Cradle to Consumer Life Cycle Greenhouse Gas Accounting of Sweet Corn in Minnesota

A Thesis

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Abstract

Minnesota is the nation's largest producer of sweet corn, the sixth most consumed vegetable in the United States and the third most popular side dish at dinner. Due to its significance within the food chain, it is important to understand the environmental impact of the greenhouse gas emissions associated with its life cycle. Many large food manufacturing companies and retailers such as Del Monte, General Mills, and Target have pledged to reduce greenhouse gas emissions by 10-20%. The goal of this study is to quantify the greenhouse gas emissions for canned and frozen sweet corn in Minnesota starting with sweet corn cultivation and ending with consumer use. To assess the greenhouse gas emissions at each stage of the life cycle, the GREET model from the Argonne National Laboratory is modified. The show that canned sweet corn emits from 1.7 to 2.6 kg of CO_2e with an average of 1.9 kg per 1 kg of processed sweet corn. Frozen sweet corn emits from 0.8 to 2.7 kg of CO_2e with an average of 1.6 kg per 1 kg of processed sweet corn. The processing stage for canned sweet corn, specifically the packaging, contributes 0.8 kg of CO_2e per 1 kg of processed sweet corn. Consumer storage for frozen sweet corn contributes up to 1 kg of CO_{2e} per 1 kg of processed sweet corn. The main contributors of greenhouse gas emissions for both canned and frozen sweet corn are transportation, energy use at the processing facility and consumer storage. Further investigation of these three stages is warranted given their importance in the life cycle and the large variability and uncertainty they present.

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Introduction

Agriculture accounts for approximately 9% (more than 600 million metric tons) of the greenhouse gas (GHG) emissions in the United States and has risen 11% since 1990 (EPA, 2017). Some of these emissions are from large production agriculture, which supplies raw materials to large food companies and retailers such as Del Monte, General Mills, and Target. These companies and others have pledged to reduce GHG emissions by 10-28% (*2015 Target Corporate Social Responsibility Report*, 2016), (*2016 General Mills Annual Report*, 2016), (Del Monte, 2017). There is variability between companies in how they calculate current GHG emissions and their plans for reduction. Some of the reduction pledges only include emissions that the company has direct control over such as electricity use in the manufacturing facility. Other companies pledge to understand the entire life cycle and work with their partners to reduce their emissions. By understanding the entire life cycle and the GHG emissions associated with each phase, manufacturers and retailers can understand if making a change at one point in the life cycle could affect emissions further up or down stream in the life cycle.

In this thesis, the life cycle GHG emissions associated with sweet corn, an important product in the United States food system, is explored. The focus is on the state of Minnesota, which is 5th overall in national agricultural production (USDA NASS, 2016). Minnesota is the largest producer of sweet corn for processing into canned or frozen sweet corn (USDA, 2011). Many studies on the life cycle GHG emissions of sweet corn or canned and frozen vegetables in general exist (for example (Weber & Matthews, 2008), (Nalley, Popp, Niederman, & Thompson, 2011), (Del Borghi, Gallo, Strazza, & Del Borghi, 2014), (Berners-Lee, Hoolohan, Cammack, & Hewitt, 2012)) but to date there is no published life cycle assessment (LCA), of sweet corn grown in Minnesota includes GHG emissions from all stages of the life cycle from farm to consumer.

Materials and Methods

Life cycle analysis (LCA) is one tool that is commonly used to tabulate GHGs. LCA is a cradle to grave analysis that allows for boundaries of a system to be set by the evaluator. Currently there are limited publicly available tools to evaluate GHGs in the food system and many of these tools focus primarily on the biofuel industry that includes the conversion of field corn to corn ethanol. GREET, which stands for "Greenhouse gases, Regulated Emissions, and Energy use in Transportation Model", is a model developed by the Argonne National Laboratory and is one of the biofuel modeling systems that includes corn ethanol production (Argonne National Laboratory, 2016). Many of the processes and inputs between biofuels and food production are similar. Since field corn, which is used for corn ethanol production, and sweet corn are closely related, GREET can be modified for use in determining the GHGs at each stage of the life cycle for canned and frozen sweet corn.

The first step in an LCA is determining the boundaries of the system and the inputs for each stage of the life cycle. In the context of this LCA, anything that is used within one cycle of the life of the product is included within the system boundary. The life cycle of sweet corn is broken into four phases; sweet corn production, processing, distribution, and consumer use.

The first stage of the life cycle is sweet corn production. This is the only stage in the life cycle that has the same inputs for canned and frozen sweet corn. Sweet corn production inputs that are in scope includes fertilizers, herbicides, insecticides, inputs for farm equipment, and transportation. Out of scope items include farm equipment and trucks for hauling as these are long life items with other uses.

Table 1. System Boundaries for Sweet Corn Production

In Scope	Out of Scope
Fertilizers (N, P, K, and S)	Farm Equipment
Herbicides (including Fungicides)	Trucks for hauling
Insecticides	
Inputs for farm equipment	
Transportation to Processing Facility	

The next phase of the life cycle is the processing of the sweet corn into either canned or frozen sweet corn, and it is here where the life cycle for canned and frozen sweet corn diverges. Inputs that are within scope for canning include salt, water, electricity for the facility, steam, cooling water, and primary and secondary packaging. Inputs that are within scope for freezing include electricity for the facility and primary and secondary packaging. Out of scope items include processing equipment, electricity of building, fork lifts, and pallets.

Table 2. System Boundaries for Processing

In Scope	Out of Scope
Other Ingredients (Canned)	Processing Equipment
Electricity for Equipment	Electricity of whole building
Steam (Canned)	Fork Lifts
Cooling Water (Canned)	Pallets
Primary Packaging	
Secondary Packaging	

The third phase of the life cycle is the distribution of the canned and frozen sweet corn, and includes transportation to a warehouse, warehouse storage, transportation to a grocery store and storage at the grocery store. The input for the two transportation stages is distance traveled. The input for the two storage stages is primarily electricity. At the grocery store the corrugated box will reach its end of life and the producer of the corrugated box already accounts for the end of the life cycle recycling credit for the box. Out of scope in distribution is truck manufacturing and maintenance and warehouse and grocery store construction.

Table 3. System Boundaries for Distribution

In Scope	**Out of Scope**
Transportation from Processing Facility	Truck Manufacturing
Electricity at Warehouse	Warehouse Construction
Transportation to Grocery Store	Grocery Store Construction
Electricity at Grocery Store	

The last phase of the life cycle is consumer use. Included in the system boundaries are miles to and from store, electricity for storage (only for frozen), and electricity for preparation. The producer of the can already accounts for the end of life cycle recycling credit for canned sweet corn.

Table 4. System Boundaries for Consumer Use

In Scope	**Out of Scope**
Miles to and from Store	Car Manufacturing
Electricity for Storage (if applicable)	Appliance Manufacturing
Electricity for Preparation	

Functional Unit

The functional unit is used to calibrate different parts of the life cycle to a common unit. Since there are many stages in the life cycle of sweet corn, it is important that each stage, inputs, and outputs are equalized to the functional unit. The functional unit for this LCA is 1 kilogram of processed sweet corn as prepared by the consumer.

For the farming inputs, 1 kilogram of processed sweet corn needs to be converted into the amount of sweet corn on the cob. It is estimated that about 30-40% of a cob of corn is kernels and the rest of the weight is cob and husk (Drozd, Hanusz, & Szymanek, 2007). The equivalent amount of sweet corn on the cob to give 1 kg of processed sweet corn ranges from 2.5 kg (at 40% kernel weight) to 3.3 kg (at 30% kernel weight). This range is tested in the model to understand the impact of this estimation using the value 2.5 kg, 2.9 kg and 3.3 kg.

For canned sweet corn, the equivalent number of cans that result in 1 kg of processed sweet corn needs to be determined. Generally speaking, a can of sweet corn is 75% corn and 25% water (Consumer Reports, 2013). A commonly accepted package size of sweet corn is 15.25 ounces and equates to 0.43 kg. Using this information, the number of cans of sweet corn equivalent to 1 kg of processed sweet corn is 3.08 cans.

For frozen sweet corn, the only ingredient is sweet corn. A typical size bag is 16 ounces (0.45 kg). The number of bags of frozen sweet corn equivalent to 1 kg of processed sweet corn is 2.21 bags.

Methods

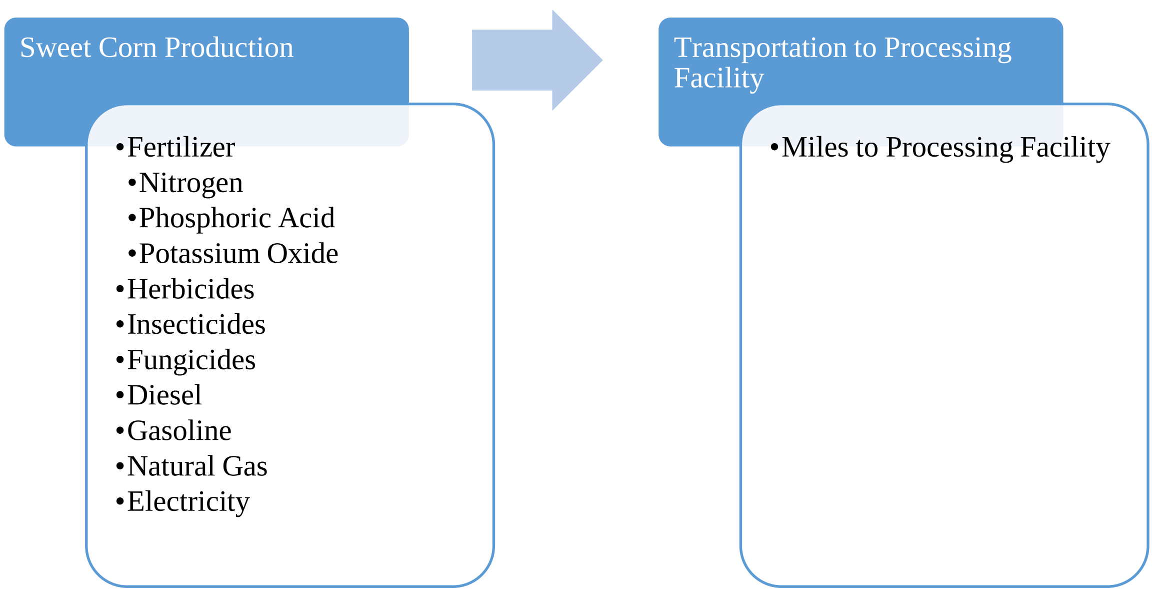
The GREET model (version 1.3.0.13081) was modified for sweet corn analysis. The model was adapted to include the the following subsections: sweet corn farming, transportation to the processing facility, sweet corn processing preparation, processing, transportation to warehouse, warehouse storage, transportation to grocery store, grocery store storage, consumer transportation, consumer storage, and consumer preparation. The sweet corn farming section was modified from the corn farming process already within GREET. All the transportation sections were modified using the existing corn transportation processes. The sweet corn processing preparation, processing, storage, and consumer preparation sections were built from scratch. The consumer transportation emissions were tabulated using the well to wheel function within GREET. Each section includes all the inputs outlined in Tables 1-4. Individual stationary or transportation processes were used to build two continuous pathways, one for canned sweet corn and one for frozen sweet corn.

Life Cycle Inventory

The life cycle inventory involves evaluating and aggregating the data for the individual inputs at each stage of the life cycle. The four main phases of the life cycle are further separated into sweet corn production, transportation to the processing facility, sweet corn processing preparation, sweet corn processing, distribution (transportation to the warehouse, warehouse storage, transportation to the grocery store, and grocery storage), and consumer inputs (travel, storage, and preparation).

Sweet Corn Production

Figure 1. Sweet Corn Production Steps and Inputs



Within the GREET model, the field corn production process is modified for sweet corn production. The inputs include fertilizer (nitrogen, phosphoric acid, calcium carbonate and potassium oxide), herbicides, insecticides, diesel, gasoline, natural gas and electricity.

Fertilizer is an important input to gain optimal yields for sweet corn. The main fertilizers used in Minnesota include nitrogen, phosphate, potash (potassium), and sulfur. While sulfur is an important added fertilizer, the GREET model does not have an equivalent resource that can be added to the model. Since the amount applied is small, it is assumed that the addition to sulfur does not have a large impact to the overall GHG total.

A main influencer of fertilizer choice is soil type. In Minnesota, sweet corn is predominantly cultivated on mollisols (Anderson, Bell, Cooper, & Grigal, 2013). Mollisols are characterized by high organic matter as well as high in calcium and magnesium (Brady & Weil, 1999). Mollisols are typically formed from grasslands and are the predominant soil order in Minnesota. Because this soil is high in organic matter, it is ideal for plant growth. Calcium carbonate (also known as lime) is applied to help neutralize the pH of acidic soils (Brady & Weil, 1999). Since sweet corn is primarily grown on mollisols that are naturally high in calcium and magnesium, it is not recommended to add calcium carbonate. In southeastern Minnesota, there may be a limited amount of calcium carbonate added to the soil every three to five years (Rosen & Eliason, 2005). Since calcium carbonate is not widely applied in Minnesota each year, it is excluded from this analysis.

Nitrogen is an important element for optimal plant growth as a lack of nitrogen can cause reduced growth as well as allow the plants to be more susceptible to diseases and pests (Brady & Weil, 1999). For sweet corn production, nitrogen was added at a rate of 126.8 kg per hectare per year in 2014 (USDA National Agricultural Statistics Service, 2016b). The amount of nitrogen needs to be allocated to the functional unit of 1 kg of processed sweet corn. As previously stated, the amount of sweet corn on the cob that yields 1 kg of processed sweet corn is 2.5 to 3.3 kg. The yield of sweet corn for processing in Minnesota varies from year to year. To have a robust number, the yield for the last 10 years is averaged using data from the USDA NASS and the average yield is 15691.9 kg per hectare. This results in an application of 20.3 g of nitrogen for 2.5 kg of sweet corn on the cob, 23.7 g for 2.9 kg of sweet corn on the cob and 27 g for 3.3 kg of sweet corn on the cob.

Phosphorus is primarily used to aid in plant growth and yield. Most soils are low in phosphorus and require additional fertilizer and is commonly applied as a phosphate (Brady & Weil, 1999). Per the 2014 USDA NASS survey, 80.6 kg per hectare was applied. Using this information, 12.8 g of phosphorus was applied for 2.5 kg of sweet corn on the cob, 14.8 g for 2.9 kg of sweet corn on the cob and 16.8 g for 3.3 kg of sweet corn on the cob.

Potassium is applied to crops to aid plant growth and yield (Brady & Weil, 1999). The most common form of potassium fertilizer used is potassium oxide. Potash is applied at a rate of 99.8 kg per hectare per the 2014 USDA NASS survey. Using this information 16 g of potash was applied for 2.5 kg of sweet corn on the cob, 18.5 g for 2.9 kg of sweet corn on the cob and 21 g for 3.3 kg of sweet corn on the cob.

Sweet corn uses a range of insecticides, herbicides, and fungicides similar to field corn as they share many of the same pests including corn borer, earworm, and others (Breitenbach, Ostlie, Hutchison, & O’Rourke, 2001), (O’Rourke & Hutchison, 2001).

Many pesticides are used for both types of corn, however, there are a few that are not approved for use in food. Per the 2014 USDA NASS survey, there were three types of fungicides, 23 types of herbicides, and five types of insecticides used for sweet corn. In GREET, insecticides and herbicides are included as part of the model while fungicides are not. For this reason, the amount of fungicides will be added to the amounts of herbicides. Many chemicals used for sweet corn production do not list specific amounts to protect the privacy of the grower. In this case, the generic mix of herbicides and insecticides is used for sweet corn production.

The number of sweet corn acres planted in Minnesota in 2014 was 116,000 acres and 8,300 kg of fungicide were applied or 0.18 kg per hectare. The amount of fungicide applied for 2.5 kg of sweet corn on the cob was 28 mg, 32.5 mg for 2.9 kg and 37 mg for 3.3 kg. The amount of herbicide applied in 2014 was 56880 kg total or 1.21 kg per hectare. For 2.5 kg of sweet corn on the cob, the amounts of herbicides applied was 190 mg. For 2.9 kg of sweet corn on the cob, 220 mg was applied. For 3.3 kg of sweet corn on the cob, 250 mg was applied. The amount of insecticide applied in 2014 is 4808 kg total or 0.098 kg per hectare. The amount of insecticide applied for 2.5 kg of sweet corn on the cob was 16 mg, 18.5 mg for 2.9 kg, and 21 mg for 3.3 kg. A summary of this data is in Table 5.

One of the main differences between growing sweet corn and field corn is how each is harvested. Sweet corn ears are harvested while the ears have full moisture while field corn ears are typically harvested after they have been left in the fields to dry. This also requires the use of different equipment. Sweet corn is harvested either by hand or by machine. There are advantages of harvesting both ways and is the decision of the farmer to decide what is most feasible. If picked by hand, anywhere from 20-40 people may be involved in the picking. Ten to twenty people harvest, inspect and sort the corn (Martin, 2011). If harvested by machine, a special sweet corn harvester is required and the most common is a four row picker (Oxbo, 2017). The corn is then transferred into a truck and delivered straight to the processing plant. Sweet corn on the cob has a short shelf life, around three to five days (Fritz, Tong, Wright, & Rosen, 2010). Because of the high moisture content (around 75%), it may begin to mold, so it cannot be stored for long periods of time. Most of the sweet corn in Minnesota for processing is picked by machine (Fritz et al., 2010). With this being the case, it is assumed that the intensity of picking sweet corn will be similar to that of field corn within GREET. In addition, since sweet corn and field corn share similar inputs and field needs, it is assumed that the inputs for farming equipment will be similar. Within the GREET model, the field corn stationary process includes amounts and allocations for electricity, natural gas, gasoline, diesel for non-road vehicles, liquefied petroleum gas, and gasoline blend stock or 6788.04 btu for 24.5 kg of dry field corn. To convert this amount to btu per acre, the United States national average bushels per acre for field corn from 2011-2015 is used. This resulted in an average of 153.62 bushels per acre (USDA National Agricultural Statistics Service, 2016a) (USDA National Agricultural Statistics Service, 2013). This results in 409.13 btu for 2.5 kg of sweet corn on the cob, 450.04 btu for 2.9 kg of sweet corn on the cob and 490.95 btu for 3 kg of sweet corn on the cob.

The sweet corn is taken directly from the field to the processing facility due to the short shelf life. According to a 2006 study prepared for the Minnesota Department of Transportation, most sweet corn is produced in close proximity to a processing facility and generally transported by truck (Cambridge Systematics, SRF Consulting Group, & Cohen, 2006). Based upon this information, an assumption is made that the distance from field to processing facility is between 20 to 100 miles. To gain a better understanding of distance, GREET can be adapted for different mileages. For this study, 20, 40, 60, 80, and 100 miles were used to understand how transportation affects GHG emissions.

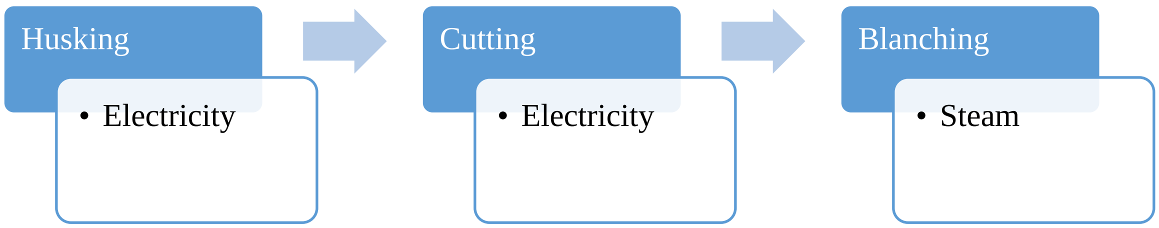
Table 5. Summary of Sweet Corn Farming Inputs

Input Type	Input Amount per 2.5 kg of Sweet Corn on Cob	Input Amount per 2.9 kg of Sweet Corn on Cob	Input Amount per 3.3 kg of Sweet Corn on Cob
Nitrogen (g)	20.3	23.7	27
Phosphate (g)	12.8	14.8	16.8
Potash (g)	16	18.5	21
Insecticide (mg)	16	18.5	21
Herbicide (mg)	190	220	250
Fungicide (mg)	28	32.5	37
Farm equipment inputs (btu)	409.13	450.04	490.95
Miles to Processing Facility	20, 40, 60, 80, 100	20, 40, 60, 80, 100	20, 40, 60, 80, 100

Processing Preparation

Once the sweet corn reaches the processing facility, it is prepped for canning or freezing. The summary of the processing preparation data is found in Table 6. The preparation process includes husking, cutting, and blanching for both canning and freezing. In addition, it is assumed there is no loss throughout the process for this model. A study done in Poland measured the energy inputs for sweet corn processing preparation including husking and cutting. The assumption is made that the energy inputs from this study will be similar to the energy inputs needed for husking and cutting in Minnesota.

Figure 2. Sweet Corn Kernel Preparation Steps and Inputs



Husking is the first step to prepare the sweet corn for further processing. For husking, it is estimated 0.56 kWh per 1,000 kg of sweet corn on the cob (Niedziółka & Szymanek, 2006). This equates to 1.4 Wh for 2.5 kg of sweet corn on the cob, 1.6 for 2.9 kg of sweet corn on the cob, and 1.8 Wh for 3.3 kg of sweet corn on the cob. For cutting, the study estimated 0.94 kWh per 1,000 kg of sweet corn on the cob (Niedziółka & Szymanek, 2006). This equates to 2.35 Wh for 2.5 kg of sweet corn on the cob, 2.72 Wh for 2.9 kg of sweet corn on the cob, and 3.1 Wh for 3.3 kg of sweet corn on the cob. The blanching is typically done post cutting of the kernels and is the last step of the preparation process (D. Smith, Cash, Nip, & Hui, 1997). The amount of steam needed to blanch 1 kg of sweet corn kernels is 0.16 kg (Drake & Swanson, 1986). At this point, the process diverges into the canning process or the freezing process.

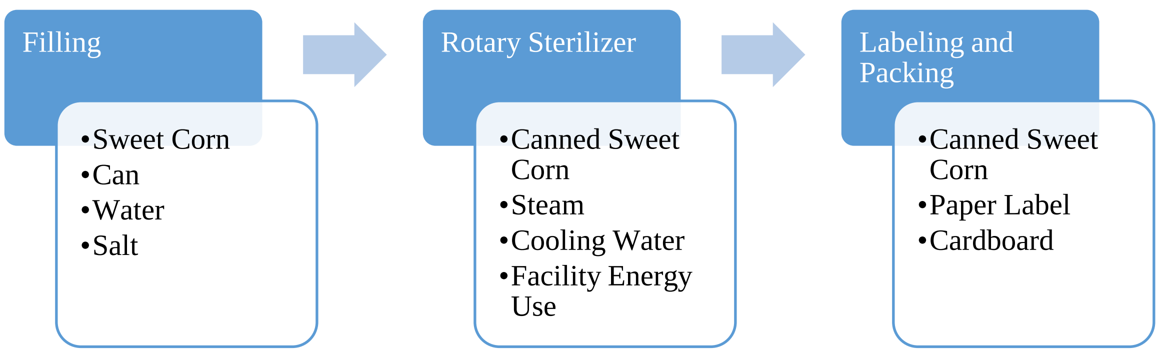
Table 6. Summary of Preparation Processing Inputs

Input Type	Input for 2.5 kg of sweet corn on cob	Input for 2.9 kg of sweet corn on cob	Input for 3.3 kg of sweet corn on cob
Husking (Wh)	1.4	1.6	1.8
Cutting (Wh)	2.35	3.1	3.1
Blanching Steam (kg)	0.16	0.16	0.16

Canning Process

The canning process flow is shown below in Figure 3 and a summary of the data is shown in Table 7. To produce canned sweet corn, there are three main stages of processing. The first stage is filling, the second stage is sterilization, and the final stage is labeling and packing.

Figure 3. Canning Process Steps and Inputs



The filling stage has four inputs which are the sweet corn kernels, the can, water, and salt. The functional unit is 1 kg of processed sweet corn, and the input for the filling stage is assumed to be 1 kg of sweet corn kernels. An assumption is made that there is zero loss in the filling stage of sweet corn kernels. The can is composed of steel. The weight of a 15.25 ounce can is 64.6 grams (Lilienfeld, 2007). This equates to a weight of 198.97 grams of steel (3.08 cans) for 1 kg of processed sweet corn. As previously stated, the amount of water in the can is approximately 25% (Consumer Reports, 2013). This equates to 333 g of water per 1 kg of processed sweet corn. According to the Green Giant website, the amount of sodium in a serving of 123 g of sweet corn is 260 mg (Green Giant, 2017). As this is only Na^+, it is necessary to convert into amount of sodium chloride that is added. There are 38.76 grams of Na^+ in 100 grams of sodium chloride or 38.76%. Therefore, 7.27 g of salt is added to 1 kg of processed sweet corn.

The rotary pressure sterilizer has a long life and therefore, it is assumed that the machinery inputs are negligible when allocated over a 10+ year life span and across many different products in a year. The rotary pressure sterilization process has four main inputs: canned sweet corn, steam, cooling water, and electricity. This critical part of thermal processing of sweet corn needs to be handled with care in order to control the presence of *Clostridium botulinum*. *Clostridium botulinum* is a gram positive bacterium that has the ability to form spores specifically in anaerobic environments and is toxic to humans (Montville & Matthews, 2007). Due to the high pH (6.1) and water activity (>0.97) of sweet corn, the best method of controlling *Clostridium botulinum* is to apply a high heat kill step using a rotary pressure sterilizer (D. Smith et al., 1997).

A rotary pressure sterilizer has two inputs, steam and cooling water (John Bean Technologies, n.d.). John Bean Technologies (JBT) is a reputable rotary pressure sterilizer manufacturer and has published information about rotary pressure sterilizer inputs in a white paper available to the public. The two cases discussed in the white paper are condensed milk and mushrooms. While these products are quite different from sweet corn, the inputs are similar between the two products and an assumption is made that these will be similar inputs for a rotary pressure sterilizer being used to process sweet corn. The amount of steam, as well as cooling water, reported by JBT is already in kg/kg of product.

To determine the energy use of the processing facility, a 10-year average of kWh/metric ton of product provided by General Mills in their 2016 Global Responsibility Report is used (*2016 General Mills Annual Report*, 2016). Additionally, for the best case, the least amount of kWh/metric ton is used and for the worst case, the highest amount of kWh/metric ton is used. While this is not specific to sweet corn, it gives an idea of the energy use for processing. Since the information is reported in kWh/metric ton, this is converted into kWh/kg of product which results in 0.52 kWh for the best case, 0.54 for the average case, and 0.58 for the worst case. It is important to include the sweet corn, water, salt, and packaging in the overall amount of product. For canned sweet corn this is 1584.98 kg. The best-case kWh is 0.83. The average case kWh is 0.86 and the worst-case is 0.92 kWh.

The final process of producing canned sweet corn is the labeling and case packing of the product. The product leaves the rotary pressure sterilization unit and moves on conveyors to receive a label. The label is 2.6 g per can or 8.01 g per 3.08 cans (Lilienfeld, 2007). Next, the cans are packed into a corrugated carton. According to Seneca Harvest States, 15.25 ounce cans are transferred into a corrugated carton that is 12’’x9’’x9’’ with 24 cans per carton (Seneca Foods Corporation, 2017). Uline is a major manufacturer of corrugated boxes and according to the technical data sheet for this box size, the weight of the box is 294 g or 37.73 g per 1 kg of processed sweet corn (Uline, 2017a). GREET does not have paper or corrugated cartons within the model and instead, GHG emissions from published LCAs are used and incorporated into the final model manually.

These are transferred to either a plastic or wooden pallet that is transported to a large ambient warehouse. The information about pallets and the recyclability is varied with no consensus on reuse. Since both frozen and sweet corn would be packed on similar pallets, pallets will be left out of this model for both.

A summary of the canned sweet corn processing inputs is in Table 7.

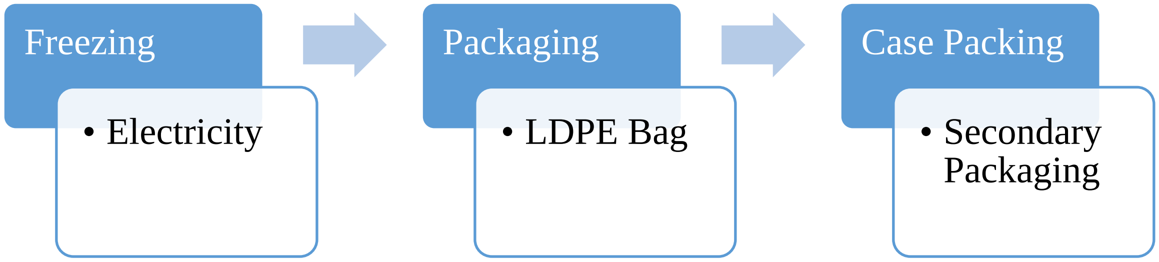
Table 7. Summary of Canning Processing Inputs

Input Type	**Input Amount**
Salt (g)	7.27
Water (g)	333
Can (g)	198.97
Steam (kg/kg product)	0.21
Cooling Water (L/kg product)	0.16
Facility Energy Use (kWh) Best Case	0.83
Facility Energy Use (kWh) Average Case	0.86
Facility Energy Use (kWh) Worst Case	0.92
Corrugated Box (g)	37.73
Label (g)	8.01

Freezing

The process for freezing sweet corn is much simpler than canning sweet corn. The process steps include freezing, packaging, and case packing as listed in Figure 4.

Figure 4. Freezing Process Steps and Inputs



The first step to producing frozen sweet corn is freezing the sweet corn kernels. The main input in this step is energy use of the facility. To determine the energy use of the processing facility, a 10-year average of kWh/metric ton of product provided by General Mills in their 2016 Global Responsibility Report is used (*2016 General Mills Annual Report*, 2016). Additionally, for the best case, the least amount of kWh/metric ton is used and for the worst case, the highest amount of kWh/metric ton is used. While this is not specific to sweet corn, it gives an idea of the energy use for processing. Since the information is reported in kWh/metric ton, this is converted into kWh/kg of product which results in 0.52 kWh for the best case, 0.54 for the average case, and 0.58 for the worst case. It is important to include the sweet corn and packaging in the overall amount of product. For frozen sweet corn this is 1.07 kg. The best-case kWh is 0.56. The average case kWh is 0.58 and the worst-case is 0.62 kWh.

In the next step, the frozen sweet corn is packed into a low density poly-ethylene (LDPE) bag. A 16 ounce LDPE bag is 5.9 g or 13.01 g per 1 kg of processed sweet corn (Lilienfeld, 2007). LDPE is available as a resource in GREET and will be incorporated into the GREET model.

The frozen sweet corn is packed in bags, then into cases. The frozen sweet corn is packed 12 bags per case and the dimensions of the case are 15 3/8'' x 8 ¼''x 6 ¾'' (Seneca Foods Corporation, 2017). This size box is not listed on Uline's website but a box of similar dimensions of 15 3/8'' x 8 3/8'' x 8 5/8'' is available and will be used as a proxy (Uline, 2017b). The individual box weight is 299.37 g or 55.01 g per 1 kg of processed sweet corn. Corrugated cartons are not in the GREET model, and therefore, need to be entered into the model manually. A summary of the freezing inputs is found in Table 8.

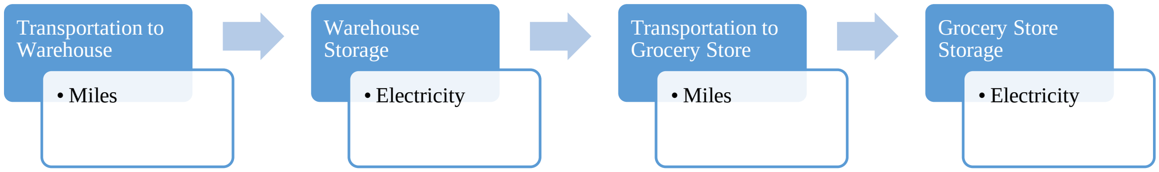
Table 8. Summary of Freezing Processing Inputs

Input Type	**Input Amount**
Facility Energy Use (kWh) Best Case	0.56
Facility Energy Use (kWh) Average Case	0.58
Facility Energy Use (kWh) Worst Case	0.62
LDPE Bag (g)	13.01
Corrugated Box (g)	55.01

Distribution

The distribution is similar for canned and frozen sweet corn. Distribution includes transportation to the warehouse, warehouse storage, transport to the grocery store, and grocery store storage as shown in Figure 5. Discussed first will be canned sweet corn distribution processes.

Figure 5. Process Flow for Distribution of Canned and Frozen Sweet Corn



The canned sweet corn departs the facility on a heavy heavy-duty truck or a tractor trailer and is distributed to an ambient storage warehouse. A maximum weight for a tractor trailer in the United States is 80,000 pounds with maximum dimensions of 48 feet in length, 102 inches in width and 13.6-14.6 feet in height (Federal Highway Administration, 2003). However, most truck weights are not permitted at 80,000 pounds so 44,000 pounds is a more realistic weight (T. Smith, 2016). GREET allocates the transportation based upon the payload or weight of the truck which in this case is 22 tons or 44,000 pounds. The total weight of 3.08 cans 1584.98 g is used to allocate the truck. This includes the individual weights of sweet corn, salt, water, steel cans, labels, and corrugated box. The distance to the warehouse is one of the more varied parts of the life cycle. To compare across the two different types of processed sweet corn, the miles from the processing plant to the warehouse will be 50, 100, 500, 1000 and 1500 miles for both canned and frozen sweet corn.

The next stage of the distribution is the ambient or room temperature storage at a warehouse. An ambient storage warehouse uses approximately 17.58 kWh of energy per year per square foot or 1.47 kWh per month (Energy Star Portfolio Manager, 2016). This energy input includes lighting, heating and ventilation (Energy Information Administration, 2014). This report does not separate natural gas from electricity, instead the data is normalized into btu which eliminates any source point bias from the data. For an ambient storage warehouse, the assumption is made that 100% of the energy is from electricity for ease of modeling. For 3.08 cans of sweet corn takes up an area of approximately 27 square inches or 18.75% of a square foot. Since the data does not account for height of the warehouse, a general assumption is made about the height of the warehouse. For the purposes of this study, it is assumed that the pallet height is no more than 48 inches tall and equates to 5 boxes high with a box height of 9 inches. Given the dimensions of the cans along with the dimensions of the box, two cans are stacked on top of each other per box. This equates to 10 cans in height per pallet per box. With the space allocation, this is 30 cans total (3 across, 2 high, and 5 boxes per pallet). An assumption is made that a racking system in a warehouse can accommodate 4 pallets high as a more conservative estimate. This equals approximately 120 cans. An assumption is made that the amount of time at the warehouse is from 2 to 10 months. This results in 4.6 Wh for 2 months, 13.3 Wh for 6 months and 22 Wh for 10 months.

Transport from the warehouse to the grocery store has a similar allocation as from the food manufacturer to the warehouse storage. The difference is the amount of product that is on the truck, as it is likely that many different products of varying weights and densities will be on a single truck. To make the transportation allocation simpler, it is assumed a tractor trailer has a payload of 22 tons as in previous transportation processes. Similar to the distribution from the processing facility to the warehouse, the truck is allocated by weight of the cans. The total weight for 3.08 cans is 1584.98 g. With no available information on distance from warehouse to grocery stores, the distance tested in the model are 5, 10, 25, 50, 100 and 500 mile increments.

The last stage of the distribution section is storage at the grocery store. The input is electricity and includes lights, heating, cooling, computers, and ventilation. This amounts to 36% of the total energy consumption of 50 kWh per year per square foot as reported by the US Energy Information Administration (Illinois Smart Energy Design Assistance Center, 2011). To allocate this correctly, the number of shelves needs to be accounted for in addition to the width of 3.08 cans. It is assumed that there will be 5 shelves per store in the canned vegetable aisle. Since grocery stores have a small volume of any one product at a given time, an assumption is made that canned sweet corn is on shelf between 7 and 30 days. Using this information, the amount of Wh for 7 days is 13 Wh, for 18 days it is 34 Wh and for 30 days it is 55 Wh.

Table 9. Summary of Distribution Inputs for Canned Sweet Corn

Input Type	**Input Amount**
Miles to Distribution Center	50, 100, 500, 1000, 1500
Electricity at Distribution Center (2 months) (Wh)	4.6
Electricity at Distribution Center (6 months) (Wh)	13.3
Electricity at Distribution Center (10 months) (Wh)	22
Miles to Grocery Store	5, 10, 25, 50, and 100
Electricity at Grocery Store (7 days) (Wh)	13
Electricity at Grocery Store (18 days) (Wh)	34
Electricity at Grocery Store (30 days) (Wh)	55

Frozen sweet corn leaves the facility on a heavy heavy-duty truck or tractor trailer and is distributed to frozen storage warehouses. The total payload and dimension of the truck is the same as canned sweet corn. To allocate the tractor-trailer, the weight of the sweet corn, bag, and corrugated box for the functional unit of 2.21 bags is used. This equates to a weight of 1.07 kg. Again the distance to the warehouse is the more varied part of the life cycle and the one with the least amount of available information. To compare across two types of processed sweet corn, the miles from the processing plant to the warehouse is assumed to be 50, 100, 500, 1000 and 1500 mile increments.

The next stage of the distribution is storage at the frozen warehouse. In this case it is assumed a frozen warehouse is identical to a refrigerated warehouse as this is the classification used by the US Energy Information Administration. A refrigerated warehouse uses 74.03 kWh per square foot per year or 6.17 kWh per square foot per month (Energy Star Portfolio Manager, 2016). For a refrigerated warehouse an assumption is made that the energy input is 100% electricity. Frozen sweet corn has a shelf life of 2 years. Using the same assumptions as canned sweet corn, frozen sweet corn may be housed at a warehouse from 2 to 10 months. A bag of frozen Cascadian Farm sweet corn is approximately 6''x8''. To account for the height of the warehouse, it is assumed that a pallet height is 48 inches and allows for a pallet to be stacked 6 boxes high. Given the dimensions of the box, it is assumed 4 bags are stacked on top of each other within a box. A general assumption is made that a warehouse has a racking system that allows for 4 pallets to be stacked. This equates to 96 bags total by height. With this information, the electricity required for the warehouse storage is 43 Wh for 2 months of storage, 126.5 Wh for 6 months of storage and 210 Wh for 10 months of storage.

The third stage of distribution is transport from warehouse to grocery store. This is similar to transportation from the processing facility to the warehouse. The weight of the sweet corn, bag and corrugated box is used to allocate the truck and this equates to a weight of 1.068 kg. In the absence of information on distance traveled, several distances are tested in the model. The miles to the store will be 5, 10, 25, 50, 100, and 500 mile increments.

The final stage of the distribution is storage at the grocery store and the main input is electricity. The United States Energy Information Administration reported in 2012, the most recent data available, a grocery store or a supercenter consumes on average 50 kWh a year. The main areas that are considered as part of the electricity inputs for frozen sweet corn include refrigeration, lighting, ventilation, cooling, heating, and computers or 89% of the 50 kWh per year or 3.7 kWh per month (Illinois Smart Energy Design Assistance Center, 2011). To allocate electricity, the shelf space needs to be calculated for of 2.21 bags of frozen sweet corn. A bag of frozen Cascadian Farm sweet corn is approximately 6’’x8’’. Since bags may be stacked on top of each other, 48 square inches will be used in the allocation of space. It is assumed that there will be 5 shelves per store in the frozen vegetable aisle. Since grocery stores have a small volume of any one product at a time, an assumption is made that canned sweet corn could be on shelf anywhere from 7 to 30 days. This results in 56 Wh for 7 days of storage, 150 Wh for 18 days, and 244 Wh for 30 days of storage.

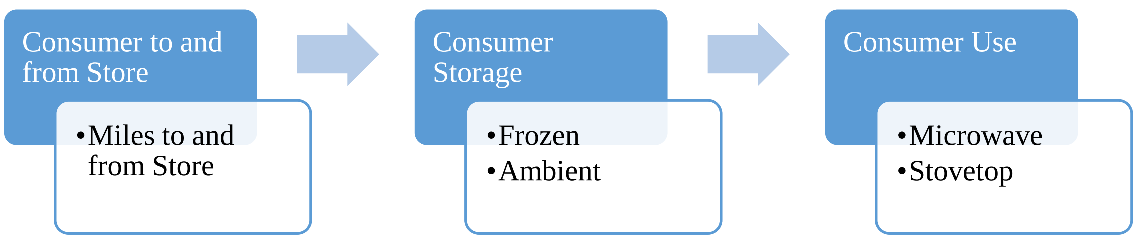
Table 10. Summary of Distribution Inputs for Frozen Corn

Input Type	Amount
Miles to Distribution Center	50, 100, 500, 1000, 1500
Electricity at Distribution Center (2 months) (Wh)	43
Electricity at Distribution Center (6 months) (Wh)	126.5
Electricity at Distribution Center (10 months) (Wh)	210
Miles to Grocery Store	5, 10, 25, 50, and 100
Electricity at Grocery Store (7 days) (Wh)	56
Electricity at Grocery Store (18 days) (Wh)	150
Electricity at Grocery Store (30 days) (Wh)	244

Consumer

The last stage of the life cycle is the consumer inputs. This includes driving to and from the store, home storage (only for frozen), and consumer preparation.

Figure 6. Process Flow for Consumer and Inputs



The first stage of the consumer portion of the life cycle is transportation to and from the grocery store. Consumers travel on average 3.8 miles to the grocery store of their choice or 7.6 miles to and from the store (Ploeg, Mancino, Todd, Clay, & Scharadin, 2015). A previous study conducted by the USDA surveyed households from around the United States that included households on food assistance as well as those without assistance. From this study, it was found that about 88% of respondents used their own vehicle, 6% of respondents borrowed a vehicle from someone else and 6% walked or took public transportation or biked. For the purpose of this study, as most of the households used a vehicle for grocery shopping, car and SUV emissions are included assuming the use of standard unleaded gasoline. In addition, the vehicle use is allocated to 1 kg of processed sweet corn. To allocate the vehicle, the average amount spent on groceries and cost of sweet corn is used. Consumers spend an average of $100.80 a week on groceries (The Hartman Group, 2015). An assumption is made that the average price of frozen and canned vegetables is $1 per package. This is based upon an informal survey of grocery stores in the Minneapolis area. An assumption is made for the vehicle allocation using the cost information that 3% of the total grocery store spend is for canned sweet corn and 2.2% for frozen sweet corn.

The next stage of the life cycle is the storage at the home of the consumer. For ambient canned sweet corn storage, it is assumed that there is no energy requirement for storage at a consumer home. For frozen storage, the electricity needed to run a standard upright refrigerator and freezer is an important component. The average consumer keeps frozen vegetables 122 days in the freezer (Maxey & Oliver, 2010). This data is from a study in the UK. For the purposes of this study, it is assumed that consumers in the US have similar behaviors as consumers in the UK. For the best case scenario, it is assumed that the consumer purchases frozen sweet corn and consumes it without storage. For the average case scenario, it is assumed that frozen sweet corn is stored for 61 days (half of the average from the study in the UK). Using an appliance estimator from the US Department of Energy, it is estimated a typical freezer has a wattage of 225 watts and is used 24 hours a day for 61 days (U.S. Department of Energy, 2013). The total amount of electricity used for this time frame is 109.8 kWh. On the Department of Energy website, the cubic footage of the refrigerator is not provided. An average sized refrigerator is 14 ft^3 or 24192 in^3. The dimensions of one package of frozen sweet corn are 6''x8''x2''. Using this information, the consumer freezer is allocated to the functional unit of 2.21 bags of frozen corn. This results in 0.96 kWh of electricity for 61 days of storage. The same appliance estimator, refrigerator and package dimensions are used to find the electricity for 122 days of storage. This results in 1.92 kWh of electricity for 122 days of storage.

The last stage in the life cycle is the consumer preparation. The two main appliances used to heat both canned sweet corn and frozen sweet corn are microwaves and stovetop. For one can of sweet corn, the microwave directions say heat for 2 to 3 minutes in the microwave but for stove top preparation, no heating time is provided. Only microwave preparation will be considered for consumer preparation for canned sweet corn. Using the appliance energy calculator from the US Department of Energy, the Wh to heat 1 kg of canned sweet corn are 5.12 Wh and 7.70 Wh (U.S. Department of Energy, 2013). For the microwave oven the wattage is assumed to be 1200 watts.

For frozen sweet corn, Cascadian Farms lists times and inputs for both microwave and stove top. For a 1200-watt microwave, it is suggested a cook time of 6 to 6.5 minutes per 16-ounce package. This equates to 13.23 and 14.33 minutes for 1 kg of processed sweet corn. The Wh are 9.18 to 9.95. For the stove top, it is assumed to be a 1200-watt burner. Cascadian Farms suggests 7 to 10 minutes for a cook time. This equates to 15.44 to 22.05 minutes for 1 kg of processed sweet corn. The Wh are 12.86 to

18.38. A summary of the consumer inputs for both frozen and canned sweet corn are shown in Table 11.

Table 11. Summary of Consumer Inputs

Input Type	Amount
Miles to and from Grocery Store	7.6
Frozen Storage Best Case (kWh)	0
Frozen Storage Average Case (kWh)	0.96
Frozen Storage Worst Case (kWh)	1.92
Microwave Heating Canned Corn 2 minutes (Wh)	5.12
Microwave Heating Canned Corn 3 minutes (Wh)	7.70
Microwave Heating Frozen Corn 6 minutes (Wh)	9.18
Microwave Heating Frozen Corn 6.5 minutes (Wh)	9.95
Stovetop Heating Frozen Corn 7 minutes (Wh)	12.86
Stovetop Heating Frozen Corn 10 minutes (Wh)	18.38

Other Data

In addition to all the inputs, one critical piece of information for this life cycle analysis is the energy mix that is used to generate the electricity in the different portions of the LCA. For this analysis, the energy mix for Minnesota will be used wherever electricity is an input. Xcel Energy is a main energy provider in Minnesota. The energy mix used by Xcel Energy for the Midwest region is shown below in Table 12 (Xcel Energy, 2016). This energy mix will be used for all electricity in this LCA.

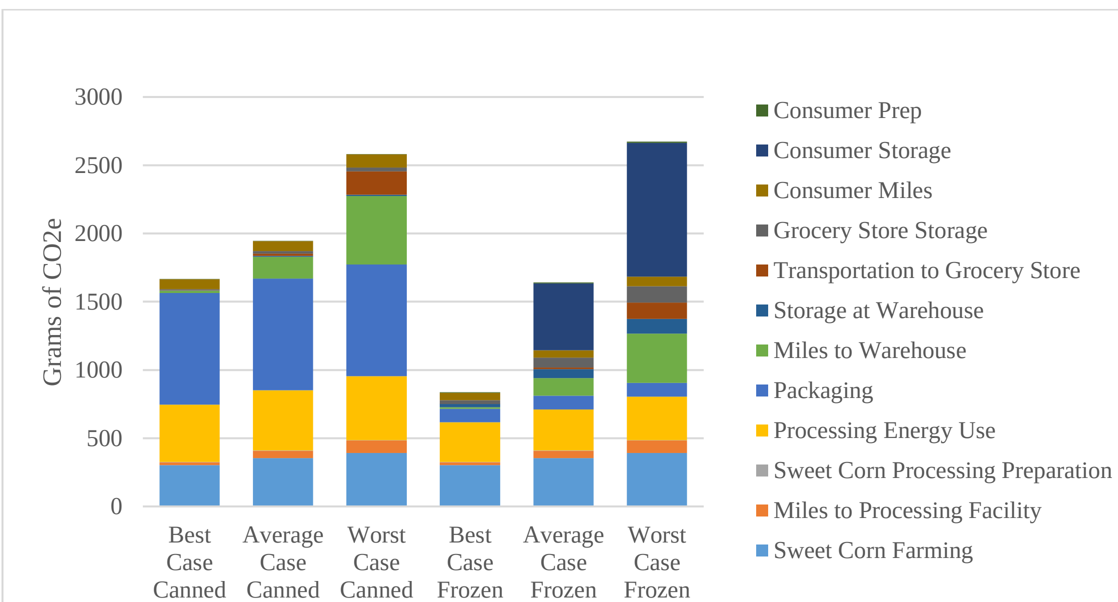
Table 12. Energy Mix for Minnesota

Energy Type	Percentage
Coal	34%
Natural Gas	15%
Nuclear	27%
Wind	14%
Hydro	7%
Biomass	3%

Results

The output from the GREET model is GHG emissions for individual processes and scenarios. The results of the analysis are classified as best case, average case and worst case. The best case includes the least amount of sweet corn on the cob needed to produce 1 kg of processed sweet corn (*i.e.*, the most kernels by weight per cob), the shortest distance traveled for the transportation processes, and the least amount of time in storage. The average case includes the average amount of sweet corn on the cob, the medium distance traveled and an average storage time. The worst case includes the most amount of sweet corn on the cob needed to produce 1 kg of processed sweet corn (*i.e.*, the least kernels by weight per cob), the furthest distance traveled, as well as the most amount of time in storage. This allows a comparison of the range of emissions from least to most. The results for the best, average and worst case scenarios are shown in Figure 7.

Figure 7. Best, Average and Worst Cases for Canned and Frozen Sweet Corn

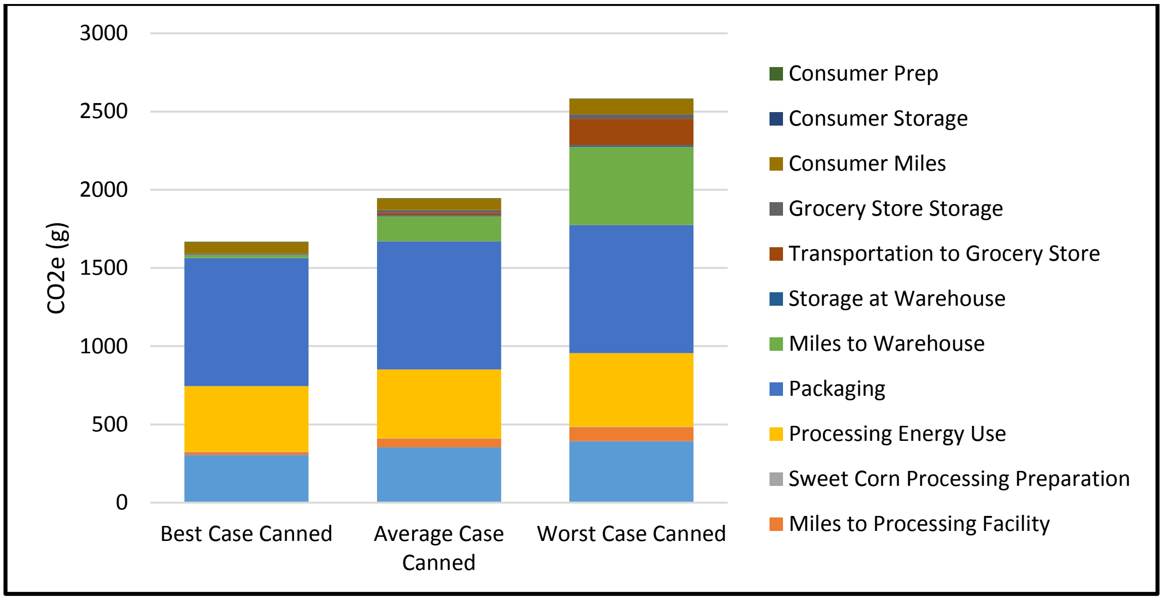


Canned sweet corn has higher emissions than frozen sweet corn in the best and averages cases while for the worst-case scenario, canned sweet corn has fewer emissions than frozen sweet corn by 90 g of CO_2e. The summary of emissions for canned sweet corn will be discussed followed by a summary of emissions for frozen sweet corn. A comparative analysis of sweet corn production, distribution, storage, and consumer inputs follows.

Summary of Canned Sweet Corn GHG Emissions

The summary of GHG emissions of the best, average and worst case scenarios for canned sweet corn is presented in Figure 8. The sweet corn farming, transportation processes, and canning process energy use drive the difference of about 915 g of CO_{2e} between the best and worst cases. The greater the number of kernels per ear of corn influences the GHG emissions for sweet corn farming with a difference of about 90 g of CO_2e. In addition, the fewer miles the canned sweet corn travels, the less overall emissions. Since Minnesota is one of the largest producers of sweet corn, the shipping of canned corn across the country is part of producing in a central location. For both the best, average and worst cases, the packaging is the largest contributor to the emissions.

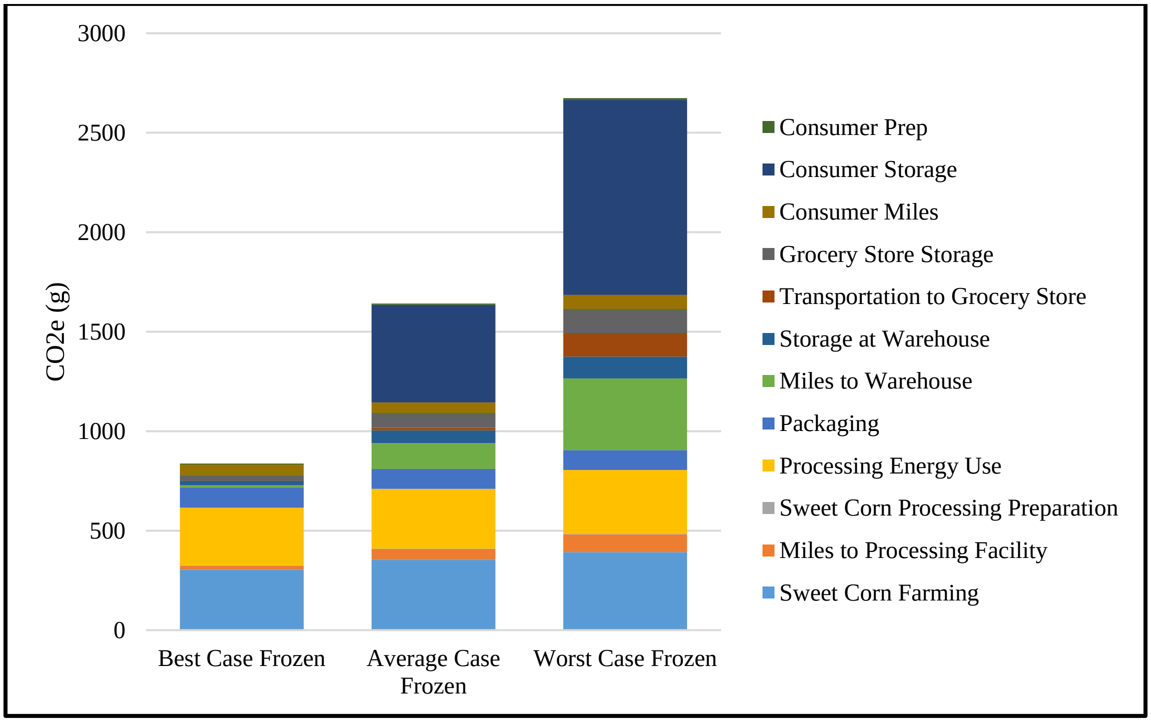
Figure 8. Summary of GHG Emissions for Canned Sweet Corn



Summary of Frozen Sweet Corn GHG Emissions

The summary of frozen sweet corn GHG emissions are presented in Figure 9. Similar to canned sweet corn, frozen sweet corn is compared by best, average and worst cases with the same parameters for each. For the consumer storage, the best case has zero emissions as it is not stored in a consumer freezer. The average case is stored for 61 days and the worst case is stored for 122 days. This is the main driver in the difference of GHG emissions between the three cases with a difference of 980 g between the best case and the worst case. Sweet corn farming and transportation contributes a difference of about 570 g of GHG emissions between the best and worst cases. Similar to canned sweet corn, the greater the number of kernels per cob greatly reduces the impact of farming to the overall emissions.

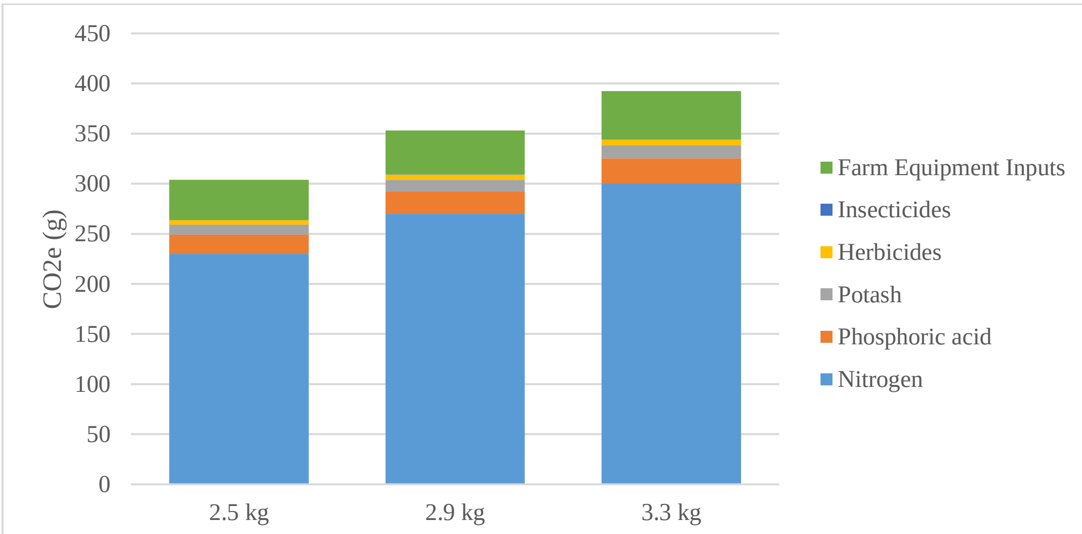
Figure 9. Summary of GHG Emissions for Frozen Sweet Corn



Sweet Corn Production

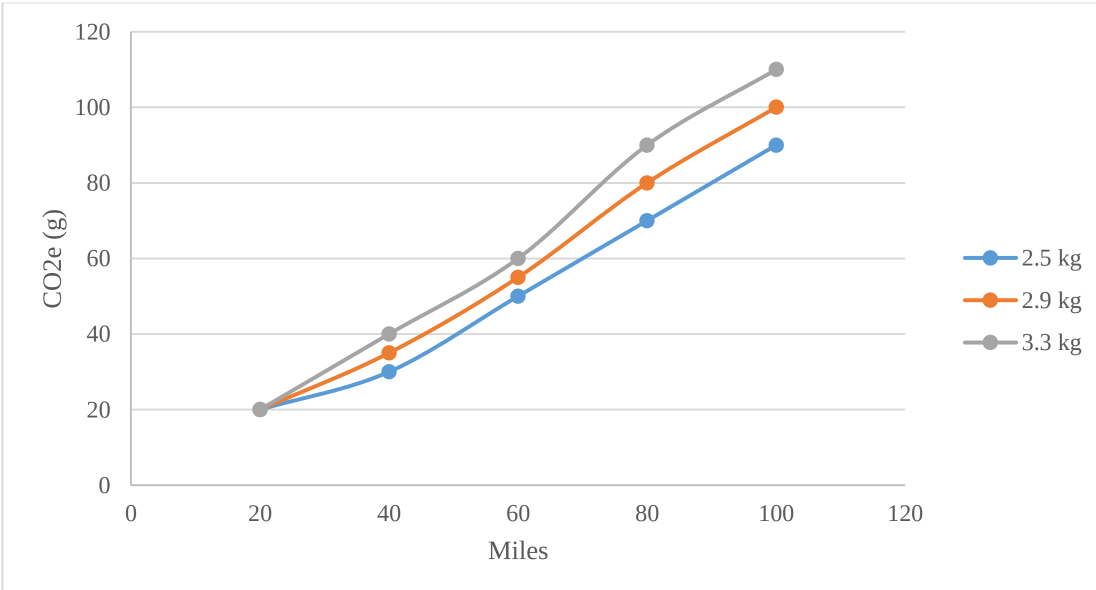
Sweet corn production includes farming, transportation to the processing facility and the processing preparation. These three phases of the life cycle are the parts of the life cycle that include the sweet corn on the cob. The range of GHG emissions for sweet corn farming is from 303.82 g to 392.45 g of CO_2e as presented in Figure 10. The largest contributor to these GHG emissions is nitrogen fertilizer with 230 g and 300 g of CO_2e for 2.5 kg and 3.3 kg of sweet corn on the cob respectively. This accounts for almost two thirds of the GHG emissions within this part of the process. The high GHG emissions is the result of the potential to produce nitrous oxide, which is about 300 times more potent a GHG than CO_2 (EPA, 2016). The remaining third of the GHG emissions from sweet corn farming are from nine unique inputs. The largest of the emissions is from diesel fuel. Diesel is used primarily for farm equipment such as tractors, which are used for seeding, tilling, applying fertilizer and harvesting.

Figure 10. GHG Emissions from Sweet Corn Production



The next phase of the life cycle is the transportation of the sweet corn on the cob from the field to the processing facility. The summary of GHG emissions for the transportation is listed in Figure 11. The greater the distance, the larger amount of GHG emitted. With this in mind, the transportation from the field to the processing facility is still not a large part of the overall life cycle for canned or frozen sweet corn. Most of the sweet corn grown in Minnesota for processing is grown in close proxmity to the facilities that process the sweet corn. The reasons for this could be cost as well as the short shelf life of sweet corn.

Figure 11. GHG Emissions from Transportation to Processing Facility



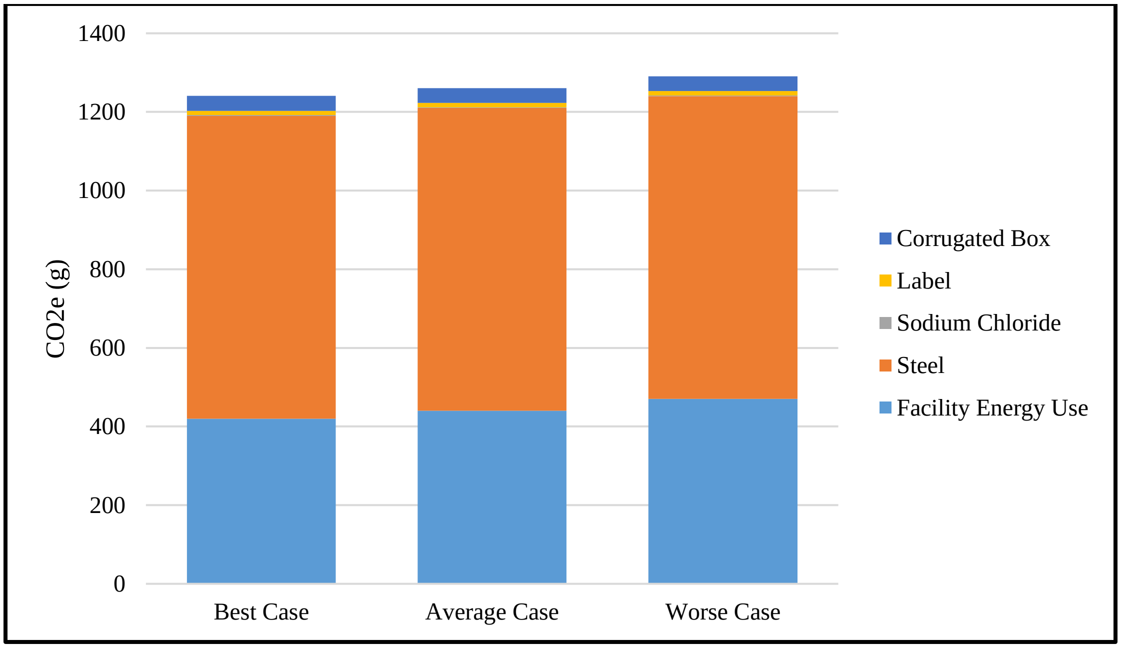
The next phase of the life cycle is the sweet corn processing preparation where the only input that generates any GHG emissions is electricity. For 2.5 kg of sweet corn on the cob, the amount is 1.91 g of CO_2e and for 3.3 kg of sweet corn on the cob, this amounts to 2.49 g of CO_2e. Overall, the sweet corn processing preparation accounts for less than 0.1% of the total life cycle. This is due to the low intensity of the process.

The 2.5 kg of sweet corn on the cob to obtain 1 kg of processed sweet corn is more efficient and as a whole has less GHG emissions for all three parts of the process. There is limitation to this data and companies that produce canned or frozen sweet corn may have more specific data as to the conversion rate of sweet corn on the cob to kernels of sweet corn.

Canning Process

The summary of the GHG emissions for the canning process is shown in Figure 12. There are a few inputs not included within the table. Water, steam, and cooling water do not generate GHG emissions within GREET.

Figure 12. GHG Emissions for Canned Processing



The two inputs tabulated manually are the label and corrugated box. For the label portion, GHG emissions from a study done by the American Forest and Paper Association are used to calculate emissions. Within this LCA study, the life cycle inventory is bound from fiber procurement to the end of life of the paper. Four different types of paper are included in the study. The paper used for canned sweet corn is the coated mechanical paper (magazine paper) as this is most similar to the can label. The study found the emissions for coated mechanical paper to be 1,393 kg of CO_2e for a bone dry short ton (American Forest & Paper Association, 2015). This equates to a GHG emission of 11.15 g for 8.01 g of labels.

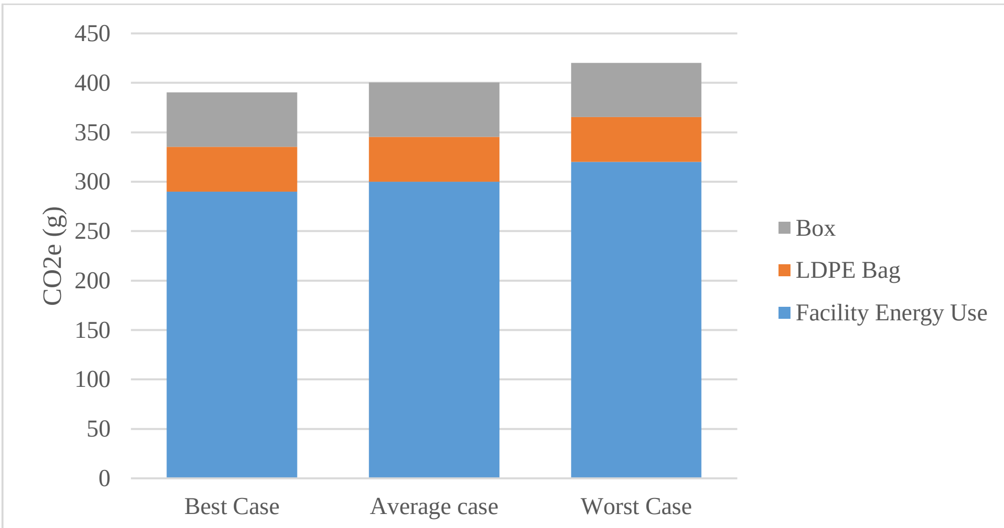
The second input to be tabulated manually is the corrugated box. A study from 2010 evaluated the production of corrugated boxes that was prepared for the Corrugated Packaging Alliance by PE-America and Five Winds International who are sustainability and LCA consultants. This study has four main phases of containerboard including virgin fiber production, converting, transportation, and end of life. For the end of life, this LCA includes about 60% of recycled cardboard into the model that is given as a credit within the LCA. There are approximately 1.01 kg of CO_2e per 1 kg of corrugated cardboard (PE-Americas & Five Winds International, 2010). Applying the information from the corrugated study to canned sweet corn, this equates to 37.73 g of CO_2e for the corrugated box.

Overall, the largest GHG contributor in the packaging is the steel for the cans. The steel making process is quite intensive with many different inputs and is the largest contributor within the life cycle of GHG emissions for canned sweet corn. The facility energy use is also a large contributor and there is not a large difference between the best, average, and worst cases. Sodium chloride is also added in small amounts which accounts for its small overall impact to the life cycle.

Freezing Process

The summary of the GHG emissions for the freezing process is summarized in Figure 13. As stated in the canning process section, the corrugated box needs to be tabulated manually. Using that same information, the corrugated box contributes 55.01 g of CO_2e. The facility energy use is the largest contributor in all three scenarios of GHG emissions in the freezing process.

Figure 13. GHG Emissions for Frozen Processing



The processing steps for the two types of sweet corn are quite different. Canned sweet corn has around three times the emissions as frozen sweet corn for the worst-case scenario. In the entire life cycle, the processing and packaging steps are the largest contributor to GHG emissions for canned sweet corn. In both canned and frozen sweet corn, the packaging accounts for a large portion of the emissions. The magnitude of this is much larger for canned sweet corn due to the intensity of the process to produce a steel can. In addition, the emissions are higher for canned sweet corn because it takes more packages to equate to 1 kg of processed sweet corn than for frozen corn as canned sweet corn has additional water.

Canned and Frozen Distribution

The summary of the GHG emissions for transportation to the warehouse is summarized in Figure 14 and transportation to the grocery store in Figure 15. The further the distance traveled, the greater the GHG emissions. The distance of 1500 miles covers the greatest distance from Minnesota to the coasts that the canned sweet corn can travel. The water and additional packaging contributes to about 500 grams of extra weight to the functional unit of 1 kg of processed sweet corn.

The difference between canned and frozen sweet corn transportation is due to the difference in weight per 1 kg of processed sweet corn. The water and additional packaging contributes to about 500 grams of extra weight for canned sweet corn. Added up over great distances, that additional weight makes a larger impact.

Figure 14. GHG Emissions for Transportation to Warehouse

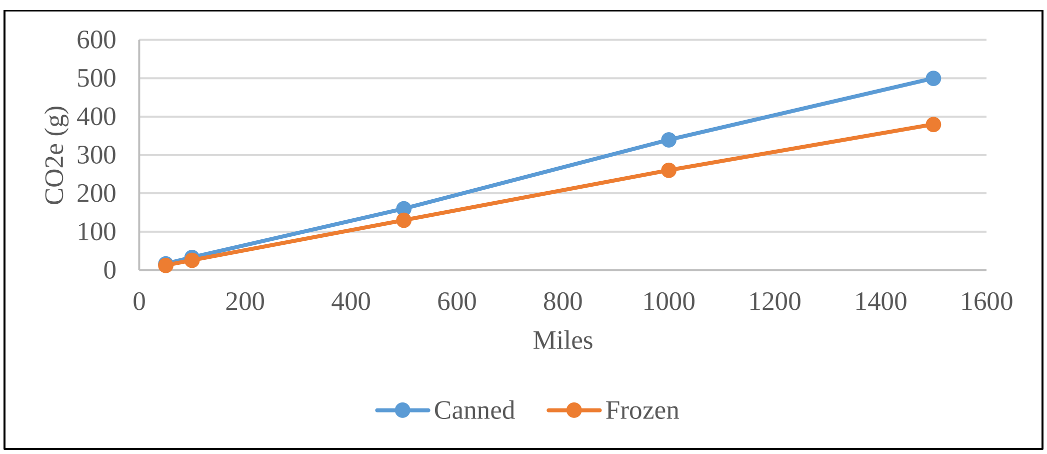
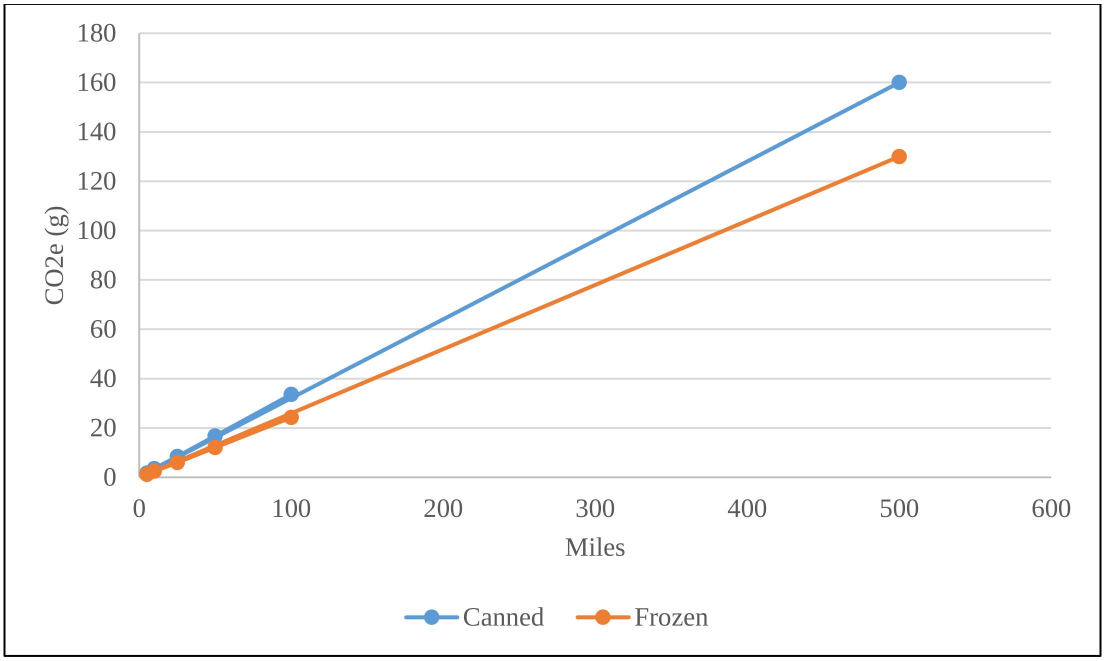


Figure 15. GHG Emissions for Transportation to Grocery Store



The GHG emissions for warehouse storage is summarized in Figure 16 and for grocery store storage in Figure 17. When comparing canned and frozen sweet corn, there is a difference of about 100 g of CO_2e for the worst case warehouse storage. It takes more electricity to keep a warehouse at freezing temperatures than at ambient temperatures. It is important to maintain low temperatures to prevent spoilage in frozen sweet corn. The grocery store storage is similar in differences between canned and frozen sweet corn.

Figure 16. GHG Emissions for Warehouse Storage

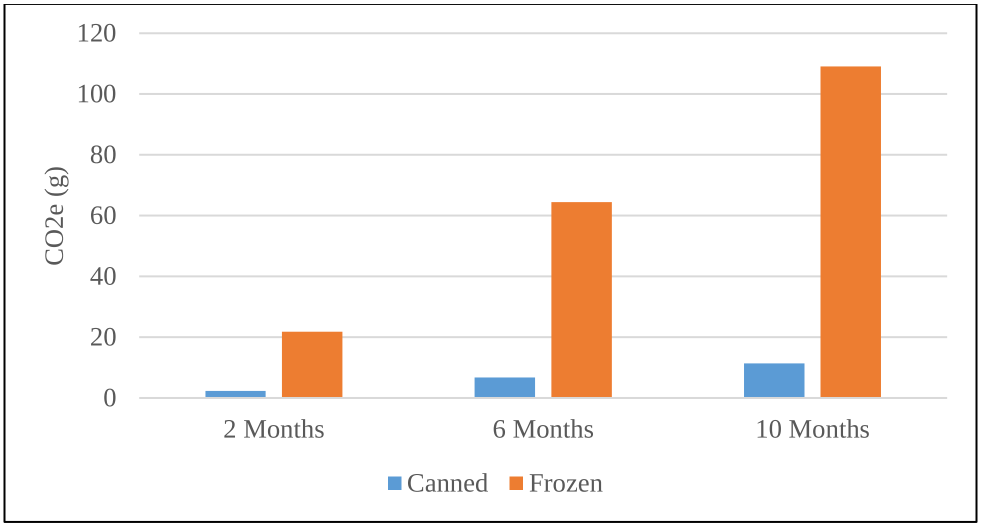
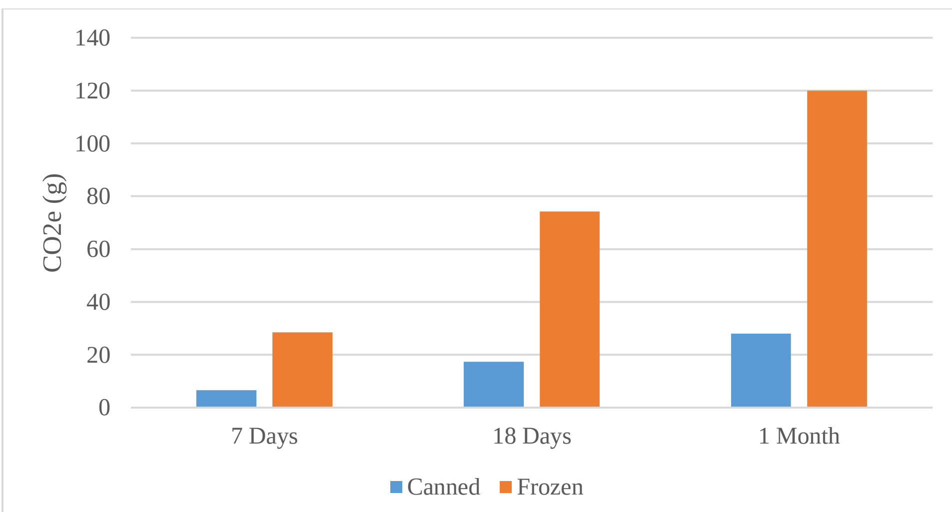


Figure 17. GHG Emissions for Grocery Store Storage



Canned and Frozen Consumer Inputs

Figure 18 provides a summary of the GHG emissions for canned sweet corn consumer inputs and Figure 19 for frozen sweet corn. For canned sweet corn the largest contributor to GHG emissions is driving to and from the store in either a car or SUV. The largest contributor for frozen sweet corn is the electricity for the refrigerator for the average and worse-case scenarios. For the average case, it is assumed that a consumer stores frozen corn for 61 days and for the worst case, 122 days. This accounts for 490 g of CO_2e for the average case and 980 g for the worst case. Due to the assumptions made about the length of time consumers store frozen sweet corn, additional storage time points of one and two years are tested in the model. If a consumer stores frozen sweet corn for one year, this results in almost 3 kg of CO_2e and for two years almost 6 kg of CO_2e. If used, for the worst case, frozen sweet corn would have three times the amount of GHG emissions than canned sweet corn for the worst case. In addition, the electricity in this case is based upon the Minnesota electricity mix and the GHG emissions could be higher or lower in other states depending on the energy mixes used.

Figure 18. GHG Emissions of Consumer Inputs for Canned

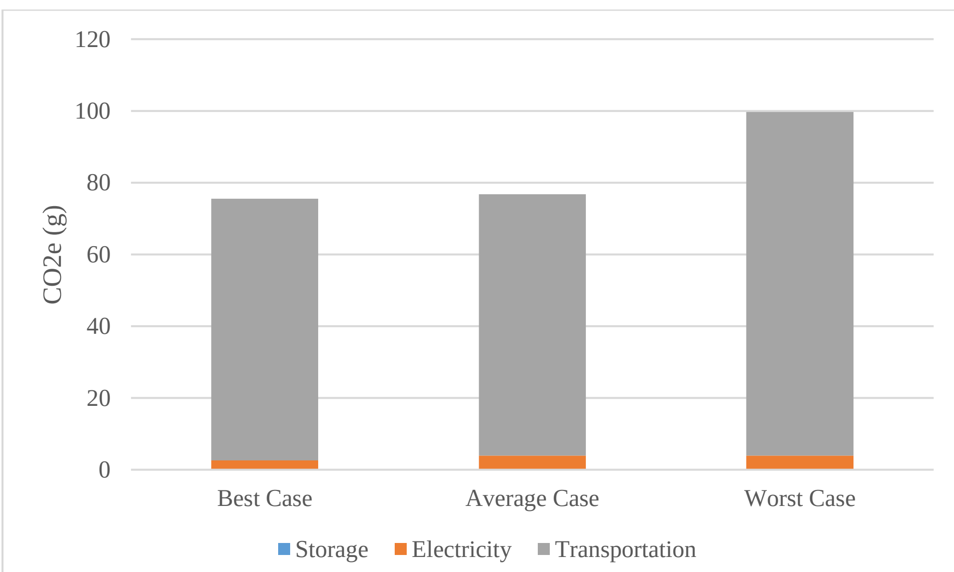
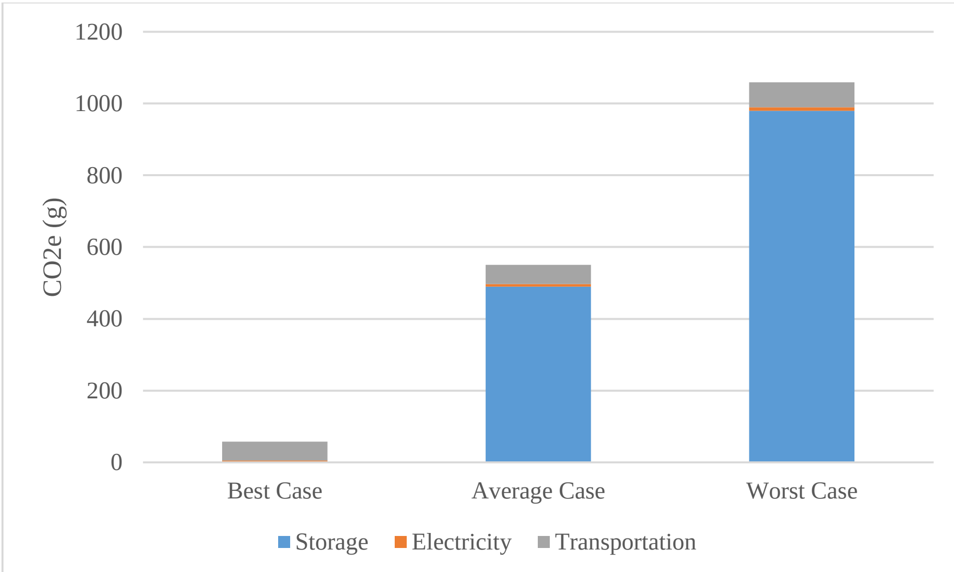


Figure 19. GHG Emissions of Consumer Inputs for Frozen



Discussion

The largest contributor to GHG emissions for canned sweet corn is in the processing stage whereas for frozen sweet corn it is in consumer storage. There are many stakeholders within the life cycle of canned and frozen sweet corn including growers, food manufacturers, transportation companies, retailers and consumers. Each stakeholder has the potential to reduce GHG emissions in different ways for both canned and frozen sweet corn.

The sweet corn production step is either second or third for GHG emissions for both canned and frozen sweet corn depending on the assumptions made. The largest contributor in sweet corn farming is in added nitrogen. One way to reduce the GHG emissions would be to reduce the amount of nitrogen applied. Nitrogen aids in increasing yield. To offset the need for additional nitrogen, nitrogen fixing crops such a legumes or other cover crops could be use in crop rotation. Much of the sweet corn grown in Minnesota is grown under contract from various companies (Meersman, 2016). Since sweet corn is grown under contract, this is where large food companies could have an impact. They could provide incentives to growers to reduce the amount of fertilizers and pesticides that are used. They could provide incentives for no-till or reduced till management practices. Food companies could also take focus on food that is cultivated but not brought to harvest. Approximately 5% of the acres of sweet corn were left in the field, which amounts to 7.4 million pounds. This was largely due to the inability to process the sweet corn fast enough. Some solutions could include additional assets to process the sweet corn or partnering with non-compete companies that have the needed assets. Another solution would be to simply contract for less sweet corn, although this would run the risk of underproduction in years with low crop yields.

Transportation is a major aspect of the life cycle and includes four separate transportation steps. The transportation steps in the life cycle have the most assumptions associated with them because transportation data is difficult to obtain. An article from 1996 in the Transportation Journal states “Time-based transportation strategies can be important sources of competitive advantage and customer value” (Morash & Ozment, 1996). This rings true today and makes it more difficult for clear assumptions to be made. In general, the less miles that the sweet corn travels, the less GHG emissions. One way to mitigate some of the GHG emissions would be to grow sweet corn closer to the final product destination. This could potentially take many food miles out of the product life cycle and help reduce overall GHG emissions, but there may be tradeoffs elsewhere in the life cycle. This case would also necessitate the required assets for processing. Another possibility for companies to consider is working with the truck manufacturing industry to improve fuel efficiency. This could greatly reduce the amount of emissions even when traveling larger distances.

Facility energy use and packaging are a large part of the GHG emissions for both canned and frozen sweet corn. Reducing the energy use in the facility does have some impact on the overall GHG emissions and a further reduction has the potential to reduce the overall impact. Packaging is another large portion of the GHG emissions particularly for canned sweet corn. Reducing the amount of packaging can be difficult due to food safety regulations and processing conditions. Food companies could partner with packaging suppliers to work through these challenges, and through the upstream steps that contribute to the GHG emissions. For frozen sweet corn, it would be advantageous if the packaging could be recycled.

Overall, the warehouse and grocery store storage is generally low in emissions for both canned and frozen sweet corn. For both areas to improve their emissions, warehouses and grocery stores could look at the possibility of clean energy sources such as wind, solar, or nuclear.

Frozen consumer storage is the largest contributor to GHG emissions for frozen sweet corn and is an important leverage point for reducing overall emissions. More research on consumer behavior and the length of time frozen sweet corn is stored would aid in refining this study as the information used is from the UK. A better understanding of consumer behavior in the United States would help with these assumptions and would allow for continued refinement of this LCA. Consumer storage is not an area that many commonly consider as having GHG emissions, and it puts an onus on consumers to be mindful of their contribution to the life cycle. The topic of climate change or greenhouse gas emissions has become highly politicized, making involvement difficult for large food manufacturing companies not wishing to alienate consumers. Large food companies could start small with brands or products such as organic frozen sweet corn. On the packaging, they could educate consumers about storing frozen sweet corn and its impact on the environment. They could also offer solutions such as storing for a shorter amount of time or purchasing a more efficient refrigerator or freezer. Purchasing a more efficient refrigerator or freezer is more likely to have a greater impact over time than storing individual foods for a shorter amount of time. Another way for large food manufacturing companies to present this information could be what the financial benefit would be for the consumer. By moving to a more efficient refrigerator/freezer, they could pay less in electric bills and this would give a clear financial benefit to the consumer.

For canned sweet corn, the consumer use stage is minimal. The biggest impact here is in the recycling of the final packaging. The rate of recycling steel cans is quite high at 70.7% (EPA, 2014), but there is room for improvement. One of the main issues is that many municipalities do not have recycling programs particularly in rural areas. Packaging and food companies could work with counties or small towns to establish recycling programs. This would give additional recycled feedstock back to the producer to use not just for cans but also corrugated boxes, paper, and other packaging types.

Another idea for large food manufacturers is to consider about how else to offset GHG emissions if it is not possible to do so within a specific life cycle stage, such as by partnering with conservation non-profit organizations or purchasing carbon offsets. Coordinated actions of a coalition or consortium of interested individuals from each life cycle step could be a powerful means of reducing GHG emissions.

Conclusions

In a study from the Barilla Center for Food and Nutrition done in conjunction with The Economist Intelligence Unit, the United States ranks as 11 of 25 countries using sustainability rankings that measures sustainable agriculture, food loss and waste, and nutrition challenges (The Economist Intelligence Unit, 2017). In the same report, the United States is 19^{th} overall in sustainable agriculture while countries such as Mexico, Brazil, and Ethiopia rank higher (The Economist Intelligence Unit, 2017). These rankings, particularly in sustainable agriculture, demonstrate there is room for improvement. To reduce GHG emissions as many food manufacturers and retailers have pledged to do, it is important to understand where GHG emissions occur within the food chain. Life cycle analysis is one tool that can help achieve this.

This thesis helps build the knowledge base of GHG emissions of food products. It shows that there is a considerable room for improvement in the life cycles of canned and frozen sweet corn. Continued refinement of this work would aid in the overall body of knowledge of LCAs of food products. Furthermore, the method of analysis described in this paper can be applied to other canned and frozen vegetables, and to other foods more broadly, to continue to expand our knowledge base of the environmental effects of food.

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Appendix

Table 13. Summary of GHG emissions for Canned Sweet Corn

Process Step	Best Case (g of CO_2e)	Average Case (g of CO_2e)	Worst Case (g of CO_2e)
Sweet Corn Production	303.82	353.17	392.45
Miles to Processing Facility	20	55	90
Sweet Corn Processing Preparation	1.91	2.2	2.49
Canning Process Energy Use	420	440	470
Packaging	818.88	818.88	818.88
Miles to Warehouse	16.77	160	500
Storage at Warehouse	2.34	6.77	11.20
Transportation to Grocery Store	1.68	16.77	170
Grocery Storage	6.62	17.31	28
Consumer Miles	72.9	72.9	95.76
Consumer Preparation	2.61	3.92	3.92
Total	**1667.53**	**1946.92**	**2582.7**

Table 14. Summary of GHG Emissions for Frozen Sweet Corn

Process Step	Best Case (g of CO_2e)	Average Case (g of CO_2e)	Worst Case (g of CO_2e)
Sweet Corn Farming	303.82	353.17	392.45
Miles to Processing Facility	20	55	90
Sweet Corn Processing Preparation	1.91	2.2	2.49
Freezing Process Energy Use	290	300	320
Packaging	100.33	100.33	100.33
Miles to Warehouse	12.1	130	360
Storage at Warehouse	21.89	64.40	109.06
Transportation to Grocery Store	1.21	12.11	120
Grocery Store Storage	28.51	74.26	120
Consumer Miles	53.46	53.46	70.22
Consumer Storage	0	490	980
Consumer Prep	4.67	6.55	9.35
Total	**837.90**	**1641.48**	**2673.90**

Table 15. GHG Emissions for Sweet Corn Production

	CO_2e (g) for 2.5 kg of Sweet Corn on the Cob	CO_2e (g) for 2.9 kg of Sweet Corn on the Cob	CO_2e (g) for 3.3 kg of Sweet Corn on the Cob
Nitrogen	230	270	300
Phosphoric acid	19.2	22.2	25.2
Potash	10.01	11.58	13.14
Herbicides	4.39	5.09	5.78
Insecticides	0.37	0.43	0.49
Diesel	19.8	21.79	23.77
Gasoline	6.08	6.7	7.3
Natural Gas	4.77	5.25	5.72
Liquefied Petroleum Gas	6.4	7.05	7.69
Electricity	2.8	3.08	3.36
Total	**303.82**	**353.17**	**392.45**

Table 16. GHG Emissions for Transportation from Field to Processing Facility

Miles	g of CO_2e for 2.5 kg of Sweet Corn on the Cob	g of CO_2e for 2.9 kg of Sweet Corn on the Cob	g of CO_2e for 3.3 kg of Sweet Corn on the Cob
20	20	20	20
40	30	35	40
60	50	55	60
80	70	80	90
100	90	100	110

Table 17. GHG Emissions for Canning Packaging and Facility Energy Use

Input	CO_2e (g)
Facility Energy Use Best Case	420
Facility Energy Use Average Case	440
Facility Energy Use Worst Case	470
Steel	770
Sodium Chloride	1.89
Label	11.15
Corrugated Box	37.73

Table 18. GHG Emissions for Freezing Process and Packaging

Input	CO_2e (g)
Facility Energy Use Best Case	290
Facility Energy Use Average Case	300
Facility Energy Use Worst Case	320
LDPE Bag	45.32
Box	55.01

Table 19. GHG Emissions for Transportation to Warehouse

Miles	Canned CO_2e (g)	Frozen CO_2e (g)
50	16.77	12.76
100	33.53	25.52
500	160	130
1000	340	260
1500	500	380

Table 20. GHG Emissions for Transportation to Grocery Store

Miles	Canned CO_2e (g)	Frozen CO_2e (g)
5	1.68	1.21
10	3.47	2.42
25	8.38	5.97
50	16.77	12.1
100	33.53	24.2
500	170	120

Table 21. GHG Emissions for Warehouse Storage

	Canned CO_2e (g)	Frozen CO_2e (g)
Electricity 2 months	2.34	21.77
Electricity 6 months	6.77	64.40
Electricity 10 months	11.34	109.0625

Table 22. GHG Emissions for Grocery Store Storage

Input	Canned CO_2e (g)	Frozen CO_2e (g)
Electricity 7 days	6.59	28.51
Electricity 18 days	17.31	74.26
Electricity 30 days	28	120

Table 23. GHG Emissions for Consumer Sweet Corn Inputs

Input	Canned CO_2e (g)	Frozen CO_2e (g)
Electricity for Refrigeration	N/A	0, 490, and 980
Electricity for microwave (2 min)	2.61	N/A
Electricity for microwave (3 min)	3.92	N/A
Electricity Microwave (6 min)	N/A	4.67
Electricity Microwave (6.5 min)	N/A	5.07
Electricity Stove (7 min)	N/A	6.55
Electricity Stove (10 min)	N/A	9.35
Car	72.9	53.46
SUV	95.76	70.22