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An Energy comparison between polycarbonate and glass half-gallon milk bottles used in a returnable refillable system

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AN ENERGY COMPARISON BETWEEN POLYCARBONATE AND GLASS HALF-GALLON MILK BOTTLES USED IN A RETURNABLE REFILLABLE SYSTEM

BY

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CERTIFICATE OF APPROVAL

of

MASTER'S THESIS

This is to certify that the Master's Thesis of

Mark A. Plezia

With a major in Packaging Science
has been approved by the Thesis Committee as
satisfactory for the thesis requirement for
the degree of Master of Science
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AN ENERGY COMPARISON BETWEEN POLYCARBONATE AND GLASS HALF-GALLON MILK BOTTLES USED IN A RETURNABLE REFILLABLE SYSTEM

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November 21, 1991

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1. Introduction

Things happen in society that cause us to take a closer look at the situations around us. An example is the homeless garbage barge, Mobro 4000 of Islip Long Island, which, on March 22, 1987, found itself on a long unwanted journey.[1] This incident is one which helped trigger the general public's awareness of the current landfill crisis, being the rapid shrinking of landfill space.

When confronted with a problem it is important to thoroughly investigate the problem before any decisions are made as to solve the problem. In most cases there are many causes that form the root of a problem; therefore, the multiple factors which cause the problem must be investigated simultaneously.

In the case of increasing solid waste, one cause of the problem is the excessive use of packaging material. The logical solution would be to reduce the amount of material used to package products. One way of achieving this reduction of material is through the reuse of some packages where appropriate. One type of reuse is the returnable refillable container, while another is reusing packages for in-home storage or other uses.

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[1] Jacob V. Lamar, "Don't be a Litterbug," <u>Time</u> 4 May 1987:26.

This research will investigate the appropriateness of a returnable-refillable system based on an energy analysis of comparable systems.

In 1985 New York State had 500 open landfills, in 1990 there were 270 left.[2] The reasons for the closing of 230 landfills range from reaching their capacity to forced closing because of leachate polluting water tables. Some have been classified hazardous and closed due to the improper disposal of hazardous waste. On the average, each New York resident produces four and a half pounds of refuse daily, contributing to the 160 million tons of garbage produced annually by Americans.[3] It is expected that the remaining operating landfills in New York State will be filled to capacity by 1995.[4]

One solution to this crisis is a reduction in the amount of waste generated. This is commonly called source reduction. Reduction in material produced and disposed of helps lower the burden placed on landfills. Packaging accounts for 30 percent of municipal solid waste (MSW) by weight.[5] This makes packaging a significant area for waste reduction (see Figure 1).

Waste reduction is defined by the U.S. Environmental Protection Agency (EPA) as the "prevention of waste at its source, either by redesigning products or by otherwise changing societal patterns of consumption or

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[2] Jon R. Luoma, "Trash Can Realities," Audubon March 1990: 88.

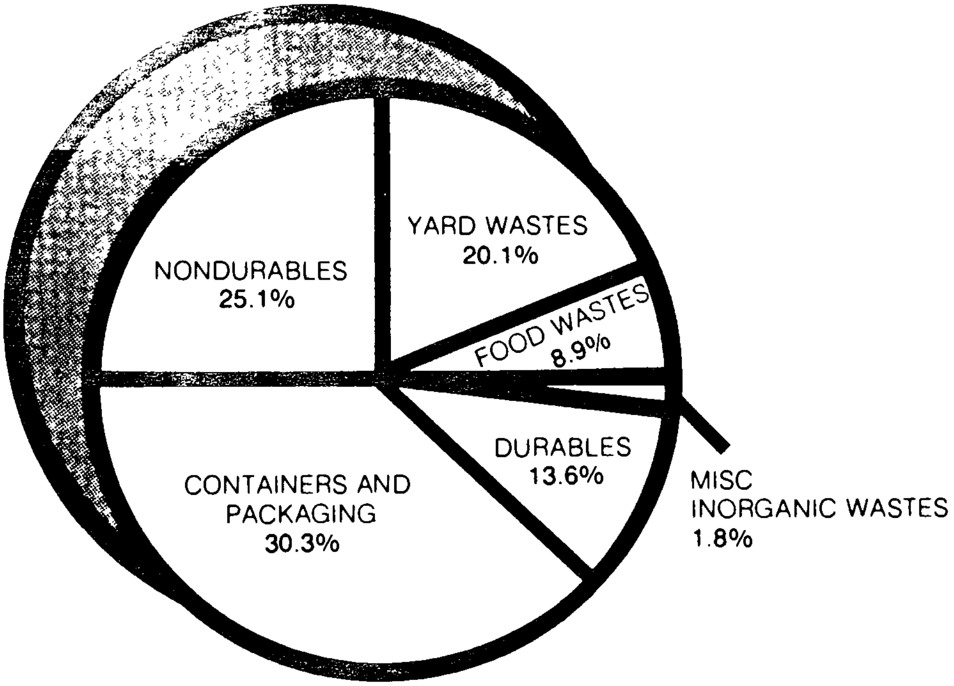
[3] Ibid.

[4] Ibid.

[5] Susan E. M. Selke, Packaging and the Environment: Alternatives, Trends and Solutions. (Lanacaster: Technomic, 1990) 50.

Figure 1

Municipal Solid Waste[6]



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[6] Susan Selke E.M. Packaging and The Environment: Alternatives, Trends and Solutions. (Lancaster: Technomic, 1990) 47.

waste generation."[7] The EPA has also outlined three approaches to waste reduction. The first approach is the reduction of material used per unit of product or less packaging per unit of product. This can be demonstrated by the manufacturing of thinner glass walls in disposable bottles and jars.

The second approach is to increase the life-cycle of durable and semi-durable goods to reduce the discarding and replacement of goods. This approach can be applied to many durable goods currently being used. This method strictly deals with the product and not the packaging aspect of the product.

The third approach is substituting single-use "disposable" products with reusable products. Reusable products should be engineered to increase the number of times that an item may be reused. This approach can be applied to the packaging as well as the product.

An approach not mentioned by the EPA is material source reduction in packaging through the recycling of used packaging. This can be seen by the efforts of communities to separate trash for curb-side pick up.

A new, added approach to waste reduction is to directly decrease the consumption of materials by persuading people to moderate their needs and desires.[8] High volume products should be the center of attention for waste reduction because they contribute the most to municipal solid waste. One such item is the consumption of fresh fluid milk in the

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[7] United States Environmental Protection Agency, <u>Resource Recovery and Waste Reduction</u>, third report to Congress by the Office of Solid Waste Management Programs (Washington D.C., 1974) 16.

[8] Ibid., 63.

United States.

So much milk is consumed that it is considered a staple. A reduction in material used to package milk would be significant due to the volume of units sold. In the New York-New Jersey marketing area, which includes Pennsylvania, Connecticut, Maryland, and Massachusetts, 1,998,248 gallons of whole fluid milk were purchased in November of 1987.[9] During that month 324,392 gallons of whole milk were sold in half-gallon quantities while 919,194 gallons were packaged in one gallon quantities (Appendix A). Assuming that consumption is constant over a twelve month period, a year's consumption of whole milk for the year of 1987 would be 23,978,976 gallons.

One way to reduce waste is through a returnable refillable packaging system. This study will analyze glass and polycarbonate returnable refillable milk jugs. The half-gallon size will be used for the study since it is the most widely used in the returnable system for milk.

There are other packaging alternatives for the milk industry but they are not returnable systems. The gable-top carton, high-density polyethylene (HDPE) milk jug, low-density polyethylene (LDPE) bag and Tetra Brik are all alternatives, but are also all disposable, not relieving any stress on the landfill crisis. Other packages such as the low-density polyethylene bag and aseptic cartons are not as widely accepted in the United States as they are in Europe and Canada. For these reasons these will not be evaluated.

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[9] Thomas A. Wilson, Administrator, The Market Administrators Bulletin, vol. 48, Qtly A (New York-New Jersey Milk Marketing Area), 14.

Of all of the disposable containers used for milk, the HDPE milk jug offers the most promise for recycling because it is made of a single material, and, if recycled, the material has several post-consumer uses. One other advantage of the HDPE jug over other package systems is that where incineration is an option, HDPE can offer up to 18,500/19,500 btu's in secondary energy.[10]

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[10] Facts about Plastic Bottles Reference Guide. Plastic Bottle Institute, The Society of the Plastics Industry, Inc.

2. Objective

One method of source reduction is the use of returnable, refillable container systems. This thesis will compare two different returnable refillable container systems presently used in the milk industry. The glass half-gallon returnable refillable bottle and the polycarbonate half-gallon returnable refillable bottle are the focus of this study. A comparative energy analysis will be conducted. The analysis will present quantified energy use for both container systems from which a conclusion as to which container system is more energy efficient can be made.

3. Literature Review

Many energy studies have been conducted on packaging container systems. One such study, conducted by Arthur D. Little, Inc., entitled The Life Cycle Energy Content of Containers, analyzed the life-cycle energy as described below. The analysis involved:[11]

* the energy needed to mine or locate the raw materials for manufacturing steel, aluminum, and glass containers;
* the energy needed to transport the raw materials for container manufacturing facilities;
* the energy to manufacture the container;
* the energy needed to transport the finished container from the manufactures to the packager;
* the energy used in packaging and distribution;

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[11] Arthur D. Little, Inc., The Life Cycle Energy Content of Containers (Cambridge, 1982) 1.

- the energy credits for any material that can be recycled;

- the energy used in recycling such materials or their disposal.

This analysis is said to be a level 2 analysis for it only accounts for the embodied energy of consumables, whereas a level 1 analysis accounts for only direct energy consumption. Calculations showed that the manufacturing of returnable glass containers required 3.5634 MMbtu/1000 containers or 12.25 btu/gram.

Though the analysis seemed thorough, the researchers left out a key factor: the container weight for the twelve-ounce refillable glass container. This was obtained by averaging the weight of current twelve-ounce bottles which is calculated to be 290 grams per container.

Another similar study of soft drink containers was conducted by Bruce M. Hannon. His energy analysis included bottles, cans, paper, and plastic containers. This research compared two package systems delivering the same quantity of soft drinks in both throwaway and returnable container styles. This was a level 2 analysis because it accounted for the embodied energy of consumables. Equations were developed for the embodied energy of throwaways and returnable bottles, as a function of the number of fills for each container.

Energy utilization figures were also given for the transportation of the raw materials and finished goods. These were calculated using figures from the "1967 Census of Transportation" and the distance traveled values were gathered from industry. The energy use for a tractor-trailer transport (360 btu/lb/mile) was calculated by dividing the energy expended to deliver "x" amount of weight by a distance of "y".

The energy ratio comparing the throwaway and returnable bottles was based on an N value (N=number of trips) of 8. Energy values for glass were calculated for bottles made of 100 percent virgin material and 30 percent recycled material to show the effects of cullet (recycled glass which assist in the melting of glass batches). The 30 percent recycled cullet represents in-house recycled waste which was the extent of recycling done at the time of the study.

The study concluded that the "returnable bottles are far superior from an energy standpoint to throwaways by 17.06 btu/gram, either bottles or cans."[12] This conclusion was based on the returnable bottles having a life-cycle of eight trips before their retirement from the system.[13] As a point of contrast, 400 percent more energy was spent on the returnable container (fifteen trips), and 975 percent on the throwaway container system, than was spent on the energy content of the beverage.[14] Comparing the two glass containers (virgin and recycled), it was found that there was even a greater energy efficiency with the recycled container. Hannon states that if the entire beverage industry were to convert to a returnable container system, the energy demand

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[12] Hannon, Bruce M., "Bottles Cans Energy." <u>Environment</u> March 1972: .

[13] Ibid., 11.

[14] Ibid., 22.

would decrease by 40 percent.[15]

The study also included the analysis of half-gallon glass milk jugs (132 grams, 50 trips) and half-gallon HDPE nonreturnable milk jugs (55 grams). The energy requirements for the HDPE were 26,750 btu/gal. for disposable and 7,850 btu/gal. for 50 return trips, giving an energy ratio of 3.4 to 1.[16]

A resource utilization and environment profile analysis was conducted by the EPA on nine different beverage containers in the soft drink and beer industry. The analysis involved seven different parameters: virgin raw material use, energy use, water use, industrial solid waste, post-consumer solid waste, air pollutant emissions and water pollutant effluents.[17] These parameters were assessed for each manufacturing and transportation step in the life-cycle of the container. The analysis started with the extraction of raw materials from the earth needed for manufacturing and ended with the final disposal of the container. The nine types of containers consisted of glass returnable bottles evaluated at nineteen, ten, and five trips, one-way glass containers, plastic coated glass containers, three-piece steel cans with aluminum closure, all steel cans, two-piece all aluminum cans (fifteen percent recycled) and ABS plastic bottles. These nine types of containers represented four different material groups: glass, steel, aluminum, and plastic.

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[15] Ibid., 23.

[16] Ibid., 20.

[17] United States Environmental Protection Agency, Resource and Environmental Profile Analysis of Nine Beverage Container Alternatives. report prepared by Midwest Research Institute.

Some packages were made of multiple materials, such as, the steel can with aluminum closure and the plastic-coated glass bottle. Paper was considered as a fifth basic group for its use in labels and shippers. The analysis considered each package's effects on the seven different parameters.

The factors which were excluded included litter, waste heat and carbon dioxide.[18] Beer containers were specifically selected for this study due to their standard twelve-ounce size. Soft drink containers were also included but in this case sixteen-ounce glass and twelve-ounce cans and plastic containers were compared. The glass containers were the only returnable container system. They were compared according to three different life cycles, nineteen-trips, ten-trips, and five-trips. Based on actual life cycle data (eight to ten trips per life cycle) the ten-trip data was select for comparison. The nineteen-trip and five-trip cycles were used to represent the upper and lower limits of the returnable refillable system.

Each container was ranked on its effect in each category in relation to the other eight containers. Containers ranked "one" were most favorable whereas those ranked "ninth" were least favorable.

The returnable glass container (ten-trips) ranked first and second in all of the categories (except for post-consumer waste where it ranked third) when compared to the three other container alternatives (nineteen-trip, five-trip, and one-way).[19] Therefore this container was

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[18] Ibid., 1.

[19] Ibid., 4.

judged to have the least overall negative effect on the environment, but not by a large margin. When compared with the one-way systems, it was found that the ten-trip containers also had a lower overall effect on the environment and resources even though the container produces 4.5 times more post-consumer waste than the aluminum and conventional three-piece steel can.

Though energy values were occasionally referenced, an energy value for glass containers could not be derived. The analysis pointed out both advantages and disadvantages of disposable and returnable systems. A disadvantage of the returnable container is the greater use of water and caustic solution needed for cleaning the returned bottles. However in the brewing industry the caustic waste water from the washing operation is used to neutralize the acid brewing waste, then becoming an advantage. This contributes to the returnable container system's overall lower environmental impact.

In 1977 the Packaging and Containers Working Party of the Waste Management Advisory Council, a body jointly sponsored by the Department of Industry and Environment, began its study of the environmental and economical effects of various containers used in the beverage industry in the U.K. As the work began the committee realized that no accurate quantitative data was available for the energy needed to produce those beverage containers. As a result I. Boustead and G.F. Hancock were asked to investigate the energy needed to produce raw materials and containers.

The methodology used by Boustead and Hancock follows the law of conservation of matter which states mass input equals mass output. The same follows for the energy inputs being equal to the energy output.

The industrial operation was broken down into sub-systems. Each sub-system's energy requirement is the sum of four contributing sources:

(a) energy directly consumed as fuels,

(b) energy needed to produce these fuels from raw materials in the ground,

(c) energy needed to erect and maintain plant and machinery,

(d) energy of labor.[20]

Both (a) and (b) normally accounted for 95 percent of the total energy associated with production of beverage containers. The manufacturing facilities were compared on the energy needed to produce 1 kg. of container glass as opposed to the energy needed to produce one container. This was done to simplify the comparison since the manufacturers did not produce the same shape and size container.

The study appeared to be the most extensive, analyzing sixteen glass manufacturing plants in the U.K. These manufacturing plants are summarized in Appendix B. The summary illustrates the wide range of efficiency in the industry. The most efficient glass manufacture had a value of 18.90 MJ/1 kg. of container glass while the least efficient plant possessed a value of 29.39 MJ/1 kg. This presented a 36 percent difference among the glass manufacturing plants. The average energy consumption for the sixteen manufacturing plants was 23.47 MJ/1 kg. for

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[20] I. Boustead and G.F. Hancock, Energy and Packaging (New York: Wiley, 1981) 23.

container glass.

Argonne National Laboratory, Energy and Environmental Systems Division published a report in February of 1981 on the energy and material use in the production and recycling of consumer-goods packaging. The author, L.L. Gaines, analyzed five packaging materials: paper, glass, steel, plastic, and aluminum. It was calculated that approximately 8700 btu/lb. (19.18 btu/g.) were used in the production of container glass. It was stated that recycling glass saves only about 25 percent of the energy need to manufacture glass from virgin materials. This number changes with the energy expended on the transportation of recycled glass to the manufacturing facility.

The final and most recent report acquired was commissioned by Tetra Pak International AB.[21] Environmental impacts were assessed for three different beverage containers marketed in the Federal Republic of Germany. The container systems assessed were the Tetra Brik, the throwaway glass containers and returnable glass bottles having a life cycle of ten-twenty trips.

The energy needed to manufacture the ten-trip returnable bottle was 670 MJ/ 1000 liters (6355 btu/600 g. container). The filling and washing of the bottle required 605 MJ/1000 liters (3803 btu/360 g. container) per life cycle, while distribution consumed 495 MJ/1000 liters. The nonreturnable glass bottle's manufacturing energy consumption was considerably higher with a value of 4010 MJ/1000 liters.

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[21] Lundholm, Mams P. and Sundstrom, Gustav. Tetra Brik Aseptic Environment Profile. Malmo: AB Falths Tryckeri, 1985.

Once more this showed that returnable systems require less energy than that of disposable systems.

The overall conclusion of the report was that Tetra Brik was more environmentally friendly than the other containers evaluated. This was based on the grounds that the package consumed less water, emitted less air and water pollutants and consumed less energy. Tetra Brik is a good example of waste reduction because of being a flexible container.

Table 1. shows a comparison of all of the energy study values cited in this chapter along with an average energy value to produce container glass. Additional information is given on the known variables of the manufacturing process. These include the cullet ratio if known and the sectors included in the analysis.

Table 1
Energy Comparison of Glass Studies

Author	Year	Energy Value Btu/grams	Percent Cullet	Processing Energy Included	Transportation Energy Included
Hannon	1972	17.06	*	no	no
R.G. Hunt	1974	13.26	15	no	no
Boustead & Hancock	1977	16.71	*	no	no
L.L. Gaines	1981	19.18	*	*	*
A.D. Little	1982	12.25	*	no	no
Lundholm & Sundstrom	1985	10.56	9.5	no	yes
	Average	**15.69			

* detail information not published
** average does not included the 1985 study for it included transportation energy that the other studies did not include

4. Methodology

The energy comparison of two containers will be done by evaluating eight areas of energy use:

1. The energy needed to convert raw materials to the desired material. This does not include the energy needed to extract the raw materials from the earth and transportation to the facility.

2. The energy needed to transport the material to the fabricator.

3. The energy needed to fabricate the container.

4. The energy needed to transport the finished container to the packer.

5. The energy needed to wash the container for use.

6. The energy needed to fill and cap the container.

7. The energy needed to transport the product and container to the retailer.

8. The energy needed to transport the container back to step four.

Due to the nature of glass manufacturing (having the processing and forming of glass in one location and by a continuous process), steps 1 and 3 have been combined while step 2 has been deleted as seen in Figure 2. The procedure for polycarbonate is demonstrated in Figure 3.

In step 4 the distances will be estimated according to the container type and availability of processing sites.

Once the analysis reaches step 5, all of the variables for the two-container systems become the same since the washing and filling of the bottles are the same.

Energy consumed by the consumer upon receiving the product at the retailer will not be evaluated for it is outside the scope of this project.

Figure 2

Glass Container Flowchart

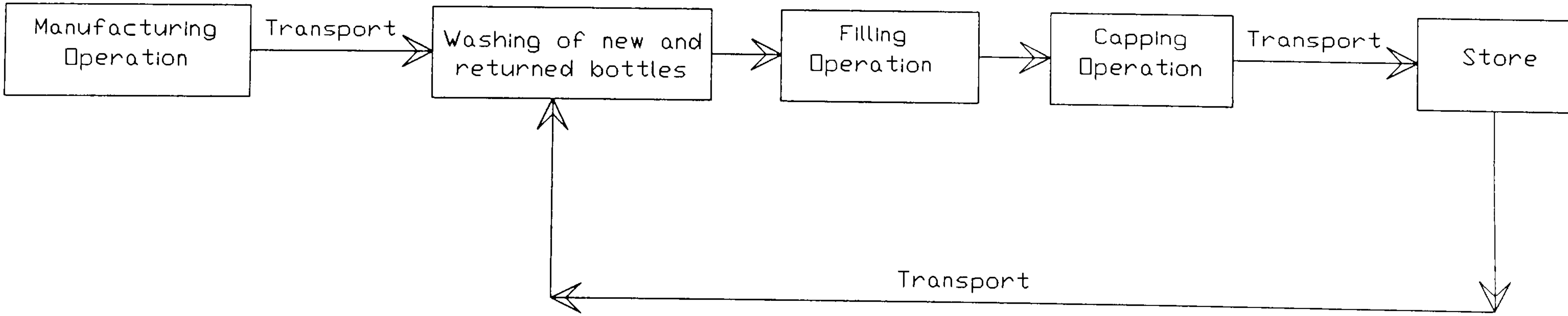
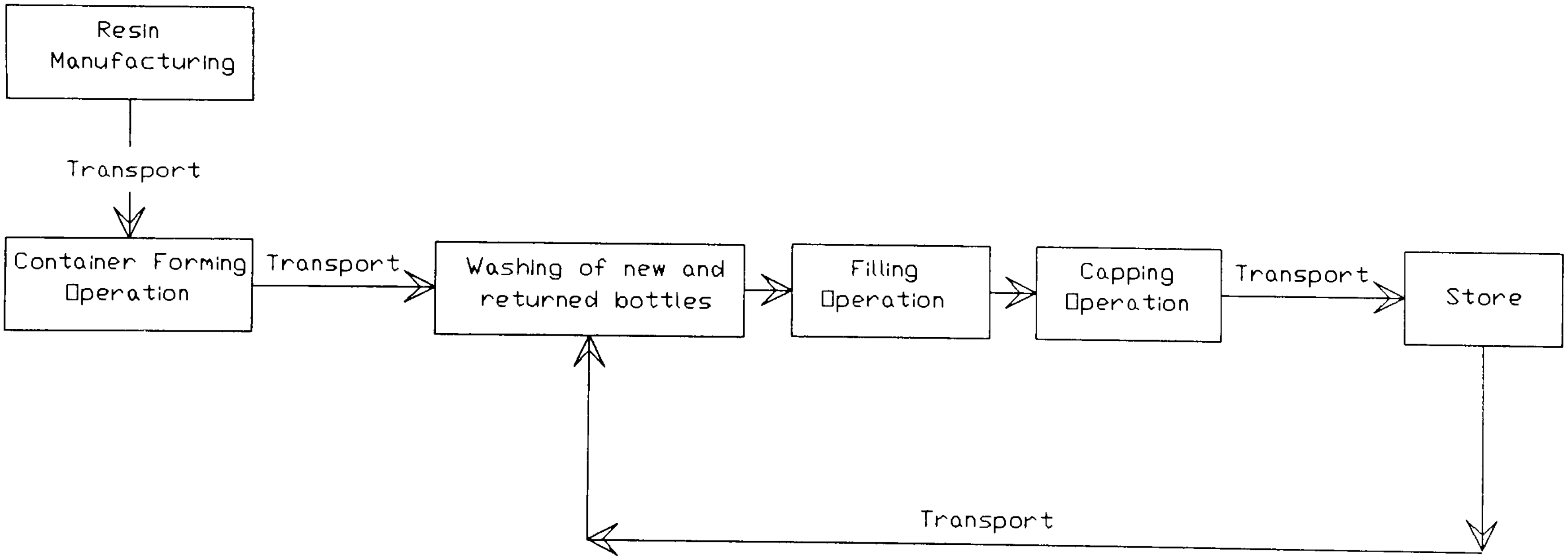


Figure 3
Polycarbonate Container Flowchart



5. Setting of Case Study

The analysis will be applied to Stewart Ice Cream Company, located in Saratoga Springs, New York. The company's product acquisition and retail sales logistics will be used for this analysis in calculating distribution distances, life cycles, and volumes of products delivered. Delivery distances for new containers will be calculated from the manufacturing site of that particular container to the Stewart plant.

On a weekly basis, Stewart produces and delivers 120,000 gallons of fresh milk, 50 percent of it packaged in half-gallon quantities.[22] Delivery is spread over nine routes, servicing 178 company-owned convenience stores. Delivery distances range from 180 miles to 304 miles per round trip.[23] An analysis of the distribution data shows that 64 percent of the milk is delivered within a 60 mile radius of the dairy. Of the 178 dairy stores, 88 were plotted, their locations are shown on the map in Appendix C. The map is divided by concentric circles radiating from Saratoga Springs, with each radius increasing ten miles from Saratoga Springs up to 120 miles. The 88 stores have been located within those 12 concentric circles and are displayed in Table 2. Delivery milage has been averaged using the data in Table 2. The

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[22] John Barnes, telephone interview, 23 Nov. 1990.

[23] Dick Clark, telephone interview, 11, Feb. 1991.

average has been calculated by multiplying the number of stores located in the outer ten miles of each radius by the distance (in miles) of each radius. This number was then calculated for each of the 12 radii added and divided by the total number of stores. This has been summarized in Table 2, showing that the average delivery distance for a half-gallon is 57 miles one-way. The milk is delivered by a 24'x7'8"x8' refrigerated diesel-powered truck having a net weight of 24,000 pounds. The trailer has a storage capacity of 1,472 cubic feet or a weight limit of 28,000 pounds, whichever is reached first. The plant's packing operations are as follows:

(1) All bottles are washed whether they are new or used, using the same process;

(2) They are fed through a Federal Filler model # 63 and than capped with a plastic closure;

(3) A human operator puts the bottles in a case and a conveyer stacks the cases six high;

(4) The cases are then temporarily held in cool storage until they can be manually loaded onto a truck.

Table 2
Distribution Data

Radius from Saratoga Springs	Number of Stores	Miles Factored
10	3	30
20	10	200
30	19	570
40	11	440
50	6	300
60	7	420
70	6	420
80	3	240
90	7	630
100	4	400
110	8	880
120	4	480
Total	88	5010

Average miles traveled per 1/2 gallon: 57 miles

6. Glass Container

In an age of technological advancements, no sooner is something incorporated than it is found to be outdated by a new development. This can also happen in the area of comparisons. In the past there have been studies conducted in the area of energy efficiencies similar to the studies cited in this thesis. Over time these studies have become outdated due to changes in technologies used for the research.

The glass industry has many energy determining factors and one actual energy utilization value for the production of glass is not a true representation of the industry. In various references, there is a 70 percent difference in the energy needed to manufacture one ton of container glass. This difference can be attributed to the manufacturing and measurement technologies at the time the studies were conducted. New technologies cannot always be implemented immediately due to high shut-down and start-up costs. A base value for energy used in glass production should reflect the best of efficiencies and conditions at the time.

A technique to simulate industry energy use has been developed by Heide, Franke, Schmidt and Straufberger. The aim of their investigation was to test a modified thermal analysis instrument for the use of determining the energy expended to heat a glass batch to its melting point under conditions similar to those in industry. A modified DTA apparatus was used to determine the energy expended to heat a 750 mg. glass batch of original consistency starting at room temperature up to 1400 degrees Fahrenheit.

Tests showed that the energy expended decreased with the increase in the cullet ratio in the glass batch. Figure 4 shows the curve passing through a minimum at a ratio of 70-80 percent. This closely represents what happens in actual industry applications. Other experiments continued to show that their observations correlated closely to those of the industry. From these experiments the formula derived is as follows:

$$E = (c * T * M) + (x * T) + (E * T * x).$$

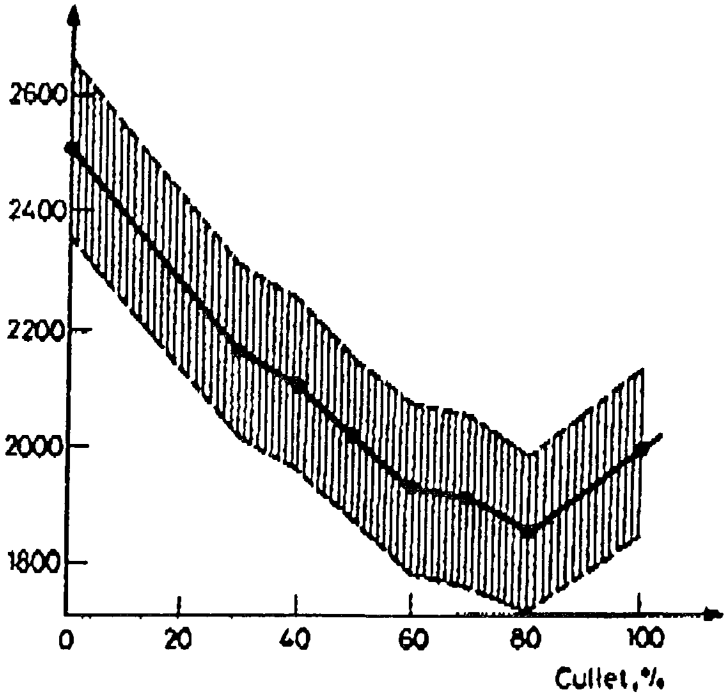
T represents the melting temperature of the batch while c is a type of heat capacity which includes the energy effects of batch reactions, M is the batch mass, x is the thermal conductivity and E is the energy content of the flue gases. At the time of the experiment the standard deviation had a mean value of ten-fifteen percent. This is not much considering that two earlier studies (Hannon and Tetra Brik) differed by 70 percent.

6.1 Glass Manufacturing

In the manufacturing of glass, sand, limestone, and soda ash are mixed with cullet (recycled glass). In the reaction, soda ash melts first, acting as a solvent for the sand which in turn lowers the melting

Figure 4

Energy Expended as a Function
of Cullet Ratio[24]



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[24] K. Heide, R. Franke, H.G. Schmidt and Straufberger. "Investigation of the Energy Expended in Heating Glass Raw Materials to the Melting Temperature." Journal of Thermal Analysis 33(1988) 617.

point of glass. The process is continually aided by heat from gas-fired ports. This keeps the temperature in the tank between 2600 and 2900 degrees Fahrenheit.[25] Gas escapes from the molten mixture causing currents that mix the batch uniformly. The mixing process continues as the molten glass approaches the bridgewall. Impurities that float to the surface are held back as the glass moves to the refiner. Glass then passes through several forehearths off of the refiner where it is cooled to 2,000 degrees and directed to feeders were it is squeezed through an orifice and cut into uniform globs. Globs are then formed into containers by a forming machine. If the container is allowed to cool too quickly the container is stressed, resulting in breakage. It is at this stage that the containers are annealed. Annealing requires that the temperature of the container be raised to 1000 degrees and held for fifteen minutes to relieve the stresses.[26]

The temperature needed to bring glass to its melting point requires so much energy the process of making glass containers is integrated into the glass fabrication plant. There are several factors which can influence the energy requirements of glass container manufacturing. The percent of cullet used in a batch has a dramatic affect on energy requirements. A study conducted by Heide, Franke, Schmidt and Straufberger researched the relation of energy expended as a function of

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[25] Joseph F. Hanlon, Handbook of Package Engineering 2 edition (New York: McGraw Hill, 1985) 9-4.

[26] Ibid., 9-8.

the cullet ratio shown in Figure 4.[27] At one time industry used anywhere from ten to twenty percent of cullet which usually came from "in-house" sources. This number has risen dramatically due to the increase in recycling efforts. Every one-percent increase in cullet is estimated to save one-quarter of one percent of energy used to make glass containers.[28] The amount of moisture in a batch of raw materials also has an effect on the melting requirements of glass as shown in Figure 5.[29] Batch mixtures also have an effect on the energy requirements as demonstrated in Figure 6.

An energy consumption value for glass containers has been derived by averaging the actual value from Table 1 (15.69 btu/g.) and Heide, Franke, Schmidt and Straufberger theoretical value (2.78 btu/g.).

Reasons for using two energy values (actual and theoretical) for this comparison is that the Heide, Franke, Schmidt and Straufberger formula is relatively new and it is important to see how it compares with actual data from the industry.

6.2 Half-Gallon Glass Container

Glass milk jugs have been used in the milk industry for over a hundred years. Not much has changed about the bottle except for design

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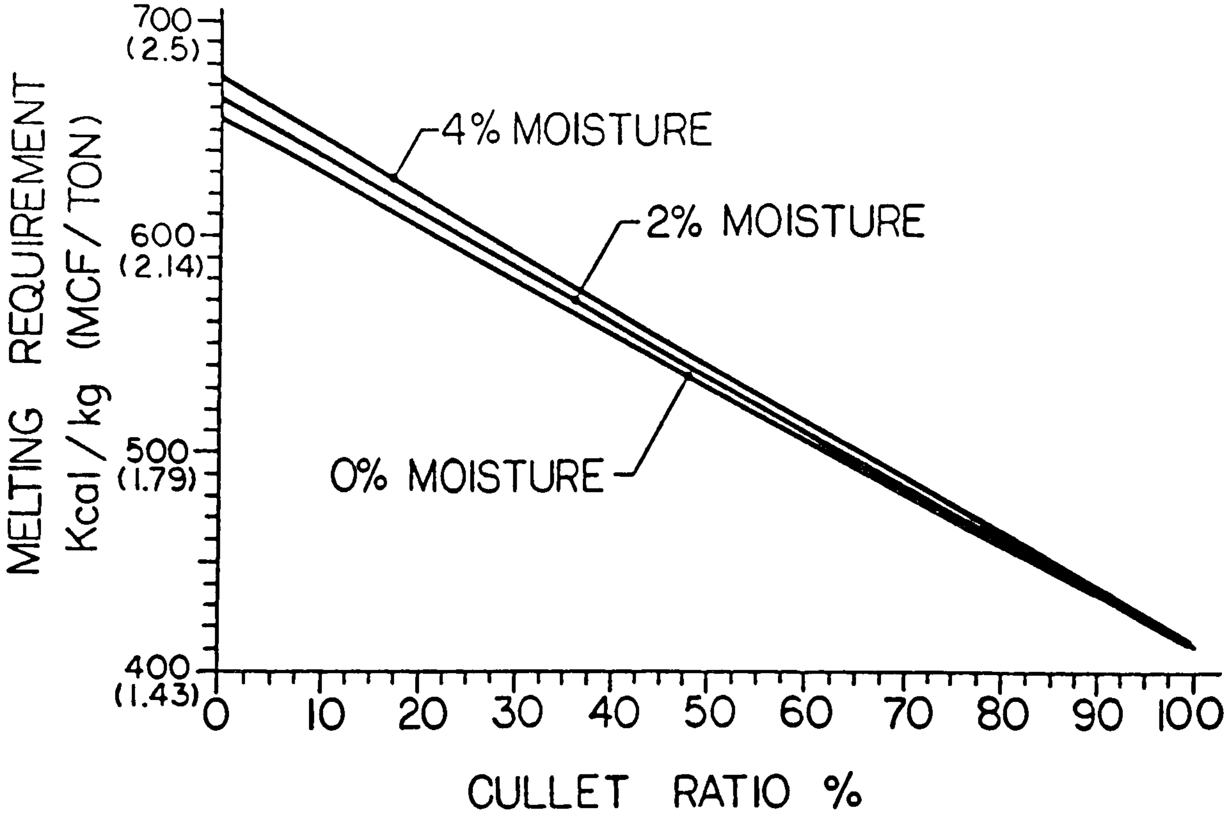
[27] Heide, E., Franke R., Schmidt, H.G., and R. Straufberger, "Investigation of the Energy Expended in Heating Glass Raw Materials to the Melting Temperature," Journal of Thermal Analysis 33 (1988): 617.

[28] Glass Packaging Institute, Glass Recycling: Why? How? Washington, D.C. (1986).

[29] Argent, Ron D. and Geoff Turton, "How to Use Energy Efficiently in Container Glass Furnaces," Glass Industry July 1988:21.

Figure 5

Moisture Effect on Batch Melting[30]



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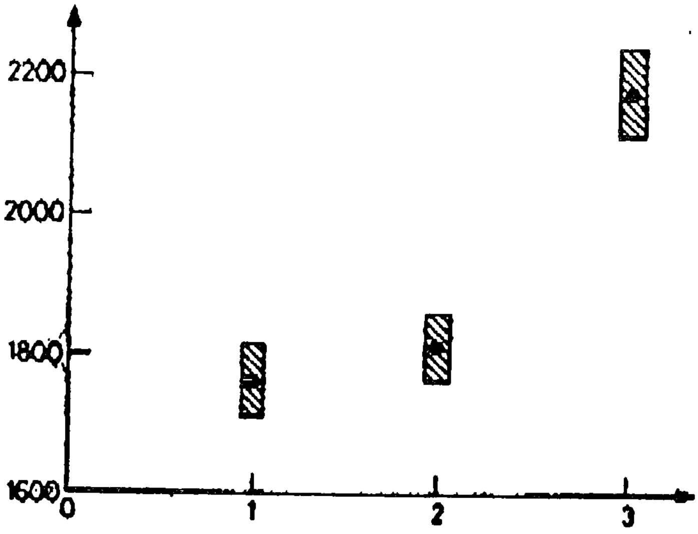
[30] Argent, Ron D. and Geoff Turton "How to Use Energy Efficiently in Container Glass Furnaces." Glass Industry, July 1988: 21.

Figure 6

Energy Expended when Different Batch Materials are Used[31]



Energy expanded when different batch materials are used
1 - batch mixture with foam slag
2 - batch mixture slag from the phosphorus furnace
3 - standard batch mixture

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[31] K. Heide, R. Franke, H.G. Schmidt and Straufberger. "Investigation of the Energy Expended in Heating Glass Raw Materials to the Melting Temperature." Journal of Thermal Analysis 33(1988) 617.

modifications, which has saved material by making the bottles lighter. The batch recipes are generally the same from manufacturer to manufacturer, consisting of sand, limestone, soda, feldspar and other additives. The milk containers have an average life cycle of about 30 trips.[32] The end of a container's life cycle is the result of a bottle break during the distribution and filling process. The average empty container weight is 910 grams (including the HDPE handle) or 32 ounces.

6.3 Energy Expended to Produce a Glass Half-Gallon Jug

Using the energy requirement average calculated in section 4.2 (15.69 btu/g.), it would take 14,168 btu's to produce one 903 gram half-gallon glass milk container. An average life cycle of 30 trips would make each trip represent 472.3 btu's of the total manufacturing energy.

When applying the same life cycle to Heide's value of 2,513 btu's per container, we find that each trip accounts for 83.77 btu's of the container's manufacturing energy.

6.4 Distribution of Bottle from Manufacturer to Dairy

The vendor for the glass milk bottle is located a distance of 194 miles from the Stewart dairy. The glass containers are delivered using a forty-foot trailer having an opening of 7'8"x8' giving us a capacity of 2453 cubic feet. A truck load contains 34 pallets, each having 4 tiers with 8 cases containing 12 bottles each. The combined weight of the shipment including the trailer is 26.44 tons. Using the energy

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[32] Joe Bashour, telephone interview, 19 Jan. 1991.

value of 2,400 btu/1 ton-mile,[33] it requires 943 btu's to deliver each container. This value does not incorporate the human or mechanical energy to load or unload the truck for it is insignificant.

6.5 Washing Operation

All bottles are washed using the same process and machinery whether new or used. This is done to assure that any foreign particulates are removed before the filling process. A D&L single-end washer is used to wash the half-gallon containers. Maximum wash speed is 2,250 bottles per hour (BPH) or 37.5 bottles per minute (BPM). It is an assumption that the washer runs at 60 percent of its potential or 1,350 BPH because most production equipment is run approximately at that percent of maximum. The washer uses 6.6 kWh of electricity during operation.[34] When the electricity is converted to btu's using the conversion factor .293 W/btu/hr., it is found that the washer uses 22,526 btu's of energy per hour. In order to wash the 120,000 containers required, the washer must operate 89 hours per week running at 60 percent of its potential. Therefore the total energy requirement for washing the bottles is 16.71 btu's per container.

6.6 Filling and Capping Operation

A processing line is as fast as its slowest operation. In this case

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[33] Arthur D. Little, Inc. The Life Cycle Energy Content of Containers. Report to the American Iron and Steel Institute. (Cambridge, 1982) D-3.

[34] John Barnes, telephone interview, 11 Nov. 1990.

the slowest operation is the washing of the bottles. On this premise the filling and capping operation will operate for the same amount of time (89 hours/week). The filler machine (Federal Filler Model #63) is equipped with a 220 volt 5 amp. motor requiring 1100 watts of electricity for operation, which is equivalent to 3754 btu/hr. An operation time of 89 hours would require 334,106 btu's or 2.78 btu's per container.

The capping machine is equipped with a 110 volt, 1 amp. motor requiring 110 watts of electricity for operation, which is equivalent to 375 btu/hr. When operated for a period of 89 hours it requires 33,375 btu's or .278 btu's per container.

The filling and capping operations are combined on a single machine; therefore their energy values are also combined. This addition of values shows that the filling and capping of one container requires 3.058 btu's per container.

6.7 Distribution of Glass Container and Product to Store

Milk is transported to the dairies using a single-axle diesel truck with a 24 foot single-axle refrigerated trailer. The net weight for this trucking configuration is 24,000 pounds. The gross allowable weight is 52,000 pounds, leaving 28,000 pounds for the product and container.

Milk weighs slightly more than water, having a weight of 8.51 lb./gal. The glass returnable-refillable container system consists of six bottles that are placed in a plastic crate (13"x11.75"x11", 48 oz.)

having a combined weight of 40.5 pounds. The crates are stacked six high and placed in the trailer. The trailer's load capacity using this configuration, is 691 crates, or 27,986 pounds. The truck and trailer loaded with product has a gross weight of 26 tons. The container weight represents 29.7 percent of the trailer gross weight (crates,bottles and milk).

The energy needed to transport the 26 tons 57 miles (average transport distance) is 3.56 MMbtu or 858 btu's per container. This figure does not include the energy needed to unload the trailer since it is done manually.

6.8 Returning Empty Glass Milk Bottles to Dairy

When the milk is unloaded at its locations the empties are simultaneously picked up to be returned to the dairy for refilling. On the return trip the empty glass containers account for 24.1 percent of the gross weight. This smaller percent is attributed to the absence of the milk. It requires 2.35 MMbtu (567 btu's per container) to transport the empty containers and crates back to the dairy excluding manual labor required for loading and unloading.

6.9 Total Energy Consumption for Glass Containers

The total energy consumption of the glass container system is represented in Table 3. The formula (Figure 7) represents the energy needed to manufacture and deliver one glass container, along with the energy required to go through one cycle. The formula also factors in the container's life cycle "X". The calculated value is the energy required to deliver one half-gallon of milk.

The total energy for the glass container has been broken down into three segments. The first segment shows the initial energy or "one time" energy that is needed to produce a container. The second segment shows the energy used for one cycle through the washer, filler, capper, delivery and return of the empty container. The final segment merges the first and second segments taking in account the container's projected life expectancy. The number that is calculated is the energy used per trip for each container in relation to its life cycle. In this case the glass bottle has an average life cycle of thirty trips. When calculated the overall energy requirement for the delivery of one half-gallon container of milk is 1,948 btu's.

Table 3
Total Energy Consumption for the Half-Gallon Glass Container

Function	* Energy Btu/Container	** Energy Btu/Container
Energy to manufacture container	14168	2513
Energy to deliver container	943	943
INITIAL ENERGY	15111	3456
Energy to wash container	16.71	16.71
Energy to fill container	2.78	2.78
Energy to cap container	0.278	0.278
Energy to deliver prod. & cont.	858	858
Energy to return container	567	567
ENERGY FOR ONE CYCLE	1444.77	1444.77
ENERGY BASED ON CONTAINER LIFE CYCLE	1948.47	163.36

Life cycle of glass container: 30 trips

* using average from Table 1

** using Heide energy value for producing glass

Figure 7
Energy Requirement Formula for Glass Containers

Energy required to manufacture container + Energy to transport containers to dairy + (Energy required for 1 container (x)/(x) to go through one life cycle*)

x = life cycle of container

* One cycle consists of

Energy to wash bottle + Energy to fill bottle + Energy to transport product and container to store + Energy to transport container back to the dairy

7. Polycarbonate

Polycarbonate bottles are fairly new to the milk industry; therefore there is limited data about the energy used in producing the resin and fabricating the container. The energy data used in this chapter has been gathered from the actual manufacturers of the resin and fabricators of the containers. In some cases, this data has been estimated using the limited information furnished by the companies and vendors.

Polycarbonate's properties of high heat resistance (melting point of 220-230 degrees Fahrenheit) and high impact strength (700-900 J/m or 13-17 ft.-lb./in.) make it a very suitable material for bottles in the milk industry.[35] The ability to produce the same container design out of a different material allowed the industry to keep the existing bottle handling machinery, saving a costly change over. The package has not changed much over the years except in design to reduce the material used and container weight.

7.1 Half-Gallon Polycarbonate Container

At the current time a new polycarbonate jug weighs approximately 140 grams or 4.94 ounces.[36] The life cycle for a Lexan® polycarbonate

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[35] "Polycarbonate," Encyclopedia of Polymer Science and Engineering, 2nd ed.

[36] Joe Bashour, telephone interview, 19 Jan. 1991.

returnable bottle averages 50 trips.[37] Sources suggest that the bottle can withstand 100 trips.[38]

7.2 Polycarbonate Processing

Polycarbonate is made by the condensation from melting bisphenol A and diphenyl carbonate, with the vacuum removal of the eliminated phenol or by leading phosgene (carbonyl chloride) gas into an aqueous alkaline solution of a bisphenol.[39] Code of Federal Regulations (CFR) 177.1580 outlines the specific processes which can be used to produce polycarbonate resins intended for use in articles or components for the production, manufacturing, packing, processing, treating, packaging, transportation, or holding of food.[40]

General Electric's Lexan® 154 is a CFR approved polycarbonate resin. Polycarbonate has been used throughout the milk industry since the 1970's in the form of half-gallon returnable milk jugs.

Lexan® is produced at GE's plastics plant located in Pittsburgh, Pennsylvania. The condensation process requires 93.10 btu's to produce 1 gram of polycarbonate resin.[41]

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[37] Ibid.

[38] "Plastic Bottle Gets 100 Refills," Packaging Oct 1988: 23.

[39] Hansjurgen Saechtling, International Plastics Handbook (New York, MacMillan, 1987) 242.

[40] Federal Code of Regulations 177.1580 Polycarbonate resins (4-1-90 Edition).

[41] Franklin Associates, Ltd., A Comparison of Energy Consumption By The Plastic Industry To Total Energy Consumption in the United States (Prairie Village, 1990) A-13.

7.3 Distribution of Resin to Bottle Fabricator

The jug fabrication plant is located 686 miles from the polycarbonate processing location. The resin is shipped in pellet form via tractor-trailer. 37,037 pounds of resin is required to fabricate the 120,000 half-gallon jugs needed to support Stewart's milk sales. The resin is transported using a 40-foot trailer having an opening of 7'8"x8' offering a maximum load capacity of 28,000 pounds. Using this data, two trailers or two trips are required to supply the 37,037 pounds of resin to the fabricator. The combined energy expended for both shipments is 20,253,600 btu's or 547 btu/pound of resin.

7.4 Energy Expended to Fabricate a Half-Gallon Polycarbonate Jug

The energy used to fabricate the resin into the finished product (polycarbonate half-gallon jug) has been estimated since no published data is available, and measuring the energy use is beyond the scope of this exercise. The energy requirements have been estimated using actual utility bills from the fabricating facility. The utility bills include the energy needed to operate all the functions of the fabricating facility, lighting, heating, air compressors, and administrative activities. These variables are the reasons that the energy value is a rough estimate. When calculated this value is estimated to be 420 btu's per container.

7.5 Energy Expended to Distribute Bottle to Dairy

The formed bottles are then transported 490 miles to Stewart's dairy.

The same size tractor-trailer and energy values were used to calculate the distribution data. 51,156,000 btu's were expended to deliver 120,000 containers (426 btu's per container) to the dairy.

7.6 Washing of Bottles

The polycarbonate bottles can be washed on the same line as the glass bottles without changing any of the parameters. It is for this reason that the energy values for washing the bottles are the same as for glass. These values have been covered in detail in chapter 6.5.

7.7 Filling and Capping Operation

The filling and capping operations are also the same as for glass with minor mechanical adjustments to the feeding guides. These adjustments do not have any effect on the line speeds or energy consumption of the line. Based on this, the same energy values and efficiencies of the glass filling and capping operations will be used. These values have been covered in detail in chapter 6.6.

7.8 Distribute Polycarbonate Container and Product to Store

The bottled milk is delivered using the same distance and trucking configurations as for the glass containers. The gross weight limit of this configuration is 53,000 pounds allowing 28,000 pound for crate, container and milk.

The case configuration is slightly different from that of the glass bottle. The crate used for the polycarbonate differs both dimensionally and by weight than that used for the glass containers. The case measures 13"x13"x11", weighing 51 oz. This larger-sized crate allows nine half-gallon containers to be carried instead of six as in the case of glass. Using a stack height of six crates high, 632 loaded crates are able to be placed in the 24-foot trailer. Each crate, when loaded with the product weighs approximately 44 pounds, having a gross vehicle weight of 51,976 pounds. When transported over a distance of 57 miles, 625 btu's are expended on each half-gallon container of milk.

7.9 Returning Empty Polycarbonate Milk Bottle to Dairy

The same exchange system occurs in the delivery of the milk as in the glass container system. Milk is unloaded and empties are picked up and returned to the dairy. On the return trip the polycarbonate bottles account for 13.6 percent of the gross weight. The return of one container requires 625 btu's. This also does not include manual labor for loading and unloading.

7.10 Total Energy Consumption for Polycarbonate Containers

The total energy consumption of the polycarbonate container system is represented in Table 4. The formula (Figure 8) represents the energy needed to fabricate and deliver one polycarbonate container, along with the energy required for the container to go through one cycle. The formula also factors in the container life cycle "X". The value produced represents the energy needed to deliver one half-gallon of milk.

The energy requirements for the polycarbonate container is also broken down into the same three segments, initial energy, energy of one cycle, and the combination of the two dependent upon the container's life cycle. These numbers are listed in Table 4. The polycarbonate bottle has an average life cycle of 50 trips. The overall energy expended to deliver a half-gallon of milk using a life cycle of 50 trips is 1,154 btu's per trip.

Table 4
Total Energy Consumption for the Half-Gallon Polycarbonate Container

Function	Energy Btu/Container
Energy to produce resin (140g) Energy to transport resin Energy to fabricate container Energy to transport container	13034 168.83 420 1102.5
INITIAL ENERGY	14725.33
Energy to wash container Energy to fill container Energy to cap container Energy to deliver prod. & cont. Energy to return container	16.71 2.78 0.278 545 298
ENERGY FOR ONE CYCLE	862.77
ENERGY BASED ON CONTAINER LIFE CYCLE	1157.27

Life cycle of polycarbonate container: 50 trips

Figure 8
Energy Requirement Formula for Polycarbonate Containers

Energy to produce resin + Energy to transport resin to fabricator + Energy to form container + (Energy required for 1 container (x)/(x) to go through one life cycle*)

x = life cycle of container

* One cycle consists of

Energy to wash bottle + Energy to fill bottle + Energy to transport product and container to store + Energy to transport container back to the dairy

8. Conclusion

The table of energy comparisons (Table 5) clearly demonstrates the energy efficiencies of using polycarbonate containers. The first segment, "Initial Energy" shows that there is a difference of 386 btu's per container between the two containers in favor of polycarbonate. A better understanding of where the energy differences lie can be seen in Tables 3 and 4. There is little energy difference in the manufacturing of the two containers. Glass requires 14,168 btu's per container (processing of raw materials and fabrication are one operation). When the processing and fabrication steps for polycarbonate are added together, the energy value is similar to that of glass, 13,453 btu's per container. From this information it can be seen that the big difference between the overall energy consumption does not lie in the manufacturing of the container, but in the transportation and life cycle of the containers.

In segment two, "Energy for One Cycle" we see that the washing, bottling, and capping operations require the same amount of energy for both containers. Further analysis of the input energies shows a noticeable difference between the distribution energies of the containers. There is a 47.4 percent difference between distribution energies in favor of polycarbonate, which can be attributed to the

Table 5
Energy Consumption Comparison
Glass versus Polycarbonate

	Glass Btu/container	Polycarbonate Btu/container
Initial Energy	15111	14725.33
Energy for one life cycle	1444.77	862.77
Energy based on container life cycle	1948.47*	1157.27**

* Average life cycle for glass is 30 trips

** Average life cycle for polycarbonate is 50 trips lighter weight of polycarbonate as opposed to glass. The glass container has an emptied weight of 910 grams/container while polycarbonate only weighs 140 grams/container, resulting in an 84.6 percent empty container weight difference. The distribution energy formula is weight and distance dependent so one can easily see that the overall energy efficiencies of these two containers is greatly dependent on their weight. There are other factors to take into account when explaining the difference between the distribution energies. These factors include distribution distances, utilization of payload space, and the bottle to crate ratio.

The final and most important factor is the life cycle of the individual container. Past studies show that glass half-gallon milk containers have an average life cycle of 30 trips,[42] while polycarbonate has a life cycle of 50.[43] The matrix in Table 6 shows the comparison of polycarbonate and glass containers having different life cycles. As the life cycle for both of the containers increases so does the energy efficiencies between the two containers. The comparison has been brought out to a life cycle of 100 trips. At this point the polycarbonate bottle is a third more efficient than the glass container.

Polycarbonate containers also offer other advantages other than weight reduction and longer life cycles. Polycarbonate also reduces product loss and bodily harm due to breakage.

In conclusion it can be said that the polycarbonate returnable

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[42] Joe Bashour, telephone interview, 19 Jan. 1991.

[43] Nick Caffentzis, telephone interview. Feb. 1991.

refillable container is more energy efficient based on its weight and life cycle capabilities. This thesis has just begun the energy comparison and analysis of two container systems. Research must continue as the technology and processes of the industry change in order to get a realistic representation of the efficiencies of the industry.

Appendix A

New York-New Jersey Marketing Area
Milk Sales[44]
(thousand pounds)

Container	Handlers' own sales				Subdealers' sales				Total sales**			
size	Glass	Paper	Plastic	Total	Glass	Paper	Plastic	Total	Glass	Paper	Plastic	Total
Whole milk												
Gallon	0	0	57,754	57,754	0	0	43,825	43,825	0	0	101,579	101,579
1/2 Gallon	594	38,243	1,712	40,549	302	44,510	742	45,554	895	82,753	2,455	86,103
Quart	75	13,012	257	13,344	711	18,542	0	19,253	786	31,554	257	32,597
Pint	0	1,427	12	1,439	0	1,813	0	1,813	0	3,240	12	3,252
1/2 Pint	0	9,035	##	9,035	0	9,565	0	9,565	0	18,600	##	18,600
1/3 Quart	0	#	0	#	0	#	0	#	0	#	0	#
6 Gallon	0	0	2,137	2,137	0	0	3,431	3,431	0	0	5,568	5,568
5 Gallon	0	0	1,189	1,189	0	0	355	355	0	0	1,543	1,543
3 Gallon	0	0	#	#	0	0	#	#	0	0	#	#
10 Ounce	0	45	0	45	0	6	0	6	0	51	0	51
4 Ounce	0	296	0	296	0	192	0	192	0	488	0	488
Total	669	62,058	63,061	125,788	1,013	74,628	48,353	123,994	1,681	136,686	111,414	249,781
Flavored whole milk												
Gallon	0	0	0	0	0	0	#	#	0	0	#	#
1/2 Gallon	82	143	4	229	1	51	0	52	83	195	4	282
Quart	1	721	2	724	0	447	0	447	1	1,188	2	1,171
Pint	0	1,279	0	1,279	0	1,312	0	1,312	0	2,591	0	2,591
1/2 Pint	0	1,664	1	1,665	0	1,181	0	1,161	0	2,825	1	2,826
1/3 Quart	0	#	0	#	0	0	0	0	0	#	0	#
6 Gallon	0	0	73	73	0	0	19	19	0	0	92	92
5 Gallon	0	0	30	30	0	0	9	9	0	0	38	38
3 Gallon	0	0	#	#	0	0	0	0	0	0	#	#
10 Ounce	0	7	0	7	0	20	0	20	0	27	0	27
Total	83	3,814	110	4,007	1	2,991	28	3,020	84	6,806	137	7,027
Low test milk (no added solids)												
Gallon	0	4	32,308	32,312	0	0	8,539	8,539	0	4	40,847	40,851
1/2 Gallon	626	18,191	827	19,644	138	10,634	822	11,594	784	28,825	1,650	31,239
Quart	4	3,506	35	3,545	199	3,426	0	3,625	203	6,932	35	7,170
1/2 Pint	0	1,230	0	1,230	0	1,242	0	1,242	0	2,472	0	2,472
6 Gallon	0	0	195	195	0	0	89	89	0	0	284	284
5 Gallon	0	0	98	98	0	0	21	21	0	0	119	119
10 Ounce	0	335	0	335	0	0	0	0	0	335	0	335
4 Ounce	0	#	0	#	0	0	0	0	0	#	0	#
Total	630	23,266	33,463	57,359	337	15,302	9,471	25,110	967	38,568	42,935	82,470
Low test milk (added solids)												
Gallon	0	0	724	724	0	0	0	0	0	0	724	724
1/2 Gallon	16	774	4	794	0	273	0	273	16	1,048	4	1,068
Quart	0	197	##	197	1	192	0	183	1	389	##	390
Pint	0	#	0	#	0	0	0	0	0	#	0	#
1/2 Pint	0	#	0	#	0	0	0	0	0	#	0	#
6 Gallon	0	0	#	#	0	0	0	0	0	0	#	#
Total	16	971	728	1,715	1	465	0	466	17	1,437	728	2,182

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[44] Thomas A. Wilson. The Market Administrator's Bulletin. 8 vol., Qtly A. New York-New Jersey Milk Marketing Area, 1988: 14.

Appendix B

Energy Consumption of individual glass manufactures[45]

Total energy required to produce 1 kg of saleable glass as containers in the U.K. factories in 1977

Factory	Item	Electricity/MJ		Oil fuels/MJ			Other fuels/MJ			
		Fuel production and delivery energy	Energy content of fuel	Fuel production and delivery energy	Fuel content of fuel	Feedstock energy	Fuel production and delivery energy	Energy content of fuel	Feedstock energy	Total energy /MJ
A	Materials	0.24	0.08	0.43	2.16	nil	0.06	0.89	nil	3.86
	Transport	0.02	0.01	0.06	0.17	neg	neg	0.01	nil	0.25
	Fuels	3.50	1.17	1.53	7.34	nil	0.07	0.88	nil	14.49
	Totals/MJ	3.76	1.26	2.00	9.67	neg	0.13	1.78	nil	18.60
B	Materials	0.23	0.08	0.42	2.13	nil	0.06	0.87	nil	3.79
	Transport	0.06	0.02	0.12	0.58	neg	neg	0.02	nil	0.80
	Fuels	3.59	1.20	1.33	6.39	nil	0.33	4.06	nil	16.88
	Totals/MJ	3.88	1.30	1.87	9.10	neg	0.39	4.93	nil	21.47
C	Materials	0.20	0.07	0.42	2.15	nil	0.06	0.90	nil	3.80
	Transport	0.01	neg	0.03	0.14	neg	neg	0.01	nil	0.19
	Fuels	4.91	1.64	2.68	12.84	nil	0.23	2.84	nil	25.14
	Totals/MJ	5.12	1.71	3.13	15.13	neg	0.29	3.75	nil	29.13
D	Materials	0.24	0.08	0.40	2.02	nil	0.06	0.84	nil	3.64
	Transport	0.01	neg	0.03	0.15	neg	neg	0.01	nil	0.20
	Fuels	4.25	1.42	0.61	2.91	nil	4.18	12.18	nil	25.55
	Totals/MJ	4.50	1.30	1.06	5.08	neg	4.24	13.03	nil	29.39
E	Materials	0.15	0.05	0.39	1.99	nil	0.06	0.84	nil	3.48
	Transport	0.01	neg	0.02	0.12	neg	neg	0.01	nil	0.16
	Fuels	3.82	1.27	1.39	6.66	nil	1.28	3.90	nil	18.32
	Totals/MJ	3.98	1.32	1.80	8.77	neg	1.34	4.75	nil	21.96
F	Materials	0.32	0.11	0.40	2.05	nil	0.06	0.87	nil	3.81
	Transport	0.02	0.01	0.06	0.30	neg	neg	0.03	nil	0.42
	Fuels	3.48	1.16	2.14	10.25	nil	0.16	1.97	nil	19.16
	Totals/MJ	3.82	1.28	2.60	12.60	neg	0.22	2.87	nil	23.39
G	Materials	0.25	0.08	0.42	2.13	nil	0.06	0.89	nil	3.83
	Transport	0.02	0.01	0.05	0.28	neg	neg	0.03	nil	0.38
	Fuels	3.46	1.15	2.16	10.31	nil	0.10	1.24	nil	18.42
	Totals/MJ	3.73	1.24	2.63	12.72	neg	0.16	2.15	nil	22.63
H	Materials	0.23	0.08	0.39	1.98	nil	0.05	0.80	nil	3.53
	Transport	0.01	neg	0.01	0.06	neg	neg	neg	nil	0.08
	Fuels	4.94	1.65	1.97	10.11	nil	0.03	0.32	nil	19.02
	Totals/MJ	5.18	1.72	2.37	12.15	neg	0.08	1.12	nil	22.63
J	Materials	0.26	0.09	0.44	2.22	nil	0.06	0.92	nil	3.99
	Transport	0.02	0.01	0.04	0.20	neg	neg	0.01	nil	0.28
	Fuels	4.38	1.46	2.54	12.16	nil	0.12	1.43	nil	22.09
	Totals/MJ	4.66	1.56	3.02	14.58	neg	0.18	2.36	nil	26.36
K	Materials	0.31	0.10	0.44	2.22	nil	0.06	0.96	nil	4.09
	Transport	0.03	0.01	0.15	0.74	neg	0.01	0.08	nil	1.02
	Fuels	4.97	1.66	2.17	10.46	nil	0.46	1.20	nil	20.92
	Totals/MJ	5.31	1.77	2.76	13.42	neg	0.53	2.24	nil	26.03
L	Materials	0.29	0.10	0.43	2.19	nil	0.06	0.94	nil	4.01
	Transport	0.02	0.01	0.08	0.40	neg	0.01	0.06	nil	0.56
	Fuels	4.09	1.36	2.62	12.66	nil	neg	0.06	nil	20.79
	Totals/MJ	4.40	1.47	3.13	15.25	neg	0.07	1.06	nil	25.36
M	Materials	0.23	0.08	0.40	2.00	nil	0.05	0.80	nil	3.56
	Transport	0.01	neg	0.07	0.34	neg	0.01	0.03	nil	0.46
	Fuels	2.03	0.88	0.88	4.20	nil	0.47	5.75	nil	14.01
	Totals/MJ	2.27	0.76	1.25	6.54	neg	0.53	6.58	nil	18.03
N	Materials	0.22	0.07	0.40	2.05	nil	0.06	0.86	nil	3.66
	Transport	0.01	neg	0.02	0.08	neg	neg	0.01	nil	0.12
	Fuels	3.34	1.11	0.16	0.77	nil	0.91	11.12	nil	17.41
	Totals/MJ	3.57	1.18	0.58	2.90	neg	0.97	11.99	nil	21.19
P	Materials	0.46	0.16	0.43	2.18	nil	0.06	0.88	nil	4.17
	Transport	neg	neg	0.02	0.10	neg	neg	0.01	nil	0.13
	Fuels	3.72	1.24	0.14	0.66	nil	1.05	12.74	nil	19.55
	Totals/MJ	4.18	1.40	0.57	2.94	neg	1.11	13.63	nil	23.85
Q	Materials	0.21	0.07	0.44	2.05	nil	0.06	0.87	nil	3.70
	Transport	0.02	neg	0.07	0.37	neg	0.01	0.06	nil	0.51
	Fuels	3.57	1.19	1.38	7.32	nil	0.53	6.42	nil	20.41
	Totals/MJ	3.80	1.26	1.89	9.74	neg	0.60	7.33	nil	24.62
R	Materials	0.26	0.09	0.45	2.27	nil	0.06	0.92	nil	4.05
	Transport	0.02	0.01	0.03	0.15	neg	neg	neg	nil	0.21
	Fuels	3.09	1.03	0.01	0.06	nil	0.94	11.44	nil	16.57
	Totals/MJ	3.37	1.13	0.49	2.48	neg	1.00	12.24	nil	20.83

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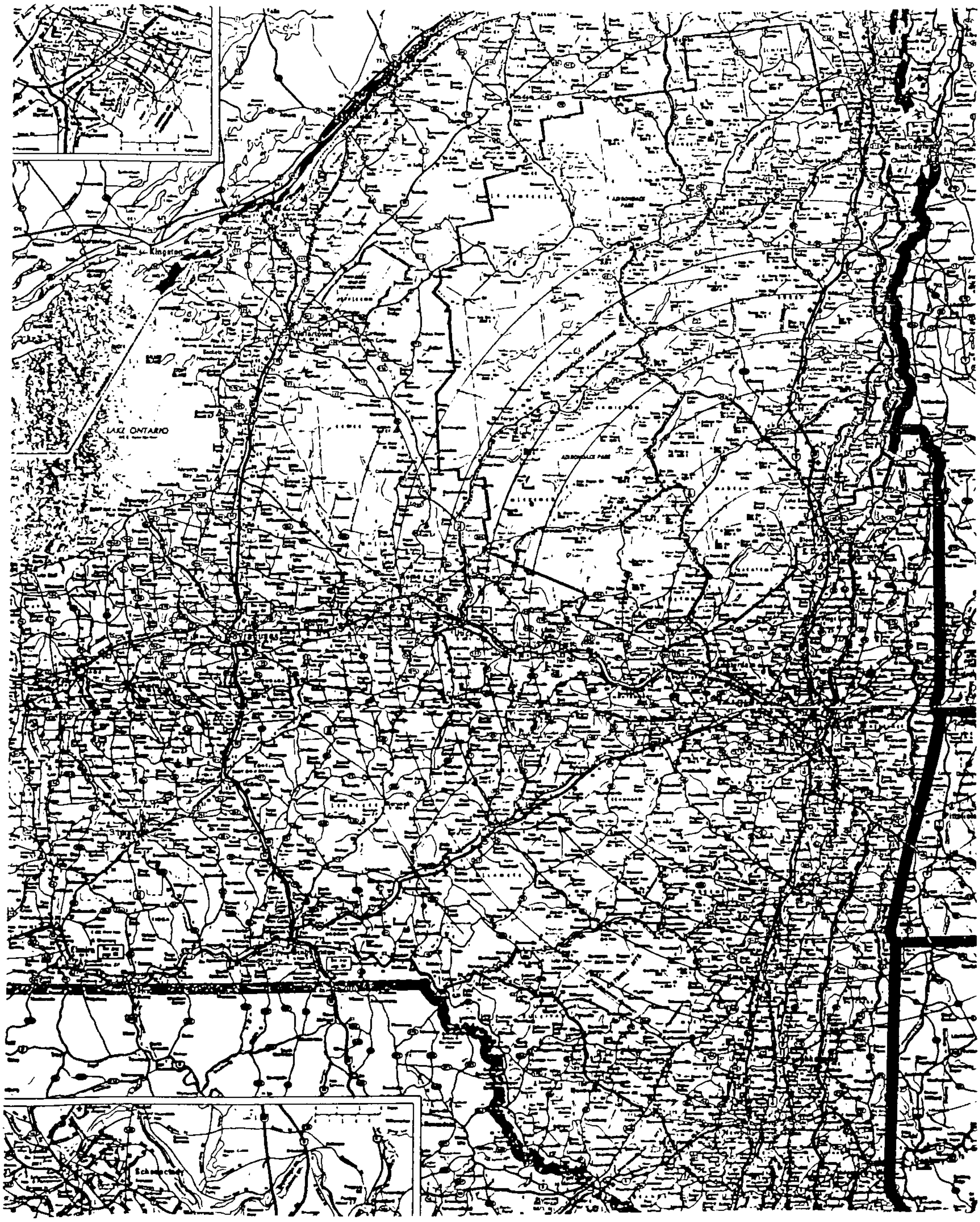
Appendix C

Distribution Map



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