# Carbon Footprint of U.S. Honey Production and Packing

## Report to the National Honey Board

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## 1. Introduction

This report summarizes the results of a project to quantify the "carbon footprint" of a kilogram of processed honey produced in the U.S., as defined by the sum of greenhouse gas emissions created throughout the life cycle of honey production and processing, excluding consumer-related stages.

## 2. Life Cycle Assessment Methodology

The calculations presented here are based on a Life Cycle Assessment (LCA) of beekeeping activities and honey packing. LCA is a well-developed, comprehensive method for estimating and analyzing the environmental impacts of products and services.[1] LCA analyzes a product from cradle to grave, i.e., from raw materials extraction through production and use, to waste management and disposal.[2] We primarily used a process-based LCA approach, which directly measures and tracks all material and energy flows through all the phases in the life cycle of the product. Our LCA methodology conforms to the standards of the International Organization for Standardization (ISO) 14040 series on LCA, with the exception of peer review. A peer reviewed journal article will be developed and serve as a surrogate for an ISO peer review process.

A standard LCA framework consists of the following distinct steps:

1. Goal and scope definition, which includes defining the system boundary and functional unit of analysis
2. Life cycle inventory, which includes identification and quantification of all inputs at each stage of the life cycle included within the system boundary
3. Impact analysis - in this study, greenhouse gas emissions at each stage of the life cycle are calculated in terms of carbon dioxide equivalents ($CO_2e$)
4. Interpretation of impacts analysis

### *2.1 Goal and scope definition*

Goal and scope definition includes defining the system boundaries and the functional unit of analysis. The goal of this project was to establish a life cycle inventory for U.S. honey production and processing, and to estimate the greenhouse gas emissions associated with honey production activities. In addition, we identified phases that contribute the most to total emissions over the honey production life cycle. Study outcomes can help beekeepers and honey processors improve environmental performance by identifying hotspots in their production process and then targeting strategies to reduce emissions from the identified activities.

The study's system boundary is represented by a flow chart including the input and output flows in the main phases shown in Figure 1.

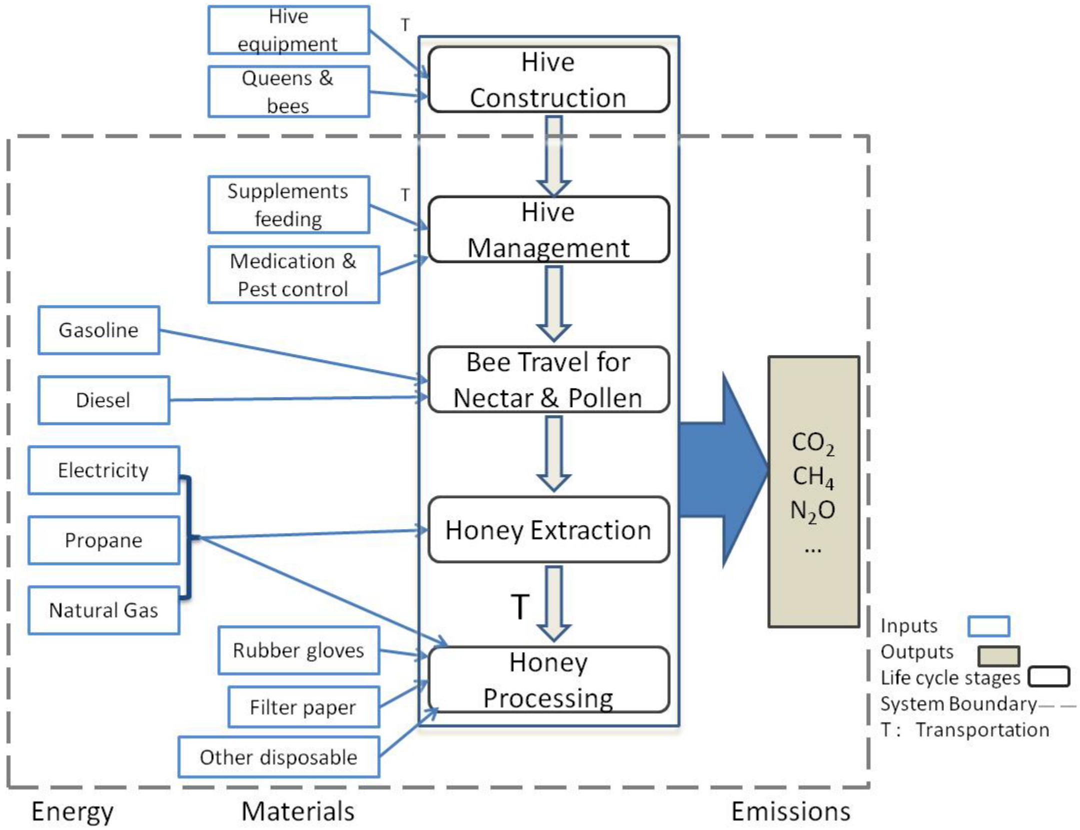

**Figure 1.** LCA Flow Diagram for Honey Production and Processing

2.1.1 System Definition and System Boundaries

The inputs can be divided into two categories: energy and materials. To calculate life cycle energy use, the upstream burdens of producing the energy resource or fuel are included. The stages in the honey life cycle are summarized as hive construction, hive management, bee travel, honey extraction and honey processing. However, hive construction is excluded from the system in this study, consistent with the treatment of long-term capital investments in other LCA studies. Beekeeping equipment can last a relatively long time, and the equipment is mostly made from wood, where energy use and air emissions are not significant. The end-of-life (recycling / disposal / reuse) of all materials is not included, although some materials are frequently recycled. Some frequently reused durable materials, like drums and barrels, are assumed to have small lifetime environmental burdens and thus are not modeled in the study. The manufacture, wear and tear, and maintenance of machines used in the extraction and packing facilities are not considered either, since the average lifespan of equipment is longer than 20 years. The storage of honey is not included, because processed honey can be stored in sealed containers at room temperature for a long time[3], and it is assumed that no energy is consumed during storage.

Finally, queen and replacement bee production were not included within the system studied, as it would have required an additional, specialized data collection effort, beyond the resource constraints of this project, and bees are often imported from abroad. Pollination services and bee products other than honey, such as wax, are considered co-products of beekeeping and are accounted for in this study.

### 2.1.2 Functional Unit

The functional unit is 1 kilogram of processed honey and inputs and outputs are assessed over a 1-year time horizon. In order to standardize the results across many different sizes and types of packaging, the functional unit does not include any packaging. Therefore, packaging materials and the final transport to retail are not considered in this study. However, energy used for filling containers is included. Though emissions from packaging materials and distribution of the final product to retailers are not included in this report, the carbon calculator created for honey producers does include options for calculating life cycle emissions associated with a wide variety of containers typically used for retail sale of honey.

## *2.2 Life Cycle Inventory (LCI)*

As mentioned in the goal and scope definition, the main sectors in this study are hive management, bee travel, honey extraction and honey processing. In this section, data sources and assumptions regarding specific data inputs are listed. Most LCI data come from published academic literature, the Ecoinvent database (last updated in 2008) accessed through the LCA software package SimaPro 7.1[4], the GaBi Professional database (last updated in 2009) accessed through the GaBi 4 software[5], and the U.S. LCI database (last updated in 2008) [6]. The Ecoinvent and GaBi databases are proprietary international databases that tally cradle-to-grave environmental impacts of a large array of commonly used and internationally traded industrial materials, products, and natural resources such as oil and gas. The U.S. LCI database is a similar, but open access database, created by the National Renewable Energy Laboratory, and focuses on materials and products produced in the U.S.

For those data based on economic values, the Carnegie-Mellon University Economic Input-Output LCA database is used[7]. If the LCI dataset for a specific product is not available, we use a surrogate dataset for a product similar in its manufacture or function.

Appendix 1 provides detailed tables that identify the specific data sources used for different inputs or processes to the honey life cycle.

### 2.2.1 Beekeeper and processor surveys

We conducted surveys of selected beekeepers and processing and packing facilities in order to obtain data on material and energy inputs required to produce and pack honey. With the assistance of the National Honey Board and Eric Mussen, Cooperative Extension Apiculturist at UC Davis, we identified beekeepers to cover the range of typical sizes of operation and geographic locations around the U.S. Six beekeepers from five states completed a mail or telephone survey (Table 1). Four of them were considered commercial beekeepers, with two considered as large scale producers and two considered as medium scale producers for the purposes of this study, based on annual honey yield. All four commercial beekeepers provided bee pollination services to agricultural crops. The other two were backyard beekeepers, classified as small scale producers.

We also received a survey from one additional small scale beekeeping operation that also packs its own honey, but we decided not to include the data from the honey production portion of this survey in our calculation of results (although we did include the packing-related data from this survey - see "Processor 4" below). The production-related responses included some key inconsistencies around pollination activities and percent of beekeeping income from honey production that rendered the quality of the data questionable and made it impossible to apply the same method of co-product allocation of emissions as was used for the other beekeepers (see Section 4.1 on co-product allocation below).

**Table 1. Geographic and Production Characteristics of Surveyed Beekeepers**

| Producer | Geographic region | Number of colonies | Annual yield of honey (kg) | Pollination | Total annual miles travel | Total annual miles for pollination |
|---|---|---|---|---|---|---|
| Large 1 | Pacific West | 4000 | 200,000 | Y | 70000 | 16800 |
| Large 2 | Mountain | 5349 | 180,000 | Y | 52000 | 12000 |
| Medium 1 | Pacific West | 3500 | 70,000 | Y | 43000 | 34720 |
| Medium 2 | Pacific West | 1500 | 40,000 | Y | 93600 | 13600 |
| Small 1 | West North Central | 3 | 90 | N | 0 | NA |
| Small 2 | South Atlantic | 5 | 70 | N | 0 | NA |

We also surveyed five honey processors (Table 2). Three of them are considered large scale operations. They own dedicated packing facilities and draw their honey supply from a large number of states within their respective regions, or, in some cases, from across the U.S. Their typical production runs from 1.4 to 40 million lbs of honey annually. In addition, we surveyed two self-packers from the South and Midwest, whose annual production are 200 and 900 lbs of honey. Self-packers surveyed do not have independent facilities and consume a small amount of energy and materials during processing. (Note that Processor 5 is the same entity as the producer "Small 1".)

**Table 2. Geographic and Production Characteristics of Surveyed Processors**

| Processors | Geographic region | Annual Production (kg) | Beekeeper? |
|---|---|---|---|
| Processor 1 | Mid-Atlantic | 18000000 | N |
| Processor 2 | Pacific West | 6800000 | N |
| Processor 3 | Mountain | 600000 | N |
| Processor 4 | South Atlantic | 400 | Y |
| Processor 5 | West North Central | 90 | Y |

Responses from both the beekeeper and processor surveys were used to develop the inventory of materials and energy used in each sector of the life cycle of honey, as described in the following sections.

### 2.2.2 Hive management

Hive management refers to both supplemental feeding and disease and pest management. Although supplemental feeding and disease management are not exclusive from each other in practice, since some bee supplements can prevent certain kinds of diseases, we did differentiate these two in this study. Supplemental feeding is considered a means to provide nutrition and to keep a hive from starving. Bees have two main natural food sources: nectar (manipulated and stored as honey) and pollen. High fructose corn syrup and sugar syrup are both good sources of carbohydrates for bees, as honey substitutes; and brewer's yeast and soybean flour are good sources of protein, as pollen substitutes. In this study, we assumed a 1:1 ratio of granulated sugar to water for sugar syrup, and we chose a typical recipe for pollen substitute patties: 8 oz soy flour, 1 oz Brewer's yeast, 10 oz granulated sugar and 5 oz hot water are mixed to make a 1.5 pound patty[a].

Pest control and medication are an integral part of beekeeping to reduce the risk of diseases and insect invaders. In this LCA, commonly used bee treatments and chemicals are included, and these are based on beekeeper survey responses. We obtained LCI data for most chemicals based on their chemical classes from LCI databases. For a few chemicals, no suitable datasets were found, in which case we used a general dataset available in these databases, such as “organic chemicals."

### 2.2.3 Transportation

The two main components of transportation are bee travel, for nectar and pollen flow; and raw honey transport, from producers to processors. Raw honey refers to extracted, unprocessed honey. The emissions data is based on the size of vehicle, fuel type, and fuel consumption. Pre-combustion and combustion emissions for fuels are both included. The fuel efficiency (MPG) is assumed constant for travel to the destination and back from the destination. For bee travel, the freight weight is mostly from the bee colonies, although the freight weight increases to a certain degree when honey is collected.

The travel distance from beekeepers to honey packers is difficult to measure due to the high variability among producers. An average distance is estimated according to packers' surveys regarding the primary states where raw honey is collected.

Emissions per gallon of diesel fuel were obtained from the U.S. LCI database. The unit of fuel in most databases is reported on a mass basis (in kilograms). Based on the density of fuels, emissions per US gallon of fuel are calculated. The density of diesel fuel, gasoline, and propane is assumed to be the average value 0.85 kg/L, 0.72 kg/L, and 0.50 kg/L, respectively.[8]

### 2.2.4 Honey Extraction and Processing

Honey extraction and processing are the two main parts of the life cycle where electricity, natural gas, propane and some other non-diesel fuels are consumed. These values are reported on a total facility basis, so process-specific energy use and air emissions were not provided in packer surveys and are not estimated in our model.

The U.S. average electricity mix data is used to estimate the total fuel cycle emissions for electricity use. The survey asked respondents to report electricity use in terms of their total utility bill; thus electricity use includes lighting and climate control where applicable. Some material used on site, such as sanitizer, soap and other cleaning agents are not accounted for.

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[a] http://www.sembabees.org/nonnavpages/recipes.html

### 2.2.5 Treatment of co-products in the LCA of honey

As mentioned in the goal and scope definition, we had to allocate some of the environmental burden (greenhouse gas emissions) generated during the course of honey production to co-products such as pollination services and wax. There are multiple ways of dealing with co-products, and the most broadly accepted are explored here.

#### 2.2.4.1 Subdivision Method

Eliminating the co-product allocation problem through subdivision of the production process is desirable if data is available for each of the sub-processes. In such a case a multifunctional process (e.g. beekeeping that yields pollination, honey, and wax) must be composed of sub-processes that can be reasonably separated, and where the amount of material and energy inputs can be identified for each.

For honey production, honey extraction and processing activities clearly do not involve pollination, but do produce wax as a co-product from honey extraction. Transportation activities can also be reasonably separated into trips for honey production and trips associated with co-products based on the primary purposes of travel.

Pollination and honey production are not always entirely separate because bees make a certain amount of honey while pollinating certain crops which produce a large amount of nectar, such as crimson clover and hairy vetch[9]. In spite of a few exceptions, most paid pollination services do not produce honey, such as pollination for almonds, which are not considered sources for commercial honey production[10]. Therefore, we can approximately divide transportation into two sub-processes, honey-related transport and transport for other purposes including pollination and overwinter relocation, and then calculate the inputs and outputs for these sub-processes.

The critical challenge for applying system subdivision is to subdivide hive management. For hive management including feeding and disease/pest control, it is not feasible to separate inputs aimed at honey production from inputs aimed at pollination and other products. Some pollination activities may provide sufficient nourishment for bees, however honey bees can also be exhausted by pollinating some crops, such as kiwis and onions[b] and increasing feed demand. Thus the relationship between pollination, feeding regimes, and honey production is complex and not always predictable. There are some studies showing that early feeding of colonies is needed to improve crop pollination[11]. Moreover, pollination may increase the chance that colonies become infected with diseases carried by other colonies in the new pollination area[12]; in this case more pest management inputs are required.

In summary, for hive management it is not possible to separate the inputs between honey and pollination, because the inputs are fundamental to the survival and health of colonies, which provide both honey production and pollination services. For the co-product beeswax, applying the subdivision method is even harder because wax is a product from the beehive, and the production of wax runs through the entire process of honey production.

Although subdivision is not feasible due to the complex relationship between pollination, feeding, disease and pest management, and honey production, a sensitivity analysis based on the percentage (0 to 100%) of feeding and disease and pest treatments attributable to honey production was conducted, and a range of emissions is calculated through the subdivision

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[b] Personal communication with E Mussen, 2010.

method to provide a result that avoids allocation, which can then be compared with the results from other allocation methods.

#### 2.2.4.2 System expansion

Another method for avoiding allocation decisions is known as system expansion, sometimes referred to as substitution[13]. System expansion requires that an alternative production process for producing a co-product can be identified, and that data can be obtained for this alternative production process[19]. Then, the production system that produces the product of interest (honey) can be credited with producing the co-products (pollination and wax) based on the alternative processes identified for those co-products [14]. The final step subtracts (or credits) the environmental burdens associated with the alternative co-product production processes, from the primary production system under study, as if those environmental impacts were avoided because of the multifunction process being modeled.

To apply this method to honey LCA, we must identify equivalent alternative production processes for the co-products (pollination and wax). Though there are other pollinators, none of them can compete with bee pollinators. While research is underway to develop self-pollinating trees[c], these trees are still under development and have not been cultivated on a commercial scale. Bee pollination is the dominant and almost exclusive way to pollinate most agricultural crops. Also, while beeswax can be used in balms, candles, cosmetics, lubricant and medical purposes, all of which may be reasonably substituted by other products; there is no single product which can be reasonably modeled as a substitute for beeswax, particularly a non-synthetic substitute.

In addition to lack of substitutable products, there are other reasons why system expansion is not suitable in this study. We considered displacing part of the environmental burdens associated with the beekeeping system with the avoided emissions resulting from increased crop yield (due to pollination services). However, this would not only increase the complexity and uncertainty (requiring models of emissions from crop production), but could also result in negative environmental load allocated to honey production. A USDA report suggests that the contributions by bees as pollinators of crops far outweigh the value of honey and beeswax[15]. Another important reason is that this study is an attributional LCA, where we characterize actual production processes. The assumption that no pollination occurs would require that we treat this study as a consequential LCA, which is only appropriate in cases where proposed changes in production processes or economics are being planned for the future (this type of LCA is appropriate, for example, in modeling potential future environmental impacts of substantial increases in biofuel production and use, beyond present conditions).

#### 2.2.4.3 Mass-based allocation

Value-based co-product allocation -- which may be either mass-based or economic-based -- is not recommended as best practice by the ISO, but it is used in cases when neither subdivision nor system expansion is applicable. According to the ISO 14041, this method of allocation should reflect the physical relationships between the environmental burdens and the functions whenever possible; thus allocation can be based on physical properties such as mass, volume, and energy content, which is generally termed as mass allocation. In this case, honey and wax

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[c] "ARS Scientists develop self-pollinating almond trees", http://www.ars.usda.gov/is/pr/2010/100406.htm

can be allocated by mass; however, the main co-product, pollination service, cannot be measured on a mass- or otherwise physical basis that is comparable to honey.

2.2.4.4 Economic value-based allocation

While not encouraged in the ISO standard, economic allocation is commonly used in LCA. This is a result, in part, of the reasoning that the economic value of a product is the driving force for a producer to produce a good or service.[16]

In fact, some LCA practitioners and developers recommend economic allocation. Economic allocation is recommended by Guinee et al. (2004) as a baseline method for most detailed LCA studies if allocation cannot be avoided. Guinee et al. also specified some principles of applying economic allocation in practice[17]. In a multi-functional process, all flows should be allocated according to their shares in the total proceeds based on prices. Alternatives to using single economic parameters have also been proposed. Frischknecht (1998) proposed a disutility function which combines cost information and environmental information into a one-dimensional figure, i.e., total "social costs", and allocation decisions should be made according to this value[18].

In this study, economic value-based allocation is applied to allocate the environmental burden between honey and co-products. To accomplish this, we asked beekeepers completing the survey to estimate the proportion of income they accrue from honey production, as opposed to the income from pollination and other bee products.

### *2.3 Life Cycle Impact Assessment*

For a carbon footprint assessment, climate change is the only impact category considered. Global warming potentials (GWP) are used to convert non-$CO_2$ greenhouse gases to $CO_2$-e. The values for GWPs are taken from the most recent report from the Intergovernmental Panel on Climate Change (IPCC), and the 100-year time horizon for potential is used[19] and shown in Table 3.

**Table 3.** Global Warming Potentials

| Greenhouse Gas | $CO_2$ | $CH_4$ | $N_2O$ |
|---|---|---|---|
| $GWP_{100}$ | 1 | 25 | 298 |

A Microsoft-Excel based model was developed to calculate the total GHG emissions from honey production and processing. Material and energy inputs were listed, and the quantity of each type of inputs was provided by the survey. Air emissions from every separate phase were calculated, and then summed.

## 3. Results

### *3.1 Emissions from Honey Production*

$CO_2$, $CH_4$, and $N_2O$ emissions were tracked in the emissions model, and then converted to $CO_2$e using the IPCC's $GWP_{100}$. $CO_2$ is the dominant GHG emitted during honey production. The data below shows the emissions for producing enough honey to deliver 1 kg of processed honey. Based on figures reported in processor surveys, the model assumes that 1.5% of the mass is lost during honey processing. Thus Figure 2 is based on 1.015 kg of unprocessed honey.

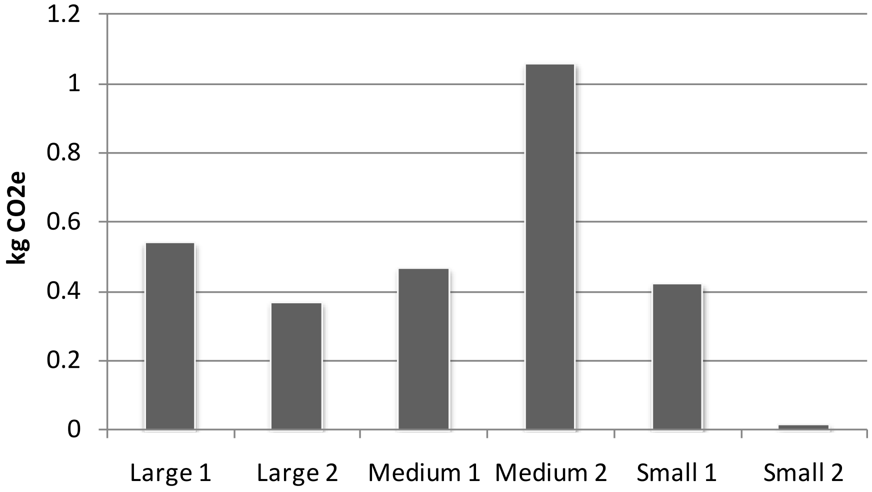

**Figure 2.** GHG Emissions (kg $CO_2e$) per 1.015 kg Unprocessed Honey (1 kg Finished Honey)

Emissions from honey production by producer *Small 2* are significantly lower than those of the other producers. An investigation of *Small 2*'s beekeeping activities revealed that almost no energy or material was used to produce honey. *Small 2* is a non-commercial operation that uses no supplemental feeding or medication, and bees were not transported elsewhere to collect nectar. The only energy use was the electricity consumed in the extraction phase.

The two small scale producers, or so-called “backyard beekeepers,” show very different GHG emissions for their operations, despite that neither one transports bees for nectar. Unlike *Small 2*, producer *Small 1* does provide supplemental feeding, which may be due to the harsher, colder winters in *Small 1*'s northern location in the mid-West, compared to *Small 2*'s location in the much milder south Atlantic region.

For commercial beekeepers there seems to be significant variability as well, particularly for the *Medium 2* producer who has significantly higher emissions than the other commercial producers. To better understand where the emissions occur within the life cycle of honey production, a comparison between these four commercial producers is explored below, and emissions are specified for each main life cycle stage, i.e., hive management, travel and extraction.

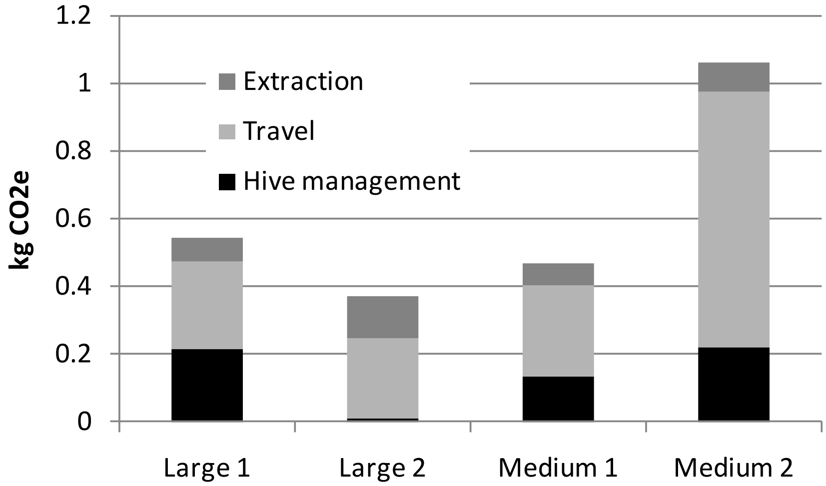

**Figure 3.** GHG Emissions from Honey Production per 1.015 kg of Unprocessed Honey, commercial producers only

Figure 3 shows that the transport of honeybees contributes the largest proportion of emissions for all commercial producers. The *Large 2* producer has the lowest emissions because the emissions from the hive management phase are very low. On a mass basis *Large 2* used far less feed and disease and pest control treatments compared to its peers: only 0.026 kg of feed and medication inputs per kg honey, drastically lower than all other producers. *Medium 2* traveled the greatest distance, outpacing even the larger operations, but had a low annual honey yield that was only 1/5 of the yield of *Large 1*.

### *3.2 Emissions from Honey Processing*

An interesting finding from the survey is that none of the small packers use any natural gas or electricity exclusively for processing honey, although they still require some heat. They achieve this by using waste heat from other domestic activities such as cooking or running home appliances that generate heat. The only environmental burden aside from packaging materials is water consumption, the environmental impacts of which are relatively low. GHG emissions for the five packers are given in Table 4.

**Table 4.** Kilogram of $CO_2$e per kilogram finished honey (packaging materials not included)

| | **Processor 1** | **Processor 2** | **Processor 3** | **Processor 4** | **Processor 5** |
|---|---|---|---|---|---|
| **kg $CO_2$e** | 7.7E-2 | 1.1E-1 | 1.6 E-1 | 7.6E-4 | 3.0E-3 |

Since the two small processors (4 and 5) only have emissions from water use, and the scale of operation is not comparable to other large packers, we are not presenting their results in detail. Figure 4 shows emissions from the three large, commercial-scale packers surveyed in the study broken down by the fuel or material flow contributing the emissions.

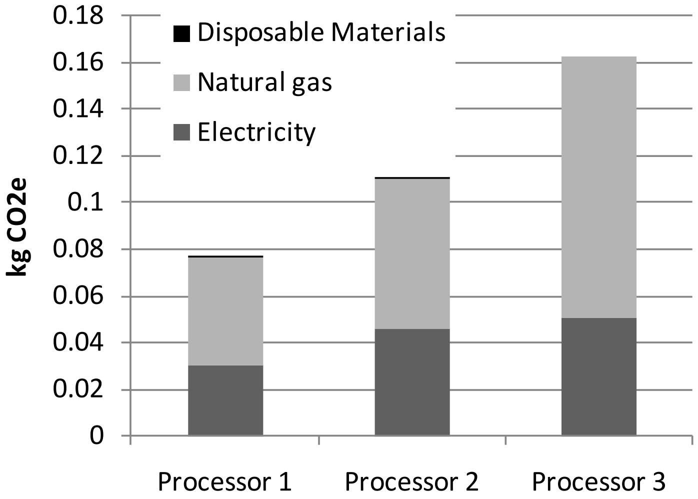

**Figure 4.** GHG emissions (kg CO2e) per kg processed honey, commercial-scale packers only.

Figure 4 shows emissions from actual processing facilities and indicates that economies of scale appear to be realized as processors increase in size (processor 1 is the largest, and processor 3 the smallest, as evidenced in Table 2). In other words, for commercial production, larger scale operations seem more efficient, with lower carbon emissions per unit of honey. However, Figure 4 does not include transport of raw honey from beekeepers to a processor's site. Adding this important parameter to assessment of processor performance could reverse the trend of larger facilities and greater efficiency, as larger facilities may require greater distances for honey transport to meet capacity. Thus, we cannot conclude that a larger processing operation will necessarily have a smaller carbon footprint.

### *3.3 Honey Life Cycle Case Studies*

The goal of this LCA study is to quantify and assess the GHG emissions from the life cycle of 1 kg of processed honey; however, the operations of honey production and honey processing are often separate for large scale businesses, and we conducted independent surveys of honey producers and packers. To calculate the total emissions per unit of processed honey, honey producer Large 1 and honey Processor 2 are chosen. The implicit assumption is that the honey producer selected sells its honey to the selected processor. In this specific case, the honey producer and processor are in close proximity, separated by only 140 miles. Based on feedback from the large processors surveyed in this study, they often source honey from much greater distances. Thus, Figure 4 below shows the emissions for the scenario based on a transport distance of 140 miles, as well as a distance of 1800 miles, the longest distance reported by a honey processor.

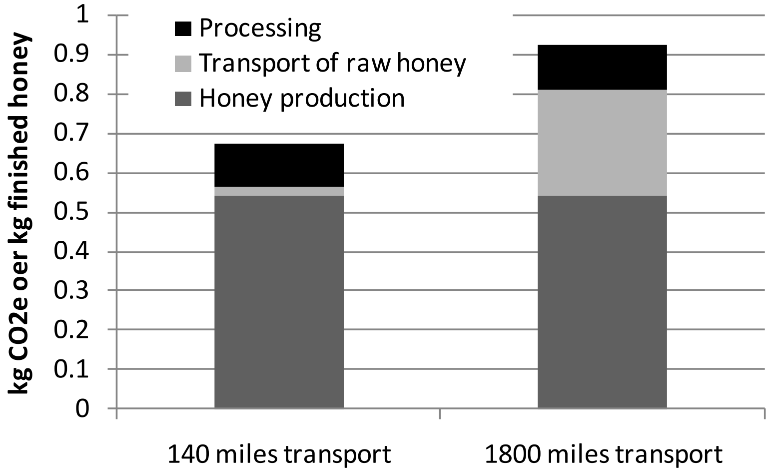

**Figure 5.** Honey Life Cycle Case Study

Figure 5 shows that 80% to 90% of the 0.67 kg $CO_2e$ emissions resulting from the production of one kilogram of honey are attributable the production of raw honey for the case where only 140 miles of transport is required. The mode of transporting raw honey is heavy duty truck, whose assumed capacity is 64 steel drums. As stated previously, packaging materials for honey are not considered.

Processing facilities receive raw honey from beekeepers from a number of states, and the amount of honey provided by each beekeeper is unknown; thus, estimating an accurate weighted average distance for honey transport is not possible. However, as Figure 5 shows, transportation of raw honey can be an important contributor to emissions if the distance between the beekeeper and the processor is large.

We can also demonstrate several hypothetical honey production supply chains using our sample of commercial honey producers and packers. Figure 6 shows the carbon footprint of these potential honey production pathways, as well as one small-scale producer who processes and packages his own honey. Only those producers and packers closer than 1800 miles were considered as realistic supply chains for honey production.

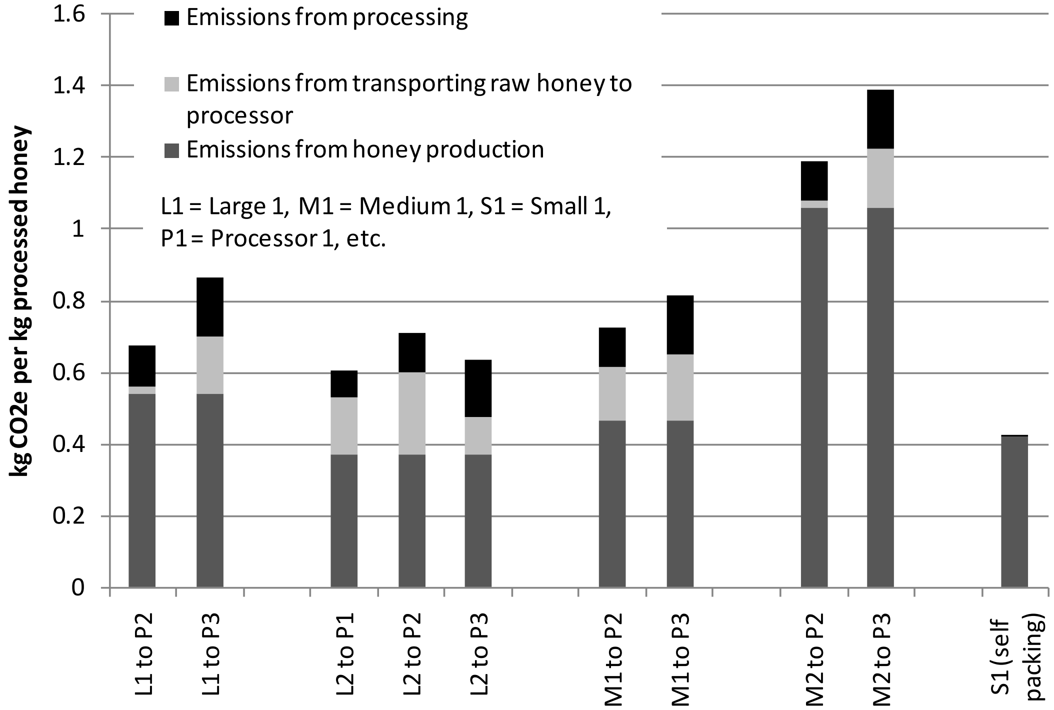

**Figure 6.** Life Cycle Greenhouse Gas Emissions (kg $CO_2$e/kg honey) for Potential Honey Production Supply Chains

Figure 6 shows a large range of potential GHG emissions from honey production, from just over 0.4 kg $CO_2$e/kg honey for "backyard beekeepers," who do not transport their colonies and process and pack on site, to nearly 1.4 kg $CO_2$e/kg honey for a commercial honey production supply chain. However most of the commercial production supply chains fall within 0.6-0.9 kg $CO_2$e/kg processed honey, very similar to the range identified in the previous case study.

## 4. Discussion

### *4.1 Co-product allocation*

Economic allocation based on the annual income share reported by beekeepers was applied to allocate the environmental burden associated with raw honey and co-products including pollination and beeswax.

The subdivision method was also used with the goal of avoiding allocation. Since hive management contributes to both honey production and pollination, and the inputs within this phase cannot be separated, complete subdivision cannot be achieved. A sensitivity analysis is shown in Figure 7 based on the percentage of feeding and medication inputs assumed to benefit honey production exclusively rather than other co-products. The lower and higher bounds are 0% and 100%, representing two extremes: 0% indicates that hive management inputs do not benefit honey production at all, and 100% indicates that all inputs exclusively benefit honey production.

Emissions from raw honey production calculated by subdivision method and emissions by economic allocation are compared, as shown in Figure 7.

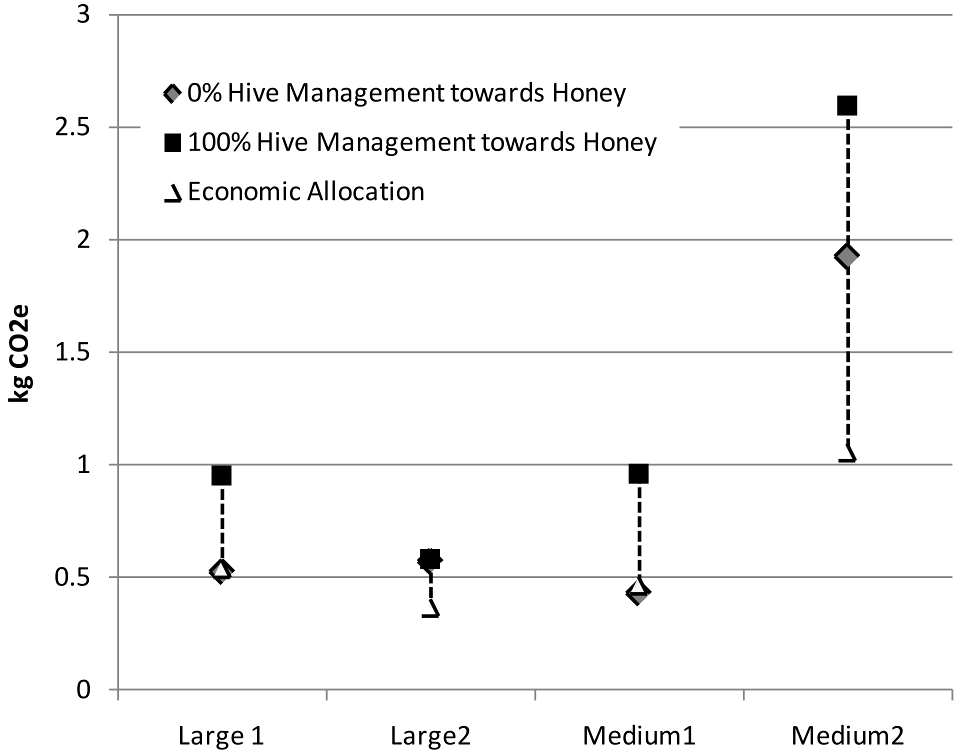

**Figure 7.** Comparison of GHG emissions for 1.015 kg of unprocessed honey using different methods of co-product treatment: subdivision versus economic allocation

The above figure shows that GHG emissions resulting from economic allocation are significantly lower than the results using the subdivision method for honey producers Large 2 and Medium 2. For the other two honey producers, the value of GHG emissions by economic allocation falls in the range of values calculated by the subdivision method, slightly higher than the lower bound of the range (0% of hive management benefits the honey production).

The emissions calculated by economic allocation are significantly lower than those by subdivision for most honey producers. This outcome is difficult to reconcile. Subdivision is recommended by the ISO to avoid allocation decisions, and subdivision logically seems more accurate since it traces emissions down to each phase. On the other hand, beekeeping operations are complex and commercial beekeepers have integrated processes for their key products; honey and pollination, so a complete subdivision is not achievable. Economic allocation provides simplicity and convenience, and reflects the business model for beekeeping in terms of the value of beekeeping products and the relative importance of different products and services in determining hive management decisions (for example, many travel decisions are made based on pollination opportunities rather than for honey production).

Because the subdivision process only yields a large range of possible results, and there are some uncertainties as to how and by what mechanisms pollination activities might affect honey production, we report our final answers based on the economic allocation process.

### *4.2 Scenario Analysis of Transport Distance*

Figure 5 demonstrates the effect of varying transport distance from producer to processor from 140 to 1800 miles. For total emissions per kg of processed honey, a change of distance from 140 miles to 1800 miles results in a 37% increase in GHG emissions.

1800 miles was based on the maximum distance information obtained from the surveyed processors. The only transport mode assumed was truck transport. This is not necessarily the case in practice, because multi-modal transport could, in theory, be used for longer transport distances.

### *4.3 Discussion of other Sweeteners*

While honey is a unique product that may provide flavor and health benefits beyond its use as a sweetener, this section explores previous studies of non-honey sweeteners in order to provide context for the magnitude of life cycle GHG emissions from honey. In all cases we compare sweeteners from cradle-to-factory-gate. We chose this system boundary because packaging decisions and final transport to retailers or consumers can vary greatly by region and market, and may distort otherwise fair comparisons.

Table 5 shows previous life cycle GHG emissions estimates for a range of sugar and corn syrup sweeteners from different studies and regions of production. Some of these estimates are for sugar streams for fermentation (largely for the production of ethanol). These estimates likely underestimate the energy and consequent emissions for products intended for human consumption.

The most unanticipated outcome is the significant variability between estimates for similar products. Table 5 includes values adjusted for equivalent sweetness to honey. This means that rather than comparing on a mass-basis, each sweetener is compared based on sweetness equivalent to one kg of honey[20].

**Table 5.** Comparison of life cycle GHG emissions for honey and other sweeteners

| Type of Sweetener | Region | Greenhouse gas emissions (kg $CO_2$-eq per 1 kg sweetener.) | kg CO2e per sweetness equivalent of 1 kg honey* | Source | Notes |
|---|---|---|---|---|---|
| Corn Syrup | United States | 2.51 | 2.58 | Gabi | Glucose from starch hydrolysis, perhaps intended for fermentation |
| High fructose corn syrup | United States | 1 | 1.16 | Renouf et al. (2008)[21] | Sugars for fermentation, not for human consumption. This would likely underestimate the energy requirements for sweeteners in the retail market |
| Honey (High) | United States | 1.39 | 1.39 | UC Davis | Case study results, not necessarily representative of all honey production supply chains, cradle to factory gate |
| Honey (low) | United States | 0.43 | 0.43 | UC Davis | Case study results, not necessarily representative of all honey production supply chains, cradle to factory gate |
| Sugar, from sugar beet | United Kingdom | 0.58 | 0.48 | Renouf et al. (2008) | Sugars for fermentation, not for human consumption. This would likely underestimate the energy requirements for sweeteners in the retail market |
| Sugar, from sugar beet | United Kingdom | 0.42 | 0.35 | Silver Spoon[22] | Industry source, verified by Carbon Trust |
| Sugar, from sugar beet | Denmark | 0.96 | 0.79 | LCAfood.dk[23] | Funded by Danish government |
| Sugar, from sugar beet | Switzerland | 0.55 | 0.45 | Ecoinvent | Cradle to factory gate |
| Sugar, from sugarcane | Australia | 0.15 | 0.12 | Renouf et al. (2008) | Sugars for fermentation, not for human consumption. This would likely underestimate the energy requirements for sweeteners in the retail market |
| Sugar, from sugarcane | Brazil | 0.19 | 0.16 | Ecoinvent | Cradle to factory gate |

Figure 8 illustrates this variability in life cycle GHG estimates across estimates of all types of sweeteners. In this case we are showing the absolute highest estimate for commercial honey production (1.39 kg $CO_2e$/kg processed honey) rather than the range of 0.6 - 0.9 obtained in our suite of case studies described in section 3.3 above. Notably, all of these estimates are still higher than most of the estimates for sugar from beets or cane. The "low" value for honey GHG emissions comes from one of the backyard beekeeping operations that also packs its own honey. This operation's footprint fits well within the range of estimates for sugar from beets. The available estimates for corn syrup have such high variability that we can draw no reasonable comparison. Since our survey sample size is smaller than statistically significant, and because transport distances for raw honey to processors are uncertain, these results should be interpreted as individual examples of possible honey production supply chains, not as an average for US honey production.

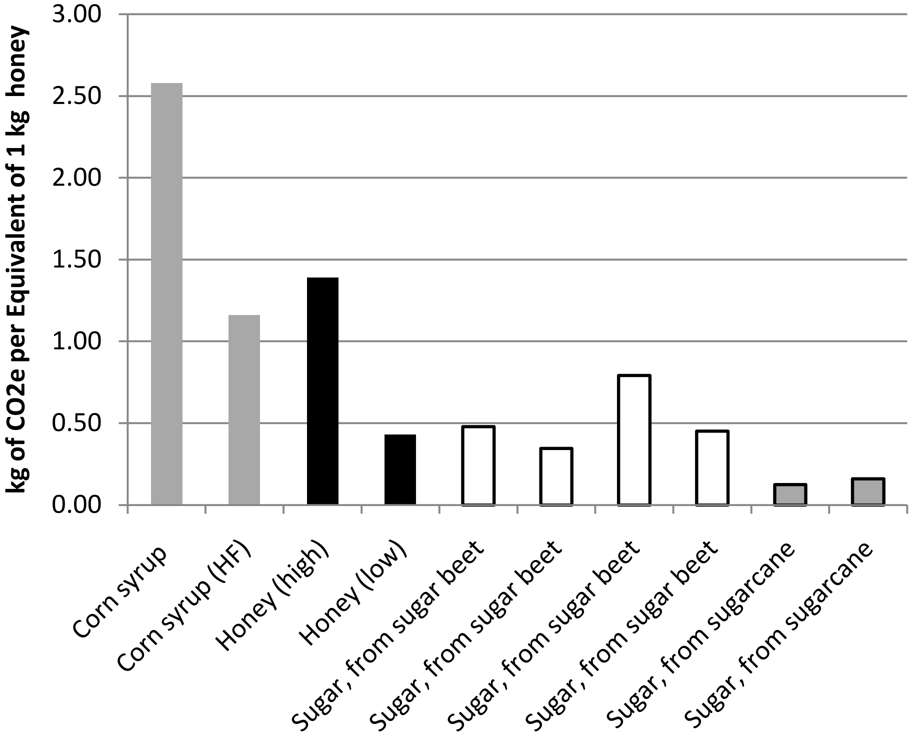

**Figure 8.** Carbon Footprints of Sweeteners

As figure 8 demonstrates, we are not able to conclude whether honey performs better or worse from a life cycle GHG emissions perspective; however, the range identified in this study falls within or near estimates of other sweeteners’ life cycle GHG emissions. In addition, backyard beekeepers that use few inputs and do not transport bees and unprocessed honey long distances may be the most "low-carbon" sources of sweetener. Commercial producers with relatively low feed inputs and short transport distances for processing and packaging may reliably deliver relatively low-carbon sources of sweetener.

## 5. Limitations of this Study

Data were collected from beekeepers for either the 2008 or 2009 calendar year, depending on the most complete records available from the survey respondents at the time they were completing the survey questionnaire. Because honey production is so closely correlated with annual weather and crop conditions and varies tremendously from year to year, it is not easy to find a typical year which can represent the average situation over several years. Disease is also an important factor affecting annual yield. As a result, one of the limitations of this study is that it is not feasible to generalize the results from 2008 and 2009 to every year. In addition, the association between geographic locations of beekeepers and environmental performance of honey production is not quantified in this study due to data limitations which resulted in a sample size well below what can be considered a statistically significant size. Another limitation of this study is the lack of some data; for example, the transportation distance of raw honey from beekeepers to packing facilities is highly uncertain. Where possible we have addressed this type of uncertainty using sensitivity and scenario analyses.

## 6. Conclusion

In summary, we calculated the greenhouse gases emissions for honey production and processing based on a limited survey sample. For commercial beekeepers, the GHG emissions from honey production range from 0.37 to 1.06 kg $CO_2$-equivalent per kilogram of processed honey (equivalently, 0.17 to 0.48 kg $CO_2$-equivalent per pound of processed honey). For large scale honey packers, the GHG emissions from honey processing range from 0.08 to 0.16 kg $CO_2$-equivalent per kilogram of processed honey (equivalently, 0.035 to 0.07 kg $CO_2$-equivalent per pound of processed honey).

A case study shows that the total life cycle GHG emissions range from 0.67 to 0.92 kg $CO_2$-equivalent per kilogram of processed honey (or 0.31 to 0.42 kg $CO_2$-equivalent per pounds of processed honey), assuming the distance between the beekeeper and the processor is within the range of 140 to 1800 miles. Other case studies show a wider range of total GHG emissions, from 0.61 to 1.39 kg $CO_2$-equivalent per kilogram of processed honey (or 0.28 to 0.63 kg $CO_2$-equivalent per pound of processed honey). These results do not include small producers and self packers who consume less energy and materials and therefore have lower emissions.

For backyard honey producers and processors, the GHG emissions are significantly lower. From the survey data of two small producers whose annual production is 200 lbs and 150 lbs, we calculated the GHG emissions, which are 0.42 and 0.02 kg $CO_2e$ for 1.015 kg of unprocessed honey. The GHG emissions from processing for small packers are 0.001 and 0.003 kg of $CO_2e$ for two small processors, whose annual production is 900 lbs and 200 lbs.

The extremely large range of values for transport distance and feeding practices means that we cannot offer a conclusive estimate of an average value for US honey. However we can offer insights and some generalizations that can help producers reduce their carbon footprint. First, transportation proved to be an important source of GHG emissions for the honey life cycle, both for nectar harvesting and transport to processors. Thus, one potential method of reducing emissions and energy consumption is to minimize transport distance and to use highly efficient transport modes for these activities. In addition, identifying a processor close to the extraction site can minimize emissions associated with this transport leg.

## Appendix 1: Data Sources

**Table A1.** Data Sources: Hive Management

| **Input** | **Data Set** | **Source** | **Data Quality (Geography, Reference year, Notes)** |
|---|---|---|---|
| Sucrose (or sugar) | Sugar from sugar beet | Ecoinvent | CH, 1998 to 2005, packaging of sugar not included. |
| Corn syrup | Glucose via starch hydrolysis | GaBi Database | U.S., 2002 |
| Sugar syrup | Sugar from sugar beet | Ecoinvent | CH, 1998 to 2005, packaging of sugar not included. |
| | Water | Ecoinvent | CH, unspecified time period |
| Brewer's yeast | Yeast paste | Ecoinvent | IE, unspecified time period. Surrogate dataset |
| Pollen patties | Soy Flour | Ecoinvent | U.S., 1998 to 2005. Surrogate dataset[d] |
| | Yeast paste | Ecoinvent | IE, unspecified time period. Surrogate dataset |
| | Sugar from sugar beet | Ecoinvent | CH, 1998 to 2005, packaging of sugar not included. |
| | Water | Ecoinvent | CH, unspecified time period |
| Vegetable grease | Soybean oil | Ecoinvent | U.S., 1998 to 2002, Surrogate dataset |
| Thymol / Menthol | Cyclohexanol | Ecoinvent | EU, 2003, Large uncertainty due to the weak data on the production process and missing data on process emissions. |
| Apistan (fluvalinate), Bayvarol(flumethrin) | Pyrethroid-compounds | Ecoinvent | U.S., unspecified time period[24] |
| Apitol (cymiazole) | Phenoxy-compounds from SimaPro | Ecoinvent | U.S., unspecified time period[13] |
| CheckMite+ (coumaphos) | Organophosphate | Ecoinvent | US., unspecified time period[13] |
| formic acid, oxalic acid | Formic acid | Ecoinvent | EU, 2007.[25] |
| Lactic acid | Lactic acid | GaBi database | U.S., 2005. |

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[d] Soy flour is made from soybean meal. Both are good protein sources for feeding. http://www.rennut.com/articles/pdf/A%20Guide%20to%20Soy%20Protei%20for%20Animal%20Nutrition.pdf.

**Table A2.** Data Sources: Transportation

| **Input** | **Data Set** | **Source** | **Data Quality** |
|---|---|---|---|
| Diesel production | Diesel, at refinery | US LCI | U.S., 2004. |
| Gasoline production | Gasoline, at refinery | US LCI | U.S., 2004. |
| On-road truck transport (single unit truck) | Transport, single unit truck, diesel powered | US LCI | U.S., 2001, taken from GREET transportation model[26]. |
| | Transport, single unit truck, gasoline powered | US LCI | U.S., 2001, taken from GREET transportation model. |
| On-road truck transport (combination truck) | Transport, combination truck, diesel powered | US LCI | U.S., 2001, taken from GREET transportation model. |
| | Transport, combination truck, gasoline powered | US LCI | U.S., 2001, taken from GREET transportation model. |

**Table A3.** Data Sources: Extraction and Processing

| Input | Data Set | Source | Data Quality |
|---|---|---|---|
| Gasoline | Gasoline, at refinery | US LCI | U.S., 2004. |
| | Gasoline, combusted in equipment | US LCI | U.S., 2001, taken from GREET transportation model. |
| Electricity | Electricity | Ecoinvent | U.S., 2004, includes domestic producers and imports from Canada and Mexico. |
| Natural gas | Natural gas, processed | GaBi database | U.S., 2004. |
| | Natural gas, combusted in industrial boiler | US LCI | U.S., 2004, taken from GREET transportation model. |
| Propane | Propane at refinery | GaBi database | U.S., 2003. |
| | LPG, combusted in industrial boiler | US LCI | U.S., 2004. |

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