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Assessing the Sustainability of First Generation Ethanol for Bioethylene Production

Master's Thesis in the Master Degree Program Industrial Ecology

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Abstract

The majority of plastic materials today are petroleum based making the plastics industry is one of the drivers of oil extraction. To portray a greener image and decrease the industry's need for oil, some plastics producers have started using bioethanol as a feedstock. Within the next five years, the demand for bioplastics is expected to increase by about 19 %, increasing the demand for ethanol. Traditionally, ethanol is mainly used as a sustainable alternative to fossil fuels. Lately however, there has been much debate regarding if ethanol really is a better alternative for the environment.

This study assesses the sustainability of first generation ethanol on behalf of the petrochemical company *Borealis AB*. The company is looking into the possibility to produce ethanol-based biopolyethylene. *Borealis AB* is part of the project *Locally Grown Plastics,* aiming to produce packaging material from second generation ethanol from Swedish forestry residues. This project is still 5-10 years away from realization, however, *Borealis AB* are considering commencing their production of bioplastics earlier, using first generation ethanol.

Scientific literature, certification schemes, and a study of actors in the ethanol industry, show that ethanol can be produced in a manner that makes it a more sustainable option for plastics production than oil. To assess the sustainability of ethanol producers in Brazil, the US and Africa, a framework was constructed. After applying the framework, comparing different feedstocks for ethanol, and looking at the certified biomass potential, three Brazilian suppliers were deemed most promising. These are recommended as the best options for *Borealis*, should they decide to produce bioplastics from first generation ethanol.

It is concluded that first generation ethanol can be a viable choice of feedstock for a European bioplastics producer, such as Borealis AB. However, appropriate and credible certification must obtained by the ethanol suppliers to ensure the sustainability of their practice. Brazilian sugarcane ethanol is found to be the most sustainable alternative and three companies operating in the area are recommended as suppliers for Borealis AB.

Keywords: First generation ethanol, Bioethylene, Sustainability, Certification, Carbon balance Sugarcane, Corn, Softwood thinnings

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List of abbreviations

DLUC	Direct Land Use Change
EU RED	European Union Renewable Energy Directive
FGE	First Generation Ethanol
GHG	Greenhouse Gas
ILUC	Indirect Land Use Change
LDPE	Low Density Polyethylene
LGP	Locally Grown Plastics
LUC	Land Use Change
PE	Polyethylene
PET	Polyethylene Terephthalate
RSB	RoundTable for Sustainable Biomaterials
SGE	Second Generation Ethanol
SOC	Soil Organic Carbon
TGE	Third Generation Ethanol

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1 Introduction

The cultivation and processing of biomass for the purpose of ethanol production for biofuels was boosted by the oil crisis of the 1970s. As the oil price rose dramatically, biofuels were seen as the solution to the problem of an increasingly expensive transport sector. Several countries made efforts to increase the production of ethanol, among them were China, the United States (US), Kenya, and Brazil. The US and Brazilian governments both instituted national programs for ethanol production but when the oil price started to decline again, only Brazil kept their focus on ethanol. Brazil had learned its lesson and the volatility of the oil price, the energy supply security, as well as the threat of climate change were incentive enough to keep the national ethanol initiative going. The main governmental policy tool implemented in Brazil was, and still is, subsidies. Brazil occupied the position as the world's largest ethanol producer until 2004, but was surpassed by the US the following year (Koizumi, 2014).

The principal driver behind a continued development of ethanol as a biofuel is the conviction that it can replace fossil options and thereby reduce the impact the transport sector has on climate change. Furthermore, energy security and the possible rural development are strong incentives for increasing ethanol production (Curran, 2012 and van Eijck, Batidzirai & Faaij, 2014). The notion of ethanol as being a climate friendly fuel has been questioned in recent years as the production is energy intensive and requires large land areas, which has lowered the enthusiasm for the biofuel. The issue that has received the most attention with regards to ethanol production is the fuel versus food trade-off. This debate was sparked by the global food crisis in 2007-2008 and concerned to what extent the increased biomass cultivation for fuel had affected the food prices. (Timilsina & Zilberman, 2014 and Koizumi, 2014).

This thesis project was initiated by *Borealis* technological research and development department. *Borealis* is an industrial company based in Vienna and active within the fields of polyolefins, base chemicals and fertilizers (Borealis Group, 2015). In Stenungsund, Sweden, *Borealis* own and run a steam cracker, making them the only domestic polyethylene producer in Sweden (Borealis Group, n.d.). Traditionally, polyethylene is made from crude oil but *Borealis* is now looking into producing bioplastics, i.e. polyethylene made from biomass.

Borealis is part of a network called *Locally Grown Plastics,* consisting of forestry firms, companies active within the process industry, and packaging producers. The network is aiming to reduce their environmental impact by using renewable raw material. The value chain for LGP can be seen in Figure 1.1. This means that *Borealis* will use ethanol produced from the residual waste from forest industry in their production of polyethylene. The infrastructure to realize this goal does not currently exist and it will take five to ten years to develop and construct. This is mainly due to the development of SEKAB's technology for ethanol production from forest residues (Personal communication: Borealis[1]).

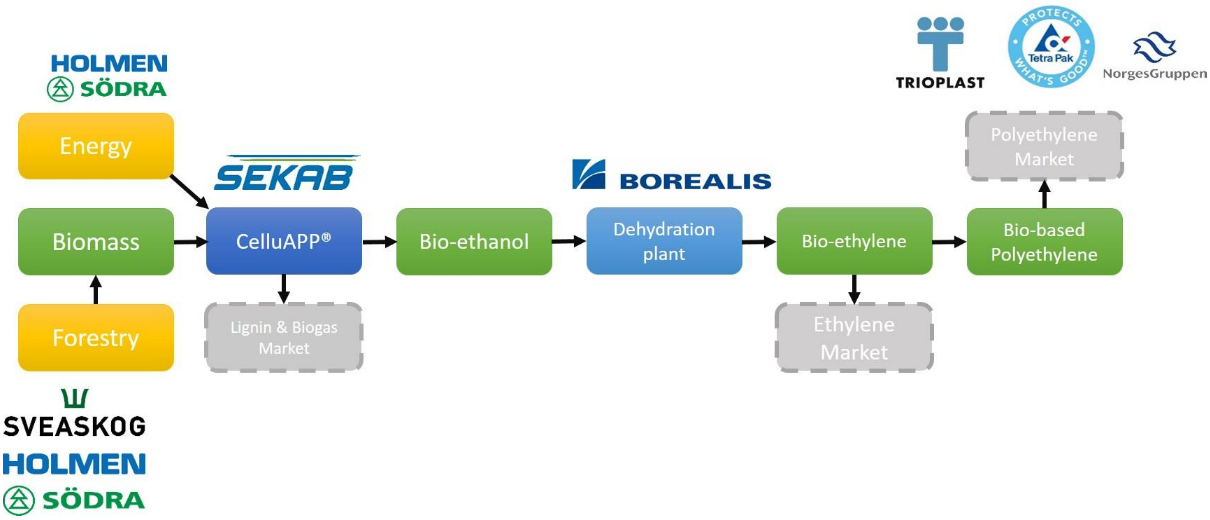

Figure 1.1 The value chain of Locally Grown Plastics. **Based on Projektförslag Värdekedja Cellulosabaserad Biopolyeten, SEKAB (2014)**

To realize their part of the chain, *Borealis* needs to build a dehydration plant that converts ethanol into ethylene. As the raw input for the plant is ethanol, *Borealis* could start building their plant right away and operate it using imported first generation ethanol (FGE), while waiting for the rest of the network to catch up to supply second generation ethanol (SGE). *Borealis* want to make sure that they use ethanol that does not have too much adverse impact on the environment and society in which it is produced. Therefore, they want to investigate if there are FGE suppliers that produce ethanol under accepTable social and environmental conditions. The use of FGE also needs to be feasible from a financial perspective.

It is currently difficult for polyethylene producers in the European Union (EU) to compete for FGE with firms that use the ethanol as fuel, as the latter benefit from tax deductions (Personal communication: Borealis[2]). The large scale producers of ethanol are situated outside of the EU, mainly in the US and Brazil, and the import of this raw material is therefore subject to high tolls (US Department of Agriculture, 2015). If the temporary FGE option is to be economically viable, an agreement with the EU to omit or reduce the tolls for FGE used for plastic production would be essential. Negotiations for such an agreement for a set amount of time is therefore in

[1] Lars Pettersson, *Expert Cracker at Borealis* (3 Sept., 2015)
[2] ibid.

progress. *Borealis* is interested in evaluating FGE suppliers in the US, Brazil and Africa (Personal communication: Borealis[3])

1.2 Aim and Research Questions

The objective of the study is to compile relevant information to provide *Borealis* with the foundation needed to make a decision on whether or not they should start the construction of a dehydration plant, before the rest of the supply chain for *Locally Grown Plastics* is in place. This requires showing if FGE is a viable alternative, both from a socially and environmentally sustainable point of view, and if there are any suppliers offering sustainably produced FGE. Thus, the report aims to give insight into the current state of ethanol production in the United States, Brazil, and Africa, as well as the sustainability efforts made and how these can be ensured by a customer or consumer of ethanol, in this case *Borealis*. Through examining scientific literature and recent media coverage about ethanol, as well as other actors within the ethanol industry and their commitment to relevant issues, the study aims to put together and apply a sustainability framework for evaluation of potential suppliers.

To achieve the objective of the study the following research questions have been formulated:

RQ1. Which environmental and social sustainability issues are most important to consider when buying ethanol as a European bioplastics producer?

RQ2. How can appropriate sustainability measures by suppliers be assured?

RQ3. Which ethanol feedstock is most appropriate from an environmental and social aspect?

   a. Which ethanol feedstock minimizes land use change (LUC) and atmospheric carbon emissions?

RQ4. Are there suppliers of FGE that are considered to be verifiably sustainable according to the framework constructed?

   a. Which suppliers can be recommended to *Borealis* based on the information found in this study?
   b. What makes them superior to their competitors?

[3] Lars Pettersson, *Expert Cracker at Borealis* (3 Sept., 2015)

2 Ethanol in Theory and Practice

This chapter presents the findings from the literature review that has been conducted to achieve the aim of the study. First, a theoretical background on ethanol is given. This is followed by a brief presentation of the studied geographical areas with regards to their current ethanol production. Other topics dealt with in this chapter is the production of bioplastics, the use of certifications, and a mapping of the effects of EU policy on biomass potential for the production of biofuels.

2.1 Ethanol

This section presents an overview of ethanol from scientific literature published on the topic. It includes sustainability issues, what feedstocks are used and how the price of ethanol has developed over time.

2.1.1 Sustainability of Ethanol

The sustainability of ethanol has been a widely debated topic for many years and was even more questioned as a result of the global food crisis in 2007-2008. This was due to the fact that prices for primary food commodities had doubled, along with the quantities of corn grain and sugarcane ethanol produced between 2001 and 2008. This was extensively reported by media, especially since increasing prices for primary food commodities struck hardest against households in low-income countries, where crop prices affect the final food price to a larger extent than in high-income countries. (Timilsina & Zilberman, 2014) The main driver behind this development was thought to be large amounts of farmland being diverted to biofuel production together with an increased demand for the feedstock (Koizumi, 2014).

Although the cultivation of biofuels partly contributed to the crisis, scientific literature published on the topic also points to other factors, having a significant impact on the increased food prices. These factors include currency fluctuations, high oil prices, and the effect that economic growth has on demand, (Timilsina & Zilberman, 2014; McCann, Buckeridge & Carpita, 2014). The effect on commodity prices that can been attributed to biofuel production has been assessed by numerous studies, of which some are listed by Timilsina and Zilberman (2014). Depending on the economic model used and which assumptions are made, the result varies from 3 % to 75 % of the food price shock attributed to the biofuel industry (Timilsina, & Zilberman, 2014).

The wide debate about the sustainability of ethanol is mainly caused by insecurity of the actual environmental impacts of ethanol, which arises from the fact that there is no universal way of measurement (Timilsina & Zilberman, 2014). According to Timilsina and Zilberman (2014), depending on how the environmental impacts, e.g. greenhouse gas (GHG) emissions, are accounted for, the extent of the impacts of ethanol varies. Three approaches are commonly used to assess the GHG emissions of ethanol: project level approach, life cycle approach and one that accounts for indirect land use change (ILUC) (Timilsina, & Zilberman, 2014), i.e. the land use change that occurs when biomass is cultivated on land that has previously been used for growing other crops or feedstocks, for which the demand remains constant, forcing the latter to take place at another location (Liptow, 2014).

The first approach described by Timilsina and Zilberman (2014), the project level approach, does not take any GHG emissions caused during production and delivery processes into consideration, but only considers at the GHG emissions generated upon combustion, assigning the GHG contents of the fossil alternative replaced by a bio-based one as GHG savings. Using this approach, any type of bio-based alternative is better than a fossil-based one as the former is carbon neutral (Timilsina, & Zilberman, 2014).

The second approach, life-cycle assessment includes the total GHG emissions throughout the product life-cycle, including emissions from cultivation, production and all transports. Furthermore, GHG emissions from upstream petroleum processes are also taken into account. The life cycle assessment approach naturally results in higher GHG emissions from ethanol than the project level approach (Timilsina, & Zilberman, 2014).

The third approach accounts for ILUC caused by the increased demand and thereby cultivation area for ethanol and food (Timilsina and Zilberman, 2014). According Liptow (2014), many studies have shown that FGE cultivation, to varying extents, is connected to ILUC. The awareness of ILUC and the associated environmental impacts, including greenhouse gas (GHG) emissions and biodiversity loss, has increased over the past few years. However, whether or not to account for them and if so, what method to use have remained subjects of debate due to large uncertainties (Liptow, 2014). It is however worth mentioning, that GHG emissions from LUC decrease with time when the same land is utilized for biofuel feedstock cultivation over and over. As a result of this, expanding ethanol production causes an increase in GHG emissions in the short run but reduces long term GHG levels as long as the physical expansion eventually ceases (Timilsina & Zilberman, 2014).

Expanding ethanol feedstock cultivation areas is inevitably linked with LUC, both direct and indirect. Direct land use change (DLUC) occurs when forest and pasture lands are converted to farmland. This affects the soil and biomass carbon stocks, causing carbon to be released into the atmosphere as carbon dioxide and other GHG emissions. Taking this into account when determining the environmental efficiency of ethanol affects the result negatively. Minimizing DLUC and the effects thereof can be done by using marginal land for feedstock cultivation, ensuring efficient agricultural practices, maximizing the yields per unit of area as well as using technology to utilize residual products (Timilsina, G. and Zilberman, D., 2014).

According to Nordborg, Cederberg and Berndes (2014), pesticide use in the cultivation of ethanol feedstocks is an issue which has received relatively little attention. However, pesticides are an integral part of agricultural systems and thus also used for ethanol feedstock cultivation. Although the use of pesticides holds many benefits, there are also negative effects including water contamination, biodiversity impacts, ecosystem impacts and impacts on human health to name a few (Nordborg, Cederberg and Berndes, 2014). Nordborg, Cederberg and Berndes (2014) assessed the potential freshwater ecotoxicity impacts of ethanol produced from corn, salix, sugarcane and winter wheat. They concluded that, both genetically engineered and non-modified corn, along with winter wheat have larger potential impacts than the salix and sugarcane based alternatives.

2.1.2 Ethanol feedstocks

Depending on the type of feedstock, ethanol is classified into three different generations. First generation ethanol (FGE) is produced from saccharification of starches and fermentation of sugars. The major FGE feedstocks are sugarcane and corn grain, other FGE feedstocks include sugar beet, cassava, sorghum and wheat. Of the FGEs, Brazilian sugarcane is considered most efficient with regards to GHG emissions reduction, with GHG emissions savings of over 50 % compared to the fossil alternative (Amarasekara, 2013). Due the large GHG emissions savings, Brazilian sugarcane ethanol has been classified as an advanced biofuel by the US Environmental Protection Agency (Crago et al., 2010). All other biofuels that entail enough GHG emissions savings to be classified as advanced are of later generations.

Second Generation Ethanol (SGE) is based on lignocellulosic raw materials such as grasses, wood and agricultural wastes. The latter one includes sugarcane bagasse and corn stover, which are residues from FGE production. Utilizing these residues efficiently to produce SGE could significantly improve the environmental performance of both feedstocks. Currently however, corn stover is mainly used for cattle feed and the bagasse combusted for power generation for the ethanol production process and excess energy is sold to the grid (Amarasekara, 2013). For example, integration of the production of sugarcane FGE and SGE from the bagasse is believed to have the potential to improve the economic and the environmental performance of sugarcane processing, doubling the yield per hectare from 8000 to 16 000 l (Raele et al., 2014). Currently, there are a large number of SGE pilot plants, including SEKAB's demonstration plant, but also a few plants producing cellulosic ethanol from various feedstocks for commercial use. SGE is believed to have an enormous future potential, as lignocellulosic materials are the most abundant biological material on earth and, since it is not edible for humans, it does not compete with food production (Amarasekara, 2013).

Third generation ethanol (TGE) refers to ethanol competing neither with land nor food crops and includes algae-based ethanol (HLPE, 2013). However, this technology is still at an early state of investigation (Baeyens et al., 2015).

2.1.3 Ethanol Economics

Due to factors such as larger feedstock yields, upscaling of farms and higher ethanol yields, the total production costs, including cultivation and processing costs, for both Brazilian sugar cane and US corn grain ethanol declined by approximately 60 % between 1975 and 2009 (Hettinga et al., 2009). By using experience curves, Hettinga et al. (2009) predict that the total production price for US corn grain ethanol will continue to decrease until at least 2020. As for Brazilian sugarcane ethanol, the production costs are also expected to decrease according to a study by Jonker et al. (2015), which examines the period from 2010 to 2030.

In general, ethanol production is feasible when energy prices are high and feedstock prices are low. The feedstock price makes up about 70 % of the production cost for FGE. Out of sugarcane from Brazil, corn grain from the US, sugar beet and wheat from the EU and cellulosic bioethanol, only the Brazilian sugarcane and to a certain extent US corn grain based ethanol have lower production costs than gasoline. This shows that these two feedstocks are currently the only ones that can compete with gasoline on price even without subsidies (Koizumi, 2014).

The ethanol industry has struggled with the low oil price resulting in the producers receiving a lower price for their product (Anderson, 2016; Parker, 2015). Besides a drop in prices, this has also lead to a drop in the support for the industry, especially in the US where people and organizations are complaining that the supporting policies for the ethanol industry are unwarranted and unfair with such a low oil price (Parker, 2015). Even with the declining oil price, at the end of 2015, there seems to have been a growth in the international ethanol production and the ethanol market was also recovering in terms of turnover (Reuters, 2015; Truitt, 2015; Lane, 2015).

2.2 Geographical Areas

Between 2007 and 2010, the world production grew at a steady rate. In 2011 and 2012 the production decreased somewhat, the decrease mainly taking place in the US due to high corn prices, resulting from a drought in the Midwest. In 2014, the ethanol production peaked, with 93 billion liters of ethanol being produced globally, out of which 83 % was produced in the US and Brazil (Timilsina & Zilberman, 2014). Figure 2.1 shows the global production between 2007 and 2014.

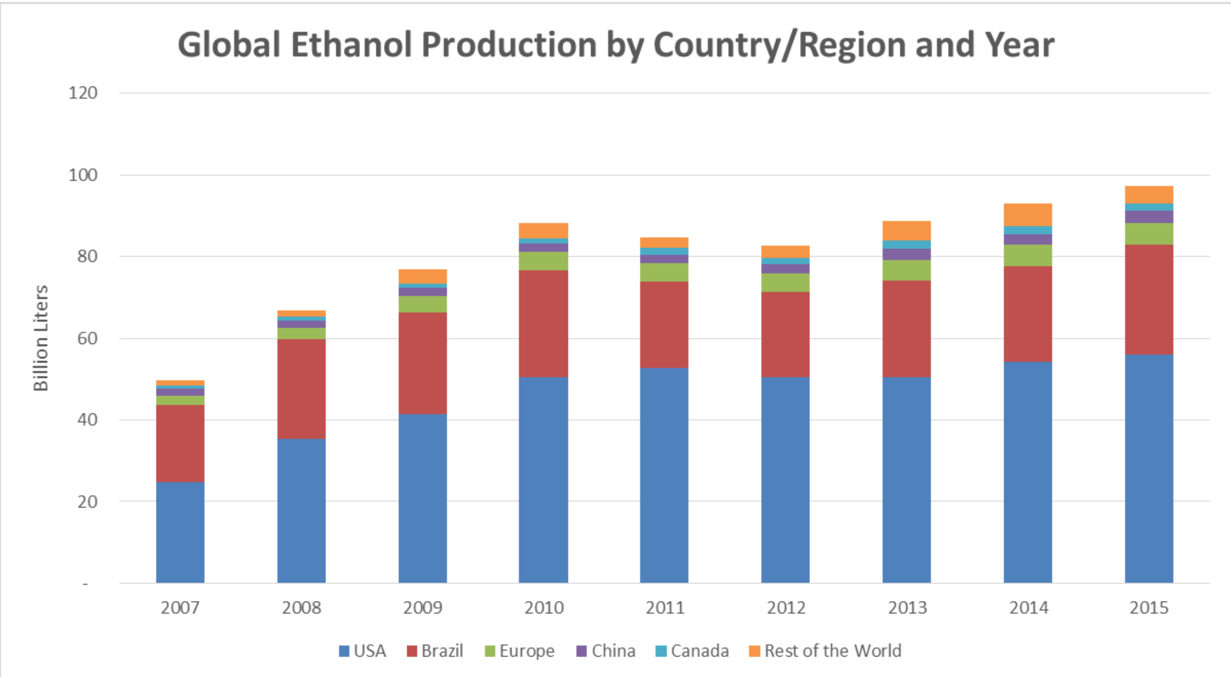

Figure 2.1 World ethanol production (billions of liters). **Source: Timilsina & Zilberman, 2014**

Next follows a brief description of the ethanol production in the three selected areas, the US, Brazil, and Africa. The description offers some background of the current operations in the areas, what feedstock is used, and what the main drivers behind the respective ethanol industries have been.

2.2.1 Production of FGE in the United States

The US is the world's largest ethanol producer and has held this position since 2005. Annually, 49 billion liters of ethanol are produced in the country (McCann et al., 2014). The most commonly used feedstock is corn. Since 2009, more than 40 % of the total corn cultivated has been used to produce ethanol in the US. The first major stimulation of the US ethanol market came with the oil crisis of the 1970s. Since then, national policy measures have played a large part in boosting the industry. With the Clean Air Act Amendments of 1990, Congress mandated the use of reformulated gasoline, promoting the use of ethanol (Koizumi, 2014).

The perhaps the most significant policy for the ethanol industry came in 2005. The Renewable Fuel Standard was established, mandating a 15 billion liters use of biofuels in 2006 that would increase to 28.4 billion liters in 2012. A second Renewable Fuel Standard came in 2007, requiring the use of approximately 136 billion liters of biofuel annually, by 2022. Out of this, 56.8 billion liters should come from FGE, in this case, corn-based ethanol, and 80 billion liters should be advanced biofuel, mainly cellulosic ethanol (Koizumi, 2014).

Most of the ethanol produced in the US is used for E10 production. The production is principally conducted in the Midwest, as this is the area where most corn is cultivated. Production that is situated elsewhere, is generally located close to large ethanol markets, along the east and west coast as the gasoline consumption is highest there (US Department of Energy, 2016).

The U.S. is the world's largest exporter of ethanol, with primary customers including China, Canada and the Philippines. The US has in the past been one of the primary exporting countries to the EU, especially between the years of 2010 and 2012. The export rate to the EU changed in 2013 however, when anti-dumping duties were put in place and the U.S. ethanol import volumes declined sharply. In 2014, only 6 % of the total U.S. exports were shipped to the EU (US Department of Agriculture, 2015). In October of 2015 the US exported 265 million liters of ethanol, of which nothing went to the EU. For the first time in history, China then served as the largest customer for U.S. ethanol, purchasing close to half of the total exported volume. Other large customers are Canada and the Philippines (Lewis, 2015).

2.2.1.1 Green Plains - Ethanol Producer Operating in the US

Green Plains is the fourth largest ethanol producer in the US, producing roughly 4.5 billion liters of ethanol annually. The company has 13 mills across the country with the majority of the plants located in the Midwest. Green Plains was founded in 2004 to construct and operate a fuel-grade ethanol production plant, using dry milling technology, in Iowa. Operations began in 2007 and the following year the company opened two new plants. Since then, Green Plains have opened or acquired at least one new plant per year, their last one being acquired in 2015 (Green Plains Inc., 2015). Three of Green Plains plants have been EU RED certified by ISCC (ISCC(1), 2015). It is however unclear if they are in fact selling any ethanol to Europe.

Besides ethanol, Green Plains are selling the co-product of corn ethanol production, distillers grains. This is used as animal feed and at current production capacity they are producing 3.4 million tons of distillers grain. Furthermore the company is selling corn oil, another byproduct of the ethanol production, to biodiesel producers and as poultry feed (Green Plains Inc., 2016).

2.2.2 Production of FGE in Brazil

Brazil is the second largest producer of ethanol in the world. Using sugarcane, the country produces 28 billion liters of ethanol per year (McCann et al., 2014). In 1975, the Brazilian government inaugurated a national ethanol program, PROALCOOL, in an effort to become more energy independent and reduce its oil import bill. The program created a very large domestic demand for sugarcane, and this demand has steadily been increasing since the start of the program. The Brazilian ethanol industry is today one of the largest energy industries in the Brazilian economy (Koizumi, 2014).

Sugarcane is the feedstock for both ethanol and sugar and most ethanol plants also produce sugar. Switching between the two products is simple, therefore the rate of sugar versus ethanol production is decided by the current market price for ethanol and the price for sugar. Since 1990, more than half of the sugarcane that is harvested has been used for ethanol production (Koizumi, 2014).

The majority of the Brazilian sugarcane production is situated in the south central part of the country, as can be seen on the map in Figure 2.2. About 10 % of the sugarcane cultivation is located in the north east. The map also points out the fact that the Amazonian rainforest, which is a large carbon sink, is at a distance of about 2,000 - 2,500 kilometers from the production heavy areas in the country (UNICA, 2015).

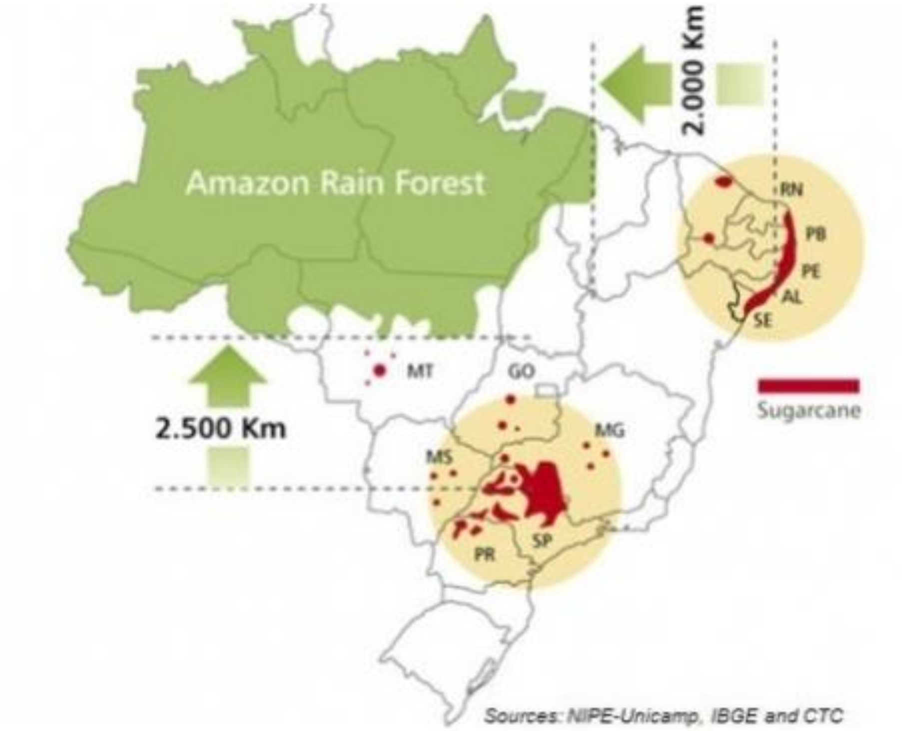

Figure 2.2. Location of sugarcane production in Brazil in relation to the Amazonian rain forest.
Source: (UNICA, 2015)

The Brazilian ethanol is most prominently used as a blend for gasoline, with a national mandate of a 25 % ethanol blend since 2007. There are currently no lightweight vehicles in Brazil running on pure gasoline (Ministério da Agricultura, Pecuária e Abastecimento, 2007). Besides a heavy domestic consumption of Brazilian ethanol, large quantities are also exported. The largest importers of Brazilian sugarcane ethanol are China, the US South Korea and the Netherlands (Pupo, 2015).

2.2.2.1 BP - Ethanol Producer Operating in Brazil

In 2008, BP purchased 50 % of the shares in the bioenergy plant Tropical BioEnergia, making them the first foreign actor to invest in Brazilian sugarcane (McIvor, 2015; BP(1), 2015). In 2011, BP acquired the rest of the shares in the plant and has since expanded its operations to double the capacity. At the time of this project, BP own and operate three different ethanol plants, with a combined capacity of 10 million tons per year (BP(1), 2015). The company is primarily supplying the Brazilian ethanol market, although they have stated that they intend to look into the potential demand markets of the EU, US, and Asia, as they increase their output (BP(2), 2015).

BP have invested more than 500 million USD in improving efficiency and productivity of their mills over the past three years (BP(1), 2015). The three plants are energy self-sufficient, as all the required energy comes from the incineration of bagasse, a cellulosic residual material from ethanol production from sugarcane. This activity generates an energy surplus, which is sold to the national energy grid (BP(3), 2015). Another waste product, vinasse, is sprayed back onto the fields, to help reduce the need for both fertilization and irrigation (BP(3), 2015). BP's Tropical plant has been granted certification by Bonsucro, the most renowned certification for sugarcane biofuel producers in Brazil (Zezza, 2013). It was also one of the first Brazilian mills to qualify for the SA8000 Standard, an international social responsibility standard (BP(4), 2015).

2.2.3 Production of FGE in Africa

Several African countries are looking to increase ethanol production in order to satisfy the increasing energy demand. The promotion of ethanol production is also conducted to develop rural areas through job creation and investments in infrastructure. African ethanol production is currently low, mainly due to lack of access to adequate equipment, fertilizers, irrigation, seeds, and proper training. It is furthermore difficult for smallholders to receive enough credit to conduct operations at any large scale (McCann et al., 2014).

Despite the challenges mentioned, the trade in biofuels in Africa is expected to increase in the long term. This is mainly driven by countries' policies for renewable energies (Timilsina and Zilberman, 2014). These policies have not always had the best outcome for the national population. The lack of proper regulatory frameworks and lack of private-public partnerships have been detrimental to the local population, as it has led to large multinationals coming in to buy the arable land, taking away any potential profit from the locals. The food versus fuel issue is more palpable in the developing world as poorer people are more affected by an increase in commodity prices, as they often eat directly off the land, without having the food go through any refining steps (Jumbe & Mkondiwa, 2013).

The largest producing country on the African continent is South Africa, with sugarcane being the main feedstock. Zimbabwe, Kenya and Malawi have been producing ethanol since the 1970s, with the aim to replace gasoline as a fuel as the three nations are still highly dependent on imports of oil. For example Kenya has set the target of reducing oil imports by 25 % by 2030, something they aim to achieve by replacing its function with ethanol. Mozambique has set the objective at producing enough ethanol to both support the local demand and export ethanol. Some other ethanol producing nations are Sierra Leone, Tanzania, Zambia and Ethiopia (McCann et al., 2014).

2.2.3.1 Addax Bioenergy - Ethanol Producer Operating in Sierra Leone

Addax Bioenergy is a sugarcane-based ethanol producer operating in Sierra Leone. Addax Energy launched their renewable energy project in 2008 in Makeni, and operations began in 2014. Besides the ethanol, the company is producing electricity from the residual biomass, which is used to run the fuel plant and to supply the Sierra Leone national energy grid with 20 % of its needs (Addax Bioenergy, 2015).

On their webpage, the Addax Bioenergy are describing a strong sustainability focus for the ethanol project. They state that they have had a long-term view of the project from the start, cooperating closely with local population and organizations, so as to conduct this in a manner that is sustainable both from an environmental and social perspective. They engage in extensive stakeholder dialogues and invest in the local infrastructure development. Before the construction of the mill started, a three-year environmental, social, and health impact assessment was carried out (Addax Bioenergy, 2015). The company has furthermore received a certification from the RoundTable for Sustainable Biomass (RSB(2), 2015). They produce both for the domestic market and export markets. The plant is expected to be running at full scale in 2017, and is then expected to produce 85 million liters of ethanol annually (Addax Bioenergy, 2015).

2.3 Bioplastics

Until 2021, the demand for bioplastics is expected to increase by approximately 19 % annually according to a market study carried out by Ceresana, a market research company, based in Germany. The study furthermore suggests that the market for bioplastics has the potential to grow even in times of economic difficulties. In order to protect the environment and engage in sustainable development, companies are adopting the practice of bioplastics, which also enables a better image among customers (Kuehner, 2015).

Currently, one of the most common applications of bioplastics is packaging and in particular food packaging. Through research and development, the technical properties of bioplastics are being improved and the economic competitiveness increased. Thus, conventional plastics can be replaced to an increasingly large extent (Kuehner, 2015). According to the International Renewable Energy Agency (2013), by 2013, small amounts of bioethylene were already in production, with the highest capacity located in Brazil. However, the share of bio based ethylene is still relatively small compared to fossil based, corresponding to less than 1 % of global ethylene production (International Renewable Fuel Agency, 2013).

A positive aspect of bio-polyethylene (bio-PE) is that it is a so called drop-in bioplastic, meaning that it has properties identical to its fossil counterpart. Thus, the value chain of bio-PE only requires adaptation at the outset whereas the rest of the route follows the same one as traditional PE does. This characteristic facilitates a switch from finite to renewable resources and thereby significantly shortens the time between development to commercialization (European Bioplastics, 2012).

According to a comparative LCA study on polyethylene based on Brazilian sugarcane and crude oil from the Middle East by Liptow and Tillman (2012), sugarcane ethanol based polyethylene leads to GHG emissions reductions by 30 % to 80 % depending on assumptions made on LUC compared to the crude oil based alternative. This is despite the fact that the bioethylene production requires a larger energy input, as this input is to a larger extent renewable than for the crude oil based plastic. Furthermore, the main contributors to the environmental impact of sugarcane based PE are ethanol production, polymerization, and the shipping from Brazil to Europe. The study also emphasizes that the impacts of LUC are uncertain and that a consistent method for assessing the effects of LUC is needed (Liptow and Tillman, 2012).

The fact that Brazilian sugarcane ethanol based plastics entails a net reduction of GHG emissions over petroleum based ones is also confirmed by a study on polyethylene terephthalate (PET) by Van Uytvanck et al. (2014). The study concludes that the GHG reduction amounts to approximately 28 % for a 500 mL PET bottle compared to traditional PET made from petroleum (Van Uytvanck et al., 2014).

2.3.1 Fuel versus Plastics

According to Alvarenga and Dewulf (2013), using sugarcane based hydrous ethanol as either a fuel or for ethylene production, reduces GHG emissions compared to using crude oil based alternatives. As for the case of monomer production, higher fossil energy and GHG emissions savings are achieved, as long as the yield is higher than 96 % of the theoretical yield, i.e. for each kg of ethanol, 0.586 kg of ethylene is produced. This result is also supported by a study by Posen et al. (2015) that concludes that fuel use of Brazilian sugarcane ethanol has higher modeled emissions compared to low density polyethylene (LDPE) from the same feedstock. The study also suggests that US switchgrass and Brazilian sugarcane based LDPE is carbon negative, meaning that these types of LDPE sequesters carbon dioxide, making their environmental performance superior compared to US corn and crude oil based LDPE (Posen et al., 2015).

2.3.2 Current Bioplastic Production and Application

The São Paulo-based petrochemical company *Braskem*, is the leading producer of polyethylene, polypropylene and PVC in the Americas. The company operates in total 36 industrial units, of which the majority is located in Brazil. The seven units that can be found outside of Brazil, reside in the US and Germany, with five and two units, respectively (Braskem(1), 2015).

Braskem is striving to maintain its reputation as a pioneer and a global reference in renewable chemicals (Braskem(1), 2015). To do this, the company works with their three basic pillars of operations, namely, (i) more sustainable operations and (ii) resources, increasingly sustainable products and (iii) solutions for a more sustainable life (Braskem(2), 2015). With their sugarcane ethanol-based *I'm Green™* polyethylene, *Braskem* is the world's largest producer of bio-PE. The *I'm Green™* polyethylene production process is certified by the seal from the organization International Sustainability & Carbon Certification (ISCC), which can only be obtained if the ethanol used in the production is certified by Bonsucro (Braskem(3), 2015). Furthermore, *Braskem* has created their own 'Code of Conduct' that ethanol suppliers must comply with. The 'Code of Conduct' is based on other models of good practices such as those described in the São Paulo State Agricultural and Environmental Protocol and the UN Global Compact among others (Braskem(4), 2015).

In Sweden, the *I'm Green™* polyethylene is used as a component in plastic bags and packaging. These products are considered to be, and are often marketed as, sustainable alternatives to traditional plastics made from fossil resources (Miljöinnovation, 2012; Dogwash AB, 2015; Jordbruksaktuellt, 2015). Swedish companies using the *I'm Green™* include *ICA Gruppen*, *Axfood* and *TetraPak* (Pettersson, 2016; Braskem, 2013).

A wide-spread bioplastic initiative is *PlantBottle*, launched in 2009 by *The Coca-Cola Company*. The *PlantBottle* beverage container is made from up to 30 % plant-based materials and recently, the company also presented a bottle made entirely from plant materials. The PlantBottle project is carried out by *The Coca Cola Company* in order to develop a more responsible alternative to commercial packaging made from non-renewable resources (The Coca-Cola Company, 2015).

Another well-known brand investing in research for bioplastics is the Danish toy producer *Lego A/S*. These are traditionally made out of petroleum based acrylonitrile butadiene styrene (ABS). According to *Lego*, the research project was launched not only to lower the carbon footprint of the company's products, but also to meet the growing consumer demand for greener products (Chao, 2015).

2.3.3 Public Opinion of Bioplastics

When searching for news articles with regards to bioplastics there are many articles praising the technology and its possibilities to reduce human negative impact on the planet (Casey, 2016; Hanley, 2016; Laird, 2016). There are however also a number of articles that are highly criticial of the actual effects bioplastics have on the environment and how they are being portrayed to the public through the marketing efforts of the companies offering them. The majority of the criticism found, focuses on the claim that bioplastics would be biodegradable. This is often not the case as they will only biodegrade under the right conditions, conditions which are rarely or never met (O'Connor, 2015; Vidal, 2008; Harman, 2014). Polyethylene, which will be produced by Borealis, is not biodegradable, regardless of feedstock.

2.4 Certification Schemes

Although using biomass as a fuel is considered to be a more sustainable alternative compared to fossil fuels, cultivating biomass carries an impending risk of overexploitation of natural resources which is unsustainable. Issues like these have called for a method to quantitatively or semi-quantitatively compare sustainability and resulted in the formation of sustainability certification schemes. Certification involves an independent third party comparing the data of an aspiring organization to a set of predetermined standards. These standards usually consist of criteria that have to be fulfilled in order to obtain the certification of a product or process (Pavanan et al., 2013).

Sustainability certification could potentially improve the environmental performance of commodity producers. Theoretically this could be achieved through offering the producers a chance of differentiating themselves from their competitors, through their environmental attributes. This could generate benefits such as better market access and facilitation of price premiums. To achieve this, certification programs face some challenges. To exclude under-performing producers they must ensure that the standards and their monitoring and enforcement are stringent enough. Being granted the certification must offer enough incentive that it is considered worth the effort and cost for the producers, something that can be hard for the certifying organizations to affect. To have real effect on the behavior of producers and their environmental effects, it is important that the certification schemes require more than what is already being done by the majority (Blackman and Naranjo, 2012).

Currently, there are many different certification schemes for ethanol. Various schemes address different aspects and therefore contain different criteria. Some are focusing on environmental aspects and others are looking at socio-economic issues. Some certification initiatives also contain requirements for GHG emissions savings as well as monitoring requirements (Scarlat & Dallemand, 2011). In an effort to reduce the negative social and environmental impacts of ethanol and other renewable fuels consumed within the European Union, the EU Commission has established an overall policy, called the Renewable Energy Directive (EU RED). It is necessary to comply with the criteria of the policy, and be certified accordingly, to be allowed to export ethanol to the EU (European Commission(1), 2015).

The EU RED covers both production within the EU and imported renewable energy produced outside the union. It was adopted in 2009 and specifies targets to be reached by the year 2020. The EU RED states that by 2020 at least 20 % of the energy requirements within the EU needs to be fulfilled by renewables, and at least 10 % of all transport fuels consumed within the EU needs to come from renewable sources. To get certified as complying with the EU RED, producers have to be audited by a third party organization. There are currently 19 organizations recognized by the EU to grant such certification schemes, or voluntary schemes as they are sometimes referred to (European Commission(2), 2015).

3 Method

The first step of this project was conducting a literature review on different aspects of FGE. The result of this study is presented, both in the *Introduction* chapter, where it serves to give a background of the aim of this study, and in *Chapter 2*, in which it provides a basis for the evaluation of FGE. Topics that were reviewed in this step include the past and current FGE production and the environmental and social impacts it entails. Furthermore, the theoretical study covered alternative ethanol feedstocks and the geographical availability of ethanol to allow for a comparison of the three areas chosen for the project, as well as their respective main ethanol crops. The extent of certification in the different geographic areas and their feedstock was also looked into for the purpose of comparison.

For the literature study, information was mainly retrieved from scientific literature, such as E-books and research articles. To obtain these sources, tools used include the online search function on the webpage of the Library of Chalmers University of Technology, as well as Google Scholar. Key terms that were used to find the mentioned information include *Ethanol*, *Sustainability* and *Certification*.

The current extent of bio-polyethylene production and primary usage was examined in *Chapter 2*. Furthermore, the attitude of the industry and the public towards the bio-polyethylene products, as well as the future outlook for bioplastics in general was assessed. The main sources for this were mainly market studies, producer and user statements on their respective websites and online news articles. Attention was also put on how the issues associated with ethanol are dealt with within the industry, how sustainability is assured, and how the sustainability efforts are communicated.

3.1 Framework Development

Ethanol production is a multi-faceted issue, as it affects many different stakeholders and aspects of society as well as the natural environment. To assess the different suppliers with regards to their impacts on the environment and society, a framework is needed. This enables consistency in the analysis as well as comparability between the different ethanol producers. Furthermore, the framework is intended to make the motivation behind the selection of suppliers more structured and clear for the reader.

Borealis has hypothesized that there are suppliers of FGE that can offer their product while living up to sufficient standards with regards to social and environmental sustainability

(Personal communication: Borealis[4]). To determine if this is in fact the case, clear guidelines for what is considered 'sustainable enough' are needed. The entire process of framework development and application can be seen in Figure 3.1.

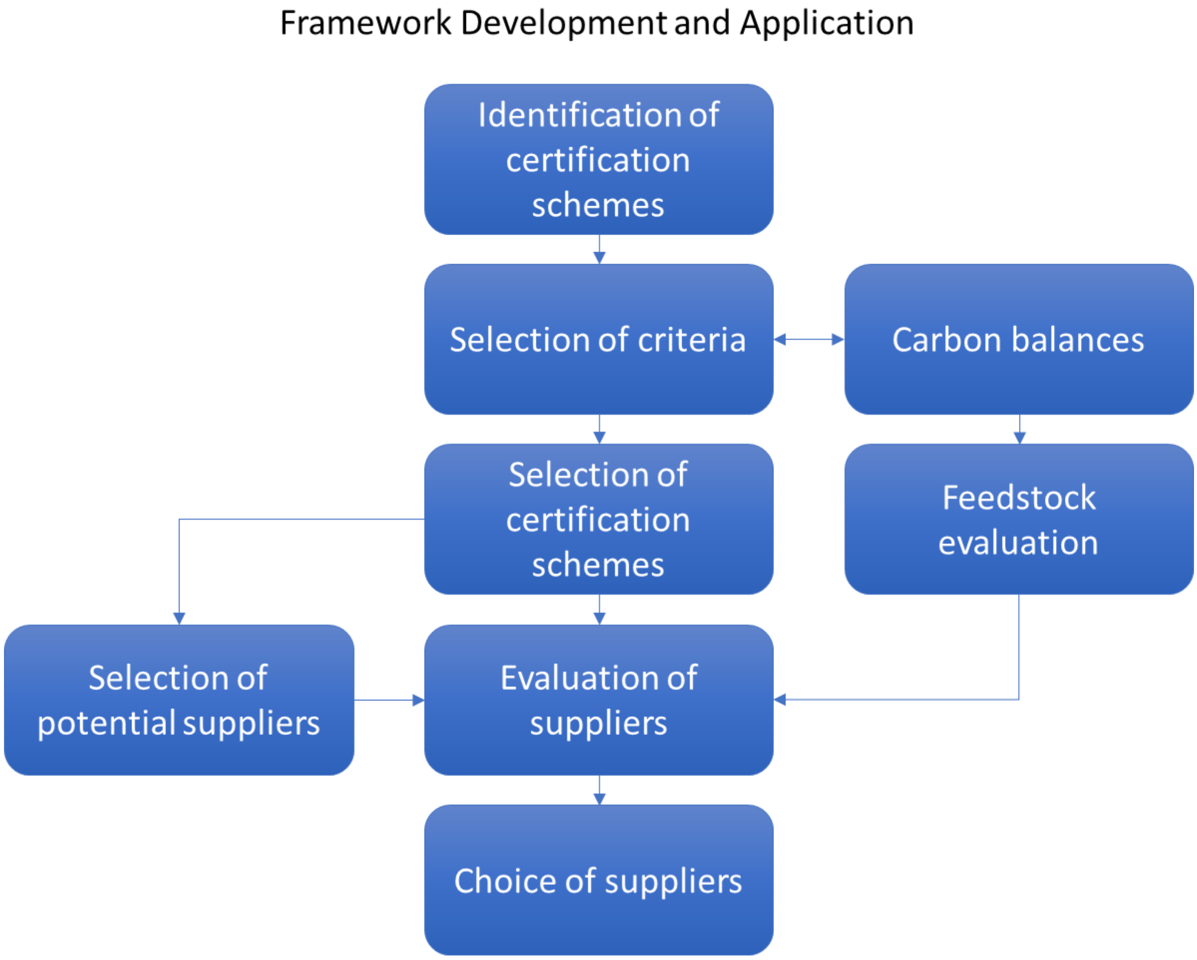

Figure 3.1 Graphic presentation of the process of evaluating and choosing suppliers

There are a number of certification schemes that address the production of ethanol. The extent and main focus of the schemes vary but together they cover most highlighted environmental and socio-economic issues in the field of ethanol production. Scarlat and Dallemand (2011) identify various environmental and socio-economic aspects considered in certification schemes. They also map which criteria are considered by which of the examined schemes. Their work gives a general overview of criteria considered for assessing the sustainability of ethanol production. It furthermore highlights which issues are covered by the majority of the certifying organizations, indicating that these are considered more important.

Along with the information gathered in the literature review, this matrix of issues and certification schemes by Scarlat and Dallemand (2011) was used to pinpoint the issues to be

[4] Lars Pettersson, *Expert Cracker at Borealis* (3 Sept., 2015)

included in the framework used to analyze potential suppliers. From this process, three certification schemes were identified as most relevant for the study. These are the production standards made by the RoundTable on Sustainable Biomaterials (RSB), International Sustainability and Carbon Certification (ISCC), and Bonsucro. These certification programs have all been officially approved by the EU to hand out EU RED equivalent certification (European Commission(2), 2015).

3.1.1 RSB Certification

The RSB certification is chosen because their production standard addresses the largest number of the environmental and social aspects covered in the matrix by Scarlat and Dallemand (2011). The organization is furthermore widely mentioned in the literature on ethanol production and its environmental and socio-economic impacts (Zezza, 2012; Murphy et al.; 2011; Scarlat & Dallemand, 2011).

The standards developed by the RSB are considered credible partly due to their diverse member base. RSB is an independent multi-stakeholder coalition operating on a global scale with promotion of sustainable biomaterials and biofuels. The organization consists of more than 100 organizations which represent different perspectives of the biomaterials industry and its affected stakeholders. According to RSB's website, the organization aims to ensure a balance between what society needs, with regards to the ethanol production, and what the business side needs. To enable this the RSB members are divided into chambers representing different sectors (RSB, 2015).

Some of the most renowned non-governmental organizations and corporations active in their fields are represented in the organization's different chambers, such as WWF International, Airbus, and Petrobras. For a complete list of the chambers as well as their respective member organizations, see Appendix I. The extensiveness of the member list further points to the standard being widely used within the biomaterials sector, which emphasizes its relevance for the project.

3.1.2 ISCC Certification

The work by the ISCC is chosen as a basis for the assessment model based on the fact that the ISCC standards are widely used by companies active in the bioproducts field (e.g. Braskem, Elopak, Sabic Petrochemicals (ISCC(1), 2015)) and recognized in the literature studied (Gold, 2010; Dallemand & Scarlat, 2011; Schlamann et al., 2013). This standard has furthermore been identified as one of the world's best certification schemes and sustainability initiatives by the World Wide Foundation (WWF) (Schlamann et al., 2013).

The ISCC was developed in Germany in 2008 as a global multi-stakeholder initiative. It is one of the forerunners in certification systems for greenhouse gas emissions and sustainability. In 2011 it was recognized by the European Commission as one of the first schemes to show compliance with the EU RED's requirements (ISCC(2), 2015). In the international market the ISCC EU has since become the most widely used certification scheme for EU RED certification (Schlamann et al., 2013). A list of ISCC's member organizations can be viewed in Appendix I.

3.1.3 Bonsucro Certification

Bonsucro is chosen because it is the largest certification organization for Brazilian sugarcane and because they are backed by the Brazilian Sugarcane Industry Association (UNICA) (UNICA, 2015). UNICA is in turn mentioned in SEKAB's own *Verifierat hållbar etanol* (English translation: *Verified sustainable ethanol*) initiative from 2008, which, according to SEKAB, is Sweden's first document of sustainability criteria for biofuels. In this document one of the main criteria listed is the "Ecological consideration according to the UNICA environmental initiative" (SEKAB, 2015).

The official launch of the Bonsucro certification system occurred in 2011 and they have since certified 42 Brazilian sugarcane mills, along with other mills in Australia and India (UNICA, 2015; Bitenieks, 2013). It is a global multi-stakeholder non-profit organization with over 100 members in 27 countries. A list of Bonsucro's member organizations can be viewed in Appendix I. The organization is dedicated to reducing the impacts of sugarcane production from a triple bottom line perspective (Bonsucro, 2013).

3.1.4 Criteria Selection

The criteria chosen for the framework have all been considered by the work of Scarlat and Dallemand (2011). The criteria that qualified for this framework are deemed most important. This qualification was based on at least one of three reasons. Firstly, the criteria that are considered by the EU RED have all been included, as that would be a minimum requirement for exporting to the EU. Secondly, if a criterion has been considered by all of the three other certification organizations RSB, ISCC, and Bonsucro it is incorporated into the framework. Lastly a criterion can be considered important and be included in the framework based on information gathered in *Chapter 2*, even if it has not been highlighted by the certification organizations mentioned. The mapping of this criteria selection is shown in Table 3.1.

Table 3.1 Evaluation and Selection of criteria for the framework

Environmental aspects of different certification initiatives	**EU-RED**	**ISCC**	**RSB**	**Bonsucro**
Environmental Impact Assessment		X	X	X
Good farming practice	X		X	X
Site history		X		
Sustainable use of resources				
Carbon conservation				
Preservation of above/below ground carbon	X	X		X
Land use change	X	X	X	
GHG emissions	X	X	X	X
Biodiversity conservation				
Biodiversity	X	X	X	X
Natural Habitats, ecosystems	X		X	
High conservation value areas	X	X	X	X
Native, Endangered and Invasive species	X		X	
GMO			X	
Soil conservation				
Soil management, soil protection		X	X	X
Residues, wastes, by-products			X	
Use of agrochemicals		X	X	
Waste management		X	X	X
Sustainable water use				
Water rights		X	X	
Water quality	X		X	X
Water management, conservation		X	X	X
Efficient water use			X	
Air quality				
Air pollution	X	X	X	X
No burning for land clearing/waste disposal				
No burning residues, waste, by-products			X	
Socio-economic aspects in different certification schemes	**EU-RED**	**ISCC**	**RSB**	**Bonsucro**
Economic development				
Economic benefits to community			X	
Economic performances			X	X
Energy efficiency		X		X
Energy balance			X	X

Social aspects				
Social impact assessment			X	X
Social benefits to community		X	X	
Human rights		X	X	X
Land right issues		X	X	
Labour conditions				
Working conditions			X	X
Contracts		X		
Health and safety		X	X	X
Freedom of association, bargaining		X	X	X
Discrimination		X	X	X
Wages		X	X	X
Working hours		X		X
Child labour		X	X	X
Forced labour		X	X	X
Training, capacity building		X		X
Description of color significance	**Additional criteria relevant for study**		**Required by min 3**	**Required by EU-RED**

A list of the criteria that were chosen for the framework can be found in Appendix II. These criteria have been divided into categories based on the work by Scarlat and Dallemand (2011). A description of these categories and why they are considered important follows below. For clarity, the categories are furthermore divided into environmental and socio-economic issues.

3.1.4.1 Environmental Issues

The world is facing increasingly large environmental and climatic problems. Agriculture is responsible for a large part of the global GHG emissions contributing to the greenhouse effect (FAO, 2014). Therefore, it is of outmost importance to consider the environmental impacts of producing ethanol based on agricultural crops. The issues covered by the EU-RED will mainly affect the environmental issues regarded in the framework as the standard focuses principally on environmental impact (Scarlat & Dallemand, 2011).

Carbon Conservation and Carbon Balance

As mentioned previously, the environmental efficiency of ethanol production has been questioned due to, among other things, land use change and energy inputs. Therefore, it is important to estimate and include GHG emission savings compared to fossil alternatives (Iyengar, 2015). This has been done by many existing certification schemes. To be able to make a fair and comprehensive comparison, the locations and farming practices must be identified and data for the specific conditions found. In this study, the GHG emissions of ILUC are not taken into account (this delimitation is motivated in sub-chapter 3.4) (Scarlat & Dallemand, 2011).

According to the EU RED (2009) a minimum of 35 % GHG emissions savings are required compared to the fossil alternative (International Food Policy Institute, 2011). Since the EU RED is a minimum requirement for the suppliers considered, this results in the framework having a minimum 35 % requirement.

A carbon balance is carried out to identify and quantify the carbon sequestrated by, and released from the feedstock. This is a mapping of how much and where the carbon is emitted, and how much ends up in the final product. Looking at the carbon pathways is considered important due to the fact that emissions of carbon compounds contribute to global warming.

The numbers used for the calculations were found in scientific literature, as the cultivators and producers are not sharing their emissions data with the public. This is assumed to be the case because it can affect the competitiveness or the actors. The outcome of the carbon balance is used as a quantitative measure for comparison of the geographically, and thus for the project, relevant ethanol feedstocks, corn grain, sugarcane and softwood forest thinnings. The result of the carbon balance is compared to the outcome from the qualitative research on ethanol feedstocks, in order to evaluate which of the feedstocks is the most suiTable one.

Biodiversity Conservation

Although species extinction is a natural process, the highly accelerated rate at which biodiversity loss occurs today is not. Human actions have been identified as the major driver of this phenomena with land use change causing the most significant effects on biodiversity. Biodiversity loss occurs at a local and regional level but can have significant effects on important Earth-systems. This fact makes it difficult to set an actual boundary for biodiversity and many of the complex relations of nature are not yet discovered (Rockström et al., 2009). Hence, biodiversity conservation is a prerequisite for sustainable development (Secretariat of the Convention on Biological Diversity, 2014).

A number of studies have shown that biodiversity loss is one of the major sustainability constraints for biomass production. Ethanol production affects biodiversity through habitat conversion and fragmentation as a consequence of agricultural expansion as well as urban development. Therefore, in order to be sustainable, ethanol feedstock cultivation must consider biodiversity protection (McCann, Buckeridge & Carpita, 2014). This can be done by making sure that land with recognized biodiversity value, such as primary forests, protected areas and wetlands, are not converted for biofuel production as established by e.g. the EU RED (Scarlat & Dallemand, 2011). Other ways to reduce pressure on habitats are making agriculture more efficient and improve fertilization methods, improving nutrient use efficiency and assuring that potentially invasive alien species are not introduced to surrounding environments (Secretariat of the Convention on Biological Diversity, 2014).

GMOs have the potential of being invasive species, given their persistent characteristics, they have the possibility to severely affect the biodiversity of surrounding ecosystems directly. Thus, usage of GMOs must either be carried out with great cautiousness or not at all in order to not harm surrounding environments and ecosystems. This is reflected by some of the examined certification schemes, although the issue is not brought up by all of them. For instance, RSB allows usage of GMOs with great precaution if significant advantages for people and planet can be demonstrated (RoundTable on Sustainable Biomaterials, 2011). ISCC certify GMOs, however, they have an add-on which can be applied for non-GMO requirements markets (ISCC, 2014). In contrast, neither Bonsucro nor the EU-RED address the use of GMOs (Scarlat & Dallemand, 2011). At present, Bonsucro do not regard GMOs as the organization only certifies sugarcane, of which there are not genetically modified alternatives (Personal communication: Bonsucro[5]).

Soil Conservation

Growing ethanol feedstock, just as all agricultural practices, impacts the soil. One important effect is soil erosion. After harvest when the soil is no longer covered and thereby protected by living plants or plant residues, soil particles can detach from the soil surface and be transported away by wind or water. These particles can also plug large pores in the soil which prevents water infiltration, leading to increased water run-off and then in turn further erosion (Cruse and Friedman, 2015). The reduced amount of water available, along with diminishing soil biota, soil nutrients, soil organic carbon (SOC), and a decreased soil depth that follow soil erosion will have a direct negative impact on the crop productivity (Pimentel, 2012).

The change in SOC stocks leads to carbon dioxide release or sequestration (Ferchaud, Vitte and Mary, 2015). The SOC level furthermore has a significant impact on the quality of the soil and thereby, the crop yield (Anderson-Teixeira et al., 2009). The changes in SOC can result from

[5] Sonia Slavinsky, *Standards Manager at Bonsucro* (29 Oct 2015)

modifications in land use, management practices, or crop type, but it can also be related to previous land-use history (Ferchaud, Vitte and Mary, 2015). By using land according to its capability, covering the soil surface to protect it, and by controlling runoff before it turns into an erosive force, the adverse impacts on the soil can be minimized (Queensland Government, 2015). It is furthermore possible to decrease the loss of SOC by returning carbon to the soil, after processing the feedstock (Personal communication: Chalmers University of Technology[6]). As the soil quality is of direct importance for the survival of our civilizations (Pimentel, 2012), and as the level of impact on the soil can be managed, the importance of considering soil conservation in the framework is clear.

Sustainable Water Use

The amount of water used for the production of ethanol is one of the main concerns of the ethanol industry (Ramchandran et al., 2013). The water used to produce ethanol can be divided into two different categories. The first type of water is used for the cultivation of the feedstock (e.g. sugarcane, corn, cassava), while the second is the water used in the process of turning the feedstock into ethanol. These two types of water are collectively known as the "water footprint" of the ethanol production. The water footprint comprises both "green water" i.e. the water that is evapo-transpired by the crop and "blue water", which is the ground or surface waters used for irrigation or the industrial process (Martinelli et al., 2015).

The ethanol sector has grown substantially all over the world and especially in the US and Brazil. In the latter for instance, the land used for ethanol feedstock cultivation has increased from 2 million ha in 1975 to 9 million ha in 2010. This has significantly increased the pressure on the local water supplies. Although the usage of water from the ethanol industry has been made more efficient, it still has a large impact on both the quantity and quality of the local water supply. The latter is mainly due to the fact that the water used in the industrial process that does not evaporate or become part of the final product is not properly treated before being released back into the natural environment. Not only does the water still contain harmful substances but it is also often not sufficiently cooled down before being released back into the watersheds (Martinelli et al., 2015). For these reasons, sustainable water use is taken into account in the framework.

Air Quality

Burning for land clearing is a major contributor to the pollution of the local air (Muñoz et al., 2013). Pre-harvest burning of sugarcane will expose workers and the population of nearby

[6] Matty Janssen, *Researcher, Energy and Environment, Chalmers University of Technology* (26 Feb 2016)

communities to high concentrations of health hazardous particulate matter (PM). The PM is known to cause a number of cardiorespiratory diseases (Ferreira et al., 2014). Studies that have been conducted in the state of São Paulo have shown a link between the concentration of PM in the air from the pre-harvest burning of sugarcane and the number of hospitalizations due to asthma and hypertension (Mauro et al., 2015). Burning for clearing is still practiced in some places in the cultivation of sugarcane (Muñoz et al., 2013). A gradual ban on pre-harvest burning has been instituted in São Paulo, which is the where the majority of the Brazilian ethanol is produced (Moraes and Zilberman, 2014).

Another discussed topic with relation to air pollution from ethanol production is the incineration of residual waste for energy. This enables the substitution of fossil sources for the energy needed to run the plants, which has a positive impact on climate change, but it can however lead to air pollution, which is why these emissions need to be monitored (McCann, 2014).

3.1.4.2 Socio-economic Issues

Due to the imminent risks of exploitation of the poor rural population in developing countries and negatively affect the human rights of indigenous people, socio-economic criteria are of great importance to include in a certification scheme (Rutz and Janssen, 2014). Also, according to Scarlat & Dallemand (2011) including these types of criteria increases the credibility and and acceptance of a certification scheme. Various issues, from economic developments to labour conditions and human and property rights can be included in a certification scheme covering socio-economic aspects. In this sub-chapter the socio-economic categories chosen for the framework are presented and motivated (Scarlat and Dallemand, 2011).

Economic Development

The production of ethanol can further the economic development of a country through e.g. the creation of jobs, by helping to develop local industry and by being a step towards energy self-sufficiency (McCann, Buckeridge & Carpita, 2014). By lowering the need for oil, ethanol production can help oil-importing countries become less vulnerable to the effects of the volatile oil price (León-Moreta, 2011).

Although there are clear community benefits there is need for critical review of the ethanol production from an economically sustainable point of view. Often cultivation for ethanol production is only financially feasible at a large scale. This leads to large agricultural conglomerates taking over, forcing the small scale farmers out of business (Timilsina &

Zilberman, 2014). Another concern is the displacement of food production which could potentially lead to price increases which can have disproportionate impacts on the poor population (Banerjee, Macpherson and Alavalapati, 2012).

Social Aspects

When discussing the positive aspects of ethanol feedstock cultivation, the main aspect brought up is the replacement of fossil fuels and the positive impacts that can have on climate change. Replacing fossil alternatives can also have positive impacts on society. One such impact is a decrease in conflict for scarce nonrenewable natural resources. Such issues are highly important and should be taken into consideration. However, growing feedstock for ethanol production can also have a negative social effect. Water, soil and biodiversity are all important factors for ethanol production. They are also essential for the fulfillment of human rights, such as the access to water, soil and land. Therefore, a change in the way such resources are utilized, impoverishment of resources, or adverse environmental impacts in the area, can reduce the availability of these natural resources. This can lead to vulnerable groups being stripped of basic human rights, such as the right to food and health (León-Moreta, 2011).

Food Competition

Food competition has been the issue that has received the most media attention with regards to the cultivation of feedstock for fuel. The magnitude of the blame that can be attributed to the biofuel industry for the past food crisis has been heavily debated both in media (Sturgeon, 2015; Sapp, 2015; Lewis, 2015) and in the scientific community (Koizumi, 2014; Bastianin, Galeotti and Manera, 2014; Meyer and Priess, 2014; Timilsina and Zilberman, 2014; Zhang et al., 2010). Regardless of the actual outcome of this debate, the planet has a finite area of arable land and an increasing population. This by extension means increased need for both food and energy, which leads to increased LUC (Timilsina and Zilberman, 2014).

Labor Conditions

Now and then, media reports about abusive labour practices for sugarcane workers in ethanol feedstock cultivating countries. For instance Nicaragua, where workers during harvest season reportedly suffer from kidney injury. This is believed to be caused by the intense heat and hard physical labour combined with insufficient hydration and can lead to chronic kidney disease (Minerd, 2015), which has killed at least 20,000 people, mainly sugar cane workers, during the last two centuries (Lakhani, 2015).

Another issue, mainly reported from Brazil, is slave labour in rural areas. This modern type of slave labour refers to forced and unfree labour as well as degrading conditions such as insufficient sanitary conditions and lack of protecting gear. Furthermore, restrictions on the freedom of workers, unrecorded working hours and salaries far below the minimum wage has occurred in some known cases, both with domestic and foreign workers involved (McGrath, 2013). The importance of fair labor conditions is reflected by the fact that it is addressed by many certification initiatives focused on ethanol production (Scarlat & Dallemand, 2011).

3.4 Limitations, Delimitations and Assumptions

Geographical Scope

The geographical scope of the project includes the US, Brazil and Africa. This is because Brazil and the US are well known ethanol producing and exporting nations and together account for the majority of ethanol produced worldwide (Kozumi, 2014). Africa on the other hand, is a region that is located close to Europe and has great potential with a suiTable climate for ethanol feedstock crops (Janssen and Rutz, 2012).

Terminology

The term ethanol can be used for both bioethanol, derived from biomass, and ethanol based on fossil resources. Throughout this report however, as long as no other specification is made, the term ethanol is used synonymously with bioethanol. This report deals mainly with two types of bioethanol, namely first and second generation. However, unless otherwise specified, the word ethanol in this report refers to FGE, i.e. ethanol produced mainly from cereals, grains and sugar crops. There is also a third generation ethanol that is produced utilizing microalgae (HLPE, 2013). The notation used in this report however, is in line with the current ratio between first, second and third generation ethanol as about 99 % of the ethanol produced worldwide today is classified as first generation (van Eijck, Batidzirai and Faaij, 2014).

The term bioplastics can be used for two types of plastic materials, those that are either entirely or partly derived from biomass and those that count as biodegradable. There are also alternatives that are both (European Bioplastics, 2015). It should however be noted that, unless otherwise stated, the term bioplastics in this report refers to the type of plastic materials that to some extent are derived from biomass.

Information

Land use change (LUC) and ILUC carry one of the largest sources of potential GHG emissions with regards to bioethanol, especially at the time of land cover conversion, as not only significant amounts of GHG emissions are released from decay or fire, but also the opportunity of future carbon storage might be lost (Hertel and Tyner, 2013). The awareness of ILUC and associated environmental impacts, such as GHG emissions, has increased over the past few years. However, whether or not to account for them and if so, what method to use have remained subjects of debate due to large uncertainties (Liptow, 2014). Due to this, along with the scope and time limitation of this project, environmental impacts from ILUC have not been addressed.

Ethanol is currently most commonly used as a transportation fuel, and thus most of the reviewed literature addresses ethanol as a biofuel. However, the ethanol used for biofuels is chemically the same type that can be used for bioplastic materials (Alvarenga and Dewulf, 2013). Therefore, all claims and facts about ethanol as a biofuel is assumed to be true for ethanol as a feedstock for bioplastics. Furthermore, it is also assumed that the ethanol produced by the suppliers can be used for bioplastics without any impediments.

As the view of FGE has changed rather drastically over time, from a promising sustainable substitute for fossil fuels to a more questionable alternative due to the alleged impact on food production and LUC (Timilsina and Zilberman, 2014), the aim has been to use as recent literature as possible and preferably not older than 2010. This has been emphasized especially for the parts of this project concerned with sustainability.

A limitation for the study is that there is often little third party information about companies operating in the ethanol industry that is relevant for the study. Much of the information about companies that are using ethanol is therefore acquired from the companies themselves. This naturally affects the result of that part of the study as companies strive for a good reputation and focus on what is good about their business. This fact entails that the information found on their webpages and in their press releases can be biased.

Sampling

The sampling choices made for the different ethanol and bioplastics actors were mainly based on availability of data, which also limited the study. This meant that the companies included in the study were not necessarily the best performer or an average representative for the industry. However, they are all large actors, indicating that they have resources to perform at a high level with regards to sustainability issues, and the information about them was therefore considered to be valuable for the study.

With regards to the sections in the literature review about the public opinion on bioethylene, the information was gathered in a sort of ad hoc manner, seeing what was found when using keywords such as *Bioplastics* and *Sustainability of bioplastics*. However, as the intention was to get a general view of how ethanol was represented in the media, this was deemed the best way of achieving this. One limitation in the information gathering might be however that the search was only conducted in English, which means that information published in other languages were not taken into consideration.

Carbon Balance

A delimitation of the carbon balance was that only the carbon fluxes after the point of harvest were investigated. However, it should be pointed out that the amount of time needed for the sequestration of biogenic carbon, i.e. the pace of carbon absorption in the plant, in the three different types of feedstocks varies due to their different growth rates (Personal communication: Chalmers University of Technology[7]). Furthermore, the type of compound that the carbon is released as is not taken into consideration, although this can have significant impacts. For instance, methane has a global warming potential 86 times that of carbon dioxide over a period of 20 years (Jackson and Jackson, 2001).

Additionally, when conducting the carbon balance, several assumptions and simplifications were made, as the required information was not readily available. When dealing with agricultural crops, there is a high degree of variation with regards to yield, moisture content, starch, sugar and cellulose content, carbon content and equipment used, depending on factors such as geographic location (Personal communication: Chalmers University of Technology[8]). However, in this project the carbon balance is based on numbers from different sources, such as scientific research articles, and aims to describe a general case. Thus, the result should be seen more as an indication.

[7] Matty Janssen, *Researcher, Energy and Environment, Chalmers University of Technology* (26 Feb 2016)
[8] Matty Janssen, *Researcher, Energy and Environment, Chalmers University of Technology* (26 Feb 2016)

4 Results and Analysis

First in this chapter, findings from the theoretical study will be analyzed to help answer the research questions and generate and motivate the conclusions of the study. Whether or not ethanol is a good substitute for oil in plastics production is then analyzed. Thereafter, the results of the carbon balance conducted will be presented and analyzed. Finally, the results of the supplier search are presented and analyzed based on the framework and other methods needed for supplier evaluation.

4.1 Production of Bioplastic from FGE

At the time of this project, ethanol has various common areas of application including biofuels, alcoholic beverages and medical uses, making it an important and widespread raw material produced in great quantities worldwide. There are already a handful of companies, including Braskem, The Coca-Cola Company and Lego A/S that are producing, or planning to produce, plant based plastics (Braskem(1), 2015; The Coca-Cola Company, 2015; Chao, 2015). This appears to be done mostly in order for the companies to be able to adopt a green profile and by extension meet the increasing demand for bioplastics. This demand is also predicted to increase within the next couple of years. For the purposes of this study, Braskem is the most comparable company to *Borealis* intended future operations, as they are producing PE from ethanol, marketed as *I'm Green™-PE*. This PE is widely used for plastic bags by large Swedish retailers, as well as the Swedish packaging industry (Pettersson, 2016; Braskem, 2013). This shows that there is a present demand for bioplastics, probably sparked by an increasing demand for more sustainable products in general.

Studies that have compared the use of ethanol instead of crude oil for plastic production have shown that ethanol based products are associated with smaller emissions of GHG compared to the fossil based alternatives (Alvarenga and Dewulf, 2013; Posen et al., 2015). According to Posen et al. (2015) this is especially true for Brazilian sugarcane based products, as this type of ethanol entails the largest GHG emissions savings compared to other first generation feedstocks. Furthermore, Brazilian sugarcane ethanol is the most cost competitive alternative to crude oil compared with other potential feedstocks (Posen et al., 2015). Other reasons to deploy bioethanol (both first and second generation) instead of crude oil include contribution to development, especially in developing countries, and the volatility of oil prices (Timilsina & Zilberman, 2014).

The technology for producing ethylene from ethanol already exists and is practiced. This means that no additional research needs to be conducted by *Borealis* to start producing their products from this feedstock, once the dehydration plant is built. Furthermore, a decision regarding which technology they intend to use has already been made and they are already in contact with BP who would be leasing the technology. *Borealis* would naturally have to pay to invest a substantial sum to have the dehydration plant built, and besides the investment this might take time away from normal operations. This investment has however already been decided on, although at a later, unspecified date. Since *Borealis* are considering Drop-in bioplastics, the ethylene that would be produced from ethanol would fit right into their existing infrastructure (Kuehner, 2015).

4.2 Quantitative Study - The Carbon Balance

A carbon balance of the harvested feedstock is carried out to identify the carbon fluxes of the carbon contained in the amount of feedstock needed for the functional unit, 1 kg of ethylene. By doing this, it is possible to estimate the share of carbon that is sequestered in the final product. It is furthermore possible to see how much ends up in the atmosphere and soil. These two endpoints are of great importance, as carbon compounds released into the atmosphere have negative effects, contributing to climate change whereas the carbon that ends up in the soil have positive effects on soil productivity (Personal communication: Chalmers University of Technology[9]). The conversion rate from ethanol to ethylene is based on the numbers from the BP Hummingbird technology, which is the technology *Borealis* are planning on using for their dehydration of ethanol. The conversion rates are presented in Table 4.1.

Table 4.1. Conversion rates for the BP Hummingbird Technology and for the fossil alternative

End product	**Input in dehydration plant**	**Weight percentage of Ethylene out of Ethanol**	**Feedstock**
1 kg ethylene	1.66 kg Ethanol (2.1 L) *Dehydration - BP Hummingbird*	1 ÷ 1.66 = 0.60 → 60 %	Sugarcane / Corn grain / Forestry residues

Complete calculations of the carbon balance conducted can be found in Appendix III. The processes and results are presented here below.

[9] Matty Janssen, *Researcher, Energy and Environment, Chalmers University of Technology* (26 Feb 2016)

4.2.1 Carbon Balance of Ethylene from Sugarcane-based Ethanol

The harvested sugarcane is crushed to extract the cane juice. The byproduct from this process, bagasse, is a fibrous material that in most cases will be incinerated together with residual straw to generate energy used in the ethanol production process. The cane juice is divided into sugars and vinasse. The latter consists of 94-97 % water and the remaining portion is made up of minerals, organic material and nutrients (Polizeli and Rai, 2013; Christofoletti et al., 2013). This liquid is most commonly sprayed back into the fields to decrease the need for irrigation and fertilization (Silva and Chandel, 2014). The sugars are sucrose, fructose, and glucose and these are through hydrolysis and fermentation converted into ethanol with carbon dioxide as a bi-product. This carbon dioxide is assumed to be emitted to the atmosphere. A chart of the the material steps and the mass flows is shown in Figure 4.1.

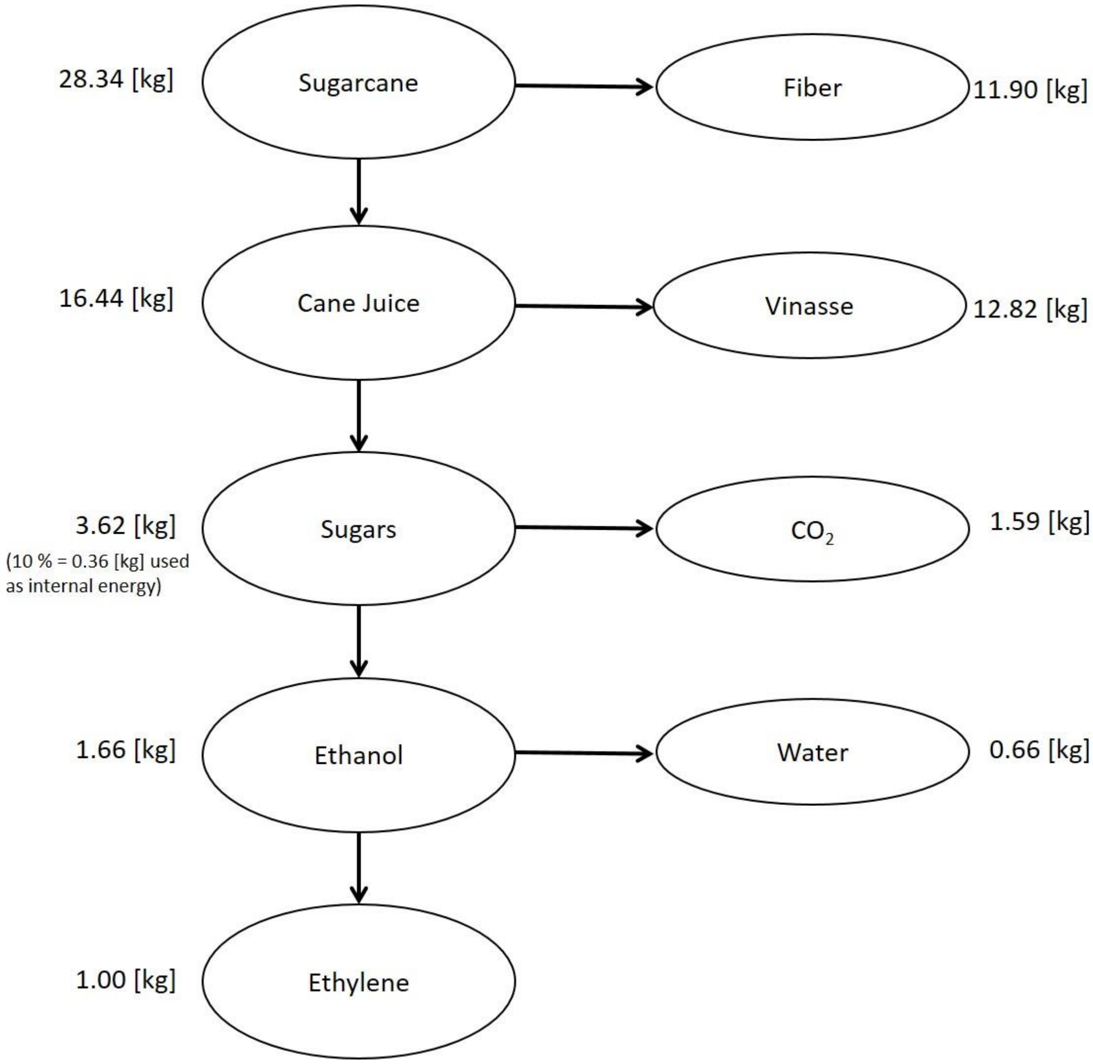

Figure 4.1. Material steps in the ethanol production from sugarcane.

With knowledge of the mass balances for the ethanol process, the following step is to identify the routes and endpoints for the carbon. The vinasse is as mentioned above assumed to be spread out on the fields. It is further assumed that this is the endpoint for the small portion of carbon that it contains. The carbon dioxide generated in the fermentation of glucose is assumed to be released into the atmosphere. The rest of the carbon from the sugarcane is contained in the fibrous material. This is all assumed to be incinerated for the purpose of energy production. In addition to supplying the ethanol production with energy, the combustion of bagasse and straw also produces surplus energy that can be sold back to the grid. According to Liptow and Tillman (2012), the production of one kilogram of ethylene yields 0.5 megajoules of surplus energy.

The incineration of bagasse results in carbon emissions to the atmosphere. According to Eljack Suliman and Fudl Almola (2011), some of the incinerated bagasse will remain as ash. This ash contains carbon and is normally spread out on the land as slurry (Bahurudeen et al., 2015), making the cropland the endpoint for that portion of the carbon in the sugarcane ethanol carbon balance. The rest of the carbon contained in the fibrous material is assumed to be released to the air when incinerated. The results of the carbon balance, with paths and endpoints for the carbon are shown in Figure 4.2 and the final percentages of carbon in each endpoint is shown in Table 4.2.

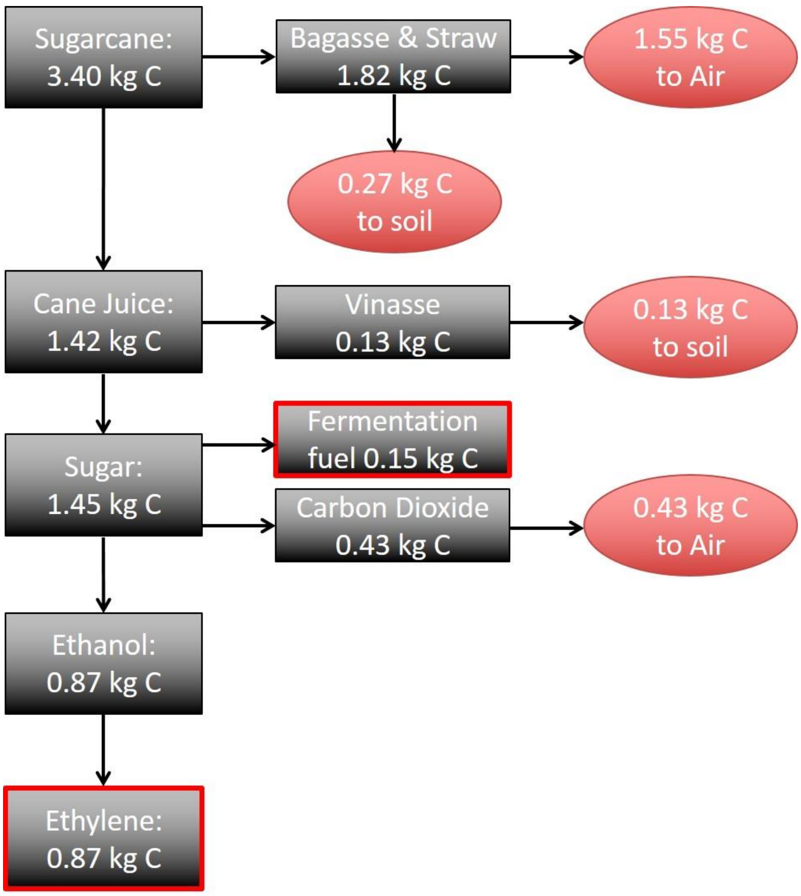

Figure 4.2. Paths and endpoints (red ovals and red framed squares) for the carbon in the ethylene production chain (own illustration).

Table 4.2. Share of the total carbon ending up in the three different endpoints.

Endpoint	**Share**
Final product	25 %
Air	58 %
Soil	12 %
Yeast maintenance	5 %

4.2.2 Carbon Balance of Ethylene from Corn-based Ethanol

Ethanol from sugarcane and corn have the same qualities and composition, as does the ethylene. The production of one kilogram of ethylene will therefore require the same amount of ethanol, regardless of the feedstock. The harvested corn plant is made of corn grain and stover (Roth, 2014). The grain consists to a large part of starch (FAO, 2015), which is what is used to produce ethanol. The remaining material in the grain is assumed to be turned into animal feed, as this is common procedure (FAO, 2015; Muñoz et al., 2013; Ertl, 2012). In three processes called gelatinization, liquefaction, and saccharification, the starch is converted into the sugar dextrose. In the liquefaction process water is added to the starch and in the other two processes enzymes are added to help convert the starch to sugar (the mass of the enzymes is assumed to be negligible) (Borglum, 1980). The material steps and the mass flow in the corn to ethylene process is shown in Figure 4.3 below.

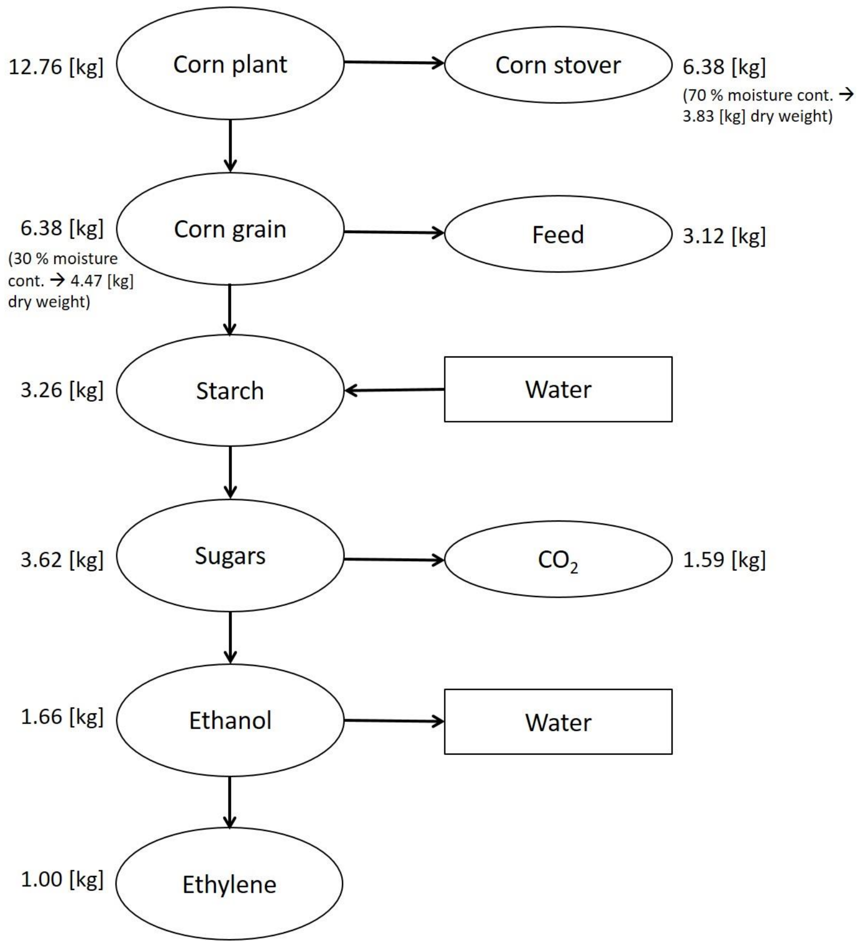

Figure 4.3. Material steps in the ethanol production from corn.

The next step is to identify the routes and endpoints for the carbon. The ethanol step and the sugar step in the carbon balance are equal to the corresponding steps in the sugarcane carbon balance. As bagasse, stover is assumed to be incinerated. Although stover is often also turned into animal feed, this assumption is made for comparative reasons this. The carbon content in the ash is assumed to be released to the soil and the remaining carbon released into the air. The carbon balance is shown in Figure 4.4 below and the final percentages of carbon in each endpoint is shown in Table 4.3.

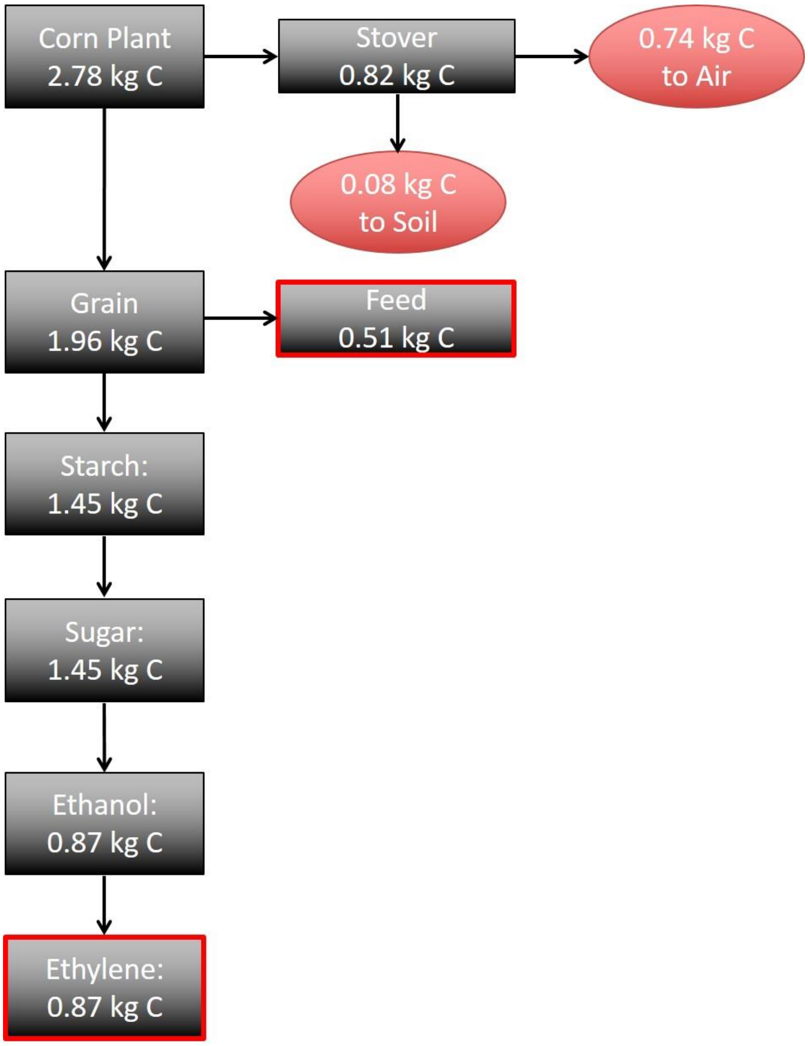

Figure 4.4. Material steps in the ethanol production from corn.

Table 5.3. Share of the total carbon ending up in the different endpoints.

Endpoint	**Share**
Final product	31 %
Bi-product	18 %
Air	43 %
Soil	3 %
Yeast maintenance	5 %

4.2.3 Carbon Balance of Ethylene from Forest Residues

The term lignocellulosic biomass describes the parts of the plant that consist mainly of cellulose, hemicellulose and lignin. Among others, these types of feedstock include sugarcane bagasse, corn stover and forestry residues (Amarasekara, 2013). In the beginning of the *Locally Grown Plastics* project, the plan is to produce ethanol from sawmill residues such as wood chips. Future plans are however, to produce ethanol from forestry residues such as tops and branches (Personal communication: SEKAB[10]). The process and the calculations in this chapter and Appendix III are based partly on the description of SEKAB CelluApp® technology on SEKAB's homepage and partly on available literature. Figure 4.5 shows the assumed steps of ethanol production from softwood forest thinnings.

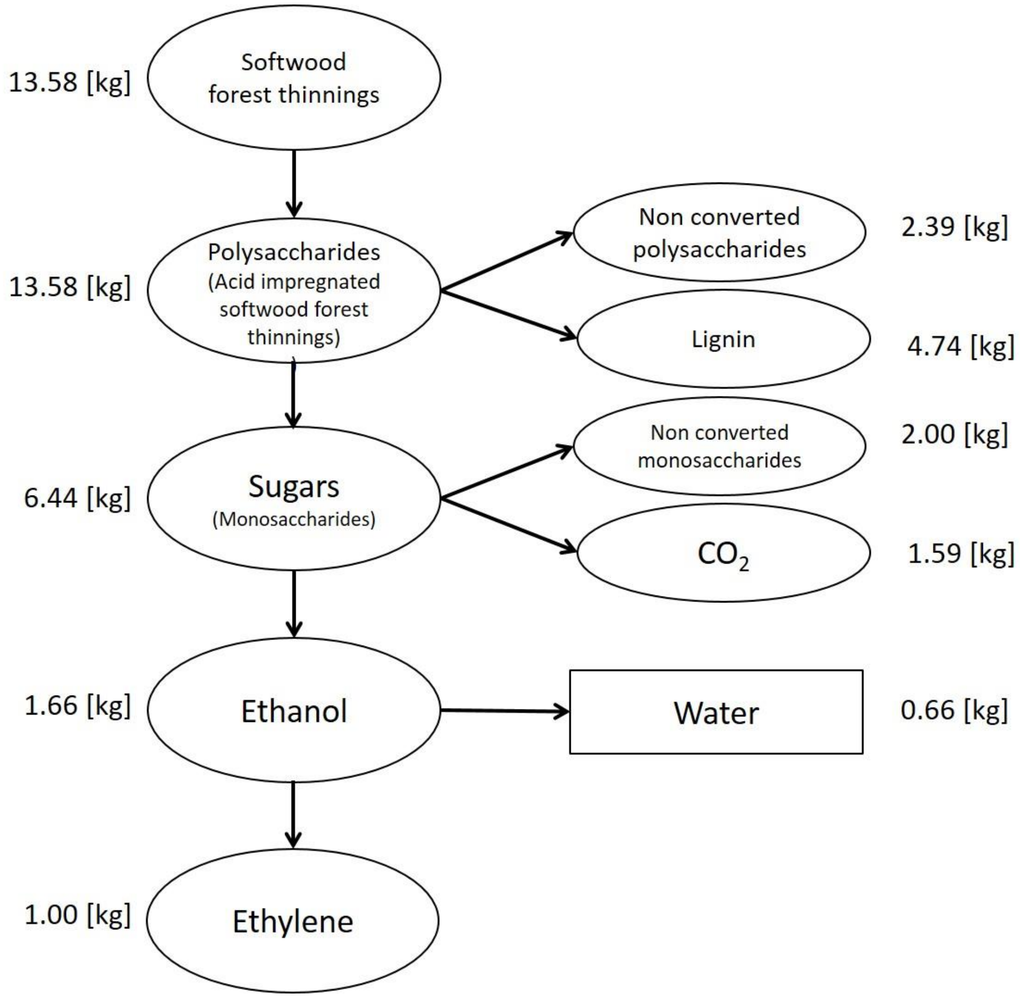

Figure 4.5. Material steps in the ethanol production from softwood thinnings.

The composition of cellulose, hemicellulose and lignin varies depending on factors such as type of biomass and growth location. Typical fractions are 25-50 %, 20-35 % and 15-30 % respectively. The cellulose and hemicellulose are the important components for bioethanol production as they are polysaccharides, made up by monosaccharides (Amarasekara, 2013). Theoretically, the monosaccharides contained in the cellulose (glucose) and in the hemicellulose (xylose, arabinose, glucose, mannose and galactose) can be fermented and thereby utilized for the production ethanol. Although C-5 sugars, xylan and arabinan, are not fermented at SEAKB's demonstration plant (Personal communication: Chalmers University of Technology[11]), this

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process is assumed to take place in the calculations for simplicity reasons. Furthermore, the share of these sugars in the wood are very small, see Appendix III, thus they are not assumed to significantly affect the end result.

Due to the way the composition fractions are structured, complete recovery of the constituent sugars has proven to be difficult. To disrupt the structure and liberate the cellulose, the raw material is pretreated (Buckeridge and Goldman, 2011). There are various pretreatment methods, the most commonly applied one being steam explosion or steam pretreatment. It is assumed that the mass remains constant over the pretreatment step (Amarasekara, 2013). Despite the pre-treatment, the polysaccharides in the cellulose and hemicellulose can only be recovered to a certain extent (Jonker et al. 2014). Thereby, conversion factors are used when calculating this process. The conversion factors can be seen in Table 1C in Appendix III. The assumed material steps and the carbon emissions to air can be viewed in Figure 4.6.

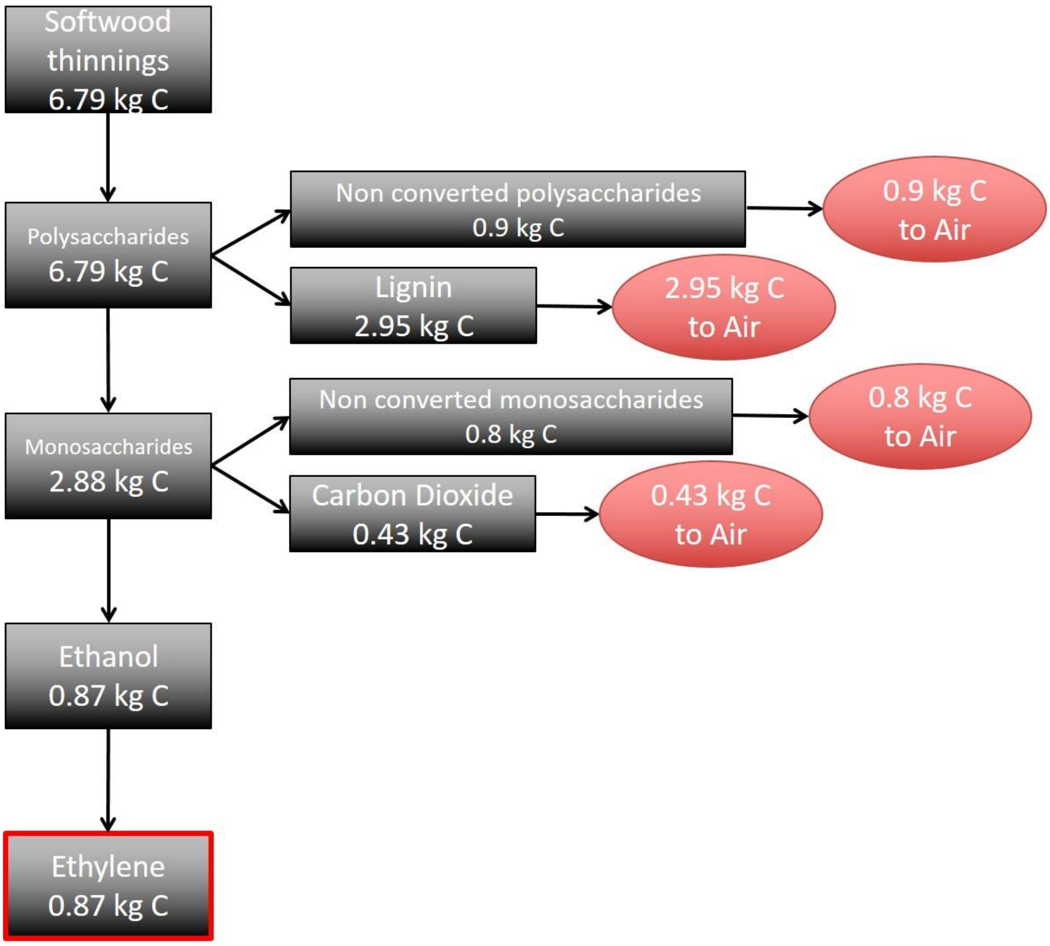

Figure 4.6. Material steps in the ethanol production from softwood thinnings.

As lignin cannot be utilized and also inhibits the fermentation process, it is removed after the enzymatic hydrolysis and combusted for powering the plant (Amarasekara, 2013). After the enzymatic hydrolysis, the monosaccharides are fermented. As with the polysaccharides, all monosaccharides cannot be fermented and are removed from the process as non-converted monosaccharides. The amount of these is also calculated with conversion factors according to Jonker et al. (2014). Based on a report by National Renewable Energy Laboratory, (2011), the non-converted poly- and monosaccharides are assumed to be anaerobically fermented into methane that is then also combusted for power generation for the plant.

4.2.4 Comparison and Analysis of Results of the Carbon Balance

The gathered results from the carbon balance are shown in Table 4.4. These show that there is more of the carbon content of the feedstock left in the final product for corn based ethanol than for ethanol from sugarcane and softwood thinnings, 31 %, 25 % and 13 % respectively. Furthermore, a larger portion of the carbon content is released into the air when using softwood thinnings and sugarcane, 76 % and 60 % to compare to 44 % from the corn alternative. These results might indicate that corn would be the preferred alternative from an environmental perspective. It is however important to keep in mind that an area of only 3 m^2 is needed to cultivate the sugarcane needed, while an area of 11.46 m^2, almost four times as much, is needed to cultivate the corn needed to produce one kg of ethylene. For softwood, the area needed is even smaller than for sugarcane. The results also show that sugarcane is preferable from a soil perspective, as 12 % of the carbon is returned to the soil after the feedstock has been processed, compared to only 3 % for corn.

The large share of carbon emitted into the atmosphere and the relatively small percentage of carbon remaining in the end product for softwood thinnings has to do with that the SGE technology is not yet fully developed and there are large conversion losses. However, it should be pointed out that softwood thinnings is a residual product from the forest industry, making it possible to account for some of the carbon emissions, for instance, to another forestry product.

Table 4.4 - Comparison of the results from the carbon balance

Feedstock	Mass needed	Cultivation area needed	Carbon content	Carbon remaining in final product	Carbon emitted to air	Carbon released to soil
Sugarcane	25.04 kg	3 m^2	3.0 kg	25 %	60 %	12 %
Corn grain	11.46 kg	11.46 m^2	2.5 kg	31 %	44 %	3 %
Forestry residues	13.58 kg	0.88 m^2	6.79 kg	13 %	76 %	<0.1 %

The recent development with SGE based on agricultural residues, such as sugarcane bagasse and corn stover, has the potential to improve the environmental performance of ethanol. This would make these alternatives even more preferable because the yield per unit area has the potential to increase remarkably. Although the SGE technology currently is more expensive than that of FGE, it is reasonable to assume that the production costs will decline due to experience curve effects and thus SGE will become price competitive in a future scenario.

4.3 Evaluation of potential suppliers

To get a first idea of the potential suppliers in the different geographical regions, Bonsucro, ISCC, and RSB were consulted. On their respective websites they have posted lists of companies with valid certifications, what type of certifications they hold, and what region they operate in (Bitenieks, 2013; ISCC(1), 2015; RSB(2), 2015). Bonsucro exclusively certifies sugarcane operations, and the majority of the certification holders are located in Brazil, where the organization was founded. There, they currently certify 25 different ethanol production facilities (along with a number of other sugarcane mills that do not produce ethanol), owned by 10 different companies. When looking into the ISCC, seven plants located in one of the studied areas held valid certifications. These were owned by five companies operating in the US. The only certified African company that produce ethanol was Addax Bioenergy Ltd, operating in Sierra Leone and certified by RSB. The result of this primary supplier search in Brazil, the U.S. and Africa is shown in Table 4.5 (More extensive information on the suppliers can be found in Appendix IV).

Table 4.5 Ethanol producers certified in Brazil, the US and Africa by Bonsucro, ISCC and RSB.

Supplier	Certified mills	Feedstock	Production	Certification Standard
Brazil				
Raízen Energía S/A	13	Sugarcane	Ethanol/Sugar/SGE	Bonsucro EU Production Standard including section 7 ChoC
Odebrecht Agroindustrial	2	Sugarcane	Ethanol	Bonsucro EU Production Standard including section 7 ChoC
Alto Alegre	1	Sugarcane	Ethanol/Sugar	Bonsucro Production Standard - Version 3.0 March 2011
BP Biocombustíveis	1	Sugarcane	Ethanol/Sugar	Bonsucro Production Standard - Version 3.0 March 2011
Bunge	2	Sugarcane	Ethanol/Sugar	Bonsucro EU Production Standard including section 7 ChoC
Copersucar	3	Sugarcane	Ethanol/Sugar	Bonsucro EU Production Standard including section 7 ChoC
Grupo São Martinho	1	Sugarcane	Ethanol/Sugar	Bonsucro EU Production Standard including section 7 ChoC
LDC SEV Bioenergia S/A	1	Sugarcane	Ethanol/Sugar	Bonsucro EU Production Standard including section 7 ChoC
Usina Alta Mogiana S.A - Açúcar e Álcool	1	Sugarcane	Ethanol/Sugar	Bonsucro Production Standard - Version 3.0 March 2011
USA				
Plymouth Energy LLC	1	Corn	Ethanol	EU-ISCC-Cert-DE105-82193704
Green Plains, LLC.	3	Corn	Ethanol/Feed/FGP*	EU-ISCC-Cert-US201-70600227
Marquis Energy LLC	1	Corn	Ethanol	EU-ISCC-Cert-DE105-81656504
Absolute Energy, LLC	1	Corn	Ethanol/FGP*	EU-ISCC-Cert-DE105-81950804
Little Sioux Corn Processors, LLLP	1	Corn	Ethanol/FGP*	EU-ISCC-Cert-DE105-81935904
Africa				
Addax Bioenergy Sierra Leone Limited	1	Sugarcane	Ethanol	RSB-STD-11-001-01-001 v2.1 & RSB-STD-11-001-20-001 v3.1 (Includes EU RED)

*FGP = First Gathering Point - the production of raw biomass that is sold for refinement.

Table 4.5 shows that Brazilian ethanol producers possess certifications to a substantially larger extent than the producers operating in the US and Africa. This suggest that Brazil has come further than any of the other regions studied in matters of sustainability. To validate these results, a further investigation into some of the producers in the US and Africa, based on their own information, industry organizations, and journals focused on ethanol production is conducted.

4.4 Sustainability Focus: US & Africa vs. Brazil

In this sub-chapter, the focus of the ethanol industry in the US and Africa, as well as individual suppliers is assessed. This is done to see if the American or African suppliers live up to the same standards as the Brazilian suppliers do with regards to sustainability matters, to determine if they should be included further in the study.

4.4.1 Focus on Sustainability: US Suppliers

In almost every case, on the individual US based producers' websites, little focus is put on sustainability and no mention of certifications with regards to sustainability can be found. This is in high contrast to the companies operating in Brazil. With regards to the American ethanol market, more focus seems to be put on the influence on the U.S. economy and the survival of the industry as well as individual farmers (Green Plains Inc., 2015; Plymouth Energy, 2015; Absolute Energy, 2015; Little Sioux Corn Processors, 2015). This is also true for the industry organizations in the U.S., as increased environmental and social sustainability is mentioned more as an added bonus than the main focus in their vision statements (National Corn Growers Association(2), 2015; Renewable Fuels Association, 2014). Some of the producers do make strong vows to increase the sustainability of their operations but they fail to communicate any third party confirmation of these efforts in form of certificates on ethanol production.

The U.S. is the world's largest exporter of ethanol and the EU has been a large customer of US ethanol, especially between the years of 2010 and 2012. Previously a larger number of production mills in the U.S. were certified by the ISCC according to the EU RED (iscc(3), 2015), but when the tolls increased they decided to export elsewhere (US Department of Agriculture, 2015).

4.4.2 Focus on Sustainability: African Suppliers

Assessing the sustainability position of suppliers in Africa proves to be more challenging than in the US. The industry association Ethanol Producers Association of Southern Africa (EPASA) has seven members in South Africa and Swaziland, however all uncertified (EPASA, 2015). At their individual websites, when such can be found, they have no or little information of any sustainability efforts. Ethanol producers in other African nations e.g. Zambia and Mozambique are often owned by multinational companies and their operations in Africa are difficult to get information about (Hanson, D'Alessandro and Owusu, 2014).

The one African EU RED certified producer is Addax Bioenergy, operating in Sierra Leone. Although they claim to have a strong sustainability focus, described at length on their webpage, the company is only expected to produce 85 million liters of ethanol annually when running at full capacity (Addax Bioenergy, 2015). This is less than Borealis require to start their operations.

4.4.3 Analysis of Sustainability Comparison in the US and Africa

Looking closer at the individual suppliers that are certified in the US and Africa from the different regions, the Brazilian producers communicate a higher focus on sustainability. This was seen both at the producers' respective websites and in news articles about the producers and the industry in general. In the US the focus was put more on the profitability of the ethanol industry as well as its impacts on individual farmers and the American economy as a whole. In Africa, very little information can be found about suppliers of ethanol in general, and sustainability focus in particular. Only one supplier is certified according to EU RED. This indicates that even if there are efforts in that area, it is difficult to find information to be able to include African suppliers in the comparison.

Based on these results, the decision was made to focus only on suppliers producing ethanol from Brazilian sugarcane. This was decided as a main focus of the study was finding suppliers that can be deemed to be conducting their production sustainably. An expressed interest and pursuit of operating sustainably was considered an important factor in this.

4.5 Brazilian Sugarcane Ethanol Suppliers

All but two of the identified characteristics that have been included in the framework, the use of agrochemicals and pre-harvest burning to clear land, are covered by the Bonsucro EU Standard. However, less agrochemicals are used in the cultivation of sugarcane than when cultivating corn (Nordborg Cederberg & Berndes, 2014), indicating that a Brazilian ethanol producer is preferable from this aspect. With regards to pre-harvest burning, it is indirectly covered by Bonsucro. This is due to the fact that to be Bonsucro certified, a sugarcane ethanol producer has to conduct mechanical harvesting, and pre-harvest burning is only carried out when manual harvest practices are applied (Moraes and Zilberman, 2014). To get certified according to the Bonsucro EU certification, the producers must live up to a number of mandatory requirements, at least 80 % of the indicators in principles 1-5 (see Appendix V), as well as the extra requirements for access to the EU market (see Appendix VI). Thereby it is shown that almost all of the chosen criteria are taken into consideration by the companies under investigation.

The first list of Brazilian suppliers that are certified by Bonsucro is shown in Table 4.5. When examining these suppliers, one thing that stands out is that not all live up to EU RED standards. Three of the Bonsucro certified suppliers do not qualify to enter the European market as they do not comply with section 6 of the Bonsucro Production Standard. This section of the standard is additional to the normal standard and contains the requirements for biofuels under the EU RED (see Appendix V and VI) (Bonsucro, 2011). The companies that do not live up to the requirements are: Alto Alegre; BP; and Usina Alta Mogiana S.A. They will not be considered as potential ethanol suppliers for *Borealis* as they are unable to export to the EU. This exclusion thereby leaves a list of seven suppliers to rank based on the framework constructed.

To further compare the certified suppliers, the plan was to see how they had performed with regards to the non-mandatory requirements in the Bonsucro EU standard, and thereby compare how they work with the different criteria identified in the constructed framework. However, Bonsucro is only able to share who have been certified by a certain standard, and what criteria that standard contains. They are not allowed to share the specific details of the audit that lead to the certification. The organization claims to be working towards increasing the transparency regarding this (Personal communication: Bonsucro[12]). For the purpose of this study, this means that the certified suppliers cannot be further compared to each other based on criteria in the framework, as they have all received the same certifications.

4.6 New Basis for Comparison

The lack of transparency from Bonsucro created a need for comparison of the suppliers beyond the framework. This required a further revision of literature, which led to the choice of a geographic comparison based on the work by Schueler et al. (2013)

4.6.1 Geographic Mapping of Biomass Potential

Article 17 of the EU RED focuses specifically on the reduction of greenhouse gas (GHG) emissions from liquid fossil fuels and the sustainability criteria to achieve this (Schueler et al. 2013). This part of the directive is chosen to serve as a basis of comparison for the EU RED certified Brazilian ethanol producers listed in Table 4.5. Article 17 is focused on what type of land the cultivation of feedstocks take place and the criteria of the article are divided into four different layers that have different focus areas. These layers are:

- The GHG layer, referring to Article 17(2)
- The biodiversity layer, referring to article 17 (3)
- The forest layer, referring to article 17(4)
- The wetlands layer, referring to both Article 17(4) and (5)

See Appendix VII for a summary of article 17 (EUR-Lex, 2009).

[12] Sonia Slavinsky, *Standards Manager at Bonsucro* (7 Dec 2015)

Schueler et al. (2013) have conducted a study on the influence the sustainability criteria in the EU directive have on the availability of biomass resources globally. The study makes a distinction between what is referred to as theoretical biomass, which means the physical supply of biomass regardless of how it is produced, and technical biomass, which refers to biomass that is produced without violating the requirements in Article 17 of the directive (Schueler et al., 2013).

The analysis of the theoretical biomass potential with regards to the EU RED results in a quantitative effect of the directive, i.e. how much biomass is still technically available if the sustainability criteria of the EU RED are followed. Their findings show that approximately 10 % of the global theoretical biomass is available as technical biomass. In South America as much as 53 % of the theoretical yield complies with the EU directive. The results for South America are presented in see Figure 4.5, which shows where the technical yield is highest (Schueler et al., 2013).

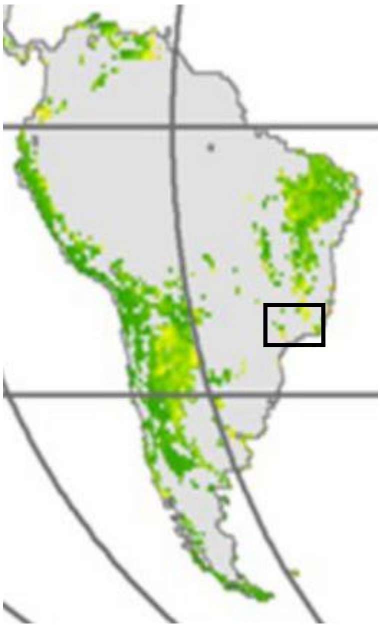

Figure 4.5 Geographic presentation of the South American distribution of the technical biomass potential. A zoom in of the area marked with the rectangle can be seen in Figure 4.6

Source: Schueler et al. (2013)

In Figure 4.5, the technical biomass potential is shown in an increasing yield scale from green to yellow. It is possible to see that the technical yields are highest in the north-east and south-central regions of Brazil. The Bonsucro EU certified ethanol producers are situated in three different states: São Paulo; Minas Gerais; and Goiás, all located in the south central part of the country. The producers that are eligible as suppliers for *Borealis* according to established framework criteria are marked with yellow stars in Figure 4.6.

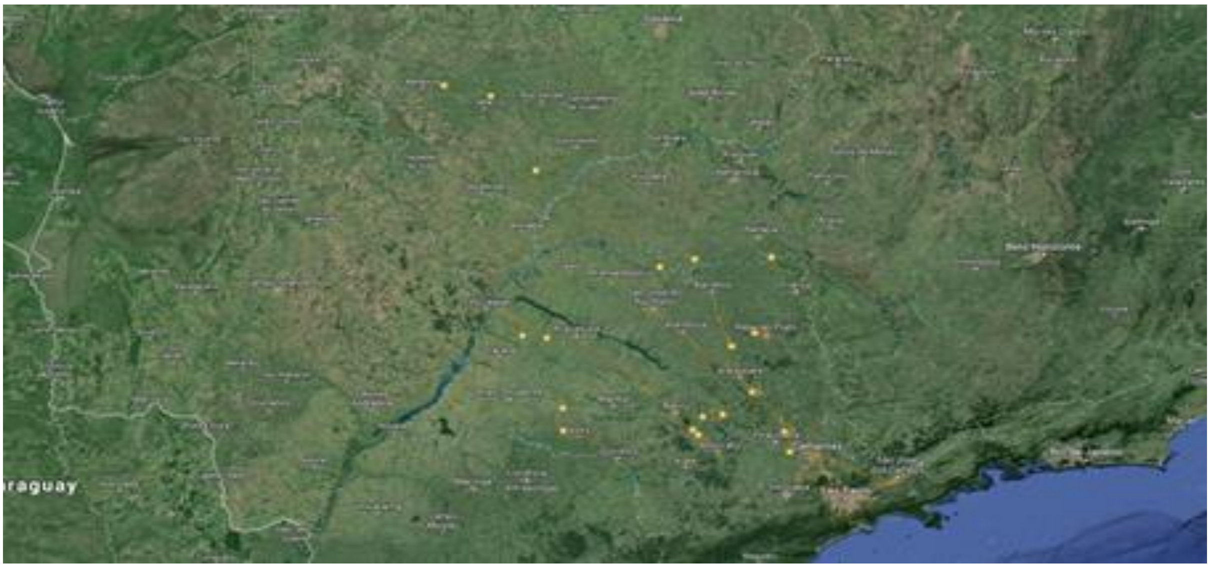

Figure 4.6. ***Location of the Bonsucro certified mills in Brazil (Google, 2015).***

When comparing the location of the certified suppliers with the work by Schueler, nine mills fall within the marked zones with higher technical yield, assuming that cane cultivation and production are located in close proximity to each other. These mills are owned by three companies: *Raízen Energía* (five mills), *Copersucar* (three mills), and *LDC SEV Bioenergia S/A* (*Biosev*)(one mill), and are all located in the state of São Paulo. This indicates that these mills have the highest technical biomass potential of the ones looked into, and that they live up the criteria stated in Article 17 (2) of the EU RED (see Appendix VII) (Schueler et al., 2013). These mills are therefore deemed most promising, as their location indicates that these suppliers have potential of expanding their operations and still comply with necessary regulation. This means that as the demand for their products increase they could possibly expand their production in the same sustainable manner that they are operating in presently.

4.7 Future Plans and Research and Development Efforts

To provide for further comparison, the future plans and research and development efforts of *Raízen Energía*, *Copersucar*, and *Biosev* were studied. A scanning of articles written about the companies, the companies' own statements as well as information from their partners at local and international research institutes gives an image of the companies' focus for the future.

Only one of the companies is presently producing SGE. *Raízen Energía* currently own a sugarcane mill in Piracicaba, SP, that is meant to produce SGE from sugarcane residue such as bagasse. Operations at the mill began at the end of 2014 and it will be capable of producing up to 40 million liters of SGE per year (Iogen, 2016). *Raízen Energía* were expected to export 10 million liters of SGE from the Costa Pinto plant in 2015. This ethanol is sold at a 26 % premium compared to FGE from *Raízen Energía* (Teixeira(1), 2015).

Copersucar are investing heavily in Centro de Tecnologia Canavieira (CTC), a research institute with the strategic goal to double the rate of innovation in the ethanol and sugar industry. One of the areas looked into, is the development of cellulosic ethanol technology. Other research efforts are put into genetically modifying sugarcane, a project *Copersucar* are highly invested in (Copersucar, 2014). The CTC are claiming that their results have a potential of doubling the yield by making the crop more resistant to external effects such as parasites. *Raízen Energía* are also a partner in this research effort (Teixeira(2), 2015). No information of SGE or GMO research being conducted by *Biosev* have been found.

4.7.1 Analysis on future plans and research efforts

The long-term goal for *Borealis* is, as stated in the *Introduction* chapter, to operate their dehydration plant with SGE produced in Sweden by SEKAB. The reason for them to look into other options is that their part of the chain can be completed prior to SEKAB being able to supply them with the feedstock needed. As it is unclear how long it will take for SEKAB it can also be of interest for *Borealis* to see whether they might be able to operate their dehydration plant not only by FGEs from Brazil but possibly also SGEs. For that reason, it is interesting to see whether the three companies that are certified and that have their operations located in promising areas are looking into branching out into SGEs.

The *Raízen Energía* plant producing SGE is one of the company's five mills that have been EU RED certified by Bonsucro (Bitenieks, 2013), and that is located in an area that shows high biomass potential as defined by Schueler et al. (2013). As these efforts are not matched by the other companies who have not published or expressed any efforts towards SGEs, *Raízen Energía* appears to be the most promising candidate from this angle. The company is exporting SGE to the EU at a price premium of 26 % (Teixeira(1), 2015).

Copersucar cannot match *Raízen Energía's* current SGE operations but they are conducting research in the area. No reports on the success of their efforts have been found, making it difficult to say anything about their future capabilities of selling cellulosic ethanol. What can be said however is that they appear to have come further than *Biosev*, as there are no reports of *Biosev* doing any research in the field of SGE. Furthermore *Copersucar*'s investments in GMO research could increase the yield and energy efficiency of their feedstock substantially. This could have large positive effects on LUC, however, GMOs are controversial as they can affect the biodiversity in the area. As there are currently no GMO sugarcane cultivated on commercial scale in Brazil, Bonsucro do not address this issue in their production standards (Personal communication: Bonsucro[13]). At the time this report is written, the use of GMOs are not brought up in the EU RED (European Commission (1), 2015). However, as the EU allows import of feed for farm animals that has been genetically modified (European Parliament, 2015), it is reasonable to assume that it would be possible to import GMO ethanol for polyethylene production.

[13] Sonia Slavinsky, *Standards Manager at Bonsucro* (29 Oct 2015)

5 Discussion

In this chapter, factors that have influenced the results of the project are discussed. These factors include assumptions made, method chosen, and lack of information, among others. This chapter shows that these factors are taken into consideration when the conclusions of the study are drawn as well in the recommendations given.

5.1 The Literary Review

The geographical areas studied were determined based on development of ethanol market and proximity to where Borealis are operating. This delimitation affected the literary review in general as it led to searching for literature that covered these areas. It also had some more particular effects on the supplier search as only producers in these areas were eligible. It should therefore be pointed that there are ethanol producers that are EU RED certified located in other areas, e.g. within the EU. It is however reasonable to assume that the European ethanol is sold at a higher price.

The decision to focus on Africa, Brazil and the US also led to only comparing corn and sugarcane as feedstocks for ethanol, as they are the most common feedstocks in these areas. As the US and Brazil accounts for over 80 % or the total ethanol production, and as these feedstocks are also common in other ethanol producing nations such as China and Thailand, they are the most interesting feedstocks to compare.

ILUC is not accounted for in the study. If it would have been considered, both by the authors and the certification schemes, the results would have turned out differently. However, as there is still so much complexity and uncertainty with regards to ILUC, it is very difficult to account for. The scientific literature is however in agreement over its substantial impact and there is research being done on the topic so perhaps this can be done in the near future.

5.2 The Framework

In the construction of the framework the most important source of information and choice of criteria were existing certifications. A lot of the information gathered regarding the criteria in the different certification schemes came from the article by Scarlat and Dallemand (2011). It is a well-cited article based on an investigation of the most prominent certification schemes at the time. It should however be kept in mind that it was written in 2011 and conditions might have changed since then, such as new issues being brought to attention or new technology to measure environmental impacts. To deal with this issue, the article was compared with facts gathered in the literary review, and it was concluded the article was still up to date and that most important issues were covered by the article. The only factors that were considered lacking from the article's matrix, based on things often considered by other literature, was ILUC. Since ILUC is excluded from the scope of the study, this did not affect the viability of the article as a basis for the framework.

All of the EU certified suppliers held the same certificate from Bonsucro, however they only need to fulfill 80 percent of part of the standard, which means that they might not have been performing equally well in all aspects. The initial plan was therefore to look at which criteria in the standard they did not fulfill and compare them to the criteria in the framework. When it became clear that Bonsucro would not disclose the information needed to do this comparison, an alternative way of comparing the certified suppliers was needed. Bonsucro did state however, that they were working on becoming more transparent. If this does happen, the framework could be further applied.

5.3 The Suppliers

As shown in the *Results* chapter, there are suppliers that are certified according to the EU RED in all of the studied areas. In Africa there is only one supplier that is certified, Addax Bioenergy. They are however not producing at a high enough capacity at the moment to satisfy the needs of *Borealis*. The lack of information about Africa in general with regards to ethanol production did affect the decision to exclude the producers operating there. There is a possibility that there are suppliers in the area that are performing well enough to be considered, but were not encountered. However, the lack of information regarding the producers is thought to reflect the current situation, i.e. that sustainability is not something that is focused on, as it is generally something that is emphasized if it is.

The certified suppliers in the US might have been viable options for *Borealis*, however as the company is looking to emphasize the sustainability of their suppliers, Brazil was deemed to be a better option. In the US, focus is mainly put on economic aspects rather than environmental, whereas in Brazil the sustainability of the ethanol producers operation is given a lot of attention and promotion. Furthermore the literature and the carbon balance clearly points to sugarcane being a more sustainable feedstock than corn for FGE production, which speaks in favor of Brazil.

Ethanol producers that were not certified according to the EU RED standard are not considered in this study. Their operations might be living up to the criteria in the standard even though they have not chosen to invest in a certification as their current customers do not require it. Such suppliers would be unable to export to the EU, thus the exclusion of them does not affect the recommendation of suppliers to *Borealis*.

The suppliers that are certified according to the EU RED are all assumed to be interested in exporting their ethanol to the EU as the certification would otherwise not be needed. However whether or not they would be able to supply *Borealis* needs to be further investigated. It is possible that the suppliers that are deemed most suitable already have contracts with other actors in the bioplastics industry, which would make them unwilling to supply another bioplastics producer.

5.4 The Carbon balance

The assumptions that were made for the approach have affected the results, however there was little difference in carbon content in the ethylene based on corn ethanol and the sugarcane-based version. The most significant difference between the two feedstocks is the yield. Therefore the effect of the assumptions on the analysis of the material after harvest have little impact of the whole lifecycle of the two crops.

For the purpose of this analysis, the emissions from the production process, such as the carbon dioxide released from the combustion of bagasse or corn stover, were taken into account. However, since this carbon was taken up by the crops from the atmosphere during the cultivation phase, these emissions are often not accounted for and the bioethanol produced is considered carbon-neutral. The reason for accounting for them here was partly to enable a comparison but also to create a “worst case scenario” of emissions. With this knowledge, Borealis can make a more informed decision regarding their dehydration plant and potential choice of suppliers.

The production process for SGE has not been deployed commercially to a large extent. This probably affected the amount of available information about the actual process of cellulosic ethanol production. Most of the reports that were found only considered the separate steps of the process in order to optimize them. Only a few studies describing the whole SGE production process in detail was found, although without any numbers or other significant indicators. However, it is reasonable to believe that this information is regarded as confidential information, since having the most efficient technology should be highly beneficial for an ethanol producer.

6 Conclusions

FGE can be a viable alternative from both a social and an environmental sustainability point of view. Already today, bio-polyethylene is produced from FGE and marketed as a more sustainable alternative to fossil based plastic materials, the demand for bio-based plastic materials is also estimated to increase within a foreseeable future. In the long run however, it might be desirable to switch to SGE sources, *Borealis* could commence their bioplastics activities with FGE, as this is a favorable alternative to oil-based plastic.

FGE is however not always produced sustainably, making it important to ensure that certain criteria are fulfilled by a potential supplier. The list of the criteria chosen as the most important is extensive and contains both environmental and social issues. It can be found in its entirety in Appendix II. To make sure that a supplier is operating sustainably, it is important that their claims are verified by a third party. Therefore it is important that they are certified, which also is necessary for the suppliers to be able to export to the EU.

The framework constructed for this project could not be used to its full potential due to the lack of transparency from *Bonsucro*. If they were to improve this, it is possible that a more thorough comparison could be conducted. It is furthermore possible that other certifying entities are more transparent, and if so, the framework could be applied further on suppliers from other areas.

The results of the study show that only one producer is EU RED certified in Africa, and although this producer seems to have a high sustainability focus, they do not currently produce at the capacity needed to supply *Borealis* with the quantity they need. Therefore suppliers in Africa are not deemed relevant for the purpose of this study.

Brazilian producers as a group pay more attention to issues of sustainability than the producers operating in the US. They are certified to a larger extent, and they put more focus on communicating their sustainability efforts to the public. The decision to focus on Brazil is furthermore supported by the fact that sugarcane is a more energy efficient crop than corn and therefore has lower GHG emissions. Sugarcane can also be seen as a more socially sustainable feedstock than corn, as the alternative product from sugarcane is sugar, which is not a staple food. Also, it is possible for the producers to easily switch between outputs, i.e. sugar and ethanol, making them less sensitive to ethanol price fluctuations.

The results of the framework application and the geographical biomass potential comparison point to three Brazilian suppliers of ethanol that are superior to their competitors. These are *Raízen Energía*, *Copersucar*, and *LDC SEV Bioenergia S/A (Biosev)*, all located in the state of São Paulo in south-central Brazil. Besides being EU RED certified by *Bonsucro*, these actors have their sugarcane cultivation located in geographical areas that have higher biomass potential than their other certified competitors. This means that they have the highest potential yield while still complying with the EU RED. *Raízen Energía* operates five mills in these areas, and *Copersucar* and *Biosev* operate three and one respectively.

Raízen Energía is the only company of the three that are currently operating a plant producing SGE from sugarcane residues. Although *Copersucar* are also investing in research regarding SGE, their lack of current operations indicate that they have not gotten as far in their efforts. *Biosev* do not appear to be conducting any efforts to branch out into SGE. With *Borealis* future plans in mind this makes *Raízen Energía* the most attractive choice of supplier.

7 Recommendations

We recommend *Borealis* to investigate the possibilities of purchasing Bonsucro EU certified ethanol from either *Raízen Energía, Copersucar,* or *LDC SEV Bioenergia S/A*. *Borealis* should also look into the possibilities to buy SGE from *Raízen Energía* or any of the other recommended producers if possible. However, the advantages with regards to sustainability of SGE should be more thoroughly examined.

Another alternative for *Borealis* is to turn to Bonsucro to find other suppliers than those recommended in this report. There is a possibility that there are other suppliers that are not yet, but on their way, to become *Bonsucro* EU certified. *Borealis* should advocate transparency from *Bonsucro* to be able to ensure that the most important sustainability criteria are met. This could facilitate further comparison of potential suppliers.

Borealis should investigate and weigh the costs and benefits of building the hydration plant before the remaining value chain for LGP is completed. *Borealis* could also look into the possibilities of producing products with long product lifetime for carbon sequestration. Therefore, an evaluation of which type of product is most suiTable for being based on bioethylene could be feasible.

A life cycle assessment should be conducted on the whole concept of LGP to ensure and be able to communicate any environmental advantages of the product. As has been mentioned in the report, ILUC, although assumed to have a significant impact, is not taken into account when looking at the environmental performance of ethanol. This has naturally affected the results of the report and should be looked into further.

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Appendix I - Members of the Certification Organizations

A. Members of the RoundTable on Sustainable Biomaterial

Member List for RoundTable on Sustainable Biomaterials	
1. Farmers and growers of biomass:	
ORGANISATION	**COUNTRY**
Argentine No-till Farmers' Association (Aapresid)	Argentina
Cosmo Biofuels Group (represented by Cosmo Biofuels Sdn Bhd)	Malaysia
The Earth Partners	USA
Global Clean Energy	USA
Great Plains	USA
GreenWood Tree Farm Fund, LP – Associate Member	USA
JOil	Singapore
National Corn Growers Association	USA
Nippon Biodiesel Fuel Co. Ltd.	Japan
Outreach International Bioenergy	Indonesia
PGF Biofuels Ltd. – Associate Member	Canada
SG Biofuels, Inc.	USA
United Soybean Board	USA
2. Industrial biofuel/biomaterial producers:	
ORGANISATION	COUNTRY
Addax Bioenergy Management SA	Switzerland
AltAir Fuels	USA
Amyris, Inc. – Associate Member	Brazil
Biofuel Weiss, Inc. – Associate Member	Canada
Brazilian Sugarcane Industry Association (UNICA)	Brazil
Bundesverband der deutschen Bioethanolwirtschat BDBe (German Bioethanol Industry Association)	Germany
CoolPlanet – Associate Member	USA
Dansuk Industrial Co., Ltd. – Associate Member	Korea
DuPont	Belgium
Ennovor Biofuels – Associate Member	UK
European Bioplastics	Belgium
European Waste-to-Advanced Biofuels Association (EWABA)	Belgium
Gevo	USA
Heliae, Inc.	USA
INEOS Bio SA	Switzerland
LanzaTech	USA
Malaysian Biodiesel Association	Malaysia
Maple Biocombustibles S.R.L. – Associate Member	Peru
Meridian Holdings Group, Inc.	USA
National Biodiesel Board	USA
Neste Oyj	Finland
Novozymes	Denmark
Partners for Euro-African Green Energy (PANGEA)	Belgium
Petrobras SA	Brazil

Shoalhaven Starches Pty Ltd (Manildra Group of Companies) – Associate Member	Australia
Solazyme	USA
Sunchem Holding Srl. – Associate Member	Italy
Tyton BioSciences, LLC d.b.a Tyton BioEnergy Systems	USA
3. Retailers/blenders, the transportation industry, the bio-product industry, banks/investors	
ORGANISATION	COUNTRY
Airbus	France
Boeing	USA
International Air Transport Association (IATA)	Switzerland
Inter-American Development Bank (IADB)	USA
International Petroleum Industry Environmental Conservation Association (IPIECA)	UK
MBP Group – Associate Member	Switzerland
ORKA NRG AG – Associate Member	Switzerland
Royal Dutch Shell (Shell International Petroleum Limited)	UK
SkyNRG	The Netherlands
South African Airways (SAA)	South Africa
Sustainable Aviation Fuel Users Group (SAFUG)	The Netherlands
Swiss International Air Lines	Switzerland
4. Rights-based NGOs (including land, water, human, and labour rights) & Trade Unions	
ORGANISATION	COUNTRY
Associated Labor Unions-Trade Union Congress of the Philippines (ALU-TUCP)	Philippines
Commission for the Verification of Codes of Conduct	Guatemala
National Union of Plantation and Agricultural Workers of Uganda (NUPAWU)	Uganda
Sucre Ethique	France
5. Rural development or food security organisations & Smallholder farmer organisations or indigenous peoples' organisations or community-based civil society organisations	
ORGANISATION	COUNTRY
Center for Empowerment and Development	Nepal
Institute of Sustainable Development (ISD)	Republic of South Africa
Civil Society Organisations Network for Sustainable Agriculture and Environment in East Africa (CISONET)	Uganda
Mali FolkeCenter	Mali
Moringa Group	South Africa
Philippine Network of Rural Development Institutes, Inc. (PhilNet-RDI)	Philippines
Rural Development Institute of Sultan Kudarat	Philippines
Sustainable Rural Growth and Development Initiative (SRGDI)	Malawi
Trowel Development Foundation	Philippines
6. Environment or conservation organisations & Climate change or policy organisations	
ORGANISATION	COUNTRY
Amigos da Terra – Amazônia Brasileira	Brazil
Applied Environmental Research Foundation (AERF)	India
The Center For Sustainable Energy Farming	USA
The Civil Society Biofuels Forum	Zambia
The Energy and Resources Institute India (TERI)	India
The Gold Standard Foundation	Switzerland
Innovation Center for Energy and Transportation	China
National Wildlife Federation	USA

Natural Resources Defense Council	USA
Public-Private Alliance Foundation	USA
Sustainable for Environment and Climate Change Association (SECCA)	Tanzania
Sierra Club	USA
The International Union for the Conservation of Nature (IUCN) – Associate Member	Global
The Union of Concerned Scientists	USA
United Nations Foundation – Associate Member	USA
Wetlands International	The Netherlands
WWF International	Switzerland
7. Intergovernmental organisations (IGOs), governments, research/academic institutions, standard-setters, specialist advisory agencies, certification agencies, and consultant experts	
ORGANISATION	COUNTRY
Aplethora Energy Services	USA
Commonwealth Scientific and Industrial Research Organisation (CSIRO)	Australia
Convention on Biological Diversity Secretariat	Global
Food and Agricultural Organisation of the United Nations (FAO) – Associate Member	Global
Green Aviation	Switzerland
Hawaii Biofuels Foundation	USA
Institute for Bioplastics and Biocomposites (IfBB)	Germany
International Food Policy Research Institute (IFPRI)	USA
International Maritime Organisation (IMO)	UK
Kenya Forestry Research Institute (KEFRI)	Kenya
Life Sciences Queensland, Ltd. (LSQ) – Associate Member	Australia
The National Non-Food Crops Centre (NNFCC)	UK
National Renewable Energy Laboratory (NREL)	USA
Office of Biofuels, NSW Trade and Investment	Australia
ProForest	UK
Schatz Energy Research Center of Humboldt University	USA
Stanford University – Sustainable Bioenergy Project, Woods Institute for the Environment	USA
Sustainable Forestry Initiative (SFI)	USA
Swiss Federal Office of Energy (SFOE)	Switzerland
Swiss Federal Office of Environment (FOEN)	Switzerland
United Nations Conference on Trade and Development (UNCTAD) – Associate Member	Global
United Nations Environment Programme (UNEP) – Associate Member	Global
University of California, Berkeley, Energy & Resources Group	USA
University of Illinois, Department of Natural Resources and Environmental Sciences	USA
U.S. Commercial Service Liaison to African Development Bank	USA/Tunisia

B. Members of the International Sustainability and Carbon Certification

Member List for International Sustainability and Carbon Certification (ISCC)	
Organization	**Country**
AAA Oils & Fats Pte. Ltd.	Singapore
Abengoa Bioenergy Trading Europe	Rotterdam, Netherlands
Adamant BioNRG S.r.l.	Milan, Italy
ADM International	Rolle, Switzerland
AGQM Arbeitsgemeinschaft Qualitätsmanagement Biodiesel e.V.	Berlin, Germany
Agroinvest S.A.	Ilioupoli, Greece
Alcogroup SA	Brussels, Belgium
Ambrian Energy GmbH	Hamburg, Germany
BASF SE	Ludwigshafen, Germany
Bayer CropScience AG	Monheim, Germany
BBE - Bundesverband BioEnergie e.V.	Bonn, Germany
Bioagra-Oil S.A.	Tychy, Poland
Bioils SpA	Santiago, Chile
BioMCN - Bio Methanol Chemie Nederland BV	Farmsum, Netherlands
Bio Oil Development sro & co ks	Spacince, Slovakia
BP Oil International Ltd	London, U.K.
Bunge Deutschland GmbH	Mannheim, Germany
Canola Council of Canada	Winnipeg, Canada
Carbon Recycling International	Reykjavik, Iceland
Cargill GmbH	Frankfurt, Germany
CBH Grain Ptd. Ltd	West Perth, Australia
Coehlo Barbosa, Daniel	Magdstadt, Germany
Danone GmbH	Haar, Germany
DEGART GLOBAL LLC	Urbandale, U.S.
Deutsche Welthungerhilfe e.V.	Bonn, Germany
Danube Soya	Vienna, Austria
EcoOils Limited	Singapore
E D & F Man Molasses B.V.	Amsterdam, Netherlands
Elopak AS	Oslo, Norway
ENMC - Entidade Nacional para o Mercado de Combustíveis E.P.E.	Lisbon, Portugal
Euronext	Paris, France
European Bioplastics e.V.	Berlin, Germany
European Waste-to-Advanced Biofuels Association (EWABA)	Brussels, Belgium
Evonik Resource Efficiency GmbH	Marl, Germany
Fabrioleo S.A.	Carreiro de Areia, Portugal
Fachhochschule Nordwestschweiz FHNW - Hochschule für Wirtschaft - Institut für Unternehmensführung	Brugg, Switzerland
von Fürstenberg, Ulrich	Paris, France
Glencore Grain BV	Rotterdam, Netherlands
GLOBALGAP c/o Foodplus GmbH	Cologne, Germany

Golden Agri Resources Ltd.	Singapore
Greenergy Fuels Ltd	London, U.K.
Grofor - Deutscher Verband des Großhandels mit Ölen, Fetten und Ölrohstoffen e.V. (German Association of Wholesale Traders in Oils, Fats and Oil Raw Material)	Hamburg, Germany
Iberol, S.A.	Lissabon, Portugal
IBP Italian Bio Products SPA	Tortona, Italy
Illinois Corn Growers Association	Bloomington, U.S.
Institut für Weltwirtschaft	Kiel, Germany
IOI Loders Croklaan B.V.	Wormerveer, Netherlands
Kraul & Wilkenning u. Stelling GmbH	Hannover, Germany
Lantmännen Agroetanol AB	Norrköping, Sweden
Lees, Robin	Lichfield, England
Lyondell Chemie Nederland B.V.	Weena, Netherlands
Management Criteria Srl	Genoa, Italy
Mannheim Biofuel GmbH	Mannheim, Germany
Mohamed Shahrir Mohamed Zahari	Terengganu, Malaysia
Morgan Stanley Capital Group Inc.	London, U.K.
Musim Mas Holdings Pte. Ltd	Singapore
Münzer Bioindustrie GmbH	Wien, Austria
NatureWorks LLC	Minnetonka, U.S.
NES Naturaleza S.A.S	Bogota, Colombia
Neste Oil Corporation	Espoo, Finland
NNFCC – The Bioeconomy Consultants	York, U.K.
OVID - Verband der ölsaatenverarbeitenden Industrie in Deutschland e.V.	Berlin, Germany
Pantaleon	Guatemala
Petrobras Global Trading B.V.	Rotterdam, Netherlands
PhytoEnergy Group	Herisau, Switzerland
PT. Inti Indosawit Subur	Jakarta, Indonesia
Rocchietta, Claudio	Milano, Italy
Roddy	Wichita, KS, U.S.
Rogoza	Victoria, Canada
SABIC Petrochemicals B.V.	Sittard, Netherlands
Schuldt	Berlin, Germany
Shell Trading	Rotterdam, Netherlands
Sime Darby Plantations Sdn Bhd	Selangor, Malaysia
Soares d'Albergaria, José	Lisbon, Portugal
Sucden Geneva S.A.	Geneva, Switzerland
University of Illinois at Chicago (UCI) - Energy Resources Center	Chicago, USA
UPM-Kymmene Corporation	Finland
Varo Energy Supply Trading B.V.	Rotterdam, Netherlands
Verband der Deutschen Biokraftstoffindustrie e.V.	Berlin, Germany
Verein der Getreidehändler der Hamburger Börse e.V.	Hamburg, Germany
Wilmar Trading Pte Ltd	Singapore
Wittmeyer, Dietrich	Langen, Germany
WWF	Berlin, Germany

B. Members of the International Sustainability and Carbon Certification

Member List for Bonsucro	
Organization	Country
Cevital Spa	Algeria
Australian Cane Farmers Association (Acfa)	Australia
New South Wales Sugar Milling Cooperative	Australia
Reef Catchments	Australia
R Quirk	Australia
Puglisi Farming	Australia
J. G Buchbach	Australia
Bundaberg Sugar Ltd	Australia
G & H Lerch Family Trust	Australia
P & F Deguara Family Trust	Australia
Australian Cane Growers Organisation Ltd	Australia
Wilmar Sugar Australia Ltd.	Australia
Coles	Australia
AGRANA Zucker GmbH	Austria
Ecover Coordination Centre	Belgium
Asociacion Gremial Union De Cañeros Guabira	Bolivia
Ingenio Azucarero Guabira S.A.	Bolivia
Union Agroindustrial De Cañeros UNAGRO S.A.	Bolivia
Adecoagro - Angelica Agroenergia Ltd	Brazil
Anicuns S.A. Alcool E Derivados (Grupo Farias)	Brazil
Bayer Crop Science Ag	Brazil
Braskem	Brazil
Usina Santa Adelia - Cooperativa De Produtores De Cana-De-Acucar, Áçúcar E Álcool Do Estado De Sao Paulo (Copersucar)	Brazil
Usina Sao Luiz - Cooperativa De Produtores De Cana-De-Acucar, Áçúcar E Álcool Do Estado De Sao Paulo (Copersucar)	Brazil
Usina Açucarera Sao Manoel - Cooperativa De Produtores De Cana-De-Acucar, Áçúcar E Álcooll Do Estado De Sao Paulo (Copersucar)	Brazil
ZILOR (Copersucar) - Açucareira Quatá S.A, Usina Barra Grande De Lençóis S.A., Usina Sao Jose - Açucareira Zillo Lorenzetti S.A	Brazil
Cooperativa De Produtores De Cana-De-Acucar, Acucar E Alcool Do Estado De Sao Paulo (Copersucar)	Brazil
Usina Santo Antonio ? Cooperativa de Produtores de Cana-de-açúcar e Álcool do Estado de São Paulo (Copersucar)	Brazil
Odebrecht Agroindustrial	Brazil
Group Bunge- Brazil	Brazil
Guarani S.A.	Brazil
Ldc Bioenergia S.A.	Brazil
Raizen	Brazil
Grupo Sao Martinho S. A.	Brazil
Usina Alta Mogiana S.A. - Áçúcar E Álcool	Brazil
Grupo USJ Açucar E Alcool S.A.	Brazil

GLENCANE BIOENERGIA S/A - Unidade Rio Vermelho.	Brazil
São Fernando Açúcar E Álcool Ltda	Brazil
Usina Alto Alegre S.A. Áçúcar E Álcool ? Unity Junqueira	Brazil
Socicana ? Association Of Sugarcane Growers Of Guariba	Brazil
Usina Trapiche	Brazil
Usina Serra Grande S/A	Brazil
Nardini Agroindustrial Ltd	Brazil
Usina Vertente Ltda	Brazil
Basf S.A. (Basf Agro Brazil)	Brazil
Fundacao Espaco Eco	Brazil
The Nature Conservancy	Brazil
Della Coletta Bioenergia S/A	Brazil
AAPA - Associação Ambientalista dos Pescadores do Alto São Francisco	Brazil
S/A Usina Coruripe Áçúcar E Álcool	Brazil
FMC Corporation (FMC Agricola Brasil)	Brazil
Vale do Tijuco Açúcar e Álcool S.A	Brazil
Solazyme Bunge Produtos Renovaveis Ltda	Brazil
Noble Brasil SA	Brazil
Cosan Biomassa S/A	Brazil
90+ Brazilian Farmers	Brazil
Signatures of Asia Ltd	Cambodia
Lantic Inc	Canada
Sucro Can, Inc.	Canada
Redpath Sugar, Ltd.	Canada
Asocaña	Colombia
Procaña	Colombia
Alguimar / Balsora	Colombia
Rg Y Cia S En C. S.	Colombia
Riopaila Castilla	Colombia
Ana Cristina Lince Cabal	Colombia
Inversanchez S.A.	Colombia
Guaduilla S.A.	Colombia
Jama & Cia SCA	Colombia
Ganaderia Tiacuante SAS	Colombia
Osaavedral & Cia SCS	Colombia
Chavarro Gaitan Hermanos	Colombia
Racines Victoria Hermanos Lta	Colombia
Josefina Barona Nieto	Colombia
Nordic Sugar - Nordzucker	Denmark
Consorcio Azucarero de Empresas Industriales (CAEI)	Dominican Republic
AGDYSA S.A. DE C.V.	El Salvador
Fedecañas	El Salvador
INGENIO EL ANGEL S.A. de C.V.	El Salvador
Sugar Research Institute Of Fiji	Fiji
Ethical Sugar	France
Fives Cail	France

Groupe Sucres et Denrees	France
Pernod Ricard	France
ECOM Agrotrade Limited (formerley Armajaro Trading Ltd)	United Kingdom
BP Biofuels Uk Ltd	United Kingdom
Ed & F Man	United Kingdom
Ragus Sugars Ltd	United Kingdom
Shell International Petroleum Company	United Kingdom
Unilever R & D Vlaardingen B.V.	United Kingdom
United Molasses Trading Ltd	United Kingdom
Trakeo	United Kingdom
Proforest	United Kingdom
Mars Incorporated	United Kingdom
HSBC Holdings PLC.	United Kingdom
Carbon Gold Ltd	United Kingdom
Czarnikow Group Ltd.	United Kingdom
Mag Alcoholes, S.A.	Guatemala
AZUNOSA- Azucarera Del Norte, S.A. De Cv	Honduras
Centro Nacional de Producción más Limpia de Honduras - CNP+LH	Honduras
Pt. Dharamapala Usaha Sukses	Indonesia
PT. SUGAR LABINTA	Indonesia
Eid Parry India Ltd	India
Rajshree Sugars and Chemicals LTD.	India
Olam Agro India LTD	India
M L Venkatakrishna	India
Oothu kadu	India
Vilangattar House	India
Viswanathan Govindasamy	India
Periyaveettu Valavu	India
Varappathi kadu	India
Modu kaani	India
shanmugha Sundaram Kacilingam	India
SAIFARM	India
RSCL	India
RSCI	India
Khedut India	India
RSCK	India
Shantilal Hari Patidar	India
Murgan S	india
Ramesh Marappan	India
BANNARI AMMAN SUGARS LIMITED	India
200+ Indian Farms	India
Sugat Sugar Refineries LTD	Israel
alimco SpA	Italy
Achard Italia SpA	Italy
Toyota Tsusho Corporation	Japan
Ferrero Trading Lux S.A.	Luxembourg

Concern Universal Malawi	Malawi
Save The Children Mexico	Mexico
Programas SustenTables Para Certificación Sociedad Civil (Psc)	Mexico
ADN Fresh SPR	Mexico
Ingenio Lazaro Cardenas	Mexico
La Isla Foundation	Nicaragua
Agricola Union	Nicaragua
Corbion	Netherlands
Rabobank	Netherlands
Solidaridad Foundation	Netherlands
Suiker Unie	Netherlands
Frieslandcampina Nederland Bv	Netherlands
eLEAF	Netherlands
Shakarganj Mills Ltd.	Pakistan
Ijaz Ahmad	Pakistan
The Thal Industries Corporation Limited (Layyah Sugar Mills)	Pakistan
Schulz Estates	South Africa
Donovale Farm's	South Africa
TSB Sugar RSA (Pty) Ltd	South Africa
Wilmar Sugar Pte Ltd	Singapore
Clarkson-Montesinos Institute	Spain
Kenana Sugar Company	Sudan
Bacardi - Martini Bv	Switzerland
Nestle Sa	Switzerland
Sabmiller	Switzerland
Alvean Sugar S.L.	Switzerland
Cloetta AB	Sweden
Tambunkulu Estate	Swaziland
Swaziland Sugar Association (SSA)	Swaziland
Swaziland Cane Growers Association	Swaziland
Thai Roong Ruang (TRR) Sugar Group	Thailand
Mitr Phol Group - Thailand	Thailand
Sugar Corporation Of Uganda Ltd. -Scoul	Uganda
Earth Innovation Institute	United States
CSC Sugar Llc	United States
International Finance Corporation (Ifc)	United States
Pepsi Co	United States
The Coca-Cola Company	United States
World Wide Fund for Nature	United States
Mondelez International	United States
General Mills Inc	United States
CHS. Inc	United States
Kellogg Company	United States
Solazyme	United States
TechnoServe	United States
Fair Trade USA	United States

Appendix II - Framework

Table 3. Framework for evaluation of potential suppliers of first generation ethanol.

Valid Certifications Attained
EU-RED Certified
ISCC Certified
RSB Certified
Bonsucro Certified
Environmental aspects of different certification initiatives
Environmental Impact Assessment
Good farming practice
Carbon conservation
Preservation of above/below ground carbon
Land use change
GHG emissions
Biodiversity conservation
Biodiversity
Natural Habitats, ecosystems
High conservation value areas
Native, Endangered and Invasive species
Soil conservation
Soil management, soil protection
Use of agrochemicals
Waste management
Sustainable water use
Water quality
Water management, conservation
Air quality
Air pollution
Pre-harvest burning
Socio-economic aspects in different certification schemes
Economic development
Economic performances
Social aspects
Human rights
Labour conditions
Working conditions
Health and safety
Freedom of association, bargaining
Discrimination
Wages

Working hours
Child labour
Forced labour

Appendix III - Carbon Balance Calculations

The carbon balance is performed on one kilogram of ethylene produced from sugarcane (FGE), corn (FGE), and SEKAB's cellulosic ethanol (SGE). The ethanol needed to produce one kg of ethylene is given by Borealis and is presented in Table 1 below.

Table 1. Conversion rates for the BP Hummingbird Technology and for the fossil alternative

End product	**Input in dehydration plant**	**Weight percentage of Ethylene out of Ethanol**	**Feedstock**
1 kg ethylene	1.66 kg Ethanol (2.1 L) *Dehydration - BP Hummingbird*	1 ÷ 1.66 = 0.60 → 60 %	Sugarcane / Corn grain / Forest residues

A. Carbon Balance of Ethylene from Sugarcane-based Ethanol

The material steps of the process in which sugarcane (SC) is converted to ethylene is shown in Figure A1 below.

Figure A1. Material steps in the ethanol production from sugarcane.

FAO (2013) states:

- 1 ha yields 85 ton of harvested SC.
- 1 ha of SC yields 5037 kg ethanol.

Cane juice contains the sugars sucrose, fructose and glucose. The two latter ones have the same chemical formula: $C_6H_{12}O_6$. Sucrose ($C_{12}H_{22}O_{11}$) is hydrolyzed to glucose:

Reaction for sucrose → glucose (sugar):

$C_{12}H_{22}O_{11} + H_2O \rightarrow 2C_6H_{12}O_6$ (Reaction A1)

All the sugar is then fermented to ethanol and CO_2:

Reaction for sugar → ethanol:

$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$ (Reaction A2)

The molar mass for one ethanol molecule (C_2H_5OH) is calculated from the information given in the periodic Table of the elements as follows:

$(2\times C + 5\times H + O + H) = (2\times 12.011 + 5\times 1.008 + 15.999 + 1.008)\ [g/mol] = 46.069\ [g/mol]$ (Equation A1)

Thereafter the amount of substance in 5037 kg (the ethanol yield from one hectare) of ethanol is calculated:

$(5037 \times 10^3)\ [g] \div 46.069\ [g/mol] = 109357.4\ [mol]$ (Equation A2)

The weight per molecule is then calculated using Avogadro's number:

Avogadro's number = (6.022×10^{23}) [molecules/mol]

46.069 [g/mol] $\div$ (6.022×10^{23}) [molecules/mol] $= 7.65 \times 10^{-23}$ [g/molecule] (Equation A3)

The weight of 2 molecules of ethanol then weighs:

7.65×10^{-23} [g/molecule] $\times$ 2 [molecule] $= 1.53 \times 10^{-22}$ g (Equation A4)

Knowing the weight of one molecular pair and the total weight of ethanol from one hectare, the number of molecular pairs can be calculated:

5037×10^{3} [g] $\div$ (1.53×10^{-22}) [g] $= 3.29 \times 10^{28}$ molecular pairs (Equation A5)

In *Reaction 1* above, it is shown that the relationship between the number of glucose molecules, ethanol molecules and carbon dioxide molecules is 1:2:2 respectively. Thereby it is shown that there will be as many carbon dioxide molecular pairs as there are ethanol molecular pairs, namely: 3.29×10^{28} molecular pairs. The weight of the carbon dioxide can therefore be calculated through the following:

Molar mass of one CO_2 molecule:

$C + 2 \times O$ [g/mol] $= 12.011 + 2 \times 15.999$ [g/mol] $= 44.009$ [g/mol] (Equation A6)

The weight per molecule is then calculated using Avogadro's number:

44.009 [g/mol] $\div$ (6.022×10^{23}) [molecules/mol] $= 7.308 \times 10^{-23}$ [g/molecule] (Equation A7)

The weight of 2 molecules of ethanol then weighs:

7.308×10^{-23} [g/molecule] $\times$ 2 [molecule] $= 1.46 \times 10^{-22}$ [g] (Equation A8)

Since the number of molecular pairs i known the total weight of the carbon dioxide is:

(1.46×10^{-22}) [g] $\times$ (3.29×10^{28}) [molecular pairs] $= 4810$ [kg] (Equation A9)

The weight of the glucose that can be extracted from one hectare of sugarcane is therefore:

5037 + 4810 [kg] = 9850 [kg] (Equation A10)

This is equal to a percentage of:

$9850 \div 85000$ [kg] $= 0.13 \rightarrow 13$ % (Equation A11)

13 % of the weight of sugarcane can be turned into glucose.

Percentage of ethanol in glucose:

$5037 \div 9850$ [kg] $= 0.51 \rightarrow 51$ % (Equation A12)

51 % of the weight of glucose can theoretically be turned into ethanol.

This results in the fermentation of glucose yielding 49 % carbon dioxide:

$4810 \div 9850\ [kg] = 0.49 \rightarrow 49\ \%$ (Equation A13)

49 % of the weight of glucose can theoretically be turned into CO_2.

This theoretical yield of 51 % is almost never achieved in practice. Instead about 90 % of the theoretical yield can be achieved, as 10 % is used as internal energy to maintain the yeast in the fermentation process.

Technical ethanol yield from glucose:

$0.51 \times 0.9 = 0.46\ [kg] \rightarrow 46\ \%$ (Equation A14)

46 % of the weight of glucose can technically be turned into ethanol.

The 1.66 kg of ethanol that Borealis needs to produce 1 kg of ethylene, will still represent 51 % of the glucose actually fermented and the relationship of ethanol to carbon dioxide from the fermentation is still the same 51:49.

Thereby, the carbon dioxide produced at the fermentation will represent 44 % of the total sugar needed, according to Equation A15:

$0.49 \times 0.9 = 0.44\ [kg] \rightarrow 44\ \%$ (Equation A15)

44 % of the weight of glucose can technically be turned into CO_2.

Silva & Chandel (2014) and Liptow & Tillman(2012) states:

Processing of sugarcane generates:

- 28 % bagasse
- 14 % straw
- 14 + 28 = 42 % fibers in total

According to figure A1 above, this indicates that the rest turned into cane juice:

$100\ \% - 42\ \% = 58\ \%$ *cane juice* (Equation A16)

58 % of sugarcane is turned into cane juice

Knowing from Equation 11 above that 13 % becomes sugar, the weight percentage of vinasse in sugarcane can be calculated:

$58\ \% - 13\ \% = 45\ \%$ *vinasse* (Equation A17)

45 % of sugarcane is turned into vinasse

Knowing these percentages, it is possible to calculate the actual mass of the different substances needed and generated from the process to make one kilogram of ethylene. Table A1 below shows the calculations of the mass of the different material and the mass results are shown in Figure A2 below.

Table A1 Weight Percentages in the Sugarcane to Ethylene Process

Materials	**Percentage of previous material mass**	**Calculation of mass needed**	**Mass needed [kg]**
Primary Materials			
Sugarcane	-	16.44/0.58	28.34
Cane Juice	58 %	3.62/0.22	16.44
Sugar	22 % of Cane Juice (13 % of Sugarcane)	1.66/0.46	3.62
Ethanol	46 % of Sugar	Given	1.66
Ethylene	60 % of Ethanol	Given	1.00
Secondary Materials			
Fibers (Bagasse & Straw)	42 % of Sugarcane	0.42 × 28.34	11.90
Vinasse (97 % water)	45 % of Sugarcane	0.45 × 28.34	12.82
CO_2	44 % of Sugar	0.44 × 3.62	1.59

Figure A2. Material steps in the ethanol production from sugarcane.

With knowledge of the mass balances for the ethanol process, the following step is to identify the routes and endpoints for the carbon.

Given by theory:

- Harvested sugarcane consists of 50 % carbon (dry mass) (Dias Paes and Marin, 2011)
- Harvested sugarcane consists of up to 24 % dry mass (FAO 1992)

With this information it is possible to calculate the carbon content in the sugarcane needed to produce one kilogram of ethylene:

$$28.34\ [kg] \times 0.24 \times 0.50 = 3.40\ [kg\ C] \qquad \text{(Equation A18)}$$

Given by theory:

- Vinasse contains up to 97 % (Polizeli and Rai, 2013; Christofoletti et al., 2013)
- Remaining part of vinasse contains 35 % carbon (Parnaudeau et al., 2008)

Carbon content in the vinasse:

0.35 × 0.03 × 12.82 [kg vinasse] = 0.13 [kg C] (Equation A19)

It is assumed that the soil is the endpoint for the small portion of carbon contained in vinasse, as the fluid is spread out on the fields.

Reaction A2 above shows that two thirds of the carbon in glucose is bound in the ethanol and the other third is turned into carbon dioxide.

The glucose mass is made up of 40 % carbon (Convertunits.com, 2016). Carbon in glucose needed to make 1 kg of ethylene is therefore:

0.4 × 3.62 [kg] = 1.45 [kg C] (Equation A20)

Knowing the amount of carbon in sugarcane, vinasse and glucose it is possible to calculate the amount of carbon in cane juice and thereafter in bagasse, see equation A21 and A22 below.

Carbon content in cane juice (sum of carbon content in glucose and vinasse):

1.45 + 0.13 [kg] = 1.58 [kg C] (Equation A21)

Carbon content in bagasse (difference of carbon content in sugarcane and cane juice):

3.40 - 1.58 [kg] = 1.82 [kg C] (Equation A22)

The carbon content in the ethanol is two thirds of the carbon content in glucose, as can be seen in Reaction A2 above. However since only 90 % of the sugar is fermented, only two thirds of 90 % of the glucose will end up in the ethanol, which is shown in equation A23 below.

(2/3) × 0.9 × 1.45 [kg C] = 0.87 [kg C] (Equation A23)

All of this carbon remains in the final product when ethanol is dehydrated to ethylene, i.e. the **carbon content in ethanol is equal to the carbon content in ethylene**.

The same reasoning is applied on the carbon content in the carbon dioxide produced in the fermentation process, i.e. one third of 90 percent of the carbon in the glucose ends up in the carbon dioxide (see equation A24 below).

(1/3) × 0.9 × 1.45 [kg C] = 0.43 [kg C] (Equation A24)

The carbon dioxide generated in the fermentation of glucose is assumed to be released into the atmosphere.

The amount of carbon contained in the glucose used for internal fermentation energy is shown in the equation below.

1.45 - 0.87 - 0.43 [kg C] = 0.15 [kg C] (Equation A25)

The final kilogram of ethylene contains 0.87 kg of carbon which is equivalent of 87 % of the total weight of the ethylene. However this represents a much a smaller portion of the total carbon contained in the sugarcane needed to produce the ethylene.

Percentage of carbon remaining in final product:

0.87 ÷ 3.40 [kg] = 0.25 → 25 % (Equation A26)

26 % of the carbon in SC remains in the ethylene.

The rest of the carbon from the sugarcane is contained in the fibrous material (bagasse and straw). For simplification reasons, this is all assumed to be incinerated for the purpose of energy production. The incineration of bagasse results in carbon emissions to the atmosphere.

Given from theory:

- 2.38 % of the incinerated bagasse will remain as ash (Eljack Suliman & Fudl Almola, 2011).
- This ash has a carbon content at about 80 % and is normally spread out on the land as slurry (Bahurudeen et al., 2015) → endpoint: soil
- The rest of the coal contained in the fibrous material is assumed to be released to the air when incinerated.

Carbon from incinerated fiber released to soil:

0.028 × 11.90 [kg C] × 0.8 = 0.27 [kg C] (Equation A27)

Carbon from incinerated fiber emitted to air:

1.82 [kg C] - 0.27 [kg C] = 1.38 [kg C] (Equation A28)

The path and endpoints of the carbon is shown in Figure A3 below, and the final percentages of carbon in each endpoint is shown in Table A2.

Figure A3. Paths and endpoints (red ovals) for the carbon in the ethylene production chain (own illustration).

Table A2. Share of the total carbon ending up in the three different endpoints.

Endpoint	Calculation	Share
Final product	0.87 ÷ 3.40 [kg] = 0.25	25 %
Air	(0.43 + 1.55) ÷ 3.40 [kg] = 0.58	58 %
Soil	(0.27 + 0.12) [kg] ÷ 3.40 = 0.12	12 %
Yeast maintenance	0.15 ÷ 2.78 [kg] = 0.05	5%

B. Carbon Balance of Ethylene from Corn-based Ethanol

Ethanol from sugarcane and corn have the same qualities and composition, as does the ethylene. The production of one kilogram of ethylene will therefore require 1.66 kg of ethanol, regardless of the feedstock.

Given by theory

- One hectare of corn yields 9969.5 kg of corn grain (FAO, 2013).
- The harvested corn plant is made of 50 % corn grain and 50 % stover (Roth, 2014).
- The grain consists to 73 % of starch dry weight) (FAO, 2015)
- The remaining material is assumed to be turned into animal feed (FAO, 2015; Muñoz et al., 2013; Ertl, 2012).

The material steps in the corn to ethanol process is shown in Figure B1 below.

Figure B1. Material steps in the ethanol production from corn.

The starch is converted into the sugar dextrose (Borglum, n.d.). In this process water is added to the starch (enzymes are also added in the conversion of starch to sugar, these do not add to mass however). This results in the sugar having an 11 % higher mass than the starch (Marine, 2009; Li, Biswas and Ehrhard, n.d.).

The reaction from starch to sugar is shown below in reaction B3.

Reaction for starch → dextrose (sugar):

Starch → Dextrose: $C_6H_{10}O_5 + H_2O \rightarrow C_6H_{12}O_6$ (Reaction B1)

Just as the glucose from sugarcane, the dextrose can be turned into ethanol with the same conversion factors as the sugarcane process above, i.e. 3.25 kilogram of dextrose is needed to make one kilogram of ethylene, which means that 3.62 kg of sugar is needed with a 90 % fermentation process efficiency.

Starch needed:

3.62 [kg dextrose] ÷ 1.11 = 3.26 [kg starch] (Equation B1)

Given by theory:

- Corn grain contain 73 % starch (dry weight)
- Corn grain has a 30 % moisture content

Corn grain needed (dry):

3.26 [kg starch] ÷ 0.73 = 4.47 [kg dry corn grain] (Equation B2)

Corn grain needed (wet):

4.47 [kg dry corn grain] ÷ 0.7 = 6.38 [kg corn grain] (Equation B3)

Knowing that the corn plant contains 50 % grain and 50 % stover, the weight of corn plant needed can be calculated:

6.38 [kg corn grain] ÷ 0.50 = 12.76 [kg corn plant] (Equation B4)

Knowing the weight of corn grain and starch the weight of the feed produced can be calculated:

6.38 - 3.26 = 3.12 [kg feed] (Equation B5)

Table B1 below summarizes the masses needed and the percentages. The chart in Figure B2 below shows the material steps in the process with the results from the calculations.

Table B1. Weight Percentages in the Corn to Ethylene Process

Materials	**Percentage of the previous material mass**	**Mass [kg]**
Primary Materials		
Corn plant	-	12.76
Corn grain (wet)	50 % of Corn plant	6.38
Corn grain (dry)	70 % of Corn grain (wet)	4.47
Starch	73 % of Corn Grain (dry)	3.26
Sugar	111 % of Starch	3.62
Ethanol	46 % of Sugar	1.66
Ethylene	60 % of Ethanol	1.00
Secondary Materials		
Corn stover	50 % of Corn plant	12.76
Feed	49 % of Corn grain	3.12
CO_2	44 % of Sugar	1.59

Figure B2. Material steps in the ethanol production from corn.

The next step is to identify the routes and endpoints for the carbon. The following reactions take place in the production:

Starch → Dextrose: $C_6H_{10}O_5 + H_2O \rightarrow C_6H_{12}O_6$ (Reaction B1)

Dextrose → Ethanol: $C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$ (Reaction A2)

The ethanol step and the sugar step in the carbon balance are equal to the corresponding steps in the sugarcane carbon balance. This means that the ethanol needed to produce 1 kg of ethylene contains 0.87 kg of carbon and that the sugar contains 1.45 kg of carbon (see equations

A20 and A23 above). It furthermore means that 0.43 kg of carbon dioxide is released into the atmosphere in the reaction from glucose to ethanol (shown in A24). As can be seen in Reaction B1, it is assumed that there is no loss of carbon in the step from starch to sugar, resulting in the same carbon content in the sugar and in the starch, i.e. 1.45 kg.

The remaining steps in the carbon balance for corn are thereby: grain; stover; distiller grain (feed); and corn plant.

Given by literature:

- The corn stover has a 70 % moisture content (Tumuluru et al., 2012)
- The corn stover is made up of 42.6 % carbon (dry weight) (Tumuluru et al., 2012).
- Carbon composes 43.6 % of the corn plant's dry weight (Latshaw and Miu, 1924).

This makes it possible to calculate the dry weight of stover:

$$0.3 \times 6.38 \text{ [kg stover]} = 1.91 \text{ [kg dry stover]} \qquad \text{(Equation B6)}$$

The carbon content of the stover:

$$0.426 \times 1.91 \text{ [kg dry stover]} = 0.82 \text{ [kg C]} \qquad \text{(Equation B7)}$$

Knowing the dry weight of grain as well as the dry weight of stover the carbon content of the corn plant can be calculated:

$$0.436 \times (4.47 + 1.91) \text{ [kg dry corn plant]} = 2.78 \text{ [kg C]} \qquad \text{(Equation B8)}$$

Assuming no loss of carbon when the corn grain is harvested and separated from the stover, it is possible to calculate the carbon content in the corn grain:

$$2.78 - 0.82 \text{ [kg C]} = 1.96 \text{ [kg C]} \qquad \text{(Equation B9)}$$

This result in turn enables the calculation of carbon content in the feed:

$$1.96 - 1.45 \text{ [kg C]} = 0.51 \text{ [kg C]} \qquad \text{(Equation B10)}$$

Like the bagasse the stover is assumed to be incinerated.

Given by theory and assumptions:

- Amount of ash produced at incineration of corn stover is 11.8 % (of the corn stover dry weight) (Morissette, Savoie and Villeneuve, 2013)
- No information on the carbon content in the ash has been found, so for this reason, the assumption that it is the same as the carbon content of bagasse ash, 80 %, is made.
- The rest of the carbon is assumed to be released into the air.

Carbon from incinerated stover released to soil:

$$0.118 \times 0.82 \text{ [kg C]} \times 0.8 = 0.08 \text{ [kg C]} \qquad \text{(Equation B11)}$$

Carbon from incinerated stover emitted to air:

0.82 [kg C] - 0.08 [kg C] = 0.74 [kg C] (Equation B12)

The carbon balance is shown in Figure B3 below and the final percentages of carbon in each endpoint is shown in Table B2.

Figure B3. Material steps in the ethanol production from corn.

Table B2. Share of the total carbon ending up in the different endpoints.

Endpoint	**Calculation**	**Share**
Final product	0.87 ÷ 2.78 [kg] = 0.35	31 %
Bi-product	0.51 ÷ 2.78 [kg] = 0.18	18 %
Air	(0.43 + 0.74) ÷ 2.78 [kg] = 0.42	43 %
Soil	0.08 ÷ 2.78 [kg] = 0.03	3 %
Yeast maintenance	0.15 ÷ 2.78 [kg] = 0.05	5 %

C. Calculations for Softwood Thinnings Based Ethanol

From Equation A12 above, it is given that the ethanol yield from fermenting glucose is 51 %. It has also previously been stated that the amount of sugar that is needed for yeast maintenance in the fermentation process amounts to 10 %, making the fermentation process efficiency 90 %. Thus, the amount of sugars needed to be fermented to acquire 1.66 kg of ethanol is 3.62. The conversion factors from sugars to ethanol are given by Jonker et al. (2014) and can be viewed in Table C1 below. As can be seen in Table C1 none of the sugars arabinose, galactose and mannose are converted into ethanol. The conversion factors from polysaccharides to monosaccharides are shown in Table C1 below.

Table C1. Conversion factors for the ethanol

	Glucan	**Xylan**	**Arbinan**	**Galactan**	**Mannan**
Polymers → Monomers	75 %	60 %	60 %	60 %	60 %
Monomers → Ethanol	80 %	75 %	0 %	0 %	0 %

Source: Jonker et al. (2014)

Assuming xylose can be fermented into ethanol with the same efficiency as glucose we get that

$G * 0.75 * 0.8 * 0.51 * 0.9 + X * 0.6 * 0.75 * 0.51 * 0.9 = 1.66\ kg\ ethanol$ (Equation C1)

Where G and X denote the amount of glucan and xylan respectively, that the initial amount of feedstock must contain. Table C2 shows the composition of acid-impregnated mixed softwood forest thinnings below,

Table C2. Composition of acid-impregnated mixed softwood forest thinnings (wt %)

Glucan	**Xylan**	**Galactan**	**Arabinan**	**Mannan**	**Lignin**	**Ash**	**Unidentified**
39.9	6.0	2.7	<0.1	10.4	34.9	0.3	5.7

Source: Nguyen et al. (2000)

From the composition the ratio between glucan and xylan can be calculated as

$\frac{39.9}{6} = \frac{6.65}{1}$ (Equation C2)

Then the initial amount of glucan required for producing 1.66 kg ethanol can be calculated using Equation C1 and C2 as follows

$$G * 0.75 * 0.8 * 0.51 * 0.9 + \frac{G}{6.65} * 0.6 * 0.75 * 0.51 * 0.9 = 1.66 \leftrightarrow (0.28 + 0.03)G = 1.66 \leftrightarrow$$

$\leftrightarrow G = \frac{1.66}{(0.28+0.03)} = 5.42\ kg\ glucan$ (Equation C3)

The amount of xylan in the required feedstock is also calculated using the ratio from Equation C2

$\frac{5.42}{6.65} = 0.85\ kg\ xylan$ (Equation C4)

The amount for forest thinnings, assuming no losses during the pre-treatment step, for the whole process is then calculated using the amount of glucan and the fraction given in Table C2 as

$\frac{5.42}{0.399} = 13.58\ kg\ acid\ impregnated\ mixed\ softwood\ forest\ thinnings$ (Equation C5)

The amount of carbon in wood is approximately 50 % (Chen, 2014), giving a total carbon input of

$13.58 * 0.5 = 6.79\ kg\ C$ (Equation C6)

In the enzymatic hydrolysis, the polysaccharides contained in the treated forest thinnings are converted by the conversion factors given in Table C1 above. Shares of the polysaccharides are not converted in this process and are thus assumed to be removed in connection to this step, the amount is calculated below

$(0.399 * (1 - 0.75) + (1 - 0.6)(0.06 + 0.027 + 0.001 + 0.104)) * 13.58 =$
$2.39\ kg\ Non\ converted\ polysaccharides$ (Equation C7)

The amount of carbon in sugars are 40 % (Convertunits.com, 2016) which gives the carbon content of the unconverted polysaccharides as

$2.39 * 0.4 = 0.9\ kg\ C$ (Equation C8)

The amount of lignin that is also removed before the fermentation amounts is calculated with the share of lignin given in Table C2 in Equation C9 below

$13.58 * 0.349 = 4.74\ kg\ lignin$ (Equation C9)

The amount of carbon in softwood lignin is given by Blunk and Jenkins (2000) to be 62.17 % and this the total amount of carbon in the lignin amounts to

$4.74 * 0.6217 = 2.95\ kg\ C$ (Equation C10)

The monosaccharides that continue to the fermentation step amount to

$13.58 - 2.39 - 4.74 = 6.44\ kg\ monosaccharides$ (Equation C11)

$6.79 - 0.96 - 2.95 = 2.88\ kg\ C$ (Equation C12)

In the fermentation step, the monosaccharides are converted by the conversion factors given by Table C1, the amount of monosaccharides is calculated as

$\left(0.399 * 0.75 * (1 - 0.8) + 0.6 * (0.06 * (1 - 0.75) + (1 - 0) * (0.027 + 0.001 + 0.104)\right) *$
$13.58 = 2\ kg\ Non\ converted\ monosaccharides$ (Equation C13)

Containing 40 % carbon gives

$2 * 0.4 = 0.8\ kg\ C$ (Equation C14)

As given in the previous calculations, the fermentation process also produces 1.59 kg carbon dioxide, 1.66 kg ethanol and 0.36 kg sugar is used in the process to maintain the yeast. The carbon content of these are 0.43 kg, 0.87 and 0.14 kg carbon respectively.

Adding the outgoing total mass and carbon from the fermentation step gives

$2 + 1.59 + 0.36 + 1.66 = 5.62\ kg$ (Equation C15)

$0.8 + 0.43 + 0.14 + 0.87 = 2.25\ kg\ C$ (Equation C16)

Of the monosaccharide input in the fermentation process, this corresponds to

$\frac{6.44-5.62}{13.58} = 0.06$ (Equation C17)

$\frac{2.88-2.25}{6.79} = 0.09$ (Equation C18)

So the error for this calculated process amounts to 6 % of the input for the total mass and 9 % for the mass of the carbon.

It should be noted that the ash and unidentified fractions have not been taken into account in these calculations.

$(0.003 + 0.057) * 13.58 = 0.81\ kg$ (Equation C19)

Neglecting these fractions have probably affected the outcome of the calculations. Furthermore, the process is highly idealized in this report and assumptions for simplifying the calculations have been made

The fraction of carbon from the initial amount of material that ends up in the final product is

$\frac{0.87}{6.7} = 13\ \%$ (Equation C20)

The lignin that is removed from the enzymatic hydrolysis as assumed to be combusted for energy generation. Blunk and Jenkins (2000) give the ash content of lignin as 0.62 % and the carbon dioxide content in the resulting ash as 3.37 %. Thus, knowing that 1 kg carbon dioxide contains 0.27 kg carbon, the carbon content of the ash can be calculated as follows

$4.74 * 0.0062 * 0.0337 * 0.27 = 0{,}00027\ kg$ (Equation C21)

Based on the process described by National Renewable Energy Laboratory, (2011), the assumption is made that the carbon that is not present in the ash is emitted in the air as carbon dioxide, this amount is approximately 2.95 kg from Equation 10 above.

The non-converted sugars are assumed to be anaerobically fermented into methane that is combusted for energy generation for the production process. Thus 0.96+0.88 = 1.84 kg carbon is emitted into air this route.

The total carbon emitted to air is thus;

$2.95 + 0.8 + 0.96 + 0.43 = 5.13$ (Equation C22)

This corresponds to 5.13/6.79 = 76 % of the carbon input in the process.

To calculate the area needed, the total dry mass yield for scots pine is given by Urban, Čermák and Ceulemans, (2014) as 15.4946 kg/m2. Thus, the area needed for cultivation of 1.66 kg ethanol is calculated

$$\frac{13.58}{15.4946} = 0.88\ m^2/kg\ ethylene$$

D. Comparison of results from the Carbon Balance

From the carbon balances above it is possible to compare the amount and carbon content of the different feedstocks needed to make one kilogram of ethylene. This comparison is shown in Table 5.4 below.

Table D1. Comparison of the results from the carbon balance

Feedstock	**Mass needed**	**Cultivation area needed** [0.12 m^2/kg SC] [1.00 m^2/kg Corn]	**Carbon content**	**Share of carbon remaining in final product**	**Share of carbon emitted to the air**

		[0.06 m^2/kg dry matter pine]			
Sugarcane (SC)	25.04 kg	25.04 × 0.12 = 3 m^2	3.0 kg	26 %	60 %
Corn	11.46 kg	11.46 × 1.00 = 11.46 m^2	2.5 kg	31 %	44 %
Forestry residues	13.58 kg	13.58 × 0.06 = 0.88 m^2	6.79	13 %	76 %

Appendix IV - Certified Ethanol Producers

Brazilian suppliers that have had their ethanol production certified by Bonsucro.

			BRAZIL			
Suppliers Group	**Unit/subsidiary**	**Feedstock**	**Certification Standard**	**Operates in**	**Products**	**Ethanol Capacity**
Raízen Energía S/A	Unidade Destivale	Sugarcane	Bonsucro EU Production Standard including section 7 ChoC	Araçatuba, SP	Ethanol & Sugar	2 billion liter
	Unidade Diamante	Sugarcane	Bonsucro EU Production Standard including section 7 ChoC	Jaú, SP	Sugarcane, Ethanol & Bagasse	
	Unidade Serra	Sugarcane	Bonsucro EU Production Standard including section 7 ChoC	Ibate, SP	Ethanol & Sugar	
	Unidade Junqueira	Sugarcane	Bonsucro EU Production Standard including section 7 ChoC	Igarapava, SP	Ethanol & Sugar	
	Unidade Dois Corregos	Sugarcane	Bonsucro EU Production Standard including section 7 ChoC	Dois Córregos, SP	Ethanol & Sugar	
	Unidade Univalem	Sugarcane	Bonsucro EU Production Standard including section 7 ChoC	Valparaiso, SP	Ethanol & Sugar	
	Unidade Gasa	Sugarcane	Bonsucro EU Production Standard including section 7 ChoC	Andradina, SP	Ethanol & Sugar	
	Unidade Bonfim	Sugarcane	Bonsucro EU Production Standard including section 7 ChoC	Guariba, SP	Ethanol & Sugar	
	Unidade Jatai	Sugarcane	Bonsucro EU Production Standard including section 7 ChoC	Jatai, GO	Ethanol & Sugar	
	Usina Bom Retiro	Sugarcane	Bonsucro EU Production Standard including section 7 ChoC	Capivari, SP	Ethanol & Sugar	
	Unidade Costa Pinto	Sugarcane	Bonsucro EU Production Standard including section 7 ChoC	Piracicaba, SP	Ethanol, 2G Ethanol & Sugar	
	Unidade	Sugarcane	Bonsucro EU Production	Araraquara,	Ethanol &	

	Araraquara		Standard	SP	Sugar	
	Usina Maracaí	Sugarcane	Bonsucro EU Production Standard including section 7 ChoC	Maracaí, SP	Ethanol & Sugar	
Odebrecht Agroindustrial	Usina Morro Vermelho	Sugarcane	Bonsucro EU Production Standard	Mineiros, GO	Ethanol	3 billion liter
	Usina Rio Claro	Sugarcane	Bonsucro EU Production Standard	Caçu, GO	Ethanol	
Alto Alegre	Unidade Junqueira	Sugarcane	Bonsucro Production Standard - Version 3.0 March 2011	Colorado, PR	Ethanol & Sugar	330 million liter
BP Biocombustíveis	Tropical BioEnergia SA	Sugarcane	Bonsucro Production Standard - Version 3.0 March 2011	Edeia, GO	Ethanol & Sugar	435-450 million liter
Bunge	Usina Frutal de Açúcar e Álcool Ltda.	Sugarcane	Bonsucro EU Production Standard	Frutal, MG	Ethanol & Sugar	-
	Usina Moema de Açúcar e Álcool Ltda.	Sugarcane	Bonsucro EU Production Standard	Orindiuva, SP	Ethanol & Sugar	
Copersucar	Usina Santa Adélia S.A.	Sugarcane	Bonsucro EU Production Standard	Jaboticabal, SP	Ethanol & Sugar	358 million liter
Copersucar (Zilor)	Asucareria Zillo Lorenzeti S.A.	Sugarcane	Bonsucro EU Production Standard	Macatuba, SP	Ethanol & Sugar	424 million liters
	Usina Barra Grande de Lençois S.A.	Sugarcane	Bonsucro EU Production Standard	Lençois Paulista, SP	Ethanol & Sugar	
	Usina Quatá	Sugarcane	Bonsucro EU Production Standard	Quatá, SP	Ethanol & Sugar	
Grupo São Martinho	Usina Iracema	Sugarcane	Bonsucro EU Production Standard	Iracemapolis, SP	Ethanol & Sugar	-
LDC SEV Bioenergia S/A	Unidade Sta Elisa	Sugarcane	Bonsucro EU Production Standard	Sertãozinho, SP	Ethanol & Sugar	1.8 MMT
Usina Alta Mogiana S.A - Açúcar e Álcool	Usina Alta Mogiana	Sugarcane	Bonsucro Production Standard - Version 3.0 March 2011	São Joaquim da Barra, SP	Ethanol & Sugar	-

First generation ethanol suppliers certified by ISCC who operates in the United States.

			USA			
Suppliers Group	**Unit/subsidiary**	**Feedstock**	**Certification Standard**	**Operates in**	**Products**	**Ethanol Capacity**
Plymouth Energy LLC		Corn	EU-ISCC-Cert-DE105-82193704	Merril, IA	Ethanol	-
Green Plains, LLC.	Green Plains, Fairmont, LLC.	Corn	EU-ISCC-Cert-US201-70600227	Fairmont, MN	Ethanol, Feed	4.5 billion liters
	Green Plains, Wood River, LLC.	Corn	EU-ISCC-Cert-US201-70600208	Wood River, NE	Ethanol	
Marquis Energy LLC		Corn	EU-ISCC-Cert-DE105-81656504	Hennepin, IL	Ethanol	-

Table 9. First generation ethanol suppliers certified by RSB who operates in Africa.

			Africa			
Suppliers Group	**Unit/subsidiary**	**Feedstock**	**Certification Standard**	**Operates in**	**Products**	**Ethanol Capacity**
Addax Bioenergy Sierra Leone Limited	Makeni	Sugarcane	RSB-STD-11-001-01-001 v2.1 & RSB-STD-11-001-20-001 v3.1	Sierra Leone	Ethanol	85 million liters

Appendix V - Bonsucro Production Standard Including Bonsucro EU Bonsucro Production Standard: Principles and Criteria

Members recognize that there are sound business reasons to identify and adopt sustainable sugarcane production and processing practices and these Principles and Criteria (P&C) provide provide a framework framework within which such practices practices can be demonstrated. demonstrated. The P&C address address sugarcane sugarcane production production in the field and processing processing issues in the mill, including including all sugarcane derived products, as they incorporate economic, financial, environmental and social dimensions and reflect good industry practices for the sugarcane sector.

We believe that adoption of these P&C's will generate business benefits and opportunities, as well as providing safe and secure employment and protection of the environment. To be effective the P&C's need to be delivered in the context of long term economic and financial viability for individual companies and the sector as a whole, and through timely and transparent disclosure of information on company environmental and social performance to stakeholders.

We further believe that the implementation of these P&C's across the sugarcane industry is an important undertaking given the significance and growth of sugarcane and all its derived products.

Specific tools will be developed in order to detail the procedures that producers will have to follow to proceed to a self-assessment of their performances against the production standard.

The standard is intended to constitute an audiTable document and not merely a reporting framework, according to ISO 65. All Indicator Notes have been amplified in the accompanying Bonsucro Standard Audit Guidance document.

Accordingly, Members undertake to:

- **Principle 1.** Obey the law.
- **Principle 2.** Respect human rights and labour standards.
- **Principle 3.** Manage input, production and processing efficiencies to enhance sustainability.
- **Principle 4.** Actively manage biodiversity and ecosystem services.
- **Principle 5.** Continuously improve key areas of the business .

In addition, the Production Standard contains Chain of Custody requirements in Section 7. These are a set of technical and administrative requirements for enabling the tracking of claims on this sustainable production of Bonsucro sugarcane and all sugarcane derived products in the cane supply area and in the milling operations including the transport of cane to the mill. The Chain of Custody requirements contained in this Production Standard are identical to the requirements of the Bonsucro Mass Balance Chain of Custody Standard.

In order to achieve compliance with Bonsucro Standard and therefore be entitled to Bonsucro certificates, 80 % of the indicators contained in principles 1 to 5 must be

satisfied and 80% of the criteria contained in the chain of custody chapter must be satisfied. In addition, there are a number of core criteria which must be fully satisfied before compliance will be considered.

The core criteria are:

- 1.1 To comply with relevant applicable laws.
- 2.1 To comply with ILO labour conventions governing child labour, forced labour, discrimination and freedom of association and the right to collective bargaining.
- 2.4 To provide employees and workers (including migrant, seasonal and other contract labour) with at least the national minimum wage.
- 4.1 To assess impacts of sugarcane enterprises on biodiversity and ecosystems services.
- 5.7 For greenfield expansion or new sugarcane projects, to ensure transparent, consultative and participatory processes that address cumulative and induced effects via an environmental and social impact assessment (ESIA).

Appendix VI - Introduction to 'Bonsucro EU'

For the production of ethanol intended to be put onto the European Union market, the following additional requirements and rules apply:

In order to obtain a 'Bonsucro EU certificate' from Bonsucro, compliance with the Bonsucro Production Standard must be met, that is to say 80% compliance with indicators contained in principles 1 to 5, as well as in Section 7, and full compliance with the core criteria set out in these principles and in Section 7. In addition, full compliance with the additional requirements listed under section 6 of the production standard is mandatory.

Section 6 covers the requirements for biofuels under the EU Renewable Energy Directive (RED) 2009/28/EC and the revised Fuel Quality Directive (FQD) 2009/30/EC. References in the Bonsucro documentation to EU requirements refer to the Renewable Energy Directive. Where the Fuel Quality Directive contains a corresponding provision, they apply equally to that Directive.

Pending recognition by the European Commission in the form of a Decision published in the Official Journal of the European Union, the Bonsucro EU scheme intends to cover:

- accurate data for the purposes of measuring greenhouse gas savings for the purpose of Article 17(2);
- mandatory land use sustainability criteria in the EU legislation within Article 17(3) to (5);
- other sustainability issues covered in the second subparagraph of Article 18(4), namely measures taken for the conservation of areas that provide basic ecosystem services in critical situations (such as watershed protection and erosion control), for soil, water and air protection, the restoration of degraded land, the avoidance of excessive water consumption in areas where water is scarce;
- issues listed in article 17(7)

Verification System

Attached to the Bonsucro Production Standard, the Certification Protocol covers the verification and audit requirements for Bonsucro EU certificates' claims. In particular, it specifies:

- the documentation management;
- how the yearly retrospective audit on a sample of claims is planned, conducted and reported upon;
- the procedure for the auditors selection, accreditation and training to ensure they are independent, external, have both the generic and specific skills to undertake the tasks required;
- the validity of a Bonsucro EU certificate, as defined in the Bonsucro Certification Protocol.

Within the Bonsucro Production Standard, the Chain of Custody chapter and its guidelines are designed to ensure that a warrant, compiling the sustainability characterics, remains assigned to a biofuel consignment. Bonsucro arranges for a Mass Balance check and balances of claims (described in the Mass Balance Chain of Custody Standard) made under the scheme, that ensures that among these characteristics are:

- a description of the raw material used (sugarcane)
- the proportion of production/processing residues (molasses) used in the production, if possible;
- the country of origin;
- evidence showing compliance with the required criteria;
- the sugarcane was obtained in a way that complies with the mandatory land use restrictions criteria;
- a GHG emissions figure derived from criterion 6.1.;
- a statement that the product was awarded a certificate of type 'Bonsucro EU' from Bonsucro.

Those Chain of Custody requirements that are applicable to the mill and its cane supply area are already included within the Production Standard (Section 7) and are identical to those of the Mass Balance Chain of Custody Standard.

Mills and their cane supply area wishing to become Bonsucro EU compliant must implement and demonstrate compliance to the Production Standard (including the Chain of Custody chapter - Section 7) and its additional EU RED requirements.

Appendix VII - Sustainability Criteria for Biofuels and Bioliquids According to EU RED Article 17

1. Irrespective of whether the raw materials were cultivated inside or outside the territory of the Community, energy from biofuels and bioliquids shall be taken into account for the purposes referred to in points (a), (b) and (c) only if they fulfil the sustainability criteria set out in paragraphs 2 to 6:

(a) measuring compliance with the requirement of this Directive concerning national targets;

(b) measuring compliance with renewable energy obligations;

(c) eligibility for financial support for the consumption of biofuels and bioliquids.

However, biofuels and bioliquids produced from waste and residues, other than agricultural, aquaculture, fisheries and forestry residues, need only fulfil the sustainability criteria set out in paragraph 2 in order to be taken into account for the purposes referred to in points (a), (b) and (c).

2. The greenhouse gas emission saving from the use of biofuels and bioliquids taken into account for the purposes referred to in points (a), (b) and (c) of paragraph 1 shall be at least 35 %.

With effect from 1 January 2017, the greenhouse gas emission saving from the use of biofuels and bioliquids taken into account for the purposes referred to in points (a), (b) and (c) of paragraph 1 shall be at least 50 %. From 1 January 2018 that greenhouse gas emission saving shall be at least 60 % for biofuels and bioliquids produced in installations in which production started on or after 1 January 2017.

The greenhouse gas emission saving from the use of biofuels and bioliquids shall be calculated in accordance with Article 19(1).

In the case of biofuels and bioliquids produced by installations that were in operation on 23 January 2008, the first subparagraph shall apply from 1 April 2013.

3. Biofuels and bioliquids taken into account for the purposes referred to in points (a), (b) and (c) of paragraph 1 shall not be made from raw material obtained from land with high biodiversity value, namely land that had one of the following statuses in or after January 2008, whether or not the land continues to have that status:

(a) primary forest and other wooded land, namely forest and other wooded land of native species, where there is no clearly visible indication of human activity and the ecological processes are not significantly disturbed;

(b) areas designated:

(i) by law or by the relevant competent authority for nature protection purposes; or

(ii) for the protection of rare, threatened or endangered ecosystems or species recognised by international agreements or included in lists drawn up by intergovernmental organisations or the International Union for the Conservation of Nature, subject to their recognition in accordance with the second subparagraph of Article 18(4);

unless evidence is provided that the production of that raw material did not interfere with those nature protection purposes;

(c) highly biodiverse grassland that is:

(i) natural, namely grassland that would remain grassland in the absence of human intervention and which maintains the natural species composition and ecological characteristics and processes; or

(ii) non-natural, namely grassland that would cease to be grassland in the absence of human intervention and which is species-rich and not degraded, unless evidence is provided that the harvesting of the raw material is necessary to preserve its grassland status.

The Commission shall establish the criteria and geographic ranges to determine which grassland shall be covered by point (c) of the first subparagraph. Those measures, designed to amend non-essential elements of this Directive, by supplementing it shall be adopted in accordance with the regulatory procedure with scrutiny referred to in Article 25(4).

4. Biofuels and bioliquids taken into account for the purposes referred to in points (a), (b) and (c) of paragraph 1 shall not be made from raw material obtained from land with high carbon stock, namely land that had one of the following statuses in January 2008 and no longer has that status:

(a) wetlands, namely land that is covered with or saturated by water permanently or for a significant part of the year;

(b) continuously forested areas, namely land spanning more than one hectare with trees higher than five metres and a canopy cover of more than 30 %, or trees able to reach those thresholds in situ;

(c) land spanning more than one hectare with trees higher than five metres and a canopy cover of between 10 % and 30 %, or trees able to reach those thresholds in situ, unless evidence is provided that the carbon stock of the area before and after conversion is such that, when the methodology laid down in part C of Annex V is applied, the conditions laid down in paragraph 2 of this Article would be fulfilled.

The provisions of this paragraph shall not apply if, at the time the raw material was obtained, the land had the same status as it had in January 2008.

5. Biofuels and bioliquids taken into account for the purposes referred to in points (a), (b) and (c) of paragraph 1 shall not be made from raw material obtained from land that was peatland in January 2008, unless evidence is provided that the cultivation and harvesting of that raw material does not involve drainage of previously undrained soil.

6. Agricultural raw materials cultivated in the Community and used for the production of biofuels and bioliquids taken into account for the purposes referred to in points (a), (b) and (c) of paragraph 1 shall be obtained in accordance with the requirements and standards under the provisions referred to under the heading ‘Environment’ in part A and in point 9 of Annex II to Council Regulation (EC) No 73/2009 of 19 January 2009 establishing common rules for direct support schemes for farmers under the common agricultural policy and establishing certain support schemes for farmers (22) and in accordance with the minimum requirements for good agricultural and environmental condition defined pursuant to Article 6(1) of that Regulation.

7. The Commission shall, every two years, report to the European Parliament and the Council, in respect of both third countries and Member States that are a significant source of biofuels or of raw material for biofuels consumed within the Community, on national measures taken to

respect the sustainability criteria set out in paragraphs 2 to 5 and for soil, water and air protection. The first report shall be submitted in 2012.

The Commission shall, every two years, report to the European Parliament and the Council on the impact on social sustainability in the Community and in third countries of increased demand for biofuel, on the impact of Community biofuel policy on the availability of foodstuffs at affordable prices, in particular for people living in developing countries, and wider development issues. Reports shall address the respect of land-use rights. They shall state, both for third countries and Member States that are a significant source of raw material for biofuel consumed within the Community, whether the country has ratified and implemented each of the following Conventions of the International Labour Organisation:

- Convention concerning Forced or Compulsory Labour (No 29),
- Convention concerning Freedom of Association and Protection of the Right to Organise (No 87),
- Convention concerning the Application of the Principles of the Right to Organise and to Bargain Collectively (No 98),
- Convention concerning Equal Remuneration of Men and Women Workers for Work of Equal Value (No 100),
- Convention concerning the Abolition of Forced Labour (No 105),
- Convention concerning Discrimination in Respect of Employment and Occupation (No 111),
- Convention concerning Minimum Age for Admission to Employment (No 138),
- Convention concerning the Prohibition and Immediate Action for the Elimination of the Worst Forms of Child Labour (No 182).

Those reports shall state, both for third countries and Member States that are a significant source of raw material for biofuel consumed within the Community, whether the country has ratified and implemented:

- the Cartagena Protocol on Biosafety,
- the Convention on International Trade in Endangered Species of Wild Fauna and Flora.

The first report shall be submitted in 2012. The Commission shall, if appropriate, propose corrective action, in particular if evidence shows that biofuel production has a significant impact on food prices.

8. For the purposes referred to in points (a), (b) and (c) of paragraph 1, Member States shall not refuse to take into account, on other sustainability grounds, biofuels and bioliquids obtained in compliance with this Article.

9. The Commission shall report on requirements for a sustainability scheme for energy uses of biomass, other than biofuels and bioliquids, by 31 December 2009. That report shall be accompanied, where appropriate, by proposals for a sustainability scheme for other energy uses of biomass, to the European Parliament and the Council. That report and any proposals contained therein shall be based on the best available scientific evidence, taking into account new developments in innovative processes. If the analysis done for that purpose demonstrates that it would be appropriate to introduce amendments, in relation to forest biomass, in the calculation methodology in Annex V or in the sustainability criteria relating to carbon stocks applied to biofuels and bioliquids, the Commission shall, where appropriate, make proposals to the European Parliament and Council at the same time in this regard.