Center for Advanced Computation

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URBANA ILLINOIS 61801

CAC DOCUMENT No. 204

ENERGY REQUIREMENTS FOR AEROSOL AND ALTERNATIVE PACKAGING: A CASE STUDY

by

Peter S. Penner

Feb. 15, 1976
2nd Revision-July 1976

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ACKNOWLEDGEMENTS

This report draws from several diverse fields of human endeavor. Without much help in each of them, I would never have been able to finish. I am grateful to all of those who have helped, and particularly to:

Dr. Arnold M. Hartley and Dr. Phillip K. Hopke, University of Illinois Environmental Research Lab.
Mr. John Robinson, Robinson-Wagner Company
Mr. Bob Joiner and Ms. Ellen Weiner, Cosmetic, Toiletry and Fragrance Association
Mr. Robert Hunt, Midwest Research, Inc.
Dr. Charles A. Evans, University of Illinois, Materials Research Lab.
Ms. Ellen Edelheit, Dept. of Physical Chemistry, University of Pittsburgh.
Ms. Margaret Ann Powers, Biophysics Department, University of Illinois.
Dr. Christopher Hill and Larry Teasley, Department of Chemical Engineering, Washington University.
Craig Foster, a co-worker, for his valiant programming efforts.
Dr. Thomas J. Hanratty and William Ruck, Dept. of Chemical Engineering, University of Illinois.
...And one national antiperspirant manufacturer and two contract fillers in the Chicago area who wish to remain anonymous.

I owe everything to my teachers, Bruce Hannon, Bob Herendeen, and Richard Klein.

Thanks to Veronica Soltys for holding everything together.

ABSTRACT

The energy required to produce and package an identical product (deodorant) in aerosol and non-aerosol form is computed. Both vertical analysis and energy input-output techniques are employed. Results show that, for this case study, aerosol packaging requires about 1.8 times the energy of the non-aerosol substitute delivering an equal amount of service. It is estimated that about six million barrels of oil equivalent would be conserved per year by shifting from aerosol to non-aerosol personal products.

1. INTRODUCTION: CONTAINER ENERGY STUDIES

1.0 Description of the Study

This report examines the energy required to deliver to the consumer the same product in aerosol and non-aerosol form in 1972. The products chosen to compare are Secret* Anti-Perspirant (aerosol, 9 oz.) and Secret* Roll-on Anti-Perspirant (boxed bottle, 1.5 fl. oz.). Both are manufactured by The Proctor & Gamble Company, Cincinnati, Ohio, 45202. These items were chosen because the identical service ("perspiration protection") could be purchased in two entirely different packaging systems. Other aerosol products, such as paints, deliver a product or service different from their non-aerosol counterparts.

Container studies have become important due to the high visibility of containers, their contribution to pollution and municipal services, their substitutability without altering the final product, and the substantial potential for material and energy savings. The Environmental Protection Agency [2] reports that redesigning a half-pint milk container resulted in 31% less paper and 16% less polyethylene used, a considerable energy savings. Hannon [1] found that returnable soft-drink package uses one-third the energy of throw-away containers. More recently, it has been estimated that if per capita packaging would be reduced from 1972 to 1958 levels, about 560 trillion Btu/year would be saved [36]. Other excellent container energy studies are available [3-7].

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*Secret is a registered trade-mark of The Proctor & Gamble Co., Cincinnati, Ohio.

As a packaging system, aerosols have gained national prominence recently due to concern for their effect on the ecosystem. Most aerosol packagings, including the product in this study, contain chloro-flurocarbon compounds known as F-11 and F-12 ($CFCl_3$ and CF_2Cl_2). These gases are produced for use both as aerosol propellants and refrigerants at a current rate of about 5×10^6 metric tons per year [31]. About half of all fluorocarbon production is used in aerosols, and more than 90% of these aerosols are personal products. (Household products such as paints do not use fluorocarbon propellants) [31, 32].

According to current studies, when these flurocarbons are released into the atmosphere, studies have shown that most of the gas molecules drift intact to the stratosphere, the highest layer of the atmosphere. There the sun photolyzes the flurocarbon into free chlorine and phosgene-type molecules. The free chlorine combines with the normally-present stratospheric ozone to form ClO and O_2, reducing the steady state ozone concentration [23, 37].

This reduced ozone cover is the source of a threefold scientific concern. First, the reduced ozone cover will increase ultraviolet radiation on earth and may increase the incidence of skin cancer. Secondly, even a slight change in the atmosphere may cause severe climatic changes, as yet unpredictable. Finally, the biological effects, summarized as "changes in physiological, biochemical, anatomical, and growth characteristics of certain plant and animal species," are not yet known [32,35].

There is also some concern over the direct medical effects of using aerosols. Some studies have established a connection between aerosols and thesaurosis (storage of foreign particles in the lungs), heart damage due to excessively high concentrations of fluorocarbons, and mutations and birth defects [34].

1.1 Methodology Overview

Most container energy studies are done in the style of a vertical analysis. In the ideal energy vertical analysis, the flow of all natural resources is traced from their extraction from the earth to their return to the earth. At any point where energy is used for processing or transport, it is summed. In practice not every flow of materials or energy can be traced, and errors from simplifying assumptions and truncation must be introduced. In this study we will point out such assumptions as we make them, as well as in the following section on methodology. We will also depart from vertical analysis techniques and attempt to reduce trunction error by making use of energy Input-Output analysis (or I/O) at certain points. Energy I/O is explained in the next section.

2. GENERAL METHODOLOGY: MONEY AND ENERGY ACCOUNTING

Economists measure all social transactions in one common unit--dollars. Scientists and engineers examine physical systems by quantifying their inputs and outputs in corporeal units. The analysis of the complex chain of events by which Secret antiperspirant comes into being requires using techniques from both economics and the physical sciences. In this report, analytic tools and language from both disciplines will be used.

The left column of Table 1 shows the economic breakdown for the average high volume toiletry in 1972, according to a study done by a toiletries trade association. The total retail price is broken down into financial categories familiar to every economist. The rightmost column of Table 1 lists the energy accounting methods that we will use to measure all the energy flows associated with these dollar categories. Energy (and material) flows can be seen much easier on a production flow chart. Figure 1 shows a simplified flowchart for deodorant production with economic categories superimposed.

Figure 1 makes apparent several important facts about money and energy accounting. First, the cost of manufacturing Secret antiperspirant takes just under one quarter of the retail cost, less than either the retail margin or administrative expenses. Yet this segment is by far the most difficult to measure in energy terms and will account for most of the total energy cost of Secret. In the parlance of energy research, manufacturing Secret is an energy-intensive activity.* Manufacturing is energy-intensive, i.e., it requires relatively many energy units consumed per dollar value produced. Retail trade and administration are much less energy-intensive activities and much more labor-intensive.

In Table 1, several technical terms appear. Energy input-output analysis is an energy accounting technique which will enable us to measure the energy cost of any transactions by applying an I/O coefficient to the dollar cost. The theoretical justification and details of computing the I/O coefficients are explained in many other documents [5,6,15,27,28]. In this report, the I/O coefficient will be employed in calculations like this:

$$\begin{bmatrix}\text{dollars in} \\ \text{transaction x}\end{bmatrix} \begin{bmatrix}\text{I/O coefficient} \\ \text{for transaction x}\end{bmatrix} = \begin{bmatrix}\text{energy required for} \\ \text{transaction x}\end{bmatrix}$$

units: dollars (energy/dollar) energy

Table 1 shows that all components of the cost of manufacturing Secret except production costs will make use of the dollar cost and energy input-output analysis. For the production costs category, the economic costs will be ignored entirely. The energy costs will be determined by tracing the manufacture of Secret from the raw materials mining stage (see Figure 2) to the point where finished Secret products roll off the assembly line.

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*The "intensity" is a renegade unit which bridges the gap between physical and monetary accounting, and clearly shows the relative importance of one factor of production to the money value of the output.

Note that in Table 1 the economic categories of taxes and profit are considered to have no energy cost, even though they do have a dollar flow associated with them. This is due to the fact that it is difficult to define and measure the energy impact of these two dollar amounts in an accurate and meaningful manner.

3. SPECIFIC METHODOLOGY

3.1 Terminology

Thus far, the terms *aerosol, container, package,* etc., have been used rather freely. From this point on, terms will be defined as follows:

container - The total physical system which holds, encloses, and delivers the antiperspirant chemicals. This includes the can or bottle as well as accompanying applicators, wrappers, and boxes.

contents - The mixture of all liquid and gaseous chemicals in the container.

aerosol
roll-on
package - The entire containerization system, comprising container, contents, and other packaging components.

Also, the terms energy cost, energy requirement, and energy use will be used interchangeably.

3.2 Basis Units and Comparison

Since this study will compare two packaging systems, they must be compared to a fair and equal standard. The essential question to ask is, "What is the service offered by these products?" The answer must be "antiperspirant efficacy" or as it is called in the advertisements, "deodorizing protection." The quantitative measure of antiperspirant efficacy present in each of these packages is not a simple matter. Differences in body types, amounts of active ingredients applied, thickness of application layer, waste, etc., must all be considered.

Fortunately, companies which make these products spend a great deal of effort measuring this sort of thing. The Proctor & Gamble Co., which makes Secret, is aware of precisely how much antiperspirant efficacy is present in the aerosol and roll-on forms of Secret. Though it regards its measurement system as highly proprietary, it did furnish us data on the comparability of aerosol and roll-on Secret. According to The Proctor & Gamble Co., nine ounce aerosol Secret and 1.5 fluid ounce roll-on Secret offer identical amounts of antiperspirant efficacy, and can therefore form comparable measuring units for this study (Appendix A).

3.3 Inclusion of Container Contents

In most container energy studies, it is common to ignore the energy embodied in the container contents. In the first place, this energy is usually the same in alternate containers. Also, the contents energy is sometimes much larger than container energy, overshadowing any *differences* between container energy requirements no matter how large. However, due to the nature of the packagings considered here, we must depart from convention and examine container and contents as total packaging systems. An example will demonstrate this.

In most studies, alternative packagings 1 and 2 contain the same amount of product P. Therefore, their energy requirements functions might be written:

$$E_1 = (N_A \cdot E_A) + (N_P \cdot E_P)$$

$$E_2 = (N_B \cdot E_B) + (N_P \cdot E_P)$$

where:

N_x is the units of x (such as lbs.) in the container system.

E_x is the energy per unit x.

Note that the second term, $(N_P \cdot E_P)$ is the same for both packages and represents the energy embodied in the contents. Dropping this term is analogous to cancelling a common factor and calls attention to the energy used for the containers.

For aerosol and roll-on packages, however, the amount of actual product (active ingredients) is not the same in the two containers despite the fact that they both provide the same amount of service. The different packages also necessitate adding different ancillary chemicals, or fillers, to the active ingredients. The two energy requirement functions for such containers may be written:

$$E_{aerosol} = (N_p \cdot E_p) + (N_F \cdot E_F) + (N_C \cdot E_C)$$

$$E_{roll\text{-}on} = (N_p' \cdot E_p) + (N_F' \cdot E_F) + (N_C' \cdot E_C)$$

where F denotes terms pertaining to the filler chemicals. Here, the contents energy terms are not the same and dropping them would be incorrect.

3.4 Energy Accounting Definitions and Conventions

In section 2 we explained that most energy measurement would be done with energy I/O, and that the manufacturing portion of the production process would be done as a separate analysis. All energies in this study are measured in British thermal units, the amount of energy required to heat one pound of water one degree Farenheit. Input-output coefficients used in this study have units Btu per dollar.

In the consideration of the manufacturing portion of this report, energy used in any manufacturing step is classified either as direct or indirect. Direct energy refers to measurable energy *in energy form* flowing into a process or industry. This does not include energy embodied in materials flowing from previous production steps which used energy, as well as the fuel value of materials used in production. Indirect energy refers to the energy used in associated activities and materials throughout the economy (on a steady state basis) which enable the process in question to occur, or the energy used for form the fixed plant for the processes studies. The latter is called "capital energy," also called factory overhead in Table 1, and is measured in this report only when I/O is used. The sum of all direct and indirect energy for any one process is referred to as total energy.

At any point where energy is measured, the delivery efficiency must be taken into account. Energy does not magically appear in our chosen form wherever we want it. The delivery efficiency, also called the conversion efficiency, refers to the amount of all forms of energy required throughout the economy to deliver one unit of one form of energy to the consumer. This efficiency differs vastly between energy forms and less so between users. Averaging between all users, delivery efficiencies used in this study are [9]:

a) 26% for electricity from electric utilities (at the bus bar in 1967).

b) 91% for natural gas from gas utilities (1967).

c) 83% for refined petroleum (1967).

When an energy figure has taken into account the delivery efficiency, it is said to be a *primary* energy figure. The conversion of a direct or indirect energy figure to primary is accomplished by dividing the figure by the efficiency associated with its form. In this study, all primary energy figures will be written in Btu, while non-primary energies will remain in their original units, such as kilowatt-hours. All Btu figures obtained with energy I/O are primary.

3.5 Organization of the Report

The next four sections of the report examine the energy used for the manufacturing step only. These sections cover energy used for making the container, chemical analysis of container contents, energy required for manufacturing these chemicals, and energy used for mixing and packaging. A detailed flowchart of the energy vertical analysis employed is shown in Figure 2, which can be compared to Figure 1. After all this, section eight uses I/O to measure the energy costs of administrating, selling, and distributing these deodorants. The final section summarizes and discusses the results.

4. CONTAINER MANUFACTURING ENERGY

4.1 Aerosol Cans

Aerosol cans used for Secret are made entirely of lacquered steel. The can has a single vertical weld and is composed of our steel pieces: the welded cylinder, top and bottom crowns (both painted white), and the metal ring holding the valve. In contrast, most steel cans, including steel beverage cans, have only three parts (Figure 3). Also, the aerosol can is made of slightly thicker steel on the cylinder than beverage cans, though not as thick as some food cans. We measured the metal in the aerosol can as .012" thick, and the steel in a popular soft-drink can as .010" thick.

The similarity between these two cans is important because we use direct energy results for steel beverage can manufacturing for aerosol cans. This is not strictly correct, but due to the similarities above, is certainly a close lower bound. The larger amount of steel contained in the thicker aerosol can will be accounted for by making the calculation weight-based. The aerosol can may use slightly more energy forming and welding the thicker sheet. Because it has four pieces, assembly energy is also greater. However, the final assembly of the value piece onto the can body is done at the contract filler, and so is measured elsewhere in this report. In sum, using steel beverage can energy data should yield reasonable (if slightly low) energy use results.

According to a study conducted for the Environmental Protection Agency, one ton of steel beverage containers required 58.83 million Btu primary.[3] The aerosol can weighs .1563 lb., requiring 4,600 Btu primary.

4.2 Glass Bottles

An excellent analysis of direct energy use for manufacture of glass containers has been done by the Federal Energy Administration. The study asserts that "the manufacture of glass containers is a 'one-step operation,' the basic raw materials being transformed into containers in a continuous process at one location." [26]. It goes on to say that direct energy impacts for containers can be assessed on a Btu-per-lb.-container basis.

The study determines the energy use in four major production steps:

1. Surface mining of glass sands, with no benefication.
2. Surface quarry of limestone, including crushing and screening.
3. Production of soda ash, either from "room-and-pillar mining" or synthetically by the Solway process.
4. Combination of the above materials, and also a small amount of feldspar, salt cake, and cullet (waste glass) in a 2800° glass furnace. The molten glass flows through a "gob-feeder" and air molder, producing a container shape. The container is completed by annealing (heat treating) and finishing.

According to the study, 18.16×10^6 Btu primary were required in 1970 for one ton of glass containers. Similar studies of glass containers have produced slightly different results (Table 2). As the bottle used for Secret weighs .1646 lb energy use is 1490 Btu primary.

4.3 Plastic Parts

Both the aerosol and roll-on container systems make extensive use of plastic parts. In the aerosol system, the cover cap, push tip, and valve mechanism are of plastic; in the roll-on it is the cap and roll-on tip. The only plastic used is polyethylene.

Energy requirements for plastics manufacturing have been measured by researchers at Washington University. [29] In this work the energy requirements for a given material is considered to have four components:

1. Material Input Energy: the fuel value of material inputs to production which are used as raw materials, not energy sources.

2. Direct Process Energy: the energy produced in energy facilities for use by industries in processing the material. Note that this includes efficiencies of power generation and the like.

3. Transportation Energy: the energy required to move materials from point to point during the processing operation and an average value for energy used to transport the finished polymer to its point of use.

4. Discovery--Removal Energy: the energy used to mine and process the raw materials from earth to the point where they may be used in manufacturing operations.

The results are in the form of total energy required per pound of polymer. One additional manufacturing step (and the associated transportation) is required to form the polymer into a finished item. For polyethylene, average figures for extrusion and finishing are used. The application of these figures to Secret plastic parts (Table 3) reveals energy use for plastics as 1610 Btu for roll-on and 1200 Btu for aerosol.

4.4 Box, Labels, and Other Container Parts

This section will consider the remaining parts of the two container systems. For aerosols, this includes the non-plastic valve parts, the paint on the can, and the can label. All except the latter are assumed to add a negligible amount to the total container energy requirement. In the roll-on package, additional materials are the box, cellophane wrapper, and two labels. The cellophane wrapper will be neglected.

4.4.1 Printed Labels

These will be assessed only for their energy requirements as paper. The paper used for all labels is of approximately the same weight; however, the aerosol label is Aluminized (a thin coating of aluminum foil is on one surface). We use a figure for average writing paper of 12,230 Btu/lb. of paper [26]. The aerosol label weighs .0062 lb. requiring 80 Btu, and the roll-on labels weigh .0008 lb., requiring 10 Btu.

4.4.2 Roll-on Box

The roll-on glass container is normally purchased suspended in a box made of SBS folding boxboard, a thin packing material similar to shirt cardboard. The energy required for such board is 10,950 Btu/lb. [26]. The box weighs .0557 lb. and so requires 610 Btu.

4.5 Intermediate Container Transportation

Thus far energy costs for manufacturing containers include all energy use from raw materials to the end of container manufacture. This section considers transportation energy required to deliver container parts to the contract packager, where they are assembled. According to Proctor and Gamble, all container parts are moved by truck (Appendix A). Data on transportation required also comes from Proctor and Gamble, and transportation energy costs have been previously computed by the Energy Research Group.[27,28] Results appear in Table 4 and indicate a transportation energy cost of 80 Btu for the aerosol and 40 Btu for the roll-on.

4.6 Summary of Container Energy Costs

Table 5 presents the results of section four of this report, the sum of all primary energy required to manufacture and transport the materials used in Secret antiperspirant containers. The next three sections will examine the energy required to create the container ingredients and the energy required to assemble container and contents into the final delivered product.

5. CHEMICAL INGREDIENTS DETERMINATION

Before beginning an energy accounting of the ingredients in the containers, it is necessary to determine the exact composition of these ingredients. The labels of both packages state only that the container contents are Zirconyl Hydroxychloride and Aluminum Hydroxychloride (the aerosol also lists .7% alcohol). However, The Proctor & Gamble Company has furnished the following breakdown for Secret antiperspirant:

	Aerosol 9 oz.			Roll-On 1.5 fl. oz.		
	%	gms.	lbs.	%	gms.	lbs.
Active	3.5	9	.020	21.6	11	.024
Propellant	88.5	225	.495	--	--	--
Vehicle/Fillers	8.0	21	.046	19.1	9	.020
Water	--	--	--	59.3	29	.064
	100.0	255	.561	100.0	49	.108

Additional tests were conducted at the University of Illinois Environmental Research Laboratory and Materials Research Laboratory. These tests agreed with the above analysis and further revealed:

(i) A ratio of 53%:47% between the two main types of propellants, F-11 (CCl_3F) and F-12 (CCl_2F_2).

(ii) A ratio of aluminum to zirconium of 6 in the aerosol and 8 in the roll-on.

6. CHEMICALS MANUFACTURING ENERGY

There are three chemical groups to be considered here for their energy requirements: flurocarbons, active ingredients, the remaining fillers and vehicles in both packages. In the previous section, the amount of each of these chemicals present in Secret antiperspirant was determined.

6.1 Propellant

Six chemical companies in the United States supply all the U.S. demand for chlorofluoromethane propellants, currently about 900 million pounds per year [32]. Much of this production uses patented processes and no domestic company will disclose its costs or use of resources. We use detailed data from the Montecatini Edison Chemical Works in Italy, a large, modern plant producing 26.5 million pounds of fluorocarbons per year [20].

Montecatini Edison uses direct methane halogenation to produce their propellants. This is basically a one-step process requiring methane, chlorine, hydrogen fluoride and sodium hydroxide, and producing as a by-product hydrochloric acid. A simplified energy flow sheet is shown in Figure 4, which shows that the energy required to manufacture the four constituents used in production is also considered. For all except hydrogen fluoride, this is the actual direct energy required to produce these chemicals from naturally occurring elements. The energy cost of hydrogen fluoride is taken to be its Gibbs free energy value.

In the direct halogenation process, equal amounts of F-11 and F-12 are produced, approximately the ratio in which they are used in Secret aerosol. Because hydrochloric acid is produced as a useful byproduct in this reaction, some allocation of energy use among outputs must be made. This is especially relevant in this case because fluorocarbon production contributes, from its byproducts, more than 75% of all industrial hydrochloric acid used today [31]. There are several energy allocation schemes and each has its relative merits and demerits. Because both these products have similar economic value, we will allocate purely on the basis of weight: HCl output is 57% of total and therefore requires 57% of total processing energy. The remainder, per ton, is assigned to the chlorofluoromethanes. Each aerosol can contains about one half pound of the 50/50 mixture, requiring 12,100 Btu primary.

6.2 Active Ingredients

Both aluminum hydroxychloride and zirconyl hydroxychloride are highly specialized chemicals made by only a handful of U.S. and foreign companies. No company we contacted was willing to disclose either the process used or data concerning production and energy use. We know only that aluminum chlorhydrate is made as a liquid for use in the roll-ons, and is then dried to a powder if used in an aerosol.

In lieu of specialized data we make the following estimate based on a Washington University study of energy use for chemical manufacturing [9] (see section 4.3). This research examined the total energy cost per pound for 71 common polymers and industrial chemicals. We use the average energy cost per pound among these chemicals, 35,600 Btu/lb., as the estimated energy cost of active ingredients. Aerosol Secret contains .020 lb. of these chemicals, or 730 Btu, while the roll-on contains .024 lb. or an estimated 880 Btu. The error introduced by using these estimates will have little effect on the outcome. For example, if aluminum hydroxychloride were to have an energy cost equal to the highest one studied by Washington University, polyisoprene, (109,200 Btu/lb.) total energy costs for these two packaging systems would change by less than 5%.

6.3 Vehicles and Fillers

Determining the exact chemical contents of the vehicles and fillers would require a complex chemical analysis of the aerosol and roll-on compounds. For example, a common emulsified cleansing lotion similar to the Secret roll-on compound contains [21]:

Petrolatum	5.0%
Water	42.3%
Paraffin Wax	1.0%
Lanolin	2.0%
Arlacel 83 (Atlas)	2.0%
Mineral Oil	45.0%
Glycerine	2.5%
Magnesium Sulfate	.2%
Perfume, preservative	8.5%
	100 %

Other formulas for roll-on and aerosol anti-perspirants and deodorants are similar [22-24], such as this one suggested by a chemical manufacturer:

Active ingredients	8.0%
Silicone	.5%
Cetyl Alcohol	1.0%
Hydrogenated Squalene	.5%
S.D. Alcohol	59.0%
Propellant (F-12/114,60:40)	30.09%
Perfume	1.0%
	100.0%

In lieu of such detailed information, for the purposes of energy accounting, we will assume that these chemicals may be classified as miscellaneous organic and petroleum chemicals (after Tealsey, [29]). Some of the chemicals above are organic and many are byproducts of the early stages of petroleum production. Despite the differences in these two types of chemicals, production energy is very similar [29]:

Miscellaneous Organic	18,060 Btu/lb.
Crude Petroleum	20,140 Btu/lb.

We use an average of these two figures; though it is a primary energy figure, it is almost certain to be a lower bound. Aerosol Secret contains .046 lb. of these chemicals requiring 890 Btu and the roll-on contains .020 lb. requiring 380 Btu. Water in the roll-on is considered energy-free.

7. CONTRACT PACKAGING

In this section we will consider the energy required to mix the Secret deodorant preparations and put them into their containers. This is called contract packaging or contract filling. Note that we will consider only direct energy, i.e., energy used for operating machinery heating and lighting. Indirect energy use, including capital energy costs, will not be included. Also neglected in most cases is intraplant transport energy, such as forklifts and conveyor belts. All direct energy use will be converted to primary.

7.1 Aerosol

We obtained data for energy use for contract aerosol filling from phone calls and a plant visit to a large aerosol packager in the Chicago area. Except for a small associated paint factory, this company does nothing but mix and fill aerosol compounds. The company is one of the largest aerosol fillers in the midwest, with an average output of about two million cans per month of all sizes between four and twenty-four fluid ounces.

The six buildings comprising the company total about 180,000 sq. ft. All are run entirely from electricity except for heating, is done with fuel oil. The same machinery is used for all sizes of cans--only the machine settings and speeds are changed. The average size can, comprising about 60% of all output, is sixteen ounces. However, these figures should apply with good accuracy to 9 oz. cans, the size of aerosol Secret.

The company runs four filling lines, two on eight hour shifts (8 a.m. - 4 p.m.) and two on double shifts (8 a.m. - 4 p.m. and 4 p.m. -

1 a.m.). All lines are identical and are diagrammed in Figure 5A. The main electrical distribution panel runs at about 760 A. 200 V. continuously during the day (max. 800 A.) and the company estimates that about 60 A. of this is for overhead lighting.

Using 1974 and 1975 plant data, it is possible to determine the overall energy balance for the plant (Figure 5A). For the entire year 1974, 55,800 gallons of No. 2 fuel oil were burned. At a heat content of 5,825,000 Btu/bbl. [10] and a conversion factor of 1.2082 Btup/Btu, primary energy use for heat was 8.844×10^9 Btup. Electricity use in Kwh was known from January 1, to May 15, 1975. This data was combined with an estimate of May and June power consumption to yield estimated electrical energy use for the first half of 1975 (Appendix B). During 1974, average output from the company was exactly 2,000,000 cans/month. This figure remained very close to the same for the first half of 1975. Combining these figures, total energy use for this contract packing operation 1974-75 amounted to 980 Btu primary/can.

7.2 Roll-on

The energy costs associated with packaging roll-on deodorants were calculated in cooperation with a prominent midwest packaging laboratory. The firm is equipped to package viscous liquids (such as Secret roll-on) in small bottles. Data for the calculations were provided in phone conversations, letters, and a plant visit.

This packaging firm occupies a brick, six story building totalling 112,626 sq. ft. of space. The building uses standard fluorescent lighting and gas heat from a Sonberg and Orr 100-horsepower Powermaster boiler. The boiler also produces process steam for various plant operations, including some packaging machines. The remaining packaging machines are electric.

The company organizes its equipment in modular "lines," and can run up to fifteen at a time. The average number of lines running at any one time is approximately eleven. The average batch of products, about twenty thousand bottles, takes about two and a half weeks from order receipt to completion.

Figure 5B shows the energy balance for this roll-on package. The task is to allocate all of the energy costs of the machinery plus one eleventh of "overhead" energy--heating and lighting.* We assume that this packager is operating these eleven lines continuously, so that overhead energy need be allocated only for the period of actual line operation. Energy costs for running a typical mixing and packaging "line" were developed for the sequence shown in Figure 5B from manufacturer's data and information from the company.
Overhead energy costs were developed from estimates of required heat and light. The details of all computations are in Appendix B.
The results are:

processing energy, per bottle:	280 Btu
overhead energy, per bottle:	375 Btu
total direct energy, per bottle:	655 Btu

*This company also has several window air conditioners at various points in the plant which are not considered.

8. ADMINISTRATION, DISTRIBUTION, AND OTHER ENERGY COSTS

8.1 Administration

This section attempts to assign an energy cost to the activities labeled in Table 1 as "selling, general, and administrative expenses," or S.G.&A. S.G.&A. costs are the largest single cost component in these products, equal to 40% of their average retail cost [14]. In 1974, the average retail prices for Secret were $1.00 for roll-on and $1.49 for the aerosol. (Appendix A)

Additional research has shown that the proportion of administrative costs devoted solely to advertising amounts to 15% for the large toiletry companies in 1972. For The Proctor & Gamble Company, 1972 media expenditures are estimated at $357 million, or 19% of retail sales [14]. The energy costs of these advertising and non-advertising administrative expenses is computed using energy I/O (Table 6).

8.2 Distribution

The cost of delivery, shipping, warehousing, and billing, represent 6% of the average retail price of toiletries in 1972 [14]. According to Department of Commerce data, these costs amount to only 4% in 1967, apportioned as follows: 1% for railroad shipping costs, 2% for motor freight transportation services, and 1% for miscellaneous transportation services [13,17]. Costs for insurance and other transportation forms are negligible. Based on this information, a weighted average energy input/output coefficient is used to calculate energy required for these distribution activities (Table 6).

8.3 Trade Margins

The Proctor & Gamble Company states that the average 1974 trade margin for Secret was $.29 (29%) for roll-on and $.35 (23%) for aerosol. The company also states that these margins are generally retail trade (Appendix A). Using energy I/O, the energy cost of these margins (Table 6) are 8,010 Btu for roll-on and 9,040 Btu for aerosol.

8.4 Disposal

Several options exist for treating the used Secret antiperspirant containers. A detailed analysis of these options and their attendant energy costs would be a considerable study unto itself. Unless disposal costs are to be neglected, introducing a definite systematic error, several assumptions must be made. We assume that the consumer disposes of all the deodorant container, and that the container proceeds through a municipal waste treatment system to land fill. The latter assumption is highly reasonable in view of these facts [3]:

> A 1968 study by HEW estimated that there were only about 300 municipal incinerators in the entire country which disposed of 8 percent of the more than 190 million tons of waste collected annually... A 1972 EPA survey estimates only 193 municipal incinerators in the U.S. Nearly all the rest of the waste ends up in landfills.

Given this scenario, disposal costs can be computed from available macro-statistics purely on the basis of container weight. As all the necessary energy data has been averaged to account for different materials in the waste stream,* disposal energy can be calculated by

---

*In 1966, the waste stream consisted of 56.26% glass, 40.03% metals, 3.2990 paperboard, 4.84% other paper, and 11.2% other [7].

multiplying container weight by the average disposal free energy cost (for 1972), 511,800 Btu/ton. The results are:

Aerosols: Container weight = .1876 lb.; disposal energy = 50 Btu.

Roll-on: Container weight = .1650 lb.; disposal energy = 40 Btu.

9. SUMMARY AND CONCLUSION

9.1 Total Energy Costs

In previous sections, we have determined the energy cost for each segment in a manufacturing process. The total energy requirement is simply the sum of all these components. Table 7 presents the energy requirements for both forms of Secret and indicates a total energy cost of 54,380 Btu (primary) for a single 9 oz. can aerosol package and 29,530 Btu (primary) for one 1.5 oz. bottle roll-on package.

9.2 Discussion

The results of this study show that buying a given amount of anti-perspirant efficacy as an aerosol requires 1.85 times as much energy as buying the same thing in roll-on form: 54,380 Btu for the aerosol and 29,530 Btu for the roll-on. This difference is significant when one considers the number of personal products sold today in aerosol form, an estimated 1.5 billion in 1973 [38]. Most of these are packaged in systems similar to Secret and, though it is impossible to speak quantitatively, it is likely that these aerosol packages use more energy than their non-aerosol substitutes, if any. To extend this pure hypothesis, if every aerosol personal product made in 1973 would have been made as a non-aerosol with savings similar to our results about 35 trillion Btu (about six million barrels of oil) would have been conserved.

This discrepancy in energy cost is not surprising when other factors are taken into account. According to The Proctor & Gamble Company (Appendix A) their aerosol selling price is also 50% larger than roll-on price. The total weights of the container systems vary by a factor of 2.5 (aerosol/roll-on) and the net contents delivered (including vehicles) varies by a factor of 4.

This suggests that another way to conserve energy in packaging these particular personal products is to alter the form of the delivery systems. For example, eliminating the roll-on outer box and cellophane would reduce energy use by 2%; reducing the weight of the bottle by 40% would lead to an energy savings of another 2%.

In view of the higher material, energy, and dollar cost of this aerosol product, as well as the health and safety questions now being raised concerning fluorocarbons, it seems appropriate to ask why such a delivery system was created. Does it offer more profit to the company? More convenience to the customer? Balancing all these factors is precisely the purpose of technology assessment. As energy and materials become more scarce, less efficient systems will certainly be called upon to defend their use of resources. It is hoped that this research is a step in that direction.

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Table 1

MONEY AND ENERGY ACCOUNTING BREAKDOWNS FOR SECRET ANTIPERSPIRANT

Economic Category	% of Retail Money Cost[a]	Means for Determining Energy Cost for the Category	Section of This Report
production costs[c]	21%	individual energy measurement	4,5,6,7
administrative costs[d]	40%	energy input-output analysis	8
distribution costs[b]	6%	energy input-output analysis	8
trade margins	25%	energy input-output analysis	8
income taxes	4%	neglected	--
net profit after taxes	4%		

[a] source: [14], p. 30.

[b] delivery, shopping, warehousing, billing and order handling

[c] includes factory "overhead"

[d] selling, general, and administrative expenses including advertising and promotion

Table 2

DIRECT ENERGY USE FOR GLASS CONTAINER MANUFACTURER

Study	Year	Value (10^6 Btu primary/ton)	Source	Notes
U.S. Census of Mfrs.	1967	17.40	[3]p.124	May not include all inputs
Diamond Glass Co.	1971	7.91	[3]p.125	May not include all inputs; output: 65% whiskey bottles, 35% food, toiletry, cosmetic bottles
Midwest Research Institute	?	21.72	[4]V.II p. 19	

Table 3

ENERGY REQUIREMENTS FOR PLASTIC CONTAINER PARTS

Part	Weight (lb)[a]	Energy (Btup/lb)	Energy (Btup)[c]
Roll-on		53,550[b]	
1. Roll-on tip	.011		590
2. White cap	.019		1,020
Aerosol			
3. Push tip	.0035		180
4. Cover cap	.0175		910
5. Valve[d]	.0023		120

[a]double beam balance; rounded after conversion from metric

[b]Production and fabrication energy for linear, high-density polyethylene from [24] p. 112.

[c]Computed by forming the product of previous two columns; rounded after calculation.

[d]Does not include metal valve parts (neglected).

Table 4

CONTAINER TRANSPORTATION ENERGY COSTS TO PACKAGER

Part	Distance[a] (miles)	Weight (lb.)	Energy[b] (Btu primary)
Aerosol			
Can	100	.1560	41
Overcap	900	.0180	41
Total			82
Roll-on			
Box	50	.0560	7
Ball	900	.011	26
Bottle	300	.1650	5
Total			38

[a]Appendix A

[b]Computed using 5,260 Btu /ton-mile, applying to Class I intercity motor freight, 1971 [27], p. 23 rounded to nearest Btu after calculation.

Table 5

CONTAINER MATERIAL ENERGY SUMMATION

Part	Weight (lb)	Energy (Btu primary)	Text Section
Aerosol			
Can	.1563	4,600	4.1
Push tip	.0035	180	4.3
Overcap	.0175	910	4.3
Valve	.0041	120	4.3
Label	.0062	80	4.4
Transportation	--	80	4.5
Aerosol Total	.1876	5,970	
Roll-on			
Bottle	.1646	1,490	4.2
Ball	.011	590	4.3
Cap	.019	1,020	4.3
Labels	.0008	10	4.3
Box	.0557	610	4.4
Transportation	--	40	4.5
Roll-on Total	.2511	3,760	

Table 6

ENERGY INPUT/OUTPUT CALCULATIONS

Line		I/O Sector	AEROSOL			ROLL-ON		
			$1974	$1967[b]	Btu[c]	$1974	$1967[b]	Btu[c]
1	Aug. Retail Price		1.49	1.10	--	1.00	.80	--
2	Advertising only (19% of 1)[a]	73.03	.28	.21	10,720	.19	.15	7,660
3	Non-Advertising (21% of 1)	73.01	.31	.31	10,800	.21	.17	5,920
4	Total Administrative (40% of 1)	--	.59	--	21,520	.40	.32	13,580
5	Distribution Costs (6% of 1)	65.01 (25%) 65.03 (50%) 65.07 (25%)	.09	.07	3,100	.06	.05	2,220
6	Retail Trade Margin[d]	69.02	.35	.26	9,040	.29	.23	8,010
7	Total Non-Manufacturing Energy	-	-	-	33,660	-	-	23,810

[a] 1972 percentages applied to 1974 prices [Appendix A and 14, p. 30, 34].

[b] Dollar amounts must be deflated to 1967 prices for use with I/O for 1974. [15]

[c] Energy is computed by forming the product of cost ($1967) and Input/Output coefficient (Btu /$1967) [$1967].

[d] See Appendix A.

Table 7

TOTAL ENERGY COSTS FOR SECRET ANTIPERSPIRANT

Item	Text Section	Methodology Code	Energy (Btu primary)
Roll-On			
Materials	4.6	A	3,760
Chemical Vehicles	6.3	B	380
Active Ingredients	6.2	B	880
Contract Packaging	7.2	C	655
S.G.&A.	8.1	D	13,580
Distribution	8.2	D	2,220
Trade Margins	8.3	D	8,010
Disposal	8.5	A	40
TOTAL			29,530
Aerosol			
Materials	4.6	A	5,970
Propellant	6.1	A	12,100
Chemical Vehicles	6.3	B	890
Active Ingredients	6.2	B	730
Contract Packaging	7.1	C	980
S.G.&A.	8.1	D	21,520
Distribution	8.2	D	3,100
Trade Margins	8.3	D	9,040
Disposal	8.4	A	50
TOTAL			54,380

Methodology Codes

A. Energy vertical analyses on specific products or processes done by other researchers.

B. Private chemical analysis and estimate of energy content based on similar Chemicals.

C. Private data collected from two contract packagers.

D. Input-Output analysis.

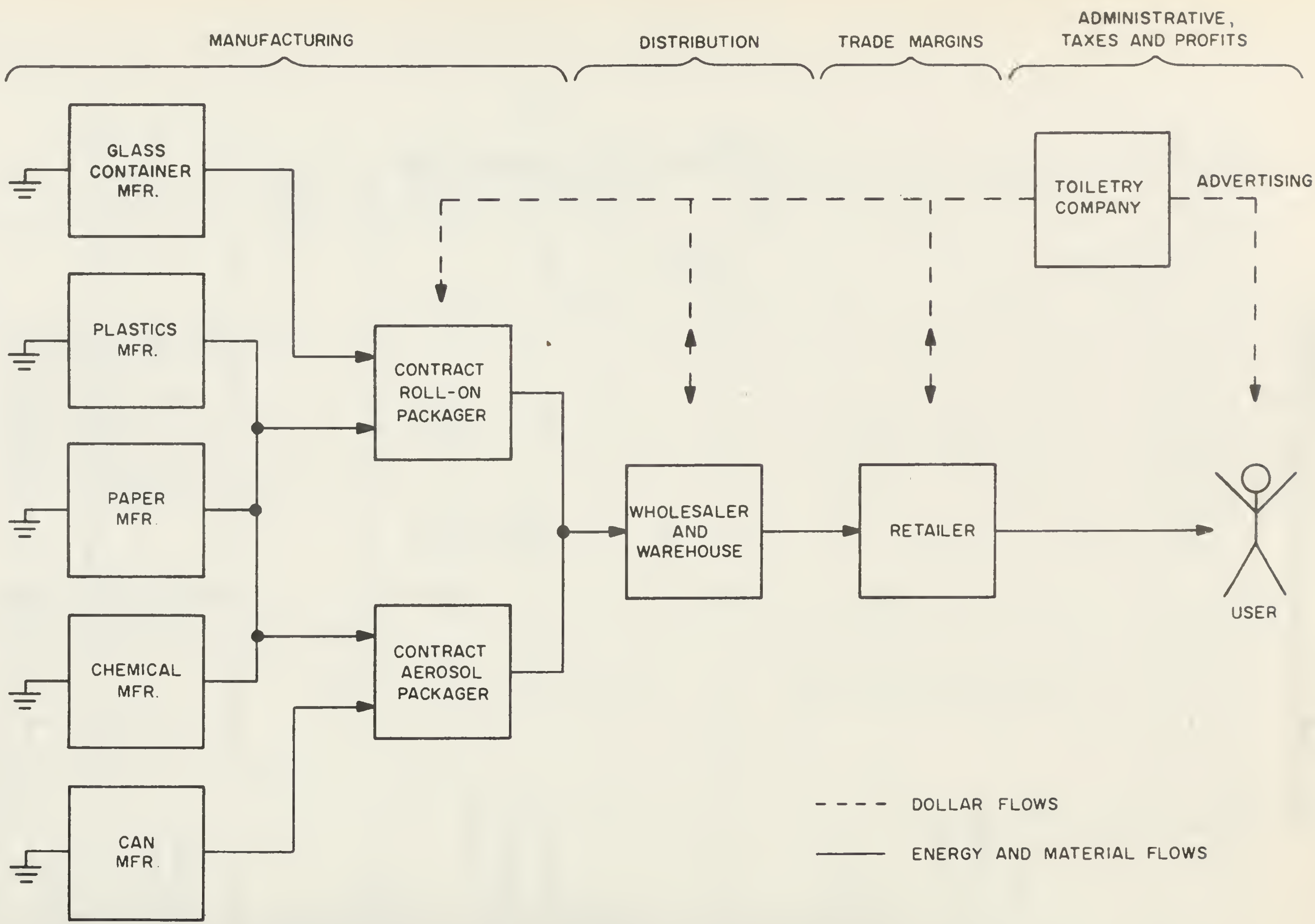


FIGURE 1. SIMPLIFIED FLOWCHART FOR DEODORANT PRODUCTION

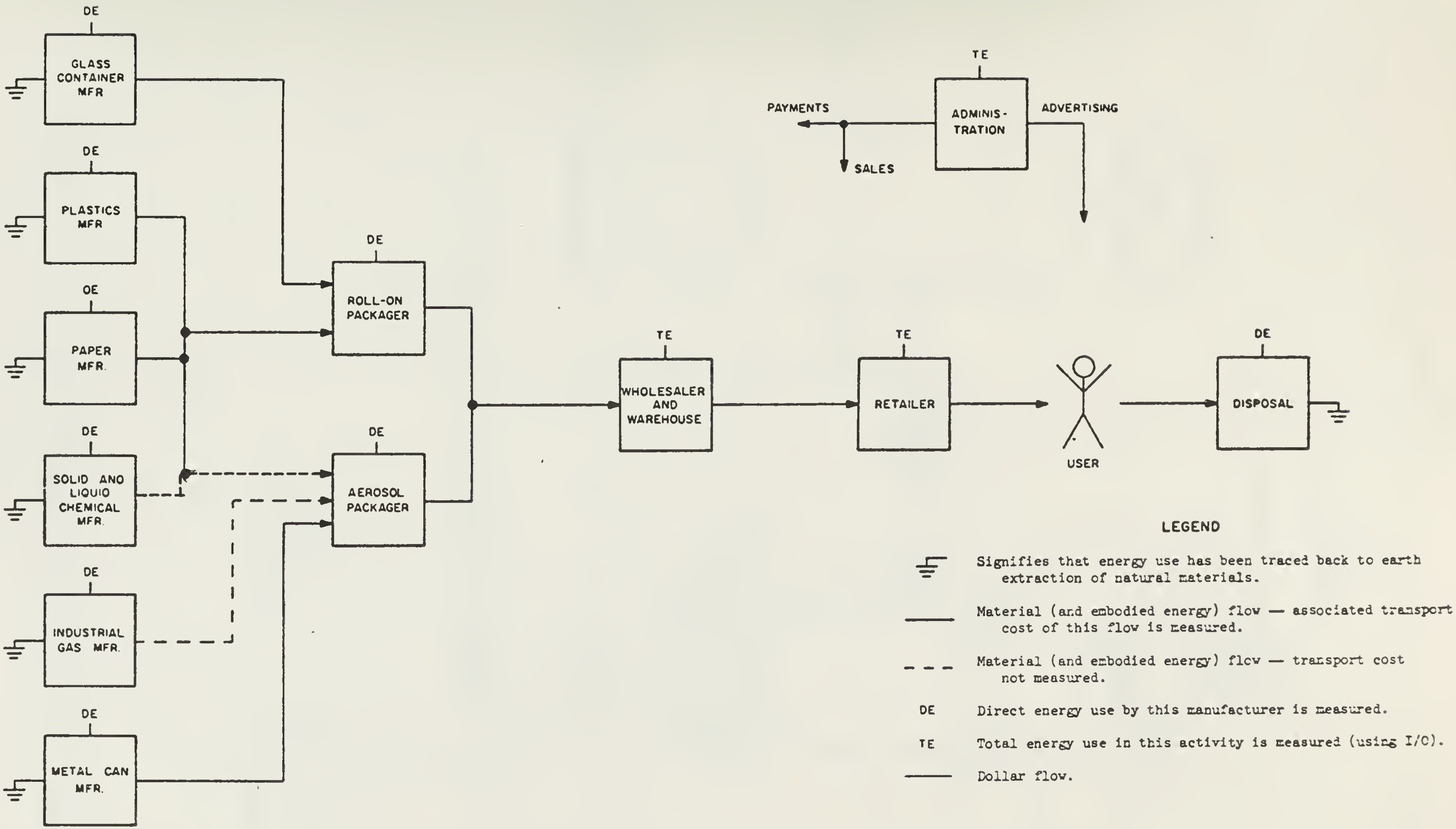


FIGURE 2. ENERGY MEASUREMENT FLOWCHART FOR SECRET DEODORANT

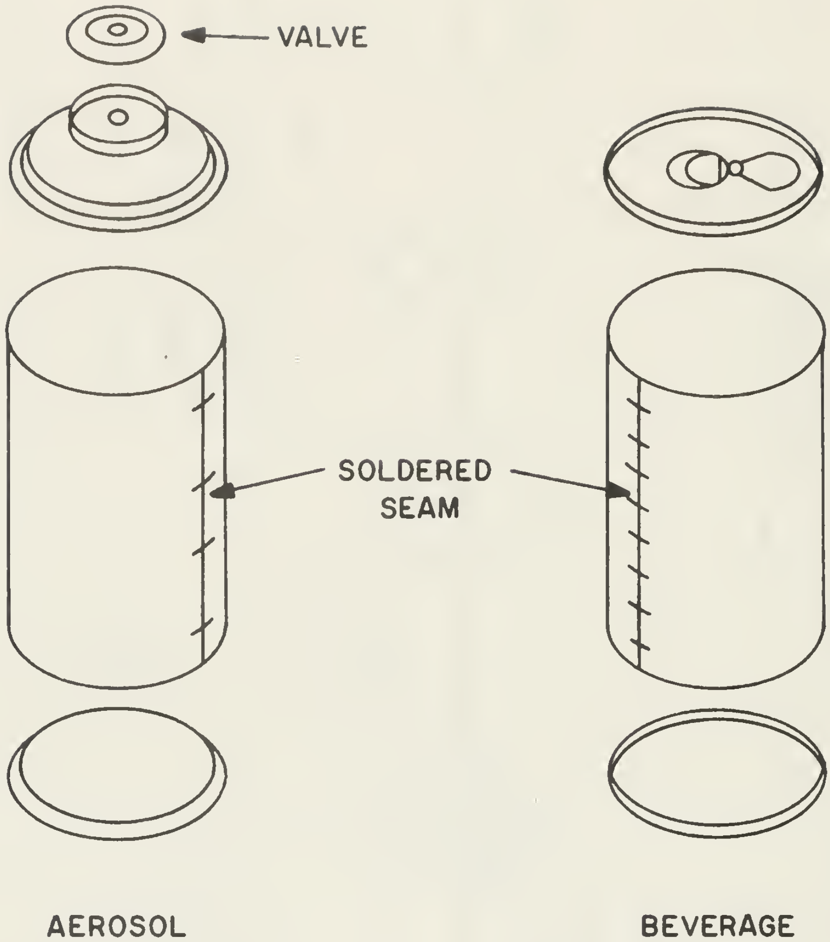


FIGURE 3. PICTORIAL OF STEEL CANS

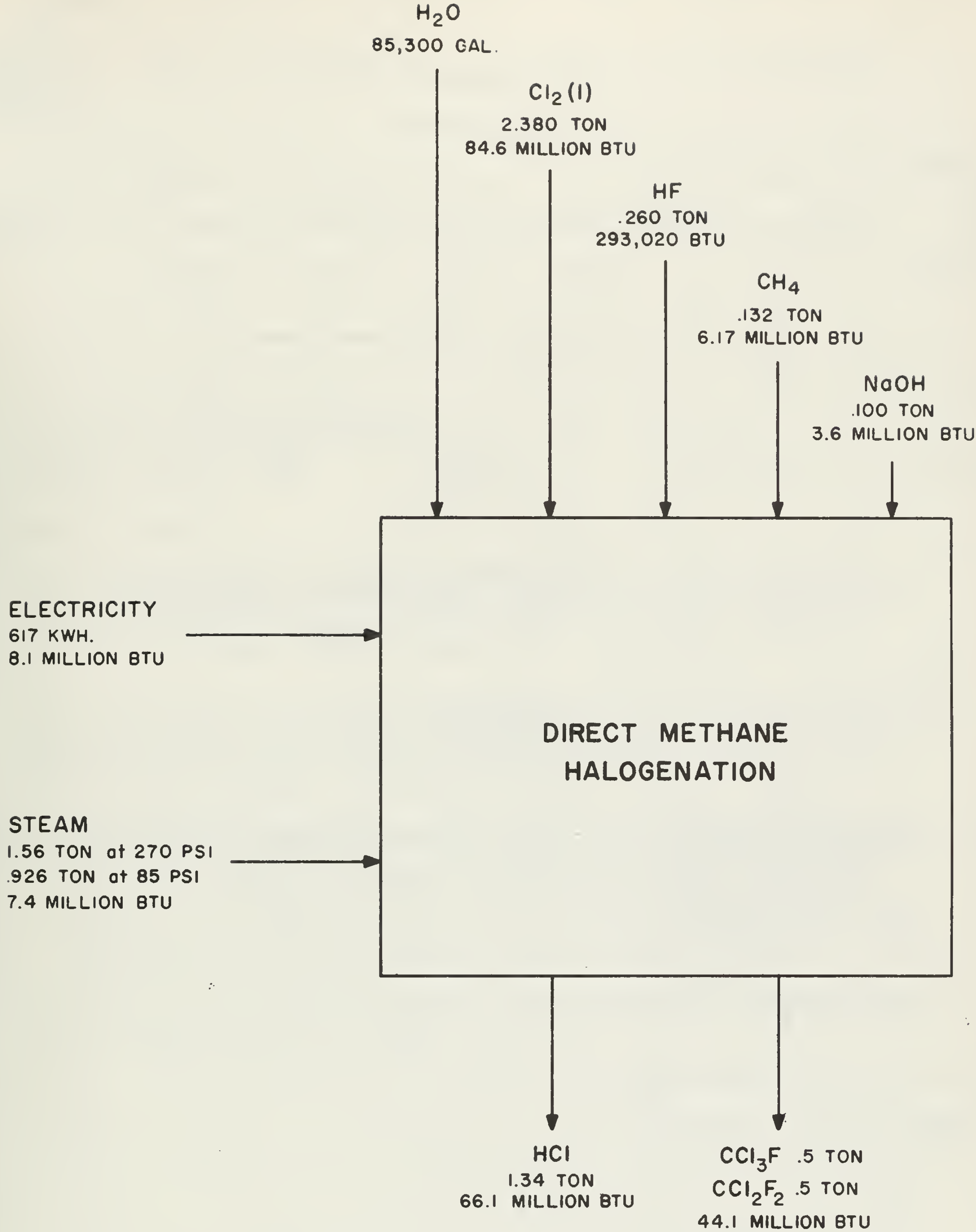
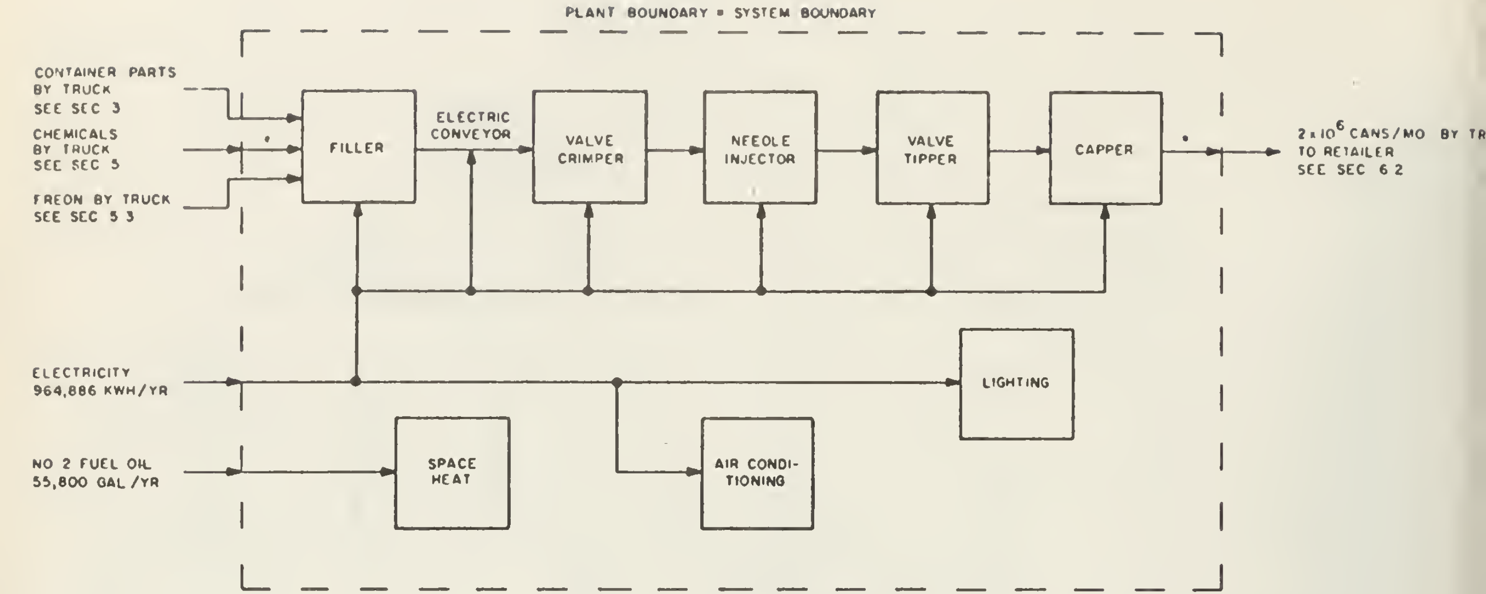


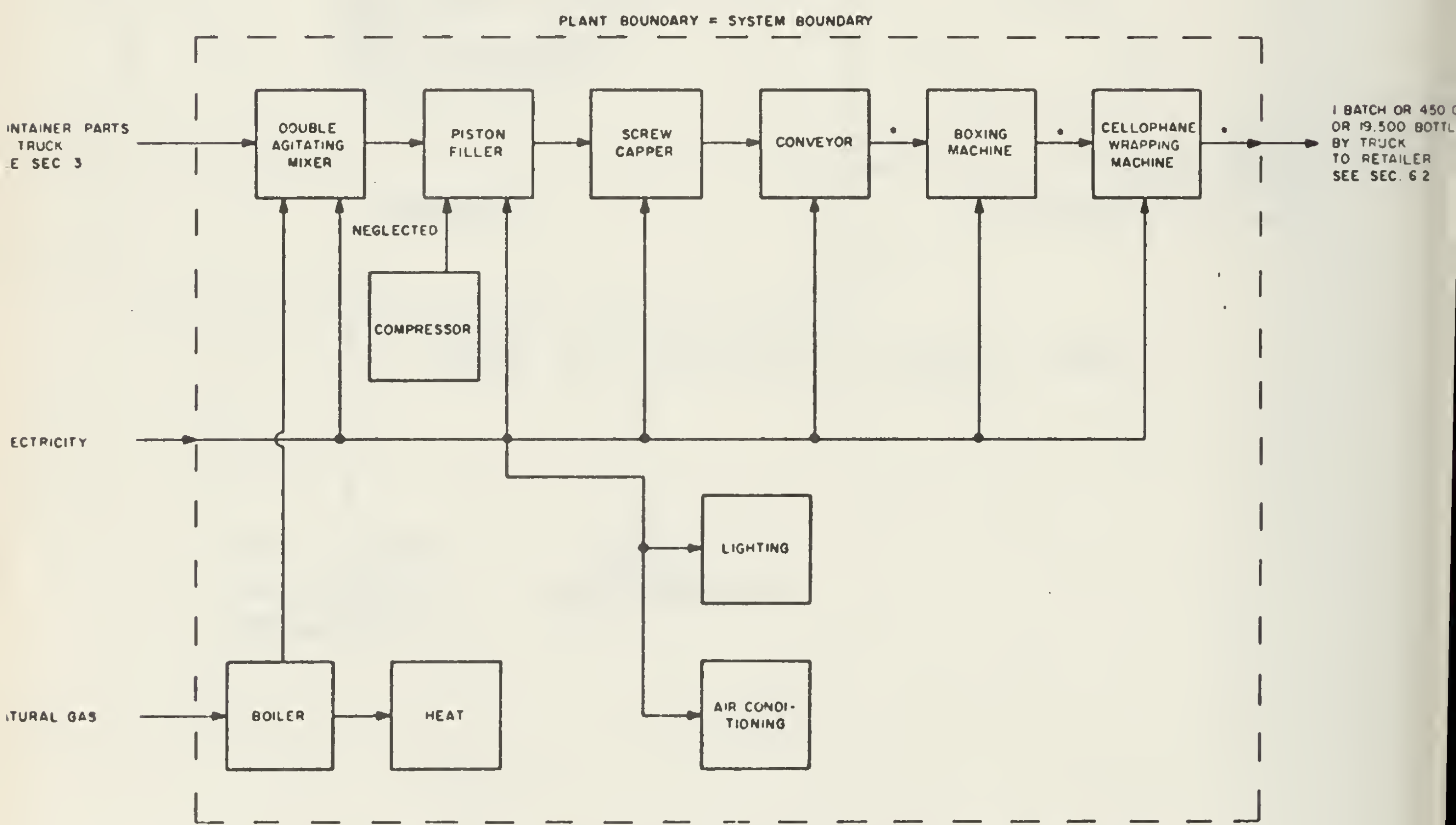
FIGURE 4. CHLOROFLUOROMETHANE PRODUCTION

A AEROSOLS



• DENOTES INTERMEDIATE TRANSPORTATION STEP WHICH IS NOT MEASURED

B. ROLL-ONS



• DENOTES INTERMEDIATE TRANSPORTION STEP WHICH IS NOT MEASURED

FIGURE 5 ENERGY BALANCES FOR CONTRACT PACKAGING

THE PROCTER & GAMBLE COMPANY

WINTON HILL TECHNICAL CENTER 6110 CENTER HILL ROAD CINCINNATI, OHIO 452

February 13, 1975

Mr. Peter Penner
Center for Advanced Computation
University of Illinois
Urbana, Illinois 61801

Dear Mr. Penner:

Attached are answers to some of the questions that you asked of us regarding comparisons between Secret Roll-On and Secret Antiperspirant. I hope that they will satisfactorily answer your primary questions regarding the proper basis of comparison.

As to your questions on the transportation steps and costs associated with each raw material, I find that we are unable to provide you with all of the detailed information that you requested. However, the following general information may be of some help to you:

> Secret Roll-On is manufactured in Cincinnati, while Secret aerosol is manufactured in Chicago. Virtually all raw materials are transported by truck, with distances ranging from under 50 miles for cartons and containers to 900 miles for Roll-On plastic balls and aerosol plastic overcaps. The Roll-On bottles come from about 300 miles, while the aerosol cans come from about 100 miles.

I hope this will be of help to you in your project, and I do apologize for the long delay in obtaining an answer for you.

Yours truly,

THE PROCTER & GAMBLE COMPANY
Toilet Goods Division

T. L. Coward

TLC/ad
Enclosure

Q: What is the right technical basis for comparing Secret Roll-On to Secret aerosol?

A: Secret aerosol antiperspirant and Secret Roll-On antiperspirant are quite similar in their effect and can be compared for your purposes, since both products are highly effective at reducing perspiration wetness and underarm odor. It must be emphasized, however, that the product formulations are quite different except for the type of active ingredient.

Although both the aerosol and roll-on forms of Secret contain the same type of active material (chemical complexes of zirconium hydroxychloride, aluminum hydroxychloride and glycine), these actives are present in different forms (liquid in roll-on; dry powder in aerosol) and different levels (more than six times as much total active in roll-on). In spite of these differences, consumer testing has shown that in normal, average use, nearly identical amounts of the active are applied to the underarms, with the aerosol resulting in a more uniform, thin coating and no touching of the skin by the application device.

In summary, a 1.5 ounce of Secret Roll-On provides the same number of uses as does a 9 ounce of Secret aerosol antiperspirant.

Q: What is the weight of the contents of each can, broken down into active ingredients and each vehicle?

A:

	1.5 oz. Roll-On %	9 oz. Aerosol %
Active	21.6	3.5
Vehicles	78.4	96.5

Q: Is ethyl alcohol an active ingredient or a vehicle?

A: It is a vehicle. Its purpose is to help keep the active suspended in the product and it is present only in the aerosol antiperspirant at a level less than 0.5%.

Q: What are the wholesale and retail markups?

A: These products are generally sold directly to retailers, and therefore there is no wholesale markup. Our list prices to the trade and the average retail selling prices are as follows:

	1.5 oz. Roll-On	9 oz. Aerosol
List Price	$ .71	$1.14
Average Retail Price	1.00	1.49
	.29	35

APPENDIX B

ROLL-ON PACKAGING ENERGY CALCULATIONS

I. Processing Energy

This applies to the processing sequence shown in Figure 5B.

1. *Groen Double Agitating Mixer.* Capacity per batch: 500 gal. Typical batch: 450 gal. Uses a 2 hp. electric motor to run double-agitating mixing blades,[1] run during the mix according to the manufacturer's instructions. The mixer has two kettles which run off 35-40 psi steam. The manufacturer states energy requirements to be about 1,200,000 Btu/hour.[2] Assuming a mix time with heat of about four hours, with no electric agitating, energy use (via the boiler) is 4.8 million Btu for 450 gallons of products. At a delivery efficiency of 73%,[3] energy use is 123 Btu/bottle. Note that this indicates a batch of about 20,000 bottles, requiring only about half of the 450 gallons mixed.

2. *Cozelli Piston Filler.* This machine fills bottles from a small holding tank at a rate of 50/hour for small bottles such as Secret. This filler has a one horsepower single phase motor in it requiring 115 V. 14 A. continuously.[4] Energy requirements are therefore:

$$\frac{450 \text{ gal}}{.023 \text{ gal/bottle}} (3000 \text{ bottles/hour})^{-1} (115 \text{ V.})(14 \text{ A.}) = 10.3 \text{ Kwh/bottle}$$
$$= 5.3 \times 10^{-4} \text{ Kwh/bottle}$$

Converting this to primary Btu's:

$$(5.3 \times 10^{-4} \text{ Kwh/bottle})(3412 \text{ Btu/Kwh})(3.85 \text{ Btup/Btu}) = 7 \text{ Btu/bottle}$$

3. *Resina Screw Capper.* Running at 50 bottles/hour, this machine uses only a one horsepower single phase motor, or 220 V at 6.5 A. nominal.[5]

Primary energy required is:

(6.5 hr/batch)(6.5A)(.22KV)(3412 Btu/Kwh)(3.85 Btup/Btu)

$(19{,}500 \text{ bottles/batch})^{-1}$ = 6 Btu/bottle

4. *Conveyor.* This uses a .5 horsepower motor running continuously at 220 V. at 2 A. Energy use is:

$(6.5 \text{ hr/batch})(2A)(.22KV)(3412)(3.85)(19{,}500)^{-1}$ = 2 Btu/bottle

5. *Crompton and Knowles Boxing Machine.* This machine is extremely fast for small bottles, and can package an entire batch (19,500 bottles) in only 5.43 hours (speed = 60/min.). The machine uses two motors drawing a combined 6.8 A at 220 V. for an energy requirement of:

$(5.43 \text{ hr})(6.8A)(.22KV)(3412)(3.85)(19{,}500)^{-1}$ = 6 Btu/bottle

6. *FMC Model 1600 Cellophane Wrapping Machine.* Using a 195 r.s. cellophane, this machine could wrap a box the size of secret roll-on at the rate of 170/minute (with two operators). An entire batch could be wrapped in 3.43 hours. The machine uses a 3 horsepower motor using about 18 A at 220 V.[6]

$(3.43 \text{ hr.})(18A)(.22KV(3412)(3.85)(19{,}500)^{-1}$ = 9 Btu/bottle.

TOTAL PROCESSING ENERGY (direct primary): 280 Btu/bottle

II. Overhead Energy

1. *Heating.* The estimate of heating load for this packaging plant can be made using ASHRAE* data:

a) for mid-Chicago, average degree-days between October and April is 5,815.[7]

b) the walls in this packagin plant are ASHRAE Type G-1, minus the gypsum, air space and plaster. Computed R value is 2.45 and U value is .41 (Btu/hour-foot^2-°).[8]

c) The floor space in thsi packaging plant is 112,626 ft^2 and the ceilings are approximately 15 feet. Wall space is therefore 20,136 ft^2.**

d) The total annual heat load, assuming average weather, and a 65° inner temperature:

$$(.73 \text{ Btu/Btu})^{-1} (5{,}815 \text{ D.D.})(.41 \text{ Btu/hr-ft}^2\text{-°})(24 \text{ hr/day})(20{,}136) = 3.95 \times 10^8 \text{ Btu/year}$$
$$= 1.90 \times 10^7 \text{ Btu/2.5 weeks}$$
$$= 1.72 \times 10^6 \text{ Btu/line}$$
$$= 352 \text{ Btu/bottle}$$

---

* American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., New York.

** Heat losses through the ceiling or windows are not considered here. These are probably more than balanced out by the waste heat generated by the equipment, particularly the mixers.

LIGHTING:

The packing plant uses long lines of fluorescent tubes mounted on the 0 ceiling for its lighting. The IES standard for packaging operations is 50 foot-candles.[o] Constructing a hypothetical system similar to this packager:[10]

a) Assume 800 mA high output lamps (each 110 W).

b) Assume fixtures hold two lamps each.

c) Assume fifty-six fixtures per floor.

Power requirements for all six floors of this packager are then:

$$(110W)(2)(56)(6) = 73.92 \text{ kilowatts}$$

with all lights burning. A more reasonable assumption is that at any one time, three-fourths of the plant's lights are burning, or 55.4 Kw. However, only one eleventh of the plant is allocated to one production line, or 5.04 Kw. One batch requires about 6.5 hours, or 32.7 Kwh of lighting to produce 19,500 bottles. Primary energy use for lighting is then 22 Btu/bottle.

TOTAL HEATING AND LIGHTING ENERGY (direct primary): 375 Btu/bottle