ABSTRACT

BABRA, DAMIEN ALEXANDER SINGH. Economic Analysis of Wood Pellet Production and Shipping in North and South America: Identifying Potential Locations in North and South America to Build Wood Pellet Mills for Export to the United Kingdom (Under the direction of Drs. Frederick Cubbage and Robert Abt).

The European Union's Renewable Energy Directive has led many electricity producers in Europe to use wood pellets in place of fossil fuels. North America has become one of the primary suppliers of wood pellets to Europe. This paper is divided into two sections. In Chapter 1 critically examines literature, economic models and data, as well as the supply chain and country risk factors, related to wood pellet production to anticipate where North and South American pellet mills should be built to meet Europe's demand. Canada, the United States, and Brazil maintain the largest natural forest area, planted forest area, and industrial roundwood production; however, South American countries achieve faster plantation growth rates. The World Bank's Logistic Procurement Index and IHS's Country Risk Index were used to score and rank countries' investment climates, based on their supply chain and risk factors. In this regard, the United States, Canada, and Chile performed best, in contrast to Venezuela, Bolivia, and Ecuador. When considering both wood supply and investment climates, the United States, Canada, and Chile were the most attractive countries to build a pellet mill, while countries, such as Argentina, Brazil, Colombia, Paraguay, and Peru present significant trade-offs between having significant wood resources and riskier investment climates. Chapter 2 develops a techno-economic model to estimate the minimum selling price required by investors to build a wood pellet mill in North and South American countries. In addition, it calculates the real internal rate of return given current market prices. Due to its low cost structure and favorable investment climate, the most ideal locations to build a large, export oriented pellet mill are in western Canada and southeastern US,

followed by northeastern and northwestern US. While Argentina, Mexico and Peru offer high IRRs, an investor would have to weigh that against higher risks and poorer supply chain conditions. Brazil, Chile and Colombia are also profitable; however, their returns would likely not be sufficient to overcome their poor investment climates. Finally, the western region of Canada as well as Uruguay are the least likely to see future investments given their higher cost of production.

Economic Analysis of Wood Pellet Production and Shipping in North and South America: Identifying Potential Locations in North and South America to Build Wood Pellet Mills for Export to the United Kingdom

by
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BIOGRAPHY

Damien Singh was born in Miami, Florida and has lived in Michigan as well as Washington DC. He graduated with a Bachelors of Arts in Economics from the University of Maryland in 2009 and worked for the US Department of Agriculture as an Agricultural Economist and Compliance Review Specialist. In pursuit of his lifelong passion for learning about international cultures, histories and markets, he entered his masters program at NC State University with the intention of developing technical skills and applying them to real world situations.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

1.1 INTRODUCTION

Environmental and natural resource policies can have widespread social, political and economic implications. The European Union (EU) recently implemented various programs, including the Renewable Energy Directive (RED) and the Emission Trading System (ETS), which mandates its member states to meet a minimum of 20% of their energy needs from renewable and carbon-neutral sources by 2020. In addition, these programs are mandating that by 2030, greenhouse gases (GHG) are to be reduced by 40% and the share of energy from renewable sources should increase to 27%, along with an 80% to 95% reduction in GHG by 2050 (European Commission 2016; European Union 2016; Lamers *et al*. 2014). While these are European-wide objectives, member states maintain their own mandatory targets and are able to design policies suitable to their circumstances, resulting in credit programs and feed-in-tariffs (FiT) that have led to an increase in wood pellet consumption (Table 1). While there are variations in policy design, electricity producers are awarded credits based on how much energy they generate from renewable and/or carbon neutral sources. These are sold to either suppliers, who are required by law to meet specific quotas, or government agencies that provide rebates. Penalty fees are commonly applied if quotas are not met. In contrast, FiTs represent direct subsidies to electricity producers based on the quantity of renewable and carbon neutral sources.

Table 1. Major European Wood Pellet Importers and Their Incentive Policies

Country	Wood pellet imports	Policy	Description
United Kingdom	5,197	Renewables Obligation Certificate Program	Renewable Obligation Credits (ROC) are issued by the Office of Gas and Electricity Markets (Ofgem). Suppliers use the ROC's pay-into or buy-out-of fund (currently at €44.33/ROC) or combination of both to meet their obligations (DECC 2015, Ofgem 2015).
Denmark	2,338	Feed-in-Tariff	The Danish Energy Agency (DEA) provides subsidies of €20/MWh for electricity produced from wood pellets (USDA 2013).
Italy	2,134	Green Certificates	Green Certificates (GC) are issued by Gestore Servizi Energetici (GSE) and prices are set as the average cost of the electricity purchased by GSE from CIP6 plants minus the average revenue of CIP6 electricity sold by GSE to the market. The reference price in 2010 was €113.1/MWh (Bimbo 2013; GSE 2012).
Belgium	725	Green Certificate Scheme	Managed on a regional basis for Flanders, Wallonia, and the Brussels-Capital area. Credit prices are €65 for Wallonia and Brussels regions, and the price varies based on supply chain considerations and fossil fuel usage (during transport) for Flanders (Elia 2016; USDA 2013).
Sweden	575	The Electricity Certificate System	Credits are allocated by the Swedish Energy Agency (SEA), and quota obligation fees for not meeting the assigned quota in 2013 were $39.91/certificate (SEA 2015).
The Netherlands	422	Stimulation of Sustainable Energy Production (Feed-in-Tariff)	The Netherlands Enterprise Agencies (NEA) provides subsidies at a maximum of $15/MWh for electricity and $41.67/GJ of renewable heat produced from renewable resources (IEA 2016; NEA 2016).
Germany	408	Renewable Energy Sources Act (Feed-in-Tariff)	The German government provides subsidies for renewable energy sources at an average of $12/MWh (FMEAE 2014).
Import data (in 1,000 tons) from International Trade Administration Fuels Top Market Report (2015) http://trade.gov/topmarkets/pdf/Renewable_Fuels_Biomass_Wood_Pellets.pdf			

Between 2012 and 2014, wood pellet exports from the United States were primarily shipped to the United Kingdom (73%), followed by Belgium (12%), the Netherlands (7%), and Europe (6%). Of those imported to the United Kingdom (UK), 82% went to the Drax Group, the UK's largest electricity provider (ELIA 2016). Because the UK's electricity sector is largely powered by coal, energy providers, such as DRAX, have been forced to develop cost-efficient ways of meeting the new policy requirements. This has motivated large-scale suppliers either to fit existing coal plants to co-fire coal with wood pellets or to convert plants to dedicated biomass in order to utilize existing infrastructure (Lowenthal-Savy 2015). The UK government views the use of wood pellets as a short- to medium-term solution (10 to 30 yrs) to meet EU's renewable energy and carbon reduction targets, while energy providers develop and build solar and wind energy infrastructure (Renewables Financial Incentives Team 2014). Although estimates vary, the projected demand of wood pellet consumption in Europe is expected to increase from 25 to 70 million metric tons by 2020 (International Trade Administration 2015).

While Europe is currently the primary demand driver, some countries consume smaller amounts and others offer potential opportunities in the future. In North America, Canada maintains a small consumer market and lacks incentivizing policies. The United States consumes approximately 80% of its wood pellet production, which is supported by the Renewable Energy Production Incentive (REPI) and various state-led economic incentives. As environmental policies strengthen, it is expected that coal power plants will co-fire with wood pellets and thus increase its market potential. In Japan and South Korea, the Renewable Portfolio Standard (RPS) is forcing energy producers to source a required amount from renewables, including biomass. In addition, South Korea subsidizes the purchase of domestically produced pellet boilers. New Zealand administers the Wood Energy Grant Scheme to promote the use of wood residues for energy; however, its abundant wood resources may limit import opportunities. Finally, industrial growth in China and a push to resolve serious environmental issues will likely present opportunities in the future; however, current policy support and consumption are underdeveloped (Goh *et al*. 2013).

Wood pellets are an energy-dense fuel source derived from forest biomass, including logging and sawmill residues, pulpwood, roundwood, and other lignocellulosic sources. The European Union classifies these resources as renewable and carbon neutral (EPRS 2015). The southeast US region has become UK's biggest supplier of wood pellets (Canada is a distant second, followed by other European countries), due to an abundance of private forests, strong logistics capacity, and competitively priced feedstock (Dewitt 2015; Goh *et at*. 2013; Lowenthal-Savy 2015). Pellet mills range in production capacity from 10,000 to 650,000 metric tons (MT) annually; however, larger mills, owned or run by medium to large firms, such as Enviva LP and Georgia Biomass, are generally built to meet export demand because they can achieve greater economies of scale and ensure more consistent and abundant supply (Pirraglia *et al*. 2010; SELC 2015). While pellet mills may provide economic benefits to landowners, loggers, and various businesses, the substantial increase in wood pellet production in the southeast US presents concerns, such as loss in biodiversity and habitat destruction (Drouin 2015). Therefore, with the demand for wood pellets on the rise, there is a need to better understand where future pellet mills should be built.

Industrial location determinants, or factors that influence where a company builds a manufacturing plant, can be segmented into various levels including, but not limited to: quantity and quality of resources (infrastructure, raw materials, labor amount and productivity, and the environment); market conditions (access to and demand from consumer markets, exchange rates, input prices, and agglomeration effects); country risk (government policies, taxes, and incentives, level of corruption, and political stability), and company strategy (companies may select locations based on long term strategy, demand trends, and the ability to negotiate with local governments and labor organizations) (Hayter *et al*. 1999; Badri *et al*. 2007). Existing literature in projecting future locations for pellet mills is scant. Young *et al*. (2011) utilize a logistic regression to identify factors influencing the locational choices of bioenergy and biofuel plants in the southern United States (US). Feedstock availability (expressed as the availability of thinnings, presence of wood using mills and unused mill residues) and high density railways had positive effects on the location of larger wood using bioenergy facilities, whereas median family income, population, low density of railway availability and harvesting costs for logging residues had negative.

Three articles compare the advantages of producing wood pellets in various countries for European consumption. Nunes *et al.* (2014) evaluate the production potential of Portugal, Germany and Sweden and find only Portugal to be economically competitive in the global market due to lower resource and labor costs. Ehrig *et al*. (2014) estimate the cost of producing in and shipping wood pellets from Canada, Australia, and Russia. Their results suggest that Australia is not competitive due to high supply costs and Canada is risky due to extremely low profit margins. However, Russia was found to be economically viable due to its raw material and shipping costs. Using a multi-criteria decision model (MCDM), Smith *et al.* (2011) find that the comparative advantages of countries varies depending on different wood pellet demand scenarios. While the US, Brazil and Western Canada maintain abundant resources, they are not cost-competitive with high shipping rates. Overall, Austria, Estonia, Czech Republic, and Sweden faired consistently better under various scenarios.

This article attempts to summarize and report on literature that may be relevant to an investor in selecting a location to build a wood pellet mill. In addition, it applies several tools in a case study examining the comparative advantages of North and South American countries.

1.2 METHODS

Relevant research was divided into four categories. The first covers research that focused directly on identifying location decision factors related to the theoretical framework of identifying potential pellet mill locations. The next section identifies tools and reports that can be used to evaluate a country's wood supply and its potential for wood supply; this is sub-divided into three sections: wood supply and potential, forest plantations, and international bioenergy. A combination of forest and bioenergy economic and optimization models, annual reports, and literature were critically analyzed. The third section includes articles about the wood pellet supply chain, including its production, distribution, and consumption. The fourth section reviews performance indices that provide insight into the countries' social, political, and economic conditions. Indices were categorized according to their specific objective, and the countries' factors were evaluated. In addition, two indices were utilized to rank the countries, based on their risk and supply chain. The conclusion of this review included a brief summary and contextualizes within the broader scope of the location determinants of starting a wood pellet plant in North or South America.

1.3 NORTH AND SOUTH AMERICAN WOOD SUPPLY AND POTENTIAL

Measuring wood's supply and potential depends on the productive capacity of land and the decision process and objectives of their owners; thus, articles and models attempting to evaluate current and future resources must account for environmental, social, and economic situations (Kallio *et al*. 1987; Wear *et al*. 1994; Buongiorno *et al*. 2003; Wear *et al*. 2003; Turner *et al*. 2006). Buongiorno *et al*. (2003) and Kallio *et al*. (2004 and 2006) review existing international trade models with forestry components, including the Global Trade Assessment Project, CINTRAFOR Global Trade Model, Timber Supply Model, Global Forest Product Supply Model, and the European Forest Institute - Global Trade Model. Incorporating various economic and biological assumptions, these models work to predict future patterns in forestry production, consumption and trade on a regional or country level basis. Several organizations collect and publish forest industry data for the public (Table 2). The Food and Agriculture Organization (FAO) leads in terms of the level of detail and years covered, followed by the International Tropical Timber Organization (ITTO) and the United Nations of Economic Commission for Europe (UNECE).

Table 2. List of Publically Available Reports and Databases for International Wood Resources

Organization	Name	Reporting frequency	Description
Food and Agriculture Organization	Global Forest Resources Assessment (GFRA)	Every 5 yrs	Provides a comprehensive analysis on wood consumption, production, and projected trends, and has been released every 5 to 10 yrs since 1948 (MacDicken 2015). The latest report was published in 2015 and collected data for 234 countries and territories via remote sensing and surveys administered to governmental bodies. It consists of a summary report that is supported by individual country assessments (FAO 2015).
	State of the World's Forests (SWF)	Every 2 to 5 yrs	Reports on the status of forests and their contributions to people's livelihoods, including food, health, shelter, and energy needs to promote productive policy making. The latest report was published in 2014 (FAO, 2014).
	Global Forest Products Outlook Study (GFPOS)	Occurred only in 2000	Provides detailed information on the current and future status of forest plantation establishment, economic and policy issues associated with forest plantation establishment, and the outlook for potential wood supplies from forest plantations (FAO 2005).
	Global Fiber Supply Model (GFSM)	Occurred only in 1998	A comprehensive study that represents a first look at some of the major factors affecting supply for producer countries in Asia/Oceana, Latin America, and Africa. They found that non-wood fiber will increase in demand for developing and developed countries seeking to utilize it, and that policy development will depend on the actions taken by the government, industry, non-governmental organization (NGO), and the investment community (Bull 1998).

Table 2 Continued

Organization	Name	Reporting frequency	Description
Food and Agriculture Organization	Global Forest Resource Assessment Database (FLUDE)	Periodically (2015)	Includes forestry data collected as part of the GFRA, including land characteristics, production, and deforestation (FAO 2016).
Food and Agriculture Organization	Statistics Database (FAOSTAT)	Periodically (2014)	The FAO's core database includes information on the economic, social, and political dimensions of the agriculture and forestry industries (FAO 2016).
International Tropical Timber Organization	Biennial Review and Assessment of the World Timber Situation (WTS)	Biennial (2014)	Provides international statistics available on global production and trade of timber, with an emphasis on the tropics (ITTO 2014).
	Tropical Timber Market Report (TTMR)	Bi-weekly (March 1 - 15, 2016)	Provides global market trends, trade news, and prices on more than than 400 tropical timber and added-value products (ITTO 2016).
	Tropical Forest Update (TFU)	Quarterly (4th Quarter in 2015)	Provides quarterly news and updates related to global tropical forests.
	Annual Review Statistics Database	Annually (2014)	Provides historical data on the international production and trade of primary wood products (ITTO 2016)
United Nations Economic Commission for Europe	Forest Products Annual Market Review (AMR)	Annually (2015)	Provides general and statistical information on the forest products markets in the United Nations Economic Commission for Europe (UNECE) region of Europe, North America, and the Commonwealth of Independent States (UNECE 2015).

FAOSTAT is the most robust database for forestry trade and production data, as it includes the most countries and the widest variety of forest products, including wood pellets. In addition, it's database goes back as far as 1961, depending on the specific variable (FAO 2016). ITTO's Annual Review Statistics Database has the advantage of disaggregating non-coniferous from non-coniferous tropical species for sawn wood, veneer and plywood products; however, it provides data only for its member countries going back to 1980 (ITTO 2016). The GRFA, WTS and AMR serve similar purposes in that they try to explain, both through qualitative and statistical analysis, international forest production, consumption, trade, and policy trends. From a wood pellet mill investor's perspective, the GRFA would likely be the most relevant as it provides detailed reports for nearly every country, covers all wood species and was published most recently in 2015 (FAO 2015). The WTS focuses only on primary and secondary products for tropical hardwood species and the latest report was released in 2014 (ITTO 2014). The AMR, while provided reports annually (the latest in 2015), it focus only on the UNECE region of Europe, North America and the Commonwealth of Independent State (UNECE 2015). In contrast to the GRFA, WTS and AMR, the SWF largely focuses on role forests play in contributing to the livelihood of people all over the world; however, Chapter 3 of the latest report maintains a section on the role of wood energy and provides some basic consumption statistics (FAO 2014). Finally, the GFPOS and GFSM occurred only once in 1998 and 2000, and would thus likely be too outdated for current investment purposes (FAO 2005; Bull 1998).

Table 3 lists the top-rated North and South American countries for wood resources (along with their wood pellet production and export quantities), as measured by forest area, planted forest area, roundwood production, and the total export value of forest products. Data from FAOSTAT was used because it combines wood pellet as well as forest area and production data. Roundwood production was included to anticipate the potential supply of sawdust, a common input for wood pellet mills. With the exception of Canada, Brazil, and the US, there is no clear association between abundant forested land and roundwood production. This could be attributed to several factors, including the political infrastructure or business environment circumstances.

Table 3. Forest Characteristics and Wood Pellet Production by Country (2014)

Country	Wood pellet production (tons)	Wood pellet export (tons)	Forest area* (000 ha)	Planted forest area (000 ha)	Roundwood production (000 m^3)	Industrial roundwood production** (000 m^3)
United States	6,503,637	4,414,820	245,332	26,364	398,693	356,812
Canada	1,910,672	1,804,917	323,145	15,784	154,259	149,934
Brazil	54,013	7,341	287,311	7,736	267,653	149,530
Chile	33,069	875	14,038	3,044	58,712	42,590
Argentina	12,125	6,438	25,176	1,202	18,261	13,666
Mexico	4,409	924	37,991	87	44,204	5,353
Honduras	4,409	924	2,257	0	478	478
Uruguay	4,409	1,609	1,532	1,062	12,424	9,668
Costa Rica	1,102	237	1,402	18	4,593	1,263
Peru	0	0	54,299	1,157	8,785	1,402
Colombia	0	0	47,978	71	12,145	3,841
Bolivia	0	0	44,084	26	3,367	943
Venezuela	0	0	22,370	557	5,514	1,317
Guyana	0	0	14,646	0	1,461	623
Suriname	0	0	13,442	13	542	492
Paraguay	0	0	12,824	98	11,062	4,044
Ecuador	0	0	7,559	55	7,432	2,440
Guatemala	0	0	1,700	185	654	654
Nicaragua	0	0	1,085	48	118	118
Dominican Republic	0	0	780	119	978	35
El Salvador	0	0	233	16	4,885	682
*Forest area does not include forest under conservation/protection						
**Roundwood production minus that for wood fuel						

FAO 2014

Research shows that forest plantations will increasingly play a significant role in roundwood production because they provide environmental, social, and economic benefits, such as reducing pressure on natural ecosystems and replacing marginal agriculture lands (Sedjo *et al*. 1999; Carle *et al*. 2002). Meanwhile, the total global forest area decreased from 4.28 to 3.99 billion ha from 1990 and 2015 and the planted forests increased from 167.5 to 277.9 million ha (4.06% to 6.95%), primarily in temperate zones and comprising approximately 88% native species (Payn *et al*. 2015). A comprehensive literature review found that the global timber harvest has increased over time and will likely continue to do so; illegal logging has increased in emerging economies, and planted forests will play a larger role in satisfying this increased demand (Nilsson *et al*. 2005).

The productive capacity of forest plantations varies regionally. Table 4 summarizes data collected by Cubbage *et al*. (2014) on common plantation species for North and South American countries and their respective growth rates. Argentina, Brazil, Chile, Colombia, Mexico, Uruguay, and Venezuela host both eucalyptus and pine species, with Argentina and Brazil achieving the highest mean annual increment yields. In addition to pine, Douglas fir is grown in the US, balsa wood is grown in Ecuador, and gahmar wood is grown in Costa Rica and Venezuela. As previously mentioned, the US and Canada are the largest producers of wood pellets. In South America, Brazil, and Chile are the largest producers (primarily for domestic markets) and are characterized by smaller mills that rely on sawmill residues as inputs (Goh *et al*. 2013). This may be subject to change because in Brazil, Suzano plans to produce 2 million tons of pellets per year and Tanac plans to produce 441,000 ton/yr for the Drax Group in 2016 (Nielsen 2011, TANAC 2014). Both Suzano and Tanac mills would source their raw materials from forest plantations.

Table 4. Common Plantation Species for Selected Countries (2011)

Country	Species	Rotation age (yrs)	Mean annual increment (m^3/ha/yr)
Argentina	*Pinus taeda* – Misiones	18	25
	Eucalyptus grandis – Corrientes	12	40
Brazil	*Pinus taeda* pulpwood/sawtbr	15	30
	Pinus taeda sawtimber	25	25
	Eucalyptus urophylla pulpwod, S.P.	6	40
	Eucalyptus grandis sawtimber	16	40
Chile	*Pinus radiata* sawtimber - Good Site	22	30
	Pinus radiata pulpwood - Poor Site	16	20
	Eucalyptus globulus pulpwood	16	25
	Eucalyptus nitens pulpwood	14	30
Colombia	*Eucalyptus grandis*	20	25
	Pinus tecunumanii	20	25
	Pinus maximinoi	20	24
	Pinus patula	20	18
Costa Rica	*Gmelina arborea*	12	31
Ecuador	Balsa	5	40
	Pinus radiata	20	20
Mexico	*Pinus gregii*	20	15
	Eucalyptus grandis	8	30
Paraguay	*Eucalyptus* sp. clones	14	30
	Eucalyptus sp. seedlings	14	26
Uruguay	*Eucalyptus globulus*	9	22
	Eucalyptus grandis pulp	10	28
	Pinus taeda	22	18
	Eucalyptus grandis sawtimber	16	25
United States	*Pinus taeda* South*	25	10 - 17.1*
	Psuedotsuga menziesii Site II	40	13
	Psuedotsuga menziesii Site I	40	17
Venezuela	*Pinus caribaea*	12	18
	Eucalyptus urophylla	7	25
	Gmelina arborea	5	25

*Range based on management intensity
Cubbage *et al*. (2014)

International Bioenergy

The current estimates of the potential bioenergy supply vary significantly according to the type of model (statistical *vs*. remote sensing and geographic information science), method (biomass availability based on inventory *vs*. economic conditions), and assumption (alternative land uses, land/crop productivity, biodiversity, water availability, commodity market conditions, food, forest, and energy production, prices and demand amounts, and varying inclusion/definitions of bioenergy categories) (Gronowska *et al*. 2009; Dornburg *et al*. 2010; Offerman *et al*. 2010; Long *et al*. 2013; Slade *et al*. 2014). Research shows that bioenergy resources are sufficient to meet increasing global demand without competing with food production, and that the short-rotation plantation systems could play a major sourcing role (Carle *et al*. 2008; Pleguezuel *et al*. 2014). In addition, woody biomass has become major sources of supply and certification would be the most suitable instrument for developing sustainable bioenergy systems (Ladanai *et al*. 2009). However, a recent study suggests there is a need to better understand the drivers of competition, technical strategies, and participatory approaches for improving biomass utilization, and integrated approaches for optimizing bioeconomic value chain networks (Lewandowski 2015).

It appears that the demand for bioenergy should be met by the current supply of wood resources without sacrificing food production. Plantations will likely play a more prominent role, especially across South America, where these growers alleviate the demand on natural ecosystems and provide income from marginal agriculture land. However, natural forests will supply the majorities of the resources because of the expanse of forested land in North and South America. Canada, the US, and Brazil, followed by Chile and Uruguay, appear the most capable of supplying Europe with wood pellets, based on their large supply of natural and plantation forests, significant roundwood production, and high growth rates. In contrast, Peru, Colombia, Bolivia, and Mexico lack the necessary resources for extensive plantations and industrial roundwood production. The remaining countries are not strong candidates for supplying wood pellets because of limited forested land and underdeveloped industries.

1.4 WOOD PELLET SUPPLY CHAIN

The supply chain of a product or raw material describes the network of buyers and sellers that connect its production, processing, distribution, and eventual sales in the target market. With regards to bioenergy, this includes landowners, forest loggers, agriculture harvesters, land transportation agents (in home and target markets), manufacturing/ biorefinery plants, storage facilities, ports, shippers, and consumers. In contrast, the value chain describes those processes and activities within each component of the supply chain that adds value to the products. For instance, this can occur at the manufacturing level, where factories convert biomass feedstock into bioenergy, or at the distribution level, where truckers provide value by making the raw material and/or goods available to users (Qian and McDow 2013; Seebaluck and Leal 2015).

The wood pellet sector can be broken into four primary components:

1. Feedstock sourcing (harvesting, inland transportation, forest consulting, and finance);
2. Pellet production (storage, pelletizing, inland transportation, and financing);
3. Distribution (ocean transportation, harbor storage, loading/unloading, and financing);
4. Consumption (inland transportation and consumption for heat and electricity) (Sikkema *et al*. 2010; Qian and McDow 2013).

With respect to bioenergy value/supply chains in general, there are various types of decision-making levels (strategic, tactical, and operational), uncertainties (feedstock supply and logistics capacity, production/operation and demand/pricing, *etc*.), different methods in which uncertainties are addressed (analytical and simulation), and sustainability concepts and models (Balaman and Selim 2015; Seebaluck and Leal 2015). Management approaches have been devised according to their logistics capacity, uncertainty, leanness, agility, managerial involvement, demand driven strategies, demand forecasting, and models utilized, by mathematical and simulation processes (Hughes *et al*. 2014).

Of the biomass feedstock types, wood pellets from southern yellow pine present minimum processing issues and are more economical than alternatives; also the torrefied pellets from yellow pine have higher energy density and are thus ideal for displacing coal (Pirraglia *et al*. 2012). Research related specifically to wood pellet production have identified a range of typical product characteristics, such as density, moisture, and ash content, their associated production processes, including drying, grinding, conditioning, pelletizing, screening for fine separation, and packaging/sorting (less common production aspects include bonding, adhesive mechanisms, and thermal treatments), as well as their financial cost characteristics (Stelte *et al*. 2012; Hughes *et al*. 2014). Torrefaction, the thermochemical process of heating biomass to above 390 °F in an oxygen-deprived environment, has recently garnered attention for its capability to increase the energy density of wood pellets. This additional step in the pelletization process could present significant market opportunities to co-fire in coal plants (Nunes *et al*. 2014).

Financial analysis of wood pellet production is scant; however, existing research identifies biomass feedstock (made up of harvesting cost, stumpage price, and transportation) as the most important cost component, followed by labor, energy (electricity and natural gas), consumables, depreciation, and taxes (Pirraglia *et al*. 2010, 2012; Uasuf and Becker 2011; Stelte *et al*. 2012; Trømborg *et al*. 2013; Qian and McDow 2013). With regards to servicing international markets, transportation and supply chain logistics play significant roles (Thek *et al*. 2004; Hoque *et al*. 2006). The April, 2016 freight on board (FOB) current market prices for wood pellets from southeastern US and southwestern Canada were approximately $123/ton and $118.00/ton, respectively (Argus Media 2016). Initial data concerning the labor and energy costs show considerable variation among countries. In Guyana, industrial electricity costs $.30/kWh, as opposed to $.0642/kWh in the US (Climate Scope 2015; Energy Information Administration 2016). The average manufacturing wage is $21.23 per hour in Canada and $1.39 in Mexico (ILO, 2016). Understanding the competitive advantages is important for future research.

Although the supply chain characteristics vary among countries, common issues often include an evolving nature of supplier markets, varying weight standards when transporting wood, and a lack of research and worker training (at least when comparing the southern US to other countries) (Siry *et al*. 2006). To address market deficiencies and aid with biomass sourcing and conversion decision-making for selling biomass-based products in the European market, Black *et al.* (2015) developed a database system that includes physical characteristics of biomass, the necessary technology to process it, and relevant policies and risk factors to assist with business decisions.

The development of standardized environmental and technical requirements in the EU may influence future potential wood pellet supply locations. For instance, Canadian forests, largely publically owned, will likely have greater traceability than forests owned by small landowners in the US (Goetzl 2015). While the EU lacks uniform obligatory requirements, member states have adopted certification systems and/or sustainability criteria of their own, including the Green Gold Label, NTA 8080 certification, Laborelec-SGS Solid Biomass Sustainability Scheme, Drax Biomass Sustainability Implementation Process, UK's Timber Standard, Germany's GINPlus, Austria's Önorm M 7135, France's NF Granules Biocombustibles, and Italy's Pellet Gold. Various industry participants are working towards establishing consistent certification systems such as ENPlus (wood pellet technical standards), ISO 13065 (environment, social and economic sustainability) and Sustainable Biomass Partnership (sustainability standards for industrial wood pellet buyers) (Goetzl 2015; Hiegl *et at*. 2009).

Given the complex nature of and rich literature covering the environmental implications of wood pellets, a comprehensive review is beyond the scope of this paper. However, a brief overview may be relevant to investors. The environmental impacts of substituting coal for wood pellets vary throughout the supply chain and depend on forest management practices, types of biomass sourced, product specifications, production processes, transportation modes and on the proximity of the pellet mill to biomass resources and final consumer markets. Such processes lead to various levels of emissions, including CO, CO_2, CH_4, N_2O, NO_2, VOC, PM and SO_x, Aldenhyde and NH_3, that can contribute to global warming, acid rain, and smog. Energy consumed throughout the supply chain varies, and includes propane, gasoline, diesel, and bunker oil for harvesting and transportation and natural gas, wood waste, electricity, and steam for pellet production. In a Canadian study, marine transportation was found to be the highest environmentally impacting activity, followed by harvesting and pellet production (Magelli *et al*. 2009; Pa *et al*. 2012).

Forest plantations have been proposed as one means to produce pellets, with less adverse impacts to native forests. Their active management would provide economic incentives that could increase wood fiber supply and increase sustainability of wood pellet use. Forest plantations require active management, and they present some concerns about intensive chemicals, water quality, and biodiversity. However, planted forest use can offset native forest harvests, which take longer to regenerate and restore their carbon losses (Abt *et al*. 2012). Forest management practices relating to harvesting, species composition, site-preparation, and tending can be adjusted to reduce their use and consequences of intensive forest management impacts (Hartley 2002). There is a vast literature on life cycle analysis of wood pellets and biomass. One example of a cradle to gate analysis by Katers *et al*. (2012) found that processing whole logs into wood pellets used less energy than dry and wet co-products. Another found that using wood pellets instead of coal to produce electricity in Europe reduces greenhouse gas emissions by approximately 74% to 85% (Wang *et al*. 2015).

Current research is insufficient to truly compare the costs and benefits of building a large-scale wood pelleting mills in North and South America. Qian and McDow (2013) and Hoque *et al.* (2006) directly address the different wood pellet supply chain components (feedstock inputs, production, inland and shipping transportation, port usage, and final consumption in Europe), accounting for their associated costs; however, their scope was limited to southern US and Canadian producers. The analyses conducted by Sikkema *et al*. (2010) and Lamers *et al*. (2015) were global; although detailed information on individual North and South American countries was absent. Given price volatility in the wood sector and the current rise of the US dollar in comparison with other currencies, it will be important to understand how Central and South American countries can contribute in European markets. In addition, those analyses which primarily examine the pellet production processes and costs assume plant capacities of less than 120,000 MT/year. Pirraglia *et al*. (2010 and 2012) assumed that production and consumption would take place in the US; while Thek *et al*. (2004) assumed that production and consumption would be located primarily in Europe. While these analyses are robust, pellet mills designed to meet demand from export markets can produce up to 650,000 MT/year of pellets in bulk SELC 2015). Furthermore, our research found no previous analyses that used one cost and production model to evaluate the competitive advantages among North and South American, making it difficult to appreciate their various differences. Thus, much work remains with regards to conducting financial analyses of wood pellet production across various countries.

1.5 COUNTRY INDICES

There is extensive research on country risk and investment climate analyses dating back to the 1960s. While various methodologies have been developed, it is beyond the scope of this article to cover them all. This section will review performance indices developed by large organizations, companies, banks, and government entities (sources likely to be used by international investors).

Performance indices can provide effective means of evaluating countries based on social, political, economic, environmental, and health-related issues; also the UN's Development Programme (UNDP) conducted a comprehensive survey of performance indices in 2008 (Bandura 2008). For example, The Economist's Big Mac index measures the status of currencies, Freedom House's Countries at Crossroads measures government accountability and civil liberties, and the Standard and Poor's Sovereign Credit Rating measures the ability of governments to service debt. Other indices have a broader scope: The Economist

Intelligence Unit's (EIU) Country Risk Rating evaluates political, economic, and industry specific risk factors, and the Forbes' Capital Hospitality Index evaluates the macroeconomic and social indicators, including GDP growth, international trade, poverty, *etc*. Generally, an index is made up of several categories and subcategories that are averaged together (weighting schemes are sometimes applied). For example, the World Bank's Ease of Doing Business Index (WBEDB), one of the most widely-used indices, is subdivided into the following ten categories: Starting a Business, Dealing with Construction Permits, Getting Electricity, Registering Property, Getting Credit, Protecting Minority Investors, Paying Taxes, Trading Across Borders, Enforcing Contracts, and Resolving Insolvency (World Bank 2016). Each is scored separately and then pooled to arrive at a total country score, from which countries are then ranked. There are a large number of indices designed to rank countries based on specific goals.

Performance indices have been used in evaluating international forestry investments. Gonzalez *et al*. (2008) used indices from Global Edge, Coface, and the Organization for Economic Cooperation and Development (OECD) in assessing the future of the global forest products sector. Cubbage *et al*. (2010, 2014) utilized the Belgium Export Credit Agency's (listed under Ducrioire in Appendix A) risk index and the World Bank Ease of Doing Business (WBEDB) to better understand current and future investments in timber.

Selecting the location for a large, export-oriented wood pellet mill requires suitable social, political, economic, and supply chain conditions and institutions. This analysis utilizes two comprehensive indices: World Bank's Logistic Performance Index (LPI) and IHS Connect Country Risk Index (IHS Risk). LPI was selected because it is the only index fully dedicated to measuring countries' supply chain factors. IHS Risk was selected because it provides a comprehensive look at the countries' social, political and economic risks and is updated on a quarterly basis. In addition, many of the indices reviewed by Bandura (2008) are limited in several ways, including being updated less frequently (or not at all in many cases) and covering fewer countries and social, political and/or economic conditions separately. Table 5 provides the definitions of categories, inclusive of LPI and IHS Risk. LPI is scored on a scale of 1 to 5, where higher is better. In contrast, IHS Risk is scored from 1 to 10, where 0 to 1.5 is considered low risk, 1.6 to 3.0 medium risk, 3.1 to 6.4 high risk, and 6.4 or greater extreme risk.

Table 5. IHS Risk and Logistic Performance Index (LPI) Category Definitions

IHS Risk		LPI	
Category	Sub-categories and definitions	Category	Definition
Political	Sub-categories: Government Instability, Political instability, and State Failure Risk the government will change in the next year; may implement broad policy shifts that lead to challenging business environments and/or state is unable to ensure law and order	Customs	Efficiency of the clearance process (*i.e.*, speed, simplicity, and predictability of formalities) by border control agencies, including customs
Economic	Sub-categories: Recession, Inflation, Depreciation, Capital Transfer, Sovereign Default, and Under-Development Risk of reduced economic growth to well below its potential sustainable pace over the next 12 months, major currency rate depreciation, added restrictions to cross boarder capital transfers and government defaulting, and degree of under-development of the economy.	Infrastructure	Quality of trade and transport related infrastructure (*e.g.*, ports, railroads, roads, and information technology)
Legal	Sub-categories: Expropriation, Alteration, and Enforcement Risk that the state will deprive, expropriate, nationalize, or confiscate the assets of private businesses, alter the terms of contracts it has with private parties without due process and/or judicial system will not enforce contractual agreements between private-sector entities because of inefficiency, corruption, bias, or an inability to enforce rulings promptly and firmly	International shipments	Ease of arranging competitively-priced shipments

Table 5 Continued

Category	Sub-categories and definitions	Category	Definition
Tax	Sub-categories: Increase and Inconsistency Risk that the overall tax burden for private enterprises will increase and/or taxes are levied in an inconsistent, unpredictable, or opaque fashion	Logistics competence	Competence and quality of logistics services (*e.g.*, transport operators and customs brokers)
Operational	Sub-categories: Corruption, Regulatory Burden, Infrastructure Disruption, and Labor Strikes Risk that individuals/companies will face bribery or other corrupt practices to carry out business, normal business operations become more costly due to the regulatory environment, disruption to and/or inadequacy of infrastructure for transport and strikes, politically motivated shutdowns, natural disasters, strikes, and other forms of industrial action disrupt normal activity and business operations	Tracking and tracing	Ability to track and trace consignments
Security	Sub-categories: Protests and Riots, Terrorism, Interstate War, and Civil War Risk of protests and riots disrupting normal activity and business operations, activities of any non-state armed group/individual causing property damage and/or injury, interstate groups engage in targeted strikes, with the aim of changing the government and/or occupation and intra-state military conflict in which rebels attempt to overthrow the government, achieve independence, or at least heavily influence major government policies	Timeliness	Timeliness of shipments in reaching their destination within the scheduled or expected delivery date

IHS Connect and World Bank Group (2016)

Categories with LPI and IHS Risk were scored and averaged together to arrive at an overall score. Because the supply chain and country risk factors were not directly correlated, a separate index was created to more effectively rank the countries. This index combined the overall scores of the LPI and IHS Risk as follows,

$$\text{Combined Index Score} = (LPI_i \times 2) - \text{IHS Risk}_i \qquad (1)$$

where the LPI_i is the average LPI score for country *i* and the IHS $Risk_i$ is the average IHS Risk score for country *I* (Table 6). A higher Combined Index Score reflected better investment climates. The US, Canada, and Chile ranked the highest based on low risk and developed supply chain factors, whereas Venezuela and Bolivia ranked the lowest.

Table 6. Logistic Performance Index and IHS Risk Scores for North and South American Countries (2014, 2016)

Country	Combined Index	World Bank Logistic Procurement Index Country Score	IHS Connect Country Risk Index Country Score
United States	6.84	3.92	1
Canada	6.82	3.86	0.9
Chile	5.02	3.26	1.5
Mexico	4.26	3.13	2
Uruguay	4.06	2.68	1.3
Dominican Republic	3.72	2.86	2
El Salvador	3.72	2.96	2.2
Costa Rica	3.5	2.7	1.9
Argentina	3.48	2.99	2.5
Brazil	3.48	2.94	2.4
Peru	3.48	2.84	2.2
Paraguay	3.26	2.78	2.3
Colombia	3.08	2.64	2.2
Guatemala	3	2.8	2.6
Nicaragua	2.7	2.65	2.6
Guyana	2.42	2.46	2.5
Honduras	2.42	2.61	2.8
Ecuador	2.32	2.71	3.1
Bolivia	1.66	2.48	3.3
Venezuela	1.22	2.81	4.4

The abundance of wood and positive investment climates in the US and Canada may explain why wood pellet production is highest in these countries. While Brazil has significant wood resources, its modest investment ranking provides international investors reason to consider Chile, Mexico, or Uruguay instead. More research is required to better understand the financial trade-offs of building and operating a pellet mill in each country in order to predict future investments. This article provides a solid foundation for researchers and investors that are interested in finding locations to build a pellet mill in North and South American countries.

1.6 CONCLUSIONS

1. Environmental policies, including credit programs and feed-in-tariffs, in the E.U. have led to a significant increase in the amount of wood pellets produced in the southeast US. The largest importer is the UK, followed by Denmark and Italy. The UK views wood pellets as a medium terms solution, and will eventually move to more solar and wind sources.

2. Wood resource supply and cost, supply chain infrastructure and cost, and investment climate and risk are important determinants in international forestry investments.

3. There are sufficient wood resources to meet future bioenergy demands and forest plantations will likely play an increasingly important role as they reduce pressure on natural forests and achieve faster growth rates.

4. FAOSTAT is the most robust database for forestry trade and production data as it includes the widest variety of products (including wood pellets) and number of countries. ITTO’s Annual Review Statistics Database has the advantage of

disaggregating non-coniferous from non-coniferous tropical species for sawn wood, veneer and plywood products.

5. Feedstock delivery price is the most important cost-component in producing wood pellets, followed by labor, energy, consumables, depreciation, and taxes (in addition to port and shipping expenses when exporting).

6. Country performance indices range in their goals, from evaluating social, economic and political risk to supply chain factors, and provide an effective way of evaluating investment climates.

7. Results from the case study suggest that the US, Canada and Chile may be best situated to receive investments in wood pellet mills given their abundant wood resources and attractive investment climates. Uruguay is also be a feasible option; however, it may be limited by a lack of natural forest area. Argentina, Brazil, Colombia, Mexico Paraguay and Peru may be suitable for investors willing to accept greater risk. Given the higher growth rates of South American countries, this risk would likely be compensated with greater rates of return. The remaining countries would likely not see interest from investors given their low wood resources, poor investment climate, or combination thereof.

1.7 DISCUSSION

Environmental policy drivers in the European Union have led to a significant increase in the amount of wood pellets produced in the southeastern US. To identify where pellet mills should be located in North and South America to satisfy this demand, a critical review of literature, economic models, and data, as well as supply chain and country risk factors related to wood pellet production, were considered. The present analysis indicates that the feedstock supply and cost, the supply chain infrastructure and cost, and the investment climate of countries are important determinants in international forestry investment decisions. This is supported by the findings of Young *et al*. (2011) that bioenergy plants in the south US are more likely to be built in areas with greater resources (availability of thinnings, unused residues, and wood-using mills) as well as infrastructure (amount of high density railways).

Our analysis found a significant lack of research looking at the comparative advantages of different countries to produce wood pellets. Smith *et al*. (2011) conducted a global analysis using a MCDM model that incorporated four types of variables, including feedstock, production costs, investment climate, and market potential and logistics. While their analysis suggests investors are likely to target North American and European regions, it is limited in several ways. First, only Brazil and Chile are considered for South America. As shown above, other countries such as Argentina, Mexico, Peru, Colombia, and Uruguay may be competitive given their significant resource capacity and fair to strong investment climates. Next, it does not distinguish between total forest area, forest area under protection, and planted forest area. This overestimates the feedstock availability of Brazil, which protects most of its amazon region. Finally, the present analysis uses capital costs (derived from interviews with industry professionals) and total river, sea, and rail networks available as measures of country risk and supply chain capacity. While these are important, indices such as IHS Risk and LPI provide more information and insight into the investment climate of countries. In addition, they are updated regularly and based either on extensive industry surveys or in-depth research by trained analysts. Other work that could be used to compare the benefits of building a pellet mill among different countries are limited in scope. Nunes *et al.* (2014) focus Portugal, Germany and Sweden whereas Ehrig *et al*. (2014) look at Canada, Australia and Russia. The objective of each is to provide market analyses and cost comparisons; however, they do not consider country risk beyond the cost of capital (a single rate is applied uniformly to each country in both papers).

This paper attempts to bring together resources of interest to an investor looking to build an export oriented wood pellet plant. It examines European policy drivers and their likely future directions, existing economic trade models and databases and tools to evaluate supply chain and country risk factors. In addition, it builds on existing literature by using North and South American regions as a case study. While the present conclusions provide significant insight into the trade-offs of different countries, additional work is needed to better understand their associated labor, energy, tax, shipping, and feedstock costs. An initial assessment of these cost components shows that they vary significantly. Combining a techno-economic model, such as one of those reviewed under the Wood Pellet Supply Chain section, with the results of this case study would provide a more complete view of the trade-offs of investing in North or South America.

CHAPTER 2

2.1 INTRODUCTION

The European Union (EU) is requiring member states to reduce greenhouse gas emissions by 40% and increase the share of energy from renewable sources to 27% by 2030 (European Commission 2016; European Union 2016; Lamers et al 2014). To accomplish this, the United Kingdom (UK) has come to rely significantly on wood pellets for electricity generation due to its status as a renewable and carbon neutral energy source (Drouin 2015). In 2015, it imported approximately 6.5 million tons of wood pellets, up 25% from 2015 and 75% in 2014 (FAOSTAT 2016). Wood pellets are thought to be an important component of UK's medium term energy strategy as it develops wind and solar capacity and he ability to retrofit coal power plants for their use makes them a relatively low-cost solution to meeting EU requirements (Lowenthal-Savy 2015). Currently, the biggest wood pellet supplier to the UK is the southeast region of the United States (US), followed by Canada and Latvia (Biomassmagazing 2016). The substantial increase in wood pellet trade has led to concerns, including loss in biodiversity and habitat destruction (Drouin 2015). Therefore, there is a need to better understand where else wood pellet mills may be built to service increasing energy demands in the UK.

Singh et al (2016) conduct a literature review relevant to locating wood pellet mills and find that several methods have been applied, including logistic regression analysis (Young et al. 2011) and a multi-criteria decision model (Smith et al. 2011). In addition, cost analysis approaches use the different feedstock, labor, energy and/or transportation (inland and shipping) costs of each location as input variables of a wood pellet cost model (WPCM). WPCMs are techno-economic models that simulate the production process, energy consumption and financial results of operating a pellet mill based on certain characteristics, such as types of feedstock utilized, production capacity and final product packaging/transportation (bag or bulk). Its parameters are established by current processing technology and market conditions. Several studies have used WPCMs to assess wood pellet production and/or delivered to EU costs in one or multiple locations (Table 7).

Table 7. Wood Pellet Cost Estimates from Previous Literature

Country	**Calculated Cost (type)**	**References**
Argentina	35 - 47 euro/mt (production)	Uasuf et al 2011
Australia	149 - 155 euro/mt (delivered to EU)	Ehrig et al 2014
Austrian	90.7 euro/mt (production)	Thek et al 2004
Canada	134 - 139 euro/mt (delivered to EU)	Ehrig et al 2014
	136 - 142 dollar/mt (delivered to EU)	Hoque et al 2006
Finland	140 - 142 euro/mt (production)	Trømborg et al 2013
Germany	150 - 158 euro/mt (production)	Nunes et al 2014
	150 - 159 euro/mt (production)	Trømborg et al 2013
Norway	158 - 160 euro/mt (production)	Trømborg et al 2013
Portugal	128 - 130 euro/mt (production	Nunes et al 2014
Russia	117 euro/mt (delivered to EU)	Ehrig et al 2014
Sweden	145 - 152 euro/mt (production)	Nunes et al 2014
	146 - 155 euro/mt (production)	Trømborg et al 2013
	62 euro/mt (production	Thek et al 2004
USA	119 - 122 euro/mt (production)	Trømborg et al 2013
	187 - 219 dollar/t (production)	Pirraglia 2010
	78 - 216 dollar/t (production)	Qian et al 2013

Country: location where wood pellet production takes place
Type: Represents either the cost of production, or the cost of production and delivery to EU
mt: metric tons; t: tons

The wood pellet supply chain consists of wood suppliers (landowners, forest product processing mills and wood dealers), producers (wood pellet mills and storage facilities), distributors (wholesalers, retailers, traders and international shipping and logistics companies) and consumers (for this analysis, industrial energy producers in the UK) (Qian and McDow 2013). Industrial location determinants can be divided into several different components (quality and quantity of resources, market conditions, country risk and company strategy) (Hayter 1997). Therefore, this analysis builds on the work of Singh et al (2016) (who found that Argentina, Brazil, Canada, Chile, Colombia, Mexico, Paraguay, Peru, United States and Uruguay have suitable wood resources and investment climates for a large, export oriented pellet mill) by developing a WPCM to compare the cost of producing wood pellets in different North and South American countries and shipping them to Europe.

This paper is broken into several components. First, it describes in detail how the model was developed and the assumptions, limitations and data utilized. Next, it provides the results from the cost analysis and puts them into context with regards to countries' investment risk and supply chain conditions. Finally, the conclusions are highlighted and a discussion elucidates future research opportunities.

2.2 THE MODEL

The WPCM utilized for this analysis was built in Microsoft Excel 2016 and expands on the work done by Pirraglia et al. (2010) by incorporating the varying energy, labor, tax, feedstock, inflation and exchange rate costs for Argentina, Brazil, Canada (Western), Chile, Colombia, Mexico, Peru, the United States (Northeastern, Southeastern and Northwestern) and Uruguay. In addition, it estimates shipping expenses from these countries and regions to the Port of Immingham in England. The WPCM can be configured for various objectives, but is used here to find the minimum sales price of a ton of delivered wood pellets and the Internal Rate of Return (IRR) given current market prices.

The technical and economic assumptions laid out in Appendix A are based on literature and current industry trends as detailed in market reports and collaborations with various professionals. This analysis assumes that the requirements of capital, maintenance, operating materials, labor, energy, feedstock as well as other fixed costs and depreciation are the same across countries. It assumes the perspective of an American based investment fund that will finance the project using US Dollars (except for labor, energy and feedstock costs) and not rely on loans. While investment risk and supply chain conditions vary significantly across countries, it is beyond the scope of this analysis to review them in-depth. Thus, harvesting and inland transportation costs, customs processing and port qualities and capacities are assumed equal across countries. Rather, the results section compares the minimum sales price for delivered wood pellets against the World Bank's Logistics Performance Index and the IHS Connect's Country Risk Index scores in order to account for such conditions.

As with Pirraglia et al (2010), this model incorporates a scaling factor of 0.7 that estimates the capital investments required to meet a target production level, set here at 500,000 tons per year to mimic a large, export oriented pellet mill. Bagging bins and systems were excluded since wood pellets shipped internationally are done so in bulk (Qian and McDow 2013). Finally, equipment and machinery is expected to last the duration of the project's life (set at 20 years) and is depreciated using MACRS 7.

Regions are designated within the United States and Canada due to greater data availability on feedstock and energy costs and that shipping costs from east and west coasts differ noticeably. In addition, while eastern Canada produces 35% of the country's wood pellets, it is characterized by small mills (50,000 ton production capacity and less) due to fiber availability (WPAC 2016). Therefore, this analysis will only consider western Canada.

Given that demand for wood pellets is expected to increase, this analysis assumes a 2% real increase in sales price annually.

Financial Analysis

National corporate tax rates were used to calculate tax expenses (the average state taxes rates were added for the US and Canada). While different states and provinces may apply their own and/or offer exemptions, an in-depth review is beyond the scope of this analysis. Next, inflation was incorporated into operating and capital expenses and their rates were calculated as the average between 2005 and 2015. Since inflation can vary significantly from year to year, it is assumed here that using an historical average would provide a stable and realistic assessment of future conditions. Further, this analysis assumes wood pellets will be traded in US dollars, and thus its inflation rate is added to their price increase. Since the capital requirements are the same across countries and shipping contracts can be established in dollars, an exchange rate component was only added to labor, energy and feedstock expenses. The dollar has appreciated significantly relative to other currencies since 2014, thus making it cheaper for American based firms to invest abroad (Tradingeconomics 2016; NYT 2016). To account for this trend, the latest currency spot rates as reported by the Treasury department was used.

Table 8. Tax, Inflation and Exchange Rates

Country	Corporate Tax Rate	Inflation	Exchange Rate (LC/$)
Argentina	35%	9.46%	15.35
Brazil	34%	5.81%	3.257
Canada West	26%	1.75%	1.316
Chile	23%	3.45%	659.2
Colombia	25%	4.08%	2890.11
Mexico	30%	4.02%	19.46
Peru	28%	2.93%	3.384
US Northeast	40%	2.09%	1
US Northwest	40%	2.09%	1
US Southeast	40%	2.09%	1
Uruguay	25%	7.56%	28.5

Corporate tax rate (Deloitte 2016); Inflation (Averaged between 2005 and 2015) (Worldbank 2016); Official Exchange Rate for September 30, 2016) (Treasury 2016)
LC: Local Currency

Plant construction is assumed to begin in 2017 and finish in 2018, and will operate 8,400 productive hours per year (based on three-day shifts, eight hours per shift, seven days per week and 50 weeks per year). Direct labor requirements are modified with the mill's annual production output. The initial structure, three production workers and one supervisor, forklift operator and maintenance technician, is based on a four ton per our production rate. These amounts are increased by one for each category based on incremental production increases of four tons per hour (there are 20 total employees given the 500,000 ton/year production output). Due to limited data availability, wage rates for production or manufacturing workers were used as a proxy for direct labor costs. The cost and structure of indirect labor (administrative personnel) is held constant across countries and is not responsive to changes in production output. Except for the US, wage rates reported in local currencies were converted to dollars using current rates.

Table 9. Wage and Labor Rates

Type	Wage Rate (LC/hour)	Wage Rate ($/hour)	Other benefits ($/year)	Yearly cost ($/year)
Direct Labor (Manufacturing)				
Argentina	31	$2.01	N/A	$335,011
Brazil	7	$2.19	N/A	$364,937
Canada West	23	$17.55	N/A	$2,931,383
Chile	2936	$4.45	N/A	$743,904
Colombia	3250	$1.12	N/A	$187,769
Mexico	41	$2.10	N/A	$350,734
Peru	9	$2.73	N/A	$455,609
US Northeast	19	$19.05	N/A	$3,181,350
US Northwest	19	$19.05	N/A	$3,181,350
US South Atlantic	19	$19.05	N/A	$3,181,350
Uruguay	251	$8.82	N/A	$1,473,643
Indirect Labor				
CEO		$115	$40,000	$260,800
CFO		$105	$25,000	$226,600
Operation manager		$85	$25,000	$188,200
Assistant		$12	$15,000	$38,040
Procurement Officer		$45	$15,000	$101,400
Sales Associate		$45	$15,000	$101,400
Employee Health Supervisor		$45	$15,000	$101,400
Logistics Analyst		$45	$15,000	$101,400
Human Resources Associate		$45	$15,000	$101,400
Total Indirect Labor				**$1,220,640**

Argentina, Brazil, Chile, Colombia, Paraguay and Peru (ILO 2014)
Canada 2016 (Statcan 2016); USA (BLS 2016 - Plant and Systems Operators); Colombia (Financecolobia 2016); Mexico (Tradingeconomics 2016); Uruguay (Tradingeconomics 2016);
LC: Local Currency

The mass balance and energy consumption component of the model determines the feedstock (roundwood and forest and sawmill residues) and energy (natural gas and electricity) requirements given a target production output. While moisture is gained throughout the stabilization phase and lost during the pelletizing and drying phases, this model reverses to process so that we can arrive at a required feedstock amount based on a target output (in this case, 500,000 tons per year). The energy required throughout the drying and grinding/pelletizing phases is determined by the total weight of feedstock being processed and is multiplied against the natural gas and electricity rates for each country in the income statement. Except for the US and Canada (where government issued data was used), this analysis uses 2013 and 2014 data from Global-Climatescope.org for industrial electricity rates. These amounts, reported in dollars, were converted to local currencies using December 31, 2013 and December 31, 2014 exchange rates, averaged, and then converted back to dollars using current rates. Electricity prices for the US were averaged for 2015 and 2016.

Table 10. Industrial Electricity and Natural Gas Prices

Country	**Natural Gas Price ($/MMbtu)**	**Industrial Electricity Price (LC/Kwh)**	**Industrial Electricity Price ($/Kwh)**
Argentina	$5.65	0.34	$0.02
Brazil	$5.65	0.26	$0.08
Canada West	$2.76	0.09	$0.07
Chile	$5.65	80.56	$0.12
Colombia	$5.65	266.29	$0.09
Mexico	$5.65	1.69	$0.09
Peru	$5.65	0.22	$0.07
US Northeast	$2.76	0.13	$0.13
US Northwest	$2.76	0.08	$0.08
US Southeast	$2.76	0.06	$0.06
Uruguay	$5.65	3.97	$0.14

Natural Gas Prices (FERC 2015)
Industrial electricity prices (CEA 2014; Climate Scope 2015; EIA 2016)

Identifying feedstock costs across the selected countries was challenging due to a lack of publicly available data. Thus, several methods and data sources were incorporated for cross checking purposes. Market reports on stumpage values were used in the United States because they represent the most up to date conditions. Ehrig et al (2014) provide feedstock estimates for western Canada. The method employed by Cubbage et al. (2010) was adopted, using 2014 data (2011 data for Colombia) from industry professionals, to estimate the cost of producing timber for various pine and eucalyptus species in South America (current exchange rates were utilized to convert to US dollars). Harvesting and transportation costs for South America and the US were estimated based on Qian and McDow (2013) and held constant at $23.18. Finally, data on delivered hardwood and softwood chip prices was collected from Fisher International, a market insight company that provides global and granular data on paper and sawmill operations. Mills were aggregated based on country (as well as by region for the United States and Canada) and their minimum, maximum, average and weighted average values are shown in Table 11. Since wood pellet mills utilize low grade inputs, the lowest observed value for each country and region among the various data sources were used. Finally, feedstock costs for Peru could not be found. Given it is on a similar latitude as Brazil, the same costs were applied (due to differences in exchange rates the values differ in Table 12).

Table 11. Feedstock Price Data

Country	Area	Fisher International Data						Price based on market reports, literature or wood cost analysis
		Wood Type	Range ($/ton)			Number of Mills	Weighted Average	
			Min	Max	Mean			
Argentina	NS	Soft	$28	$31	$29	2	$41	$32.42 (Soft)*
		E. Hard	$65	$65	$65	1		
Brazil	NS	E. Hard	$45	$112	$70	3	$48	$34.47 (Hard)*
		Soft	$6	$75	$39	7		
Canada	West	Soft	$5	$184	$128	18	$128	$28.48 (Residues)**
Chile	NS	E. Hard	$23	$59	$41	2	$37	$32.52 (Soft)*
		Soft	$23	$48	$36	4		
Colombia	NS	E. Hard	$78	$78	$78	1	$55	$36.25 (Soft)*
		Soft	$32	$32	$32	1		
Mexico	NS	E. Hard	$33	$33	$33	1	$32	$31.23 (Hard)*
		Soft	$18	$45	$31	2		
United States	NE	Hard	$9	$122	$22	8	$26	$32.14 (Mixed Pulp)***
		Soft	$7	$176	$30	6		
	NW	Hard	$11	$80	$21	4	$62	$42.55 (Mixed Small logs)***
		Soft	$40	$283	$80	9		
	SE	Hard	$0	$120	$27	31	$33	$34.64 (Mixed Pulp)***
		Soft	$1	$188	$37	42		
Uruguay	NS	E. Hard	$230	$230	$230	1	$230	32.31 (Hard)*

Fisher International (2016)

*Calculated using industry data and based on Cubbage et al (2010)

**Ehrig et al (2014)

***DACF (2016); DORWS (2016); TMS (2016)

NS: None specified; NE: Northeast; NW: Northwest; SE: Southeast; Soft: Softwood; E: Eucalyptus; Hard: Hardwood; Pulp: Pulpwood

Table 12. Feedstock Price Data Used in Model

Country	**Cost (LC/ton)**	**Cost ($/ton)**
Argentina	260.95	$17.00
Brazil	79.84	$24.51
Canada West	93.24	$28.48
Chile	37.48	$28.48
Colombia	94274.18	$32.62
Mexico	390.49	$20.07
Peru	99.90	$29.52
US Northeast	25.59	$25.59
US Northwest	42.55	$42.55
US Southeast	32.85	$32.85
Uruguay	786.86	$27.61

LC: Local Currency

Inland transportation costs from mill to port is based on truck transportation of approximately 100 miles (representing the least ideal conditions) and assumed to be equal ($15 per ton) across countries (Qian and McDow 2013). The shipping component of the WPCM builds off of Wuehlisch (2011) and collaborations with industry professionals. It assumes use of an Ungeared Supramax vessel leased under Time Charter contracts (contract costs are calculated as the number of days the vessel is in port and sea multiplied by the daily rate). Port and harbor costs are calculated based on the net tonnage value. Wood pellets are assumed to have a stowage factor of 1.5 m^3/ton, and thus a 50,000 ton shipment would take up 75,000 m^3 of space and have a net tonnage of 26,486 100 ft/m^3 (SEAL 2016). The ports included in this analysis were selected because they can process bulk commodities and are located near wood resources. They are assumed to operate equally in terms of loading times and costs. For shipments passing through the Panama Canal, an additional cost was added based on the established base and weight rates.

Table 13. Shipping Component

Country	Port	Distance (Miles)	At Sea	
			Days	Panama
Argentina	Buenos Aires	6397	19.04	No
Brazil	Rio Grande	5991	17.83	No
Canada	Quebec City	2898	8.62	No
	Prince Rupert	9182	27.33	Yes
Chile	San Antonio	7580	22.56	Yes
Colombia	Puerto Bolivar	4422	13.16	No
Mexico	Veracruz	5108	15.20	No
Paraguay	Rio Grande	5991	17.83	No
Peru	San Nicolas	6498	19.34	Yes
United States	Portland, ME	3092	9.20	No
	Seattle, WA	8900	26.49	No
	Norfolk, VA	3511	10.45	No
Uruguay	Montevido	6285	18.71	0

Searates (2016)
Destination port: Port of Immingham, England
Paraguay excluded because it does not have an ocean port
Eastern Canada excluded due to resource limitations (WPAC 2016)

2.3 RESULTS

Based on the designated production output, rates for storage, indirect and contingency costs, feedstock inputs and energy requirements in Appendix A, capital expenditures total $53.1 million and require 740,000 green tons per year of feedstock to operate (Tables 14 and 15).

Table 14. Mass Balance Calculations

Production Phase and Target/Required Feedstock Amounts		**Feedstock Type**				**Total**	**Energy Required**
		Round	**Forest res.**	**Sawmill res.**	**Starch**		
Target Wood Pellet Production Amount		195	250	50	5	500	
Stabilize	Water Loss	-2	-2	-0.5	-0.1	-5	
	Resulting Mass	193	248	50	5	495	
Grind/ Pelletize	Water Gain	4	5	1	0.1	10	206,317,477 (Kwh/t)
	Resulting Mass	197	253	51	5	505	
Dry	Water Gain	97	124	2	-	223	380,661 (Mmbtu/t)
	Resulting Mass	294	377	52	5	728	
Total Biomass Gain		1	5	4	1	11	
Required Feedstock		295	382	56	6	739	

Amounts expressed at thousands of tons (except energy required)
Round: Roundwood; res: residues

Table 15. Capital Costs

Equipment	**Capacity (T/hour)**	**# units**	**Scaled # units**	**Equip. costs**	**Install. costs**	**Total costs**
Conveyors/misc equip.	-	8	36	$1,044	$360	$1,404
Front-end loader	-	2	9	$1,017	$0	$1,017
Feed hopper	-	13	58	$580	$232	$812
Dryer, burner, air syst	6	5	22	$3,080	$4,488	$7,568
Hammer mill	9	2	9	$495	$702	$1,197
Live bottom bin	-	13	58	$10,150	$812	$10,962
Pellet mills(s)	6	2	9	$4,815	$1,512	$6,327
Pellet cooler	6	2	9	$1,350	$333	$1,683
Pellet shaker	9	2	9	$135	$360	$495
Boiler (800 Kwh)	-	4	18	$1,980	$18	$1,998
Fork lift	-	2	9	$198	$0	$198
Site and site preparation	-	1	4	$624	$0	$624
Paving, receiving station, load area	-	1	4	$240	$0	$240
Building/office space	-	1	4	$4,080	$0	$4,080
Total equipment costs				$29,788	$8,817	$38,605
Storage warehouse cost						$318
Indirect costs						$9,342
Contingency costs						$4,826
Total capital costs						$53,091

Amounts expressed in thousands of dollars

#: Number; Equip: Equipment; Install: Installation; equip: equipment; misc: miscellaneous; syst: system

Figure 1 summarizes the varying direct and indirect costs associated with each country. Energy is generally the largest cost component, followed by feedstock, depreciation and shipping.

Figure 1. Summary of Direct and Indirect Costs

This analysis uses a real discount rate of 6% and, for each country, inflation was added to arrive at a nominal rate which was then used in NPV calculations. The Excel function Goal Seek was used, setting each country's NPV to zero by modifying the minimum sales price. In order to better understand the relative competitiveness of each country, Figures 2 and 3 plot the minimum sales price of wood pellets for each country against their IHS Connect Country Risk Index (IHSRisk) and the World Banks Logistic Procurement Index (LPI) scores. Both country risk and supply chain conditions are important factors when determining a suitable location for a wood pellet mill. IHSRisk provides quarterly updates on a country's risk level based on six categories, including political, economic, legal, tax, operational and security and lower scores represent lower risk. LPI examines supply chain conditions also based on six categories, including customs, infrastructure, international shipments, logistics competence, tracking and tracing and timeliness and higher scores represent better conditions. Together, these indices should provide investors with a sense of the risk and supply chain quality each country provides (Singh et al 2016).

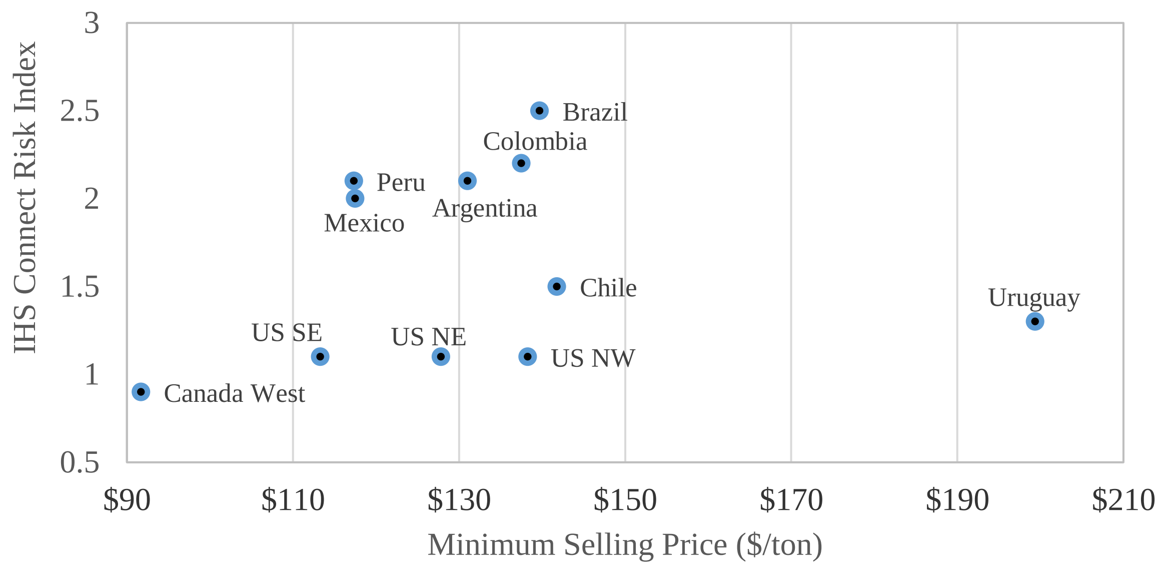

Figure 2. Minimum Wood Pellet Selling Price as a Function of IHS Risk

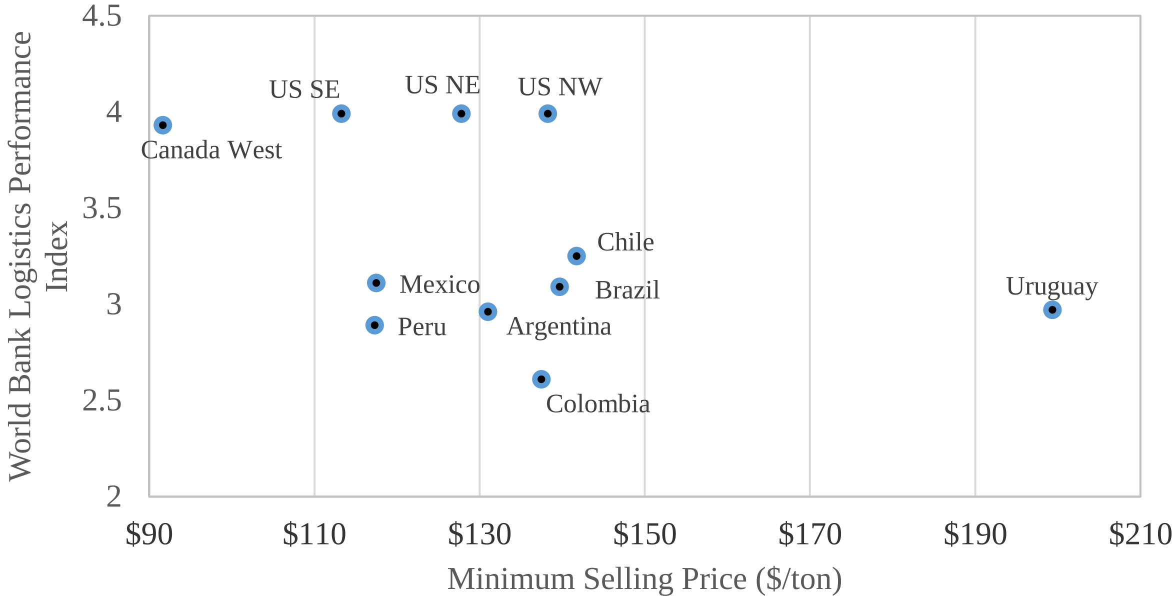

Figure 3. Minimum Wood Pellet Selling Price as a Function of WB LPI

The cost, insurance and freight (CIF) contract rate requires the seller to arrange for the costs of both the inland and shipping transportation, and can thus be used as a proxy for the sales price of delivered wood pellets. Using the Argus Biomass Markets report from April 2016, the CIF rate for wood pellets delivered to the Amsterdam/Rotterdam/Antwerp area is $138.76 (Argus 2016). The real internal rate of return (IRR) for each country was found by setting the minimum sales price in the model to this amount and using Goal Seek to set the NPV equal to zero (Figure 4).

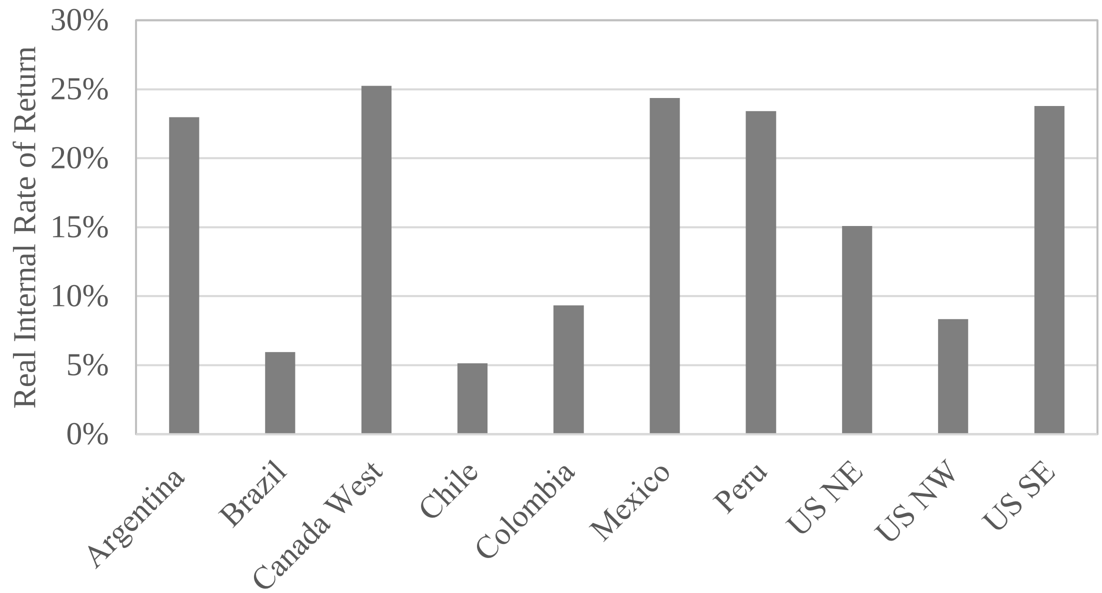

Figure 4. Real Internal Rate of Return

2.4 CONCLUSIONS

Due to its low cost structure and favorable investment climate, the most ideal locations to build a large, export oriented pellet mill are in western Canada and southeastern US, followed by northeastern and northwestern US. While Argentina, Mexico and Peru offer high IRRs, an investor would have to weigh that against higher risks and poorer supply chain conditions. Brazil, Chile and Colombia are also profitable; however, their returns would likely not be sufficient to overcome their poor investment climates. Finally, the western region of Canada as well as Uruguay are the least likely to see future investments given their higher cost of production.

2.5 DISCUSSION

This analysis provides a comprehensive, quantitative based assessment of building and operating pellet mills in various countries throughout North and South America and should help investors to determine an optimal location. To accomplish this, many assumptions were made that could potentially influence the results. These include availability of capital and technology, labor and energy as well as holding constant costs and capacities for inland transportation and port operations. Future research could address these assumptions and build on the above results to provide a more in-depth view of country conditions.

The fact that western Canada and southeast US came out as the most ideal location for a pellet mill is not entirely surprising and is supported by current trends. Significant supply side capacity has been developed by companies in both regions and this will likely continue until feedstock prices rise significantly or environmental concerns lead to a shift in policy. One might expect Canada is at a disadvantage given its distance; however, persistently low shipping contract and fuel rates since 2014 means it is cost competitive. This situation could change significantly if global economic conditions and trade, and thus prices, improve. While Argentina, Mexico and Peru provide similar returns, the nature of landownership as well as the inherent risk and lack of supply chain capacity should be further studied prior to making an investment decision.

There are several unexpected results from this analysis. First, Brazil and Uruguay are not cost competitive relative to other countries. This is due to relatively high energy and feedstock costs (also labor in Uruguay), as well high inflation rates. Finally, Argentina's strong performance was not expected; however, it has among the lowest energy, labor, feedstock and shipping costs.

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APPENDIX

Appendix – Model Inputs Consistent Across Countries

Pellet Mill		**Labor**		**Financial**	
Plant capacity	500,000	Hours per shift	8	Real Pellet Price Increase	2.0%
Scaling factor	70%	Shifts per month	20	Project evaluation period	20
Delivered Feedstock to Mill		**Shipping (Ungeared Supramax)**		Years of depreciation (MACRS-7)	7
Proportional Input		Bunker Costs		Maintenance % / year	2.0%
Forest residue	50%	HSFO 380CST		Capital maintenance % / year	2.0%
Roundwood	39%	Price ($/ton)	$257	Working capital requirement	10%
Sawmill residue	10%	Consumption (t/day)	30	Storage cost rate	8%
Starch	1%	LSMGO		Indirect cost rate (CAPEX)	24%
Moisture		Price ($/ton)	$404	Contingency cost rate	10%
Forest residue	40%	Consumption (t/day)	2.5	Operating Materials	20%
Roundwood	40%	Cargo (t)	50,000	Other Mill Fixed Cost	10%
Sawmill residue	10%	Net Tonnage (100 ft/m3)	26,486	Constant Costs ($/ton)	
Starch	7%	Panama Canal Rate	$130,800	Starch	$1,000
Production Process		T/C Contract Rate ($/day)	$7,507	Harvest and transport to mill	$23.18
Dry Mass Loss		Vessel Speed (knot/h)	14	Mill to port	$15.00
Biomass storage	1.00%	Departure Port		Upfront Capital Costs	
Drying	0.10%	Time in Port (days)	4	Period 1	30%
Pelletizing	0.10%	Unloading ($/t)	$4.50	Period 2	70%
Product storage	0.10%	Harbor ($/nt)	$2.00	Loan Terms	
Moisture Level During Each Phase		Arrival Port		Percentage from total investment	0%
Drying	7%	Time in Port (days)	4	Interest rate (inflation+)	0%
Pelletizing	5%	Discharge ($/t)	$4.50	Duration	0
Stabilizing (Final)	6%	Harbor ($/nt)	$2.00		
Energy Used					
Drying (MMbtu/t)	1.71				
Grinding/Pelletizing (Kwh/t)	279				

Dry Ship Inc (2016); FERC (2016); Pancanal (2016); Pirraglia et al (2010); S&P Global (2016); Wuehlisch (2011); Qian and McDow (2013)