Cost Assessment for Cornstalk Supply Chain for Bioprocessing Purposes

Prepared for:

Ontario Federation of Agriculture

Prepared by:

Lynn Marchand

UNIVERSITY of GUELPH
RIDGETOWN CAMPUS
CHANGING LIVES IMPROVING LIFE

September 2015

Acknowledgements

Thanks and appreciation is extended to the project committee including corn stover producers, industry members and Project Lead, Charlie Lalonde. Their insight and thoughtful questions have been invaluable. As well, the author acknowledges the efforts of Randy Duffy, formerly of University of Guelph, Ridgetown Campus.

It is also important to acknowledge the generous support of the Ontario Federation of Agriculture and La Coop fédérée.

Funding for this Agri-Science Cluster project, administered through BIC, was made available under the AgriInnovation Program of Agriculture and Agri-Food Canada http://www.agr.gc.ca.

Executive Summary

This cost assessment is a follow-up to a business case report prepared in 2013 on the feasibility of a cornstalk to bioprocessing facility to be built in Southwestern Ontario. This project continues to explore the potential and refine the earlier work by conducting research, identifying costs and gaining knowledge in other areas to better understand the issues involved.

Farm stover harvest trials conducted for this project have assisted by providing Ontario specific information regarding harvest techniques and costs resulting in lower producer costs. To acquire the large amount of cornstalks needed for a commercial scale venture it will be necessary to harvest stover in the fall and spring given the unpredictable fall weather in Ontario. Harvesting stover in the fall will provide insurance for bioprocessors that a large part of their inventory is already in storage. Harvesting corn stover in the spring should allow the stover to dry down and be lower in moisture.

Analyses of the nutrients removed in the stover and the sugar content in stover baled in 2014 show that Ontario stover values are consistent with the literature. Nutrient removal from the field is taken into account in determining producer costs as additional nutrients may have to be added for the following year's crop. The sugar content and profile affects the amount of revenue that could be generated by a cellulosic sugar plant.

In the financial analysis for the 2013 report it was assumed that a biomass producer co-op was fully operational. A 2 year ramp-up phase has been modelled in this project in which stover will be collected and stored, and plant operations will be tested. The plant is expected to be fully operational in the third year. Assuming a base price for sugar of $C400/tonne the price that can be paid for stover is $C68.73/tonne at 15.5% moisture. This takes into account the plant achieving a target 15% ROI over 10 years.

Sensitivity analysis showed that the price received for cellulosic sugar and co-products is very important in determining the price that can be paid for cornstalk feedstock. As well, the moisture content of the stover affects the price paid to producers because as the moisture content increases the plant must process more tonnes to achieve their targets. The technology to extract the sugars can work on materials with higher water content so it's not a limiting factor. This additional volume does not generate any income and will put pressure on the price paid for stover.

There are risks associated with the development of a commercial scale cellulosic sugar plant based on agricultural crop residues. They include the price of sugar, exchange rate, harvest length and weather conditions, and markets for cellulosic sugar and co-products.

There is a need for further work to be done, such as identifying additional revenue opportunities to mitigate the risk of prices in the model. In particular high value markets for C5 sugar and lignin co-products are needed. In the future there could be new biochemical products

and pathways, fermentation pathways, or co-generation opportunities that create greater value.

In terms of sustainability, corn producers want to ensure the long-term productivity of their land. That is, the partial removal of cornstalks should not reduce land productivity. Also, it has been documented that partial removal can have a positive impact on the yield of the following crop. A more precise method of determining sustainable stover removal rates at the field level would increase producer comfort that agronomic concerns are taken into consideration. New tools and protocols would help to encourage producer participation, and thereby also affect the size of the feedstock basket and the cost of stover.

Also, it needs to be clear when ownership of the stover bales would change. At what point does ownership of the stover change from the producer to the processor. This will affect who is responsible and bears the costs for insuring the bales against fire or other liabilities, protection from the weather and rodents, access to the bales, etc.

A variety of payment options for cornstalks exists and should be further explored. These options would take into account covered versus not covered bales, and time of delivery. For example, it could be argued that producers that store bales for longer periods of time should receive a higher price as an incentive for doing so. A quality grid to assess the acceptable ash and moisture levels will be needed.

Investigation into a cornstalks to bioprocessing venture continues in Southwestern Ontario. With over 500,000 tonnes of cornstalks available in Southwestern Ontario in an average year, there is increasing interest at the farm level to look at this new market outlet. With corn yields continuing to increase, residue levels are also growing. Providing a way for corn producers to move up the value chain and participate in the production of cellulosic sugar for use in green chemical production is attractive from a financial, land use efficiency and also an environmental standpoint with respect to reducing greenhouse gases by substituting green products in the economy.

Table of Contents

List of Tables

List of Figures

1.0 Introduction

There have been many advances in grain corn production over time as improved technology has resulted in increased yields, better standability of the crop in the field, and resistance to pests. Improvements in corn yields have also resulted in increasing amounts of corn stover (the leaves, stalks, husks and cobs) left in the field after the grain is harvested. In this report corn stover and cornstalks will be used interchangeably. While it is recognized that stover provides important functions such as limiting erosion from wind and water and contributing to soil organic matter and nutrient cycling, the increasing amounts of cornstalks remaining after harvest has become a concern for some high yielding corn producers. This is because cornstalks can take a long time (several years) to decompose, and high volumes of stover slow soil warming in the spring, and may reduce seed to soil contact and result in uneven germination. In Ontario some farmers remove cornstalks for use in livestock bedding, particularly when wheat straw is in short supply. However, there is the potential for producers to remove some of the excess stover if there were a market for bioenergy or other bioproducts.

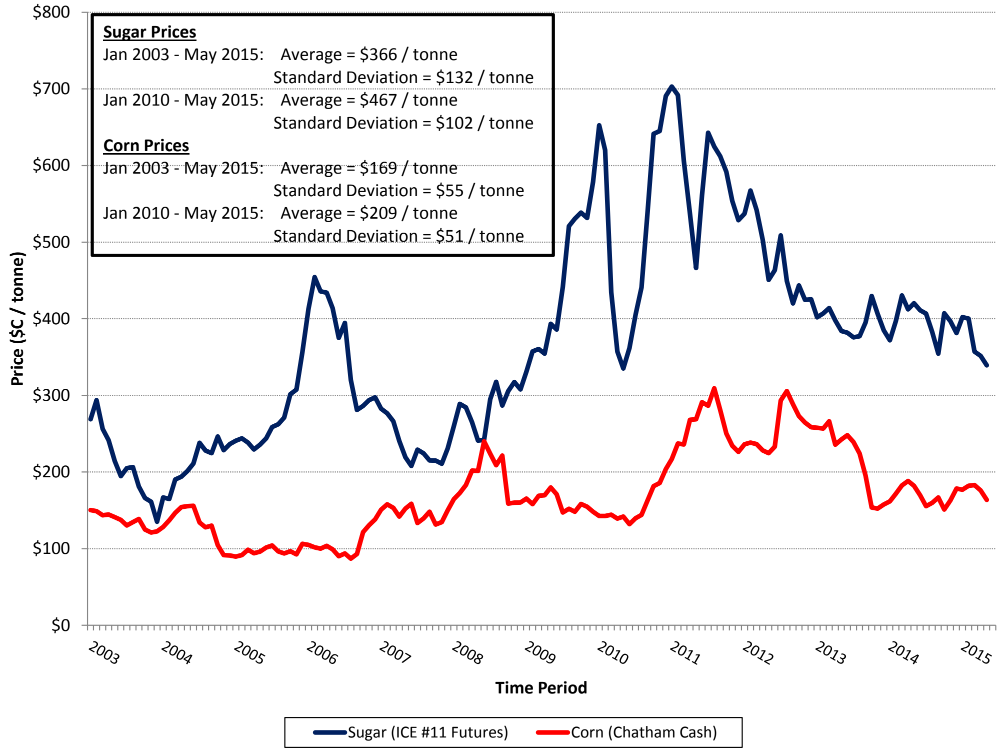
In the US there are three commercial scale cellulosic ethanol plants that use cornstalks. Facilities such as these require significant amounts of cornstalks or other types of biomass. For example the POET-DSM plant in Emmetsburg, Iowa requires 285,000 Tons of cornstalks at 0% moisture to produce 20 million gallons of cellulosic ethanol annually (POET-DSM). In order to access this amount of stover economically and efficiently these facilities tend to locate in regions where large amounts of grain corn are grown and crop yields are high. Iowa is an example where two cellulosic ethanol plants are now operating. Iowa grows about 2.2 billion bushels of corn per year and grain yields were in the range of 137 to 178 bushels/acre in the last five years with an average of 163 during that time. In comparison, Ontario produces about 300 million bushels yearly, and yields ranged from 152 to 164 in the last five years and averaged 158 bushels/acre.

1.1 Background

A study was undertaken in 2013 to develop a business case for cornstalks to biochemical processing (Duffy and Marchand, 2013). The primary objectives were to examine possible pricing options and business models based on a venture converting 250,000 dry tonnes of cornstalks into cellulosic sugar annually.

In recent years there has been interest from both sugar users and corn producers in exploring the potential for such a facility due to the variability in sugar and corn prices over time. This is shown in Figure 1. Both corn producers and sugar producers (or users) can face large fluctuations in prices due to supply and demand conditions and market speculation and they are looking for ways to stabilize prices. Converting cornstalks to cellulosic sugar is considered to be a possibility, particularly in Southwestern Ontario and Southern Quebec, because there is a plentiful supply of stover from high yielding farms. Also, prices of sugar and corn do not always move in the same direction and magnitude at the same time. Corn producers could potentially benefit by having this additional market and stover would provide a band on input costs for sugar producers if the stover can be obtained at a more stable price.

Figure 1. Monthly Sugar and Corn Prices ($C/tonne)



Source: USDA; ICE; Bank of Canada; Farm Market News, University of Guelph, Ridgetown Campus.

A project such as this is timely as an environmentally conscious public is pushing for changes to many agricultural practices such as land use efficiency and greener products and cleaner industries. With first generation ethanol the food versus fuel debate emerged when the public questioned the use of food crops (such as grain corn and wheat) to make ethanol. New technologies that can use the straw or stem of the plant are preferred as they don't impact the supply of grain for food markets and do not require additional land. Agricultural crop residues as well as high yielding, purpose grown biomass such as switchgrass and miscanthus can provide renewable alternatives in replacing petroleum based chemicals with less GHG-intensive bio-based chemicals.

1.2 Recap of the 2013 Report

The "Development of a Business Case for a Cornstalks to Bioprocessing Venture" report prepared in 2013 contained several highlights. Some are provided below.

- Target region – The target region in the study was the 4 county area of Chatham-Kent, Lambton, Middlesex and Huron. This was due to the region having a large proportion of Ontario's corn production and the proximity to Sarnia which could be a potential plant location due to existing infrastructure. There are approximately 500,000 dry tonnes of cornstalks available annually in this region.

- Stover pricing options - Four methods were reviewed as possible ways to price stover in Ontario based on work done in the US and adjusted for Ontario conditions. Iowa was used as a benchmark because of their experience with baling, handling and pricing stover. The options included the following: pricing based on harvest, nutrient removal and storage costs; pricing based on feed replacement value; pricing based on wheat straw value; and pricing based on further processed bioproducts value.
- Business models – Four potential business models – direct sale, request to purchase, supply co-op, and bioprocessing co-op – were assessed.
  - Direct sale – This option would require a processor to have dedicated staff to contract with many individual producers in order to secure a sufficient supply over a long period of time.
  - Request to purchase – For this option aggregators would source the cornstalks, harvest and deliver the product. However, it is difficult to estimate what price the end-user would be required to pay and farmers may be hesitant to commit to selling their stover since they would have little control over the process.
  - Supply co-op – This co-op would consist of producer members and would act as the aggregator and then sell the stover. Farmers would likely be more receptive to this option as they would move a little further up the value chain. The primary risk is that this model would generate a low return on investment for the sugar company. This would make it difficult to attract investment partners.
  - Bioprocessing co-op – This structure was identified as the preferred option as a way to involve all members of the value chain and reduce risk. Corn producers would have a market to sell stover and could potentially benefit from co-op dividends. The price received for the stover would depend on sugar prices and sugar yields. A bioprocessor would have access to a secure supply of material at a less variable price.

The 2013 Report also identified areas where further work was needed. These included selecting a technology to convert cornstalks or other biomass into cellulosic sugars, developing a harvest calendar for a reliable feedstock supply, improving supply system efficiencies, constructing a demonstration size plant, and educating producers and the public about the opportunity.

The focus of this report is to update work that was completed in 2013 (referred to hereafter as the 2013 Report) and to advance the understanding of factors that impact this type of venture. Research is ongoing with respect to harvesting cornstalks under Ontario conditions. This research has provided more accurate information regarding the costs associated with harvesting cornstalks in Ontario. This new information has been incorporated into the bioprocessing cost model that was developed in the 2013 project.

2.0 Making the Case for Cornstalk Removal

As grain corn yields have increased so has the amount of stover left after the grain is harvested. Corn producers in Ontario have expressed an interest in removing some of this excess stover, i.e. partial stover removal that could be sold to a non-food market. This section will briefly review the pros and cons of doing this and provide updated Ontario corn information relevant to the study.

2.1 Sustainable Cornstalk Removal Rates

There are advantages and disadvantages of cornstalk removal. Advantages of removing cornstalks include reduced tillage to manage excess stover, better seed to soil contact and therefore improved germination, faster warming of the soil in spring, possibility of reduced disease in corn on corn crop rotations (Ertl), and an additional income source for farms. Potential disadvantages include soil erosion if too much is removed, removal of nutrients, loss of organic matter, compaction if stover is removed from wet fields, and practical constraints, for example, when the timing of stover harvest occurs when producers are busy with grain harvest.

As stated in the 2013 Report, in order for producers to consider harvesting cornstalks from their fields it is important that they do so in a way that is environmentally sustainable over the long term. As yields have increased over time there is more stover left in the field after harvest making it possible to remove a portion of the stover on high yielding fields. However the main question is what amount of stover needs to be left in the field to not deplete soil carbon over the long term. Lal (2014) states that soil organic carbon concentration above 2% is needed for productive soils. The literature indicates that there is no one single value, and that removing cornstalks in a sustainable manner is site specific taking into consideration slope of the land, crop rotation, the tillage used, whether cover crops are used, manure applied and so on (Kludze et al., 2010; US DOE, 2011).

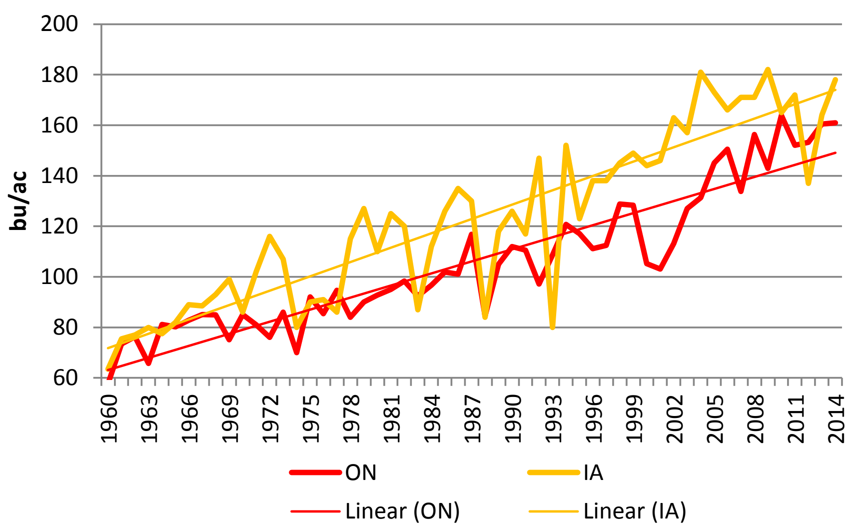
Suggested stover removal rates in the US typically fall within the range of 25% to 38% per year (POET-DSM; Thompson and Tyner, 2011; Perlack and Turhollow, 2012;) although most sources indicate that removal rates could vary by site depending on the factors stated previously. Also, removal rates can vary with the grain yield. As it is generally assumed that the production of corn stover and grain corn are related in a 1:1 ratio (US DOE, 2011; Glenn Farris, AGCO, personal communication January 7, 2015), more stover per acre could potentially be removed in higher yielding fields. Karlen et al. (undated) recommends average grain yields of at least 175 bu/ac and field slope less than 3% while Wortmann et al. (2012) suggest that stover should not be removed from fields with yields less than 150 bushels/acre. In the US it is common for 50% stover removal on fields that yield 180 to 200 bushels/acre of corn (Glenn Farris, AGCO).

In this project, the minimum yield of 150 bushels per acre of grain corn, was assumed to be the starting point for consideration of stover harvest. That is, areas producing less than this amount were not considered to be eligible for stover removal.

2.2 Cornstalk Availability in Ontario

Given that large volumes of cornstalks (greater than 100,000 dry tonnes) would be required each year, it is important to look at grain corn yields over time. In Ontario average corn yields have increased from 117.1 bushels/acre in 1995 to 160.9 bushels/acre in 2014 – a 37% increase over 20 years or about 2%/year (OMAFRA). Figure 2 shows average annual corn yields for Ontario and Iowa. While there is variability in grain corn yields throughout the time series, it is clear that there is an upward trend in average yields and therefore stover yields over time. Iowa is used for comparison and benchmark purposes because it is the largest corn producing state and cornstalks are being harvested there on a large scale. The corn yield in Iowa increased from 123 to 178 bushels/acre, 45% over 20 years (USDA, NASS).

Figure 2. Ontario and Iowa Average Annual Corn Yields (bu/acre)



Source: Statistics Canada; USDA, NASS

In the 2013 Report it was determined that about 500,000 dry tonnes of cornstalks could be harvested in an average year within the four-county study area. This assumed a removal rate of 0.94 to 1.05 dry tonnes/acre.

Weather at time of planting as well as weather during the cropping season plays a critical role in corn yield at harvest. Table 1 provides updated information on the corn acreage for the four county region in 10 bushel yield increments starting at 150 bushels/acre. The data show that the distribution of corn acreage by yield category varied significantly over the eight year period from 2007 to 2014. The 2014 crop year was characterized by late planting and a cool growing season, and fewer acres in the "greater than 180 bushels per acre" yield category. Nevertheless, there were over 420,000 acres with corn yields greater than 150 bushels/acre.

Table 1. Corn Acres by Average Yield Category for Four County Region

	2007	2008	2009	2010	2011	2012	2013	2014
Total 4-county corn acres*	689,800	489,000	545,100	547,000	542,230	688,717	559,749	NA
150-159 bu/ac	67,245	33,623	76,975	50,295	42,453	37,104	45,273	55,956
160-169	54,229	52,731	69,602	61,660	79,082	66,210	69,226	76,751
170-179	29,542	50,497	61,889	88,071	90,721	66,473	80,012	91,382
>=180	40,114	248,197	123,329	204,139	221,073	308,880	277,207	197,272
% of acres >=150	28%	79%	61%	74%	80%	70%	84%	NA

Source: Agricorp. Data represents the acres that premiums are paid on. *OMAFRA, Statistics Canada: Field Crop Reporting Series. NA = data not available

Table 2 shows the average corn yield for Ontario and Iowa in 10 year increments. Although corn yields in Iowa are higher than in Ontario, the yield gap of the last 5 years is much smaller than in the previous decade. This is due to the drought that occurred in 2012 in Iowa and resulted in an average Iowa yield of 137 bushels/acre that year.

Table 2. 10 Year Average Corn Yield, Ontario vs Iowa (bu/ac)

Period	ON	IA	Difference IA vs ON
1960's	76.2	82.5	6.3
1970's	84.4	100.0	15.6
1980's	98.4	114.7	16.3
1990's	114.7	131.5	16.8
2000's	130.8	165.4	34.6
2010-2014	158.1	163.2	5.1

Source: Statistics Canada; USDA, NASS

In Iowa the availability of plentiful amounts of cornstalks has been key to the development of two cellulosic ethanol plants. Having access to large amounts of stover within a short distance enables the plants to achieve efficiencies and reduce costs – for example DuPont aims to source all the stover within a 30 mile radius (48 km).

In summary, large scale removal of cornstalks from high yielding fields could be possible in the four county study region in Southwestern Ontario provided certain agronomic criteria are met.

3.0 Updating the 2013 Report

Much has been learned since the 2013 Report was completed. This section will discuss several factors relating to stover harvest in Ontario.

3.1 New Information Since 2013

A small committee comprised of producers, equipment manufacturers and other industry stakeholders has been instrumental in moving this project forward by providing data, asking insightful questions and providing guidance.

Areas where information has been updated or new information has been added include the following:

- stover quality assessment levels;
- target harvest costs for stover removal in the US;
- harvest methods used on two Ontario farms, bale weights and moisture and nutrient analyses;
- revised harvest costs based on a model of producers and custom operators performing the activities and a combination of fall and spring baling;
- updated bioprocessing model with new information;
- investigating the value of different sugars derived from cornstalks and the resulting price that could be paid for the stover based on that value.

It was noted in the 2013 Report that the cost of acquiring cornstalks represented nearly three-quarters of the total operating costs for the bioprocessing co-op model. Therefore, determining whether cornstalks can be obtained in an economical way is an important question that needs to be answered. That is, there is a need to further investigate stover harvest activities that would work under Ontario conditions and the costs associated with them to establish a workable price point.

3.2 Stover Quality: Moisture and Ash Content

There are several factors to take into consideration when baling and storing cornstalks. Some of these relate to bale size or shape requirements but feedstock quality is also important. The stover moisture and ash content will affect the total volume of stover required by the plant to meet operational targets, and the need for pre-processing.

Stover moisture varies by field, within fields and within bales (Cecava, 2010). This can make obtaining an accurate “average” moisture reading difficult. When sampling individual bales, ideally samples should be taken from different parts of the bale. A common protocol needs to be established to determine the moisture of baled stover.

Higher moisture in bales - when stored over time or when the material is subject to rain or snow - could promote microbial activity and degradation of sugars in the stover (INL, 2013).

This is referred to as shrinkage or dry matter loss. Analysis of Ontario stover completed for the 2013 Report, showed the hemicellulose, cellulose and lignin composition stayed close to literature values throughout the one year storage period.

The literature reports that when corn stover is 18% moisture or less at the time of baling there is very little microbial activity (Shah and Darr, 2014). The amount of dry matter loss in stover baled at less than 25% moisture is about 5% when bales are stored under a tarp but losses increase to 9% when moisture is more than 25% (Shah and Darr). Shinners et al. as reported by Morey et al. (2010) indicated that storing bales uncovered for 8 months resulted in 10% loss.

Also, high moisture content can impact the integrity of the bale. Over time depending on how much shrink occurs it can be difficult to transport the bales (Peter Thoma, an Ontario dairy farmer with experience harvesting cornstalks). Tight, uniform bales at time of baling are needed so that bales can be stacked and stored for long periods of time. If not, stacks may fall resulting in potential safety hazards for people working around the stacks and it makes logistics of loading bales more difficult and time consuming.

Moisture content of the stover is difficult to control given the role weather plays prior to and during stover harvest. The method of storage influences moisture content as well. Storing in a permanent structure such as a barn or shed is the best option but not economical. Storing stover under a tarp, outside, is the next best option to provide protection from the weather in an economical way (Shah and Darr).

Propionic acid is used as dry hay preservative to prevent mould when baling high moisture content hay. It is sprayed onto the hay before it enters the baler, acting as a fungicide, inhibiting the growth of aerobic micro-organisms that can cause heating and moulding. This allows farmers to bale hay that is higher in moisture than desired for safe storage and a quality product. For hay in Ontario, if the moisture content in large square bales is above 14% then adding a preservative would be considered. It is also possible to use propionic acid on straw. Straw above 12% moisture does not store well without using a preservative (personal communication June 15, 2015 with Terry Nuhn, Nuhn Forage Inc.). Straw that is too damp or has soil contamination is difficult to treat with propionic acid and can be very costly. In the spring, some corn producers applied propionic acid when they were baling cornstalks, but very little research has been done to date on its effectiveness for cornstalks. The cost of applying this type of preservative is $6 to $10/tonne (Terry Nuhn).

High levels of inorganics in the stover, measured as ash, can negatively affect the bioprocessing process and result in decreased efficiencies and added costs (INL). Ash is derived from the soil, stones and other foreign material picked up during stover harvest. Although single pass harvest systems result in lower levels of ash (Schon and Darr; Kenney et al.) it is more likely that a double pass system would work better under wetter Ontario conditions. This type of system could increase the level of inorganics, and require more attention be placed on the monitoring of ash content.

Table 3 presents moisture and ash specifications from three US sources. Work completed by the Idaho National Laboratory (2013) suggested that ash levels greater than 5% should be penalized at $2.25/dry Ton for every percent ash greater than 5% (see Source 3) for stover delivered for biofuel production. With known quality specifications producers will strive to minimise inorganics content during harvest. Refinements to harvest systems including reducing the number of harvest activities should reduce the amount of ash.

Table 3. Corn Stover Quality Assessments

Source 1	**Moisture**	**Dockage**	**Ash**	**Dockage**
	0 – 35%	$0	0 – 15%	$0
	35 – 50%	$5/BDT	15 – 25%	$10/BDT
	50%+	Rejected	25%+	Rejected
Source 2	**Grade**	**Moisture**	**Ash**	**Penalty**
	1	< 20%	< 10%	$0
	2	20% and < 28%	< 15%	$8/Ton
	3	28% and < 36%	< 15%	$17/Ton
	4	36%+	> 15%	100% of price
Source 3			**Ash**	**Penalty**
			> 5%	$2.25/ dry Ton per % ash above 5%

Source: 1 POET-DSM Project Liberty Biomass Producer Handbook; 2 Thompson & Tyner, 2011; 3 INL, 2013.
BDT – bone dry ton.

3.3 US Corn Stover Cost Estimates

The Idaho National Laboratory (INL) has been involved in quantifying the total costs of supplying various types of biomass for conversion to lignocellulosic fuels. Previous work done by INL only took into account the logistics costs of getting the biomass delivered whereas more recent research takes into account costs associated with collecting, storing, handling and transportation as well as quality parameters. Table 4 shows a breakdown of cost estimate targets for 2017 for multi-pass corn stover. It should be noted that the grower payment/access cost item provides a value for nutrients removed and a 15% profit for the grower. Harvest and collection activities include a flail chopper to chop and windrow the stover followed by baling and collecting bales in the field and transporting to the field edge. Transportation of the corn stover is within a 25 mile radius. Storage costs assume bales are tarped and stored at the field edge.

Table 4. US Multi-Pass Corn Stover Target Costs for 2017

	$C/tonne at 15.5% moisture
Grower payment/access cost	31.22
Harvest & collection	22.04
Transportation	9.53
Storage	7.46
Total	**70.25**

Source: INL, 2013. Transportation based on hauling in a 25 mile radius.
Note: Original values provided in $US/dry Ton and converted to $C/tonne, 15.5% moisture by Ridgetown Campus using Bank of Canada noon exchange rate on June 15, 2015.

Other methods are available to estimate a value for cornstalks. They include pricing the stover based on using it to replace hay in a feed ration; using custom rates for harvest costs such as stalk chopping, baling, stacking, transporting and nutrient replacement; and finding a market value if there is a local market such as a biorefinery (Edwards, 2014b). These were discussed in the 2013 Report. Depending on whether a producer or custom operator is delivering cornstalks the harvest and transportation (up to 25 miles) costs would be in the range of $C41.06 to $C60.70/tonne, not taking into account storage or nutrient replacement (Edwards, 2014a). Stover costs in Iowa are reported to range from $US40 to $US60/Ton plus $15 to $20/Ton to account for potassium and phosphorus removal (Ertl).

3.4 Nutrient Removal and Replacement Costs

Corn stover contains nutrients and removal from the field means that these nutrients are not available for the soil and next crop. In the 2013 work, corn producers who were involved in focus group meetings indicated they wanted compensation for nutrients (N, P, K) in the stover based on the amount of nutrients removed and current fertilizer prices. For this study N, P and K quantities reflect the amount of N, P_2O_5 and K_20.

However it can be difficult to determine how much is removed in the stover without analysis. This is mainly due to time of harvest and translocation of nutrients. For example, potassium leaching occurs the longer the stover is left in the field since potassium is water soluble. In addition, the portion of the plant removed can impact the amount of nutrients lost from the field (Darr et al., 2014). For example, there are more nutrients in the leaves and husks, and less in the stalks (Wortmann et al.).

Nutrient analysis was conducted on stover that was harvested in Ontario during the fall of 2014. Obtaining a representative sample of an entire bale has proven to be difficult. However, the results to date indicate that the nutrient removal is similar to that reported in the literature with levels of nitrogen of 8.68 kg/tonne, phosphorus of 2.07 kg/tonne and potassium of 8.91 kg/tonne. Based on average fertilizer prices and assuming 25% availability of N for the next crop, 40% for P and 90% for K this amounts to a cost of $11.67/dry tonne of stover removed (or $9.86/tonne at 15.5% moisture). By comparison, estimated US nutrient replacement values range from $US15 to $20/Ton (Ertl) for phosphorus and potassium only to $US28.90/Ton (Wortmann, et al.) for nitrogen, phosphorus, potassium and sulphur.

Table 5 provides information from numerous US sources regarding nutrient contents of corn stover. There is some variance in the values. This could be due to time of sampling or the composition of the sample. In the US literature, there are differing views with respect to the inclusion of nitrogen when assessing nutrient replacement values. That is, less nitrogen might be needed to break down the stover that remains after harvest. This will depend on the crop rotation.

Table 5. Nutrient Levels in Corn Stover

	lb/dry Ton of stover removed			
Source	**N**	**P_2O_5**	**K_2O**	**S**
Darr et al, 2014	9.6*	3.3	17	
Wortmann et al, 2012	17	4	34	3
Ertl, D		3	19	
Karlen et al	14	1.4	16	
Sawyer & Mallarino, 2014	12	3	19	1

*Single pass harvest only

It is important to monitor macro and micro nutrients when stover is removed (Wortmann, et al; Sawyer and Mallarino, 2014). Also, the potential availability of the nutrients for the next crop should be taken into account since the total nutrients removed would not necessarily be the same amount that could actually be available for the next crop. This requires longer term monitoring of both the residue and the soil over several rotations.

3.5 Ontario Cornstalk Harvest

Two corn producers in Southwestern Ontario have been baling cornstalks for this project. In the fall of 2014 cornstalks were baled and removed. Based on the harvest data provided in Table 6 it is estimated that 38% (Farm 1) and 40% (Farm 2) of the stover was removed from the respective sites.

The wet conditions of the fall of 2014 made it difficult to get the stover to dry down in the field. Farm 2 carried out baling at the end of December when the ground was frozen but the plastic wrap kept freezing during baling, resulting in frequent interruptions.

Spring baling was also carried out at Farm 2 to identify opportunities and challenges that might arise under Ontario conditions. The spring of 2015 proved to be ideal for harvesting stover with a wide window of time when conditions were dry. The moisture content of the stover at the time of baling was 10% to 10.5%. Round baling is recommended for spring to reduce compaction.

Table 6. Ontario 2014 Farm Harvest Data

	Farm 1 - Fall	Farm 2 -Fall	Farm 2 - Spring
Grain yield (bushels/acre) at 15.5% moisture	190	170	170
Grain yield (tonnes/acre)	4.83	4.32	4.32
Stover produced (tonnes/acre)*	4.83	4.32	4.32
Bale moisture (%)	38%	40%	10.5%
Bales/acre removed	4.8	4.5	1.7
Bale weight (t) at 15.5% moisture	0.43	0.36	0.42
Stover removed (t/acre) at 15.5% moisture	2.08	1.63	0.72

* Assumption that stover production is equal to corn grain production on a dry matter basis. The harvest index ratio of biomass to grain production remains constant at 1:1.

As stated previously, the cornstalk moisture at time of harvest is an important factor to consider particularly if the bales will be stored for a long period of time. This is because bales may lose their integrity, become softer and bales at the bottom of the pile are squished or misshapen. At the plant, receiving higher moisture bales will result in the plant having to use more bales in order to achieve desired throughput. This will increase costs for the plant.

Moisture readings taken in March 2015 at one of these farms showed that the moisture content ranged from 33% to 39% moisture in large square bales and 28% to 38% in round bales. The readings were very variable, even within the same bale. It is speculated that the location of the moisture probe inside the bale and whether it is in a corn stalk versus a leaf will affect the moisture reading. If the probe is inside a stalk the moisture reading will be higher. Being able to obtain reliable moisture readings will be critical if payment for stover is based on moisture content.

The estimated harvest costs for 2013[1] and 2015 are presented in Table 7. The values have changed quite significantly from the 2013 Report. The new costs for windrowing, baling and stacking at end of field activities are the primary contributors to the overall $27.15 decrease in total stover costs. In particular, the costs of the flail chopper and baling activities are much lower in 2015. The revised numbers are from harvesting scenarios developed by Oo (2015) that take into account producer owned and custom operator equipment, harvesting round and square bales, fall and spring harvest, and participation rates of producers and custom operators. Please see Appendix A and Appendix B for detailed information on the harvest models developed by Oo. (Note: In the 2013 Report estimated prices were reported as dollars per tonne at 0% moisture. For this project however there was interest from grain corn producers to have stover prices expressed on a 15.5% moisture basis. Corn producers receive payment for corn adjusted to 15.5% moisture so this is a natural fit for them.)

[1] The values in the 2013 Report have been updated to reflect calculations on a 15.5% moisture basis.

Nutrient analysis that has been completed to date for the 2014 fall farm trials has been incorporated. The data also take into account discussions with producers and equipment manufacturers who are familiar with cornstalk baling. Raking was included as a harvest activity in 2013 but has been removed because a flail chopper or hay inverter would likely be used instead. A flail chopper combines the activities of stalk chopping and windrowing the residue resulting in one less pass in the field thereby creating efficiencies and reducing the amount of soil in the stover. The cost for production management remains at 15% of harvest costs, nutrient replacement and storage. This is intended to cover losses due to compaction, erosion, bale shrink/loss, and liability. The estimated cost at the farm-gate is $54.44/tonne at 15.5% moisture based on harvest activities, storage and production management.

The cost for transportation increased due to changing the distance from 75 km to 100 km and taking into account transporting square and round bales (Oo). To secure sufficient quantities of cornstalks it may be necessary to transport stover 100 km depending on the plant location. The administration cost should cover contract management, logistics, managing the supply of cornstalks and paying producers. The total delivered cost is estimated to be $82.07/tonne at 15.5% moisture.

Table 7. Assumptions Used in Financial Analysis

	$/tonne at 15.5% moisture	
Harvest Costs	**2013 values**	**2015 values**
Flail chopper/inverter	17.28	9.43
Rake	7.68	--
Large square baling	36.45	14.03
Stack end of field	4.55	5.72
Storage end of field, tarped[1]	6.76	8.30
Nutrient replacement	9.78	9.86
Production management issues[2]	12.38	7.10
Corn Stover Cost – farm gate	**94.88**	**54.44**
Transportation 100 km[3]	13.49	26.78
Administration	0.85	0.85
Corn Stover Cost - delivered	**109.22**	**82.07**

Sources: Producer communication; Industry sources; Oo, 2015; Duffy and Marchand, 2013
Note: Nutrient replacement is based on availability of nutrients to subsequent crop, analysis of stover harvested in 2014 and fertilizer prices in October 2014 and May 2015. [1]Cost may be either cost to farmer or plant depending on time of sale. [2]15% of chopping, baling, stacking, storage and nutrient replacement. [3]75 km in 2013.

Compared to the US multi-pass stover target costs reported by INL of $C70.25/tonne (Table 4), the estimated Ontario costs are higher. One reason is transportation costs since it is 40 km (25 miles) in the US study versus 100 km for this study. It is speculated that another reason for higher costs in Ontario could be different rates of stover removal due to different yields in

Ontario versus Iowa and therefore different efficiency levels. Also, the methodologies for calculating the costs will be different. For example, Ontario's costs have been estimated based on producer and industry discussion, a combination of producer and custom operator participation, spring and fall baling, etc. This Ontario specific approach is reflected in the costs. Although the methodologies to calculate the US and Ontario costs differ somewhat the results are useful for discussion and benchmark purposes.

4.0 The Financial Model

In the 2013 Report a bioprocessing co-op model was recommended as the preferred business structure that would benefit agriculture producers. This recommendation is reviewed because new information has been added. Also a second method of determining the value of the sugar product that can be obtained from processing cornstalks is discussed. Finally, a sensitivity analysis is included as well as risks that exist for the project.

4.1 Bioprocessing Co-op Model

The premise in the bioprocessing co-op is to estimate the price that can be paid for cornstalks in order to achieve a target return on investment (ROI) of 15% at the sugar plant based on sugar prices and yields. The model assumed 250,000 tonnes of stover at 0% moisture yields 115,000 tonnes of cellulosic sugar and 90,000 tonnes of lignin co-product.

For the 2013 Report the financial analysis assumed the sugar plant was fully operational. However, it is more realistic to model a ramp-up period that would occur if a new plant was starting up. It is assumed that this would be approximately 18 months to 2 years in duration. During this time cornstalks would be sourced and plant operations would be tested before full operations begin in year 3. Specifically the following assumptions have been made: Year 1 – 50% of fixed costs, 25% of variable costs and no revenue; Year 2 – 100% of fixed costs, 75% of variable costs and 50% of revenue. The administration costs were held constant at $C250,000 per year because even though full operations are not attained in Year 1 and Year 2 there will be considerable work involved in communicating with producers, sourcing biomass, logistics, etc. It is still assumed that the ROI calculation is over ten years even though full revenue potential is not reached until Year 3. A summary of key parameters is shown in Table 8.

Table 8. Key Parameters for Bioprocessing Co-operative

General Parameters	Value
Plant biomass capacity (tonnes/year)	250,000
Unit capacity cost ($C/tonne/year)	$280.00
Debt to equity ratio	1.00
Interest rate (%)	5.00%
Loan repayment period (years)	10.00
Total capital cost ($C million)	$70.00
Initial loan ($C million)	$35.00
Initial equity ($C million)	$35.00

In the 2013 Report the base price for sugar was assumed to be $C400 with a Canada/US exchange rate at par. This is representative of the previous 3 year average price based on a par Canada/US exchange rate. The target 15% ROI can be achieved by paying an average price of $81.33/tonne at 0% moisture (or $68.73/tonne at 15.5%) for cornstalks during the first ten years as shown in Table 9. Ideally this should cover the harvest costs, nutrient replacement, storage and transportation. Corn producer co-op members could share in the returns of the plant. The calculations take into account the two year ramp-up period during which the sourcing of cornstalks begins and revenue is generated from the sale of some cellulosic sugar and lignin co-product in Year 2. The cornstalks price is quite a bit lower than in the 2013 Report ($81.33/tonne vs $110.52/tonne) due to this ramp-up phase and still keeping the target 15% ROI over 10 years.

Table 9. Financial Model for Bioprocessing Co-operative

	Value
Price of cellulosic sugar ($C/tonne)	**$400.00**
Price of co-products ($/tonne)	$40.00
Cost of cornstalks ($/tonne) at 0%	$81.33
Cost of cornstalks ($/tonne) at 15.5%	$68.73
Production and Revenue	**Value**
Cellulosic sugar revenue ($ million/year)	$39.10
Co-product revenue ($ million/year)	$3.06
Total revenue ($ million/year)	$42.16
Cost Items	**Value**
Operating costs	
Cornstalks cost ($ million/year)	$18.30
Operating costs ($ million/year)	$9.75
Financing costs	
Interest ($ million/year)	$1.47
Loan repayment ($ million/year)	$6.08
Sub-total financing costs ($ million/year)	$7.55
Net income ($ million/year)	$6.56
Return on investment (%)	15.0%

Note: Costs related to pre-processing activities, if needed, have not been included.

The model uses a three year average price for sugars. The challenge as the work progresses towards an investment is to create better value for co-products derived from cornstalks such as the C5 sugar stream and the lignin. As commercialization is likely to happen in a three to five year horizon, there will be significant value improvements for these co-products. For example, biochemical platforms are going through extensive research to create new pathways and products; new enzyme approvals could open up fermentation pathways for C5 sugars; and possibilities to capture US RINs on bioethanol are all examples of new revenue streams to consider in project development. Finally, for bioprocessors located in areas not serviced by natural gas lines, there is opportunity to develop co-generation options and qualify for FIT electricity rates. These are some of the opportunities that will facilitate project implementation in the future.

4.2 Value of Cellulosic Sugar in Cornstalks

In Section 4.1, the price that can be paid for cornstalks in a bioprocessing co-op model was determined relative to the world sugar price. However analysis of the potential revenue from the different cellulosic sugars that can be obtained from processing cornstalks is another way to assess what this type of venture could afford to pay for stover.

Cellulose (C6 polysaccharide) and hemicellulose (C5 polysaccharide) can be hydrolyzed into sugars for use in biochemical production. Lignin can be used as a source for fuel until better chemical pathways emerge. The composition of cornstalks is shown in Table 10.

Table 10. Composition of Cornstalks

	(dry weight %)			(dry weight %)
Glucan	35.05		Extractives	14.65
Xylan	19.53		Arabinan	2.38
Lignin	15.76		Galactan	1.43
Ash	4.93		Mannan	0.60
Acetate	1.81		Sucrose	0.77
Protein	3.10			

Source: INL, 2013

This cost analysis takes into account detailed information regarding the sugar conversion rate for cornstalks and differences in prices and yields for C5 and C6 sugars. Cornstalks generally have a sugar conversion rate of 80% based on existing commercial technology. Of this, C6 and C5 sugars typically comprise 55% to 60% of the 80%. The cost analysis assumed a C6 sugar content of 37% and C5 sugar content of 22%, or 59% combined.

Based on these assumptions, corn stover has the sugar yield and value per tonne as shown in Table 11. One tonne of stover was estimated to have a sugar value of $C114.83 at 15.5% moisture or $C135.89 at 0%.

Table 11. Cornstalks Sugar Yield and Value

Variable	Yield/tonne (15.5% moisture)	Value/tonne (15.5% moisture)
C6 sugar	0.250	$83.53
C5 sugar	0.149	$31.30
Total sugar	**0.399**	**$114.83**

*Based on June 15, 2015 sugar price and exchange rate

Note that the ICE Contract 11 nearby futures price was used as the price for C6 sugar. It is not well understood what benchmark price should be used for C5 sugar. For purposes of this assessment, the Louisiana molasses price was used. These are benchmark prices that would need to be adjusted to account for transportation, local supply and demand conditions, and the quality of the sugars relative to their intended uses. In order to estimate a value for Ontario the Canada/US exchange rate is taken into account.

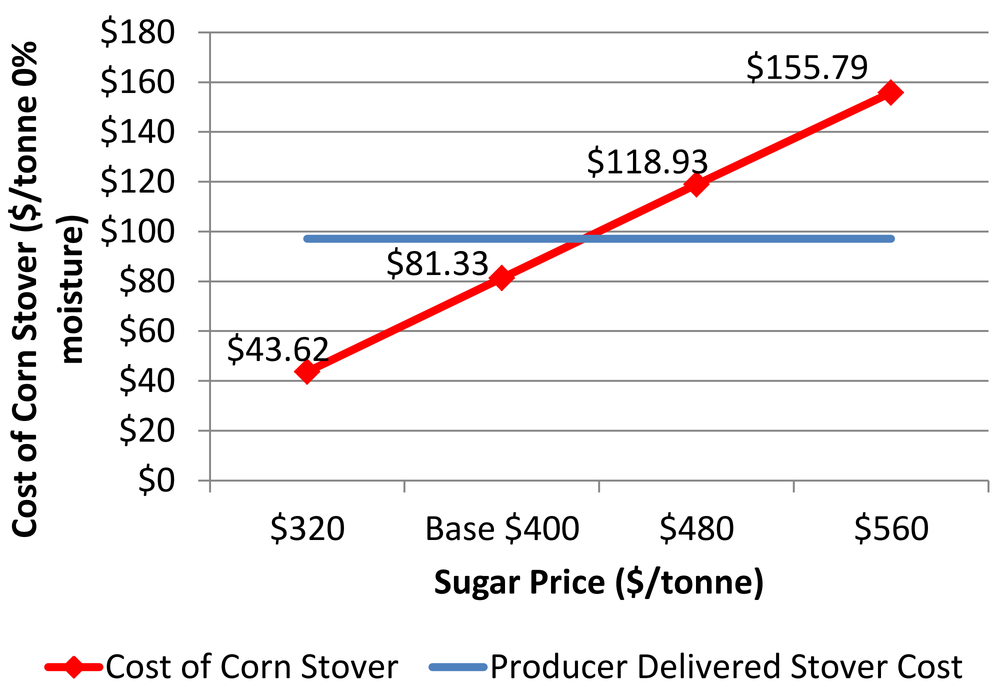
The model discussed previously assumed that 115,000 tonnes of sugar would be produced from 250,000 tonnes of cornstalks. As stated above, the total estimated value for C5 and C6 sugars produced is $135.89/tonne of stover at 0% moisture. If this value can be obtained from 250,000 tonnes of dry stover delivered to the plant resulting in 115,000 tonnes of sugar then the average sugar price is $C295/tonne on the 115,000 tonnes of sugar produced. This value can then be input as the price of sugar into the bioprocessing co-op model. Taking into account the ramp-up phase the maximum amount that can be paid for cornstalks is $C31.83/tonne ($C26.90/tonne at 15.5% moisture).

The results indicate lower estimated cornstalk prices than were reported in the 2013 Report due to including the two year ramp-up phase and maintaining the 10 year ROI of 15%.

4.3 Sensitivity Analysis

The bioprocessing co-op model is based on the financial performance of the plant. This means that finding high value markets for both the C6 and C5 sugars is very important. The amount that can be paid for cornstalks is directly impacted by the price that can be obtained when selling the sugars. Figure 3 depicts the anticipated price a plant could pay for stover based on the price of cellulosic sugar. At a sugar price of approximately $C435/tonne the price that can be paid is equal to the producer costs of delivering to the plant.

Figure 3. Effect of Sugar Price on Cost of Stover

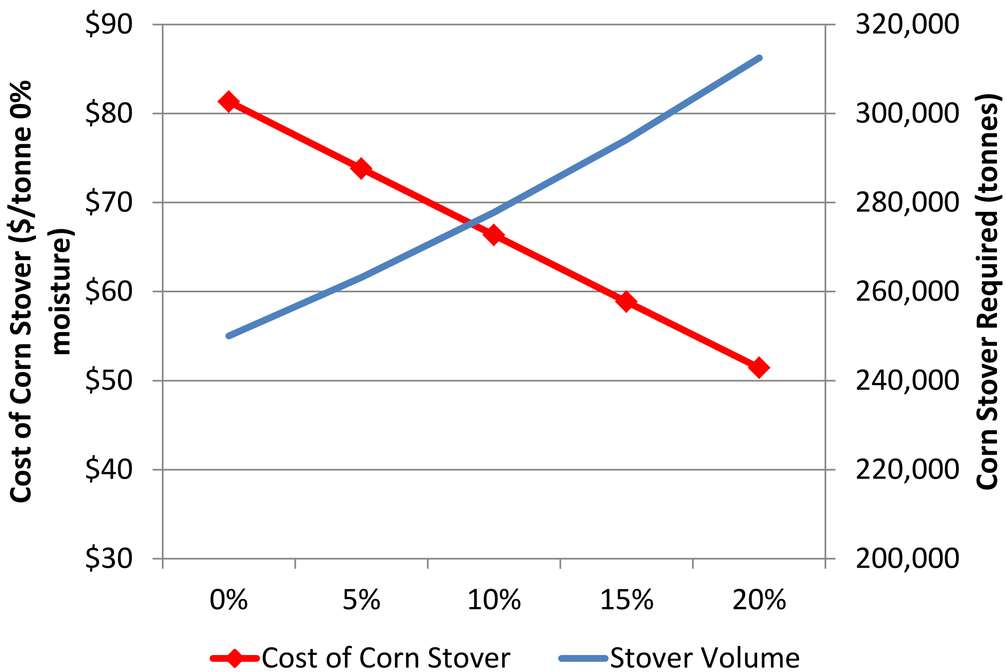


Assuming a target ROI of 15% and a sugar price of $400/tonne the co-op would be able to pay $81.33/tonne at 0% ($68.73/tonne at 15.5% moisture). As the price of sugar increases, the co-op is able to pay more for stover while still assuming a target 15% ROI. Figure 3 shows the price that can be paid for cornstalks based on different prices of sugar and assuming the sugar plant achieves a 15% ROI over 10 years. As well, the producer costs of delivering stover to the plant identified previously (consisting of harvesting, nutrient replacement, storage, transportation, administration, production management) are shown. Note that the prices in Figure 3 are based on 0% moisture.

The moisture content of the stover at the time of baling is important. If the stover is used soon after baling a higher moisture content may not have much impact on the conversion of sugars but it would result in more biomass being required. A plant as described in this project would require the equivalent of 250,000 dry tonnes of stover. Delivering stover at higher levels of moisture will affect the total quantity that needs to be processed, and therefore total operating costs for running more feedstock in the front end of the process. For example, a plant this size would need about 21,000 tonnes of dry stover each month. If the moisture content of the stover is 20% then 25% more stover is required or a total of 312,500 tonnes on an annual basis. This means that the plant needs to have access to an extra 3 months supply in order to guarantee sufficient amounts to meet the plant targets.

Higher moisture content means delivering extra water and the additional stover through the plant does not generate any income. This could lower the price the plant pays for stover. Bioprocessors utilize protocols with tolerances to indicate when penalties apply. Figure 4 shows the impact on cornstalk cost at different average moisture content levels assuming a base sugar price of $400/tonne and sugar and lignin conversions remaining constant.

Figure 4 Effect of Cornstalk Moisture on Stover Cost and Stover Requirements



4.4 Project Risks

There are a number of risks associated with this type of project. They are outlined below.

1) Exchange rate – The 2013 report was completed when the Canadian dollar was at par with the US dollar. Products or equipment priced in US dollars are impacted when the Canadian dollar is relatively weak as it is currently.

2) Timing and length of harvest period – Harvesting the large amount of cornstalks needed for this project requires good, dry harvest conditions in the fall and spring. One way to mitigate this risk is by using other feedstocks such as wheat straw if the plant technology is flexible.

3) Sugar price – The model uses the world price of sugar. Historically this price has been quite variable and this will affect the price that can be paid for stover.

4) Markets for cellulosic sugar and co-products – This is a new concept and high value markets need to be sought out.

5) Technology - Is the conversion technology proven at scale? As new technologies emerge they need to be thoroughly tested before being implemented at a plant.

6) Are there downstream buyers for all products and co-products? – One of the strengths of the region is that there is a demand for chemicals. Creating a bio-based sugar for these industries allows them to capture new markets. Also, there are ethanol producers that are interested in meeting future ethanol needs through cellulosic feedstock.

5.0 Conclusions and Next Steps

Corn producers in Southwestern Ontario are interested in sustainably harvesting excess cornstalks for use in a bioprocessing venture. Total corn acreage in the four-county region of Chatham-Kent, Lambton, Middlesex and Huron varies by year but corn yields have been quite consistent, even in challenging growing seasons such as in 2014. At least 400,000 acres are expected to be available from high yielding corn farms.

This report builds on work that was completed in 2013. Much of the 2013 work was based on literature from the US because information such as harvest costs was lacking for Ontario. A bioprocessing model that would incorporate partners along the value chain was recommended as a model to de-risk the venture for both the corn producer and the sugar plant. Cornstalks would be priced based on the sugar plant attaining a target 15% ROI over 10 years and corn producer members could share in dividends if issued.

When comparing the 2013 Report to the current analysis several things should be highlighted.

There are new Ontario harvest cost estimates. The corn stover harvest costs have been reduced by 25% to $97.11 per delivered dry tonne ($82.07 at 15.5% moisture). At the farm-gate the cost is $54.44/tonne at 15.5% moisture. These numbers are based on assumptions that stover harvesting will occur both in the fall and spring, with a combination of producer harvesting and custom operators and large square bales as well as round bales. Harvesting all of the stover in the fall is unlikely given the unpredictable weather that occurs. Removing raking from harvest activities and instead using a flail chopper or hay inverter removes one field activity reducing the amount of soil in the stover.

Additional information is available from nutrient removal and sugar yield analysis that has been completed to date on bales harvested in the fall of 2014. The levels are consistent with those reported in literature from the US. Analysis will continue to monitor moisture levels and nutrients in the bales, bale weights, and sugar composition in bales during storage and in stover harvested in different years.

The world sugar price has decreased and the exchange rate has changed. This affects the financial model and the price that can be paid for cornstalks.

The model now includes a two year ramp-up phase during which cornstalks would be accumulated and plant testing would begin prior to being fully operational in the third year. The model is based on a target 15% ROI at the plant over ten years. The model used in the 2013 Report assumed the plant was fully operational and did not include a ramp-up period.

Cornstalk moisture levels will affect the total amount of stover needed by the plant to meet operational targets. As the average moisture level increases the amount of stover required on a wet basis also increases without any increase in revenue. This increases the stover handling and transportation cost. This reduces the amount that can be paid for stover and highlights the importance of harvesting low moisture cornstalks and protecting bales from the weather during storage.

There is a need for further work to be done such as identifying additional revenue opportunities to mitigate the risk of prices in the model. In particular high value markets for C5 sugar and lignin co-products are needed.

In terms of sustainability, corn producers want to ensure the long-term productivity of their land. That is, the partial removal of cornstalks should not reduce land productivity. A scientifically sound protocol of determining sustainable stover removal rates at the field level would provide producers and buyers with assurance that good agronomic practices are being followed, research is ongoing, etc. The availability of such a protocol could encourage producer participation.

Also, it needs to be clear when ownership of the stover bales would change. At what point does ownership of the stover change from the producer to the processor. This will affect who is responsible and bears the costs for insuring the bales against fire or other liabilities, protection from the weather and rodents, access to the bales, etc.

A variety of payment options for cornstalks exists and should be further explored. These options would take into account covered versus not covered bales, and time of delivery. For example, it could be argued that producers that store bales for longer periods of time should receive a higher price as an incentive for doing so. A quality grid to assess the acceptable ash and moisture levels will be needed.

Investigation into a cornstalks to bioprocessing venture continues in Southwestern Ontario. With over 500,000 tonnes of cornstalks available in Southwestern Ontario in an average year, there is increasing interest at the farm level to look at this new market outlet. With corn yields continuing to increase, residue levels are also growing. Providing a way for corn producers to move up the value chain and participate in the production of cellulosic sugar for use in green chemical production is attractive from a financial, land use efficiency and also an environmental standpoint with respect to reducing greenhouse gases by substituting green products in the economy.

References

Cecava, M.J. 2010. *Storage and processing of Corn Stover Easter Iowa Mid-Scale Trials: Practical Considerations*. Near-term Opportunities for biorefineries Symposium October 11-12, 2010. http://bioenergy.illinois.edu/news/biorefinery/pp_cecava.pdf

Darr, M., K. Webster, B. Schon, D. Schau. 2014. *Nutrient Removal from Corn Stover Harvesting.* Corn Stover Harvest PM 3051K. Iowa State University, Extension and Outreach.

Duffy, R. and L. Marchand. 2013. *Development of a Business Case for a Cornstalks to Bioprocessing Venture*. University of Guelph, Ridgetown Campus.

Edwards, E. 2014. *Economics of Harvesting and Transporting Corn Stover*. Corn Stover Harvest PM 3053B. Iowa State University, Extension and Outreach.

Edwards, E. 2014. *Estimating a Value for Corn Stover*. Corn Stover Harvest PM 3053C. Iowa State University, Extension and Outreach.

Ertl, D. Undated. *Sustainable Corn Stover Harvest*. Iowa Corn Promotion Board

Idaho National Laboratory (INL). 2013. *Feedstock Supply System Design and Economics for Conversion of Lignocellulosic Biomass to Hydrocarbon Fuels. Conversion Pathway: Biological Conversion of Sugars to Hydrocarbons*. “The 2017 Design Case”. Draft. Kenney, K.L., K.G. Cafferty, J.J. Jacobson, I.J. Bonner, G.L. Gresham, J.R. Hess, L.P. Ovard, W.A Smith, D.N. Thompson, V.S. Thompson, J.S. Tumuluru, N. Yancey. Idaho National Laboratory. INL/EXT-13-30342

Idaho National Laboratory (INL). 2014. *Feedstock and Conversion Supply System Design and Analysis. The Feedstock Logistics Design Case*. Jacobson, J.J., M.S. Roni, K.G Cafferty, K. Kenney, E. Searcy, J. Hansen. Idaho National Laboratory. INL/EXT-14-33227

Karlen, D.L., J.L. Kovar, S.J. Birrell. *Undated. Corn Stover Nutrient Removal Estimates for Central Iowa.* Online. Accessed June 11, 2015 from http://poetdsm.com/nutrients

Kludze, H., B. Deen, A. Weersink, R. van Acker, K. Janovicek, A. De Laporte. 2010. *Assessment of the Availability of Agricultural Biomass for Heat and Energy Production in Ontario.* Report prepared for Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA)

Lal, R. 2014. Societal value of soil carbon. Journal of Soil and Water Conservation 69(6):186A-192A doi:10.2484/jswc.69.6.186A

Lee, D., V.N. Owens, A. Bee, P. Jeranyana. 2007. *Composition of Herbaceous Biomass Feedstocks.* Online. North Central Sun Grant Center, South Dakota State University. Accessed May 14, 2015 from http://ncsungrant.sdstate.org/uploads/publications/SGINC1-07.pdf

Morey, R.V. N. Kaliyan, D.G. Tiffany, D.R. Schmidt. 2010. A Corn Stover Supply Logistics System. *Applied Engineering in Agriculture Vol. 26(3):* 455-461. American Society of Agricultural and Biological Engineers ISSN 0883-8542

Ontario Ministry of Agriculture, Food and Rural Affairs. *Field crop statistics*, annually. http://www.omafra.gov.on.ca/english/stats/crops/index.html

Oo, A. 2015. *Cornstalk Harvesting for Cellulosic Sugar Production – Interim Report*. Western Sarnia-Lambton Research Park.

Perlack, R.D., A.F. Turhollow. 2012. *Assessment of Options for the Collection, Handling, and Transport of Corn Stover*. Oak Ridge National Laboratory. ORNL/TM-2002/44.

POET-DSM Advanced Biofuels. *Project LIBERTY Biomass Producer Handbook*. Online. Accessed January 1, 2013 from http://www.projectliberty.com/handbook/

POET-DSM Advanced Biofuels. Undated. *Biomass Program Overview*. Accessed from http://poet-dsm.com/biomass

Sawyer, J.E. and A.P. Mallarino. 2014. *Nutrient Considerations with Corn Stover Harvest*. Corn Stover Harvest PM 3052C. Iowa State University, Extension and Outreach.

Schon, B. and M. Darr. 2014. *Corn Stover Ash*. Corn Stover Harvest PM 3051L. Iowa State University, Extension and Outreach.

Shah, A. and M. Darr. 2014. Corn Stover Storage Losses. Corn Stover Harvest PM 3051E. Iowa State University, Extension and Outreach.

Thompson, J. and W.E. Tyner. 2011. *Corn Stover for Bioenergy Production: Cost Estimates and Farmer Supply Response*. Purdue Extension RE-3-W, Rev 9/11.

US Department of Agriculture. National Agricultural Statistics Service. Quick Stats.

US Department of Energy. 2011. US Billion-Ton Update, Biomass Supply for a Bioenergy and Bioproducts Industry.

Wortmann, C.S., R.N. Klein, C.A. Shapiro. 2012. *Harvesting Crop Residues*. NebGuide G1846. University of Nebraska – Lincoln Extension, Institute of Agriculture and Natural Resources.

Appendix A

Harvest Models (Oo, 2015)

Description of Models

Ontario producers harvest approximately 8.7 million tonnes of biomass, mostly hay and straw, annually. The cellulosic sugar plant, which is expected to consume 250,000 – 350,000 tonne/year of cornstalk, will slightly increase the capacity utilization of existing biomass harvest equipment. The harvest models, therefore, are developed to estimate the marginal cost of harvesting cornstalk in Ontario.

The cornstalk harvest models considered in this study are producer-based, custom harvest and end-user harvest. The dedicated equipment to harvest cornstalk only with the end-user harvest model will have a higher capital cost per tonne of cornstalk harvested. The most likely case is that cornstalk in Ontario will be harvested by both producers and custom service providers.

Cornstalk can be harvested in fall or spring. If the higher moisture content of cornstalk in fall is not acceptable due to greater dry matter losses for the year round storage, the likely harvest scenario is that about 30-50% of total cornstalk required by the cellulosic plant can be harvested in fall and the rest in spring. This will minimize the total dry matter losses and secure biomass supply year-round. The models, therefore, examine both spring and fall harvests.

In estimating the cost of harvest, storage and transportation, the following are considered:

- Capital costs of equipment/facilities
- Useful life and salvage value of equipment
- Annual use of equipment/facilities
- Labour charges
- Repair and maintenance
- Fuel
- Return on investment
- Financing costs, and
- Administration costs.

Marginal Cost Analysis for Cornstalk Fall-Harvesting in Ontario

Harvest and General Parameters	*Value*
Hay acreage in Ontario (M acres)	2.1
Annual hay yield (tonne/acre)	3.5
Hay harvest window (days/year)	60
Wheat acreage in Ontario (M acres)	1.1
Wheat straw yield (tonne/acre)	1.2
Wheat harvest window (days/year)	30
Corn acreage in Ontario (M acres)	2.1
Sustainably harvestable cornstalk (tonne/acre)	1.8
Moisture content of cornstalk (%)	35
Cornstalk harvest window (days/year)	25
Square balers (% of total baling capacity in Ontario)	30
Producer participation in cornstalk harvest (%)	10
Custom harvestors participation (%)	50

Machinery Performance	*Value*
Hay harvest -20' windrower (tonne/day)	150
Wheat straw harvest - 20' windrower (tonne/day)	220
Baling - round baler (tonne/day)	80
Baling - square baler (tonne/day)	220
Bale stacking - round bale (tonne/day)	500
Bale stacking - square bale (tonne/day)	1000

Existing Machinery Capacity in Ontario	*Value*
Number of 20' windrowers equivalent	817
Number of round balers	1072
Number of square balers	167
Number of stackers	208
Number of tractors	2056

Cornstalk Harvesting with Existing Capacity in Ontario	*Value*
Hay harvest (tonne/year)	7,350,000
Wheat straw harvest (tonne/year)	1,320,000
Sustainably harvestable cornstalk (tonne/year)	3,780,000
Cornstalk by existing harvest capacity(tonne/year)	918,750

Cornstalk Harvest Cost Using Existing Machinery Capacity	*Producer-Harvest*	*Custom-Harvest*
Windrowing ($/tonne)	8.44	10.55
Baling ($/tonne)	10.16	12.70
Stacking ($/tonne)	5.08	6.35
Total harvest cost ($/tonne)	23.68	29.61

Cornstalk Harvest Cost (Windrower)

General Parameter	*Value*
Discount rate (%)	10
Fuel cost ($/l)	1.2
Overhead charge (%)	25
Margin for custom harvest (%)	25

20' Windrower	*Value*
Capital cost of windrower and tractor ($)	430,000
Useful life (year)	10
Salvage value (%)	20
Repair factor 1	0.46
Repair factor 2	1.7
Speed of harvest (km/h)	20
Fuel consumptions (l/acre)	2.2
Turnaround time (% of harvest time)	15
Labor cost ($/hr)	20
Annual use without cornstalk harvest (hour)	539
Annual use with cornstalk harvest (hour)	663
Harvest rate (hr/acre)	0.04
Cornstalk harvest cost	
Machinery capital cost ($/tonne)	2.77
Repair and maintenance ($/tonne)	1.05
Fuel ($/tonne)	1.95
Labor ($/tonne)	0.56
Overhead charge ($/tonne)	2.11
Total harvest cost-producer harvest ($/tonne)	8.44
Total harvest cost-custom harvest ($/tonne)	10.55
Return on Investment for custom operator	11.80

Cornstalk Harvest Cost (Square Baler)	
General Parameter	*Value*
Discount rate (%)	10
Fuel cost ($/l)	1.2
Overhead charge (%)	25
Margin for custom harvest (%)	25
Square Baler	*Value*
Capital cost of square baler and tractor ($)	675,000
Useful life (year)	10
Salvage value (%)	20
Repair factor 1	0.43
Repair factor 2	1.8
Speed of baling (km/h)	22
Fuel consumptions (l/acre)	1.7
Turnaround time (% of harvest time)	15
Labor cost ($/hr)	20
Annual use without cornstalk harvest (hour)	566
Annual use with cornstalk harvest (hour)	600
Baling rate (hr/acre)	0.03
Cornstalk harvest cost	
Machinery capital cost ($/tonne)	4.36
Repair and maintenance ($/tonne)	1.24
Fuel ($/tonne)	1.51
Labor ($/tonne)	0.51
Overhead charge ($/tonne)	2.54
Total harvest cost-producer harvest ($/tonne)	10.16
Total harvest cost-custom harvest ($/tonne)	12.70
Return on Investment for custom operator	10.19

Cornstalk Harvest Cost (Round Baler)	
General Parameter	*Value*
Discount rate (%)	10
Fuel cost ($/l)	1.2
Overhead charge (%)	25
Margin for custom harvest (%)	25
Round Baler	*Value*
Capital cost of Round baler and tractor ($)	330,000
Useful life (year)	10
Salvage value (%)	20
Repair factor 1	0.41
Repair factor 2	1.7
Speed of baling (km/h)	5.5
Fuel consumptions (l/acre)	1.3
Turnaround time (% of harvest time)	15
Labor cost ($/hr)	20
Annual use without cornstalk harvest (hour)	566
Annual use with cornstalk harvest (hour)	702
Baling rate (hr/acre)	0.14
Cornstalk harvest cost	
Machinery capital cost ($/tonne)	7.29
Repair and maintenance ($/tonne)	2.71
Fuel ($/tonne)	1.15
Labor ($/tonne)	2.05
Overhead charge ($/tonne)	4.40
Total harvest cost-producer harvest ($/tonne)	17.61
Total harvest cost-custom harvest ($/tonne)	22.01
Return on Investment for custom operator	10.38

Cornstalk Harvest Cost (Bale Stacker)

General Parameter	*Value*
Discount rate (%)	10
Fuel cost ($/l)	1.2
Overhead charge (%)	25
Margin for custom harvest (%)	25

Bale Stacker	*Value*
Capital cost of bale stacker	250,000
Useful life (year)	10
Salvage value (%)	20
Repair factor 1	0.43
Repair factor 2	1.6
Speed of collection and stacking (km/h)	23
Fuel consumptions (l/acre)	1.5
Turnaround time (% of harvest time)	15
Labor cost ($/hr)	20
Annual use without cornstalk harvest (hour)	512
Annual use with cornstalk harvest (hour)	621
Stacking rate (hr/acre)	0.03
Cornstalk harvest cost	
Machinery capital cost ($/tonne)	1.49
Repair and maintenance ($/tonne)	0.50
Fuel ($/tonne)	1.33
Labor ($/tonne)	0.49
Overhead charge ($/tonne)	1.27
Total harvest cost-producer harvest ($/tonne)	5.08
Total harvest cost-custom harvest ($/tonne)	6.35
Return on Investment for custom operator	12.58

Cornstalk Transportation Cost

General Parameter	*Value*
Gross vehicle weight restriction (lb)	121,275
Weight of 53' flatbed and tractor	30,000
Average cost per trip within 100 km ($)	300
Handling cost per square bale ($/bale)	3
Handling cost per round bale ($/bale)	2
Weight of large square bale (3'*4'*8')	1100
Weight of round bale (4'*5')	650

Item	*Value*
Maximum numbers of square bales per dimension restriction	39
Maximum number of round bales per dimension restriction	38
Maximum numbers of square bales per weight restriction	83
Maximum numbers of round bales per weight restriction	140
Actual numbers of square bales per truck	39
Actual numbers of round bales per truck	38
Total cost per trip for square bales ($)	417
Total cost per trip for round bales ($)	376
Transportation cost	
Transportation cost per square bale ($/bale)	10.69
Transportation cost per round bale ($/bale)	9.89
Transportation cost of square bale per tonne ($/tonne)	25.05
Transportation cost of round bale per tonne ($/tonne)	39.23

Cornstalk (Fall Harvest) Storage Cost

General Parameter	*Value*
Unit cost of tarps ($/sq. ft)	0.30
Unit cost of hoop barn ($/sq. ft)	9.00
Unit cost of permanent structure ($/sq. ft)	21.00
Tonnage per storage site	200
Storage land annual rental cost ($/acre)	250
Service life of tarps (year)	5
Service life of hoop barn (year)	10
Service life of permanent structure (year)	20
Weight of large square bale (3'*4'*8')	1,100
Weight of round bale (4'*5')	650

Item	*Square Bales*				*Round Bales*			
	Uncovered	*Tarped*	*Hoop Barn*	*Structure*	*Uncovered*	*Wrapped*	*Hoop Barn*	*Structure*
Storage facility cost ($/year)	0.00	128.29	1924.36	2245.09	0.00	203.54	3053.08	3561.92
Storage facility cost ($/tonne)	0.00	0.64	9.62	11.23	0.00	1.02	15.27	17.81
Dry matter loss (%)	18.00	15.00	12.00	12.00	18.00	15.00	12.00	12.00
Dry matter loss ($/tonne)	12.54	10.45	8.36	8.36	15.09	12.58	10.06	10.06
Storage land cost ($/tonne)	0.08	0.08	0.08	0.08	0.10	0.10	0.10	0.10
Total storage cost ($/tonne)	12.62	11.17	18.06	19.66	15.19	13.69	25.42	27.97

Marginal Cost Analysis for Cornstalk Spring-Harvesting in Ontario

Harvest and General Parameters	*Value*
Hay acreage in Ontario (M acres)	2.1
Annual hay yield (tonne/acre)	3.5
Hay harvest window (days/year)	60
Wheat acreage in Ontario (M acres)	1.1
Wheat straw yield (tonne/acre)	1.2
Wheat harvest window (days/year)	30
Corn acreage in Ontario (M acres)	2.1
Sustainably harvestable cornstalk (tonne/acre)	1.2
Moisture content of cornstalk (%)	10
Cornstalk harvest window (days/year)	35
Square balers (% of total baling capacity in Ontario)	30
Producer participation in cornstalk harvest (%)	50
Custom harvestors participation (%)	75

Machinery Performance	*Value*
Hay harvest -20' windrower (tonne/day)	150
Wheat straw harvest - 20' windrower (tonne/day)	220
Baling - round baler (tonne/day)	80
Baling - square baler (tonne/day)	220
Bale stacking - round bale (tonne/day)	500
Bale stacking - square bale (tonne/day)	1000

Existing Machinery Capacity in Ontario	*Value*
Number of 20' windrowers equivalent	817
Number of round balers	1072
Number of square balers	167
Number of stackers	208
Number of tractors	2056

Cornstalk Harvesting with Existing Capacity in Ontario	*Value*
Hay harvest (tonne/year)	7,350,000
Wheat straw harvest (tonne/year)	1,320,000
Sustainably harvestable cornstalk (tonne/year)	2,520,000
Cornstalk by existing harvest capacity(tonne/year)	1,575,000

Cornstalk Harvest Cost Using Existing Machinery Capacity	*Producer-Harvest*	*Custom-Harvest*
Windrowing ($/tonne)	7.94	9.13
Baling ($/tonne)	14.48	16.65
Stacking ($/tonne)	4.87	5.60
Total harvest cost ($/tonne)	27.28	31.38

Assumption: 70% of cornstalk are round bales for spring-harvest

Cornstalk Harvest Cost (Windrower)	
General Parameter	*Value*
Discount rate (%)	10
Fuel cost ($/l)	1.2
Overhead charge (%)	15
Margin for custom harvest (%)	15
20' Windrower	*Value*
Capital cost of windrower and tractor ($)	430,000
Useful life (year)	10
Salvage value (%)	20
Repair factor 1	0.46
Repair factor 2	1.7
Speed of harvest (km/h)	20
Fuel consumptions (l/acre)	2.2
Turnaround time (% of harvest time)	15
Labor cost ($/hr)	20
Annual use without cornstalk harvest (hour)	539
Annual use with cornstalk harvest (hour)	641
Harvest rate (hr/acre)	0.04
Cornstalk harvest cost	
Machinery capital cost ($/tonne)	3.10
Repair and maintenance ($/tonne)	1.11
Fuel ($/tonne)	2.12
Labor ($/tonne)	0.61
Overhead charge ($/tonne)	1.00
Total harvest cost-producer harvest ($/tonne)	7.94
Total harvest cost-custom harvest ($/tonne)	9.13
Return on Investment for custom operator	13.65

Cornstalk Harvest Cost (Square Baler)	
General Parameter	*Value*
Discount rate (%)	10
Fuel cost ($/l)	1.2
Overhead charge (%)	15
Margin for custom harvest (%)	15
Square Baler	*Value*
Capital cost of square baler and tractor ($)	675,000
Useful life (year)	10
Salvage value (%)	20
Repair factor 1	0.43
Repair factor 2	1.8
Speed of baling (km/h)	22
Fuel consumptions (l/acre)	1.7
Turnaround time (% of harvest time)	15
Labor cost ($/hr)	20
Annual use without cornstalk harvest (hour)	566
Annual use with cornstalk harvest (hour)	594
Baling rate (hr/acre)	0.03
Cornstalk harvest cost	
Machinery capital cost ($/tonne)	4.77
Repair and maintenance ($/tonne)	1.33
Fuel ($/tonne)	1.64
Labor ($/tonne)	0.56
Overhead charge ($/tonne)	1.20
Total harvest cost-producer harvest ($/tonne)	9.49
Total harvest cost-custom harvest ($/tonne)	10.92
Return on Investment for custom operator	11.72

Cornstalk Harvest Cost (Round Baler)	
General Parameter	*Value*
Discount rate (%)	10
Fuel cost ($/l)	1.2
Overhead charge (%)	15
Margin for custom harvest (%)	15
Round Baler	*Value*
Capital cost of Round baler and tractor ($)	330,000
Useful life (year)	10
Salvage value (%)	20
Repair factor 1	0.41
Repair factor 2	1.7
Speed of baling (km/h)	5.5
Fuel consumptions (l/acre)	1.3
Turnaround time (% of harvest time)	15
Labor cost ($/hr)	20
Annual use without cornstalk harvest (hour)	566
Annual use with cornstalk harvest (hour)	678
Baling rate (hr/acre)	0.14
Cornstalk harvest cost	
Machinery capital cost ($/tonne)	8.18
Repair and maintenance ($/tonne)	2.87
Fuel ($/tonne)	1.25
Labor ($/tonne)	2.23
Overhead charge ($/tonne)	2.10
Total harvest cost-producer harvest ($/tonne)	16.62
Total harvest cost-custom harvest ($/tonne)	19.11
Return on Investment for custom operator	11.86

Cornstalk Harvest Cost (Bale Stacker)

General Parameter	*Value*
Discount rate (%)	10
Fuel cost ($/l)	1.2
Overhead charge (%)	15
Margin for custom harvest (%)	15

Bale Stacker	*Value*
Capital cost of bale stacker	250,000
Useful life (year)	10
Salvage value (%)	20
Repair factor 1	0.43
Repair factor 2	1.6
Speed of collection and stacking (km/h)	23
Fuel consumptions (l/acre)	1.5
Turnaround time (% of harvest time)	15
Labor cost ($/hr)	20
Annual use without cornstalk harvest (hour)	512
Annual use with cornstalk harvest (hour)	601
Stacking rate (hr/acre)	0.03
Cornstalk harvest cost	
Machinery capital cost ($/tonne)	1.67
Repair and maintenance ($/tonne)	0.53
Fuel ($/tonne)	1.44
Labor ($/tonne)	0.53
Overhead charge ($/tonne)	0.70
Total harvest cost-producer harvest ($/tonne)	4.87
Total harvest cost-custom harvest ($/tonne)	5.60
Return on Investment for custom operator	14.84

Cornstalk Transportation Cost

General Parameter	*Value*
Gross vehicle weight restriction (lb)	121,275
Weight of 53' flatbed and tractor	30,000
Average cost per trip within 100 km ($)	300
Handling cost per square bale ($/bale)	3
Handling cost per round bale ($/bale)	2
Weight of large square bale (3'*4'*8')	1100
Weight of round bale (4'*5')	650

Item	*Value*
Maximum numbers of square bales per dimension restriction	39
Maximum number of round bales per dimension restriction	38
Maximum numbers of square bales per weight restriction	83
Maximum numbers of round bales per weight restriction	140
Actual numbers of square bales per truck	39
Actual numbers of round bales per truck	38
Total cost per trip for square bales ($)	417
Total cost per trip for round bales ($)	376
Transportation cost	
Transportation cost per square bale ($/bale)	10.69
Transportation cost per round bale ($/bale)	9.89
Transportation cost of square bale per tonne ($/tonne)	20.41
Transportation cost of round bale per tonne ($/tonne)	31.97

Cornstalk (Spring Harvest) Storage Cost

General Parameter	*Value*
Unit cost of tarps ($/sq. ft)	0.30
Unit cost of hoop barn ($/sq. ft)	9.00
Unit cost of permanent structure ($/sq. ft)	21.00
Tonnage per storage site	200
Storage land annual rental cost ($/acre)	250
Service life of tarps (year)	5
Service life of hoop barn (year)	10
Service life of permanent structure (year)	20
Weight of large square bale (3'*4'*8')	1,100
Weight of round bale (4'*5')	650

Item	*Square Bales*				*Round Bales*			
	Uncovered	*Tarped*	*Hoop Barn*	*Structure*	*Uncovered*	*Wrapped*	*Hoop Barn*	*Structure*
Storage facility cost ($/year)	0.00	128.29	1924.36	2245.09	0.00	203.54	3053.08	3561.92
Storage facility cost ($/tonne)	0.00	0.64	9.62	11.23	0.00	1.02	15.27	17.81
Dry matter loss (%)	9.00	6.00	3.00	3.00	9.00	6.00	3.00	3.00
Dry matter loss ($/tonne)	6.01	4.01	2.00	2.00	7.05	4.70	2.35	2.35
Storage land cost ($/tonne)	0.08	0.08	0.08	0.08	0.10	0.10	0.10	0.10
Total storage cost ($/tonne)	6.09	4.73	11.70	13.31	7.15	5.82	17.71	20.26

Crop Budgets for Corn-Soybeans-Winter Wheat Rotation						
Expense/Revenue Items	*Without Cornstalk Harvest*			*With Cornstalk Harvest*		
	Corn	*Soybeans*	*Winter Wheat*	*Corn*	*Soybeans*	*Winter Wheat*
Seed	113.35	82.15	52.55	113.35	82.15	52.55
Seed treatment	1.60	10.10	0.00	1.60	10.10	0.00
Fertility	123.70	44.45	101.30	123.70	54.95	101.30
Pesticides	14.10	16.60	23.80	14.10	16.60	23.80
Total Inputs	252.75	153.30	177.65	252.75	163.80	177.65
Tillage	48.15	0.00	0.00	0.00	0.00	0.00
Planting	22.05	23.05	23.05	22.05	23.05	23.05
Spraying	10.00	20.00	20.00	10.00	20.00	20.00
Fertilizing	10.00	10.00	10.00	10.00	10.00	10.00
Harvesting & trucking	72.70	50.65	124.40	155.20	50.65	124.40
Total Machinery	162.90	103.70	177.45	197.25	103.70	177.45
Drying	75.20	12.15	0.00	75.20	12.15	0.00
Crop insurance	13.85	11.55	9.75	13.85	11.55	9.75
Interest	9.75	5.15	8.75	9.75	5.15	8.75
Marketing & other	33.15	11.60	1.80	33.15	11.60	1.80
Total Costs	547.60	297.45	375.40	581.95	307.95	375.40
Yield (bu/acre)	175.00	45.00	80.00	175.00	47.25	80.00
Price ($/bu)	4.50	11.80	6.60	4.50	11.80	6.60
Cornstalk/straw yield (tonne/acre)	0.00	0.00	1.50	1.50	0.00	1.50
Price ($/tonne)	80.00	0.00	120.00	80.00	0.00	120.00
Gross Return	787.50	531.00	708.00	907.50	557.55	708.00
Gross Margin ($/acre)	239.90	233.55	332.60	325.55	249.60	332.60
Gross Margin per Rotation ($/acre)	806.05			907.75		
Increased Margin per Rotation ($/acre)	101.70					

Appendix B

Progress Report Presentation on Modelling (Oo, 2015)

Cornstalk Supply-Chain Modelling

June 22, 2015

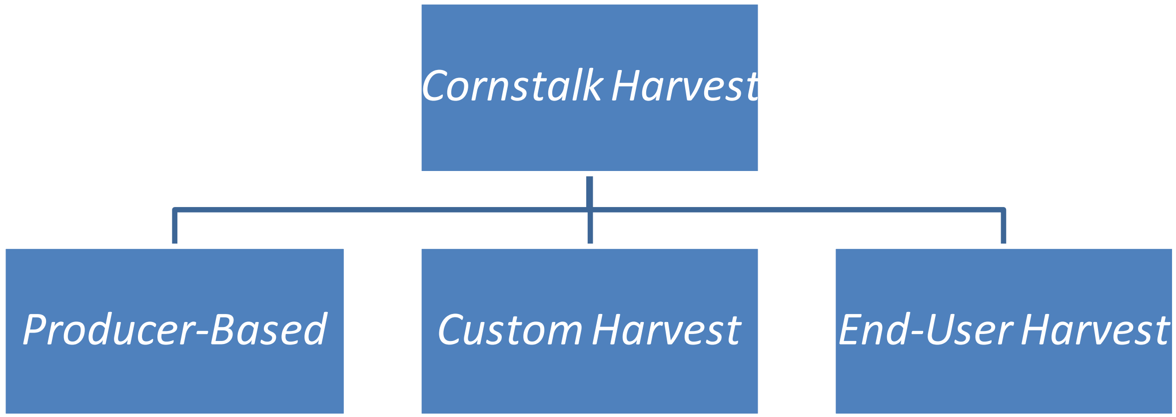
Western Sarnia-Lambton Research Park

Sarnia, Ontario

Western
Sarnia-Lambton
Research Park

1

Cornstalk Harvest Models



Pros	*-Greater producer participation -Lower capital requirement -Less storage area at sugar plant*	*-Higher capital utilization of harvest equipment -Specialized skill workers*	*-Better quality control -Supply security*
Cons	*-Mostly round bales -Quality control issues -Low fall harvest participation -Variable bale densities -Difficult harvest monitoring*	*-Lower producer participation -More concerns on field damage*	*-Lower producer participation -High capital requirement -Larger storage area at sugar plant or more aggregation yards -Higher harvest cost*

- *Combination of 2 or more models could be possible*

Western
Sarnia-Lambton
Research Park

2

Fall-Harvest vs. Spring-Harvest

	Fall-Harvest	Spring-Harvest
Pros	-Higher biomass yield (1.5 - 2 tonne/acre) -Both round and square bales -Less soil compact issues	-Lower moisture content (~10%) -Greater producer participation -Wider harvest window -Higher harvest equipment availability -Better sustainability
Cons	-Higher moisture content (~ 35%) -Lower producer participation -Narrow harvest window -Lower harvest equipment availability	-Lower biomass yield (1-1.5 tonne/acre) -Mostly round bales -Soil compaction concerns

- *Cellulosic ethanol producers in Iowa accept cornstalk with moisture content less than 35%*
- *Higher moisture content of cornstalk in fall in Ontario's climate could be an issue*

Western
Sarnia-Lambton
Research Park

3

Biomass Harvesting – Existing Capacity

- *Annual biomass harvest in Ontario:*
  - *Hay: 7.4 M tonne*
  - *Wheat straw: 1.3 M tonne*
- *About 50% of biomass is harvested by custom service providers*
- *Square balers represent about 30% of total capacity*
- *Annual biomass harvest in four counties (Chatham-Kent, Middlesex, Lambton, Huron):*
  - *Hay: 0.78 M tonne*
  - *Wheat straw: 0.47 M tonne*
- *Cornstalk consumption of a sugar plant: 0.15 - 0.25 M tonne/year*

Western
Sarnia-Lambton
Research Park

4

Fall Harvest – Existing Capacity

Cornstalk Harvest Cost Using Existing Machinery Capacity	*Producer-Harvest*	*Custom-Harvest*
Windrowing ($/tonne)	8.44	10.55
Baling ($/tonne)	10.16	12.70
Stacking ($/tonne)	5.08	6.35
Total harvest cost ($/tonne)	23.68	29.61

- *Cornstalk by existing capacity: 918,750 tonne/yr in Ontario*
- *Producer participation rate: 10%*
- *Custom operator participation rate: 50%*
- *Both square and round bales (all could be square bales)*
- *For comparison: estimates by Iowa State University US$ 16.77/tonne; current average custom rate of US$ 29.69/tonne in Iowa*
- *Nutrient replacement: $ 12.05/tonne*

Western
Sarnia-Lambton
Research Park

5

Spring Harvest – Existing Capacity

Cornstalk Harvest Cost Using Existing Machinery Capacity	*Producer-Harvest*	*Custom-Harvest*
Windrowing ($/tonne)	7.94	9.13
Baling ($/tonne)	14.48	16.65
Stacking ($/tonne)	4.87	5.60
Total harvest cost ($/tonne)	27.28	31.38

Assumption: 30% of cornstalk is baled by square balers for spring harvest

- *Cornstalk by existing capacity: 1,968,750 tonne/yr in Ontario*
- *Producer participation rate: 50%*
- *Custom operator participation rate: 75%*
- *Mostly round bales to minimize soil compaction; reduced cornstalk removal rate and lower operation efficiency of round balers lead to slightly increased costs*
- *For comparison: estimates by Iowa State University US$ 17.66/tonne; current average custom rate of US$ 28.57/tonne in Iowa*
- *Nutrient replacement is less: $ 8.02/tonne*

Western
Sarnia-Lambton
Research Park

6

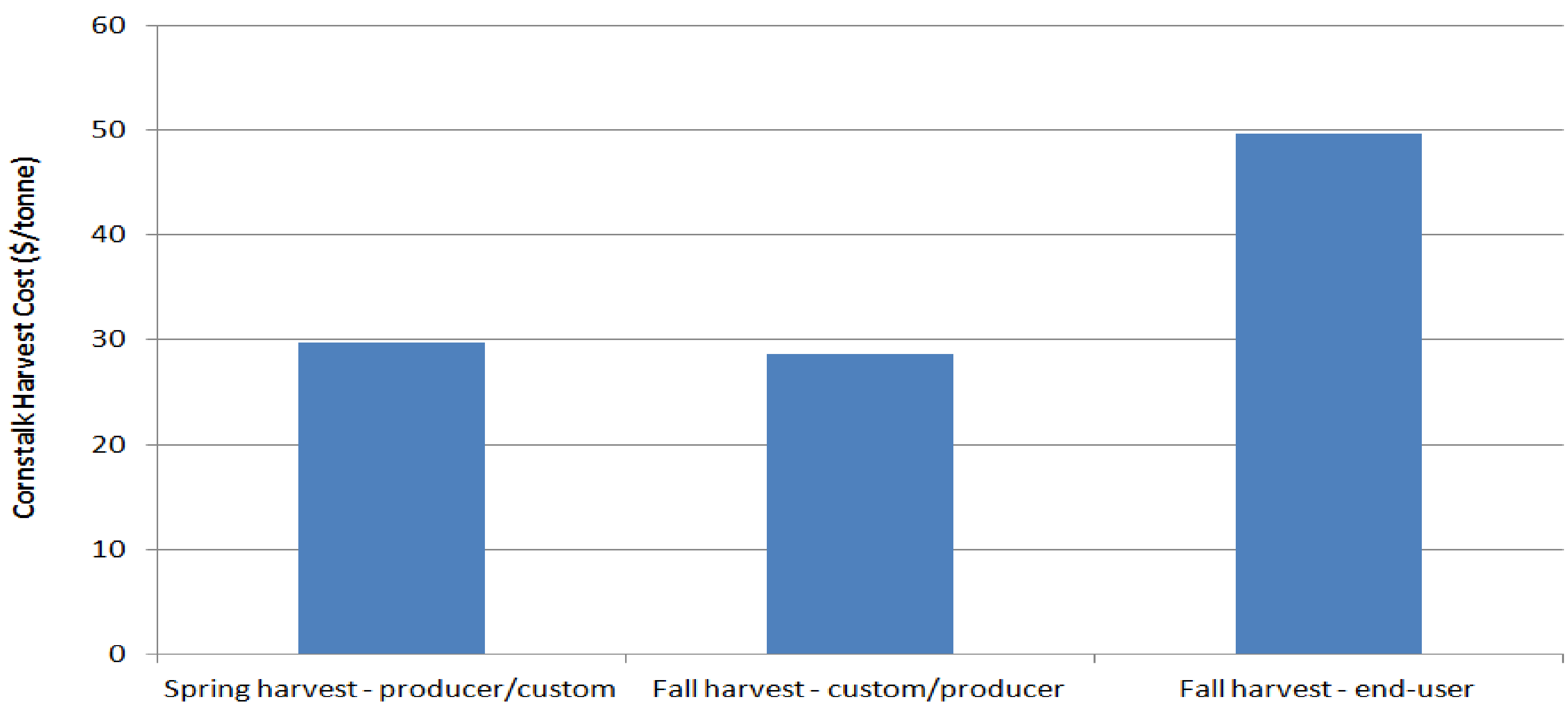
End-User Harvest – Dedicated Equipment

- *Harvest equipment requirements for a 350,000 tonne/year of cornstalk (AGCO's presentation):*
  - *70 square balers*
  - *105 shredders*
  - *35 collection wagons*
  - *210 tractors*
- *Capital cost of ~US$ 70 M*
- *Additional equipment cost of >$ 20/tonne to cornstalk harvest due to lower equipment utilization factor*
- *Equipment could be rent out for hay and straw harvests to increase equipment utilization factor*

Western
Sarnia-Lambton
Research Park

7

Cornstalk Harvest Costs



- *Spring harvest is likely preferable considering the moisture content, equipment availability, harvest window, producer participation, cost, sustainability and total cornstalk availability*

Western
Sarnia-Lambton
Research Park

8

Cornstalk Transportation

- *Transportation distance is ~ 100 km for the capacity of the sugar plant*
- *Numbers of bales per a flatbed trailer:*
  - *39 square bales (3' × 4' × 8')*
  - *38 round bales (4' H × 5' D)*
- *Transportation costs:*
  - *Flat fee per trip: $ 300*
  - *Bale handling cost: $ 3/bale for square bales; $ 2/bale for round bales*
- *Higher moisture content of cornstalk increases transportation cost*
- *Transportation cost of round bales is higher due to lower tonnage per truck*

Western
Sarnia-Lambton
Research Park

9

Cornstalk Transportation Cost

- *Fall harvest:*

Transportation cost	
Transportation cost per square bale ($/bale)	10.69
Transportation cost per round bale ($/bale)	9.89
Transportation cost of square bale per tonne ($/tonne)	25.05
Transportation cost of round bale per tonne ($/tonne)	39.23

- *Spring harvest:*

Transportation cost	
Transportation cost per square bale ($/bale)	10.69
Transportation cost per round bale ($/bale)	9.89
Transportation cost of square bale per tonne ($/tonne)	20.41
Transportation cost of round bale per tonne ($/tonne)	31.97

Western
Sarnia-Lambton
Research Park

10

Cornstalk Storage

- *Storage options:*
  - *Outdoor uncovered*
  - *Outdoor tarped/wrapped*
  - *Hoop barn structure*
  - *Permanent structure*
- *Important factors:*
  - *Initial moisture contents of cornstalk*
  - *Dry matter losses due to microbial degradation*
  - *Handling losses*
  - *Storage facility/land costs*

Western
Sarnia-Lambton
Research Park

11

Cornstalk Storage Costs

- *Fall harvest:*

Item	Square Bales				Round Bales			
	Uncovered	Tarped	Hoop Barn	Structure	Uncovered	Wrapped	Hoop Barn	Structure
Storage facility cost ($/year)	0.00	128.29	1924.36	2245.09	0.00	203.54	3053.08	3561.92
Storage facility cost ($/tonne)	0.00	0.64	9.62	11.23	0.00	1.02	15.27	17.81
Dry matter loss (%)	18.00	15.00	12.00	12.00	18.00	15.00	12.00	12.00
Dry matter loss ($/tonne)	12.54	10.45	8.36	8.36	15.09	12.58	10.06	10.06
Storage land cost ($/tonne)	0.08	0.08	0.08	0.08	0.10	0.10	0.10	0.10
Total storage cost ($/tonne)	12.62	11.17	18.06	19.66	15.19	13.69	25.42	27.97

- *Spring harvest:*

Item	Square Bales				Round Bales			
	Uncovered	Tarped	Hoop Barn	Structure	Uncovered	Wrapped	Hoop Barn	Structure
Storage facility cost ($/year)	0.00	128.29	1924.36	2245.09	0.00	203.54	3053.08	3561.92
Storage facility cost ($/tonne)	0.00	0.64	9.62	11.23	0.00	1.02	15.27	17.81
Dry matter loss (%)	9.00	6.00	3.00	3.00	9.00	6.00	3.00	3.00
Dry matter loss ($/tonne)	6.01	4.01	2.00	2.00	7.05	4.70	2.35	2.35
Storage land cost ($/tonne)	0.08	0.08	0.08	0.08	0.10	0.10	0.10	0.10
Total storage cost ($/tonne)	6.09	4.73	11.70	13.31	7.15	5.82	17.71	20.26

- *Outdoor tarped/wrapped is the most cost effective storage option*

Western
Sarnia-Lambton
Research Park

12

Total Cornstalk Cost Estimates ($/tonne)

	Spring Harvest	Fall Harvest
Harvest (cut and windrow + bale + stack)	29.74	28.62
Nutrient replacement	8.02	12.05
Tarped storage	5.50	11.09
Transportation	28.50	25.05
Producer payment	6.49	7.76
Total Cost	78.25	84.57

Note: cornstalk with 15.5% moisture content; transportation distance of <100 km; producer-based + custom harvest models
Producer payment: 15% of harvest+nutrient+storage costs

- Total cost of cornstalk is slightly lower for spring harvest
- Spring harvest: 30% of cornstalk in square bales & 70% in round bales assumed
- Fall harvest: all cornstalk in square bales assumed

Western
Sarnia-Lambton
Research Park

13

Increased Margin with Cornstalk Harvest

Expense/Revenue Items	*Without Cornstalk Harvest*			*With Cornstalk Harvest*		
	Corn	*Soybeans*	*Winter Wheat*	*Corn*	*Soybeans*	*Winter Wheat*
Seed	113.35	82.15	52.55	113.35	82.15	52.55
Seed treatment	1.60	10.10	0.00	1.60	10.10	0.00
Fertility	123.70	44.45	101.30	123.70	54.95	101.30
Pesticides	14.10	16.60	23.80	14.10	16.60	23.80
Total Inputs	252.75	153.30	177.65	252.75	163.80	177.65
Tillage	48.15	0.00	0.00	0.00	0.00	0.00
Planting	22.05	23.05	23.05	22.05	23.05	23.05
Spraying	10.00	20.00	20.00	10.00	20.00	20.00
Fertilizing	10.00	10.00	10.00	10.00	10.00	10.00
Harvesting & trucking	72.70	50.65	124.40	155.20	50.65	124.40
Total Machinery	162.90	103.70	177.45	197.25	103.70	177.45
Drying	75.20	12.15	0.00	75.20	12.15	0.00
Crop insurance	13.85	11.55	9.75	13.85	11.55	9.75
Interest	9.75	5.15	8.75	9.75	5.15	8.75
Marketing & other	33.15	11.60	1.80	33.15	11.60	1.80
Total Costs	547.60	297.45	375.40	581.95	307.95	375.40
Yield (bu/acre)	175.00	45.00	80.00	175.00	47.25	80.00
Price ($/bu)	4.50	11.80	6.60	4.50	11.80	6.60
Cornstalk/straw yield (tonne/acre)	0.00	0.00	1.50	1.50	0.00	1.50
Price ($/tonne)	80.00	0.00	120.00	80.00	0.00	120.00
Gross Return	787.50	531.00	708.00	907.50	557.55	708.00
Gross Margin ($/acre)	239.90	233.55	332.60	325.55	249.60	332.60
Gross Margin per Rotation ($/acre)	806.05			907.75		
Increased Margin per Rotation ($/acre)	101.70					

Western
Sarnia-Lambton
Research Park

14

Concluding Remarks

- *Existing biomass harvest capacity in Ontario can handle the cornstalk supply chain for the sugar plant requiring 150,000 – 250,000 tonne/yr of cornstalk*
- *The cost of cornstalk is expected to be $ 75 – 85/ tonne delivered at the sugar plant*
- *Majority of cornstalk will likely be harvested in Spring considering the moisture content, equipment availability, harvest window, producer participation, cost and sustainability*
- *Accepting both square and round bales will allow greater producer participation and lower soil compaction concerns*
- *The expected increased margin from cornstalk harvest for the typical corn-soybeans-wheat rotation is about $ 100/acre*

Western
Sarnia-Lambton
Research Park

15