Fontenot & Wilson, 1997; Morgan & Hunt, 1994; Rinehart, Eckert, Handfield, Page, & Atkin, 2004; Wilson, 1995). In the following section, these sixteen variables will be briefly discussed.

Commitment is an important variable in determining successful relationships (De Ruyter et al., 2001; Wilson, 1995). According to Fontenot & Wilson (1997), commitment is the motivation to stay with a valuable supplier or customer, and the willingness to invest time, effort and resources to the relationship. Meanwhile, commitment is negatively related to propensity to leave, which indicates one’s expectation that they may soon exit the relationship (Fontenot & Wilson, 1997). The higher the motivation to maintain the relationship, the larger the probability that the quality of the relationship will increase (Parsons, 2002). Morgan & Hunt (1994) explored the nature of relationship marketing and concluded that commitment lead directly to effective cooperation that is conducive to relationship marketing success.

Trust is central and fundamental to relationship model and refers to the confidence in relationship partners’ reliability and integrity. Specifically, trust is the belief that their counterpart
in the relationship will perform expected actions that will result in positive outcomes (Anderson & Narus, 1990; Morgan & Hunt, 1994). Trust is a multidimensional construct and plays a significant role in long-term partnership (Anderson & Narus, 1990; Ganesan, 1994; Ganesan & Hess, 1997; Mohr & Spekman, 1994). Two dimensions of trust, including credibility and benevolence, have been included in several studies (Ganesan, 1994; Mayer, Davis, & Schoorman, 1995).

**Cooperation** is defined as coordinated, joint efforts taken by firms in interdependent relationships to achieve mutual goals or singular goals with expected reciprocation over time (Anderson & Narus, 1990). Anderson and Narus (1990) implied that cooperation is an antecedent rather than a consequence of trust. On the other hand, Morgan & Hunt (1994) proposed that cooperation arises directly from commitment and trust.

**Dependence** is an important variable. Dependence occurs when one partner cannot obtain the same resources and outcomes from the alternative relationship (De Ruyter et al., 2001). In the relationship marketing literature, researchers showed that the more dependent one party is on the other, the larger desire that party will develop a strong, collaborative long-term relationship with its counterpart (De Ruyter et al., 2001). Dependence is highly correlated with **power**, which is the ability to influence the decisions or actions of the others (Fontenot & Wilson, 1997). Scholars have indicated that mutual dependence or interdependence would result in collaborative relationships while power/dependence imbalance would lead to competitive relationships (Rinehart et al., 2004).

**Communication** can be “defined broadly as the formal as well as informal sharing of meaningful and timely information between firms” (Anderson & Narus, 1990). Communication captures the efficacy of the information exchanged (Mohr & Spekman, 1994). Past communication is the antecedent of trust while the accumulated trust leads to meaningful future communication (Morgan & Hunt, 1994). Communication in a buyer-seller relationship, therefore, focuses on communication quality (such as accuracy, timeliness, and credibility), the extent of proprietary information sharing between partners and joint planning (Mohr & Spekman, 1994).

**Functional conflict** is beneficial to the establishment and maintenance of long-term relationships (Claycomb & Frankwick, 2010). Functional conflict refers to relationship partners’ conflict resolution mechanisms, which may result in “productive discussion”, mutually satisfactory solution and, thus, successful partnership (Anderson & Narus, 1990; Claycomb & Frankwick, 2010; Mohr & Spekman, 1994). Former researchers indicated that firms that have developed strong trust in a relationship are more likely to develop amicable conflict resolution
techniques (Anderson & Narus, 1990; Dwyer, Schurr, & Oh, 1987). These productive conflict resolution mechanisms include joint problem solving, persuasion and smoothing (Mohr & Spekman, 1994). Other researchers also indicate that resolving conflicts may strengthen inter-organizational relationships and lead to greater trust and commitment (De Ruyter et al., 2001; Gundlach, Achrol, & Mentzer, 1995).

**Relationship-specific investments/nonretrievable investments** are resources committed to the dyadic relationships, such as time, money, facilities, training, and equipment (Rinehart et al., 2004; Wilson, 1995). These resources are often referred to as “asset specific resources” (Dyer, 1996), and are difficult to switch to another relationship (Morgan & Hunt, 1994). Several researchers have demonstrated a positive correlation between relationship-specific investments and increased commitment and trust, which lead to long-term relationships (De Ruyter et al., 2001; Dyer, 1996; Ganesan, 1994; Rinehart et al., 2004).

**Shared values** are the extent to which partners have beliefs in common about the importance, appropriateness of certain behaviors, goals, and policies (Fontenot & Wilson, 1997; Morgan & Hunt, 1994). Morgan & Hunt (1994) posited that shared values among exchange partners would lead to greater commitment to the relationship. This idea is further confirmed by later researchers, such as Wilson (1995) and Fontenot & Wilson (1997). Wilson (1995) also defined a similar but narrower concept, **mutual goals** as “the degree to which partners share goals that can only be accomplished through joint action and the maintenance of the relationship.”

**Relationship termination cost** is a common term in the relationship marketing literature and is generated when a terminated party seeks an alternative relationship (Morgan & Hunt, 1994). Relationship termination cost is investments that are difficult to switch to another relationship and switching costs will lead to dependence. Buyers anticipating high switching costs are more likely to remain in current relationship (Fontenot & Wilson, 1997). Also, termination costs are all expected losses from termination and result from the perceived lack of comparable potential alternative partners (Morgan & Hunt, 1994).

**Opportunistic behaviors** are negatively related with trust and commitment (Fontenot & Wilson, 1997). When a party believes that a partner engages in opportunistic behavior, such perceptions will lead to decreased trust.

**Adaptions** happen when one party in a relationship alters its processes or the product exchanged to accommodate the other party (Wilson, 1995). Adaptation behavior will vary over the continuum of the relationship. In the early stages adaptation will help develop trust, and in the mature stage it will expand and solidify the relationship (Wilson, 1995).
Regardless the broad range of marketing literature on buyer-supplier relationships, variables characterizing the relationships within the U.S. biofuels industry are not well specified.

**Relationship Management**

Relationship management is critical to meeting an organization’s ultimate goals of financial performance and competitive advantage (Carr & Pearson, 1999; J. R. Carter, 2006). Carter (2006) suggested that relationship management is an integrated set of business activities. Fontenot and Wilson (1997) summarized a list of eleven relationship activities which were empirically tested by Wilson and Vlosky (1997). These relationship activities including new product development programs, pricing, logistics, dealer promotion, advertising, salesforce activities, marketing planning, performance reviews, manufacturing, communication, and information exchange. More recently, existing literature has found that activities to better understand buyer’s need and generate a good performance will help the supplier gain buyer’s trust and loyalty (Monczka, Handfield, Giunipero, & Patterson, 2015).

**Research Design**

**Sample population**

The present study used non-probability purposeful sampling. Of the five U.S. lignocellulosic ethanol producers at commercial scale in fall 2015, three agreed to participate in this study (response rate = 3 of 5 [60%]) (Table 7-2). The three participants were accessed at the following two industrial conferences:

1. **5th National Advanced Biofuel Conference & Expo (NABC&E)**, October 26-28, 2015, Omaha, NE. This conference is tailored for industry professionals engaged in producing, developing and deploying advanced biofuels, biobased platform chemicals, and polymers
   (http://www.advancedbiofuelsconference.com/ema/DisplayPage.aspx?pageId=The_Conference___Expo); and
(2) **12th Advanced Bioeconomy Leadership Conference (ABLC)**, Nov. 2-5, 2015, San Francisco, CA. This conference provides a venue for senior leadership in the advanced bioeconomy focusing on advanced low carbon fuels, chemicals, and materials, plus advanced policies and financing strategies ([http://advancedbiofuelssummit.com/](http://advancedbiofuelssummit.com/)).

**Data collection**

Primary data was collected through semi-structured personal interviews from October to November 2015. Each interview was audiotape-recorded and transcribed for a more thorough analysis. Interviews ranged from 20 to 45 minutes. Interviews offer free choice in the form of response and the possibility of dialog; this allowed the researcher to facilitate greater interaction between the interviewer and the person surveyed (García-Maroto, Muñoz-Leiva, & Rey-Pino, 2014). Personal one-on-one interviews also provide participants with a sense that they are the focus of attention and interviewers can probe at length to reveal feelings and motivations that underlie statements of respondent (McDaniel & Gates, 2004).

Standardized questions are a good means of obtaining the same kind of information and the three interviews were based on a data collection guide with a list of five questions in the same order and with the same wording for all the subjects interviewed (García-Maroto et al., 2014; Kvale, 2007).

**Thematic analysis**

Thematic analysis is a process for encoding qualitative information (Boyatzis, 1998). The coding of a text’s meaning into categories makes it possible to quantify how often specific themes are addressed in a text, and the frequency of themes may then be compared and correlated with other measures (Kvale, 2007). By categorization, the meaning of long interview statements is reduced to a few simple categories. This method simplifies understanding of the phenomena under study and also signals the most significant dimensions with which respondents touched-upon (García-Maroto et al., 2014). The categories can be developed in advance or they can arise ad hoc during the analysis. Theory driven, prior data or prior research driven, and data driven are
three different ways to develop categories or thematic codes (Boyatzis, 1998). This study developed thematic codes by analyzing collected data; thus deploying a data driven approach to allow for a quantitative approach to the man points of interest, based on the frequency of the identified themes.

Empirical Results

Qualitative research has proven to be a valid methodological option to explore phenomena within the applied social science field (Creswell, 2012). Qualitative interviews in this paper provided in-depth information regarding key buyer-supplier relationship issues across the value chain of the U.S. biofuels industry. To examine these important issues, the findings are organized as follows: customer types of renewable ethanol, variables characterizing relationships between renewable ethanol supplier and buyer, and activities strengthening this relationship.

Customer types of renewable ethanol

To explore the customer types of corn-grain ethanol and lignocellulosic ethanol, participants were asked three questions in a queue.

Question #1: Who are the customer(s) of the corn-grain ethanol industry in general?

This study’s three participants indicated that gasoline refiners and blenders were the major customers for the corn-grain ethanol industry. Also, fuel marketing companies were the industry’s secondary customers, who serve as middlemen and then subsequently sell corn-grain ethanol to blenders or refiners.

“In corn ethanol [industry] the biggest customers are the petroleum industry. The blenders or the refiners of the petroleum-based gasoline are obligated by the RFS2 [2007 revised Renewable Fuel Standard] to blend a certain volume of renewable fuels. A refiner is a company that takes crude oil, distills it and separates impurities into various products, of which gasoline is one. Most refiners will blend E10 [10% ethanol blended with 90%
petroleum-based gasoline] onsite. Others [refiners] will sell a gasoline to a blender who is not a refiner. And they [blenders] will have a tank or something to blend ethanol with gasoline." (Subject A)

“There are also some marketing companies that don’t necessarily produce blends, but also purchase [corn-grain ethanol] from time to time. And then they go ahead to sell ethanol to blenders. So that’s a secondary customer. But primarily, it’s the petroleum industry, the blenders and the refiners.” (Subject C)

Based on these responses, the supply chain connecting corn-grain ethanol producers with gasoline retailers is depicted in Figure 7-2, of which the arrows indicate the flow of corn-grain ethanol.

**Question #2: In general, are the customers for lignocellulosic ethanol different from corn-grain ethanol?**

All of the three participants indicated that the customers for lignocellulosic ethanol were the same as corn-grain ethanol, since they are the same products and should go to the same market. However, there are differences between corn-grain ethanol and lignocellulosic ethanol in terms of customer preferences as stated by subject C.

“At the same time, there are some differences. There are some states that prefer lignocellulosic ethanol. For example, the State California, in particular, is a huge market for fuel. The State of California has a law of Low Carbon Fuel Standard [LCFS]. As a result of this law, the State of California is trying to reduce their greenhouse gas emissions from their transportation fuels. So they highly value fuels that have lower carbon content and have fewer greenhouse gas emissions than another fuel.” (Subject C)

Also, mentioned by participants A and B, another difference between corn-grain ethanol and lignocellulosic ethanol is the Renewable Identification Number (RIN).
“Corn starch ethanol and lignocellulosic ethanol differ in terms of RIN values. Apparently, the RIN values are accounting based items. We [renewable ethanol producers] have to track how much is based on lignocellulosic and how much is based on corn starch.” (Subject A)

More specifically, RIN is a mechanism that measures the compliance with the RFS; when qualifying biofuels are produced, each gallon is assigned a RIN value (Yacobucci, 2013). A RIN is a unique 38-character number that is issued in accordance with EPA guidelines by the biofuel producer at the point of biofuel production (Yacobucci, 2013). Each qualifying gallon of renewable fuel has its own unique RIN, which is formulated by RFS2 as

\[
\text{RIN} = \text{KYYYYCCCCFFFFBBBRRDSSSSSSSSSEEEEEEEE}
\]

Where

- K = distinguishing RINs still assigned to a gallon from RINs already separated
- YYYY = the calendar year of production or import
- CCC = the company ID
- FFFFF = the company plant or facility ID
- BBBBB = the batch number
- RR = the biofuel energy equivalence value
- D = the renewable fuel category
- SSSSSSSSS = the start number for this batch of biofuel
- EEEEEEEE = the end number for this batch of biofuel

Under the RFS2 RIN formulation, code D identifies and differentiates the categories of biofuels: total, advanced, lignocellulosic, or biodiesel (Yacobucci, 2013). In January 2014, EPA released 2014 RIN data. In total, 17.2 billion RINs were generated with 33.0 million RINs for lignocellulosic biofuel (D3) and 14.3 billion RINs for corn ethanol (D6) (EPA, 2015).

Meanwhile, the RIN values for different categories of biofuels are different. According to ethanol & biodiesel information service, the average weekly RIN value for corn ethanol (Sept. 23 – Sept. 29, 2016) is $0.88/RIN; and for lignocellulosic biofuel, $2.05/RIN (OPIS, 2016).

**Question #3: Is it common to sign contracts with buyer in the corn-grain ethanol industry?**
As indicated by participants A and C, buyer-supplier relationships in the U.S. corn-grain ethanol industry are commonly non-contractual. Informal contracts do exist within this industry, but they are often short term.

“We [Corn-ethanol producers] do not do long-term contracting in the ethanol industry on a commodity market. Mostly, the purchases are transactional.” (Subject A)

“I think it is common to have ethanol contracts one quarter a time. I think they’re informal contracts rather than long-term contracts. That’s how the customer wants to buy it. They decide how and when to buy it.” (Subject C)

**Variables characterizing supplier-buyer relationships within the U.S. biofuels industry**

**Question 4:** If I ask you to select your ‘BEST’ customer among all your biofuel customers, how would you define your ‘best’ customer(s)? In other words, what are the TOP 3 attributes that your company values when choosing the ‘BEST’ biofuel customer(s).

The four most important variables characterizing the relationship between biofuel supplier and their customers identified by three participants included shared values, trust, communication, and commitment (Figure 7-3).

**Shared values**

Shared values are specified by all the three participants as an important attribute concerning the selection of “best” biofuel customers. Environmental benefits and low carbon footprint are the key words mentioned by biofuel producers. This suggests that biofuel producers prefer educated customers who understand the benefits of renewable biofuels.

“... An educated consumer is the best. Someone understands the environmental benefits of ethanol. And someone understands they can get higher octane. I think our industry has more
to do to educate them. Consumers know all the facts; they would be more willing to buy our products.” (Subject A)

“Our best customer turns out to be our west coast customers who pay more attention to the carbon credits of biofuels. We get a premium price for our low carbon footprint product. This is largely because of the low carbon fuel standard there. Our best customer pays more for environmentally-friendly biofuels, and contributes to our ROI.” (Subject B)

**Trust**

Trust is also mentioned by three participants as one of the most important attributes when biofuel producers choose their “best” customer(s). Specifically, trust refers to a customer that has a good reputation or brand identity, and customers who have done a long-time business, because this type of customer is more reliable, as indicated by subject B:

“In general, I would say, someone who has done business with us for a long time, someone who has a good credit rating, or a good history, would be our ideal customer.”

Other company characteristics, such as company size and number of production infrastructure, are potential indicators of the buyers’ reliability.

“We also look for people [customers] who are large, who have multiple output sites, [and] who have the ability to take ethanol at more than one location. Large volume customer can be flexible on the delivery dates; they have adequate tank volume to store products. That gives flexibility to find a less expensive way to ship. Very often, we view this kind of customer trustworthy, since it may be easier for us to arrange the shipment.” (Subject C)
Communication

Communication is regarded by two respondents as one of the top 3 attributes characterizing their “best” biofuel customer(s). Communication refers to exchanging information for demand projection and delivery arrangement.

“We try to get projections from our established customers via frequent communications.” (Subject B)

“We often times will try to make arrangements with customers, for example, multiple delivery points. And if it is less expensive to ship to one place from the other, we work with customers to share the profit of doing something in a less expensive way.” (Subject C)

Commitment

As shown in Figure 7-3, commitment was mentioned by one interviewee as an additional important attribute when choosing their “best” customers. Analysis of the responses reveals that commitment refers to customers who have “consistent and long term demand” (Subject B).

Activities to strengthen relationship with biofuel customer(s)

Question #5: Please share 1-2 examples of relational activities for strengthening the relationship with your “best” customer X?

Quality assurance, on-time delivery, and education of biofuel benefits are three relationship management activities. Responses of this study’s three participants are detailed as follows.

Quality assurance:

“In order to maintain reliability, we have quality control programs. We are ISO registered for both quality and environmental compliance.” (Subject C)
“We offer really consistent products. If it [ethanol] doesn’t meet specifications, we don’t sell it until it does.” (Subjects A)

On-time delivery:
“We do everything we can to deliver products on time, and to build good relationships with those customers by being a good supplier. I think that’s probably our big asset.” (Subject B)

Education of biofuel benefits:
“We are trying to educate the world, not a customer. So our strategy is to participate and educate, and transfer the fact [benefits of renewable biofuels] to the world.” (Subject A)

**Conclusion**

In the United States, corn-grain ethanol has served as a major alternative to petroleum-based gasoline over the past few decades to address growing concerns over climate change, energy security, and oil price volatility. Today, renewable ethanol produced by 217 plants account for around 10% market share in the U.S. gasoline supply (Renewable Fuels Association, 2016). Research interests are also focusing on biofuels recovered from lignocellulosic biomass due to the food-fuel controversy and the ethanol blend wall issue. However, the sustainable development of the U.S. lignocellulosic biofuels industry is facing a variety of challenges, such as feedstock costs and availability, high production costs, high capital requirements, as well as policy and market turbulence. Existing literature has suggested that relationship management between biofuels producers and their customers has the potential to solidify the supply chain and bring stability to commercialization plans. Therefore, research may benefit from a focus on relationship management across the value chain of the U.S. biofuels industry.

This study’s participants represent two-thirds (n=3/5) of the U.S. commercial-scale lignocellulosic ethanol companies in fall 2015. Also, this study highlights a number of implications for the formation of buyer-supplier relationship within this industry.

This study found that refiners and blenders of gasoline were the primary customers of corn-grain ethanol with fuel marketing companies as secondary intermediaries. Ethanol supplier-customer relationships are often transactional but sometimes they do form informal (short-term) contracts. Additional study findings suggest that the growth of the U.S. corn-grain ethanol
industry is heavily influenced by political supports from the U.S. government, for example, the obligated blend volume of ethanol with gasoline by the revised Renewable Fuel Standard (RFS2).

Because corn-grain ethanol and lignocellulosic ethanol are the same molecules, lignocellulosic ethanol sells to the same markets, enjoys the same price, and has the same customers as corn-grain ethanol. However, there are differences between corn-grain ethanol and lignocellulosic ethanol customers in terms of customer preference and Renewable Identification Numbers (RINs). Lignocellulosic ethanol is more accepted in California due to Low Carbon Fuel Standard (LCFS), which is an alternative approach to RFS. California has taken a leadership role in developing and implementing the LCFS with the goal of establishing average carbon intensity (CI) values for various fuels such as gasoline, diesel, biofuels, natural gas, and electricity (Langston et al., 2011). Meanwhile, RIN, a unique 38-character number, is a mechanism that measures the compliance with the RFS; each gallon is assigned a RIN value at the point of biofuel production. Corn-grain ethanol and lignocellulosic ethanol have different RIN formulation; and lignocellulosic ethanol has significantly higher RIN value than corn-grain ethanol.

Existing literature identified fifteen common variables to characterize buyer-supplier relationships, including commitment/propensity to leave, trust, cooperation, dependence/power, communication, functional conflict, relationship-specific investment/nonretrievable investments, shared values/mutual goals, relationship termination costs, opportunistic behavior, adaption, and shared technology. When selecting a “best” customer(s), lignocellulosic ethanol producers consider four significant customer attributes, such as, credibility and reputation, shared values of the benefits of renewable biofuels, frequent communication, and commitment to long-term relationships. Quality assurance, on-time delivery, and education of biofuel benefits are three relational activities to strengthen the relationship between biofuel producers and their downstream customers. The implications are critical to bridge the knowledge gap in the U.S. second generation (lignocellulosic ethanol) industry, thus assisting decision makers to better manage relationships with downstream biofuel customers. Also, this exploratory study contributes to providing a list of constructs for future research to further examine the buyer-supplier relationship within the U.S. biofuels industry.
Limitations

The findings of this study should be interpreted with care. The qualitative approach employed provides rich insights into the dynamics of relationships between renewable ethanol suppliers and downstream customers. However, our results should not be treated as generalizable to the U.S. biofuels industry as a whole. Additional interviews with biofuel customer companies would provide a more complete picture of the context of buyer-supplier relationships across the biofuel supply chain. Also, interviews with more corn-grain ethanol producers and comparison of their answers with this study would validate constructs and generate additional implications for existing players, new comers, and policy makers within the U.S. biofuels industry.

Acknowledgement

This work, as part of the Northwest Advanced Renewables Alliance (NARA), was funded by the Agriculture and Food Research Initiative Competitive Grant no. 2011-68005-30146 from the USDA National Institute of Food and Agriculture.
Figure 7-1. Lignocellulosic biorefinery supply chain from field/forest to wheel/wing.
Source: (An, Wilhelm, & Searcy, 2011; Hoekman, 2009; Yue, You, & Snyder, 2014)
Figure 7-2. Distribution channel of corn-grain ethanol.
Figure 7-3. Participants’ (n=3) views regarding the top 3 variables characterizing their biofuel buyers.
Table 7-1. Five commercial-scale lignocellulosic ethanol companies in fall 2015.

Source: ("Four commercial", 2014; DuPont, 2015; INEOS, 2013)

<table>
<thead>
<tr>
<th>Companies</th>
<th>Location</th>
<th>Production capacity</th>
<th>Launch date</th>
</tr>
</thead>
<tbody>
<tr>
<td>DuPont</td>
<td>Nevada, IA</td>
<td>30 MGY</td>
<td>Oct. 30, 2015</td>
</tr>
<tr>
<td>INEOS Bio</td>
<td>Vero Beach, FL</td>
<td>8 MGY</td>
<td>July 31, 2013</td>
</tr>
<tr>
<td>POET-DSM “Project Liberty”</td>
<td>Emmetsburg, IA</td>
<td>25 MGY</td>
<td>Sept. 3, 2014</td>
</tr>
<tr>
<td>Quad County Corn Processors</td>
<td>Galva, IA</td>
<td>2 MGY</td>
<td>July 1, 2014</td>
</tr>
</tbody>
</table>
Table 7-2. Profile of three participants from the U.S. biofuel producing companies.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Title</th>
<th>Years of experience</th>
<th>Years of production</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>CEO of corn-grain and lignocellulosic ethanol company</td>
<td>5</td>
<td>13</td>
</tr>
<tr>
<td>B</td>
<td>CTO of corn-grain and lignocellulosic ethanol company</td>
<td>9</td>
<td>20</td>
</tr>
<tr>
<td>C</td>
<td>CEO of corn-grain and lignocellulosic ethanol company</td>
<td>13</td>
<td>30</td>
</tr>
</tbody>
</table>
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APPENDIX A

EMAIL MESSAGE TO POTENTIAL RESPONDENTS

Dear XXX Attendee:

I am a Ph.D. Candidate at The Pennsylvania State University, working with the FAA’s Aviation Sustainability Center (ASCENT) and the USDA’s Northwest Advanced Renewables Alliance (NARA) to understand the impact of product diversification to the scale-up of the 2nd Generation (cellulosic) biofuels industry. In addition, we are investigating the impact of collaboration across the value chain for biofuels. This survey of all attendees of the XXX annual meeting attempts to address those questions. Collectively, you represent a unique set of knowledge and experience on relevant aspects of (advanced) biofuels supply chains. As such, your responses are critical.

Please take the time to complete this brief survey which should take approximately 5 to 10 minutes of your valuable time. Your participation is voluntary. Or you can complete this survey through an online link at your convenient time.

Survey URL: https://www.surveymonkey.com/r/XXX_Survey

All your views are entirely confidential, and no identifiable information will be associated with responses in any research reports. A summary of our research results will be made available, if you so choose.

As this is part of my Ph.D. research project, your responses are highly appreciated and critical to the completion of my doctoral research. If you have any questions or concerns, please contact me at 814-865-3089 or muc283@psu.edu.

Thank you for your time and assistance.

Sincerely,
Min Chen

Ph.D. Candidate and Graduate Research Assistant
Department of Agricultural and Biological Engineering
The Pennsylvania State University

Paul M. Smith

Professor of Bioproducts Marketing
BRS Graduate Program Coordinator
The Pennsylvania State University
APPENDIX B

QUALITATIVE SURVEY INSTRUMENT – INTEGRATED CELLULOSIC BIOREFINERIES

1. In your opinion, what are the key benefits of the integrated production of cellulosic biofuel and biochemical, compared to cellulosic biofuel only production? “Integrated production of cellulosic biofuel and biochemical” is a scenario where a biorefinery produces cellulosic biofuel as the major product and non-fuel, bio-based chemical(s) as co-product(s).

2. In your opinion, what is the most important driver for the integrated production of cellulosic biofuel and biochemical?

3. In your opinion, what is the highest barrier to the integrated production of cellulosic biofuel and biochemical?

4. Can this barrier be overcome? How so or why not?

5. What is your title?

6. How long have you been engaged in bioenergy or bio-based products research?

7. If I may contact you for a brief interview on the specific questions within this survey, please add contact information below.
APPENDIX C

QUANTITATIVE SURVEY INSTRUMENT – CELLULOSIC BIOFUELS & INTEGRATED CELLULOSIC BIREFINERIES

PART- I  Demographics
1). Please provide us with your basic background information (check one please).
□ Government  □ University  □ Biofuels industry
□ Biochemical industry  □ Other (please specify) __________________________

2). Approx. how long have you been engaged in the biofuel/biochemical industry? ____ Years

3). Your title? __________________________

4). Please check the description(s) which best describe(s) your AFRI CAP project research focus (check all that apply).
□ Feedstock  □ Conversion (incl. pretreatment)  □ Product outputs
□ System sustainability  □ Education  □ Extension & outreach
□ Other (please specify) __________________________

PART- II  Scale-Up of the 2nd Gen Biofuels Industry
5). From your perspective, what are the chances of achieving commercial success for the following 2 SCENARIOS in the next 5 years in U.S.? Please rate on a scale from 1=very low chance to 10=very high chance.

<table>
<thead>
<tr>
<th>SCENARIOS:</th>
<th>Chance of success (1 to 10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 1: Production of 2nd Gen (cellulosic) biofuels ONLY</td>
<td>[ ]</td>
</tr>
<tr>
<td>Scenario 2: Integrated production of 2nd Gen (cellulosic) biofuels AND biochemicals</td>
<td>[ ]</td>
</tr>
</tbody>
</table>
6). From your perspective, how important are the following 8 FACTORS AFFECTING the scale-up (commercialization) of the U.S. 2nd Gen (cellulosic) biofuels industry?

<table>
<thead>
<tr>
<th>Scale-up FACTORS:</th>
<th>Not important at all</th>
<th>Somewhat unimportant</th>
<th>Neither important nor unimportant</th>
<th>Somewhat important</th>
<th>Very Important</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon emission reduction</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Government policies</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Fossil fuels dependence</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Rural economic development</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Volatile oil prices</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Food-vs.-fuel debate</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Energy security</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>High value non-fuel co-products</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

7). Please provide your opinion of the following 9 potential BARRIERS to the scale-up (commercialization) of the U.S. 2nd Gen (cellulosic) biofuels industry.

<table>
<thead>
<tr>
<th>Scale-up BARRIERS:</th>
<th>Not a barrier</th>
<th>Low barrier</th>
<th>Moderate barrier</th>
<th>High barrier</th>
<th>Very high barrier</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Consistent feedstock supply</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>B. Feedstock costs</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>C. Technology availability</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>D. High production costs</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>E. Competition vs. 1st Gen biofuels</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>F. Competition vs. petrofuels</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>
### Scale-up BARRIERS:

<table>
<thead>
<tr>
<th>BARRIERS</th>
<th>Not a barrier</th>
<th>Low barrier</th>
<th>Moderate barrier</th>
<th>High barrier</th>
<th>Very high barrier</th>
</tr>
</thead>
<tbody>
<tr>
<td>G. Policy uncertainty</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>H. Cellulosic biofuels logistics</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I. Capital availability</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

Please indicate the 3 highest barriers by placing the **LETTER** of the barrier in the parenthesis below.

#1 ( ) #2 ( ) #3 ( )

8). To integrate the production of biochemicals into a 2nd Gen (cellulosic) biofuel plant, please provide your opinion of the following 9 potential BARRIERS.

<table>
<thead>
<tr>
<th>BARRIERS to integrated production:</th>
<th>Not a barrier</th>
<th>Low barrier</th>
<th>Moderate barrier</th>
<th>High barrier</th>
<th>Very high barrier</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. New technology availability</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>B. Process complexity</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>C. Compatibility with existing infrastructure(s)</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>D. High production costs</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>E. Capital availability</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>F. Product/market expertise</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>G. Competition vs. petro-chemicals</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>H. Policy uncertainty</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I. Long-term off-take agreement(s)</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

Please indicate the 3 highest barriers by placing the **LETTER** of the barrier in the parenthesis below.

#1 ( ) #2 ( ) #3 ( )
APPENDIX D

SURVEY INSTRUMENT – BUYER-SUPPLIER RELATIONSHIPS

1. Background
   a). What is your title and what primary functions does your job involve?
   b). How long have you held your current position?
   c). How many years have your company engaged in the production of corn-based ethanol and/or cellulosic ethanol?

2. Who are the customer(s) of the corn-grain ethanol industry in general?

3. In general, are the customers for lignocellulosic ethanol different from corn-grain ethanol?

4. Is it common to sign contracts with buyer in the corn-grain ethanol industry?

In Your Opinion:

5. If I ask you to select your ‘BEST’ customer among all your biofuel customers, how would you define your ‘best’ customer(s)? In other words, what are the TOP 3 attributes that your company values when choosing the ‘BEST’ biofuel customer(s).

6. Please share 1-2 examples of relational activities for strengthening the relationship with your “best” customer X.
Min Chen was born in Wuxi, China, on October 11, 1987. She earned her Bachelor and Master Degrees in Wood Science and Technology in 2009 and 2012 from Nanjing Forestry University. Upon completion of her master degree, Min enrolled in BioRenewable Systems program at The Pennsylvania State University to sharpen her research skills. Supervised by Dr. Pau M. Smith, her dissertation focused on evaluating academic and industrial experts’ perspectives on potential factors driving and impeding the commercialization of the U.S. cellulosic biofuels industry and integrated cellulosic biorefineries and shed light on variables characterizing strategic relationships between biofuel suppliers and downstream customers. Her work highlights the critical issues for decision-makers when considering industry entry options and incentives for the U.S. cellulosic biofuel industry. Also, this research will help business-to-business marketers of biofuels better understand the strategic considerations of forming relationships.