Arthur D Little

Disposable versus Reusable Diapers: Health, Environmental and Economic Comparisons

Report to Procter and Gamble

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I. Executive Summary

A. Background

Products, especially disposable products such as diapers, have come under scrutiny recently due to the national solid waste disposal crisis. However, prior to making judgements on the environmental compatibility of a disposable product, it is important to consider all aspects of that product when making these decisions. This report considers disposable diapers in comparison with their reusable counterparts, noting the health, environmental and economic advantages and disadvantages of the two diapering alternatives.

B. Conclusions

As a result of our analysis, we found that disposable diapers offer distinguishable health and economic advantages over their reusable counterparts. In particular, they can offer better protection against diaper dermatitis, as well as decreasing the potential spread of infection in day care settings. These benefits are achieved at a lower weekly cost compared to cloth diapers. In terms of environmental considerations, neither disposable nor reusable diapers are clearly superior in the various resource and environmental impact categories considered in this analysis. Disposable diapers consume more raw materials and generate more post-consumer waste. However, cloth diaper usage consumes significantly more energy resources and water than does disposable diaper usage. In addition, reusable diapers use results in greater air and water pollutant emissions. This report concludes that the specific human health, environmental and economic advantages of disposable products would appear to outweigh the more limited advantages of the reusable diapering materials, as discussed in this report.

C. Approach

This comparison of disposable and reusable diapers addressed the product life cycle, from original component manufacture through use and disposal. The analysis considers all diapering components comprising over five percent of the diaper weight, including packaging and auxiliary materials. Figures I-1 and I-2 illustrate the components of the evaluation. The analysis was made by comparing the weekly "average" diaper requirements of a child. The analysis considered "average" diapering conditions, as shown below.

- Disposable Diapers
  - Size: 0.18 square yards
  - Weight: 0.12 pounds
  - Number required: 1 per diaper change
  - Life: Single use

Figure I-1: Disposable Diaper Life Cycle Analysis

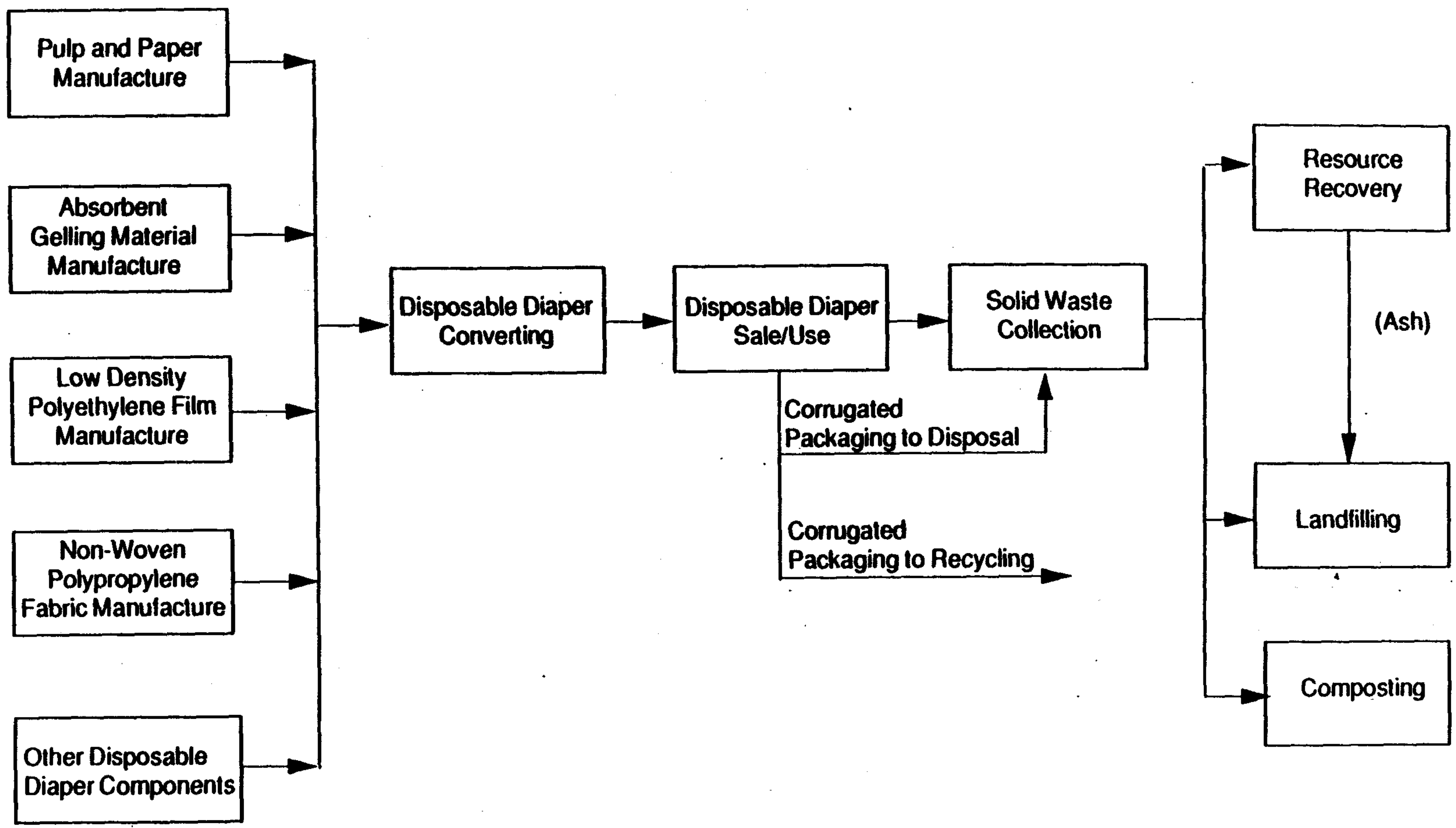
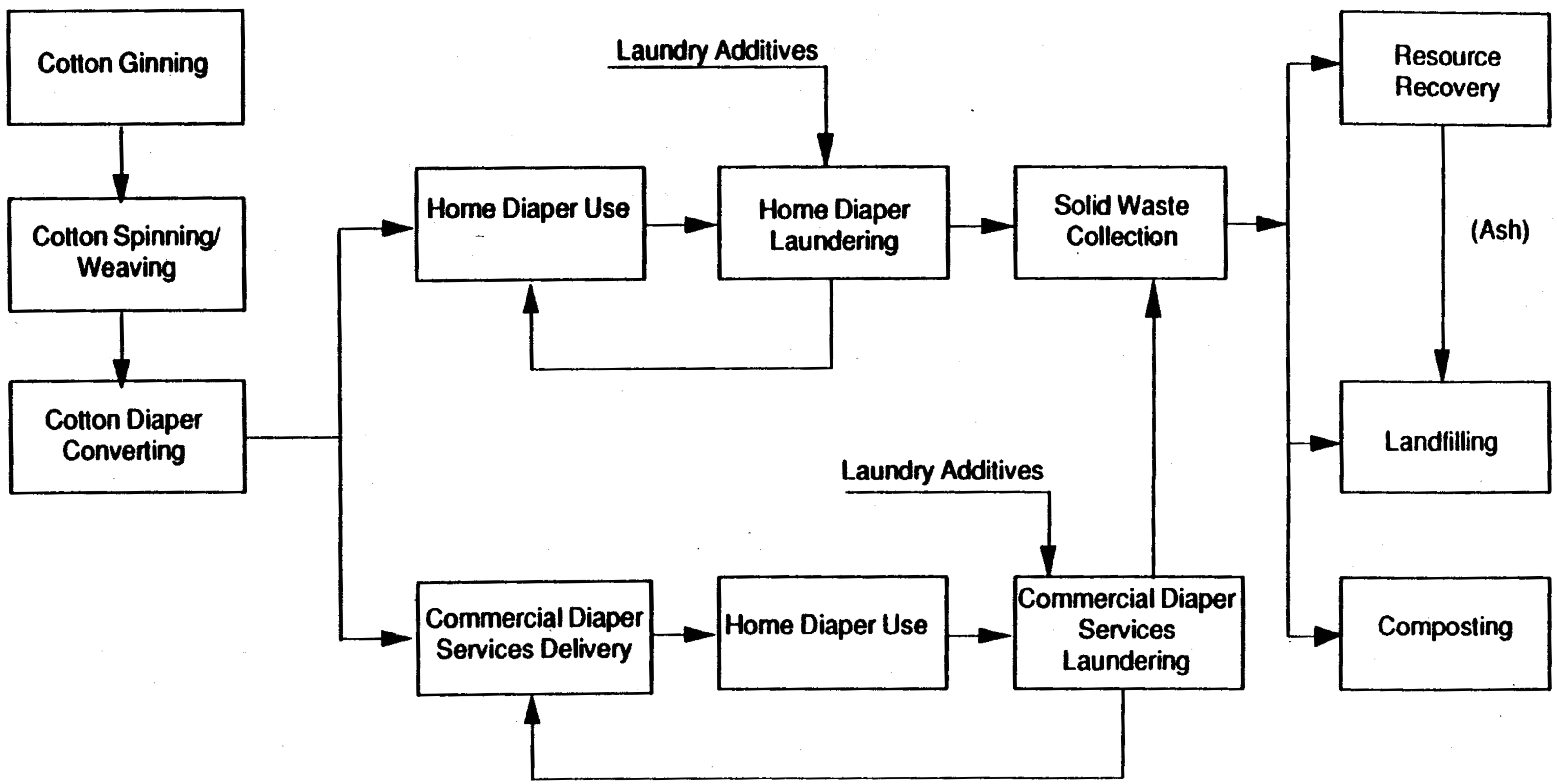


Figure I-2: Reusable Diaper Life Cycle Analysis



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- Reusable Diapers
  - Size: 0.64 square yards
  - Weight: 0.13 pounds
  - Number required: 1.9 per diaper change
  - Life: 90 uses

These "average" diapers were derived in the following manner. We purchased major brands of both disposable and reusable diapers, in a variety of sizes and thicknesses. Several diapers within each package were evaluated in the laboratory for average size, weight, and material content. These data were then used for calculations within this report wherever appropriate.

A detailed discussion of diaper use rate assumptions chosen for this study is presented in Appendix A. Generally, Arthur D. Little determined base use rates which closely approximate the weekly number of diapers used by a consumer using only one type of diaper on a child. These rates reflect the high end of average use estimates. For this reason, this study assumes the same number of daily changes for disposable diapers as for reusable diapers, although this factor has been estimated by other sources to be lower due to better absorbency with disposable diapers. Similarly, published average use rates for reusable diapers generally estimate approximately 1.5 diapers per change and a total use of between 65 and 70 diapers per week. These figures include mothers using both disposable and reusable diapers, however. This study has adopted more conservative estimates of 1.9 diapers per change and a total use of 85 reusable diapers per week based upon information from a variety of sources as detailed in Appendix A.

The environmental analysis considered consumption of raw materials, water and energy in addition to environmental releases such as air pollution emissions, waste water effluents, process solid wastes, hazardous wastes, waste oils and post consumer wastes. The data from this analysis are presented in Table I-1. The goal of the analysis was to provide a comparison within each of the impact categories identified above. However, the relative importance of the various impact categories was not quantified, as this is highly subjective and variable from one location to another.

The analysis of diapering health impacts focused on the effects of fecal and urine contents of diapers. It addressed the four groups that are potentially at risk from using or being exposed to the contents of diapers:

- individual users,
- family members and close contacts,
- persons who handle diapers in their workplaces, and
- persons living near uncontrolled landfills.

Table I-1: Environmental Impacts of Diaper Usage[a]

	Reusable Diapers[b]	Disposable Diapers
Raw Materials Consumption		
• Renewable Resources	0.4 pounds	21.6 pounds
• Non-Renewable Resources	3.2 pounds	3.7 pounds
Water Consumption	1,195 pounds (144 gallons)	196 pounds (23.6 gallons)
Energy		
• Renewable Sources	14,890 Btu	3,720 Btu
• Non-Renewable Sources	64,000 Btu	19,570 Btu
Total	78,890 Btu	23,290 Btu
Atmospheric Emissions		
• Particulate Matter	0.26 pounds	0.003 pounds
• Nitrogen Oxides	0.15 pounds	0.006 pounds
• Sulfur Oxides	0.32 pounds	0.007 pounds
• Carbon Monoxide	0.03 pounds	0.008 pounds
• Chlorine/Chlorine Dioxide	--	0.001 pounds
• Chloride	--	negligible
• Hydrocarbons	0.10 pounds	0.068 pounds
Total	0.86 pounds	.093 pounds
Waste Water Effluents		
• Total Suspended Solids	0.013 pounds	0.007 pounds
• Chemical Oxygen Demand	0.004 pounds	negligible
• Biological Oxygen Demand	0.012 pounds	0.003 pounds
• Hydrocarbons	--	0.002 pounds
• Phosphorus	0.005 pounds	--
• Nitrogen	0.083 pounds	--
Total	0.117 pounds	0.012 pounds
Process Solid Waste	3.13 pounds	2.02 pounds
Post-Consumer Waste	0.24 pounds	22.18 pounds

[a] Based on the average weekly diapering requirements per child and considering current post-consumer waste disposal practices.

[b] Considers the approximate use of home laundering and diaper services for 90 percent and 10 percent of the respective diaper changes. Lehrberger (1988) and Arthur D. Little estimates.

The analysis identified the means by which these various groups of people could be exposed to hazards by developing simple exposure scenarios. The potential health impacts that could result from such exposures were identified. An assessment was then made to determine whether the health risks differed depending on the type of diaper used.

The comparative economics of disposable and reusable diapers were evaluated on the basis of their respective selling prices, laundering costs (of the reusable product), and the cost of disposal. Selling prices were analyzed to derive a national average, considering the various diaper sizes and frequency of use of each size. For reusable diapers, the costs of both commercial laundering and home laundering were considered, based on their relative shares of practice. Finally, a national average disposal cost was determined, considering the average costs of the most prevalent disposal methods, landfilling and incineration. The national cost of disposal was estimated as a weighted average of the costs of these two disposal methods.

D. Results

1. Resource and Environmental Impacts

Table I-1 presents the aggregated results of the environmental impact analysis for disposable and reusable diapers. Neither the disposable nor reusable diapers are clearly superior in all seven resource and environmental impact categories considered in this analysis. The primary difference is that the resource and environmental impacts from disposable diapers are generated before and after the productive life of the product. On the other hand, the resource and environmental impacts from reusable diapers are almost exclusively generated during the productive life of the product. On an equivalent use basis, a life cycle comparison of disposable and reusable diapers indicates:

- Disposable diapers consume about 7 times the raw materials of cloth diapers and result in the generation of over 90 times the post-consumer solid waste;
- Reusable diaper use generates 50 percent more process solid waste than disposable diapers;
- Reusable diaper use consumes over 3 times more non-renewable energy resources and just over 4 times more renewable energy resources;
- Reusable diaper use consumes 6.1 times more water and releases nearly ten times higher levels of total water pollutants; and
- Reusable diaper use results in the emission of over 9 times higher levels of total air pollution.

Since the relative importance of the various resource and environmental categories is subjective and highly variable from one location to another, this study did not assign a value to each category and thereby derive an overall numerical "rating" for inter-product comparison.

2. Product Evolution

A historical review of disposable diapers shows a steady focused effort to improve the product, brought about by the natural competitive environment and in response to consumer demand. A resultant reduction in product weight and volume (bulk) has been brought about through material refinements and the introduction of new materials in disposable diaper construction. Every major material component of the disposable diaper has been modified to the point where an overall reduction in volume of 35 to 50 percent has occurred for almost all products in the last three years alone.

The initial disposable diapers were relatively unsophisticated products constructed of cellulose pulp and tissue. Since the first U.S. disposable diaper patent was issued to Procter and Gamble in 1961, a steady stream of product improvements has followed. This evolution has been rapid and responsive to consumer needs via significant product improvements and has substantially reduced post-consumer diaper wastes.

Reusable cloth diapers have remained essentially unchanged since their introduction, with the exception of prefolded stitched diapers.

3. Packaging

Packaging of disposable diapers consists of either a polyethylene bag (which constitutes 75 percent of the disposable diaper market) or a fibreboard box (25 percent of the market) for primary packaging. Corrugated containers are used for shipment of four to six consumer units of diapers to the retailers. The primary packaging is designed to provide a convenient quantity of diapers for consumer purchase for a typical week's usage. The quantity per package ranges from 12 to 60 diapers depending upon the size of the diaper. The younger the child, the more frequently changing is required, therefore, a greater number of diapers constitute a week's supply. Reusable (cloth) diapers are packaged in a polyethylene pack, twelve of which are shipped in a corrugated container. The typical number of reusable diapers per package is twelve.

The majority of the primary packaging components for both disposable and reusable diapers do not constitute greater than five percent of the total product weight and are therefore not included in the life cycle analysis. However, the packaging component has only recently moved below the five percent level. Just as the disposable product has undergone enormous change since its introduction, so has packaging. First, compression packaging (the compacting of diapers prior to insertion in the package) greatly reduced the volume (bulk) of the consumer package units. Then in 1988 the major produces of disposable diapers began to convert from paperboard packages to plastic, still utilizing compression packaging. This resulted in a greater than 87 percent reduction in packaging material by weight, and an even greater reduction by volume.

The corrugated fibreboard (secondary packaging) comprises greater than five percent of the total product weight, but because the large quantities of corrugated arriving at retailers are easily recycled, 40 percent of all corrugated board in this country is recycled. The polyethylene bags are typically disposed of in the solid waste stream by consumers.

Additional "hidden" packaging includes the polyethylene bags in which the reusable diapers are transported to laundering facilities, particularly in the case of diaper services. A new polyethylene bag is used for each round trip to/from the user's residence. Over the life of a reusable service diaper (reportedly 90 uses), this constitutes nearly 58 percent of the weight of the product itself. Although diaper services comprise only 10 percent of reusable diaper usage (calculated using cotton import and industry sources), this becomes a significant amount of polyethylene added to the product life cycle.

4. Health Impacts

The health risk associated with diaper use can be effectively managed through good hygiene, by a variety of methods, as noted below:

- by preventing prolonged wearing of wet and soiled diapers,
- by changing diapers before leaks occur,
- by decontaminating hands, surfaces and objects that contact fecal matter,
- by adequate containment of fecal matter, and
- for reusable diapers, by adequate laundering.

However, in practice these requirements are not always met and, as a result, disposable diapers offer a better degree of protection than do reusable diapers. For example, for protection from dermatitis, disposable diapers that incorporate absorbent gelling materials offer better protection from dermatitis than do other brands of disposable diapers or home laundered reusable diapers (Austin, et al., 1988, Campbell et al., 1987).

For protection from infection in the home, day care, or nursing home environments, disposable diapers result in reduced opportunities for exposure compared to reusable diapers, both through superior containment and by eliminating the risks associated with home laundering and handling protective covers and soiled diapers (Berg, 1989). They also contribute to an improved quality of life for persons with incontinence (Beber, 1980).

Occupational and environmental risks associated with laundering of reusable diapers and disposal of disposable diapers have been studied by governmental agencies, academic research scientists and health organizations (Clark, et al., 1979; Engelbrecht et al., 1974, 1975; Pahren, 1987; Sobsey, et al., 1974, 1975, 1978, 1989; Turnberg, 1989; Ware, 1980). Their studies indicate that the presence of soiled diapers in the solid waste stream has not caused a public health problem. Available hygiene practices have been sufficient to control any potential risk among other occupational groups that handle soiled diapers.

5. Economic Issues

Disposable diapers provide an economical method of dealing with infant incontinence and are generally less costly on a life cycle basis than their reusable counterparts. The only instance in which reusable diapers provide a competitive economic advantage is when the cost of labor for home laundering is not considered. While there have been numerous attempts at placing a value on home labor, no single equivalent wage rate has been universally adopted. Even at the prevailing minimum wage, in-home laundering labor costs contribute significantly to the life cycle cost of reusable diapers. In fact, reusable diapers are nearly 20 percent more costly than their disposable counterparts when home labor is valued at the minimum wage rate. When a more realistic in-home laundering labor cost of $6.00 per hour is used, the life cycle cost of reusable diapers is approximately 60 percent greater than that of disposable diapers. Diaper services generally provide a more cost effective approach to cotton diaper maintenance than in-home laundering. This is due primarily to economies of scale. Nonetheless, the use of a diaper service is slightly more costly than disposable diapers on an equivalent use basis. The life cycle costs of disposable and reusable diapers are reported in Table I-2.

6. Societal Issues

The number of women in the work force has dramatically risen over the past 30 years. Currently, almost 55 percent of these women have one or more children under the age of three. In addition to active participation of married mothers in the labor force, there are many more divorced and single mothers now in the labor force. With this dramatic rise in women in the workforce, the amount of free time at home is limited. This change resulted in new products that offered increased discretionary time for parents to spend with their children. The so-called "disposable society" did not just happen, and products like disposable diapers, were created in response to significant societal needs.

E. Perspective

Public and governmental concerns regarding specific disposable products are significant and require thorough analyses of the life cycle impacts from

Table I-2: Diapering Life Cycle Cost Analysis - Average Cost Per Week Per Diapered Child

	Disposable Diapers	Reusable Diapers[a] Scenario 1	Reusable Diapers[a] Scenario 2	Reusable Diapers[a] Scenario 3
Average Cost Per Child Per Week ($)				
• Amortized Purchase Price	9.45	0.78	0.78	0.78
• Home Laundering	NA[b]	10.86	15.03	5.58
• Diaper Service	NA	1.11	1.11	1.11
• Waste Collection/Disposal[c]	0.86	neg[d]	neg	neg
Total average cost per child per week	10.31	12.75	16.92	7.47

a. Reusable Diaper Costs reflect 10 percent use of diaper services. Scenarios 1 and 2 include the value of in-home laundering at $3.35/hour and $6.00/hour, respectively. The former is the current minimum wage rate, while the latter reflects a more typical value for this service. Secnario 3 excludes the value of in-home labor and is provided for comparative purposes only.

b. NA = Not Applicable

c. Disposal costs are based upon weighted average of current disposal methods of landfilling (93%) and incineration (7%)

d. neg = negligible

Sources: Lehrberger (1988) and Arthur D. Little estimates.

socioeconomic, health and environmental perspectives. Disposable diapers gained the overwhelming majority of the market share almost overnight because consumers wanted them. They have provided substantial innovations with respect to the mobility and freedom of the infant caretakers and to the health of infants themselves.

The laundering of reusable diapers and the energy generation to support it result in impacts to resources that are significantly greater than the impacts from disposable diaper manufacture and use. Disposable diapers constitute a very small percentage of the nation's solid wastes. As such, they should not be singled out for unique consideration as post-consumer wastes, but rather should be treated as but one component of a much larger entity. Instead, as the Office of Technology Assessment notes in *Facing America's Trash* "a coherent strategy will be required to avoid the piece meal approach of past MSW (Municipal Solid Waste) policies," (U.S. Office of Technology Assessment, October 1989).

The growing concern over the management of certain specific post-consumer wastes -- such as used disposable diapers -- can only be put into the proper context through an analysis of life cycle concerns. In some cases, the use of disposable products could provide potential advantages over their replacement by reusable alternatives. In the case of diapers, specific human health, environmental and economic advantages would appear to outweigh the more limited advantages of reusable diapering materials.

II. Introduction

A. Background

Within the coming decade, initiatives already undertaken and others that are on the horizon will have a profound effect not only on how our solid waste stream is managed, but also on how consumers and industry make choices that affect the composition of these wastes. Many states are considering initiatives to promote reuse, recycling and resource recovery of solid wastes. Increasingly, the decision to use disposable rather than reusable products will be revisited. Recycling programs will be implemented or expanded, providing a significant increase in available recycled resources such as paper pulp, glass and plastics. Industry will be strongly encouraged to utilize these recycled materials in the production of a wide range of commercial and consumer products. Composting will provide an attractive means of managing solid wastes to produce a useful by-product. Waste-to-energy projects will find increasing support, as opposed to traditional landfill disposal methods.

With this in mind, the Procter and Gamble Company has commissioned this analysis of the relative environmental, health, energy and economic impacts of using disposable versus reusable diapers. The relative merits of these products are considered on a life cycle basis, i.e., from the point of raw material production through post-consumer waste disposal. It is only through such a life cycle analysis that a true, comprehensive comparison can be made.

The remainder of this section provides background information on disposable and reusable diapers, in particular, the history of their use, their characteristics and their markets. Section III provides an overview of the manufacturing operations for these products, while Section IV addresses their in-use management (i.e., laundering of cloth diapers) and disposal. These sections provide a baseline against which the environmental, health and economic analyses presented in Sections V, VI and VII, respectively, can be made. Finally, our results and conclusions are summarized in Section VIII.

B. Historical Perspective

For the purposes of this study, we focused on the general consumer. This means that the demographic segment of the population which we studied was the civilian, non-institutionalized segment. We analyzed only this population when considering consumer preferences and usage patterns.

Most of our population data have been derived from the *Statistical Abstract of the United States, 1989, 109th edition*, U.S. Department of Commerce, 1988. This source was chosen as a key resource for the development of population and labor force data because it is authoritative, and because it is readily available to those who may choose to consult it for additional information in the reference section of most libraries.

Whenever possible, we have used government sources as the source of our data. When more specific or timely information was needed, we have used trade publications which are known to provide good technical and marketing information.

Diapering with cloth, usually cotton, was the traditional approach to the management of infant incontinence in the United States. However, as the number of women participating in the labor force increased from 13.8 million in 1940 to 17.8 million in 1950 and to 22.5 million in 1960, the availability of women to manage the supplies necessary for cloth diapering decreased. Diaper services flourished during this period, and the market was ready for an innovation in the product.

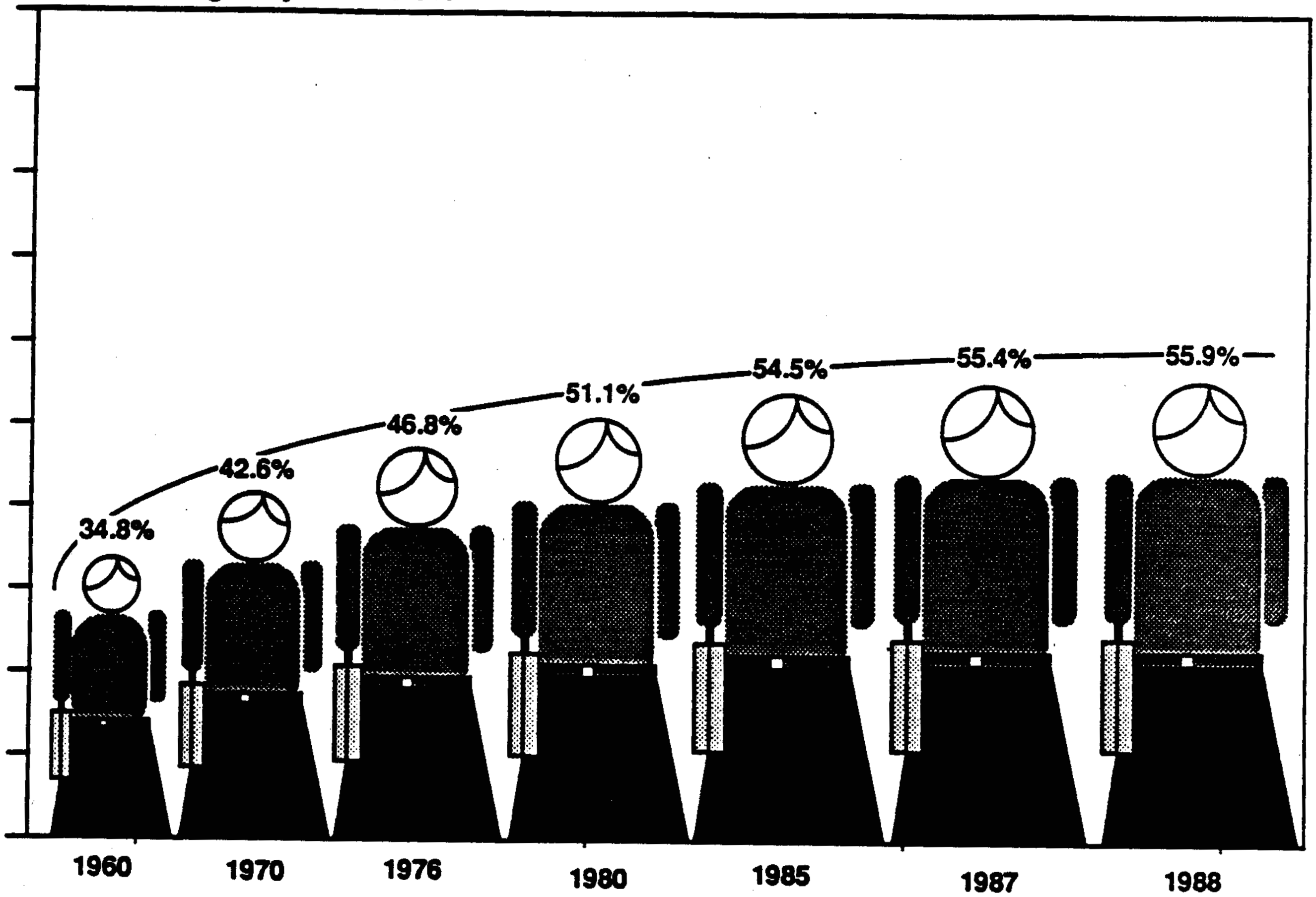
1. Societal Forces

With the change in attitudes about the acceptability of women in the labor force, especially in non-support positions, also came a change in attitude about how much time "good mothers" need spend on the care of their children. The emphasis shifted to the "quality time" concept rather easily. It became apparent that the dedicated mothers, and other family care givers, prior to this time did not feel a strong connection between how well their children developed as good citizens and how much time they spent scrubbing floors and doing hand laundry.

The disposable diaper was introduced to a population which was embracing the ideals of a new society: more white collar jobs, individual homes for nuclear families, modern clothes washers and dryers in every home, family cars, commuting to work, organized sports for grammar school age children, fast food, and the exercise of more individual discretion about the expenditure of time. Since the realization of these ideals also created counterbalancing stresses, any convenience that offered stress-relief was at least welcomed, and frequently accepted into a permanent place in our culture. The so-called "disposable society" did not just happen, it was created in response to some significant needs.

Women have remained in the labor force in significant numbers to enable their families to maintain at least the minimal standard of living acceptable in the postwar era. As can be seen graphically in Figure II-1, the percentage of the female population in the labor force jumped between 1960 and 1970, and has grown steadily ever since. More than 56 percent of the married women in the United States in 1988 were actively participating in the labor force. The concept of the wife working outside the home has become widely accepted and practiced. These women probably have less actual discretionary time available to themselves than before, however, because almost 55 percent of the married women in the labor force have one or more children under the age of three. The growth of this

Figure II-1: Female labor force as a percentage of the female population, age 16 years and over



Source: U.S. Bureau of the Census, Population reports as cited in the *Statistical Abstract of the United States 1989, 109th edition.*, U.S. Department of Commerce, 1988

group of workers since 1975 is shown in Figure II-2. In addition to the active participation of married mothers in the labor force, there are many more divorced and single mothers now in the labor force. Although data are not readily available to quantify their presence in the labor force in 1960, by 1970 45 percent of the separated women in the labor force had children under the age of six, as did 63 percent of their divorced counterparts. By 1987, these percentages of participation in the labor force had risen to 55 percent and 70.5 percent respectively.

One of the most striking changes that has occurred during the "baby boom" is the changing perception of the mobility of the child. Newborns can be observed in shopping malls throughout the country. Infants and toddlers are taken out to dinner to all types of eating establishments. Vacations are no longer postponed because of the recent birth of a child; in fact, the long distance first-visit-to-Grandma is happening earlier in the baby's life than ever before, especially since Grandma may have difficulty getting time off from her job to make the visit herself. This is partly a result of alterations in our thinking about the vulnerability of newborns and infants to threats to their health.

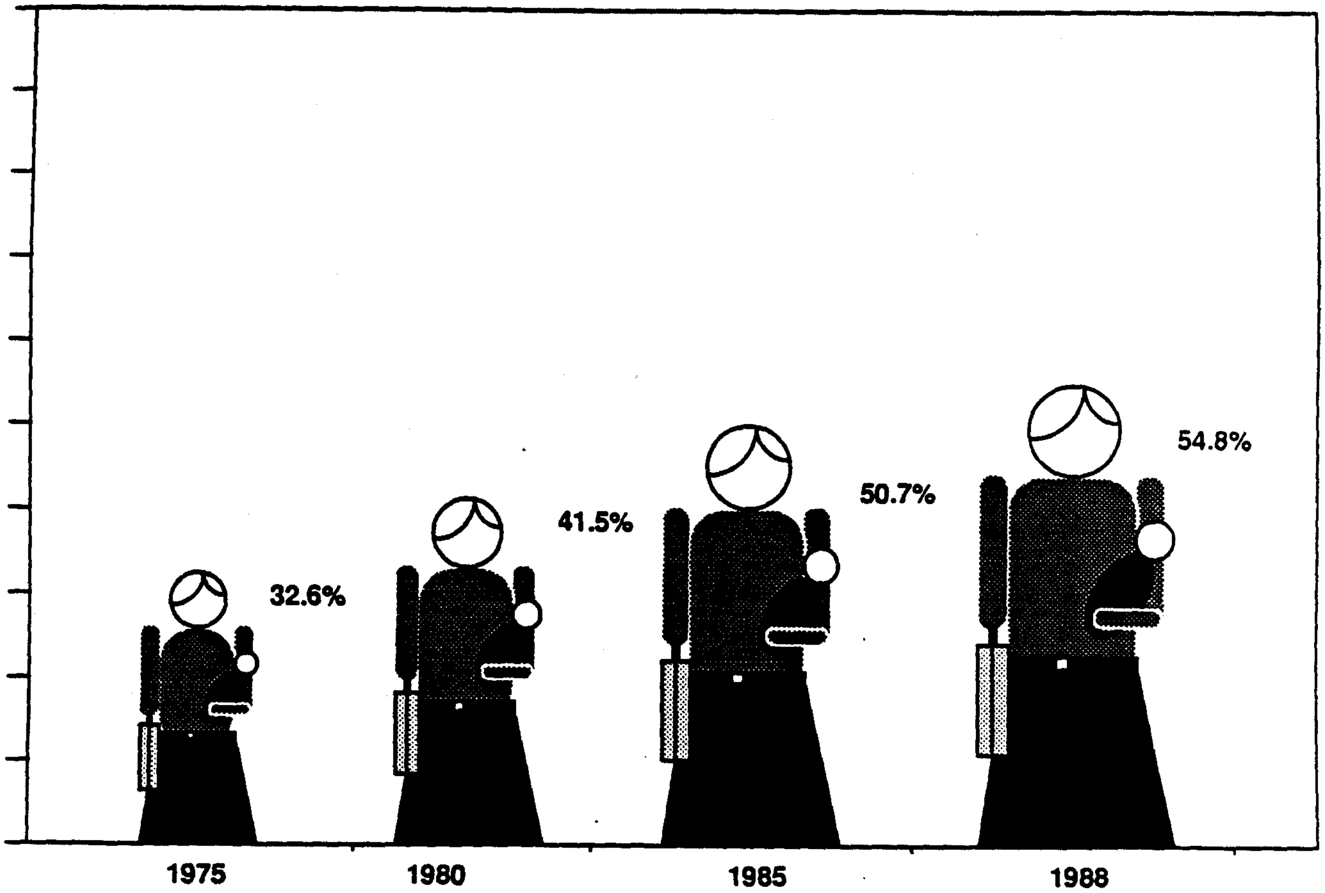
Another aspect associated with the increase in mobility of small children in the postwar society is the increase in the number of children cared for by others than their mothers and the changes in the nature of that care. In 1950, 12 percent of the women in the labor force had children under the age of six years, and by 1988 that segment of the labor force had increased to 57 percent. In 1965, 9.4 percent of preschool children were cared for by relatives, sitters, or family day care. By 1985, 51 percent of preschool children were cared for at day care centers, by sitters, or at family day care situations, and the percentage of care given by relatives had dropped from 62 percent to 48 percent.

These and other changing social characteristics of American society created a market for improved hygiene products of all types, and especially for the management of infant incontinence. Technological developments occurring at the same time enabled product designers to address these opportunities practically and successfully with new product introductions, including the disposable diaper.

2. Technical Developments

When looking at the social forces contributing to the rapid acceptance of this product, we must remember that there was also a call for the continual introduction of product modifications. Although these developments were made partly in response to competitive forces in the marketplace, the primary motivation was customer satisfaction, which is strongly dependent upon how well the product works. The primary driving force in the use of disposable diapers is the fact that they successfully manage infant incontinence.

Figure II-2: Percent of Wives in the Labor Force with One or More Children Under the Age of 3



Source: U.S. Bureau of the Census, Population reports as cited in the *Statistical Abstract of the United States 1989, 109th edition.*, U.S. Department of Commerce, 1988

An historical review of disposable diapers shows a steady focused effort to improve these products, in the competitive desire for consumer approval. The Scantrack (R) data in Figure II-3 illustrates clearly direct correlation between product introductions and improvements and consumer response in the marketplace. A reduction in product weight and volume (bulk) has also been brought about through material refinements and the introduction of new materials in disposable diaper construction. Every major material component of the disposable diaper has been modified to the point where an overall reduction of 50 percent of diaper volume has occurred for some products in the last three years alone.

The initial disposable diapers were relatively unsophisticated products constructed of cellulose pulp and tissue. Since the first U.S. disposable diaper patent was issued to Procter and Gamble in 1961, a steady stream of product improvements has followed, as shown in Table II-1. Clearly, the evolution of these products has been rapid and responsive to consumer needs. Moreover, the product changes have had the added advantage of substantially reducing post-consumer diaper wastes, which is a significant environmental improvement.

C. Characterization of Diapers

1. Disposable Diapers

The major producers of disposable diapers in the United States are Procter and Gamble (Pampers and Luvs), Kimberly Clark (Huggies) and Weyerhauser (private brands). Additionally, Rocky Mountain Medical (Tender Care), Dafoe & Dafoe (Nappies) and others distribute diapers labeled as biodegradable. As Table II-2 illustrates, diapers are sold in a wide range of sizes and quantities per package. As a rule, package quantities reflect a typical week's usage for the size and age of the child. For example, a newborn will require more frequent changes than an older child; therefore, the quantity will range from 60 per package for small diapers to 28 for extra large. Recently, manufacturers have introduced larger economical packages which would provide more than a typical week's usage.

a. Diaper weight. Table II-3 illustrates the average weight of each diaper size, average weights by brand of diaper, and average packaging material weights. There are considerable differences in weights of individual diapers, both between brands and among diapers within a brand category. The newer "ultra"-style diaper uses absorbent gelling material to minimize the thickness of the diaper and maximize absorbency and containment. The overall weight of this style of diaper is considerably less than "regular" and "thick" styles. Also noticeable are differences between private and "biodegradable" brands, one of which was drastically heavier than the others, and one of which was not too far off the average. The average diaper weight, taking these factors into account and weighing the average by market share and percentage of diapers sold by size

Figure II-3: Market Responses to Diaper Improvements

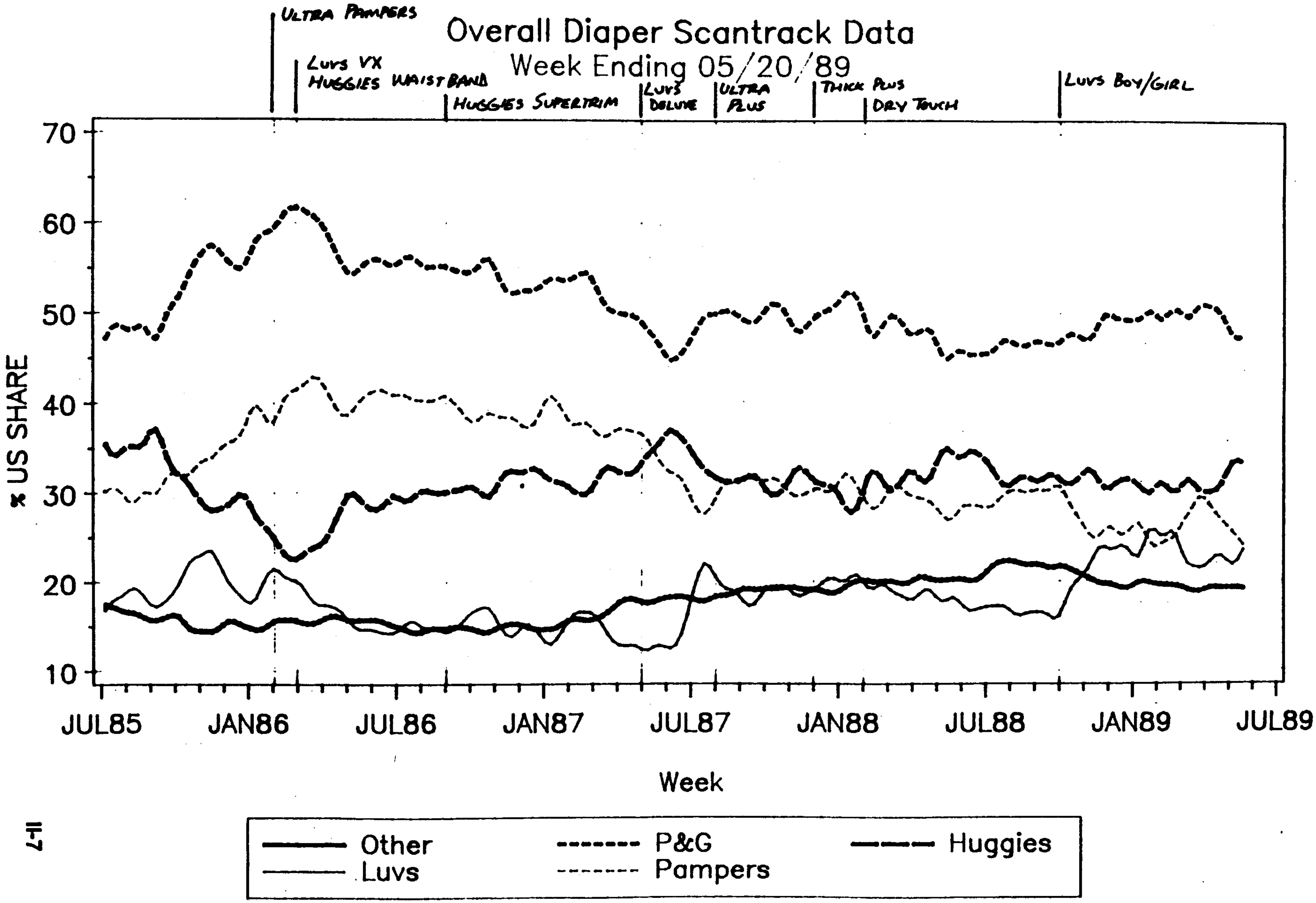


Table II-1: Significant Disposable Diaper Developments

1961	-	Procter and Gamble applies for disposable diaper (Duncan) patent
1965	-	Pampers Disposable Diaper patent issued (Duncan-first wing fold diaper)
1974	-	Improved taping system patent issued • One-piece tape • Reduced polyethylene usage
1975	-	Improved design patent issued • Leg cutouts - reduced backsheet, topsheet, and core material usage • Elasticized leg portion of diaper - improved containment
1979	-	Kimberly-Clark introduces leg elastic diaper, Huggies
1980	-	Procter and Gamble introduces elasticized legs in Luvs product
1982	-	First Absorbent Gelling Material use in Japanese diaper products
	-	Procter and Gamble introduces elasticized legs in Pampers product
1983	-	Procter and Gamble introduces Pampers product with extra absorbency and refastenable tape
	-	Kimberly-Clark Huggies product introduced with refastenable tape
1984	-	Procter and Gamble Luvs product introduced with elastic waist - superior containment
1985	-	Procter and Gamble introduces Pampers with waistshield and improved shape - containment improvements
1986	-	Procter and Gamble patent issued for Absorbent Gelling Material
	-	Pampers introduced with Absorbent Gelling Material • Reduced the volume of the materials used in diaper manufacturing by about 50 percent • Improved absorbency
	-	Procter and Gamble patent issued for an improved gluing process to reduce the amount of glue used in diaper manufacture
	-	Procter and Gamble Luvs and Kimberly-Clark Huggies introduced with Absorbent Gelling Material

Table II-1: Significant Disposable Diaper Developments (continued)

1987	-	Procter and Gamble patent issued for improved core design • Reduced airfill further (fewer materials used) • Dual layer design for improved performance (Absorbent Gelling Material in layer closer to backsheet)
	-	Procter and Gamble Luvs gender specific products introduced
1988	-	Procter and Gamble Pampers product in polybag introduced • Change from fiberboard cartons significantly reduces packaging materials per diaper, from 0.018 pounds per diaper of fibreboard material to 0.002 pounds per diaper of polyethylene material
1989	-	Procter and Gamble issued Luvs gender specific patent - more effective placement of absorbent materials in zones

Table II-2: Survey of Diapers

Description		Diaper Sizes	Small	Medium	Large	X-Large
		Pounds	6-14	12-24	23 +	27 +
Pampers	Ultra Plus	Count:	24 **60**	**18,44** 48,87	12,32 64	**28**
	Thick P Plus		--	**48**	22-35 lbs.	--
	Regular Absorbtion		--	**48**	32	--

Description		Diaper Sizes	Small	Medium	Large	X-Large
		Pounds	Up to 14	12-24	22-35	30+(lbs.)
Huggies	Supertrim	Count:	60	**44,88**	32,64	28
	Thick			**44**	33	--
Luvs	Deluxe Girl (G) Boy (B)		66	**44**	32	27+lbs. 28
OSCO Brand	Extra Absorbent Extra Thin			48,96	20-32 lbs. 32,64	
	Regular Absorbent			48	24+ lbs. 33	
	Elastic Leg Extra Absorbent				24+ lbs. 28	
	Diaper Doublers (40 Count)					

Bold Count Sizes = Purchased for Lab Analysis

Table II-2: Survey of Diapers (continued)

Description			Diaper Sizes: Small	Medium	Large	X-Large
		Pounds	6-14	12-24	23 +	27 +
Nappies	Biodegradable	Count:	--	**44**	--	--
Bradlees Brand (Distribution Stop N Stop)	Ultra thin		66	48		

Description

Cloth diapers which are:

- prefolded
- "flat"

Dundee Birdseye	-	12 Count
Curity Gauze Weave	-	12 Count
Soft Care Birdseye (Also Curity)	-	12 Count

Bold Count Sizes = Purchased for Lab Analysis

Table II-3: Diaper Total Weights, in Pounds

Brand	Small	Medium	Large	X-Large	Simple Wtd. Avg.[1]	6/89 ~Mkt. Share[2]	Actual Wtd Avg.[3]	~Avg. Diaper/ Pkg. Weight[4]	% Corr.[5]
Huggies BLC Supertrim	.077	.115	.135	.149	.123				
Huggies Softwaist Supertrim	.079	.120	.138	.154	.126	27%	.125	.015	85%
Huggies Thick	.097	.127	.143 est.		.134	7%	.134	.015	83%
Weyerhauser DFS "Ultra"		.122	.135		.128				
Drypers Ultra		.125	.134	.145	.130				
Cozies Ultra		.115 est.	.130		.122 est.	19%	.130	.015	85%
Tendercare Bio	.090	.136	.151	.171	.150				
Nappies (Bio)		.111	.125 est.		.118				
Pampers (Ultra)	.060	.097	.107	.119	.100	21.5%	.100	.013	84%
Pampers - Regular		.099	.111 est.		.104 est.	2%	.104	.032	56%
Thick Pampers Plus		.128	.143 est.		.135 est.	2%	.135	.043	47%
Luvs - girl		.113	.127 est.		.119	21.5	.120	.032	46%
Luvs - boy		.115	.129 est.		.121				
Total Avg. (Not wtd. by mkt. share)	.081	.116	.130	.148	.121	100%	0.120*	.019	81.5%

Table II-3: Diaper Total Weights, in Pounds (continued)

Footnotes:

1. Simple Weighted Average

   Calculated by weighting small, medium, large, and X-large diapers by percent sold, which was determined in a Procter & Gamble market survey of 9,834 babies.

2. Market share, as of 6/1/89, as recorded by Scantrack.

3. Actual weighted average within Brand is calculated by averaging the diapers having the same brand name, and weighting this average by market share. The private brands and claimed biodegradables were considered "other" in the Scantrack data.

4. Approximate average package weight per diaper in grams. (Some estimations were used where complete data were not available.)

5. Percentage of packaging per diaper which is corrugated fibreboard material. Approximately 50 percent of all corrugated boxes are recycled** and most corrugated containers use approximately 10 percent recycled material in initial manufacture.

* Average diaper weight including those labeled Biodegradable.

** Reference: (API 1988, 1989)

category, is 0.120 pounds. For the purposes of this report, this is the number which will be referred to whenever we are discussing the "average disposable diaper".

b. Diaper composition. This "typical diaper" is manufactured using numerous materials, including pulp, absorbent gelling material, tissue, polyethylene film, polypropylene nonwoven material, tapes, elastics, and adhesives.

The materials used vary in composition and proportion between different diaper styles and manufacturers. These materials and combinations are the key to diaper manufacturing, ongoing containment improvements, competition between brands, and reductions in materials usage and waste. This has been the primary focus of developments and improvements. The result has been a continually improving product for the consumer. At the same time producers of the product have reduced the amount of material used, reduced their contribution to solid waste from their factories, and reduced the amount of diaper material for the consumer to discard.

Figure II-4 illustrates the percentages of each component by weight in the "typical" "ultra"-style diaper, that is, those which utilize the absorbent gelling materials.

c. Packaging. Disposable diapers are packaged in either polyethylene bags or fibreboard boxes. Polyethylene bags began to be used to package disposable diapers in 1988 and quickly became the package of choice. Consumers quickly accepted the package for its lighter weight and greater convenience. It is more flexible for transporting, the handle is easier to grip in combination with other shopping items, and the bag collapses as the diapers are used, which makes it easier to identify the number of remaining diapers. The trend is toward packaging of all diapers in polyethylene bags, although at present 75 percent of diapers are packaged in polyethylene bags and 25 percent in fibreboard boxes.

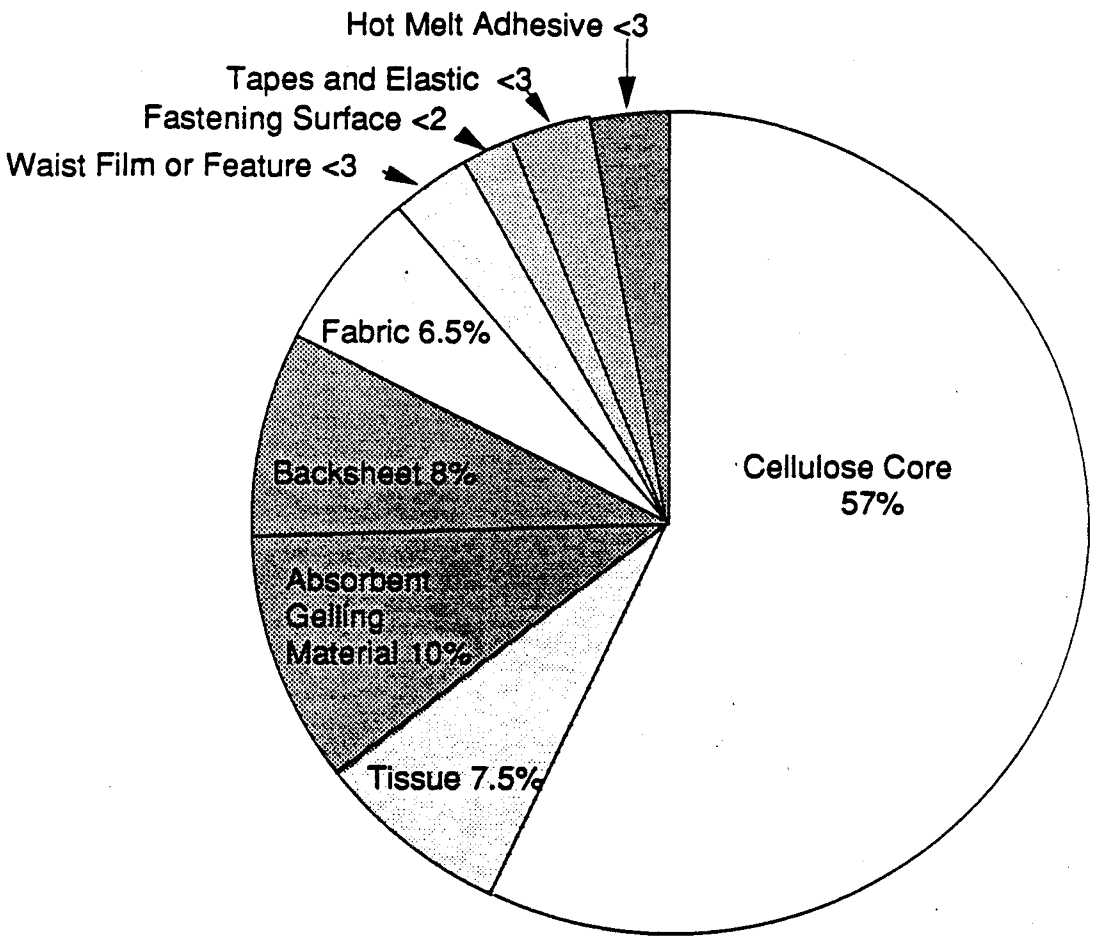
Diaper packaging also includes corrugated shipping containers which typically contain four to six salable units of diapers. This secondary packaging adds considerably to the total packaging used in the transportation of diapers. Of the total weight of the packaging on a per diaper basis, the corrugated shipping container comprises 81.5 percent of the package weight, on average.

The average packaging weight was derived in the same manner as the typical diaper weight. It takes into account differences between and among brands, as well as market shares. The average packaging material per diaper weighs 0.019 pound, 81.5 percent of which is the corrugated material. Although the corrugated board contributes a majority of the packaging weight on a per diaper basis, it is recycled at a much higher rate than the other packaging materials in this study. Most consumers dispose of the primary packaging materials in which the diapers

Table II-4: Reusable Diaper Weights

Diaper	Lbs/Diaper	Market Share	Package	Lbs/Diaper	Other
Birdeye:					
Dundee-flat	0.096	62%	Prefolded:		
Curity-flat	0.102		plastic:	0.0015	Diaper Pail:
Curity-prefolded	0.130		corrugated:	0.0119	0.0004 lbs/
				0.0134	diaper
Other:					
Curity-prefolded	0.132	28%	Unfolded:		
Curity-flat	0.100		plastic:	0.001	
			corrugated:	0.0095	
				0.0105	
			Service:		
			plastic:	0.001	
			return trip		
			plastic:	0.0008	Plastic Pants:
				0.0109	0.00004 lbs/
					diaper
Overall Average Diaper Wt:	0.13 lbs		Average:		
			plastic:	0.0012	
			corrugated:	0.0097	
				0.0109	

Figure II-4: Disposable Diaper Components



are sold through their normal solid waste stream, while most stores recycle some or all of the secondary corrugated packaging material. Approximately 40 percent of all post-consumer corrugated board in this country is recycled. (API, 1988 and 1989)

A "composite" package of 75/25 polyethylene and fibreboard is used, when appropriate, for calculations of solid waste streams. On a per week usage basis, this typical composite diaper package would consist of 0.039 pounds of polyethylene, 0.118 pounds of paperboard, and 0.7 pounds of corrugated board.

For purposes of simplicity, in some discussions in this report we will use an either/or scenario (fibreboard or poly bags) for the alternative packaging materials, rather than the less realistic combination of the two packaging materials.

In addition to the added convenience of the polyethylene bag from the consumer's point of view, there have been many other advantages of recent packaging changes. Not the least of these is the tremendous reduction in total packaging material usage resulting from the change to poly bags. This is a greater than 87 percent reduction in material by weight, and an even greater reduction by volume. Although plastics tend to be targeted for their apparent environmental unfriendliness, no practical difference in degradability exists between plastic and fibreboard in a landfill environment. Therefore weight and volume reductions are the most helpful actions that can be taken from a solid waste point of view.

Another packaging improvement was the change to compression packaging of disposable diapers in both plastic and fibreboard. This has reduced the amount of packaging material used, as well as cut transportation costs because of significantly reduced bulk.

2. Reusable Diapers

Reusable diapers, more commonly known as cloth diapers, also are manufactured in a variety of types and sizes. Although essentially all reusable diapers are cotton, several different fabric weaves are available, including Birdseye, flannel, taffeta, and gauze weaves. The most popular and well-known of these is the Birdseye weave. Sixty-two percent of all diapers sold are the Birdseye weave, 10 percent are a heavy weave sold exclusively to diaper service companies, and the remaining 28 percent of diapers are "other" weaves. Of all cloth diapers manufactured, roughly half are 27 inches by 27 inches and the remainder percent are prefolded and stitched to a size of 14.5 inches by 20.5 inches. The majority of cloth diapers has been imported from China in recent years.

a. Diaper weight. As Table II-3 illustrates, prefolded diapers weigh considerably more on average than flat diapers, and the service diapers (which are also prefolded) are more than twice as heavy as the average flat diaper. The "typical"

Table II-4: Cotton Diaper Weights

Diaper	Lbs/Diaper	Market Share	Package	Lbs/Diaper	Other
Birdeye:					
Dundee-flat	0.096	62%	Prefolded:		
Curity-flat	0.102		plastic:	0.0015	Diaper Pail:
Curity-prefolded	0.130		corrugated:	0.0119	0.0004 lbs/ diaper
				0.0134	
Other:					
Curity-prefolded	0.132	28%	Unfolded:		
Curity-flat	0.100		plastic:	0.001	
			corrugated:	0.0095	
				0.0105	
			Service:		
			plastic:	0.001	
			return trip plastic:	0.0008	Plastic Pants: 0.00004 lbs/ diaper
				0.0109	
Overall Average Diaper Wt:	0.13 lbs		Average:		
			plastic:	0.0012	
			corrugated:	0.0097	
				0.0109	

cloth diaper was determined using the same criteria as the disposable average, involving different styles and market shares. The typical reusable diaper weighs 0.13 pound.

b. Packaging. The packaging of reusable diapers typically consists of 12 diapers, regardless of size or weave, in a heat-sealed polyethylene bag. Twelve of these packages are usually contained in a corrugated shipping container for distribution to stores. The service diapers are sold in larger bulk quantities to the diaper service companies, but this comprises only about 10 percent of the reusable diaper market (Lehrberger, 1988). For the purposes of this study, the same packaging is assumed for service diapers as for consumer diapers.

The average weights of the polyethylene bag and the corrugated container are 0.0012 pound and 0.0097 pound, respectively, on a per diaper basis. On a per week basis, using a weighted average between consumer and service diapers (service cloth diapers use considerably more plastic on a weekly basis than consumer-purchased diapers because they are transported back and forth in plastic bags for laundering), the packaging material consists of 0.008 pound of polyethylene and 0.009 pound of corrugated material. As discussed above, the corrugated material is recycled at a rate of 40 percent, while the majority of the polyethylene bags are disposed of in the solid waste stream.

c. Other materials. Additional materials required when using cloth diapers are the diaper pail, liners for the pail, and, typically, plastic pants (although pants made of other materials exist). A plastic diaper pail lasts an average of one to two years, so an average of two pails are required over the diapering life of a child. This is included in Table II-4, allocated on a per diaper basis of 0.0004 pounds per diaper.

Diaper pail liners are used in the pail in the case of a diaper service because the diapers are typically returned in the bag in which they were delivered. The clean diapers are removed from the plastic bag, and the bag is inserted into the pail. When diapers are used without a service, diapers are discarded either into a pail or into a garbage bag pail liner for ease of transport to the laundry area. In the case of service and home laundering use, this bag averages to 0.0008 pound of polyethylene material per diaper use.

Some type of moisture proof pant is required when using cloth diapers for the purpose of urine containment. This is usually best accomplished with urethane coated nylon pants, which have elastic legs. Over the diapering life of the child, between six and ten plastic pants are required, considering approximately two to three plastic pants per size range (i.e., small, medium and large) of the child.

D. Diaper Market Characteristics

The infant diaper market is defined by the characteristics of the consumers, who represent two groups, infants and care givers. Market size is limited by the number of children of diapering age (typically, newborn to 30 months). Positioning of the various types and brands of diapers is determined by the choices made by the care givers. However, these are not the only characteristics to be considered when evaluating the diaper market and its future. In addition to the influence of these consumer forces, this section will also consider the effects of competition among the manufacturers and the influence of the retail trade on the market.

1. Infants

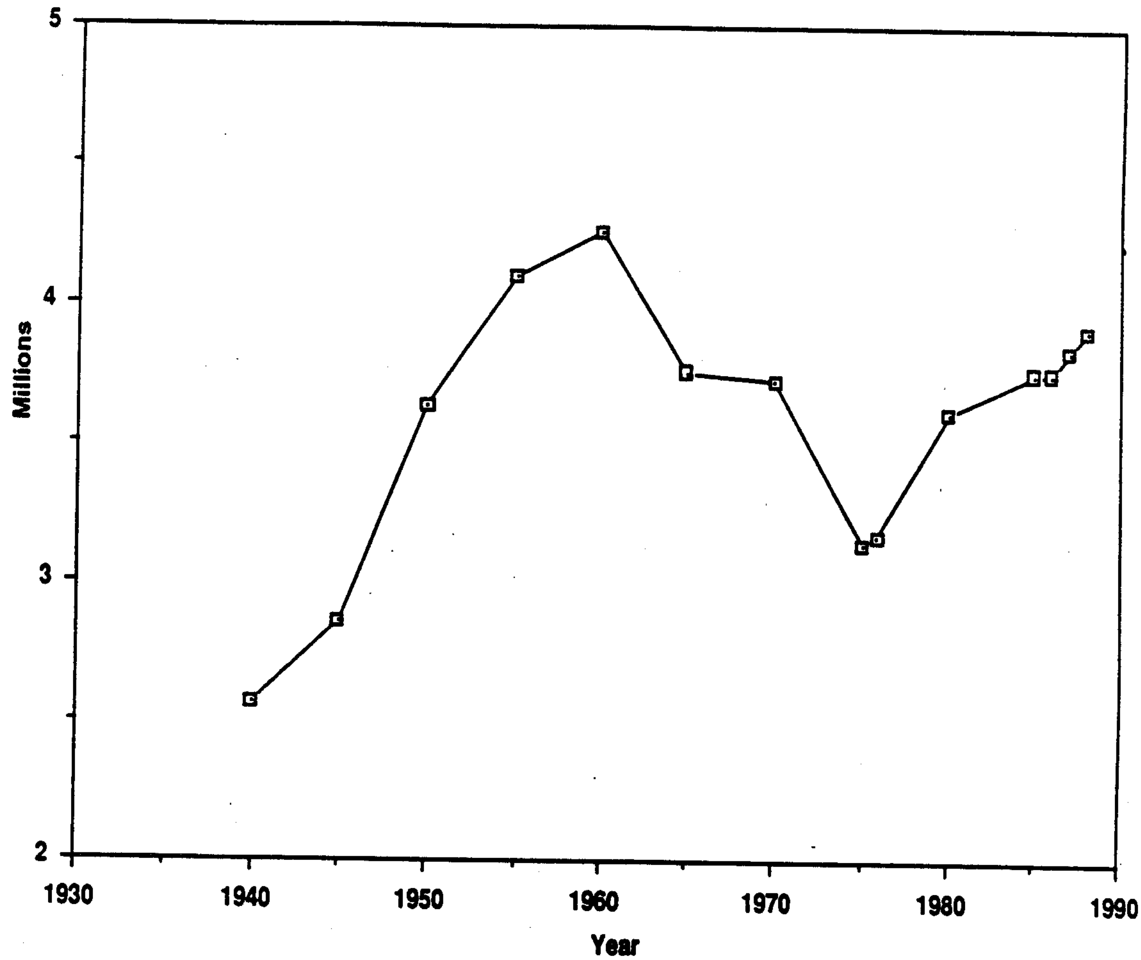
Diaper manufacturing is considered a mature industry based on the degree of market saturation by the existing products. For all practical purposes, 100 percent of the babies in the United States are diapered. Thus, the number of babies is the major driving force in the diaper industry. As shown in Figure II-5, the number of births in the United States has fluctuated widely in the last 48 years.

Although there are examples of children who are extraordinarily resistant to toilet training and examples of children who have developed sufficient sphincter control to be toilet trained at a very young age, the duration of the diapering period is, on average, 2.5 years (30 months). The diapering needs of this population declines throughout this period. Newborn infants require approximately nine or ten diaper changes a day and babies of two to four months require about eight changes. During the period of six to 17 months, the diapering demand fluctuates around seven changes per day, and really can't be expected to drop to six changes until the ages of 18 to 23 months. Around the time of the second birthday, the demand for diapering is steadily reduced until it is not required at all. Throughout the child's diapering period, the average number of daily diaper changes is approximately 6.4.

One thing that should be noted when considering the number of changes per day is that they are not solely tied to the number of times the baby urinates or defecates. There are a number of changes that are more event-driven than need driven. Examples of event-driven changes are those that occur when the baby is being bathed or prepared for bed, as well as before leaving the house. Although data indicate that cloth diapers are changed more frequently due to decreased absorbency, the analyses in this report assume equal change frequencies.

For whatever reason, diaper changes do occur and represent a substantial market opportunity. It is estimated that 85 percent of these diaper changes are satisfied through the use of disposable diapers, and therefore represent a 1987 market of approximately 18 billion units. The reusable diaper market is estimated at 6.2

Figure II-5: Live Births in the United States



Source: U.S. Bureau of the Census, Population reports as cited in the *Statistical Abstract of the United States 1989, 109th edition.*, U.S. Department of Commerce, 1988

Source for 1987 & !988 data: National Center for Health Statistics

pg3/90fcn

Arthur D Little

billion in 1987, because spokespersons for the reusable diaper industry estimate that, on average, babies use approximately 12 reusable diapers per day throughout their diapering cycle. Although there are indications that reusable diapers are changed more frequently because they are comparatively less absorbent, we used 6.4 as the average number of changes per day for both reusable and disposable diapers.

Another influence the baby population exerts on the diaper market is specific to their individual physical characteristics: each baby has its own pattern of need for containment, its own special shape, and its own type of skin sensitivity. Although these needs can be standardized in the aggregate, anyone familiar with diapering a baby can attest to the variation. These variations contribute to the market dynamics which have brought us prefolded cloth diapers, as well as super absorbent and gender-specific disposable diapers with improved waist bands and elasticized legbands. The refastenable tape has eliminated the waste associated with unnecessary changes. Previously, "checking" on the need for a change in diaper resulted in the destruction of a certain number of clean diapers.

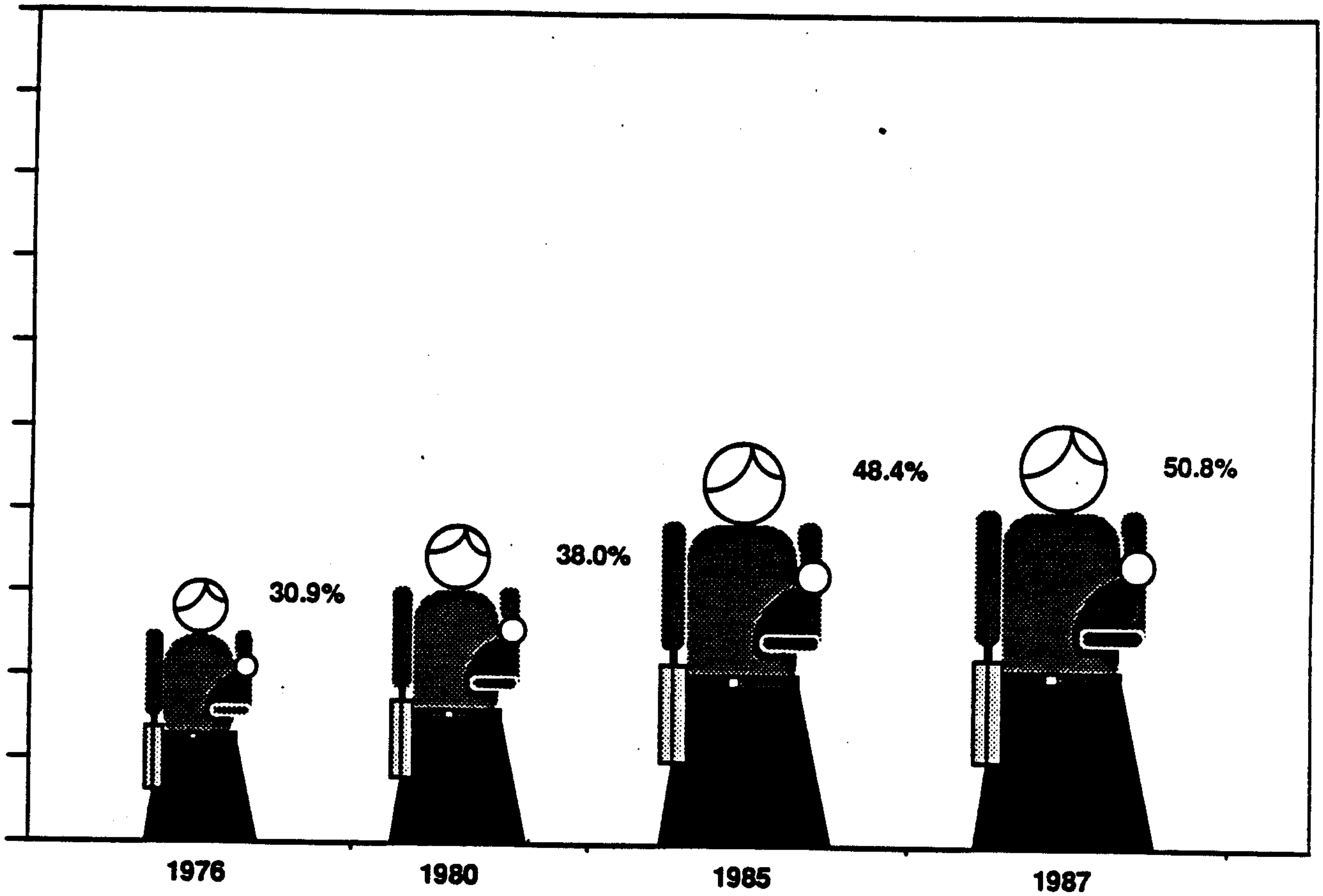
2. Care Givers

It must be recognized that the time required to deal with the diapering needs of children is a primary motivation of the care givers. These people represent the major influence on the purchasing consumer, and they know that the containment effectiveness of the disposable diaper significantly reduces the demands on their time. Cloth diapers are more difficult to handle; pins are dangerous, and children who are diapered in cloth more frequently require a complete change in clothing and bedding (Lehrberger, 1988).

While the number of children requiring diapers may define the market in absolute terms, the birth rate is not solely responsible for the success of the disposable diaper. It is probable that the major driver of this market is the changing character of the labor force. The increased participation of women in the labor force, particularly women with children, has had a significant effect on the amount of available time they have to spend attending to diapering needs. Their rising expectations for the quality of life and increases in the amount of discretionary income available have also been influential in the growth of this market.

In 1950, 30 percent of the labor force were women. By 1988 this percentage had increased to 55.9 percent. Women with children under the age of six represent one of the largest growth categories in the labor force, having grown from a 12 percent participation rate in 1950 to about 57 percent in 1988. As can be seen from the Figure II-6, these women are also extending the time they spend in the labor force by remaining in the labor force when they have very young children at home.

Figure II-6: Percent of Women in the Labor Force Who Have Had a Child Within the Last Year



Source: U.S. Bureau of the Census, Population reports as cited in the *Statistical Abstract of the United States 1989, 109th edition.*, U.S. Department of Commerce, 1988

To understand the context within which care givers are making decisions about diapering methods, it should also be noted that these increases in the number of women with children participating in the labor force are also taking place at a time when more married mothers are working. The traditional American household of a married couple with children and one parent in the labor force represented fewer than 10 percent of the households in 1988. As can be seen in Figure II-2, significant changes have taken place in this category even within the last 13 years.

Mothers have accepted the use of disposable diapers with a minimum of societal pressure. The association of the term "good mother" with the use of cloth diapers crumbled rapidly when successful containment was demonstrated. Hospitals recognized that disposable diapers did not adversely affect good skin care, took advantage of their time-saving feature, and sent newborns home with a supply of disposable diapers. Not only are disposable diapers perceived to be beneficial to the child, but many care givers believe that they are more sanitary since there is less leakage than with cloth diapers and they require less handling during changing and disposal.

The diaper age children of these working mothers are cared for by people to whom they are unrelated in more than 60 percent of the instances. Although it may be possible to convince a relative that it is important to manage a supply of clean cloth diapers, monitor the need for changing, spend the extra time required for the actual diapering with cloth, and to deal with the soiled cloth diapers and other clothing, it is very difficult to find other care givers who will provide that level of attention to this particular task. In a survey of 11 licensed day care centers operating in the metropolitan Boston area, six said that they were willing to accept children in cloth diapers, and five said that it was the policy of the center or its parent chain not to accept children in cloth diapers. In practice, none of the day care centers had any children in cloth diapers.

In terms of the environmental implications of using disposable diapers, *The Gallup Poll: Public Opinion 1988* (Scholarly Resources, Inc., 1989) showed that while 41 percent of the respondents were "extremely concerned" about garbage and trash disposal, this concern was most dominant in adults over 50 years of age. The population dealing with children in diapers is concerned, but indications are that in general they do not actively consider the implications for the solid waste stream when deciding how to deal with infant incontinence.

Speaking generally, the implication of the changing status of women in the labor force is that they have less time to spend as care givers and feel stressed because of it. They have embraced the convenience offered by such technological advances as the microwave oven and the disposable diaper because those technologies shorten the time required to conduct necessary tasks and simultaneously allow them to maintain an acceptable level of quality.

A. Disposable Diaper Production

Disposable diapers are produced from materials commonly used in the manufacture of a variety of consumer products. This section describes the basic manufacturing processes for disposable diapers and their principal components, providing the necessary background information for the life cycle environmental impact analyses that follow.

1. Pulp and Tissue

a. Manufacturing process. The major components of disposable diapers are paper products produced from natural cellulose derived from wood. Disposable diapers are but one of many products that incorporate fluff pulp and tissue derived from wood pulp and account for the consumption of much less than one percent of the pulp manufactured in this country. When pulp is manufactured from logs in a typical process, the principal wood components are separated. Approximately half of the wood is water, the bulk of which is released to the environment as water vapor or waste water when pulp is manufactured. One third of the solid wood constituents is ultimately converted to pulp, while the bulk of the remaining materials, including bark, irregular wood chips and lignin, are burned to recover energy.

In pulp manufacture, logs are harvested and delivered to the mill for processing. The bark is removed from the logs, and the remaining wood is cut into small, uniform-sized chips in preparation for pulping. The bark and any irregular chips are waste materials representing up to 15 percent of the raw wood used in pulp manufacture. These wastes are burned to generate steam for the pulping process or for electric power generation.

The wood chips are "digested" to segregate the cellulose pulp fibers from the lignin that binds them together. This is achieved by steaming and soaking the wood chips under pressure with a hot water-based digestion solution. The chemicals in the solution cause the lignin to be separated from the cellulose fibers and dissolved in the water. At the culmination of the digestion process, the lignin-rich solution is drained from the pulp and is sent to a recovery unit. The residual pulp is washed, generating nearly 3.5 gallons of waste water per pound of pulp manufactured.

A portion of the cellulose wood chips will not be completely processed at the conclusion of the digestion process. These residual wood chips are too large to be incorporated in a finished paper product and will be recovered and reprocessed in the digester. Certain fibers are smaller in size than required for fluff pulp manufacture and must be removed.

The lignin-rich digestion solution contains a variety of chemicals. By-products, such as turpentine and soap, can be recovered from the solution. A typical fluff pulp mill recovers approximately 0.04 pounds of turpentine and 0.11 pounds of soap per pound of pulp produced. Water is also recovered and reused. The remaining material, which is primarily lignin, is burned in a boiler to generate steam and a solid residue comprised of chemicals used in the digestion process and some impurities. The impurities are segregated and disposed of as a solid waste.

The digesting solution is a complex mixture of chemicals that is produced at the pulp mill. Recovered chemicals are recycled and reused in the digestion solution. Since no recovery system is completely efficient, new components must be produced at the pulp mill by a series of chemical reactions. A by-product of these reactions is recovered and converted to lime, another chemical in the digestion solution. The lime is produced in a combustion system such as a calciner or a kiln.

The pulp leaving the digester must be purified with bleach to provide pulp that is highly water absorbent. Enhanced water absorbency characteristics are obtained by the removal of various hydrophobic substances, such as fatty acids, resin acids and triglyceride compounds. Bleaching is also used to remove lignin, resulting in whiter pulp. The pulp may be treated with oxygen, a brightening agent, in addition to the common bleaching chemicals, chlorine dioxide and chlorine. The chlorine dioxide and chlorine used for pulp bleaching are also produced at the pulp mill. Approximately 0.04 pounds of a by-product, sodium sulfate, are generated per pound of pulp produced. A portion of the by-product is used in the digestion process, and the remainder can be sold for other purposes. The chlorine dioxide/chlorine production unit produces gases that must be vented to the atmosphere. These gases are treated to remove over 99 percent of the chlorine and chlorine dioxide prior to being discharged. The bleaching process generates approximately two gallons of waste water per pound of pulp manufactured.

The pulp is suspended in water as it leaves the bleaching operation. The pulp suspension flows over a fine mesh screen, allowing the water to drain from the fibers, leaving a pulp mat. The mat is pressed and formed into a sheet prior to being dried. The paper is first placed on a large roll and subsequently cut and wound into smaller rolls that are appropriate for shipment. The water recovered from the paper forming and drying operation is reused in the pulp manufacturing operation.

b. Water discharges. Waste water from the digested pulp washing and bleaching operations accounts for over 99 percent of the waste water generated in fluff pulp manufacture, with sanitary waste water and runoff comprising the remaining waste water. With proper treatment, the waste water's Total Suspended Solids (TSS) content and biological oxygen demand (BOD) can be reduced to 0.002 and 0.001 pounds per pound of pulp produced, respectively. Color, which has limited environmental consequences, with the exception of aesthetics, is also released with treated waste water.

c. Solid wastes. As a matter of economic prudence, fluff pulp manufacturing facilities incorporate provisions for energy recovery from combustible non-hazardous solid wastes. The bark, undersized wood chips, and lignin are commonly burned to supply over 90 percent of the pulp mill's energy requirements. Fossil fuel consumption is relatively low and is on the order of 0.009 gallons per pound of pulp produced.

No hazardous solid wastes are produced as a consequence of fluff pulp manufacture. Non-hazardous solid wastes that are disposed of include ash from the energy and chemical recovery boilers, impurities removed in the digestion chemical recovery system, sludge from waste water treatment, and oversized wood chip wastes which are commonly disposed of in landfills at the pulp manufacturing site. Alternatively, the combustible wood chip waste could be incinerated. The solid waste generation rates are noted in Table III-1.

Table III-1: Solid Waste Generation From Fluff Pulp Manufacture

Solid Waste	Generation Rate (pounds/pound pulp)
Oversized Wood Chip Wastes	0.10
Waste Water Treatment Sludge	0.05
Ash from Boilers	0.04
Impurities from Chemical Recovery	0.01
Total	0.20

d. Air emissions. Air pollutants are discharged from the boilers and the chemical generation and recovery units. Air emissions from a typical fluff pulp production facility are summarized in Table III-2.

Table III-2: Air Emissions From Fluff Pulp Manufacture

Air Pollutant	Emission Rate (pounds/pound pulp)
Sulfur Dioxide	2×10^{-3}
Particulate Matter	1×10^{-3}
Nitrogen Oxides	1×10^{-3}
Chlorine Dioxide	2×10^{-4}
Methanol	5×10^{-5}
Total Reduced Sulfur	3×10^{-5}
Chlorine	3×10^{-5}
Acetone	3×10^{-6}

2. Absorbent Gelling Material

The absorbent gelling material used in disposable diapers is a polyacrylate gel produced by the polymerization of acrylic acid using a cross-linking agent. This section provides a model of the absorbent gelling material production operation. It is followed by a description of the acrylic acid production process.

a. Polyacrylate Gel.

(1) Manufacturing process. Acrylic acid is the primary raw material used in the manufacture of polyacrylate gels; approximately 0.83 pounds of acid are required for the manufacture of a pound of absorbent gel. The absorbency of the gel is increased by neutralizing a portion of the acid with sodium hydroxide (0.23 pounds per pound of product) prior to forming the polymer. The resulting acrylic acid/sodium acrylate mixture is dissolved in water, forming a solution that is approximately three parts water and one part acrylic acid/sodium acrylate. The water is given off when the subsequent polymerization operation is undertaken. Considering all cooling water used in the process, approximately 16 pounds of cooling water are used to produce a pound of absorbent gelling material. The polymerization is started by the addition of an initiator compound. A cross-linking agent is also added to produce the desired polymer structure. The cross-linking agent is typically proprietary to a specific manufacturer. Approximately 0.001 pounds of initiator and 0.03 pounds of cross-linking agent are consumed per pound of absorbent gelling material produced. The polymer is dried and recovered as a

powder. The powder is then melted, formed into pellets, and packaged into bags or drums. There are negligible amounts of acrylic acid in the final polymer.

(2) Water discharges. Waste water is recovered from the absorbent gel dryer. This waste water contains some amount of residual sodium acrylate and acrylic acid, along with trace impurities from the acrylic acid (e.g., formaldehyde, acetic acid, etc.) that were not incorporated into the polymer. Purification and recovery of the water will result in approximately 0.08 pounds of waste water per pound of product, containing 5 percent organics. This waste water may be sent to waste water treatment or incinerated.

(3) Solid wastes. The only solid residue from the manufacture of absorbent gelling material is the particulate matter released from the pelletizing and packaging equipment and product handling. A rough estimate of solid waste would be the production of 0.05 pounds of solid per pound of product, which can either be incinerated or landfilled.

(4) Air emissions. The only potential source of air emissions from the absorbent gel manufacturing operation is the vapor stream removed from the dryer. The hot air stream leaving the dryer will contain trace amounts of unreacted acrylic acid and small particulates from the powdered polymer. Incineration of this stream will produce volatile organic compounds (VOC) at about 5×10^{-4} pound per pound of product.

b. Acrylic Acid

(1) Manufacturing process. In the manufacture of acrylic acid, quantities of propylene, air, and steam are mixed and added to a reactor where they are converted to acrolein. Approximately 0.68 pounds of propylene and 5.2 pounds of air are required to produce one pound of acrylic acid. A molybdenum, cobalt, iron, or other metal catalyst is required to promote the synthesis of acrolein. The addition of steam serves only to help control the process and is omitted from some processes. The acrolein is subsequently oxidized to acrylic acid using a vanadium oxide or molybdenum oxide catalyst. Both conversions result in net steam generation of 2.2 pounds per pound of acrylic acid produced.

The acrylic acid is extracted from the condensed steam by a hydrocarbon solvent. The water leaving the extractor is distilled to recover solvent, and the remaining water is sent to a waste water treatment facility. The acrylic acid/solvent mixture is distilled for solvent recovery and acrylic acid product purification. Utilities consumed in acrylic acid manufacture include electricity (0.04 kiloWatt-hours per pound of product), steam (4.4 pounds per pound of product) and cooling water (30 pounds per pound of product).

2. Liquid discharges. A total of 0.004 pounds of waste water are generated for each pound of acrylic acid manufactured. These streams may contain acrylic acid, polymers, acetic acid, and the hydrocarbon solvent at an average concentration of one percent volatile organic compounds (VOC). Waste water is usually biologically treated or incinerated. Bioxidation of these waste streams is estimated to produce 3.0 x 10^{-5} pound VOC per pound of product.

3. Air emissions. The gaseous stream from solvent recovery/product purification is a major potential source of process emissions. One manufacturer has indicated that the emission ratio for this stream as 0.12 pounds of volatile organic compounds (VOC) per pound of product. A sample composition for this waste gas stream is given in Table III-3. This stream is commonly incinerated.

The extraction column and subsequent separations and purifications are possible sources of organic emissions. Additional gaseous emissions from process vents total 4 x 10^{-3} pound VOC per pound of product, mostly comprised of the solvent and acrylic acid. Carbon dioxide, carbon monoxide, and methane may also be present in vent streams.

Fugitive losses can occur at valves and seals, and may contain propylene, acrylic acid, solvent, and other organics. Fugitive emissions are estimated to total 1.5 x 10^{-3} pound VOC per pound of product. Storage emissions related to acrylic acid and solvent storage and handling emissions arising from acrylic acid loading total 2 x 10^{-3} pound VOC per pound of product.

4. Solid wastes. Acrylic acid manufacture produces small amounts of polymer by-products which must be cleaned and removed from process equipment between 4 and 12 times per year, generating approximately 6.6 x 10^{-6} pounds of solid waste per pound of acrylic acid. The solids may be incinerated or landfilled. Incineration of these solids is estimated to produce 8 x 10^{-7} pounds of VOC per pound of product.

3. Polyolefins

Ethylene and propylene are two petrochemicals which are the principal products of olefins manufacture, as well as the raw materials used to manufacture low-density polyethylene (LDPE) film and non-woven polypropylene fabric used in disposable diapers. Disposable diapers consume only a small fraction of the ethylene and propylene manufactured in this country, accounting for less than one percent of the total volume produced. This section describes the manufacturing of these materials.

a. Olefins Production.

(1) Manufacturing process. The olefins manufacturing process consists of numerous chemical and physical operations that produce ethylene and propylene, together with by-products such as hydrogen, and gasoline. The raw materials include naphtha, atmospheric gas oil, and other hydrocarbons. The raw materials

Table III-3: Composition of Acrylic Acid Air Emissions

Component	Weight Percent	Emission Ratio (pound/pound acid)
Acetaldehyde	<0.0020	<0.0001
Acetic acid	0.027	0.0014
Acetone	0.0251	0.0013
Acrolein	0.087	0.0045
Acrylic acid	0.347	0.0180
Ethyl acrylate	0.0231	0.0012
Propane	1.45	0.0753
Propylene	0.337	0.0175
Water	1.71	0.0886
Carbon dioxide	5.19	0.2695
Carbon monoxide	2.28	0.1185
Nitrogen*	86.0	4.4666
Oxygen*	2.48	0.1288

*Components of air

are preheated, diluted with steam, and then heated and rapidly cooled. This process, breaks down or cracks the raw materials, forming the desired products. The high temperature product from the cracking process is cooled and the by-products, a gasoline mixture and fuel oil, are separated.

The remaining cracked gas is treated to remove the acidic gases, mainly hydrogen sulfide and carbon dioxide. A small amount of moisture (water) remaining in the cracked gas must be completely removed to prevent any ice formation during subsequent low temperature processing. The moisture free cracked gas is chilled to separate and recover by-products such as hydrogen and methane. Ethane, ethylene and acetylene, are separated from the remaining products. The acetylene and ethane are recovered and used as fuels internally within the olefins plant. The resulting ethylene product can be used for further processing to polyethylene or other products.

Propylene and related compounds are also separated from the remaining cracked gas. The related by-products are recovered and are also used as a fuel within the plant. The propylene is condensed for use in the manufacture of polypropylene or other products.

Resource requirements and emissions for olefins manufacture are shown in Tables III-4 and III-5, respectively. A discussion of relevant environmental considerations follows.

(2) Water discharges. The waste water from the olefins plant is collected and directed to a waste water treatment system. Sulfur compounds are converted into stable sulfates, and then neutralized. This treatment resolves a potential odor problem.

(3) Air emissions. Methane, ethane and propane are recovered from gaseous emissions and used as the fuel for the olefins manufacturing process. This clean fuel gas is substantially destroyed within the high efficiency combustion system. Any gaseous hydrocarbons released from vents, safety valves, or equipment purges are collected and burned by a flare system. Since the waste gases are mainly hydrocarbons, they can be effectively incinerated in a smokeless combustion system before discharge to the atmosphere, thereby minimizing air pollution.

(4) Solid wastes. The sludge formed in the waste water treatment process is disposed of by incineration, and the incinerated ash is landfilled. In order to control heavy metal pollution, the inactive metal catalysts discarded from the olefins plant are recovered by suppliers.

b. Polyethylene. Low density polyethylene (LDPE) used in the manufacture of disposable diapers is produced from heated ethylene, using initiators to promote

Table III-4: Olefins Plant Resource Requirements and Products

Item Description	Quantity Generated/Consumed
Input	
Raw Materials:	
Naphtha	1.33 lb/lb ethylene & propylene
De-aromatic Naptha	0.71 lb/lb ethylene & propylene
Other Raw Materials	0.21 lb/lb ethylene & propylene
Utilities:	
Water	0.69 lb/lb ethylene & propylene
Steam	2.88 lb/lb ethylene & propylene
Electricity (Net Generation)	0.08 kW-hr/lb ethylene & propylene
Output	
Ethylene	0.67 lb/lb ethylene & propylene
Propylene	0.33 lb/lb ethylene & propylene
Other Hydrocarbons	0.89 lb/lb ethylene & propylene
Hydrogen	0.01 lb/lb ethylene & propylene

Table III-5: Environmental Emissions from Olefins Manufacture

Environmental Emissions	Generation Rate
Air Emissions	
Hydrocarbons	$1.2x10^{-6}$ lb/lb ethylene & propylene
Carbon Monoxide	$6.2x10^{-6}$ lb/lb ethylene & propylene
Nitrogen Oxides	$1.1x10^{-4}$ lb/lb ethylene & propylene
Particulate Matter	$5.9x10^{-6}$ lb/lb ethylene & propylene
Waste Water	0.6 lb/lb ethylene & propylene
Solid Waste	
Recovered Catalyst	$6.7x10^{-5}$ lb/lb ethylene & propylene
Aluminum/Silicon Oxide Waste	$4.4x10^{-5}$ lb/lb ethylene & propylene
Oil Sludge	$3.3x10^{-6}$ lb/lb ethylene & propylene

polymer formation. Unused ethylene is separated from the polyethylene and is recycled. The product is cooled and a small quantity of impurities may also be removed. The polymer is then formed into pellets. The production of polyethylene film from these pellets consists primarily of mechanical equipment action. The LDPE resin is melted and formed into a thin film; it is then cooled and stored on rollers. Heating and cooling results in an energy input. Emissions to the atmosphere are negligible. Scrap polyethylene or solid waste that is generated is either sold or recycled into the process. Resource requirements and environmental emissions for LDPE film manufacture are summarized in Table III-6.

c. Polypropylene. Polypropylene is manufactured using a diluent, propylene, a catalyst and modifiers. Propylene is converted to polypropylene and is subsequently purified to remove the catalyst, diluent and undersized byproduct polymers. Unreacted propylene is collected along with the diluent and is recovered or recycled. The polymer is dried, mixed with various additives, melted, and formed into pellets. The number of additives used is large and varied, depending on the ultimate use of the polypropylene.

A staple fiber for use in disposable diapers may be produced from the polypropylene resin. A small amount of water is required to cool the product. This staple fiber is formed into a card web, and a thermal bonding process follows. This non-woven mat is ready for use in diaper manufacture.

Table III-7 provides the resource requirements and emissions/effluents from polypropylene and non-woven polypropene fabric manufacture.

4. Converting and Packaging

Diaper manufacturing is a converting process, not unlike other converting operations. Minimization, waste control and efficiency are of utmost importance in converting, and diaper manufacturers have demonstrated continuing improvements in these areas. This is also true of the manufacture of the packaging involved. Both industries have been highly competitive from their beginnings, and this has accentuated the need for efficiency. Reducing internal waste scrap and the use of a high percentage of the unavoidable scrap in the operation has been an ongoing practice. The product improvements discussed earlier in this report have also dramatically reduced material usage in converting and packaging. The diaper has developed into a sophisticated engineered product, and the manufacturing of the product is likewise sophisticated.

Disposable diapers were one of the first major product categories to capitalize on the minimization trend that became the standard in converting. Diaper manufacturers have been willing to make product improvements and take the inherent risks within this competitive environment because the response from consumers has been an immediate regard, as shown in the Scantrack data in

Table III-6: Resource Requirements and Emissions from LDPE Manufacture

Resource Requirements	
Raw Materials	
– Ethylene	1.7 lb/lb LDPE
– Impurities	$6.6x10^{-2}$ lb/lb LDPE
Utilities	
– Water	$8.0x10^{-2}$ lb/lb LDPE
– Steam (Net Consumption)	$2.8x10^{-3}$ lb/lb LDPE
– Electricity	0.33 kW-hr/lb LDPE
Emissions	
Air Emissions	
– Hydrocarbons	2,400 ppm
– Carbon Monoxide	1,000 ppm
– Nitrogen Oxides	30 ppm
Waste Water	0.07 lb/lb LDPE
– COD	95 ppm
– BOD	45 ppm
- Suspended Solids	60 ppm
Solid Wastes	$2.1x10^{-4}$ lb/lb LDPE
Products	
– High Density Polyethylene	1 lb/lb LDPE

Table III-7: Resource Requirements and Environmental Emissions from Non-Woven Polypropylene Fabric Manufacture

Resource Requirements	
Raw Materials	
– Propylene	1.07 lb/lb fabric
Utilities	
– Water	15 lb/lb fabric
– Steam	5.04 lb/lb fabric
– Electricity	0.45 kW-hr/lb fabric
Emissions	
Total Air Emissions	0.04 lb/lb fabric
– Hydrocarbons	0.03 lb/lb fabric
– Other	0.01 lb/lb fabric

Section II of this report. The benefits and improvements to the industry and to consumers have been some of the noticeable rewards of this market competition.

The environmental effluents from disposable diaper converting are limited and include:

- particulate matter - 6.2 x 10^{-6} pound per diaper,
- sanitary sewage - 0.027 gallon per diaper, and
- solid waste - 8.3 x 10^{-4}.

In most converting plants, an active recycling program has been implemented for scrap materials. The remaining solid wastes are typically disposed by traditional methods, i.e., landfilling or incineration.

B. Reusable Diaper Manufacturing

Reusable diapers are produced from cotton fibers using typical textile manufacturing methods. The harvested cotton is dried and ginned to separate the fibers used for cloth manufacture from the flower bracts, seeds, field trash and a byproduct known as fuzz or linters. Linters are used as a source of cellulose in chemical manufacturing operations and are also used in upholstery and batting. Solid wastes account for over 50 percent of the raw cotton delivered to the ginning facility. Fine cotton fibers are fugitive air emissions that require environmental controls.

The cotton fibers must be disentangled before they can be spun into yarn. This process, known as carding, uses a wire-toothed brushing mechanism to align the fibers. In the spinning process, the cotton fibers are drawn out and twisted to form the yarn strand. The spinning process generates a small quantity of non-reworkable solid waste, amounting to six percent of the product weight. Fiber dust is also released to the atmosphere in quantities equal to one percent of the product weight.

A portion of the yarn will be strengthened with a sizing compound in preparation for weaving. Starch is most commonly used to coat cotton yarns, such as those used to weave diapers, and can add as much as 15 percent to the weight of the yarn. Wetting agents, softeners, and other additives may be incorporated into sizing formulations. The sized yarns are mounted on a loom for weaving, and form the warp threads, i.e., the basic backbone of the final fabric. These warp yarns are bound together with unsized yarns which are woven through them at right angles.

Woven diaper fabrics must go through a finishing process before they are ready for use. The finishing process is highly energy intensive and has significant environmental implications, since large quantities of water and chemicals are used. The first step, known as desizing, is a cleaning operation to remove the sizing. The fabric is coated with a desizing solution of either sulfuric acid or animal/vegetable enzymes to decompose the starch. The starch decomposition residues are readily solubilized and are removed by soaking the fabric in a hot water bath. Desizing generates a significant amount of waste water. For an average cotton fabric manufacturing plant, 45 percent of the waste water BOD, 36 percent of the total solids and 6 percent of the alkalinity originate in the sizing operation (EPA, 1979).

Scouring is a fabric finishing process that removes impurities. A hot water based solution of sodium hydroxide, soap and sodium silicate is used to scour the fabric for six to twelve hours, removing the natural impurities of cotton, such as wax, pectins and alcohol, as well as processing impurities such as residual sizing, desizing compounds, dirt and oil. The fabric must be completely rinsed to remove the scouring chemicals. Scouring is the major source of waste water from the diaper fabric manufacturing operation, providing 16 percent of the waste water BOD, 43 percent of the total solids and 60 percent of the alkalinity (EPA, 1979).

As the fabric leaves the scouring process, excess water is removed and sodium hydroxide is added. The fabric is heated to 175°F or higher, converting any residual wax or fats to soaps. They are then rinsed with hot water and bleached at 195°F using hydrogen peroxide and sodium silicate. The bleached fabric is rinsed with hot water, and may be subjected to a second stage of bleaching using sodium hypochlorite, followed by a final rinse. Hydrogen peroxide bleaching contributes very little to waste water loads. Most pollutants from bleaching include sodium silicate, sodium hydroxide, sodium phosphate, surfactants, chelating agents and dissolved solids.

On average, 13.6 gallons of waste water are generated per pound of diaper fabric produced in a complex cotton fabric finishing operation that incorporates desizing. The median untreated waste characteristics are as follows (EPA, 1979):

- Biological Oxygen Demand - 45.1 pounds per 1000 pounds of diaper fabric
- Chemical Oxygen Demand - 126 pounds per 1000 pounds of diaper fabric
- Total Suspended Solids - 14.8 pounds per 1000 pounds of diapers

These waste waters must be treated to reduce pollutants to acceptable levels, noted in Table III-8, prior to being released to the environment.

Table III-8: Effluent Guidelines Limitations for Waste Water from Cotton Diaper Fabric

	Effluent Guidelines Limitations (lb/1000 lb fabric)	
	Existing Plants	New Plants
BOD	3.3	1.8
COD	34.0	23.4
TSS	3.6	2.6
Total Phenol	0.007	0.005
Total Chromium	0.06	0.06
Total Copper	0.06	0.06
Total Zinc	0.11	0.11
Color	220.0	120.0

Treated waste water is expected to contain pollutants at or below these levels. Phenol, chromium, copper and zinc are primarily associated with dyed fabric and are not anticipated to be found in diaper manufacturing waste waters in significant quantities.

Sludge is generated as a result of waste water treatment. This residue is commonly disposed of in a landfill. Sludge volumes range from 0.2 to 48 gallons per 1000 gallons of waste water treated or 0.003 to 0.65 gallons per pound of diaper fabric manufactured. Other solid wastes include:

- dirt, stems, bracts, etc. from cotton ginning - 1.3 pounds per pound of diaper fabric;
- non-reworkable waste from spinning - 0.06 pounds per pound of diaper fabric; and
- non-reworkable waste from weaving - 0.02 pounds per pound of diaper fabric.

Atmospheric emissions from cotton diaper manufacture are primarily dusts. These fugitive emissions are estimated to be:

- emissions from drying/ginning - 1.3 pound per pound of fabric;
- fugitive air emissions from spinning - 0.06 pound per pound of fabric; and
- fugitive air emissions from weaving and finishing - 0.002 pound per pound of fabric.

Table III-9 summarizes the environmental emissions and effluents from cloth diaper manufacturing. Table III-10 summarizes the principal resources consumed in cloth diaper manufacture, including cotton, energy and water. Approximately 2.55 pounds of raw cotton are used to produce a pound of diaper fabric. Electric power

Table III-9: Cloth Diaper Manufacture Environmental Effluents and Emissions

Parameter	Units	Units/Pound of Fabric
Raw Waste Water		
• Quanitity	gallons	13.6
• BOD	pounds	0.045
• COD	pounds	0.126
• TSS	pounds	0.015
Treated Waste Water		
• BOD	pounds	≤0.0018-0.0036
• COD	pounds	≤0.023-0.034
• TSS	pounds	≤0.0026-0.0036
• Color	pounds	≤0.12-0.22
Solid Waste		
• Waste Water Treatment Sludge	pounds	0.003-0.65
• Ginning Waste	pounds	1.3
• Spinning Waste	pounds	0.06
• Weaving Waste	pounds	0.02
Fugitive Dust		
• Ginning Dust	pounds	1.3
• Spinning Dust	pounds	0.06
• Weaving Dust	pounds	0.002

Table III-10: Cloth Diaper Manufacture Resource Consumption

Resource	Units	Units/Pound of Fabric
Energy		
• Electric Power	kW-hr[a]	3.5
• Natural Gas	scf[b]	0.8
Water	gallons	13.6
Cotton	pounds	2.4

[a]kW-hr = kiloWatt-hour
[b]scf = standard cubic feet

consumption is on the order of 3.5 kiloWatt-hour per pound of diapers. Approximately 0.8 standard cubic feet of natural gas are required to dry the cotton used to produce a pound of diaper fabric. An estimated 13.6 gallons of water are used to generate a pound of diaper fabric.

A. Reusable Diaper Laundering

This section provides models for in-home and commercial diaper laundering.

1. Home Laundering

This analysis of washing reusable diapers at home is based on a number of assumptions involving equipment, laundry materials, consumption, water use, and diaper washing practices. These assumptions were chosen to be representative of general practices in the United States. The weighted computations of resource consumption and outputs reflect the estimated percentages of appliance ownership, and frequencies of laundry practices involving wash cycles, water temperature selection, and laundry supply use. These assumptions are discussed below.[1] Appendix B contains a detailed description of assumptions and calculations.

a. Equipment. The analysis of home laundering is based on the use of a standard 16 pound capacity washing machine. It has a tub size of 2.3 cubic feet that contains 19.2 gallons of water for a full wash load. Its basic wash/rinse cycle consumes 43.7 gallons of water and requires 0.216 kilo-Watt hour (kWh) of electricity. The electric dryer is assumed to have a 6.75 pound capacity with a cycle energy requirement of 2.51 kWh. It requires 5.95 kWh to dry the contents of a full washing machine load. The gas dryer is assumed to have a 7 pound capacity with a 9,910 British thermal unit (Btu) requirement per cycle, or approximately 27,000 Btu to dry a full washer load. The electric water heater is assumed to have a standard efficiency of 80.6 percent for 373,000 Btu input per week. It requires 3.49 kWh of energy to produce the hot water needed for a wash cycle using a cold rinse. The natural gas water heater has a standard efficiency of 55.3 percent at 543,000 Btu input per week. It requires 17,400 Btu to provide hot water for a wash cycle with a cold rinse.

b. Diaper load. The average diaper load was estimated to be 4.3 pounds, or approximately 30 percent of a full washer load. Using an average diaper weight of 0.13 pounds, 33 diapers constitute a 4.3 pound load. The calculations of water, energy and materials use for this analysis are based on this average load size and frequency, which reflect a diaper use pattern of 6.4 changes per day consuming an average 1.9 diapers per change. An estimated 2.5 loads of diapers are washed per week. Plastic pants which are worn over diapers may or may not be included in the load. A pair of plastic pants weighs 0.05 lbs and is not a significant factor in these calculations. Additional laundering requirements, such as soiled sheets and clothes resulting from diaper leakage, were not considered.

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[1] Calculations were performed using a computer spreadsheet. Minor computational discrepancies are the result of rounding.

c. Laundering practices. Soiled diapers containing feces will be rinsed in a toilet. This operation consumes approximately four gallons of water as a result of toilet flushing. Of the 33 diapers in a standard laundry load, 12 will have been subject to this treatment. Since 1.9 diapers on average are worn at a time, six such operations will have been performed for each load of laundry.

Diapers are generally presoaked with bleach or a diaper formulation in preparation for laundering. This provides a more sanitary storage environment during the period between diaper use and washing. The supplies used in presoaking include 1/4 cup of bleach or 1/2 cup of diaper formulation per gallon of water. Approximately one quart of water is used to soak each diaper. Available data indicate that this practice is not always adhered to, but the frequency of this occurrence is slight and is not advisable from the perspective of hygiene.

When the soaking diapers are transferred to the wash, approximately 50 percent of the water is poured off first. The remainder is transferred to the washer with the diapers. This factor has been accounted for in the water requirement calculation to avoid double counting.

d. Washing machine cycle. All loads are assumed to be washed with the regular cycle setting. We estimate that 30 percent of these loads are washed by themselves, and the remaining 70 percent are washed with other items. In the composite washes, diapers constitute 75 percent of the total load. The washes containing only diapers utilize the small load water setting on the washer, which uses 80 percent of the water requirement for a full load. The composite washes utilize the medium load washer setting which requires 90 percent of the full load water volume. The model also assumes that 25 percent of all loads use a second rinse, and this frequency has been applied to the combined pool of both diapers-only and composite loads. Water temperature settings are an important factor for energy usage. Our model assumes that 80 percent of all wash portions of the wash/rinse cycle use hot water, 12 percent use warm and 8 percent are cold. First and second rinses are 30 percent warm and 70 percent cold. In calculating water use, it is assumed that the spin cycle removes 99.99 percent of the water from the diapers. The water remaining in the diaper is equal to 50 percent of the dry diaper weight.

e. Drying. Dryers are estimated to be used for 60 percent of all home washes. Gas dryers are estimated to be used 25 percent of the time, and electric dryers 75 percent of the time. The frequency for washes dried on the line is estimated at 40 percent.

f. Hot water. Electric hot water heaters are owned by 47 percent of all households, and gas hot water heaters are owned by 53 percent of all households.

g. Resource requirements. The energy, water, and laundry supply requirements were calculated per 85 diapers, or one week's consumption. These data are reported below.

Energy		
Hot Water:	electricity	3.0 kWh
	gas	16,900 Btu
Washer:	electricity	0.61 kWh
Dryer:	electricity	1.8 kWh
	gas	2,270 Btu
Water		
Prerinse:		60 gallons
Presoak:		20 gallons
Wash:		75 gallons
Total		155 gallons
Laundry Materials		
Diaper soak product		21 ounces
Powder detergent		4 ounces
Liquid detergent		2.5 fluid ounces
Bleach		34 fluid ounces (21 ounces presoak; 13 ounces wash cycle)
Fabric softener		1.6 ounces

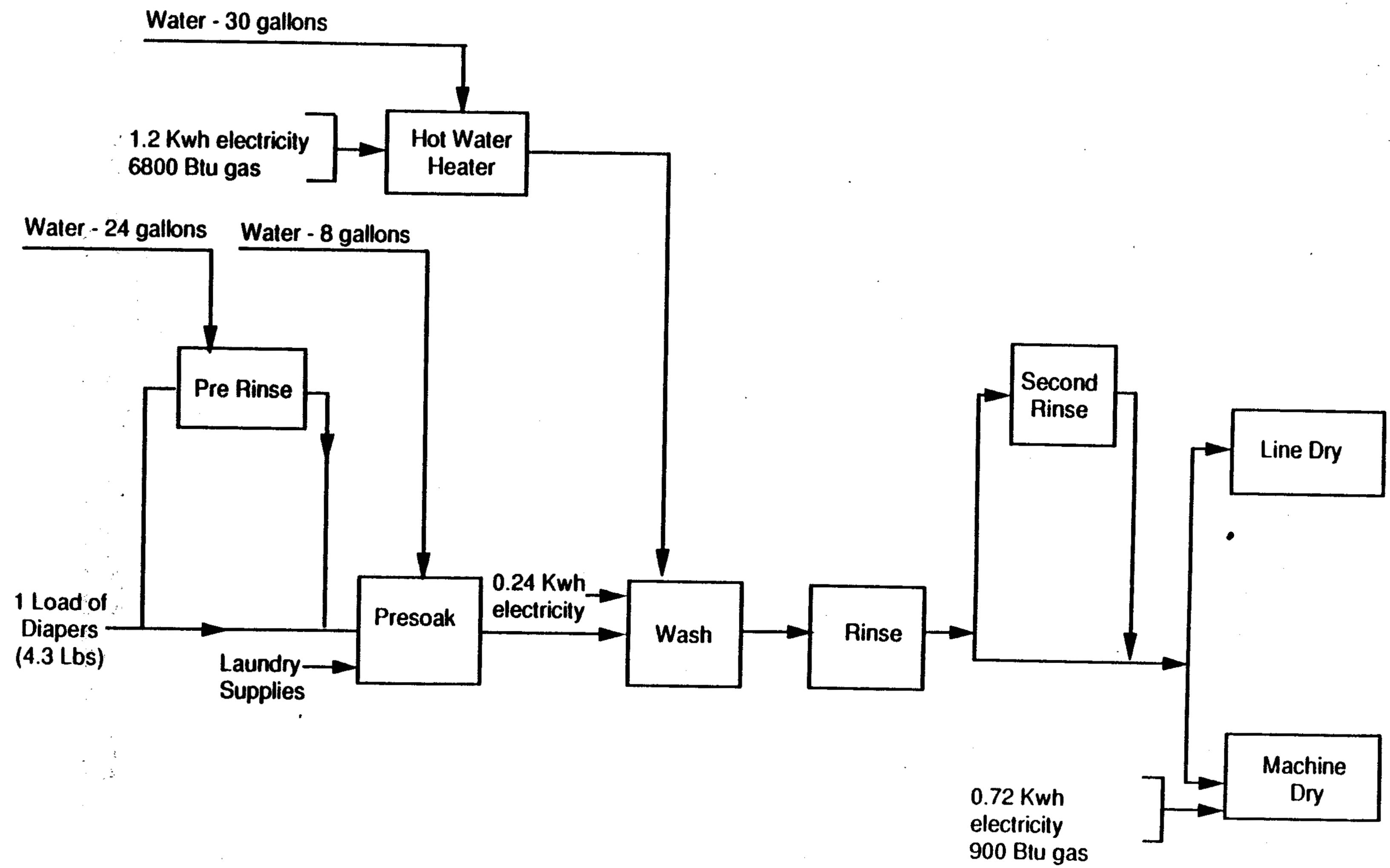
The home laundering process is depicted schematically in Figure IV-1.

2. Diaper Service

The analysis of the resource requirements and outputs from diaper services is based on a number of assumptions derived from interviews of equipment suppliers and published equipment specifications. The assumptions were chosen to be representative of normal diaper service practices, although it should be noted that these businesses vary dramatically in size and do not all follow the same wash procedures. An estimated 10 percent of the consumers who prefer cotton diapers subscribe to commercial diaper services to avoid the unpleasant task of home diaper laundering.

We also examined the potential existing use of laundramats as another laundering alternative. Having consulted several owners and operators, we determined that the

Figure IV-1: Home Laundering Model: Requirements for One Composite Load of Diapers



practice, if it exists, is extremely infrequent and also ill-advised from the perspective of public health. This study does not analyze this potential alternative.

a. Equipment. This analysis of commercial diaper laundering assumes the use of a 250 pound capacity commercial washer with an average cycle time of 50 minutes. Energy requirements are 3.52 kWh, and the final spin (extraction) removes 99.99 percent of the water. The model uses a 200 pound capacity gas dryer that requires 720,000 Btu per hour with a 20 minute cycle. The calculations assume that 85 diapers weigh 11 pounds and represent 4.4 percent of a full washer load and 5.5 percent of a full dryer load.

The water heating requirements were estimated on the basis of a commercial hot water heater with a 75 percent efficiency. The incoming water to the hot water heater is assumed to be at a temperature of 50 degrees Fahrenheit. The model also assumes a heat recovery system that reduces energy requirements by 15 percent. A detailed presentation of assumptions and calculations is shown in Appendix C.

b. Water use. Based on interviews with equipment manufacturers and distributors who work with diaper services, a water use rate of two gallons per pound has been used. This includes a factor for reuse of 10 percent of the total amount of water required for a full cycle.

c. Laundry supplies. The detergent is assumed to be a concentrated non-phosphate formulation used at a rate of 9 fluid ounces per 100 pounds of laundry. The sanitizer is assumed to be an 8.6 percent active solution of sodium or calcium hypochlorite, and is used at a rate of 6 ounces per 100 pounds, or a concentration of 100 ppm in the water. The sour is a dilute organic acid that is used to alter the pH of the water dramatically as a method of bacteria control. It is assumed to be used at a rate of 1 ounce per 100 pounds. Fabric softener is assumed to be used at a rate of 1 fluid ounce per 100 pounds of laundry. These chemicals combine with the feces and/or urine washed from the diapers to produce a waste water flow that has high levels of biological oxygen demand and total suspended solids.

Resource requirements were estimated for 85 diapers (1 week requirement) and are reported below.

Water	22 gallons
Energy	
Hot water	18,000 Btu
Washer	0.13 kWh
Dryer	13,000 Btu
Laundry Supplies	
Detergent	1 ounce
Sanitizer	0.7 ounce
Sour	0.1 ounce
Fabric softener	0.1 ounce

The commercial diaper service laundering model is depicted schematically in Figure IV-2.

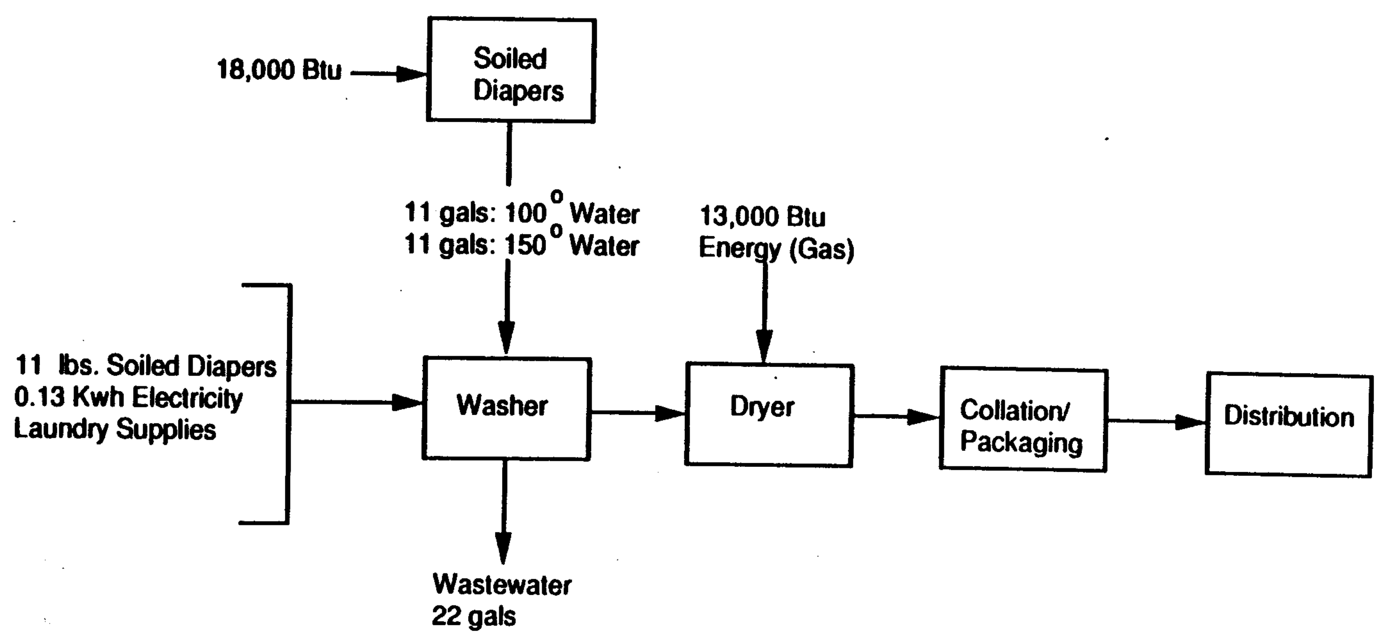
B. Diaper Waste Management

1. Overview

Disposable diapers comprise a small fraction of the nation's solid wastes. Estimates of their contribution to waste volumes range from less than one percent to just over two percent, depending on the use of the landfill. Like the majority of the solid wastes generated in this country, disposable diapers are disposed of primarily by landfilling. Approximately 83 percent of the country's municipal refuse is disposed of in landfills. Despite its wide practice, this disposal method is facing limited future capacity due to increased regulatory and public pressures. Resource recovery, composting, recycling and source reduction are attractive alternatives to landfilling. In resource recovery, municipal solid wastes are burned in engineered incinerators, releasing heat that can be used to generate steam or electricity. The ability to recover a valuable by-product provides an impetus for increased resource recovery applications. Only seven percent of the nation's waste is presently processed in resource recovery facilities. Currently, approximately 11 percent of the nation's municipal solid waste is recycled or composted. Although recycling and composting facilities are being developed, these waste management options have not yet been widely applied for diaper disposal. Source reduction has been an important by-product of disposable diaper improvements.

This section will describe the principal diaper disposal methods, landfilling and resource recovery, as well as emerging alternatives. It will also address post-

Figure IV-2: Diaper Service Laundering Model: Requirements for 85 Diapers



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consumer waste collection, a costly element of most solid waste management programs.

2. Source Reduction

A variety of disposable diaper improvements have been introduced throughout the last decade with the principal intent of improving product performance. However, these improvements have significantly reduced disposable diaper wastes through a variety of mechanisms. The introduction of refastenable tapes in 1983 reduced diaper wastes by providing a means of reusing diapers after checking diaper wetness. Prior to this time, a diaper had to be disposed of even if it was not soiled, because there was simply no method to refasten the diaper closures. The introduction of absorbent gelling material has had the effect of reducing the amount of materials used in disposable diapers while reducing the number of diapers used daily. Other product improvements include a reduction in the amount of adhesives used, reduced materials in the core design, and the use of polybags rather than bulkier packaging. These product improvements have had a net impact of reducing disposable diaper wastes.

3. Recycling

Disposable diapers could theoretically be recycled to recover pulp fibers and plastic, although this practice has only been implemented on a pilot scale. Effective disposable diaper recycling will depend on reliable markets for recovered pulp and plastic. An effective means of segregating diapers from the general refuse stream and delivering them to a recycling facility is essential to the success of this recycling opportunity.

4. Composting

Disposable diapers can be effectively composted in an in-vessel municipal waste composting process. Approximately 90 percent of the diaper volume is incorporated into the compost. Tests conducted at St. Cloud, Minnesota in the municipal solid waste compost process show that diapers were fully compatible with the composting process. According to Procter and Gamble, no problems were observed in this test of disposable diapers in solid waste and the small volume of non-compostable diaper parts were recovered in the compost screening step.

5. Resource Recovery

Incineration is emerging as an important municipal solid waste disposal method, principally as a result of mounting regulatory, economic and public pressures on landfilling. Until recently, incinerators were used primarily in confined urban areas where land was either unavailable or prohibitively priced for landfill operations. The ability to recover energy in the form of steam or electricity is an added incentive to pursue this disposal method.

Incineration is a controlled process for burning combustible wastes, thereby producing gases and a residue of ash and other non-combustible materials. The

•residue from incineration includes particulate matter, waste from air pollution control systems and solid residues. This material requires further disposal, typically in sanitary landfills.

Disposable diapers consist primarily of combustible cellulosic and polymeric materials. A small amount of noncombustible compounds (approximately seven percent) is also incorporated in these materials; the noncombustible fraction forms an ash residue when the disposible diapers are incinerated. Table IV-1 provides the characteristics of ash from disposable diaper incineration. The diapers also contain small amounts of sulfur (0.2 percent) and chlorine (0.1 percent). These chemicals are oxidized upon combustion of the diaper. They are typically collected in an air pollution control system.

Table IV-1: Characteristics of Ash from Disposable Diaper Combustion

Ash Component	Percentage (weight basis)
Silica (SiO_2)	3.79
Alumina (Al_2O_3)	5.35
Titania (TiO_2)	7.20
Ferric Oxide (Fe_2O_3)	0.60
Lime (CaO)	0.40
Magnesia (MgO)	0.52
Potassium Oxide (K_2O)	0.10
Sodium Oxide (Na_2O)	50.20
Sulfur Trioxide (SO_3)	0.40
Phosphorus Pentoxide (P_2O_5)	0.03
Unburned Carbon	30.69
Unidentified Constituents	0.72
	100.00

Source: Reuther, J.J., B.W. Rising and R.B. Engdahl, "Combustion Assessment of Procter and Gamble Waste Product", Final Report by BATTELLE Columbus Laboratories, Columbus, Ohio, for the Procter and Gamble Company, May 29, 1985.

Municipal solid wastes can be incinerated directly with little or no processing, or they can be converted to refuse derived fuel (RDF) and burned in boilers. The former method has found the greatest application for resource recovery from municipal solid wastes and will be the focus of this discussion.

Municipal solid waste incinerators are generally operated with sufficient heat and oxygen to ensure complete degradation of polymeric or carbonaceous materials to carbon dioxide, water and other appropriate combustion products. As an alternative to complete combustion, wastes can be destroyed by high temperature treatment in the absence of oxygen (pyrolysis), with limited oxygen (partial combustion) or in reactive atmospheres (gasification), forming combustible gases, organic liquids and/or char. These alternative incineration processes have found limited application for municipal solid waste disposal and will not be addressed further in this report. There are a variety of solid waste incinerator types and numerous variations in auxiliary incineration equipment. However, most municipal solid waste incinerator systems share the same general components, as shown in Figure IV-3.

When disposable diapers are delivered to an incineration facility as part of the municipal solid waste stream, they will be placed along with other solid wastes in a storage pit or hopper awaiting transfer to the incinerator.

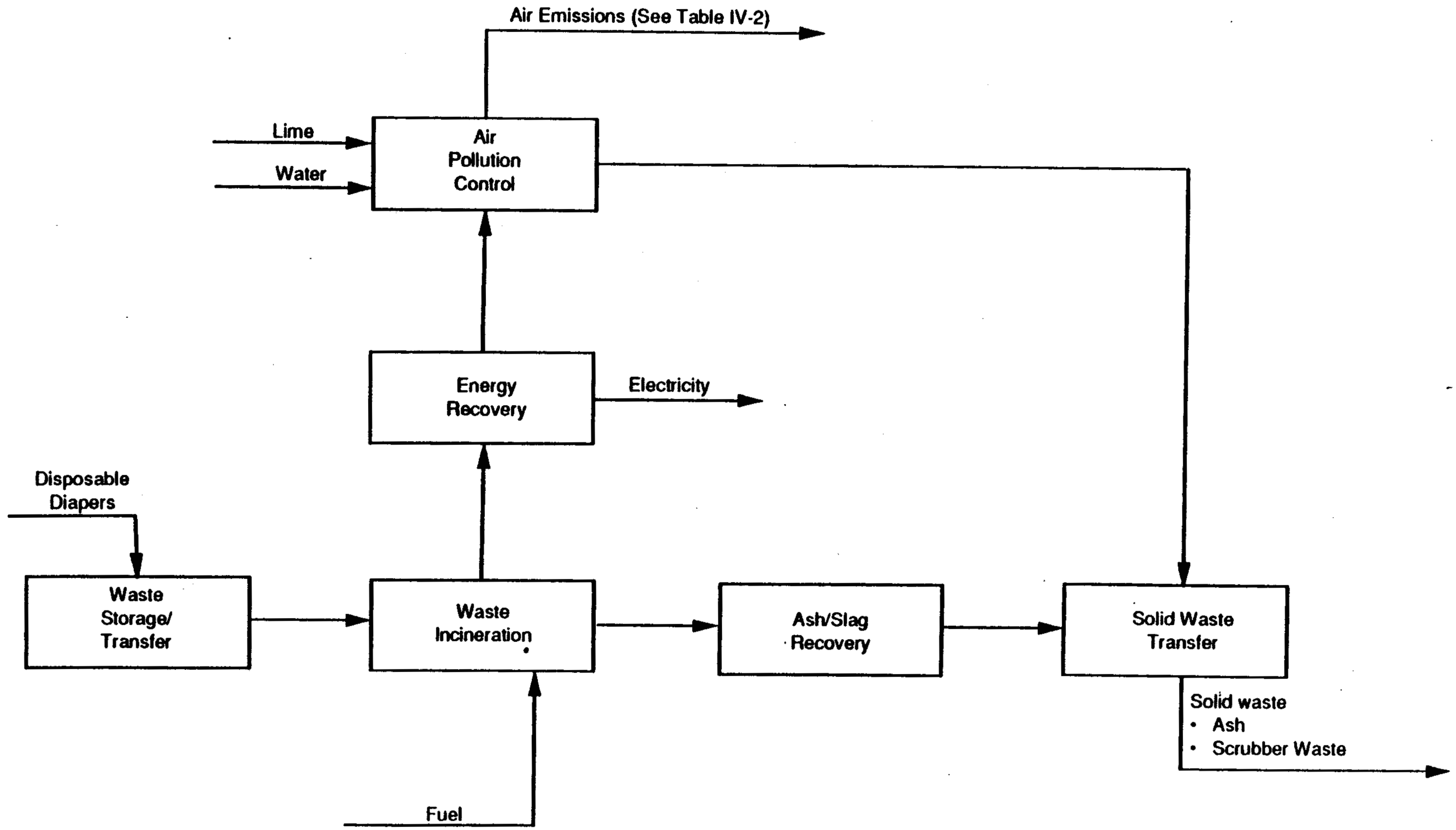
When wastes enter an incinerator, they are first dried and preheated by radiation from the hot combustion gases and furnace walls. As the refuse is heated further, it thermally decomposes, vaporizes and ignites. To achieve efficient combustion, it is necessary to provide even heating of the waste and good exposure to combustion air. Moreover, the materials must be moved through the incinerator to prevent the accumulation of noncombustible materials at the furnace entrance.

The heated combustion gases contain significant quantities of energy, which can be recovered by transfer of the heat to water, forming steam. The steam can be used for heating in buildings and in a variety of manufacturing operations. It can also be used to generate electric power. Disposable diapers have high energy contents. Approximately 475 kiloWatt-hours of electric power can be generated per ton of post-consumer disposable diapers incinerated.

Ash and other non-combustible waste components are removed from the incineration system in either of two areas. Very small particles are usually entrained in the combustion gases and collected in an air pollution control system. The remaining ash is removed from the incinerator and cooled with water. Both solid waste streams are sent to a sanitary landfill. Approximately 140 pounds of ash are generated per ton of diapers incinerated.

Air pollution control equipment is an important and costly component of a municipal solid waste incineration system. State and local governments have promulgated strict air emissions regulations addressing a variety of air pollutants, including particulate matter, sulfur oxides, nitrogen oxides, carbon monoxide, hydrogen chloride and hydrocarbons. These pollutants can result from the combustion of municipal solid waste, including post-consumer diapers. However, with proper engineering controls, solid wastes, including disposable diapers, can be

Figure IV-3: Disposable Diaper Incineration



burned without producing adverse environmental impacts. For example, the emissions of combustible pollutants such as carbon monoxide or hydrocarbons can be controlled by ensuring the combustion gases are maintained in the incinerator for a sufficient period of time to ensure complete combustion of all wastes and their degradation products. Nitrogen oxides are formed in most air-based combustion systems, but their formation can be controlled to appropriate levels in a properly designed incinerator.

Particulate matter and acidic gases such as sulfur oxides and hydrogen chloride are generated in municipal solid waste incineration. Particulate matter may be collected by a variety of devices, including mechanical, electrostatic and scrubbing systems. The acidic gases are collected using water-based caustic scrubbing systems which produce either a solid waste or an aqueous waste solution. For disposable diaper incineration, a lime-based acidic gas scrubber operating at 99 percent efficiency collects 36 pounds (dry basis) of waste per ton of diapers burned. This includes 100 percent excess lime. Air emissions of sulfur oxides and chlorides would be limited to 0.1 and 0.02 pounds per ton of diapers destroyed, respectively. The profile of air emissions attributable to disposable diaper incineration has been estimated by Arthur D. Little and is provided in Table IV-2. The concentrations attributable to disposable diaper combustion are comparable to or lower than the amounts of these pollutants released in general refuse incineration. The majority of air emissions are non-toxic, environmentally safe materials, including nitrogen, oxygen and water.

Table IV-2: Gaseous Emissions from Disposable Diaper Incineration

Component	Emission Rate (pounds/ton diapers)
Nitrogen	15,000
Carbon Dioxide	3,600
Oxygen	1,500
Water	1,300
Carbon Monoxide	10
Nitrogen Oxides	3
Fly Ash	1
Sulfur Dioxide	0.1
Chloride	0.02

6. Landfilling

Early land-based disposal operations involved open dumping or burial of solid wastes. Later, some garbage dumps were burned to reduce the waste volume. These practices led to environmental and health problems, including air pollution, odor generation, groundwater contamination and the transmission of disease by rodents or other animals. In the 1930's, the American Society of Civil Engineers introduced an improved land-based disposal method, sanitary landfilling. This method utilizes engineering principles "to confine the refuse to the smallest practical area, to reduce it to the smallest practical volume, and to cover it with a layer of earth." More recently, landfill designs have become increasingly complex as the containment of leachate and runoff has been identified as an environmentally prudent course of action. Moreover, gases generated by bacterial degradation of solid wastes (e.g., methane), are being managed in increasing numbers of landfills. There are two basic methods of sanitary landfilling that are used alone or in combination. The area method is the least complex landfilling method, in that the solid waste is spread on the existing ground surface, covered with earth obtained from another location and compacted. This method can be used on flat or gently sloping terrain, as well as in land depressions such as valleys, quarries and ravines.

In the trench method of sanitary landfilling, waste is spread and compacted in a previously excavated trench. The soil obtained from the excavation is typically stockpiled and used as cover material for the landfilled waste on an as-needed basis. The trench can be as deep as soil and groundwater conditions allow.

The progressive slope or ramp method combines the area and trench landfilling approaches. The solid waste is spread and compacted on a slope. At the end of the workday, an excavation is made directly in front of the waste slope to obtain the required cover material. Waste will be placed into the excavation and applied to the slope during the following day's operation.

Improperly designed landfills have been shown to contribute to water pollution, as hazardous or toxic chemicals are transported via runoff or leachate into receiving water bodies or groundwater. However, engineering controls are available to alleviate these environmental problems. Landfills must be sited in areas where the geology and hydrology do not promote contaminant transport. Engineering practices to reduce the potential for contaminant transfer include proper compaction of base soils, installation of clay or membrane liners, installation of leachate collection/treatment systems, and pumping out the groundwater in the vicinity of the landfill to lower the water table and to create an additional soil filtration distance between the landfill and the groundwater.

The plastic components of disposable diapers are essentially inert in landfills, while the paper components may be subject to degradation, volatilization and leaching. Cellulose may be incorporated into bacterial protoplasm, particularly in the presence of a nitrogen source such as urine and feces. Cellulose decomposition can release carbon dioxide, methane, ammonia and nitrogen. Although some biodegradation can occur over time, landfills are specifically designed in a manner that minimizes the presence of oxygen and water which are critical to the process. Cotton fabric may also decompose and be incorporated into microbial protoplasm in landfills, releasing carbon dioxide and other decomposition products. Since these materials are not generally disposed of with feces or urine, but rather as rags, the nitrogen required to promote bacterial degradation of cloth diapers is limited in the landfill. Degradation of cotton diapers would, thus, be expected to be somewhat slower than that of disposable diapers. Bacterial decomposition products may include methane, nitrogen, and ammonia. Hydrogen sulfide and mercaptan may be formed through degradation of trace sulfur impurities in these wastes.

7. Waste Collection.

Municipal solid wastes are commonly collected at their source by municipal governments or by private collection firms under contract to these governments or specific waste producers. Private contractors are, by far, the principal collectors of municipal solid waste.

In urban or suburban areas, residential wastes are typically collected from individual residences or groups of residences. Collection practices are highly variable, both in terms of frequency and approach. Residential refuse from single family homes is typically collected either on a weekly or twice-a-week basis. The wastes may be collected at the curbside, or the collection personnel may be required to retrieve the refuse from the storage site. In rural areas, residents may be required to transfer their wastes to a central collection point. Multifamily dwellings and commercial, institutional or industrial facilities may require more frequent waste collection. Since the majority of post-consumer diapers are collected from homes, the following discussion of diaper collection will focus on residential requirements.

The enclosed-bodied compactor truck is the most common collection vehicle for municipal refuse such as post-consumer diapers. These trucks compress the wastes to reduce their volume, in keeping with sound economic and environmental practices. A wide range of truck sizes is available, with capacities of 20 to 25 cubic yards representing the most common sizes. Compactor trucks are operated by crews typically ranging from one person to three people, depending on the truck design, degree of mechanization, labor contact conditions and other relevant factors. Except for the driver, collection crews have significant nonproductive time during the period when wastes are transported to the disposal facility. For this reason, side- or front-loading vehicles that can be operated solely by the driver are gaining acceptance. Collection vehicles are also being equipped with mechanical devices to eliminate the need for manual refuse pickup, thereby reducing the collection crew to the driver only. In spite of these advances, the average collection crew is currently comprised of two people.

Municipal solid wastes are commonly transferred to the disposal site using the collection vehicles. This may, however, prove to be excessively costly, particularly when the disposal site is located far from the point of collection. It may also cause undue traffic congestion in and around the disposal facility. To alleviate such problems, transfer stations are incorporated into some waste management systems. Local collection vehicles are thereby able to transfer their loads to larger haul vehicles that will transport the wastes to the final disposal site. This encourages more effective utilization of collection vehicles and their crews for collection activities, while larger, more efficient tractor trailers, trains or barges are employed for waste transport.

Municipal solid waste collection is highly labor intensive. The principal resource consumed in this operation is the diesel fuel used to power the collection vehicles. Fuel consumption is highly variable and is dependent on a variety of factors including distance to the disposal or transfer facility, population density and collection method. For a suburban neighborhood located roughly 30 miles from the disposal site, fuel consumption would be on the order of 2.5 to 3.0 gallons per ton of waste collected. Environmental emissions are generally limited to exhaust from transport vehicles.

V. Resource and Environmental Analysis of Diaper Usage

This section compares the resource consumption, energy characteristics and environmental impacts associated with disposable diapers and reusable cloth diapers. The scope of our analysis includes the manufacturing, use (including laundering) and disposal of these products. Using the data discussed in Sections III and IV, the resource and environmental impacts were determined on the basis of the weekly diaper usage of an average-sized child of diapering age. As cloth diapers are either laundered in the home or by a commercial service, the resource and environmental impacts from both operations were calculated. The combined impacts from home and commercial laundering were then averaged on the basis of relative market shares of 90 and 10 percent, respectively. The specific process steps that were considered in the evaluation are shown in Figures V-1 and V-2.

The goal of this analysis is to provide a general guideline to compare the resource and environmental impacts of diapering alternatives and does not attempt to place an absolute value on these impacts. The analysis is primarily a quantitative comparison of eight resource and environmental categories as shown in Figure V-3. The resource input categories include the consumption of raw materials, water, and energy. The environmental output categories include air emissions, waste water effluents, process solid wastes, hazardous wastes, waste oils, and post-consumer wastes. The individual categories were selected to provide a relatively equal ground of comparison.

A. Parameters of the Environmental Analysis

1. Raw Materials

The quantities and types of raw material inputs to each process were defined in terms of a given product output. Raw materials are considered to be those materials that are intended to become a part of the final product and do not include the materials consumed during the growing and extraction of raw materials. For example, the fertilizer, insecticides and herbicides used to grow cotton are not considered to be raw materials for the purposes of this analysis. Within this category, the amount of renewable and nonrenewable resources were estimated. Impacts from materials that comprise less than five percent by weight of the final product and packaging were not included.

2. Energy

The energy required for each process was calculated and converted to a common British thermal unit (Btu) basis. Fuel and electric power were considered in this analysis. Transportation energy was considered for the use and disposal of the diapers only; our study does not include transportation energy consumed during material extraction, processing or product distribution, (e.g., energy consumed in the importation of cotton from China or in the transportation of logs to a pulp mill were not considered).

Figure V-1: Process Steps for Disposable Diapers

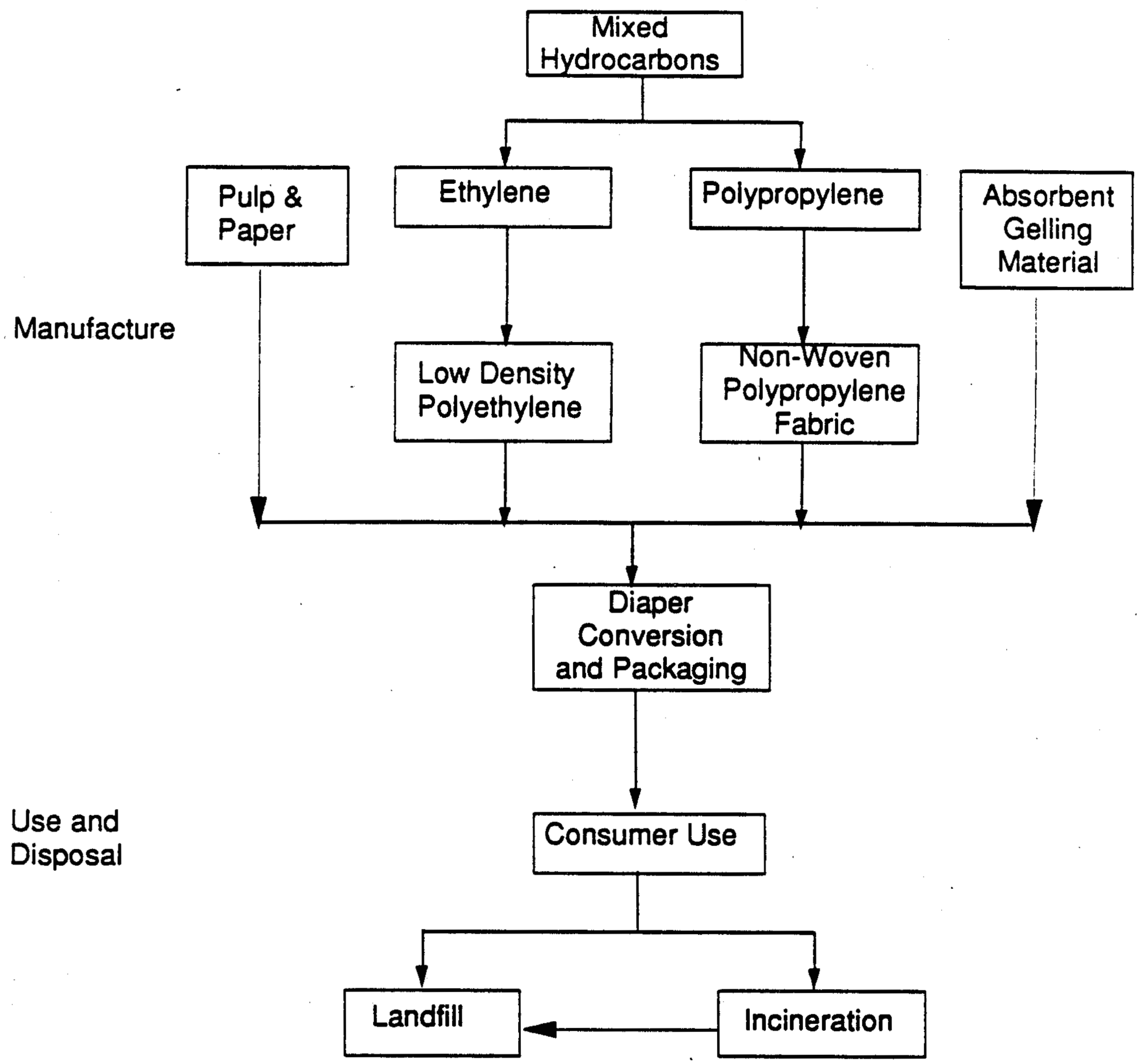


Figure V-2: Process Steps for Reusable Diapers

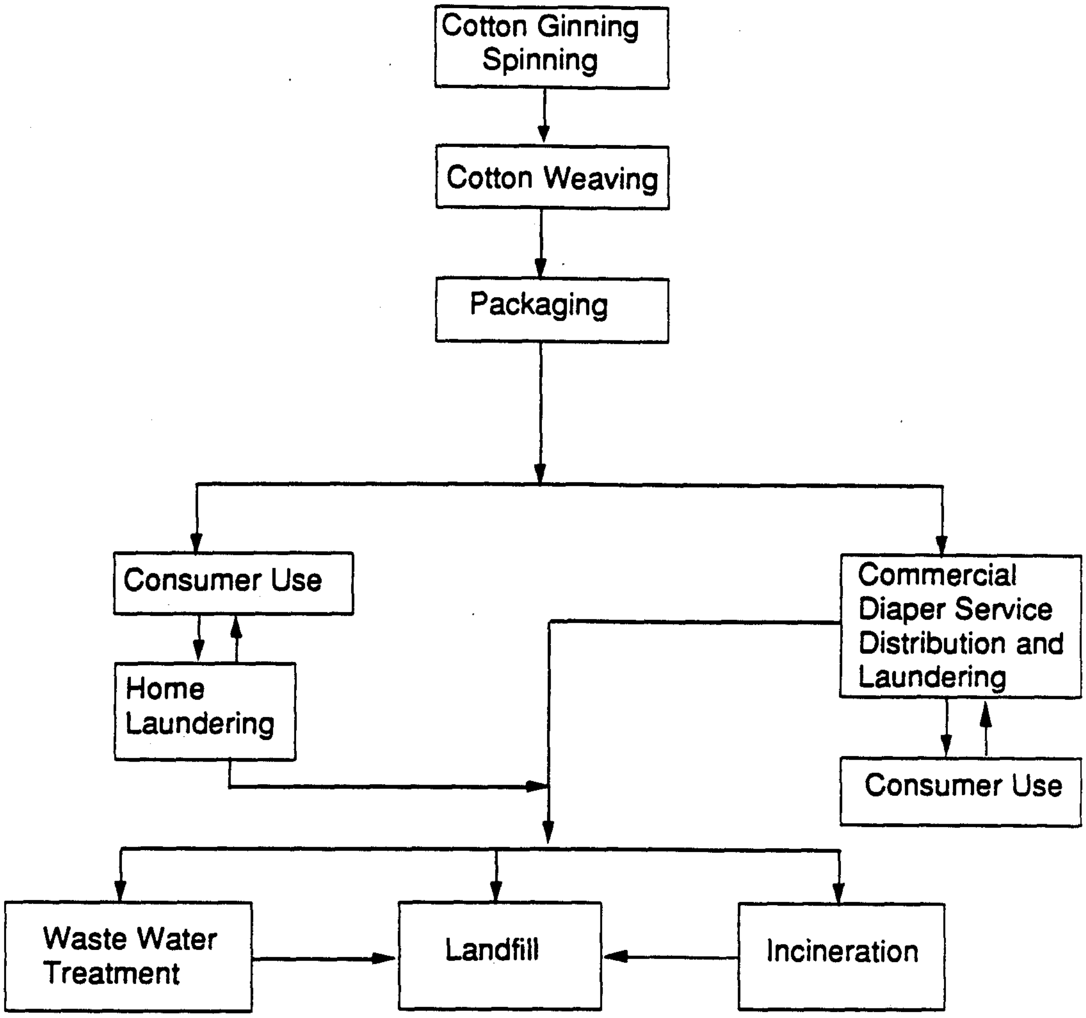
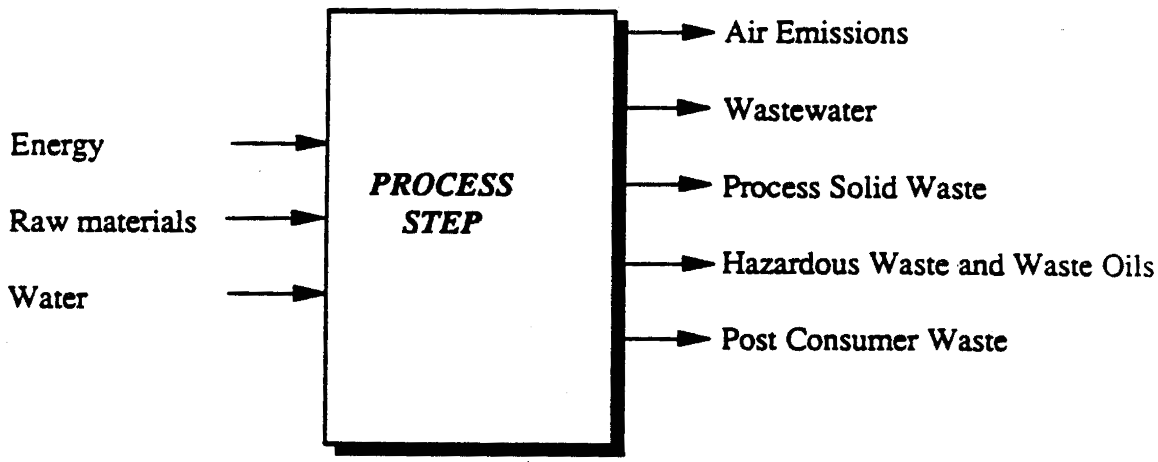


Figure V-3: Resource and Environmental Impact Categories



There are four groups that are potentially at risk from using or being exposed to the contents of disposable and reusable diapers. These groups are (1) the individual users, both infants and adult incontinents, (2) family members and close contacts, (3) persons who handle diapers in their work places such as employees in day care centers, nursing homes, and laundry and waste disposal services and (4) persons living near uncontrolled solid waste landfills.

Our approach for evaluating potential health impacts has involved assessing how these various groups of people could be exposed to hazards by developing simple exposure scenarios. Then, we addressed the potential health impacts that could result from these exposures and, finally, assessed whether the risks differed depending upon the type of diaper used.

A. Individual Health Impacts

Individual users of diapers include infants and older adults who suffer from incontinence.

1. Infant Diaper Dermatitis

Common diaper dermatitis is a group of skin disorders that result from attack of the skin by physical, chemical, enzymatic, and microbial factors in the diaper environment. These include excessive skin hydration, increased skin pH, attack by fecal enzymes and other irritants in urine and feces, mechanical abrasion, and infection by *Candida albicans* (Berg, 1987).

Infants typically use diapers from birth to about 30 months of age. Prompt changing of wet or soiled diapers is generally regarded as important in the control of diaper dermatitis. However, the ideal of changing the diaper immediately following each wetting or soiling is rarely met. Newborns urinate more than 20 times per day, and infants one year and older average 6.5 urinations per day (Shepard, 1968). The average frequency of diaper changes falls short of these numbers, particularly among younger infants. In a market research survey study involving 2,358 infants, change frequencies ranged from nine to ten per day at one to three months, to four to five per day at later stages of diapering (Procter & Gamble, 1986). Diapered skin is therefore frequently exposed to irritant materials in urine or feces, often for prolonged periods, particularly during overnight use.

A disposable diaper habits and practices study (Procter & Gamble, 1986) indicates that the daily use of reusable diapers is almost twice as great as for disposable diapers. However, the study also found that the number of changes per user per day is only slightly larger for reusable types. This is due in part to the practice of doubling or tripling cloth diapers to increase absorbency and achieve a snugger fit on smaller infants. Also, the difference in diaper change rates observed in this study may be due to an association between frequency of leakage and frequency of changing, suggesting that reusable diapers have a greater tendency to leak. Although protective cover pants help contain leakage, disposable diapers still result in a lower changing rate. Clinical and epidemiologic studies indicate that disposable diapers containing absorbent gelling material (AGM) reduce the risk of diaper dermatitis compared to home-laundered cloth diapers and non-AGM disposable diapers (Austin, et al., 1988; Campbell, et al., 1987, 1988; Seymour, et al., 1987a, 1987b).

For example, Campbell, et al., (1987) conducted a series of clinical trials involving 1,614 infants divided into AGM disposable, non-AGM premium disposable, and home-laundered cloth diaper user groups. The use of AGM disposable diapers resulted in significantly reduced skin wetness and closer to normal skin pH when compared to the wearing of conventional disposable or home-laundered cloth diapers. The AGM disposable diapers were also associated with a significantly lower incidence and severity of diaper dermatitis. Similar results were obtained in a study involving infants with atopic dermatitis (Seymour, et al., 1987a, 1987b). These studies did not include diaper-service cloth diapers, so it is not possible to evaluate the influence of laundering effectiveness and how the potentially elevated microbial loading in the home-laundered diaper may have interacted with increased exposure to wetness and elevated pH. There is some evidence that home-laundering is a risk factor. An uncontrolled study by Grant, et al. (1973), reported that diaper service reusable diapers and the early (non-AGM) brands of disposable diapers were associated with equivalent prevalence rates of diaper rash (24.4 percent and 25.0 percent, respectively). In contrast, home-washed diapers were associated with a rash prevalence of 35.6 percent. However, skin wetness and contact with urine and feces are key factors in the etiology of diaper dermatitis, and the method of laundering of cloth diapers would not be expected to affect these factors. Additives used by commercial laundries, such as antimicrobials and buffers, may reduce contamination; however, their direct effect on skin health has not been investigated.

Austin, et al. (1988), in a survey of more than 10,000 infants in 36 pediatric offices, demonstrated a significant reduction in the prevalence of diaper dermatitis among infants who were reported to be users of AGM diapers compared to users of premium disposable, cloth, and other disposable diapers. For AGM users, approximately seven percent of infants were reported to have diaper dermatitis. Among premium non-AGM disposable diaper users, the prevalence was about nine percent and about ten percent for cloth diaper users. The prevalence was 15 percent among users of other disposable types. Again, no distinction was made between cloth diapers which were home-laundered and those which were processed by a diaper service.

The prevalence of skin problems other than diaper dermatitis followed a similar pattern increasing from 3.3 percent among AGM users to 3.8 percent for premium brands, 3.7 percent for cloth, and 4.4 percent for other disposable brands. These results were interpreted as additional evidence of a beneficial effect of AGM diapers; however, they could also be indicative of a confounder such as poor hygienic practice or less frequent changing of diapers. In the absence of evidence regarding the effects of these potential confounders, it appears that the AGM type of disposable diaper provides a significant reduction in the prevalence of diaper dermatitis and other skin problems in infants.

The importance of diaper change rate has been demonstrated by Jordan, et al., (1986). In a study of 1,089 infants, the prevalence of more severe rash was significantly lower when the mean number of reported changes per day was above average. A related study examined the prevalence of rash and the relationship with type of diaper used and the presence of diarrhea. The results indicated that the AGM and premium non-AGM disposable brands resulted in a lower prevalence of rash than did cloth or other disposable brands among healthy children (Austin, et al., 1988).

Benjamin, et al., (1987) reported that the results were somewhat different among children with diarrhea. In that situation, the prevalence of skin rash for cloth diaper users was essentially the same as the rates for AGM and premium diaper users. The rate for users of other disposable brands was about 68 percent higher than the rates for the cloth, AGM, and premium groups. Again, there is no information about relative rates of diaper changing or about the socioeconomic status and hygiene practices of the study participants. It may be that the leakage from cloth diapers resulted in a relatively greater increase in the change rate than occurred for disposable brands, thus reducing the usual differential in risk associated with exposure to rash-causing conditions.

The overall model of diaper dermatitis suggests that it is a condition with a multifactorial etiology (Berg, 1988). It has been described as an episodic disease that is caused by a combination of physical, chemical, enzymatic, and microbial factors. Prevention occurs by preventing excessive skin hydration, maintaining skin pH at normal physiologic levels, and minimizing interaction of urine and feces (Berg, 1987). This can be achieved by assuring frequent diaper changes and by using a product like the AGM diaper which minimizes contact with the liquid contents of the diaper and promotes a more normal skin pH.

2. Adult Incontinence

Urinary and fecal incontinence occurs in 10 to 20 percent of the population older than 65 years and 40-50 percent of elderly persons living in nursing homes (Ouslander et al., 1982). In a study of seven nursing homes, in which 50 percent or 419 persons were found to be incontinent, 72 percent had more than one episodes of fecal incontinence. In terms of severity, 55 percent of incontinents living at home are classified as having severe conditions. For persons living in institutions, two percent are classified as having light conditions and 70 percent are classified as having severe conditions (Ouslander et al., 1982).

Incontinence is managed, in part, by the use of specialized protective clothing and bedding including undergarments, sanitary napkins, bed pads, and disposable briefs. Limited research on disposable briefs suggests that they represent a dramatic improvement over the other methods of control resulting in an improved quality of life for both institutionalized and non-institutionalized persons. In a study of 149 totally incontinent patients in seven Florida nursing homes who tested the Attends brand of disposable briefs, 40 of 53 who were judged to be sufficiently alert for evaluation were found to have an improved quality of life as a result of using the product. Seven of the 53 objected to the concept of wearing a diaper and the remainder were judged to have no change in their quality of life (Beber, 1980). Perceptions of the nursing home staff were cited as being favorable, indicating that use of briefs resulted in reduced workload for the staff, improved mobility for the more capable patients, and improved quality of the nursing home environment.

No research was available regarding transmission of infectious diseases between nursing home residents or between residents and staff, however if any risk is present, it seems reasonable to assume that it would be reduced with better control of feces. Probably the greatest advantage of improved containment of urine and feces in adult incontinents is the physical and psychological benefits of enhanced mobility.

B. Family Members: Caregivers and Siblings

The fecal contents of diapers represent a potential hazard for family members and other primary adult caregivers as well as for siblings. The hazard results from the presence of pathogenic microbes in feces and poor hygienic practice in changing and handling diapers and related materials such as washcloths and wipes. Potential exposure to fecal material is a common occurrence in the typical household and is directly related to the frequency of bowel movements and the frequency of diaper changing. Jordan et al. (1986) in their study of diaper dermatitis in a population of 1,089 infants, ages one to 20 months, provided data on the distribution of bowel movements. In this population, the mean number of bowel movements per day was 2.4 with 4.4 percent of the infants having four or more bowel movements. Thirty-three percent of the infants were reported to have one or fewer bowel movements per day.

In an experimental study, Berg (1989, unpublished) showed that cloth diapers were more likely to leak and, upon leaking, the volume of leakage was greater than for disposable diapers. In this study, only eight percent of the disposable diapers leaked, while 50 percent of the cloth diapers leaked. Peterson (1974) collected disposable diapers from a municipal solid waste facility for a study of viral contamination. The author reported that 33 percent of the diapers studied contained fecal material with an average weight of 60 grams. The fecal contents of diapers contain a wide variety of bacterial, viral, fungal, and parasitic pathogens not unlike the microorganisms found in adult feces (Scherago, 1972; Pahren, 1987; and Sobsey, 1989).

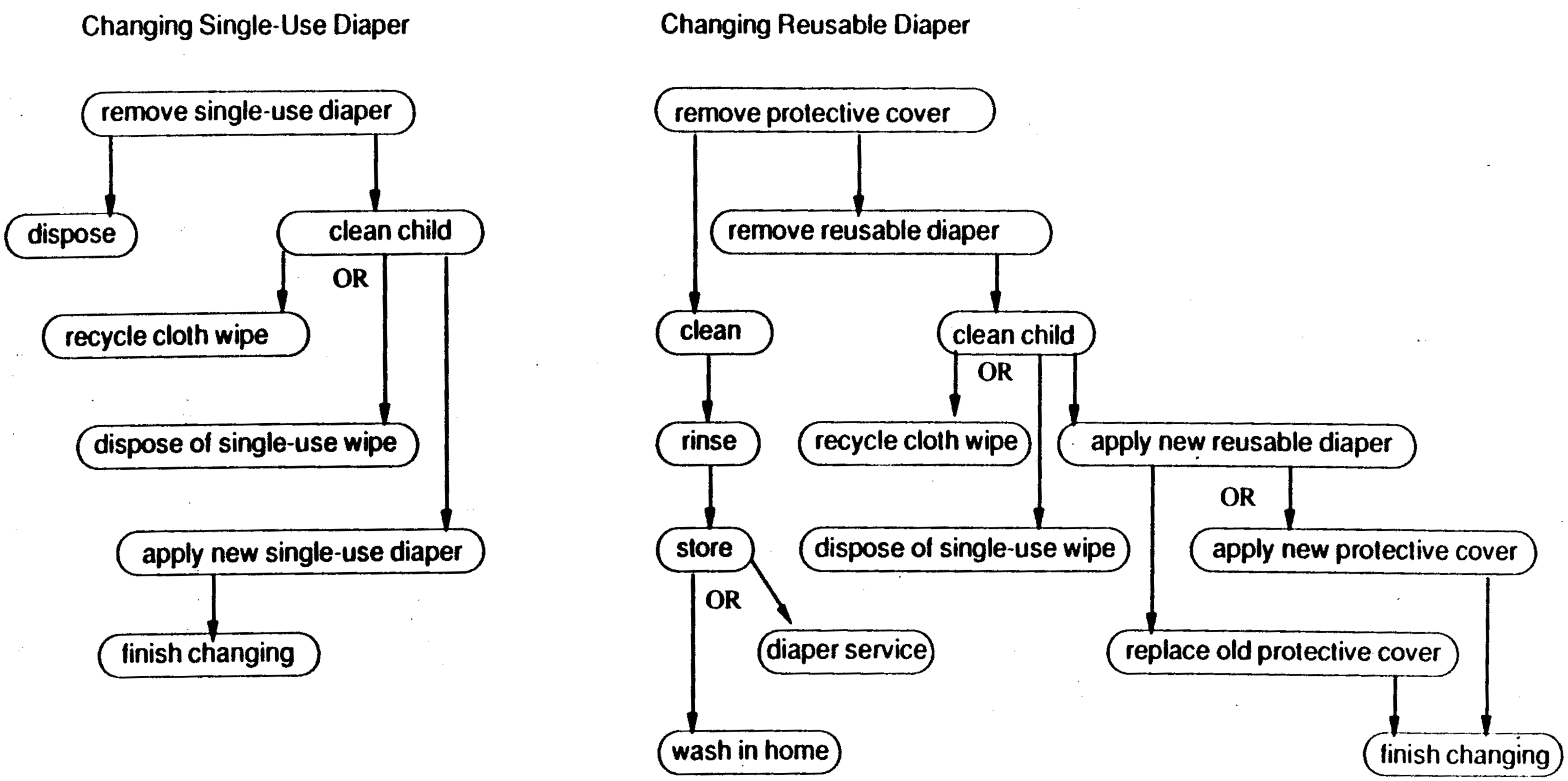
1. Exposure Among Parents and Other Caregivers

In the home, parents and other caregivers, who may be other adults or older children, are responsible for changing diapers. This may occur at a dedicated changing table or at other locations inside and outside the house. The process of changing is illustrated in Figure VI-1 which shows that the process is somewhat more complicated for reusable diapers than for disposable diapers. The additional steps required with reusable diapers involve the use of protective rubber, wool, or cloth pants and the steps required to rinse, store, and clean the diapers.

All of the steps involved in changing diapers, whether they are disposable or reusable, can be conducted with a minimal degree of exposure to fecal material and the use of good hygiene can eliminate the potential adverse effects if such exposures do occur. Nevertheless, in terms of comparative risks, reusable diapers clearly represent a greater potential risk than the disposable diapers because there are more opportunities for exposure in handling protective covers and soiled diapers and the frequency and magnitude of leakage is greater.

Also, reusable diapers which are laundered at home are a potential hazard for the household if washing is conducted in sinks or washing machines used for other purposes under conditions which fail to inactivate the microbial population (Arthur D. Little, 1977). For example, washing diapers in domestic washing machines could result in contaminant of subsequent batches of laundry. Such contamination also can occur regardless of the type of diaper used. For example, hand cloths and towels used for cleaning infants and soiled infant clothing can contaminate sinks and domestic washing machines. Scherago (1972) reported that even unapparently soiled clothes can harbor microorganisms for days and that relatively harsh conditions such as pasteurization or chlorination are required to inactivate certain pathogens. Lehrburger (1988) also recognized the risks associated with home laundering of diapers citing handling of soiled diapers, washing diaper covers in the sink, and failure to achieve sufficiently hot washing conditions as activities which contribute to the potential for infection.

Figure VI-1: Diaper Changing Process



2. Exposure Among Siblings

Young siblings can be exposed to fecal material either by direct contact with an infant wearing leaking diapers or by contact with surfaces contaminated by leaking diapers. They also can be exposed indirectly if sinks or domestic washing machines are contaminated by fecal material resulting in subsequent contamination of their clothing or other household items. In part, the risk to siblings is related to leakage which can occur with either disposable or reusable diapers. However, the exposure pathways associated with home washing of reusable diapers are unique to that product.

C. Occupational Health Impacts

There are four principal occupational groups which are potentially at risk from handling diapers on the job. They are employees of day care centers, nursing homes, laundry services, and sanitation or waste disposal services. In addition, the children who attend day care centers, the residents of nursing homes, and their intimate contacts are also at risk.

1. Day Care Centers

Day care centers provide care for infants and children up to about five years of age. Some centers restrict their admissions to children above a certain age such as 18 months, while others accept all ages. In 1986, approximately five million children received full or part-time care outside of the home and the size of the population was projected to be 6.3 million in 1990 (Haskins and Kotch, 1986). In 1982, more than one million persons were engaged in providing care for these children (Pickering and Woodward, 1982). Data from the Bureau of labor Statistics indicate that in 1983, of the slightly more than one million persons providing day care, 61 percent provided care outside of private homes. By 1989 the number of day care workers had grown to 1.2 million and the proportion working outside of private homes had increased to 71 percent (U.S. Department of Labor, 1984, 1990).

The day care center provides an environment which promotes person-to-person transmission of infectious diseases including those which are spread by the respiratory route and by the fecal-oral route. Pickering et al. (1981), in one of the first prospective studies of diarrhea in day care center children, families, and employees reported that during the 19 month study period, nine of 20 centers studied experienced a total of 15 outbreaks of diarrhea. Of 471 persons at risk during these outbreaks, 195 became ill yielding a diarrhea attack rate of 41 percent.

The infectiousness of fecal material depends upon the type of pathogen present. Shigella and Giardia lamblia require a small inoculum to produce disease and so are often associated with person to person spread while salmonella, Escherichia coli, and Vibrio cholerae require a larger inoculum and are often spread through contamination of food or water (Pickering and Woodward, 1982). The size of the inoculum of rotavirus or Norwalk virus required to produce disease is unknown. Keswick et al. (1983) have reported that up to 10^{10} rotavirus particles per gram of feces can be shed by children with diarrhea. They also demonstrated that viruses can remain viable on environmental surfaces long enough to represent a source of infection for children. In a limited sample, the authors found that 16 percent of apparently clean surfaces in one day care center, including the refrigerator door handle, were contaminated with rotavirus. They also cited previous work which demonstrated that 13-17 percent of samples collected from toys, baby walkers, and teachers' hands were contaminated with diarrhea-causing bacteria.

The implications of this widespread contamination are an increased risk of illness for day care center participants, caregivers, parents, and siblings. For example, during Hepatitis A outbreaks, attack rates of clinical illness average 15-20 percent among household contacts of one to two year old day care children (Pickering, 1986). Similar or higher attack rates would be expected among day care center employees. The risk of diarrhea is reported to be 30 percent higher for children attending day care centers than for similar children cared for at home or in family day care. Haskins and Kotch (1986) report that attack rates during outbreaks of gastrointestinal illness are often more than 40 percent for children and 25 percent for adults.

Prevention of fecal-borne illness in the day care environment can be achieved by good hygiene which includes separating diapering areas from play areas, proper storage of soiled diapers, preventing fecal leakage from diapers and disinfecting hands and surfaces contaminated with fecal material. While most of the exposure opportunities are common to both disposable and reusable diapers, the additional potential exposures associated with handling the protective diaper cover and the soiled diaper suggests that the risk of illness should be greater when reusable diapers are worn.

An important concept to consider in evaluating public health control programs is that the goal of preventing illness can be achieved in several different ways. The basic principle is to break the chain of transmission. For example, in the case of fecal-oral transmission of pathogens in the day care setting, one could try to prevent fecal material from being contacted. Alternatively, one could try to decontaminate hands, surfaces, or objects as quickly as possible after contamination occurs. Another prevention strategy involves prophylaxis through immunization and, finally, one could prevent the adverse consequences of infection through prompt and effective treatment and isolation of persons who are infectious.

Usually, passive techniques which require little human intervention are the most effective. A relevant example here would involve not only preventing leakage from diapers, but also reducing the handling of soiled diapers. Disposable diapers require less handling and the plastic outer covers prevent direct contact with urine and feces. In addition, studies have shown a decrease in leakage and subsequent environmental contamination with disposable diapers (Berg, unpublished). More active approaches such as decontamination can also be effective. Black et al. (1981) demonstrated the effectiveness of a rigorous hand-washing program in preventing diarrhea in a day care center. In a trial conducted in four day care centers, the incidence of diarrhea in two control groups was nearly twice that in the two groups which implemented the hand-washing program. The incidence of diarrhea in the control group was 8.1 cases per 100 child-weeks of exposure compared to 4.2 cases per 100 child-weeks of exposure in the hand-washing group.

2. Nursing Homes

Nursing home employees must frequently deal with incontinent patients. In fact, 50 percent of the population in a typical nursing home is likely to have both urinary and fecal incontinence (Ouslander et al., 1982). Like the day care environment, poor hygiene on the part of residents and staff can lead to direct fecal-oral transmission of disease or indirect fecal-oral transmission through contamination of surfaces which could include bedding, furniture, and clothing. To the extent that disposable briefs can improve hygiene by providing greater control of feces, they will reduce risk in comparison to reusable products.

Kerchner and Eliopoulos (1988) conducted a trial of cloth diapers and disposable briefs among 321 incontinent residents of 4 long-term care facilities. The comparison involved a 4-week observation period during which residents used a cloth system consisting of cloth flat pads and pinned cloth diapers. The test involved a 4-week trial of *Attends* disposable briefs and washcloths. The observations during the trial involved diary studies, time and motion studies, and assessments of decubitus ulcers or pressure sores. The authors reported that the disposable product resulted in a substantial time savings in caring for incontinent patients. The average daily time requirement for incontinence care was 55 minutes per resident versus 29 minutes per resident with the disposable system. Facility staff reported that the disposable system resulted in less leakage, fewer clothing and liner changes, and less clean-up of urine on floors. On a weighted average basis, the incidence of leakage per incontinent resident per day was 2.7 with the cloth system and 0.6 with disposables. No information was provided to distinguish between leakage of urine and leakage of feces.

An additional advantage of the disposable system was a reduction in the frequency of changes. The diary data indicated that the cloth system was changed on average seven times per incontinent per day, while the disposable system only required 5.3 changes. This difference was attributed to the ability of the disposable system to contain its contents. Despite the reduced frequency of changes, the disposable system was associated with a substantial improvement in decubitus ulcers. From a baseline prevalence of 12 percent, after four weeks on the disposable system the authors reported that 85 percent of existing pressure sores improved, 58 percent of existing pressure sores healed completely and no new pressure sores developed.

3. Laundry Service Employees

Laundry service employees are potentially exposed to fecal material contained in reusable diapers during the cleaning process. According to Lehrburger (1988), parents are unaware that diapers do not need to be rinsed before they are picked up by a diaper service. Changing awareness could result in increasing the potential for fecal exposure in the laundry. While no information is available to evaluate the extent of exposure and subsequent illness, it is reasonable to assume that the hazard, while real, is manageable with training and compliance with requirements for good hygiene and use of protective clothing.

4. Waste Disposal Workers

Waste disposal involves two distinct activities: the collection of refuse containing disposable diapers and their disposal in municipal solid waste landfills or incinerators. Employees in either of these activities can be potentially exposed to fecal material by direct contact, through generation of aerosols, or through contact with contaminated leachate. Again, there are no data to evaluate the extent of exposure to fecal material from disposable diapers.

It is well known that municipal solid waste contains a wide variety of microorganisms including human pathogens from sources which include disposable diapers; paper products such as facial tissue; plastic, rubber and textiles; food waste; and sewage sludge. Solid waste also contains fecal material from domestic and wild animals that may contain human pathogans. Pahren (1987) reviewed the public health implication of microorganisms in municipal solid waste and reported that, while there was little information on this subject, there were no proven adverse effects from the microorganisms contained in the waste. Clark, et al. (1979) indicate that waste collection workers do not experience increased rates of viral infection despite handling waste which is likely to contain infectious material. A 1989 report to the Washington state legislature discussed disease risks among waste industry workers, stating, "To date, no comprehensive epidemiologically-sound study has been published to identify disease transmission" (Turnberg, 1989).

Sobsey (1989) in his review of the same topic points out that sewage sludge is often the major contributor of human pathogens to municipal solid waste facilities, along with infectious wastes from the health care industry, pet feces, soiled disposable diapers, and other household waste. Furthermore, he states that disposable diapers contribute a small proportion of the total load of pathogens in the solid waste system. Also, a panel of academic experts in environmental microbiology and infectious disease has determined that "based on existing data, the presence of soiled infant and adult disposable diapers in the solid waste stream does not pose a significant health risk to solid waste collection workers or landfill operators" (Procter & Gamble, 1989).

D. Environmental Health Impacts

The potential environmental health consequences of the disposal of disposable diapers result from the potential release of pathogens from landfills, through leachate or dust generation, and subsequent exposure in neighboring communities. The reviews by Pahren (1987) and Sobsey (1989) indicate that community infection from municipal solid waste landfills is unlikely. Sobsey (1989) states that it is not possible to make quantitative predictions regarding their behavior in the environment on the basis of previous studies. He concluded, nevertheless, that the risks associated with disposable diapers in solid waste are likely to be small due to containment, dilution, inactivation, and barriers to exposure. Also, a panel of academic experts in environmental microbiology and infectious disease has determined that "the existing data indicate that soiled infant and adult disposable diapers ... do not present a public health risk to the nearby community" (Procter & Gamble, 1989). In addition, Turnberg (1989) discussed the infectious waste risk to the community and stated, "A documented report of infectious disease transmission to the community resulting from improperly diseased infectious waste has not been identified by this study."

This section addresses the comparative economics of disposable and reusable diapers in home use. The comparison is based on their respective selling prices, laundering costs (of the reusable product), and the cost of disposal. Selling prices and costs are estimated national averages.

The analysis is based on published data and information obtained from commercial laundries, diaper services, diaper manufacturers, and diaper retailers. A significant body of original cost information was developed by Arthur D. Little in the performance of this assignment or related nonconfidential studies. All cost estimates are reported in 1989 dollars.

A. General Methodology

The costs that were considered in this analysis are listed in Table VII-1 and are based on the weekly diaper usage of an average child.

Although data indicate that disposable diapers are changed less frequently than reusable diapers, this difference in change frequency was not considered in these calculations. An average change rate of 6.4 diapers per day was used for both cloth and disposable diapers. Appendix A contains a discussion of the basis for assumptions relating to diaper use rates.

Table VII-1: Component Costs

Product	Initial Cost	Reuse Cost	Disposal Cost
Disposable Diaper	Purchase Price	None	Immediate Disposal
Reusable Diaper	Purchase Price (Amortized)	Washing, Drying, Preparation for Reuse	Ultimate Disposal

Selling prices for the respective products were obtained. The range was documented, as well as the typical or average price. For reusable diapers, two alternatives were considered: in-home diaper maintenance and diaper rental service. The reusable diaper model assumes that non-commercial laundering would be done at home, since this practice appears to be far more common than the use of a neighborhood laundromat. In addition, the average cost of using reusable cloth diapers was addressed, considering the relative distribution of home maintenance versus the use of a diaper rental service.

Finally, the cost for the disposal of the discarded product was estimated. This analysis considered the two most prevalent disposal methods in use today -- landfilling and resource recovery. Again, national average costs associated with typical methods of disposal were used as a basis for analysis.

This analysis considered not only the cost of the studied products but also their cost/performance characteristics. For example, it would be inappropriate to compare the cost of a single disposable diaper directly with the cost of a single cloth diaper, because two or three cloth diapers may be used at one time to diaper a child. For this analysis, Arthur D. Little estimated that an average of 1.9 cloth diapers is used per reusable diaper change. The weekly reusable diapering costs were developed on the basis of this cost/performance characteristic or equivalency factor.

B. Selling Prices

Disposable diapers are made in various sizes and weights, as discussed earlier in Section II of this report. The three principal sizes are newborn (the smallest), daytime, and overnight or toddler; actual dimensions vary with the manufacturer, and each size is sold in two or more weights. The cloth diapers made by a given manufacturer may vary in terms of size and weight, and other brands may also differ in these characteristics.

The range in diaper selling prices is even greater than the range of their physical characteristics. Table VII-2 shows the breadth of the price range for diapers in the metropolitan Boston area. These numbers generally are believed to be representative of the ranges elsewhere in the country, although regional pricing factors may cause some variations. The following are points for consideration in this analysis:

- Unless there is a specific reason for using only one brand of disposable diaper, such as fit or skin care, consumers of disposable diapers have limited brand loyalty. They are willing to use two or three different brands, depending on which has the best price.

- Consumers of all diaper products practice comparison shopping and bargain hunting. The only exception to this appears to be emergency situations when the need is urgent and the source of supply is limited.

- The practice of redeeming coupons is pervasive in the disposable diaper product. According to the marketing literature (and verified by the manufacturers) virtually all purchases of disposables are accompanied by

Table VII-2: Observed Range of Diaper Purchase Prices

Retailer & Brand	Size	Count	Price	Unit Price
Disposables				
Store A				
Pampers Ultra Plus,	Small	60	$ 9.99	$0.17
Pampers Ultra Plus,	Large	32	9.99	0.31
Pampers Ultra Plus,	X-Large	28	9.99	0.36
Store B				
Pampers Ultra Plus,	Medium	44	10.49	0.24
Pampers Thick Plus,	Medium	48	10.49	0.22
Store C				
Pampers Regular,	Medium	48	9.99	0.21
Store B				
Huggies Supertrim,	Medium	44	10.49	0.24
Store C				
Huggies Thick,	Medium	44	9.99	0.23
Store B				
Luvs Deluxe Girl,	Medium	44	10.49	0.24
Store C				
Luvs Deluxe, Boy,	Medium	44	9.99	0.23
Biodegradable				
Store B				
Nappies,	Medium	44	8.99	0.20
Cloth				
Store B				
Birdseye flat,	one size	12	11.99	1.00
Curity prefolded,	one size	12	11.99	1.00
Store D				
Birdseye prefolded,	one size	12	10.94	0.91
Birdseye flat,	one size	12	9.94	0.83

Source: Arthur D. Little estimates.

coupon redemption ranging from $0.50 to $2.00. These coupons are traded extensively around the country.

- Diapers are sold in a wide variety of stores with a range of price reduction practices. In addition, some stores use their extremely low prices for disposable diapers as a loss leader to attract consumers.

- Within each store, diaper prices tend to be consistent among the brands and sizes. The selling price of a given product, thus, partly depends on where it is bought, i.e., drug store, discount store, supermarket, toy store, etc. It also varies with package size, region of the country, sale promotion "specials," and brand (major private-label). Consequently, apart from the obvious distinction between disposable and reusable diapers, an economic comparison must be based on a series of assumptions about size, brand, point of sales, etc. Since any number of assumptions may be used with equal validity, the findings of the analysis must be interpreted with reference to the assumptions actually used.

Table VII-3 specifies the particular products, selling prices, and assumptions used in making the economic comparison. Note that this table includes typical prices for diaper rental services. As will be explained in more detail in the discussion of amortization and laundering of reusable diapers, the price for rental services includes these two costs. Hence, for the reusable diapers provided by rental services, the listed prices are those paid to the rental service and represent a single use; they include the amortized purchase price, laundering cost, and disposal cost.

C. Reuse Costs

1. Home Laundering

The cost of laundering diapers at home has been calculated in detail to include capital requirements, maintenance, depreciation, laundry supplies, water, sewer, energy and labor. These costs do not include the laundering of plastic pants which would add to the final cost. This cost is based on assumptions chosen to be representative of general practices in the United States as discussed in Section IV. The computation reflects weighting based on estimated percentages of appliance ownership, and frequencies of laundry practices involving wash cycles, water temperature selection, laundry supply use, and drying.

The weighting of different factors in the laundering process allows the calculation of the requirements, outputs and costs of a composite load of laundry. The assumptions relating to procedures, energy and material usage, labor and equipment expenses were developed on the basis of available data and are Arthur D. Little

Table VII-3: Diaper Prices and Characteristics Used for Economic Analysis

Disposable Diaper

Size:	0.18 square yards
Weight:	0.12 pounds
Purchase Price:	$0.23/diaper
Number Required:	1.0 per change

Reusable Diaper

Size:	0.64 square yards
Weight:	0.13 pounds
Purchase Price:	$0.94/diaper
Life:	90 uses
Number Required:	1.9 per change

Plastic Pants (worn with reusable diaper)

Sizes:	small, medium, large
Weight:	0.05 pounds
Purchase Price:	$1.00
Estimated Number Used:	9 over 2.5 years

Note: Purchase prices for disposable and reusable diapers in the metropolitan Boston area were surveyed and form the basis for our cost estimates. This study considered the average surveyed purchase prices for medium sized disposable diapers and cloth diapers.

estimates. The laundry cost model is organized around the assumption that the average load of diapers weighs 4.3 pounds and is comprised of 33 diapers. Some of these diapers are washed alone, and some are washed with other baby items. These frequencies, as well as those involving other aspects of the home laundering model listed in Section IV are not intended to be precise indicators. Rather, they should be considered as valid general approximations of highly variable practices throughout the United States.

The cost of this load has been computed using three different wage factors. The total cost for laundering 85 cloth diapers, (i.e., the weekly average usage derived as the product of the average diaper changes per day [6.4], the average number of diapers used per change [1.9], and the number of days per week [7]) is $6.20, if no wage is assumed for in-home labor. At a wage of $3.35 per hour, the current national minimum wage, the cost rises to $12.07. If a wage of $6.00 per hour is paid, the cost climbs to $16.70.

The most significant cost factor is labor, which accounted for 49 and 63 percent of the total home laundering costs for the two options in which labor costs were considered. Laundry supplies represent 42 percent of non-labor costs, and presoak supplies represent nearly 74 percent of all laundry supply costs. The dominance of the presoak supplies is due to the high amounts suggested for presoaking by the manufacturers. Maintenance and depreciation costs each represent approximately another 43 percent of all non-labor costs. Energy contributes 8 percent to this total, while water and sewer together comprise of only 6 percent. The sewer cost component is based on the assumption that 74 percent of all households discharge to municipal sewer systems.

The equipment chosen as the basis for the home laundering calculations are all standard models. These include a 16 pound (2.3 cubic feet) clothes washer, a 6.75 pound capacity electric dryer, a 7 pound capacity gas dryer, an electric water heater with an 80 percent efficiency rating and a gas water heater with a 65 percent efficiency. Frequency of ownership for the dryers and water heaters were derived from published sources, as were the specifications for all models. The average capital costs associated with this equipment were estimated based on data published in Consumer Reports magazine, as well as interviews with dealers.

Depreciation was calculated by the straight line method over twelve years, with $50.00 salvage value for appliances. Annual maintenance was determined to be ten percent of the equipment purchase price.

Table VII-4 summarizes the results of the home laundry cost analysis for all cost elements other than labor. Table VII-5 adds the labor component, considering the

Table VII-4: Home Laundering Costs Exclusive of Labor

Basis: Laundering of 85 Diapers (i.e., Weekly Diaper Usage)

	Cost ($/week)	Percent of Non-Labor Costs
Water	$0.20	3.2
Sewer	0.17	2.7
Laundry Supplies	2.58	41.6
Plastic Pants	0.07	1.3
Energy	0.49	7.9
Maintenance	1.38	22.2
Depreciation	1.31	21.1
Total	6.20	100.0

Source: Arthur D. Little estimates.

Table VII-5: Home Laundering Costs Including Labor

Basis: Laundering of 85 Diapers (i.e., Weekly Diaper Changes)

Wage Rate ($/hr)	Labor Cost ($/Week)	Labor Percent of Total Costs	Total Laundering Cost (Week)
0.00	0.00	0	6.20
3.25	5.87	49	12.07
6.00	10.50	63	16.70

Source: Arthur D. Little estimates.

three labor wage rates described previously. Table VII-6 summarizes the costs estimated for home diaper laundering equipment.

2. Diaper Service

The cost for a commercial diaper service is given as $0.13 per diaper, or $11.05 per week. This is an average cost charged by diaper services in the United States, and is an Arthur D. Little estimate based upon discussions with diaper service operators. Plastic pants must be purchased by the consumer. As with home laundering, the cost of these pants has been calculated to be $0.07 per week. Thus, the total cost associated with the use of a commercial diaper service is $11.12 per week. This price reflects all consumer costs including diaper rental, transportation and laundering.

D. Disposal Costs

1. Collection

Municipal solid waste collection and transport costs vary due to differences in collection methods and distances between the collection area and the disposal site. For the purpose of this cost analysis, we have selected curbside collection in an urban or suburban setting as a typical collection scheme. The cost model considers the costs of a private collection firm handling 1,000 tons of residential refuse per day on a five days per week basis. Capital investment includes the costs of 98 collection vehicles (including spares) and supporting maintenance, parking and office facilities. Vehicle costs were obtained from vendor quotations. Construction costs were estimated on the basis of engineering judgment, using national average costs of site preparation, paving, and building construction.

Variable costs include operating labor and fringe benefits, utilities, vehicle maintenance and fuel. Labor costs account for over half the cost of collection, and collection crews comprise the majority of workers associated with waste collection. Two man crews are most common and were considered in this analysis. We used the national average wage rate for municipal sanitation workers, as reported in the U.S. Department of Labor's *Employment and Earnings* summary, to estimate collection crew labor costs. Supervisory and other personnel account for only two percent of the collection workforce. Their salaries were estimated on the basis of engineering judgment. Fringe benefits were estimated at 35 percent of the labor cost.

Fuel efficiency of collection vehicles is very low and is on the order to three miles per gallon. Considering a 100 mile collection and transport circuit, fuel costs were estimated using the average national costs for motor gasoline, $1.152 per gallon, as reported in the U.S. Department of Energy's *Monthly Energy Review*. Maintenance

Table VII-6: Appliance Purchase Costs

Washing Machine

Purchase price	$475.00
Installation	65.00
Sales Tax @ 8%	38.00
	$578.00

Electric Dryer

Purchase price	$405.00
Installation	75.00
Sales Tax @ 8%	32.40
	$512.40

Gas Dryer

Purchase price	$465.00
Installation	75.00
Sales Tax @ 8%	37.20
	$577.20

Source: Arthur D. Little estimates.

and utility costs were estimated on the basis of engineering judgement. Fixed costs include overhead, insurance, taxes, depreciation, interest, general and administrative expenses and capital related charges. Table VII-7 shown the basis for estimating fixed costs for curbside waste collection and disposal. Table VII-8 presents the cost data developed for curbside waste collection.

On average, 45 disposable diapers are disposed per week per child. The weight of these diapers and their associated wastes is estimated at 22.44 pounds, and includes 5.40 pounds of diapering materials, 0.86 pounds of packaging, 14.16 pounds of urine and 2.02 pounds of feces. The average cost of collecting and transporting disposable diapers to a disposal facility is estimated at $0.54 per child per week on this basis.

2. Landfilling

Municipal solid waste landfilling costs have risen dramatically in recent years, with 32 percent increases from 1987 to 1988 alone. As shown in Table VII-9, national average landfilling costs have demonstrated a constant upward trend during the latter part of this decade.

Landfilling prices show significant regional price differences, with those regions having the most severe landfill shortages exhibiting the highest average price. Regional average prices for landfilling range from a low of $13.06 per ton in the western United States, to more than three times that value, $45.48 per ton, in the northeast as shown in Table VII-10.

Regional capacity differences have the most significant influence on landfill price differences. A significant fraction of the nation's landfills are currently concentrated in relatively few states. Moreover, landfill capacity appears to be declining in real terms, since many landfills are reaching their design fill capacity, while new landfill construction has been curtailed. By 1990, nearly 55 percent of the landfills in operation today will be retired (EPA, 1988). This trend exerts further pressure on landfill prices. Moreover, it will increase reliance on non-local disposal, with accompanying high costs for refuse shipment.

The United States Environmental Protection Agency is developing new rules for landfill disposal. These rules will have a profound effect on landfill disposal costs, as a result of increased requirements for expensive environmental controls such as groundwater monitoring, liners, gas collection equipment and other similar controls. Most existing landfills do not meet these requirements. Approximately 27.3 percent of the landfills in use today incorporate clay or soil liners, only while 1.1 percent include synthetic liners (EPA, 1988). As existing landfills are replaced with more costly systems, the average landfill disposal price will continue on its current increasing course.

Table VII-7: Fixed Collection and Transport Cost Estimation Factors

Fixed Cost Element	Estimation Factor
Overhead	15 percent of operating labor plus maintenance
Insurance and Taxes	1.2 percent of total fixed capital
Depreciation	Straight line depreciation over the service life of vehicles and facilities, considering the salvage value
Interest	Average at 8.5 percent interest over service life with 25 percent initial equity
General and Administrative Expenses and Insurance	10 percent of variable costs plus taxes
Capital Related Charges	15 percent of averge equity (50 percent of total fixed capital plus working capital)

Table VII-8: Curbside Waste Collection Cost Model

Basis: 1000 tons of refuse collection per day, 5 days per week

Capital Investment

Garage/Offices/Parking	$ 1,295,000
Vehicles	8,935,000
Other Fixed Capital	240,000
Total Fixed Capital	$10,470,000
Working Capital	630,000
Total Capital Investment	$11,100,000

Annualized Costs

Variable Costs	
• Operating Labor and Fringe Benefits	$25.18/ton
• Maintenance and Utilities	2.88
• Fuel	3.08
Fixed Costs	
• Overhead	4.21
• Insurance and Tax-Related Charges	0.50
• Depreciation	4.08
• Interest	1.62
• General and Administrative Expenses	3.02
• Capital Related Charges	3.52
Total Annual Cost	$48.09/ton

Source: Arthur D. Little estimates

Table VII-9: National Average Municipal Solid Waste Landfill Tipping Fees

Year	Average Price ($/ton)
1988	26.93
1987	20.36
1986	13.43
1985	11.93
1984	10.59
1983	10.80
1982	10.80

Source: National Solid Waste Management Association Annual Tip Fee Survey, 1988.

Table VII-10: 1988 Regional Average Municipal Solid Waste Landfill Tipping Fees

Regional	1988 Regional Average ($/ton)
Northeast	45.48
South	15.87
1986	17.95
1985	13.06
Nation	26.93

Source: National Solid Waste Management Association, "Facts on File", Volume 2, Number 1, 1989.

It is not possible to project with certainty the future requirements or costs for new landfills. For this reason, our economic analysis considers only current landfill disposal costs.

The 1988 national average municipal solid waste landfilling cost was adjusted to $27.95 per ton to reflect current, i.e., 1989, economic conditions. This adjustment considered only inflation. Considering a disposable diaper waste generation rate of 22.44 pounds per child per week, the average current cost of landfill disposal is estimated to be $0.31 per child per week.

3. Resource Recovery

Resource recovery costs have not risen as dramatically as landfilling costs, but nonetheless have increased steadily in recent years, as shown in Table VII-11.

Table VII-11: National Averge Municipal Solid Waste Resource Recovery Tipping Fees

Year	Average Price ($/ton)
1988	39.86
1987	33.64
1986	30.42
1985	23.17
1984	17.36
1983	14.96
1982	12.91

Source: National Solid Waste Management Association Annual Tip Fee Survey, 1988.

The 1988 resource recovery fee was updated to a 1989 estimate of $41.37 per ton using standard inflation factors. The average weekly cost of incinerating disposable diaper wastes is estimated at $0.46 per child on this basis.

4. Disposal Cost Summary

Table VII-12 summarizes the cost components that were used to derive the total waste management costs for disposable and reusable diapers. This table is based on an assumption that all post-consumer diaper wastes are managed by landfilling and resource recovery and reflects the relative use of these two practices.

Table VII-12: Diaper Waste Management Cost Summary

Basis: Volumes and Costs Reported as Average Weekly Units Per Child

	Curbside Collection	Mass Burn Incineration	Landfilling	Total
Percent of Diaper Wastes to Specific Practice	100	7	93	100
Disposable Diapers				
• Volume Processed	22.44 lb	1.57 lb	20.87 lb	22.44 lb
• Cost	$0.54	$0.03	$0.29	$0.86
Reusable Diapers				
• Volume Processed	0.11 lb	0.01 lb	0.10 lb	0.11 lb
• Cost	$0.003	$0.00021	$0.001	$0.0042

E. Summary Cost Comparison

Table VII-13 summarizes the costs of diaper usage in a home application and indicates that disposables are economically competitive with reusable diapers under the $3.35 per hour home laundering wage rate scenario, and significantly more competitive under the $6.00 wage rate scenario on the basis of *cost per equivalent use*. Reusable diapers are more economical than disposable diapers only when the labor costs for their rinsing, soaking, washing, and drying are excluded. Table VII-13 includes a provision for some cloth diaper management by commercial diaper services (i.e., 10 percent).

While double and even triple diapering is practiced with cloth diapers to provide extra absorbance, the same effect is achieved by using an absorbent disposable diaper; the latter are available in weights ranging from 27 to 70 grams. In this cost analysis, we used 0.12 pound disposable diapers as the weighted average over the diapering age of the child.

The cost of using reusable diapers is also determined in this analysis. This cost is weighted to reflect nationwide frequencies of both home laundering and the use of a commercial diaper service. A hypothetical scenario was assumed (representative of diaper service market share) in which 90 percent of the consumers use purchased cloth diapers and a diaper rental service is used by the other 10 percent.

The specific costs derived above are based on particular site-specific assumptions. Other assumptions could have been used with equal validity and would affect the value obtained. To analyze a different situation, one need only substitute the appropriate costs, diaper sizes and weights, etc.; the basic method of calculation would be the same.

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Table VII-13: Cost Summary for Disposable Versus Reusable Diapers

	Disposable Diapers	Reusable Diapers[a] Scenario 1	Reusable Diapers[a] Scenario 2	Reusable Diapers[a] Scenario 3
Average Cost Per Child Per Week				
• Amortized Purchase Price	9.45	0.78	0.78	0.78
• Home Laundering	NA[b]	10.86	15.03	5.58
• Diaper Service	NA	1.11	1.11	1.11
• Waste Collection/Disposal[c]	0.86	neg[d]	neg	neg
Total	10.31	12.75	16.92	7.47
Basis of Estimate				
• Diaper Size (Square Yards)	0.18	0.64	0.64	0.64
• Diaper Weight (Pounds)	0.12	0.13	0.13	0.13
• Purchase Price ($/Diaper)	0.21	0.92	0.92	0.92
• Diaper Service Charge ($/Rental)	NA	0.13	0.13	0.13
• Reuse Frequency	NA	90	90	90
• Diapers Per Week	45	85	85	85
• Diapers Per Changes	1.0	1.9	1.9	1.9
• Home Laundering Labor Wage ($/hour)	NA	3.35	6.00	0.00

a. Reusable Diaper Costs reflect 10 percent use of diaper services. Scenarios 1 and 2 include the value of in-home laundering at $3.35/hour and $6.00/hour, respectively. The former is the current minimum wage rate, while the latter reflects a more typical value for this service. Secnario 3 excludes the value of in-home labor and is provided for comparative purposes only.

b. NA = Not Applicable

c. Disposal costs are based upon weighted average of current disposal methods of landfilling (93%) and incineration (7%).

d. neg = negligible

Source: Arthur D. Little estimates

Solid waste management is rapidly becoming an issue of national importance and is gaining significant public and governmental attention. Many initiatives are under consideration to relieve future stresses resulting from diminishing landfill capacity and resources. These initiatives focus on increased utilization of three waste management alternatives:

- source reduction,
- reuse, recycling, composting, and
- resource (i.e., energy) recovery.

In this vein, certain disposable consumer products have come under scrutiny. This report considers disposable diapers in comparison with their reusable counterparts.

It is important to note that the nation's solid waste management problem cannot be addressed through fragmented efforts aimed at only portions of the total solid waste stream. Instead, a concerted waste management program dealing with all facets of the solid waste problem is required. While source reduction, reuse, recycling, composting and resource recovery have their place in a comprehensive waste management scheme, a secure means of disposing of solid wastes must also be provided. The U.S. Environmental Protection Agency and a variety of state and local agencies are in the process of promulgating regulations aimed at improving the quality and environmental soundness of landfill and incineration disposal facilities.

Disposable diapers constitute a very small percentage of the nation's solid wastes. As such, they should not be singled out for unique consideration as post-consumer wastes, but rather should be treated as but one component of a much larger entity. Instead, as the Office of Technology Assessment notes in *Facing America's Trash* "a coherent strategy will be required to avoid the piecemeal approach of past MSW (Municipal Solid Waste) policies," (U.S. Office of Technology Assessment, October 1989).

More importantly, consideration of alternative waste management practices must include an analysis of life cycle concerns. In some cases, the use of disposable products could potentially provide advantages over their replacement by reusable alternatives. In the case of diapers, specific human health, environmental and economic advantages of disposable products would appear to outweigh the more limited advantages of the reusable diapering materials, as discussed below.

A. Health Issues

While much of the health risk associated with diaper use is manageable in theory through good hygiene, by preventing prolonged wearing of wet and soiled diapers, changing diapers before leaks occur, by decontaminating hands, surfaces and objects that contact fecal material, laundering adequately, and by proper containment of fecal material in soiled diapers, it is not always practical. Single-use diapers offer a better degree of protection than do reusable diapers. For example, single-use diapers that incorporate absorbent gelling material offer better protection against dermatitis than do other brands of single-use diapers or home-laundered reusable diapers.

For protection from infection in the home, day care, or nursing home environments, single-use diapers result in reduced opportunities for exposure when compared to reusable diapers. This is accomplished through superior containment and the elimination of the risks associated with home laundering, and the handling of protective covers and soiled diapers.

Occupational and environmental risks associated with laundering of reusable diapers and disposal of disposable diapers have been studied by governmental agencies, academic research scientists and health organizations (Clark, et al., 1979, Pahren, 1987, Sobsey, 1989). Their studies indicate that the presence of soiled diapers in the solid waste stream does not represent a public health risk and that available hygiene practices are sufficient to control any potential risk among other occupational groups that handle soiled diapers.

B. Environmental Issues

Neither disposable nor reusable diapers are clearly superior in all seven resource and environmental impact categories considered in this analysis. The primary difference is that the resource and environmental impacts from disposable diapers are generated before and after the productive life of the product. Conversely, the resource and environmental impacts from reusable diapers are almost exclusively generated during the productive life of the product. On an equivalent use basis, a life cycle comparison of disposable and reusable diapers indicates:

- Disposable diapers consume about 7 times the raw materials of cloth diapers and result in the generation of over 90 times the post-consumer solid waste;
- Reusable diaper use generates 50 percent more process solid waste than disposal diapers;
- Reusable diaper use consumes over three times more non-renewable energy resources and just over four times more renewable energy resources;
- Reusable diaper use consumes 6.1 times more water and releases nearly ten times higher levels of total water pollutants; and
- Reusable diaper use results in the emission of over nine times higher levels of total air pollution.

Since the relative importance of the various resource and environmental categories is subjective and highly variable from one location to another, this study did not assign a value to each category and thereby derive an overall numerical "rating" for inter-product comparison.

C. Economic Issues

Disposable diapers provide an economical method of dealing with infant incontinence and are generally less costly on a life cycle basis than their reusable counterparts. In fact, the only instance in which reusable diapers provide a competitive economic advantage is when the cost of labor for home laundering is not considered. While there have been numerous attempts at placing a value on home labor, no single equivalent wage rate has been universally adopted. Even at the prevailing minimum wage, in-home laundering labor costs contribute significantly to the life cycle cost of reusable diapers. In fact, reusable diapers are over 20 percent more costly than their disposable counterparts when home labor is valued at the minimum wage rate. When a more realistic in-home laundering labor cost of $6.00 per hour is used, the life cycle cost of reusable diapers is over 60 percent greater than that of disposable diapers. Diaper services generally provide a more cost effective approach to cotton diaper maintenance than in-home laundering. This is due primarily to economies of scale. Nonetheless, the use of a diaper service is slightly more costly than disposable diapers on an equivalent use basis.

D. Legislative Initiatives

Initiatives introduced in response to local solid waste problems are deflecting attention from the national scope of the issues and creating a great deal of confusion. Local initiatives such as imposing taxes or banning the sale of a particular type of item are frequently unsuccessful at eliminating the product from the waste stream. These measures, however, can increase the cost to the consumer to obtain the item locally or elsewhere. Governing bodies below the federal level in the United States are organized within 50 states; 3,139 counties, parishes and independent cities, 9,393 cities; and an additional 19,097 incorporated places. There is a potential for each of these 31,679 different political entities and their agencies to promulgate solid waste regulations.

Given this complex situation, manufacturers are left to deal with a variety of conflicting, and sometimes confusing, legislative initiatives. They will inevitably mount educational programs to inform their buying public of the issues and alternatives available to them and call for a rational approach to the larger problem. Advertising campaigns can be expected to emphasize the characteristics of their specific products which make them acceptable consumer choices. In the case of disposable diapers, these characteristics would include the health and containment aspects of the absorbent gelling material. The advertiser also can be expected to draw attention to the success of the absorbent gelling material and significant materials reduction efforts in minimizing the product's contribution to the waste stream.

We have learned from the experience of eliminating phosphates from detergents that the removal of one chemical or product from a waste stream will not solve a crisis of the magnitude of eutrophication of our national water supplies or the filling of our national supply of landfills. Most environmentally focused organizations and aware individuals know that solutions to the crisis in municipal solid waste management will have to be devised within the context of the overall quality of life of the citizenry at large; life cycle environmental, health and economic issues; and the availability of alternatives.

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Arthur D. Little determined base use rates for each diaper type which closely approximate the weekly number of diapers used by a consumer using only one type of diaper on a child. Previous studies and news articles on the subject have noted that mothers use both single-use and reusable diapers during the week. This practice is attributed to the convenience and/or increased absorbency of using single-use diapers during travel, shopping, overnight, and day care situations. In addition, the study chose frequencies which were conservative within these use categories. As a result, Arthur D. Little chose to make assumptions regarding diaper use which reflected the high end of average use estimates for each diaper type. These conservative assumptions are reflected in estimates for both daily diaper changes and the reusable diaper use rate per change.

Daily Diaper Change Frequency

The daily frequency for both diaper types was assumed to be 6.4 changes per day and was based upon data provided in a Procter and Gamble rebuttal of a 1987 Consumer Reports comparison of reusable and single use diapers. The data was taken from a Procter and Gamble research diary on Disposable Diaper Habits and Practices Study (1986).

The 6.4 changes frequency rate was actually identified with reusable diapers, while a 5.4 changes frequency rate was assigned to single use diapers. ADL determined that it would adopt the 6.4 changes per day rate for both diaper types in order to establish a conservative assumption for single-use diaper usage.

Reusable Diaper Usage Rates

Arthur D. Little has estimated use rates of 1.9 diapers per change and 85 diapers per week for reusable diapers. The decision to use these figures followed consideration of information provided in the Procter and Gamble market study cited above, and interviews with mothers and diaper services.

The Procter and Gamble report cited an average number of diapers used per change of 1.5 and a total usage of 68 per week. These figures are stated as averages and in all probability include mothers using both single use and reusable diapers. All interviews conducted with mothers with mothers using reusable diapers indicated that two diapers were used per change in order to prevent leakage. Diaper services indicated that the high end of the use range was approximately 80-90 per week, although they noted that at this use rate a few of these diapers might be used for purposes other than diapering. These uses would include use as a pad on a changing table, and as a cloth used during burping and feeding. These diapers are still washed by the diaper service, however, and represent a component of the weekly diaper wash load. Assuming the midpoint in this range, i.e, 85 diapers per week, and a factor of 6.4 changes per day, the number of diapers used per change is 1.9.

It is important to note that reusable diaper use rates fluctuate significantly with varying assumptions of the frequency of single-use diaper usage. Assuming between 1.5 and 2.0 reusable diapers per change, and the use of one single-use diaper per day during activities such as travel, shopping, and/or day care, 7 single use diapers replace between 10 and 14 reusable diapers per week.

Arthur D. Little performed a sensitivity analysis as part of its work to identify an acceptable rate of diapers used per change. A reduction in this assumption from 1.9 to 1.8 lowers total weekly diaper use by approximately 5 percent. For the home laundering model, this change produces a negligible effect on the resources, time, and energy required. This is due to the small decrease in total diapers used and the fixed requirements of any given washing machine cycle. For families using a commercial diaper service, this reduction represents a 5 percent cost savings. After considering this analysis, as well as information from a variety of sources as detailed in this Appendix, Arthur D. Little concluded that a conservative estimate of consumption by a child using only reusable diapers is 1.9 per change and a total of 85 diapers per week.

Equipment

Washer:

16 lb. or 2.3 cu. ft. (tub size) washer with basic cycle (wash and one rinse) water consumption of 43.7 gals.; one complete fill of tub is 19.2 gals. Medium water level is 90% of full load water requirement; small loadwater level = 80% of full load water requirement. Energy consumption is .216 kWh for full cycle, one rinse.

Electric Dryer:

6.75 lb. capacity; 2.51 kWh/dryer cycle; Avg. 4.3 lb. diaper load is 64% of full capacity. Frequency in the home: 45%.

Gas Dryer:

7 lb. capacity; 9910 gas BTU/dryer cycle; Avg. 4.3 lb. diaper load is 61% of full capacity. Frequency in the home: 16.5%

Electric Water Heater:

.806 efficiency (std. efficiency) @ 372744 BTU input/week; 3.494 kWh/full washer load; cold rinse. Frequency in the home: 47%.

Natural Gas Water Heater:

.553 efficiency (std. efficiency) @ 542804 BTU input/week; 17370 gas BTU/full washer load; cold rinse. Frequency in the home: 53%.

Sources:

Dryer and water heater frequencies in homes: Appliance Magazine, Sept. 1989.
Dryer energy requirements: Association of Home Appliance Manufacturers.
Water heater energy requirements and efficiencies: Consumer Reports, Jan. 1986.

Diaper Wash Load Practices

Diaper Load

Average diaper wash load is 4.3 lbs.; average diaper weight is 58 grams.

Calculations: diaper wt. = .058 kilograms x 2.2 lbs (conversion factor) = .13 lbs
diapers/load = 4.3 / .13 = 33; load size (as % of full load) = 4.3 / 16 = 30%.

This is will be considered to be a "load" of diapers in this analysis.

There are approximately 2.5 loads of diapers/week/rinse; 100% use regular wash cycle; 30% of loads are washed alone with small load water req. and 70 % are washed with other items with medium load water requirement and constitute 75% of that load. 25% of loads have second rinse, 30% warm water, and 70% cold water.

Calculation: 43.7 gals. x [(.3 x .8) + (.7 x .9 x .75)] = 31 gals. or 71% of full load requirement.

Second rinse water requirement = 19.2 x .25 x [(.3 x .8) + (.7 x .9 x .75)]= 3 gals.

Total wash/ rinse and second rinse water requirements = 34 gals.

Source: Arthur D. Little estimates based on industry contacts

Drying Practices

Water removed by final spin: 99.99%

Drying: 60% of washes dried with dryer; of these, 25% gas dryer and 75% electric dryer; 40% of washes air dried on line

Calculation for dryer percentages:

% of washes dried w/ gas = .25 x .6 = 15%
% of washes dried with elctricity = .75 x .6 = 45%

Energy

Hot Water

Hot water wash: 80% frequency; 71% of full capacity; 30 % warm rinse

Electricity:

With Warm Rinse

Electric use : 47% frequency
Hot wash frequency: 80%
Warm rinse: 30% frequency
Energy requirement (full load): 5.241 kWh (hot wash and 1/2 amt. req. for rinse)
Load volume: 71% of full capacity

(. 47 x .8 x .3 x 5.241 x .71) = .42 kWh

With Cold Rinse

Electric use : 47% frequency
Hot wash frequency: 80%
Cold rinse: 70% frequency
Energy requirement (full load): 3.494 kWh (hot for wash only)
Load volume: 71% of full capacity

(. 47 x .8 x .7 x 3.494 x .71) = .65 kWh

Gas:

Warm Rinse

Gas use : 53% frequency
Hot wash frequency: 80%
Warm rinse: 30% frequency
Energy requirement (full load): 26055 Btu
Load volume: 71% of full capacity

(. 53 x .8 x .3 x 26055 x .71) = 2353 Btu

Cold Rinse

Gas use: 53% frequency
Hot wash frequency: 80%
Cold rinse: 70% frequency
Energy requirement (full load): 17370 BTU
Load volume: 71% of full capacity

(. 53 x .8 x .7 x 17370 x.71) = 3660 Btu

Warm water wash: 12% frequency; 71% of full capacity; 30% warm rinse

Electricity:

With Warm Rinse

Electric use : 47% frequency
Warm wash frequency: 12%
Warm rinse: 30% frequency
Energy requirement (full load): 3.494 kWh (1/2 hot for wash; 1/2 hot for rinse)
Load volume: 71% full capacity

(. 47 x .12 x .3 x 3.494 x .71) = .042 kWh

With Cold Rinse

Electric use : 47% frequency
Warm wash frequency: 12%
Cold rinse: 70% frequency
Energy requirement (full load): 1.747 kWh
Load volume: 71 % full capacity

(. 47 x .12x .7 x 1.747 x .71) = .049 kWh

Gas:

With Warm Rinse

Gas use : 53% frequency
Warm wash frequency: 12%
Warm rinse: 30% frequency
Energy requirement (full load): 17370 BTU
Load volume: 71% full capacity

(. 53 x .12 x .3 x 17370 x.71) = 235 Btu

With Cold Rinse

Gas use : 53% frequency
Warm wash frequency: 12%
Cold rinse: 70% frequency
Energy requirement (full load): 8685 BTU
Load volume: 71% full capacity

(. 53 x .12 x .7 x 8685 x.71) = 275 Btu

Second Rinse: 25% frequency; 30% warm water

Electric:

Warm Rinse

Electric use : 47% frequency
Second rinse frequency: 25%
Warm water use: 30% frequency
Energy requirement (full load):1.747 kWh
Load volume: 71% full capacity

(. 47 x .25 x .3 x 1.747 x .71) = .043 kWh

Gas:

With Warm Rinse

Gas use : 53% frequency
Second rinse frequency: 25%
Warm water use: 30% frequency
Energy requirement (full load): 8685 Btu
Load volume: 71% full capacity

(. 53 x .25 x .3 x 8685 x .71) = 245 Btu

Total water heating energy requirement: 1.205 kWh and 6768 Btu

Source: Arthur D. Little estimates and industry contacts.

Washer/Dryer

Washer:

Washer wash/rinse cycle: 75 % frequency;

Electric: .216 kWh for full load
(.216 x .75) = .162 kWh

Washer wash/rinse/rinse cycle: 25% frequency @ 50% more power than wash/rinse cycle

Electric: (.216 x1 .5 x .25) = .081 kWh

Total washer energy = .243 kWh

Dryer (60% frequency ; 75% electric dryer and 25% gas dryer)

Electric: 2.51 kWh for full load; 64% capacity;

(2.51 x .6 x .75 x .64) = .723 kWh

Gas: 9910 BTU for full load; 61% capacity;

(9910 x.6 x .25 x .61) = 907 Btu

Total dryer energy = .723 kWh and 907 Btu

Total Energy Requirements per load (hot water, washer, dryer)

2.171 kWh of electricity and 7675 Btu of gas

Total Energy Costs per load (hot water, washer, dryer)

@ $.0745/kWh : $.16 for electricity

@ $.47 per 100,000 Btu: $.04 for gas

Source: Arthur D. Little estimates and industry contacts.

Water and Sewer

Calculations For Water Use

Assumptions

Number of children in diapers: 1
Avg. number of diapers washed/wk: 85
Avg. number of loads/wk: 2.5
Avg. laundry load size: 4.3 lbs
Avg. wt. of diaper: .13 lbs
Avg. number of diapers per load: 33

Washing Machine Specifications:

Capacity: 2.3 cu. ft.
Water use: wash/rinse cycle at full capacity 43.7 gals.
Water use for small load: 80% of full cycle use
Water use for medium load: 90% of full cycle use
Water use for 2 nd rinse: 19.2 gals.

Wash Practice:

30% of diapers are washed alone on small load setting
70% of diapers are washed with other items on medium load setting
75% of mixed wash volume is diapers
25% of diapers get 2 nd rinse

Prerinse Practice:

30% of all diapers are soiled or 11 diapers/load
1.9 diapers/change are soaked in toilet (one flush per two diapers)
Approx. 6 flushes
Approx. 4 gals./flush
24 gals. of flush water per load

Presoak Practice:

All diapers presoaked (33 diapers/load)
1 qt. soak water/diaper (approx. 8 gals. soak water)
50% of soak water is transferred to washer with diapers (subtract 4 gals to avoid double counting)
Total of 4 gals soak water/load

Water Use Calculations:

Wash/Rinse Cycle: (full load water demand) x [(% of diapers washed alone) x (% of full load water demand required by small load) + (% of diapers washed with other items) x (% of full load water demand required by medium load) x (% of the load consisting of diapers)] - [water contributed by presoak]

Equation: 43.7 x [(.3 x .8) + (.7 x .9 x .75)] - 8 = 27 gals.

2nd Rinse Cycle: (full load rinse water demand) x (% of diapers 2 nd rinsed) x [(% small load use) x (% of full load water demand required by small load) + (% medium load use) x (% of full load water demand required by medium load)]

Equation: 19.2 x .25 [(.3 x .8) + (.7 x .9 x .75)] = 3 gals.

Water Use Totals:

Prerinse: 24 gals./load
Presoak: 8 gals./load
Wash/Rinse Cycle: 27 gals/load
<u>2nd Rinse Cycle: 3 gals./load</u>

Total Water Use 62 gals./load

Water Cost: $1.33/1000 gals., based on monthly consumption of 7,480 gals.

Calculation: Cost of water: (62 x $.00133) = $ .08/load.

Sewer Cost: $ 1.45/1000 gals., based on monthly consumption of 7,480 gals. Approximately 74% of all homes send their sewage to wastewater treatment plants.

Calculation:
Total discharge: .74 x(62) = 46 gals./load

Cost of Discharge: (46 x $ .00145) = $.07/load

Total Water and Sewer Cost: $ .15/load

Sources: Arthur D. Little estimates
American Waterworks Association
Arthur Young and Company, 1988 National Waste and Wastewater Rate Survey
National Flows Clearinghouse

Labor

Prerinse: 11 diapers @ 1 min./diaper = 11 min.

Presoak: 33 diapers (full load) @ .5 min./diaper = 16.5 min.

Wash (sort and load): 33 diapers (full load) = 2 min.
(unload): 2 min.

Total for wash = 4 min.

Dryer (load): included in 2 minute washer unloading
(unload, sort, and fold): @ 15 sec./diaper = 8 min.

Total for dryer @ 60% frequency = 4.8 min.

Air Dry (unload and hang up): @ 10 sec./ diaper = 5.5 min.
(remove from line): @ 5 sec./diaper = 2.8 min.
(sort and fold): @ 10 sec./diaper = 5.5 min.

Total for air dry @ 40% frequency = 5.5 min.

Total Labor requirements: 42 minutes

Total Labor Costs: @ Federal Minimum Wage of $ 3.35/hr. = $2.35/load

@ $6.00/hr. = $4.20

Source: Arthur D. Little estimates.

Laundry Supplies

Presoak:

Diaper formulation (50 % frequency):

1 cup = 4.13 oz. @ $.075/oz. =$ .31
1/2 cup/gal. water = $ .155
1 quart soak water / diaper w/ .125 cups/quart of water @ 50% freq. = $.02/diaper

@ 33 diapers soaked/load = $.64/load

Liquid bleach (50% frequency):

1/4 cup / gallon water @ $ .12/cup
1 quart soak water / diaper w/ .0625 cups/quart of water @ 50% freq. = $.004/diaper

@ 33 diapers soaked/load = $.13/load

Wash Cycle

Heavy duty detergent powder (65% wash frequency):

1 cup / full load = 3.4 oz. @ .061 /oz. = $.21
For 71% full load @ 65% frequency = $ .21 x .71 x .65 = $ .10/load

Heavy duty liquid detergent (35% wash frequency)

1/2 cup/full load = 4 oz. @ $.07/oz. = $ .28
For 71% load @ 35% frequency = $ .28 x .35 x .71 = $ .07/load

Liquid bleach (90% wash frequency):

1 cup/load = $.12
For 71% full load @ 90% frequency w/ heavy duty powder or liquid = $ .12 x .71 x .9 = $ .08/load

Fabric softener (30% rinse frequency):

3 oz./full load = $ .09/full load
For 71% load @ 30% frequency = $ .09 x .71 x .3 = $ .02/load

Total Materials Cost: $1.04/ load

Source: Arthur D. Little estimates.

Plastic Pants

Cost: $3/pkg of 3 pr.
Sizes available: small, medium, and large
Use assumption: 3 pr. (1 pkg.) of each size over 2.5 years (30 months of diaper use)

Calculations:

$3/pkg. x 3 pkgs. = $9 total cost
Cost per wk. over 2.5 yrs. = (9 / 2.5) / 52 wks. = $ .07/wk
Cost per load = $ .03

Source: Arthur D. Little estimates.

Equipment Costs

Washer: (100% frequency)

Purchase price:	$ 475.00
Installation:	65.00
Sales tax @ 8%:	38.00
	$ 578.00

Annual maintenance @ 10% equipment cost = $47.50

Annual depreciation: 12 years w/ $50 salvage value) = $ 44

Total cost/load (130 loads/yr) = $ .70

Electric Dryer:

Purchase price:	$ 405.00
Installation:	75.00
Sales tax @ 8%:	32.40
	$ 512.40

Annual maintenance @ 10% equipment cost = $40.50

@ 60% frequency for dryer use and 75% frequency for electric dryers:
= $ .14/load

Annual depreciation: 12 years w/ $50 salvage value) = $ 38.50

@ 60% frequency for dryer use and 75% frequency for electric dryers:
= $.13/load

Total cost/load = $ .27

Gas Dryer:

Purchase price:	$	465.00
Installation:		75.00
Sales tax @ 8%:		37.20
	$	577.20

Annual maintenance @ 10% equipment cost = $46.50

@ 60% frequency for dryer use and 25% frequency for gas dryers: $.05/load

Annual depreciation: 12 years w/ $50 salvage value) = $ 44

@ 60% frequency for dryer use and 25% frequency for gas dryers: $.05/load

Total gas dryer cost/load = $ .10

Total equipment maintentance and depreciation cost per load = $ 1.07

Source: Arthur D. Little estimates.

Total Cost Summary: Cost Per Load Basis

A. Federal Minimum Wage Labor Rate ($3.35/hr.)

Component	Cost/load
Energy	$ .20
Water and Sewer	.15
Labor	2.34
Materials/pants	1.07
Equipment(maint./deprec.)	1.07
Total	$4.83

B. Wage Labor Rate of $6.00/hr.

Component	Cost/load
Energy	$ .20
Water and Sewer	.15
Labor	4.20
Materials/pants	1.07
Equipment (maint./deprec.)	1.07
Total	$ 6.69

C. No Wage Labor Rate

Component	Cost/load
Energy	$ .20
Water and Sewer	.15
Materials/pants	1.07
Equipment (maint./deprec.)	1.07
Total	$2.49

Detailed Cost Model for Home Laundered Diapers For One Week

Average weight of diapers/load: 4.3 lbs. (33 diapers)
Load size: 71% of full load water requirement
Diaper wash frequency: 2.5 loads/week

Variable Costs (adjusted for use frequency)

Item	Units	Unit Cost $	Units per week	Cost per week $
Water and Sewer				
Water	gal.	.00133	155	.20
Sewer	gal.	.00145	115	.17
Laundry Supplies				
Presoak				
bleach	fl. oz.	.015	21	.32
other	oz.	.075	21	1.58
Wash				
powder deterg.	oz.	.061	4	.25
liquid detergent	fl. oz.	.07	2.5	.18
bleach	fl. oz.	.015	12.5	.19
Rinse				
fabric softener	fl. oz.	.03	2	.06
Plastic pants				.07
Energy				
electric	kWh	.0745	5.4	.40
gas	Btu	.0000047	19188	.09

Labor (use one of the following):

Fed. Min. Wage	hr.	3.35/hr.	1.75	5.87
Higher Wage	hr.	6.00/hr	1.75	10.50

Maintenance

washer	$	.90
electric dryer	$	.35
gas dryer	$	.13

Fixed Costs

Depreciation: (straight line over 12 years w/ $ 50 salvage value)

washer	$	.85
electric dryer	$	.33
gas dryer	$	.13

Total Laundering Costs Per Week

Federal Min. Wage of $ 3.35/hr.	$ 12.07
Wage of $ 6.00	16.70
No wage for labor	6.20

For one week use of diapers: 85 diapers weighing 11 lbs.

Washer

Specifications:

250 lb. (dry wt.) commercial washer
3.52 kWh/hr. of operation
Wash cycle: 50 minutes (.83 hrs.)

Assumption:

2 gal. water per lb. diapers

Calculations:

11 lbs. diapers = 4.4 % (0.044) of full washer load (250 lbs.)

Wash cycle energy requirement:

.83 hrs x 3.52 kWh/hr. x 0.044 = .13 kWh
Water requirement @ 2 gals./lb.: 22 gals.

Dryer

Specifications:

200 lb. (dry wt.) commercial dryer
Drying Cycle: 20 minutes (.33 hrs.)
720,000 Btu/hr. energy requirement

Calculations:

11 lbs. diapers = 5.5% (.055) of full dryer load (200 lbs.)

Energy requirement for 11 lbs. of diapers:

.33 hrs. x 720,000 Btu/hr. x .055 = 13,068 Btu

Hot Water Heater

Specifications:

Commercial hot water heater with 75% efficiency

Assumptions:

One Btu raises 1 lb. water 1 degree in temperature
One gal. water weighs 8.34 lbs.
Incoming water temperature: 50 degrees
Two gals./lb. diapers:
One gallon heated to 100 degrees
One gallon heated to 150 degrees
Total water requirement 22 gallons

Calculations:

Theoretical heat requirement to raise 11 gallons 50 degrees:
(11 x 8.34 x 50) = 4,587 Btu
Theoretical heat requirement to raise 11 gallons 100 degrees:
(11 x 8.34 x 100) = 9,174 Btu
Total theoretical energy requirement = 13,761 Btu
@ 75% efficiency, actual heat requirement is:
(13,761 / .75) = 18, 348 Btu

Laundering Materials

Usage assumptions: (per 100 lbs. laundry)

Detergent:	9 fl. oz.
Sanitizer:	6 fl. oz.
Sour:	1 fl. oz.
Fabric softener:	1 fl. oz.

Calculations:

Convert use assumptions to requirement for 85 diapers, or 11 lbs. of laundry
Factor = 11 lbs./100 lbs. = .11

Detergent:	.11 x 9 fl. oz. = 1 fl. oz.
Sanitizer:	.11 x 6 fl. oz. = .7 fl. oz.
Sour and fabric softener:	.11 x 1 fl. oz. = .1 fl. oz.

Purchased electric power was converted to its fuel equivalent. The conversion of kiloWatt-hours (kW-hr) to Btu's was not accomplished with a standard factor of 3413 Btu per kW-hr, since this factor does not account for the energy consumed to produce and distribute electricity. According to the Edison Electric Institute, over 75 percent of the electric power generated in the United States is produced in fossil fuel fired power plants, over 50 percent of which are coal fired. The cumulative efficiency for the combustion of coal to the transmission of electricity is approximately 28 percent. Thus, a value of 11,225 Btu per kW-hr was used in making the conversion.

3. Water Volume

The net consumption of cooling and process water was estimated for each process step. Recycled water was not included in the water requirements.

4. Waste Water Effluents

The water pollutants considered in this study include effluents from waste water treatment and represent discharges into receiving waters. Five pollutant types are included -- total suspended solids (TSS), chemical oxygen demand (COD), biological oxygen demand (BOD), chlorine, and others. BOD measures only the short term impact (oxygen depletion) on water quality; COD measures both the short and long term impact (addition of non-biodegradable material) on waste quality. Some factors such as heat and turbidity were not included in this analysis, because there was no acceptable way to quantify their relative impacts.

5. Air Emissions

As with the waste water category, atmospheric emission categories were selected on the basis of available information and general indicators of environmental pollution. Five pollutants types were included in this analysis -- carbon monoxide (CO), sulfur oxides (SO_x), nitrogen oxides (NO_x), particulate matter, and specific toxic air pollutants.

6. Process Solid Waste

The generation of nonhazardous solid wastes was estimated for each process. This analysis considers only those wastes that will be disposed of in a landfill or incinerator. Process solid wastes that are recycled are not included. This category includes wastes from process losses, fuel combustion residues (ashes) and mining wastes.

7. Hazardous Waste and Waste Oils

This category includes hazardous wastes, as classified by the U.S. Environmental Protection Agency, as well as waste oils.

8. Post-Consumer Solid Wastes

The quantity weight of wastes disposed after consumer use of the product was quantified. Post-consumer wastes are differentiated by product and material type. Post-consumer wastes that are typically recycled are not included as a contribution to the waste stream. For instance, the corrugated containers used for distribution of diapers are recycled at a rate of approximately 40 percent in the United States (API 1988, 1989). Therefore, 40 percent of the corrugated containers were not included in this category.

B. Results

1. Raw Materials Consumption

The raw materials included in this analysis are those materials that enter the manufacturing processes for pulp and paper, polyethylene, polypropylene, absorbent gelling material, disposable diaper conversion, cotton ginning, and cotton weaving. Raw materials consumed in the laundering process and incineration were also considered. However, the analysis did not include the raw materials required to manufacture the bleach, detergents, softeners and sours used in the laundering process.

As shown in Table V-1, the consumption of non-renewable materials for cloth diapers and disposable diapers is roughly of the same order of magnitude. When the consumption of renewable resources is factored in, disposable diapers consume seven times more raw materials than reusable diapers. These raw materials are primarily wood that is consumed in the pulp manufacturing process. Only one sixth of the incoming wood, which is 50 percent water, is actually incorporated into the final product. The remaining scrap wood and lignin are used as fuel for the production process. Over 90 percent of the energy requirements at the pulp manufacturing plants is supplied by recovered raw materials.

2. Water Consumption

Table V-2 identifies the water consumption by process step and a total for each of the products being compared. At 144 gallons per child per week, the use of reusable cloth diapers consumes 6.1 times more water than the use of disposable diapers. The water consumption estimate used here represents an overall average for home and commercial laundering, understanding that the home laundering process could be performed in a more efficient mode by increasing the number of diapers washed per load. However, this would require prolonged storage of soiled diapers, a practice that is generally avoided for aesthetic and hygienic reasons.

Table V-1: Raw Materials Use - Averge Per Diapered Child Per Week (Pounds)

Process Step		Reusable Diapers[1]		Disposable Diapers	
		Renewable	Non-Renewable	Renewable	Non-Renewable
	Pulp and Paper	--	--	20.78	--
	LDPE/Polypropylene	--	0.03	--	2.52
Manufacture	Absorbent Gelling Material	--	--	--	0.43
	Diaper Convesion	--	--	--	0.63
	Cloth	0.30	--	--	--
	Corrugated Cardboard	0.09	--	0.70	--
	Paperboard	--	--	0.12	--
	Poly Bag	--	--	--	0.04
	Bleach	--	1.5	--	--
Use	Detergent/Pre-Soak/Soap	--	1.6	--	--
	Softener	--	0.09	--	--
Disposal	Polyethylene Bag	neg.	0.007	neg.	0.04
	Lime-Incineration	neg.	--	neg.	0.03
Total		0.39	3.2	21.60	3.69

[1]Assumes 90 percent of cloth diaper users home launder and 10 percent of cloth diaper users employ a commercial laundering service.

Table V-2: Water Volume Consumption – Average per Diapered Child per Week (gallons and pounds)

	Process Step	Reusable Diapers(1)	Disposable Diapers
Manufacture	Pulp and Paper		19.0
	Corrugated Fibreboard	neg.	neg.
	Low Density Polyethylene	neg.	0.1
	Polypropylene		0.7
	Absorbent Gelling Material		2.6
	Diaper Conversion		1.2
	Cloth Diaper	2	
Use	Laundering	142	
Disposal	Incineration	neg.	neg.
Total (gallons)		**144**	**23.6**
Total (pounds)		**1,195**	**195.9**

1. Assumes 90% of cloth diaper users home launder and 10% of cloth diaper users employ a commercial laundering service

3. Energy Production and Consumption

Table V-3 identifies the energy production and consumption by process step and a total for each product. The laundering process -- at home and commercially -- consumes more energy resources than any other process step for the two products. In total, cloth diaper use consumes over three times the non-renewable energy resources and just over four times the renewable energy resources that the disposable diaper use consumes.

Disposable diapers are comprised of a significant amount of renewable resources. Under current conditions, where seven percent of the nation's solid wastes are disposed of by incineration, disposable diapers provide a net release of energy from renewable sources. The net energy consumption by disposable diapers could decrease dramatically in the future with an increased use of incineration. For instance, if the use of incineration were to match that of Europe (where approximately 50 percent of the post-consumer wastes are burned for energy recovery), the incineration-based energy production would nearly equal the energy from both non-renewable and renewable resources that is consumed during the manufacture of disposable diapers.

Of particular importance in the manufacture of disposable diaper products is the unique energy efficiency of a pulp and paper manufacturing operation. In integrated mills, roughly 90 percent of the energy used is provided by the combustion of residue fuels (spent liquor and bark); less than 10 percent is purchased fuel or power. Since the residue fuels are by-products of the pulp and paper manufacturing operation and do not deplete the fossil fuel supply, the energy impacts associated with these waste materials are included in the raw material category, but not in the energy category.

4. Atmospheric Emissions

Air pollution control in the pulp and plastic manufacturing operations and mass burn incinerators has improved dramatically over the last decade due to a proliferation of air pollution control regulations by the U.S. Environmental Protection Agency and state and local governments. Therefore, as Table V-4 indicates, the total air emissions from the production and use of disposable diapers are minimal.

Air pollution emissions from the reusable diaper life cycle are over nine times higher than from disposable diapers due to the emissions from burning coal and petroleum to provide the energy required in the laundering processes and to relatively inefficient hot water heaters. The major pollutants from the burning of fossil fuels include nitrogen oxides, hydrocarbons from incomplete combustion, and sulfur dioxide (which is particularly high due to a high reliance on coal as a fuel source for electricity in the United States). Particulate matter from the combustion of fuels or refuse consists of noncombustible solid particles or

Table V-3: Energy Production and Consumption – Average Per Diapered Child Per Week (Btu)[a]

Process Step		Reusable Diapers[b] Renewable	Reusable Diapers[b] Non-Renewable	Disposable Diapers Renewable	Disposable Diapers Non-Renewable
	Pulp and Paper	--	--	--	640
	LDPE/Polypropylene	--	--	1,860	5,580
Manufacture	Absorbent Gelling Material	--	--	540	2,140
	Conversion	--	--	4,020	12,070
	Cloth	1,210	3,720	--	--
	Corrugated Fibreboard	neg.	neg.	neg.	neg.
	Washer	1,580	4,740	--	--
Use	Dryer	4,550	15,800	--	--
	Hot Water Heater	7,580	39,740	--	--
Disposal	Incineration-Recovery	-30	--	-2,700	-1,490
	Collection	--	neg.	--	630
Total		14,890	64,000	3,720	19,570

a. Purchased electrical power was converted to its resource fuel value, assuming coal was the energy source. Considering combustion, generation and transmission efficiencies, a conversion factor of 11,225 Btu/kW-hr was used.

b. Assumes 90 percent of cloth diaper users launder in the home and 10 percent use a commercial diaper service.

Table V-4: Atmospheric Emissions -- Average per Diapered Child per Week (pounds)

Pollutant	Reusable Diapers(1)	Disposable Diapers						
	Total	Pulp	AGM	LDPE	Polypropylene	Converting	Incineration	Total
Particulates	0.26	0.003		neg.				0.003
NOx	0.15	0.003		neg.			0.003	0.006
Hydrocarbons	0.10	neg.	0.057	neg.	0.011	neg.		0.068
SOx	0.32	0.007					neg.	0.007
CO	0.03						0.008	0.008
Chlorine and Chlorine Compounds		0.001						0.001
Chloride							neg.	neg.
Total	**0.86**	0.014	0.057	neg.	0.011	neg.	0.011	0.093

1. Assumes 90% of cloth diaper users home launder and 10% of cloth diaper users employ a commercial laundering service

condensed materials. The majority of the particulate matter from cloth diapers is the cotton fiber generated during the cotton ginning and cloth manufacturing processes.

As the majority of solid waste products from both reusable and disposable diapers are organic materials, the majority of the carbon content of these wastes is oxidized to carbon dioxide when they are incinerated. Incineration of these materials can also release carbon monoxide if they are not maintained in the incinerator for a sufficient period to provide for the complete conversion of the carbon in the waste to carbon dioxide. Urine and feces in the waste stream could be a contributor to the presence of nitrogen oxides in the air emissions. However, nitrogen from air can be oxidized in combustion systems under certain circumstances, again leading to nitrogen oxide formation. The waste products are comparatively low in sulfur and would generate less sulfur dioxide than does the combustion of coal.

Anaerobic and aerobic decomposition of wastes in landfills can produce primarily methane and carbon dioxide gases. Other organic chemicals in gaseous forms are emitted as well, but at significantly lower levels. Methane emissions are a concern due to their explosive nature and effect on global warming. The explosive hazard from methane emissions have been controlled by collecting and flaring the methane and converting it to carbon dioxide. This methane has also been tapped as an energy source at several landfills. Over 25 percent of the solid waste landfills in the United States vent, flare, or collect and recover methane emissions. It is expected that this practice will find increased practice in the future. Rates of methane production depend on the moisture content of the landfill; concentrations of nutrients and bacteria; pH, age and volume of degrading material; and the presence or absence of sewage sludge. Due to lack of quantifiable information, methane emissions were not included in the quantitative comparison of air effluents.

Particulate matter has significant human health impacts because it can be inhaled by humans and irritate the respiratory system. Included in this category of air pollutants are cotton fibers and airborne ash from incinerators and heat recovery units. Moreover, organic compounds and trace heavy metals can adsorb onto it (U.S Office of Technology Assessment, October 1989). Particulate matter and sulfur oxides are major ingredients of what we typically refer to as "smog". Sulfur oxides and nitrogen oxides can potentially contribute to acid rain. Nitrogen oxides are primarily precursors to the reduction of stratospheric ozone, allowing more harmful ultraviolet radiation to reach the earth. Carbon monoxide reduces the oxygen-carrying capacity of blood, impairs judgement, and can cause headaches and fatigue. In the life cycles of both the reusable and disposable diapers, however, the total emissions of these pollutants are minor.

5. Waste Water

Table V-5 displays the waste water effluents for each product by parameter and the process steps that generate them. Overall, cloth diaper use generates nearly ten times the waste water pollutants as disposable diaper use. Biochemical Oxygen Demand (BOD) and Total Suspended Solids (TSS) are relatively equal for both products. The major difference is in the release of nitrogen and phosphorus by cloth diaper laundering. In estimating the waste water emissions from sewerage (primarily from the cloth diapering laundering), we assumed that these effluents are processed in a conventional waste water treatment plant incorporating primary and secondary treatment. Primary treatment involves the removal of all floating and settleable solids by flotation and/or sedimentation. Secondary treatment involves biochemical treatment of waste water using bacteria to consume the organic wastes through a trickling filter or activated sludge process. Such systems typically have approximately a 96 percent removal efficiency for BOD and TSS. In calculating the ultimate effluent from the laundering process, we assumed a strong waste water input of 0.002 lb/gallon BOD and 0.002 lb/gallon TSS.

A high BOD load in waste water effluent is an indication of the consumption of oxygen by organisms that decompose organic materials. Since the amount of dissolved oxygen in surface water is limited, a high BOD load would result in a reduction of available oxygen to other organisms, such as fish. Suspended solids coat the bottoms of rivers and lakes -- potentially smothering aquatic plants and animals. The BOD and TSS loads to the environment are of concern from the pulp and paper manufacturing, cloth manufacturing, and laundering processes.

The environmental regulations directed towards control of the pulp and paper industry are concerned primarily with BOD, TSS and, more recently, toxicity. For instance, the release of chlorine, chloramines and chlorinated lignins from the chemical pulp bleaching process has been reduced significantly by employing bleaching processes that eliminate the use of chlorine.

The majority (typically 45 percent) of the BOD load from the cloth manufacturing operations originates from the desizing operation (an enzyme or acid washing process to remove sizing compounds used to facilitate weaving). In addition, desizing waste waters frequently contain mildewcides, fungicides and other contaminants.

Both cloth diaper manufacturing and laundering operations also release phosphorus and nitrogen compounds. These compounds are primary nutrients in any ecosystem. Release of these compounds into surface waters can increase the eutrophication of ponds and lakes. Eutrophication is the aging process of a pond

Table V-5: Wastewater Effluents -- Average per Diapered Child per Week (pounds)

Pollutant	Reusable Diapers(1)			Disposable Diapers			
	Cloth	Laundry	Total	Pulp	PP & LDPE	AGM	Total
TSS	0.001	0.012	0.013	0.007	neg.		0.007
COD	0.001	0.003	0.004		neg.		neg.
BOD	0.0003	0.012	0.012	0.003	neg.		0.003
Hydrocarbons						0.002	0.002
Phosphorus		0.005	0.005				
Nitrogen		0.083	0.083				
Total	0.002	0.115	**0.117**	0.010	neg.	0.002	**0.012**

1. Assumes 90% of cloth diaper users home launder and
10% of cloth diaper users employ a commercial laundering service

or lake into a marsh which results in its eventual disappearance. During eutrophication, the lake is choked by abundant plant life. An efficiently operated conventional secondary waste water treatment plant can remove up to 85 percent of the phosphorus compounds, but only 10 to 30 percent of the nitrogen compounds. A more complete removal of the nitrogen compounds can be achieved with the technologies employed in a tertiary treatment plant. However, we do not anticipate wide-scale use of this technology is not anticipated in the near future due to its high costs.

It is difficult to estimate the environmental risks associated with groundwater contamination by leachate from a landfill. Products of decomposition from cotton cloth and paper, such as aldehydes, organic acids, sulfates, phosphates, ammonia, and reduced sulfur compounds will remain in the landfill by incorporation into microbial protoplasm or they may leach to the groundwater or leachate collection system. However, as the primary pollutants of concern from landfill leachates appear to be toxic organics (primarily solvents) and heavy metals, the leachate from disposable or cloth diaper wastes apparently is not a significant contributor to this contamination.

6. Process Solid Wastes

Table V-6 lists the solid wastes generated by the various steps in the life cycle of the three product types. Overall, the manufacture of cloth diapers generates over 50 percent more process solid wastes than does the production of disposable diapers on an equivalent use basis. Sludge generated by treating waste water from the laundering operations is the most significant contributor to the total process solid waste generated by the reusable diapers. Sludge from pulping and ash/sludge from incineration are the primary process solid wastes generated by disposable diapers.

7. Hazardous Wastes and Waste Oils

The production of disposable and reusable diapers generates neither hazardous wastes (as classified by the U.S. Environmental Protection Agency) nor waste oils at levels of consequence. Minimal quantities of hazardous and oily wastes (e.g., from equipment maintenance or cleaning) are generated by all of the manufacturing and use operations described. Although the bottom and fly ash from a solid waste incinerator may contain heavy metals at levels that would classify the ash as hazardous waste, neither reusable nor disposable diapers are a source of these contaminants.

8. Post-Consumer Solid Wastes

The quantities and points of disposal for post-consumer solid wastes are identified in the life cycle diagrams in Figures V-4 and V-5. Table V-7 lists the post-consumer wastes by material type for each product. Organic waste from disposable diapers are the most significant contributor to the diaper post-consumer solid waste stream. Overall, disposable diaper use generates approximately 90 times more post-consumer solid waste than does the use of reusable diapers.

Table V-6: Process Solid Waste -- Average per Diapered Child per Week (pounds)

	Process Step (1)	Reusable Diapers	Disposable Diapers
Manufacture	Pulp and Paper		0.69
	Corrugated Fibreboard	neg.	neg.
	Low Density Polyethylene	neg.	neg.
	Polypropylene	--	neg.
	Absorbent Gelling Material		0.03
	Diaper Conversion		0.04
	Cloth Diaper	0.50	--
Use	Wastewater Treatment Sludge	2.63	
Disposal	Ash/slag	neg.	1.26
Total		**3.13**	**2.02**

1. Recycled scrap is not included

Figure V-4: Disposable diaper flow diagram of post consumer waste (pounds per week per diapered child)

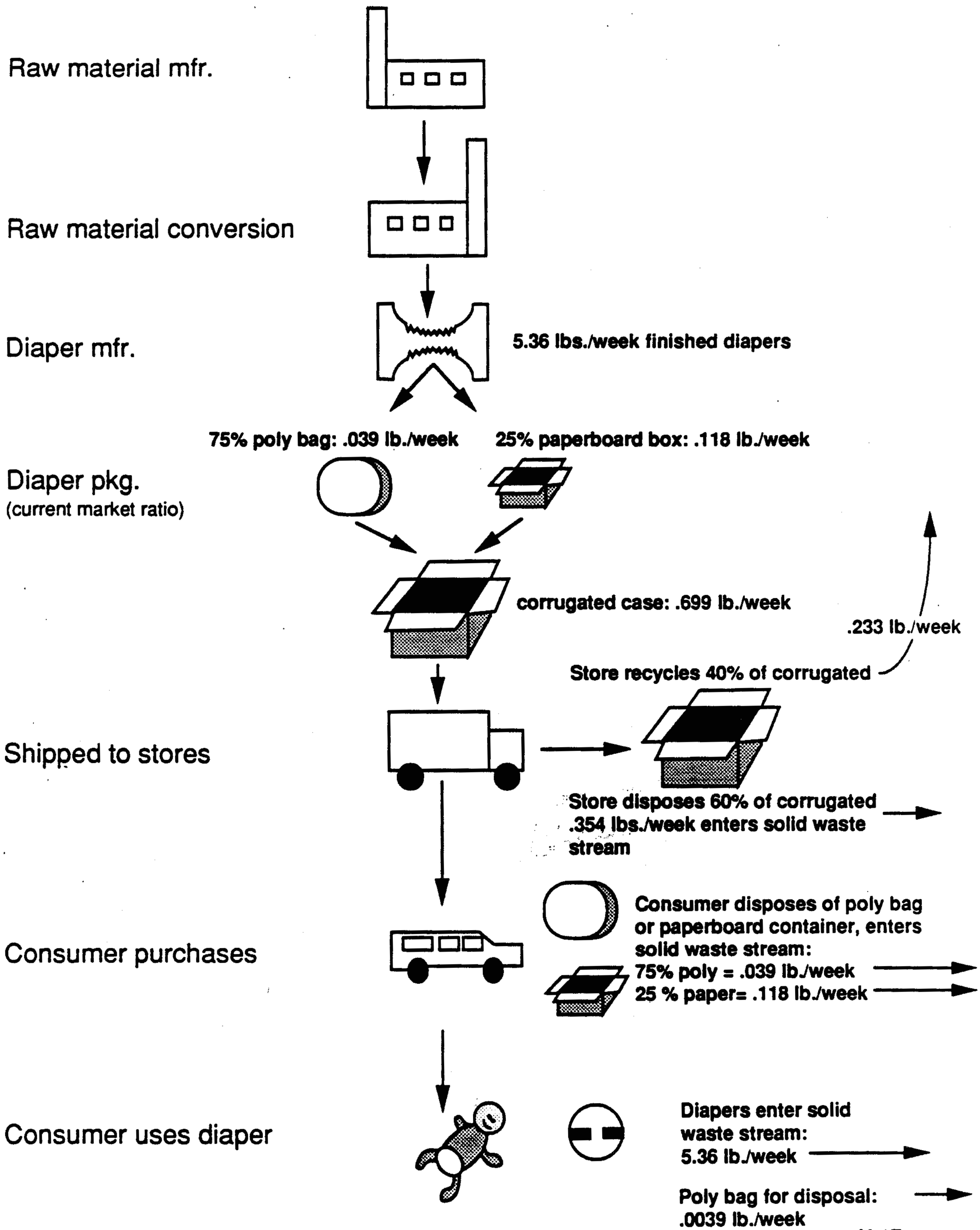

Figure V-5: Cloth diaper flow diagram of post consumer waste (pounds per week per diapered child)

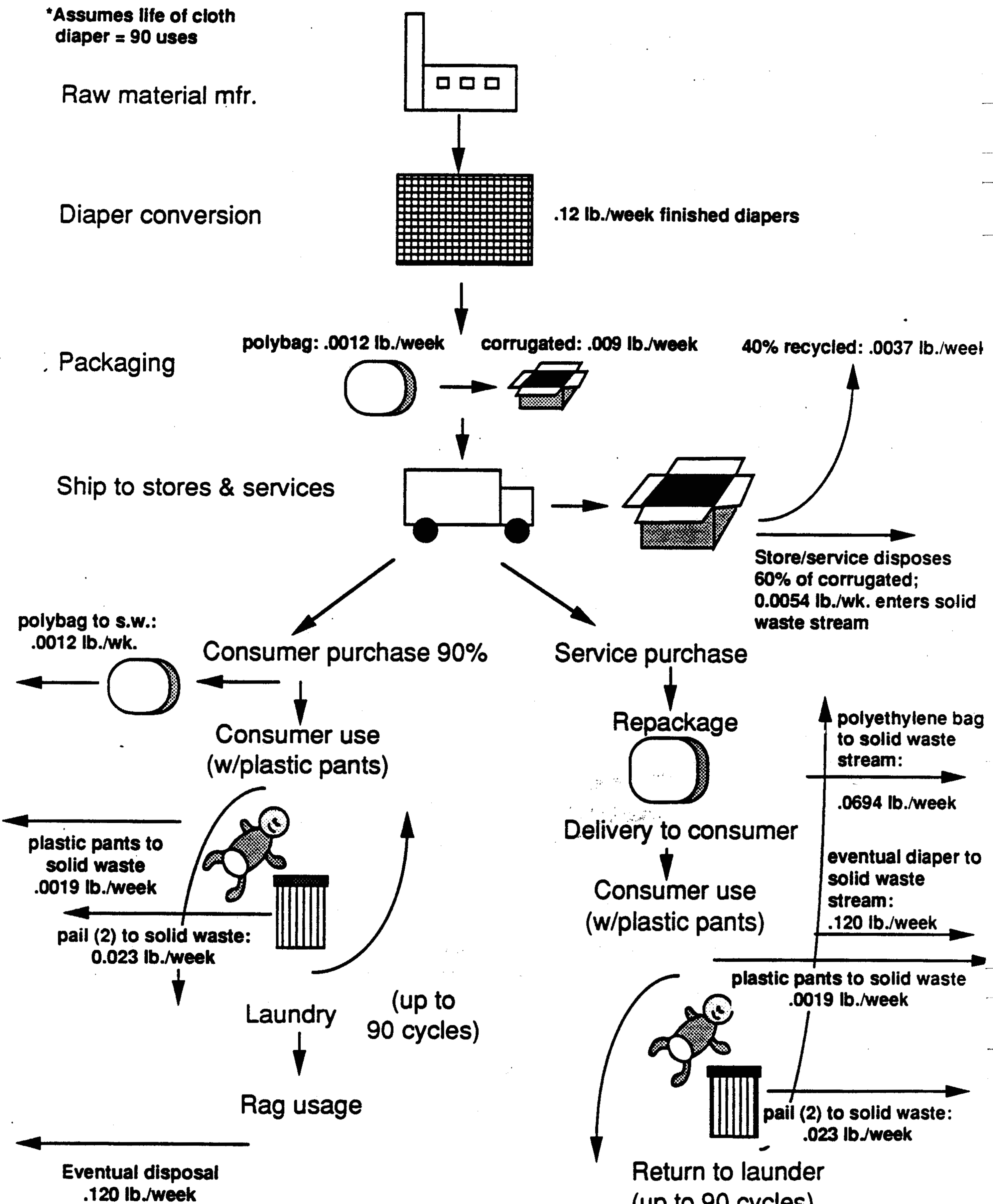

Table V-7: Post Consumer Solid Waste -- Average per Diapered Child per Week (pounds)

Material	Reusable Diapers(1)	Disposable Diapers
organic wastes	N/A	16.19
diaper	0.12	5.37
corrugated fibreboard	0.001	0.42
paperboard	neg.	0.12
polyethylene bags	0.01	0.08
plastic pants	neg	
diaper pail	0.02	
plastic detergent containers	0.09	
fabric sofner - dryer sheets	neg.	
Total	**0.24**	**22.18**

1. Assumes 90% of cloth diaper users home launder and 10% of cloth diaper users employ a commercial laundering service

Arthur D Little