STEEL FOR PACKAGING

From farm to table:

An energy consumption assessment of refrigerated, frozen and canned food delivery Scientific Certification Systems Kirsten Ritchie, B.S., M.S., P.E. Civil Engineering

Introduction

Within the context of creating greater efficiencies in society's use of energy, one of the most important industries to consider is the food industry. Providing the most basic fuel of all from the human perspective, the food supply chain utilizes energy at every stage of moving agricultural produce from the field to the table: growing/harvesting, processing, packaging, transporting, storing for wholesale and retail distribution; and preparing the food in the nation's home kitchens. Quantifying the energy requirements at every stage depending on the form of packaging gives us an opportunity to provide energy efficiencies that will affect not only the industry, but the environment, as well.

Table i-1. Relative use of energy within the entire food production system

ENERGY CONSUMPTION

	Refrigerated		Frozen		Canned	
Stage	Kcal/lb	%	Kcal/lb	%	Kcal/lb	%
Production	320	19-28%	320	13-14%	320	20-26%
Processing	9	1%	825	34-37%	261	16-23%
Packaging	160-670	14-40%	180-236	7-10%	374-659	33-41%
Transportation[1]	306-360	21-27%	136-158	6-7%	119-239	11-15%
Storage[2]	187-209	11-18%	537-764	25-32%	0	0%
Preparation	146	9-13%	159	7%	61-127	5-8%
Total	**1152-1692**	**100%**	**2250-2046**	**100%**	**1136-1607**	**100%**

[1] Based on 1500 mile transport distance
[2] Based on 10 day storage cycle for refrigerated goods and 90 days for frozen

The consuming public in general does not understand the complexities of the modern global food system. They tend to live and shop for groceries far away from where food was produced and processed. They rarely stop to consider whether the food was imported and sold at a grocery chain that takes five minutes by automobile to reach, or whether it was grown by local farmers and sold at a greengrocer within walking distance of their homes. (Jones, 2002) When considering the price of food, few take into account the environmental costs related to producing, processing, storing or transporting food. Among the largely unseen environmental costs is the increased amount of fossil fuel required to transport food over long distances combined with the electricity needed to keep these foods cold or frozen. As is clearly shown in Table i-1 these energy related impacts are considerable.

Consumers in the U.S. and other developing countries have come to expect a continuous supply of diverse foods. This requires significant reliance on processing and packaging to preserve food, as well as transportation of fresh foods from production regions of the nation to parts of the country with limited growing seasons. The energy consumed in this process is a good indicator of environmental impact. In general, the energy to process and package food today is much greater than the energy provided by the product.

In this study we are assessing the energy requirements for transporting perishable foodstuffs such as fruits and vegetables in three forms of packaging: refrigerated fresh produce, frozen, or canned. In addition, we will be comparing all three packaging approaches in two delivery formats: bulk (e.g. green beans and lettuce) and portion servings (e.g. blueberries sold in small packets).

Assessment Boundaries

This assessment considers energy expenditures for the energy consumed in the movement of produce from farm to table for the three primary modes of delivery: refrigerated, frozen and canned.. However, as is common in life cycle assessment practice, the energy used to build the processing and distribution facilities, the stores, the homes or the trucks and cars used to transport the goods is not included.

Product Groupings

While the original intent of the study was to investigate specific product groups, namely green beans, sweet corn, blueberries, peaches, chicken and ravioli, during the course of investigation, it became apparent that an alternative assessment approach would prove more informative.

Hence, the decision was made to move from a product specific assessment to a packaging/processing combination. The following combinations were selected:

A – Bulk refrigerated product (e.g. green beans, broccoli, asparagus, lettuce, apples, and peaches)

B – Portion packaged refrigerated product (e.g. 4 oz blueberries, raspberries, sliced mushrooms)

C – Bagged frozen product (e.g. blueberries, sliced peaches, green beans, corn kernels)

D – Boxed frozen product (e.g. spinach, frozen ready meals)

E – Canned ready meals, full content utilization (e.g. soup, ravioli, chili, tomatoes)

F – Canned goods with processing liquid (e.g. green beans, sliced peaches, blueberries, tuna, chicken)

1. Production

comestible products reaching the marketplace. Energy inputs derive from such varied components of the production phase as seed sourcing and irrigation, herbicides and insecticides, as well as direct fuel consumption associated with harvesting and transport to processing facilities or market (Pimentel & Pimentel, 2003).

Based on currently available literature from Pimentel (1996 & 2003) as well as others (Duke 1983; Wilkins & Eames-Sheavly), the energy inputs associated with key crops range from approximately 130 Kcal/lb for oranges (1.23 Mj/kg) to 518 Kcal/lb for spinach (4.78 Mj/kg) as shown below in Table 1-1.. While the range of energy required to grow different crops is definitely measurable, the result set is still within the same order of magnitude.

Table 1-1: Production Energy Consumption (Growing and Harvesting)

ENERGY CONSUMPTION

	Production Yield	Energy Inputs	Energy consumption per unit			Data source
Product	**kg/ha**	**kcal/ha**	**kcal/kg**	**kcal/lb**	**Mj/kg**	
Apples	54,743	28,980,000	529	240	2.22	1
Oranges	40,370	11,862,000	293	133	1.23	1
Potatoes	34,384	16,038,455	466	212	1.96	1
Spinach	11,200	12,759,849	1139	517	4.78	1
Tomatoes	49,616	16,560,443	333	151	1.40	1
Brussels sprouts	12,320	8,060,328	654	297	2.75	1
Soybeans	1,882	1,827,223	970	441	4.07	1
Snap beans	4,995	4,623,482	925	420	3.88	2
Corn	7,965	7,047,000	884	402	3.71	3
Strawberries				390	3.60	4
Average				**320**	**2.96**	

1 - Pimentel and Pimental 1996
2 - Duke JA 1983
3 - Pimentel and Pimental 2003
4 - Wilkins J & Eames-Sheavly M (online access 2005)

Interestingly, the energy inputs per hectare do not directly translate to energy consumption. It is important to consider the yield, as well as the total energy inputs per hectare, in quantifying the energy consumption associated with production of a particular product.
For example, the energy requirement to produce a hectare of apples is close to 29 million kcal/ha, compared to corn at 7 million kcal/ha. However, the significantly higher yield of apples (about 55,000 kg/ha) as compared to corn (about 7900 kg/ha) results in corn requiring 80% more energy to be consumed per hectare of production than apples.

For the purposes of this report, we assume that the upstream life cycle stages associated with agricultural components until the processing phase are essentially the same regardless of whether the produce ends up being canned, refrigerated or frozen. It is true that in some cases, the variety of fruit or vegetable to be grown is selected for its characteristics relative to canning or freezing, but the energy consumption differential (for machinery, fuel, pesticides or fertilizers) is not considered to be of measurable difference. Therefore, for purposes of a comparative energy evaluation the average energy input value of 320 Kcal/lb was used for all product groupings.

Clearly, those interested in assessing the relative energy impacts for a particular crop such as Brussels sprouts or snap beans can utilize the specific data provided. For example, if we were interested in a comparative evaluation of corn, we'd replace the average value of 320.75 Kcal/lb for the actual value of corn of 402.16.

Examining the total energy inputs in the farm to table food chain, energy consumed in production activities (growing and harvesting) as a percent of the total energy consumption from 11% for frozen goods to 28 % for select refrigerated and canned goods as shown in Table i-1.

It should be noted that the data used to derive this information necessarily lags a couple years behind, and the recent expansion of organic production requiring less energy-intensive inputs, e.g. synthetic fertilizers, suggests addition research to update the data set.

2. Processing

This study focuses on the three primary processing methods used for moving product from farm to table: refrigeration (fresh with minimal processing), freezing and canning. There are other methods used such as drying, smoking, salting and freeze drying, but far and away the largest majority of product moves to market today refrigerated, frozen or canned.

Previous studies from such industry experts as David and Marcia Pimentel have assumed no energy inputs associated with the movement of fresh product. As described below, this is no longer accurate given that fresh (e.g. refrigerated product) typically involves as a minimum some rapid cooling step, such as forced air or hydro cooling.

Refrigeration:

According to studies by the Nova Scotia (Canada) Department of Agriculture and Fisheries (1994), it is imperative to have proper post-harvest cooling and handling of fruits and vegetables to ensure maximum quality. The rate of deterioration after harvest is mainly influenced by the respiration rate of the harvested product. Since the rate of respiration is related to temperature, removal of field heat before storage, "pre-cooling", will reduce the respiration and deterioration rates. Pre-cooling also reduces the growth of decay organisms, reduces water loss and reduces the production of ethylene, a gas produced by plants that accelerates ripening and senescence.

The two most important factors, according to the Canadians, are temperature and time, i.e. a fruit or vegetable must be cooled in the shortest time possible, preferably within one to 15 hours. Product cooling follows a logarithmic function, with rapid cooling initially followed by a slower and slower rate.

Typical pre-cooling methods include: room cooling, forced air (pressure cooling), hydro-cooling, package icing and vacuum cooling.

In room cooling, a refrigerated room is designed to hold produce once the field heat is removed. For most fruits and vegetables room cooling is generally considered inadequate due tot he slow rate of cooling, e.g. days instead of hours and excessively dehydrates the product (bring this up into sentence).

Forced air or pressure cooling is achieved by pulling refrigerated room air through a stacked product. This is generally accomplished using fans which can move at least 1 cu. ft. per pound of air under vacuum under 1 inch (25 mm). "In a properly designed forced air system the evaporative coils in the refrigeration system have more surface area than conventional coils, allowing for more rapid heat removal," according to the researchers in Nova Scotia. Since they do not need as low a temp as conventional coils there is less dehydration of air. "This method is considered the more versatile because it is easily incorporated into existing cold rooms, does not require sophisticated technology, and can be used on the widest array of fruits and vegetables, and types of packaging."

Hydro cooling cools the product by immersing or showering it in cold water. It is faster than forced air, and does not de-hydrate the product, but should only be used if the product can tolerate being wetted and not damaged by falling water disinfectants. This activity is more energy-intensive than forced air-cooling, as the water must be cooled by mechanical refrigeration. However, due to its limited product applicability, we are recommending using forced air refrigeration as a more reasonable comparative basis in this study.

Package-icing: Some products can be cooled by adding ice to the packed container. This method can cool product faster than forced-air, but the product must be able to tolerate contact with water and ice. Although the easiest method is to add flaked ice to the top of the container, greater contact with the product can be achieved by injecting a slurry of water and ice into the package. Care must be taken to ensure complete distribution in the package. Containers must be watertolerant with holes for water drainage. (Novia Scotia, 1994)

Vacuum cooling: In vacuum cooling, the packaged product is placed in an air-tight chamber and the air is evacuated. Although this method can cool product in less than 30 minutes it is only effective in products with a high surface-area-to-volume ratio. Vacuum coolers are limited in use because they are expensive to purchase and operate, and can only be used on a limited range of products.

While there are ranges of pre-cooling technologies available for use, the most common and versatile is forced air. It is estimated to take 1 BTU to lower the temperature of one pound of product one degree Fahrenheit. Therefore, assuming an average 35 degree required temp drop e.g. from a field temp of 70 degrees to a cool room temp of 35 degrees, this would result in an energy consumption of 8.83 kcals/lb (0.08 mj/kg).

Freezing:

Many of the desirable qualities of the fresh food are retained for relatively long periods of time with freezing. The temperatures employed, -18° or lower, retard or prevent the growth of harmful microbes. Their growth is also inhibited by lack of water, which is frozen. (Pimentel & Pimentel, 1996)

Fruits can be frozen dry with added dry sugar, or in syrup. Vegetables must be blanched (boiled or steamed for a short time) prior to freezing to inactivate plant enzymes that cause deterioration of natural flavors and colors. Pimentel (1996) also notes that the energy input for freezing fruits and vegetables is much greater than that for required for canning, averaging 1815 kcal/kg of frozen food versus only 575 kcal/kg for canning. (The figure of 575 kcal/kg represents only the energy expended in actual processing by heat and does not include the energy input required for making the container.)

Canning:

Since Louis Pasteur proved that microorganisms, invisible to the eye, caused foods to putrefy and that this putrefaction was not spontaneous decomposition, various methods of heating foods to temperatures high enough to kill harmful micro-organisms have been used to make preserved food safe for human consumption. The basic process in canning foods is to heat the food to boiling or higher, pack, and completely seal it in sterilized containers. The precise processing temperatures and times used depend upon the acidity, density, and other characteristics of the particular foodstuffs being processed. Foods with a pH of 4.5 or higher require the high heat of pressure canners to ensure complete destruction of the Clostridium botulinum heat-resistant spore. (Pimentel, 1996)

As reported by Pimentel, energy inputs associated with canning range from 575 kcal/kg of food processed when processing occurs at a large industrial facility, to as high as 1200 kcal/kg for home processing.

Summary of Processing Energy Inputs

Provided below in Table 2-1 is a summary of the energy inputs required for processing. It is important to note that in this study we are relying on information provided by Pimentel for the freezing and canning energy figures. However this data is over 10 years old and therefore it would be appropriate to assess its veracity due to potential processing changes that have occurred in the intervening time.

Table 2-1: Energy Inputs associated with product processing

Method	Package	Processing Energy Inputs		% of Total Energy Inputs
		MJ/kg	kcal/lb	%
Refrigerated	Bulk	0.08	8.8	0.8
	Portion	0.08	8.8	0.5
	Average	**0.08**	**8.8**	**0.6**
Frozen	Bagged	7.62	825	34.3
	Boxed	7.62	825	36.7
	Average	**7.62**	**825**	**35.5**
Canned	Ready Meal	2.41	261	23.0
	Fruit & Vegetable	2.41	261	16.3
	Average	**2.41**	**261**	**19.6**

Our findings indicate that even with the introduction of pre-cooling such as forced air, the energy inputs associated with processing of refrigerated product are significantly less than for canned, i.e. forced air cooling 8.8 kcal/lb (0.08 mj/kg) versus 260 kcal/lb (2.41 mj/kg) for canned product. However, the energy inputs for canning, in turn, are significantly less than those reported for frozen goods (260 kcal/lb (2.41 mj/kg) compared to 825 kcal/lb (7.62 mj/kg).

Examining the total energy inputs in the farm to table food chain, the range of percentages of energy consumed in processing as a percentage of the total energy consumption ranges from less than one percent for bulk refrigerated goods to more 30% for select frozen goods.

3. Packaging

One of the most critical steps in the food supply chain is the packaging of product. However, this is also one of the most energy intensive steps. Packaging is necessary to protect food from environmental impacts, as well as maintenance of product quality.

In evaluating the energy inputs associated with packaging it is necessary to consider both the range of material types used, as well as the converting operations required to turn the material (such as rolled steel) into a useable product (i.e. a steel can). In addition, one must consider both the primary package, e.g. the steel can used to hold the soup, as well as the cardboard tray and film containing 12 cans, used primarily for efficiencies in transport.

Shown below Table 3-1 are field findings regarding packaging materials used for various commonly available products in today's marketplace, along with an assessment of the package material to food weight ratio.

Table 3-1: Summary of packaging material and weights

Manufacturer	Product	Package	Gross Weight	Net Weight (stated)	Food Product Weight	Package Weight	Package weight to Food weight ratio	Packaging Material	Dimensions
			oz	oz	oz	oz	oz/ oz		
				Primary Packaging					
Del Monte	Cut Green Beans	Canned - F&V	16	14.25	8	1.9	0.24	Steel Can	2-7/8 x 4-3/8
Oregon Fruit Products	Blueberries in Light Syrup	Canned - F&V	16.2	15	6.7	2	0.30	Steel Can	2-7/8 x 4-3/8

Manufacturer	Product	Package	Gross Weight	Net Weight (stated)	Food Product Weight	Package Weight	Package weight to Food weight ratio	Packaging Material	Dimensions
			oz	oz	oz	oz	oz/ oz		
Swansons	White Premium Chicken Breast	Canned - F&V	5.9	4.5	3.4	1.2	0.35	Steel Can w/ pull tab top	3-1/8x1-1/2
Hain	Organic Whole Kernel Corn	Canned - F&V	17.5	15.25	9.7	1.9	0.20	Steel Can	2-7/8 x 4-3/8
Amy's Organic Soups	Chunky Tomato Bisque)	Canned -Meal	16.5	14.5	14.5	2	0.14	Steel Can	2-7/8 x 4-3/8
Campbells	Chicken Noodle Soup	Canned -Meal	12.3	10.75	10.9	1.4	0.13	Steel Can	2-5/8 x 4
Progresso	Beef Barkely Soup	Canned -Meal	22.4	19	19.7	2.7	0.14	Steel Can	3-3/8x4-1/2
Big Valley	Frozen Blueberries	Frozen - Bag	12	12	12	0.2	0.02	LDPE	1x9x6
C&W	Frozen Whole Petite Beans	Frozen - Bag	14	14	14	0.2	0.01	LDPE	1x9x7
Stouffers	Spinach Souffle	Frozen - Box	13.3	12	12	0.7	0.06	Coated Lquidboard	6-3/4x5x1-1/4
C&W	Spinach Souffle	Frozen - Box	10.9	10	10.2	0.7	0.07	Coated Lquidboard with film	5-1/2x4-1/4x1-3/8
Altar	Asparagus	Refrigerated - Bulk	280.5	240	240	40.5	0.17	Coated cardboard	7-3/8x12-3/8x17-1/4
Healthy by Choice	Broccoli	Refrigerated - Bulk	365.9	320	320	45.9	0.14	Coated cardboard	12-1/8x11-5/8x19-5/8
Driscoll's	Fresh Raspberries	Refrigerated - Portion	6.8	6	6.4	0.4	0.06	PS	5x5x2

Manufacturer	Product	Package	Gross Weight	Net Weight (stated)	Food Product Weight	Package Weight	Package weight to Food weight ratio	Packaging Material	Dimensions
			oz	oz	oz	oz	oz/ oz		
Very Berry Marketing (VBM)	Blueberries - Chile	Refrigerated - Portion	5.4	4.4	5	0.4	0.08	PET	4-1/4x4-1/4x1-1/2
Secondary Packaging									
Newman's Own	Herb Salad (bagged)	Refrigerated	118.9	105.6	105.6	13.3	0.13	Cardboard Box	7-1/4X11-5/8X15-5/8
Muir Glen	Crushed Basil Tomato	Canned	340.1	336	336	4.1	0.01	Cardboard Tray	2-1/8x12-1/2X16-3/8
Muir Glen	Crushed Basil Tomato	Canned	336.8	336	336	0.8	0.00	Plastic Stretch Film	
Deicabo	Cherry Tomatoes	Refrigerated	137.1	128	128	9.1	0.07	Cardboard Tray	3-7/8x11-7/8x15-5/8

Energy consumption in production of packaging materials

The primary packaging materials that are used in the transport of refrigerated, frozen and canned goods include tin-plated steel, cardboard, LDPE, polystyrene, PET and coated paperboard (liquid board). For this study, we are using life cycle inventory data primarily prepared for the Swiss Packaging Institute by the Swiss Federal Laboratories for Materials Testing and Research (EMPA). While this data is based primarily on Swiss factors, it is of sufficient quality to support comparative analysis for use in North America.

Table 3-2 below, provides the calculated energy requirements for production and conversion of these key materials on a kilogram weight basis. Included are energy requirements for production of the primary material as well as for converting operations, such as converting tin-plated steel sheet into cans. As shown, the energy requirements for material production range from a low of 9 mj/kg for recycled content corrugated cardboard to 18 mj/kg for recycled content steel sheet, to 80 mj/kg for polystyrene. For converting operations, energy consumption ranges from less than 0.5 mj/kg for cardboard to 6.2 mj/kg for canned production. The data presented for the plastics (LDPE, PET and polystyrene) include values for total energy consumption as well as that just associated with production, e.g. excluding gas and oil used as feedstock in the manufacture of these polymers.

Table 3-2: Energy inputs associated with package material production and conversion

Packaging Material	Primary Energy Consumed	Feedstock Energy Consumed	Conversion Energy Consumed
	MJ/kg	MJ/kg	MJ/kg
Tin Plated Steel (60% recycled content)	18.0	0	6.2
LDPE	36.4	42.7	0.3
Corrugated Cardboard (from mixed fibers)	9.1	0.1	0.5
Liquid Packaging Board	24.8	0.3	1.4
PET	34.8	41.1	3.6

Energy impacts of refrigerated goods packaging

As you can see from the table above, refrigerated goods can be delivered in both bulk, e.g. 15-20 lb. boxes of asparagus and broccoli, or in apportioned containers, e.g. 4-6 oz. packages of blueberries and raspberries. For portioned product, there is additional secondary packaging, typically stackable cardboard trays that contain anywhere from 24 to 48 individual units.

As shown on the table for bulk products, the typical package weight-to-food weight ratio ranges from 0.14 to 0.17 (ounce to ounce), that is .14 lbs of package to every pound of actual food delivered. In the case of portioned product, this ratio drops to 0.06 to 0.08. This is due in large part to the lightweight nature of the plastic packaging (PET or PS) used in lieu of heavy-duty cardboard for the bulk products. The packaged weight-to-food ratio for secondary packaging is calculated to be about 0.07 pounds of package to one pound of food delivered. Again, this material is primarily cardboard.

Applying these package weight ratios to the material energy requirements shown above in Table 3-2. results in packaging energy loads for refrigerated goods ranging from 160 kcal/lb to 670 kcal/lb. See table 3-3, below:

Table 3-3: Packaging Material Energy Consumption, Refrigerated Goods

	Bulk Refrigerated			Portion Refrigerated			Average	
	MJ/kg	Kcal/lb	% Total	MJ/kg	Kcal/lb	% Total	Kcal/lb	% Total
Primary								
Material	1.43	153.15	13.30%	5.31	569.85	33.68%	361.50	23.49%
Converting	0.07	7.48	0.65%	0.25	27.04	1.60%	17.26	1.12%
Secondary							0.00	
Material	0.00	0.00	0.00%	0.64	69.17	4.09%	34.58	2.04%
Converting	0.00	0.00	0.00%	0.03	3.38	0.20%	1.69	0.10%
TOTAL PACKAGING	1.50	160.64	13.95%	6.24	669.43	39.57%	415.04	26.76%

Energy impacts of frozen goods packaging

For frozen goods, delivery is generally either in bagged or boxed form. Bags are typically manufactured using low-density polyethylene (LDPE), and boxes are coated containerboard or liquid board. As shown on table A/PK, the ratio of package weight to food weight for bags ranges from 0.1 to 0.2, whereas boxes range from 0.06 to 0.07. Combining this ratio data with the materials information provided in Table B/PK, we find the energy consumption associated with frozen goods ranges from 180 kcal/lb to 236 kcal/lb as shown below in Table 3-4. Approximately 65% of this energy is associated with the primary packaging and 35% with the secondary packaging, i.e. cardboard boxes in which the bags and individual boxes are shipped.

Table 3-4: Packaging Material Energy Consumption, Frozen Goods

	Bagged Frozen			Boxed Frozen			Average	
	MJ/kg	Kcal/lb	% Total	MJ/kg	Kcal/lb	% Total	Kcal/lb	% Total
Primary								
Material	1.19	127.39	5.29%	1.63	174.90	7.77%	151.14	6.53%
Converting	0.00	0.49	0.02%	0.09	9.62	0.43%	5.06	0.22%
Secondary							0.00	
Material	0.46	49.40	2.05%	0.46	49.40	2.20%	49.40	2.12%
Converting	0.02	2.41	0.10%	0.02	2.41	0.11%	2.41	0.10%
TOTAL PACKAGING	1.67	179.70	7.47%	2.20	236.34	10.50%	208.02	8.99%

Energy impacts of canned goods packaging

When evaluating the packaging of canned goods, one must be cognizant of the impacts resulting from the actual quantity of food delivered. For example, as shown in Table 5, a 16 oz. can of green beans with a declared net weight of 14.25 oz. of product in actual effect is only delivering 8 oz. of green beans, with the remaining 6.25 oz. being ancillary liquid. On the other hand, a 16 oz. can of soup with a net weight of actual soup of 14.5 oz. delivers 14.5 oz of food product. Taking these variables into account, we find that the package weight-to-food weight ratio for canned fruits and vegetables, as well as for canned meats such as tuna and chicken, ranges from 0.2 to 0.35 pounds of packaging per pound of food. This compares to a ratio of 0.13 to 0.14 pounds of packaging per pound of food for such ready to eat items as soup and chili.

As shown below in Table 3-5, the resulting energy inputs for packaging of canned product ranges from 373 kcal/lb for ready meals to over 650 kcal/lb for fruits and vegetables. The energy associated with the primary packaging for canned goods represents over 90% of the total packaging load. This is due in significant part to the fact that the steel container is strong enough to support its own weight and therefore only minimal secondary packaging is required to expedite transport and warehousing.

Table 3-5: Packaging Material Energy Consumption, Canned Goods

	Canned Ready Meals			Canned Fruits & Vegetables			Average	
	MJ/kg	Kcal/lb	% Total	MJ/kg	Kcal/lb	% Total	Kcal/lb	% Total
Primary								
Material	2.53	271.11	23.86%	4.45	477.67	29.73%	374.39	26.80%
Converting	0.86	92.37	8.13%	1.52	162.75	10.13%	127.56	9.13%
Secondary								
Material	0.09	9.88	0.87%	0.16	17.29	1.08%	13.59	0.97%
Converting	0.00	0.49	0.04%	0.01	0.85	0.05%	0.67	0.05%
TOTAL PACKAGING	3.48	373.85	32.91%	6.14	658.56	40.99%	516.20	36.95%

Final thoughts on packaging

Shown below in Table 3-6 is a summary of energy inputs associated with of different product packages, both primary and secondary packaging typically found in today's marketplace.

Table 3-6: Energy inputs associated with primary and secondary packaging

Method	Package	Packaging Energy Inputs		% of Total Energy Inputs
		MJ/kg	Kcal/lb	%
Refrigerated	Bulk	1.50	160.64	13.95%
	Portion	6.24	669.43	39.57%
	Average		415.04	26.76%
Frozen	Bagged	1.67	179.70	7.47%
	Boxed	2.20	236.34	10.50%
	Average		208.02	8.99%

Method	Package	Packaging Energy Inputs		% of Total Energy Inputs
		MJ/kg	Kcal/lb	%
Canned	Ready Meal	3.48	373.85	32.91%
	Fruit & Vegetable	6.14	658.56	40.99%
	Average		516.20	36.95%

Examining the total energy inputs in the ‘arm to table food chain, the range of percentages of energy consumed in packaging activities (including both primary and secondary, material as well as converting operations) as a percent of the total energy consumption across the food chain ranges from 6% for frozen goods to over 40% for select canned and refrigerated items.

4. Transportation

Another key consumer of energy in the food supply chain is transportation. The impacts of this sector have grown significantly in recent years due in no small part to the further distances that product is moved. Whereas in previous times food was grown and harvested within a 500-mile radius, today’s product for the American consumer is typically grown and produced 2000 miles away. In some cases such select products such as raspberries, are flown in from Chili or winter green beans from Africa.

In calculating transportation energy consumption, one must consider not only the distance traveled, but the quantity of product that can be moved as well as the temperature in which it must be controlled. For purposes of this study we are focusing on the shipment of product by truck within the continental U.S. We recognize that other shipping techniques such as rail, and ocean and air transport, play an important and increasingly significant role in the movement of product, but at this point in time in North America, the majority of product is moved by containerized truck transport.

On average, the fuel efficiency (mile per gallon) of containerized truck transport is 8 miles per gallon. When a container requires refrigeration, an additional one gallon per hour is consumed. (Source: personal conversation with trucking industry) Assuming an average 50 miles per hour distance traveled, the fuel efficiency for a refrigerated container changes from 8 miles per gallon to 6.9 miles per gallon. The energy input of fuel (i.e. diesel) is 135 MJ/gallon.

Shown below in Table 4-1 is the of energy consumed for the distance traveled.

Table 4-1: Energy consumption for selected travel distances

Transport Type	100 miles	500 miles	750 miles	1000 miles	1500 miles	3000 miles
	MJ	MJ	MJ	MJ	MJ	MJ
Insulated (8 mpg)	1.688	8.438	12.656	16.876	25.313	50.625
Refrigeration Add-on (1 gph)	270	1.350	2.025	2.700	4.050	8.100
Refrigerated Total	1.958	9.788	14.681	19.575	29.363	58.725

When determining the energy consumed in the transport of a kilogram of product, one must take into account, as mentioned before, how much product can be moved in a container. The nature of food and differing packaging types result in a wide variation of food density within a given container. As shown in table 4-2, below, product densities can range from a low of 10.8 lbs/cu.ft., e.g. apportioned blueberries, to a high of 50 lbs/cu.ft. for canned soups. Assuming an actual 75% available capacity in a standard 40-foot container, the net weight of food transported can range from a low of 17,000 lbs. (blueberries) to a high of 80,000 lbs. (soup). However, weight constraints in effect limit the higher end allowed to only 60,000 lbs. Therefore, while theoretically possible to transport over 90,000 lbs of canned products in a truck, federal transportation rules prohibit this, resulting in a reduction of overall transportation efficiencies for canned precuts.

Table 4-2: Product volume and densities, select food products

Manufacturer	Product	Volume (calculated)	Net Density (calculated)	Food Product Density (calculated)	Gross Weight in 40 ft3 container (75% capacity)	Food Weight in 40 ft3 container (75% capacity)	Storage Volume (ft3/lb)
		ft3	lb/ft3	lb/ft3			
			Primary Packaging				
Del Monte	Cut Green Beans	0.016	54.21	30.44	95097.89	47548.94	0.03
Oregon Fruit Products	Blueberries in Light Syrup	0.016	57.07	25.49	96286.61	39822.24	0.04
Swansons	White Premium Chicken Breast	0.007	42.26	31.93	86569.59	49887.56	0.03
Campbells	Chicken Noodle Soup	0.014	47.70	48.36	85258.68	75554.44	0.02
Progresso	Beef Barkely Soup	0.023	51.00	52.88	93927.46	82605.85	0.02
Hain	Organic Whole Kernel Corn	0.016	58.02	36.90	104013.31	57653.09	0.03
Amy's Organic Soups	Chunky Tomato Bisque)	0.016	55.17	55.17	98069.69	86182.46	0.02
Driscoll's	Fresh Raspberries	0.029	12.96	13.82	22946.33	21596.54	0.07
Very Berry Marketing (VBM)	Blueberries - Chile	0.029	9.50	10.80	18222.08	16872.30	0.09
Big Valley	Frozen Blueberries	0.029	25.92	25.92	40493.52	40493.52	0.04
C&W	Frozen Whole Petite Beans	0.029	30.24	30.24	47242.44	47242.44	0.03
Stouffers	Spinach Souffle	0.024	30.72	30.72	53191.49	47992.32	0.03
C&W	Chopped Spinach	0.019	33.60	34.27	57219.82	53545.15	0.03
Altar	Asparagus	0.911	16.46	16.46	30061.51	25721.08	0.06
Healthy by Choice	Broccoli	1.601	12.49	12.49	22317.85	19518.21	0.08

Combining transportation energy consumption requirements with payload variables, the energy consumed for transport of products is found to range from a low of 120 kcal/lb. for ready meal canned goods to a high of 360 kcal/lb. for portioned product (see Table 4-3 below). This is based on an average 1500 miles transport distance utilizing a 40 foot transport container, with a 75%

volume capacity or 50,000 pound payload constraint. The majority of the energy consumption is associated with the distance traveled, although the component associated with refrigeration is still significant enough to warrant consideration.

Table 4-3: Energy consumption for product transportation

	Bulk Refrigerated			Portion Refrigerated			Average	
	MJ/kg	Kcal/lb	% Total	MJ/kg	Kcal/lb	% Total	Kcal/lb	% Total
Transport	2.46	264.13	22.94%	2.90	310.62	18.36%	287.38	20.65%
Refrigeration	0.39	42.26	3.67%	0.46	49.70	2.94%	45.98	3.30%
TOTAL - Refrigerated Goods	2.86	306.39	26.61%	3.36	360.32	21.30%	333.36	23.96%

	Bagged Frozen Goods			Boxed Frozen Goods			Average	
	MJ/kg	Kcal/lb	% Total	MJ/kg	Kcal/lb	% Total	Kcal/lb	% Total
Transport	1.27	136.19	5.66%	1.10	117.68	5.23%	126.94	5/45%
Refrigeration	0.20	21.79	0.91%	0.18	18.83	0.84%	20.31	0.87%
TOTAL - Frozen Goods	1.47	157.99	6.57%	1.27	136.51	6.07%	147.25	6.32%

	Canned Ready Meals			Canned Fruits & Vegetables			Average	
	MJ/kg	Kcal/lb	% Total	MJ/kg	Kcal/lb	% Total	Kcal/lb	% Total
Transport	1.11	119.49	10.52%	2.23	238.98	14.87%	179.24	12.70%
Refrigeration	0.00	0.00	0.00%	0.00		0.00%	0.00	0.00%
TOTAL - Canned Goods	1.11	119.49	10.52%	2.23	238.98	14.87%	179.24	12.70%

Examining the total energy inputs in the 'farm to table' food chain, the range of percentages of energy consumed in transportation activities (both miles as well maintaining refrigerated temperatures) as a percent of the total energy consumption across the food chain ranges from over 5% for frozen goods to over 27% for select refrigerated items.

5. Storage

While in transit from farm to table, food products require storage along the way. For canned goods, this storage typically consists of space available in the distribution warehouse, on store shelves or in a kitchen cabinet. However, for refrigerated and frozen products, storage in appropriate temperature-controlled units, such as refrigerators and freezers, is required. The energy associated with such storage is not insignificant.

Storage of refrigerated and frozen goods occurs in three relatively distinct units:
1 – Walk-in Refrigerators and Freezers used in distribution facilities and back of retail outlets
2 – Temperature controlled display (reach-in) cases at point of purchase
3 – Self-contained combination refrigerators/freezers within the home.

Walk-in coolers and freezers are room-sized insulated compartments which are refrigerated. As the name implies, walk-ins have an access door large enough for entry of people. They are used primarily for refrigerated storage of food and other perishable non-food items, such as flowers. In addition to use in the distribution chain, walk-ins are also used at retail centers for temporary storage of food prior to transfer to display cases. In supermarkets, walk-ins are generally served by larger central refrigeration systems which also serve display case circuits. In the distribution chain, the walk-ins generally have dedicated refrigeration systems.

As shown below in Table 5-1, energy consumption for refrigerated walk-ins is estimated at 0.41 mj/day/cf , assuming a 50% effective capacity for food storage. For a walk-in freezer, energy consumption is estimated to be 0.51 mj/day/cf.

Table 5-1 Energy consumption for different refrigerated and frozen goods storage

Storage Mechanism	Theoretical Storage Volume	Energy Consumption			
	cf	kwH/yr	MJ/yr	MJ/day	MJ/day/cf (50% effective storage)
Distribution Storage[1]					
Walk In Freezer	607	15555	55998	153	0.505
Merchandising Walk In Cooler	2040	42306	152301.6	417	0.409
Retail Storage and Display[1]					
Med Temp System					
Med Temp Racks		485700	1748520	4790	
Med Temp Display - 380 LF	3167	129600	466560	1278	
Med Temp Walk-Ins		83800	301680	826	
Condensers		49650	178740	489	
Med Temp Total	3167	748750	2695500	7384	4.66
Low Temp System					
Low Temp Racks		373300	1343880	3681	
Low Temp Reach In - 268 LF	3752	348200	1253520	3434	
Low Temp Single Level Open - 128 LF	640				
Low Temp Walk-Ins		50000	180000	493	
Condensers		49650	178740	489	
Low Temp Total	4392	2956140	2695500	8099	3.68

Storage Mechanism	Theoretical Storage Volume	Energy Consumption			
	cf	kwH/yr	MJ/yr	MJ/day	MJ/day/cf (50% effective storage)
Residential Storage[2]					
Side by Side 4.91*AV + 507.5	22	615.52	2215.872	6.070882	0.551898
Sid by Side with ice pass through 10.10*AV + 406	22	628.2	2261.52	6.195945	0.563268

[1] Source-Westphalen et al

[2] Source – Energy Star, 2004, Residential. AV = Adjusted Volume (1.63 x volume)

Retail refrigeration is typically divided into two distinct segments which have different technology and which are governed by different issues. The most visible, and energy intensive, part of these systems are the display cases which hold food for the self-service style of supermarkets. Hence they are primarily evaluated considering two criteria: food preservation and sales enhancement. The most common case types are:
a. Glass-Door Reach-Ins (commonly used for milk, butter, boxed frozen goods)
b. Open Multi-Deck (commonly used for fresh fruit and vegetable display, meats, cheese)
c. Open-Tub Freezers (commonly used for bagged frozen products and frozen meats & poultry)
d. Seafood/Deli Display Case.

A typically supermarket will have from 60 to 80 or more display cases. About half with be low and very low temperature cases (-15F to -35F) and the remainder medium temperature cases (10F to 35F)

As shown in Table 5-1, the energy consumption associated with the low and medium temperature retail displays is considerable, averaging 3.68 MJ/day/cf for low temperature systems and 4.66 mj/day/cf for medium temperature systems. The higher energy load for the medium temperature systems can be attributed to the higher percentage of open display footage in lieu of closed door display. For open displays, the air flow is blown over the open section of the case, creating an air curtain which separated food from the warmer store air. This is inherently a more energy intensive system than continuous cooling within a closed container.

While in previous times, stand-alone refrigerators and freezers for home storage were common, in today's households they are typically combined into a single unit. In order for a home refrigerator (side-by-side unit) to carry an Energy Star certification, it must consume less than 4.91xAV+507 kw-hrs/yr., or 10.10xAV+406 kw-hrs/yr. for a side-by-side unit with an ice pass through. Assuming a 22 cu.ft. volume refrigerator and a 50% effective storage rate, this translates to 0.55 mj/day/cu.ft. for the side-by-side, and 0.56 mj/day/cu.ft. for the side-by-side with the ice pass through.
For purposes of the home refrigeration/freezing energy load, we have utilized the 0.55 mj/day/cu.ft. consumption rate.

In addition the energy requirements to run the refrigerator/freezer, one must consider the duration of time that products are stored. Personal behavior and literature references inform us that refrigerated product typically is stored for five days within the distribution system, two days at retail display and three days at home, whereas frozen products can be assumed to be stored 30 days in the distribution chain, 15 days at retail and 45 days at home, for a total of 90-day shelf life.

The storage space requirement for these different types of packaging is shown below in Table 4-2 in the previous section. Combining these storage factors with the energy and time requirements indicates that the energy consumed for the storage of refrigerated goods ranges from 142 to 158 kcal/lb, with approximately 25% of this associated with home storage, the remainder for distribution chain storage (see Table 5-2 below). In the case of frozen goods, the energy requirements are significantly higher due to both the longer storage time and the higher energy Scientific Certification Systems – March 16, 2005 18 demands for keeping product frozen. The calculated energy consumed for the storage of frozen goods ranges from 940 kcal/lb to 1253 kcal/lb with approximately 80% of the energy associated with the distribution chain and 20% with home storage energy requirements.

Table 5-2: Energy consumption during distribution, retail and home storage

	Bulk Refrigerated			Portion Refrigerated			Average	
	MJ/kg	Kcal/lb	% Total	MJ/kg	Kcal/lb	% Total	Kcal/lb	% Total
Distribution	0.36	38.99	3.39%	0.31	34.12	2.02%	36.55	2.70%
Retail	1.64	177.70	15.43%	1.44	155.48	9.19%	166.59	12.31%
Home Storage	0.29	31.52	2.74%	0.29	31.52	1.86%	31.52	2.30%
TOTAL - Refrigerated Goods	1.93	209.21	18.17%	1.73	187.00	11.05%	198.11	14.61%

	Bagged Frozen Goods			Boxed Frozen Goods			Average	
	MJ/kg	Kcal/lb	% Total	MJ/kg	Kcal/lb	% Total	Kcal/lb	% Total
Distribution	1.34	144.71	6.01%	1.00	108.53	4.82%	126.62	5.42%
Retail	4.87	527.66	21.93%	3.65	395.74	17.59%	461.70	19.76%
Home Storage	2.18	236.37	9.82%	1.64	177.28	7.88%	206.83	8.85%
TOTAL - Frozen Goods	7.05	764.03	31.76%	5.29	573.02	25.47%	668.53	28.61%

Examining the total energy inputs in the 'farm to table' food chain, the range of percentages of energy consumed in storage activities (including both distribution chain as well as home) as a percent of the total energy consumption across the food chain ranges from negligible or zero for canned goods to over 40% for frozen items.

6. Meal Preparation

While there are many different ways to prepare products in the home, for purposes of this assessment we are evaluating the use of a microwave oven, as it is a common tool for heating or cooking fresh, frozen and canned product. On average microwaves consume approximately 1500 kilowatts when running.

According to manufacturers' directions, the estimated time required to microwave 14 ounces of frozen beans is 5 1/2 to 7 1/2 minutes; for 8 ounces canned beans 2 1/2 to 3 1/2 minutes; and for fresh green beans, 5 to 7 minutes for 14 ounces. For canned soup, the recommendation is 2 to 3 minutes. Using the average time, we find that that the energy consumed for preparation of these products ranges from 0.7 mj/kg (canned soup) to 1.47 mj/kg (frozen green beans) (see Table 6-1 below).

Table 6-1: Energy consumption to heat select products using a microwave

	Power Input	Time	Energy consumed		Weight of product heated	Energy Consumed per product weight	
	Watts	Min	kwh	mj	kg	mj/kg	kcal/lb
Frozen Green Beans	1500	6.5	0.16	0.59	0.40	1.47	159.34
Fresh Green Beans	1500	6	0.15	0.54	0.40	1.36	147.08
Canned Green Beans	1500	3	0.08	0.27	0.23	1.19	128.70
Canned Soup	1500	2.5	0.06	0.23	0.40	0.57	61.28

Examining the total energy inputs in the farm to table food chain as shown below in Table 6-2, the range of percentages of energy consumed in meal preparation (as applied to products that are heated) as a percent of the total energy consumption across the food chain ranges from 5% to 13% of the total energy consumed.

Table 6-2: Preparation Energy Inputs

Method	Package	Packaging Energy Inputs		% of Total Energy Inputs
		MJ/kg	Kcal/lb	%
Refrigerated	Bulk	1.35	146.25	12.70%
	Portion	1.35	146.25	8.64%
	Average		146.25	10.67%
Frozen	Bagged	1.47	159.25	6.62%
	Boxed	1.47	159.25	7.08%
	Average		159.25	6.85%
Canned	Ready Meal	0.57	61.42	5.41%
	Fruit & Vegetable	1.18	127.83	7.96%
	Average		94.63	6.68%

It should also be noted that there are many situations where products may be used directly from the package without heating. For example using canned green beans directly in a three-bean salad, using canned chicken in chicken salad, or using frozen blueberries in making a smoothie. In these situations, the energy consumed for food preparation is assumed to be negligible (i.e. zero). Therefore when performing a comparative evaluation across product options (e.g. fresh, frozen of canned green beans), energy used for meal preparation should be noted accordingly. For example, in preparing a three green salad, fresh and frozen beans would require cooking before use, whereas the canned beans can be used directly without additional heating.

7. Conclusions

As shown below in Table 7-1, the energy consumed in delivery products from farm to table is both significant in quantity as well as significantly variable across package options,

	Bulk Refrigerated			Portion Refrigerated			Average	
	MJ/kg	Kcal/lb	% Total	MJ/kg	Kcal/lb	% Total	Kcal/lb	% Total
Production	2.96	320.00	27.79%	2.96	320.00	18.91%	320.00	23.35%
Processing	0.08	8.83	0.77%	0.08	8.83	0.52%	8.83	0.64%
Packaging	1.50	160.64	13.95%	6.24	669.43	39.57%	415.04	26.76%
Transport	2.86	306.39	26.61%	3.36	360.32	21.30%	333.36	23.96%
Storage	1.93	209.21	18.17%	1.73	187.00	11.05%	198.11	14.61%
Meal Preparation	1.35	146.25	12.70%	1.35	146.25	8.64%	146.25	10.67%
TOTAL - Refrigerated Goods	10.68	1151.32	100.00%	15.72	1691.83	100.00%	1421.57	100.00%

	Bagged Frozen Goods			Boxed Frozen Goods			Average	
	MJ/kg	Kcal/lb	% Total	MJ/kg	Kcal/lb	% Total	Kcal/lb	% Total
Production	2.96	320.00	13.30%	2.96	320.00	14.22%	320.00	13.76%
Processing	7.62	825.00	34.29%	7.62	825.00	36.66%	825.00	35.48%
Packaging	1.67	179.70	7.47%	2.20	236.34	10.50%	208.02	8.99%
Transport	1.47	157.99	6.57%	1.27	136.51	6.07%	147.25	6.32%
Storage	7.05	764.03	31.76%	5.29	573.02	25.47%	668.53	28.61%
Meal Preparation	1.47	159.25	6.62%	1.47	159.25	7.08%	159.25	6.85%
TOTAL - Frozen Goods	22.25	2405.96	100.00%	20.81	2250.12	100.00%	2328.04	100.00%

	Canned Ready Meals			Canned Fruits & Vegetables			Average	
	MJ/kg	Kcal/lb	% Total	MJ/kg	Kcal/lb	% Total	Kcal/lb	% Total
Production	2.96	320.00	28.17%	2.96	320.00	19.92%	320.00	24.04%
Processing	2.41	261.36	23.00%	2.41	261.36	16.27%	261.36	19.64%
Packaging	3.48	373.85	32.91%	6.14	658.56	40.99%	516.20	36.95%
Transport	1.11	119.49	10.52%	2.23	238.98	14.87%	179.24	12.70%
Storage	0.00	0.00	0.00%	0.00	0.00	0.00%	0.00	0.00%
Meal Preparation	0.57	61.42	5.41%	1.18	127.83	7.96%	94.63	6.68%
TOTAL - Canned Goods	10.54	1136.13	100.00%	14.92	1606.74	100.00%	1371.43	100.00%

Based on this data, it appears the most energy effective method for product delivery is canned ready meals (1136 kcal/lb) followed by bulk refrigerated (1152 kcal/lb), canned fruits & vegetables (1607 kcal/lb), refrigerated portion (1692 kcal/lb), frozen boxed products (2250 kcal/lb) and frozen bagged products (2406 kcal/lb). In essence, bulk refrigerated items and canned goods such as soups move to market with the same level of energy consumption (1150 kcal/lb).. Canned fruits and vegetables, along with portion refrigerated product consume an additional 30% energy, increasing consumption to 1650 kcal. The most energy intensive methods, frozen bagged and boxed product require 100% more energy to bring the food from farm to table than the less energy intensive bulk and canned meals.

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