per diaper change. 1.2 diapers per change is considered a conservative estimate based on this survey.

C. Home laundered reusable diapers: 1.8 diapers per diaper change. No comparable study for home laundered reusable diapers has been identified. It is generally agreed that doubling of diapers is a prevalent practice, particularly with older babies and during the night. It is considered to be unreasonable to assume all home laundered diapers are double diapered (i.e. 2.0 diapers per change), particularly since thicker diapers are now available. Based on the personal experience of the authors and a review of estimates included in four previous studies on the subject[11], 1.8 diapers per change appears to be a reasonable estimate.

D. Weighted average of commercially and home laundered reusable diapers: 1.72 diapers per change. Assuming an 87 percent market share for home laundered diapers, and a 13 percent market share for commercially laundered diapers, the weighted average equals 1.72 diapers per change.

5. Number of uses per diaper:

A. Single-use diaper: 1 use per diaper.

B. Commercially laundered reusable diapers: 78 uses per diaper. An estimate derived from a survey of 37 diaper service operators performed by the authors.

C. Home laundered reusable diapers: 180 uses per diaper. Estimate derived from two market statistics:

- 70 percent of infant reusable diaper sales are home laundered retail and 30 percent are sold to diaper services; and

- 87 percent of reusable diaper changes are home laundered and 13 percent are laundered by commercial diaper services.

Since it was determined by the authors in a survey to diaper service operators that commercial laundries get 78 uses per diaper, the following calculation results in 180 uses per home laundered diaper (with X being the number of uses per home laundered diaper):

$$78/X = 13/30 \ (X = 180).$$

D. Weighted average of commercially and home laundered reusable diapers: 167 uses per diaper. Assuming 78 uses per commercially laundered diaper and 180 uses per home laundered diaper, the weighted average equals 166.7 or 167 uses per diaper.

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[11] The four studies are: ADL2 (1990), Franklin Associates Diaper Profile (1990), MRI (1977), and ADL1 (1977).

6. Weight of unused diapers:

   A. Single-use diaper: .12 pounds per diaper. Derived from Arthur D. Little comparison of diaper total weights.[12]
   B. Commercially laundered reusable diapers: 0.225 pounds per diaper.[13]
   C. Home laundered reusable diapers: 0.12 pounds per diaper.[14]
   D. Weighted average of commercially and home laundered reusable diapers: 0.13 pounds per diaper. This assumes an 87 percent market share for laundered reusable diapers among reusable diaper users (13 percent market share for commercial diaper services).

7. Weight of used diapers:

   A. Single-use diaper: .48 pounds
   B. Weighted average of commercially and home laundered reusable diaper: .49 pounds

[12] ADL2 (1990), Table II-3, pp. 11-12.

[13] Franklin Associates Diaper Profile (1990), Table 3-1.

[14] Franklin Associates Diaper Profile (1990), Table 3-1.

E. Summary of Findings[15]

1. Materials Utilization

Reusable diapers use 72 percent fewer raw materials per equivalent use than do single-use diapers. Raw materials contributing to manufacture of single-use diapers enter the solid waste stream immediately after use, adding to the burden of solid waste disposal. Reusable diapers are used an average of 78 times by commercial diaper services, and an estimated 180 times by home users before most are recycled as rags. From a raw materials allocation and use perspective, reusable diapers are clearly preferable.

Input materials not incorporated into the final product, such as fuels, catalysts, cooling water, solvents, etc., are not counted as raw materials. Energy and water inputs are accounted for in other categories such as energy, water use, etc.

In the following summary table, all of the raw materials contributing to the manufacture of intermediate products, such as chlorine, are included in the major category figures. Therefore the cotton category includes raw material inputs to fertilizer and process chemicals.

Raw materials impact (in pounds)	1,000 single-use diapers	1,000 reusable diaper changes
polymer production	29.5	
pulp and paper production	216.5	
cotton production		4.6
detergent mfg		64.5
Totals	**246**	**69.1**

A significant quantity of raw material inputs to single-use diapers consists of petrochemicals. Because they are derivatives of petroleum and natural gas, petrochemical feedstocks are in direct competition with other uses of petroleum and natural gas products, namely fuels. While fertilizer and pesticide production use petrochemicals also, the petrochemical contribution to plastics for single-use diaper manufacturing is much greater, especially when reusable diaper inputs are divided by the large number of uses prior to disposal.

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[15] Complete tables and documentation are shown in sections VI, VII, and VIII. of the full report.

2. Energy Consumption

Available data suggests that single-use diapers use over 70 percent more energy than the average reusable diaper per equivalent use, that is, per diaper change.

Energy Impact (in British Thermal Units)	1,000 single-use diapers	1,000 reusable diaper changes[1]
Manufacturing	3,455,480	578,338
Laundry		1,452,290
Total BTUs	**3,455,480**	**2,030,628**

[1] Weighted average of home and commercially laundered reusable diapers.

A portion of the energy used in manufacturing both plastics and pulp and paper is produced from on site combustion of by-products generated during manufacturing of the primary product. This process efficiency is demonstrated by the reduction in process waste. However, because combustion of fuels for energy produces greenhouse gases and other air pollutants, the benefits of combusting waste materials are not calculated into the energy consumption categories.

Commercially laundered reusables use one-half the energy of home laundered reusables, and one-third the energy of single-use diapers on an equivalent use basis. The dramatic difference between commercially and home laundered reusables is a result of the economies of scale, reliance on gas instead of electricity, and the assumption that 1.2 commercial diapers are used per diaper change versus 1.8 diapers per change for home laundered diapers. The following table distinguishes energy use between single-use, commercially and home laundered reusable diapers.

Energy Impact: 1,000 diaper changes (in British Thermal Units)	Single-use Diapers	Commercial Diaper Services	Home Laundered Reusables
Manufacturing	3,455,480	652,562	578,338
Laundry		456,431	1,576,355
Total BTUs	**3,455,480**	**1,108,994**	**2,154,693**

3. Water Consumption

This study concludes that single-use diapers use greater volumes of total water on a per diaper change basis. It is estimated that about 3.8 gallons of total water use is associated with the average reusable diaper change. Single-use diapers use about 6.0 gallons of total water per diaper.

Gross water use (in gallons)	1,000 single-use diapers	1,000 reusable diaper changes[1]
Manufacturing	5,236	638
Laundry	0	1,957
Toilet flushing	750	1,184
Total gallons	**5,986**	**3,779**

[1] Weighted average for home and diaper service: 87 percent home laundered and 13 percent commercial diaper service laundered. Assumptions: 1.72 diapers per change and 167 uses per diaper.

This comparison is sharpened if reusable diaper water use includes a distinction between home laundered and commercially laundered reusables. Because of economies of scale, commercial laundry operations are considerably more efficient than home laundering, as shown in the following table of net water use, which excludes water recycled during the manufacturing process.

Net water use (in gallons)	1,000 single-use diapers	1,000 reusable diaper changes diaper service[1]	1,000 reusable diaper changes: home laundered[2]	1,000 reusable diaper changes Home & Commercial weighted average[3]
Manufacturing	1,230	101.5	48	55
Laundry	0	1,200	2,070	1,957
Toilet flushing	750	75	1,350	1,184
Total Gallons	**1,980**	**1,376.5**	**3,468**	**3,196**

[1] Assumptions: 1.2 diapers per diaper change; 78 uses per diaper.
[2] Assumptions: 1.8 diapers per diaper change; 180 uses per diaper.
[3] Weighted average of reusables: 13% commercial diaper service and 87% home laundered diapers.

When net water use is analyzed the results depend on estimates for rinsing fecal material from diapers into a toilet. This study estimates that 33 percent of all infant diapers changed contain fecal material. Since single-use diaper manufacturers do recommend emptying of diaper contents prior to disposal of the diaper, this study makes the assumption that 50 percent of all single-use diapers with fecal material would result in a toilet flush, even though this is currently not a common

practice. For home laundered diapers, 90 percent of diapers with fecal material are estimated to result in a toilet flush. Because diaper services do not require rinsing, 5 percent of diapers with fecal material are estimated to result in a toilet flush for commercially laundered diapers.

The calculations show that commercially laundered reusables use 30 percent less water than single-use diapers. Because of the preponderance of home washing of reusable diapers, single-use diapers use nearly 40 percent less water than the average reusable diaper change on a net-water-use basis.

Excluding toilet flushing, single-use diapers use 1.2 gallons per diaper and commercially laundered diapers use 1.3 gallons per diaper change. Home laundered diapers use significantly more water than either single-use or commercially laundered reusables.

4. Solid Waste Generation

From a perspective of total waste generation, including process waste and post-consumer waste, single-use diapers generate over 7 times more waste, even assuming that all reusable diapers enter the solid waste stream. Reusable diaper manufacturing generates approximately one-third less process solid waste than does single-use diaper manufacturing on a per-diaper-change basis. By their very nature, reusable diapers conserve resources and exemplify the preferred approach to diapering by emphasizing waste reduction and materials conservation.

Solid Waste Impact (in pounds)	1,000 single-use diapers	1,000 reusable diaper changes
Process solid waste (manufacturing)	14	4
Post-consumer solid waste	428	55
Total pounds	**442**	**59**

In comparing solid waste from two products or processes, quantity is not the only factor to be considered. Quality of the waste and its potential for adverse impacts on public health or the environment are important factors. The majority of the waste generated by manufacture of cotton is agricultural waste in the form of cotton fibers and dirt. Post consumer solid waste is primarily sludge from waste water treatment. Cotton fibers have relatively little impact on the environment. This impact is further reduced on a per-change basis over multiple uses. Assuming that there are no industrial inputs to the waste water treatment process resulting sludge is non-toxic and often suitable for beneficial reuse in agriculture.

Manufacture of pulp and paper and plastics, on the other hand produces a low volume of potentially higher impact waste materials, which include solvents, sludge, heavy metals, unreacted polymers, dioxins and furans as well as other chlorinated hydrocarbons. The potential environmental impacts of disposal of these materials are considerable.

5. Air Emissions

On an equivalent change basis, single-use diapers create significantly more carbon monoxide (CO) and particulate emissions, while reusable diapers produce slightly higher levels of nitrogen oxide (NO_x) emissions. Sulphur oxide (SO_x) emissions are roughly the same.

Air Pollution Impact (in pounds)	1,000 single-use diapers	1,000 reusable diaper changes
Nitrogen oxide (NO_x)	1.18	1.32
Sulphur oxide (SO_x)	2.29	2.29
Carbon monoxide (CO)	2.76	0.81
Hydrocarbons (HC)	1.01	0.74
Particulates	1.28	0.45

The potential impact of air emissions is difficult to estimate from the available data. Long-term effects such as acid rain and the greenhouse effect are consequences of release of chemicals to the environment. Air quality standards and emissions are measured and regulated in terms of rate of release or concentration. Because of the large geographical scope of this study, which covers manufacturing facilities and use locations all over the U.S. and world, emissions have been normalized to a mass basis for comparison. This treatment of the data makes it impossible to study dose and effect impacts on public health and the environment.

Compounds such as NO_x, SO_x, CO and carbon dioxide (CO_2) are the largest contributors to acid rain and global warming. Since CO_2 is a by-product of all combustion processes, its generation is proportional to energy consumption. Therefore, it is assumed that single-use diapers contribute more CO_2 to the atmosphere than do reusable diapers on an equivalent change basis.

In the absence of emission concentration data and site specific risk assessment, it can only be concluded that the impacts of air emissions from both diapering modes are comparable.

6. Waterborne Emissions

From an analysis of the available information reusable diapers generate more waterborne emissions in each category than do single-use diapers on an equivalent change basis.

Biological oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), and total dissolved solids (TDS) levels reported for reusable diapers come primarily from laundering activities, while the contributions to each category from single-use diapers come from manufacturing activities. Because of the nature of pulp and paper operations and plastic manufacturing processes, the sources of BOD and COD from industry are likely to include solvents and potentially toxic complex organic compounds. Industrial COD of that nature presents more of a difficult treatment problem than removal of conventional BOD, COD and TDS sources from domestic waste water.

Water Pollution Impact (in pounds)	1,000 single-use diapers	1,000 reusable diaper changes
Biological oxygen demand (BOD)	1.500	1.887
Chemical oxygen demand (COD)	1.227	4.266
Total suspended solids (TSS)	1.939	1.796
Oil and grease (O & G)	0.002	0.803
Total dissolved solids (TDS)	1.811	4.188

Data available for the analysis of water borne emissions was incomplete at best. Regulations establish maximum discharge levels and monitoring and reporting levels for a small fraction of the contaminants ultimately released. Industry is not anxious to publicize emissions data, and applicable data on present manufacturing operations is not prevalent, especially for the pulp and paper, textile and plastics industries. On the other hand, due to the public nature of municipal waste water treatment systems, there is an abundance of data on the characteristics of domestic and municipal waste waters.

Waterborne emissions from fertilizer and pesticide application to cotton crops are extremely difficult to monitor because of the non-point source nature of the emissions. Cotton cultivation uses significant quantities of the fertilizer and pesticides produced in the U.S. However, cotton attributable to diapers represents less than 0.2 percent of all cotton produced in the U.S., and therefore fertilizer and pesticide impacts are not included in this analysis. However, even the small percentage of emissions contributed by cotton diapers is an added environmental burden from a potential toxicity standpoint.

From a relative resource impact perspective, the waste water burdens of reusable diapers are readily treated in conventional waste water treatment plants and pose less of a threat to the environment and public health than do waste waters generated by the paper and plastics industry. The perception of threat from single-use diaper manufacturing is documented by continued updates to the Clean Water Act, which is increasing the number of regulated substances while lowering permitted release levels.

It is also interesting to distinguish the system boundaries for industrial waste water treatment versus municipal or domestic waste water treatment. Industrial water quality data is measured from the point of discharge, after treatment. Domestic waste water quality is measured prior to treatment from the point of discharge to the municipal treatment system. Municipal waste water treatment facilities may be the ultimate water recycling system, but the benefits are not measured here. Perhaps the quality of effluent leaving the municipal waste water treatment system should be the measure against which industrial effluent quality is measured.

7. Toxicity Impacts

Previous resource assessments and other product lifecycle analyses have usually added all the pollutants in a given category to obtain a sum of air pollutants or water pollutants. This procedure ignores the fact that mass is not the only measure of the impact of a pollutant. As manufacturing practices have become more sophisticated, and the use of solvents, small quantity catalysts, process additives, dyes, etc. has become prevalent, another category of materials and wastes has been created for management purposes: toxic materials and hazardous wastes.

This study attempts to catalog the pollutants emitted by diaper manufacturing operations, but reliable data is not prevalent. If data were available, risk assessments would be necessary to quantify the impacts and risks to public health and the environment from the catalogued pollutants, a task beyond the scope of this study. Instead, toxicity of wastes and emissions from manufacturing and use operations are considered from a qualitative perspective.

The majority of potentially toxic compounds are generated during manufacturing operations for both diapering modes. When the production of toxins from cotton manufacturing are distributed over the many uses of a reusable diaper the relative contributions are significantly lower than for single-use diapers.

In 1981, 71 percent of hazardous wastes generated in the U.S. were generated by SIC groups 28 and 29, which include the petroleum refining, petrochemical and chemical manufacturing industries. Manufacture of fertilizers, pesticides and plastics, as well as the production of petroleum products for energy, all contribute to hazardous waste generation.

Specifically, manufacture of plastics involves the use of organic solvents, metal catalysts, pigments and other additives which, along with unreacted monomer and feedstock, can end up in waste water effluent grouped under the broad parameters of BOD and COD. Manufacture of pulp involves extensive use of chlorine and alkalies which often end up in effluent and result in the synthesis of other potentially harmful substances like dioxins and furans. There are documented cases of release of dioxins and furans from pulp and paper mills to the Great Lakes region, with associated bio-accumulation in lake fish.

Growth and manufacture of cotton also entails the use and release of potentially toxic materials. Pesticides used in the cultivation of cotton require chlorine, hydrogen cyanide, and concentrated acids and caustics as raw materials. Waste waters generated from pesticide manufacture contain volatile hydrocarbons, metals, as well as COD, BOD and TSS. Due to the large number and type of pesticides used data is difficult to quantify for the purpose of this study.

Even as single-use diapers have been found to contain dioxins in the paper component, so too have cotton diapers, but at less than 20 percent of the concentrations found in single-use diapers.[16]

8. Cost to the Consumer

Out-of-pocket expenses for single-use diapers are approximately two-thirds higher than for reusable diapers laundered at home and one-third higher than for reusable diapers laundered commercially. Allowing for a value for household labor services of $6.00 per hour for home laundering raises the cost of home laundered reusable diapers to slightly below the cost of commercially laundered reusables. However, both are well below the unit costs of single-use diapers, especially when solid waste disposal and collection costs of single-use diapers are taken into account.

The average lifecycle per-unit costs for infant diapers in 1990 are as follows:

Cost to consumers per diaper change	$/diaper change
Single-use diaper	$0.26/use
Reusable laundered by a diaper service	$0.17/use
Reusable laundered at home	$0.09/use
Reusable laundered at home including labor at $6/hour	$0.15/use

[16] K. Wiberg, K. Lundstrom, B. Glas and C. Rappe, "PCDDs and PCDFs in Consumers' Paper Products," Chemosphere, vol. 19, no. 1-6, (1989), pp. 737.

9. Public Policy Issues

Solid Waste Management: Reusable diapers produce less solid waste than single-use diapers and their use should be promoted as a component of integrated solid waste management programs. States developing such plans should consider reusable diapers as a waste reduction opportunity.

Encouraging Reusable Diapers: Because reusable diapers reduce solid waste and offer additional environmental benefits over single-use diapers, their use should be encouraged. This can be accomplished, for example, by providing economic incentives to reusable diaper services; mandating government funded and operated institutions to assess the economic, environmental and health impacts of making reusables available and/or switching from single-use to reusable products; and challenging the practice of not allowing reusable diapers in day-care settings.

"Biodegradable" Diapers: So-called biodegradable single-use diapers degrade poorly when placed in a landfill environment lacking water and oxygen. State proposals and commercial efforts aimed at promoting "biodegradable" single-use diapers as a waste reduction strategy are misplaced and should be challenged.

Public Education: Public education is the most direct means to help consumers understand the impacts of diapers, and governments could either promote or sponsor educational campaigns on the environmental impacts of diapering methods.

Discouraging Single-Use Diapers: To help make the transition from a throwaway society to a conservation oriented society, use of single-use diapers that rely on the solid waste disposal system should be discouraged and use of reusable diapers should be encouraged as a long-term policy. Taxes or other economic disincentives for using wasteful products can be influential tools to increase the use of reusable products, thereby reducing solid waste.

F. Review of Other Diaper Assessments

This study's findings can be compared with those of previous studies of single-use and reusable diapers. Six noteworthy studies of lifecycle costs and environmental impacts of diapering modes are available for public review. The four most recent are:

1. Arthur D. Little, Inc., "Disposable versus Reusable Diapers: Health, Environmental and Economic Comparisons", Report to Procter and Gamble," March 16, 1990 (**ADL2**).

2. Franklin Associates, Ltd., "Energy and Environmental Profile Analysis of Children's Disposable and Cloth Diapers", Report to the American Paper Institute Diaper Manufacturers Group, July 1990 (**Franklin Associates Diaper Profile**).

3. Roland Lentz, Marina Franke, and Karl J. Thome-Kozmiensky, "Does the Use of Cloth Diapers Instead of Disposable Diapers Cause Less Environmental Impact?" Paper presented at the International Recycling Congress, Berlin, November 28-30, 1989 (**LENTZ**).

4. Carl Lehrburger, "Diapers in the Waste Stream: A Review of Waste Management and Public Policy Issues", Report to the National Association of Diaper Services, December 1988 (**Lehrburger**).

Two reports published in the 1970s are:

5. Midwest Research Institute, "Study of Environmental Impacts of Disposables versus Reusables," Draft Report for the U.S. EPA, February 11, 1977 (**MRI**).

6. Arthur D. Little, Inc., "Comparative Analysis of Selected Characteristics of Disposable and Reusable Diapers," Prepared for the American Paper Institute, New York Tissue Division, January 1977 (**ADL1**).

These early reports are useful for qualitative comparison, although their numerical estimates may be outdated because of progress in energy efficiency, water use, and pollution control of industrial and domestic production processes.

In broad terms, with the exception of Lehrburger (who focused on solid waste impacts), these studies consider direct costs, energy use, water use, process solid waste, post-consumer solid waste, air pollution, and water pollution, or a subset of these categories. The reports also develop varying assumptions regarding home laundering practices, the prevalence of double-diapering with reusable diapers, and the number of times a cotton diaper can be reused. Except for LENTZ, whose estimates are for the Federal Republic of Germany, the research focuses on utilization and impacts in the United States.

All studies concede that single-use diapers utilize more raw materials by weight and create more post-consumer solid waste. In reviewing these studies it is important to specify whether the comparison of single-use diapers is with commercially laundered, home laundered, or combined home and commercially laundered reusables.

In terms of recent studies, it is noteworthy that LENTZ determines that in all categories except some air pollution emissions, single-use diapers have greater resource and environmental impacts than reusable diapers. Both LENTZ and the present study show contrasting performances in different air emissions categories for the two diaper modes.

Major differences between the conclusions of ADL2 and the present study are a result of the broader boundaries of the present study. The present study includes the manufacture of raw and intermediate materials, electrical energy generation, production of fuels and polymer production for single-use diapers, as well as steps in cotton growth and harvest, none of which were included in ADL2.

Franklin Associates Diaper Profile also provides a complete analysis with broad boundaries encompassing the full cycle of diaper production from raw materials acquisition through final disposition. Interpretation of results is approached differently in the present study which seeks to identify the relative impacts of each diapering mode on resources and the environment. In contrast, both ADL2 and Franklin Associates Diaper Profile consider absolute resource impacts, indicated by adding the impacts in each major resource category for the purposes of direct comparisons of reusable and single-use diapers. Adding such disparate pollutants as Biological Oxygen Demand, total solids and metals implies incorrectly that their environmental impacts are qualitatively equivalent. A major difference between ADL2, the Franklin Associates Diaper Profile and the present study is the number of reusable diapers assumed per diaper change: ADL2 uses a figure of 1.9 reusable diapers per change, Franklin Associates Diaper Profile uses 1.79 diapers per change, while this study uses a weighted average between commercially and home laundered diapers of 1.72 diapers per change. This figure is based in part on the results of a survey of diaper service customers indicating that, on average, diaper service customers use 1.12 diapers per change.

Two surveys were conducted to provide data not otherwise available: one survey of 37 diaper service operators, and another of more than 500 of their clients. The average number of diapers delivered by diaper services to customers per week (the average "pack-out") was determined to be 64 diapers per customer. The life of a commercially laundered diaper is 78 washes per diaper (the average response from 27 operators). During the summer of 1990, the average cost for a diaper service was $11.34 per 80 diapers, or $0.14 for each delivered diaper.[17]

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[17] The difference between $0.14 per delivered diaper and $0.17 per diaper change cited in per unit cost tables in section IIE and VIIIC is a result of the use of multiple diaper per

Twenty-one participating diaper services administered the second survey to a random sample of their client base.[18] Out of 569 respondents, 92 or 16.17 percent had two or more children in diapers concurrently. On a per child basis, an average of 7.2 cloth and 0.7 single-use diapers were used per day. The number of diapers per week used for diapering was 53, while 5 diapers per week were used for non-diapering purposes such as burping and wiping up spills. The most significant information was the average figure of 1.12 cloth diapers used per average diaper change for diaper service customers. This number differs drastically from the 1.9[19] and 1.7[20] figures used in other recent reports for reusable diapers, and perhaps reflects the advantages of the use of a more modern diaper and diaper cover.

Energy consumption results vary considerably between the present study, ADL2 and Franklin Associates Diaper Profile. Differences can be attributed to three main elements:

1) Boundaries of the scope of study. Both Franklin Associates and the present study perform "lifecycle" analyses from raw materials acquisition through manufacture, use and final disposition, be it disposal, reuse or recycle. ADL2 studied a more limited manufacturing system, and hence arrived at lower over-all resource impacts. In contrast to the present study, the scope of ADL2 did not include some manufacturing operations which have high resource use and environmental impact. Franklin Associates includes transportation energy and impacts, which the present study addresses qualitatively, not quantitatively.

2) Differences in use parameters for reusable diapers. Assumptions concerning the number of diapers used per change and the number of uses per life of a diaper affect the results for energy use during manufacturing and laundering. The present study assumes a weighted average of 1.72 diapers per change and 167 uses per life. Franklin Associates Diaper Profile assumes 1.79 diapers per change and a weighted average of 92.5 uses per life. ADL2 assumes 1.9 diapers per changes and 90 uses per life. The number of diapers used per change has a significant impact on the use of energy in laundry, while the number of uses per life of a reusable diaper affects the percentage of manufacturing impacts attributable to each diaper change.

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change.

[18] The questionnaires were provided and tallied by the authors.

[19] Arthur D. Little, Inc., "Disposable Versus Reusable Diapers: Health, Environmental and Economic Comparisons," (Cambridge, MA: Arthur D. Little, Inc, 1990).

[20] Arthur D. Little, Inc., "Comparative Analysis of Selected Characteristics of Disposable and Reusable Diapers," Report to Tissue Division, American Paper Institute, Inc., (Cambridge, MA: Arthur D. Little, Inc., 1977).

3) Differences in energy consumption estimates for both home and commercial laundering. The present study uses a combination of laundry data from the ADL2 study and a survey of 37 diaper services conducted in conjunction with this study. Franklin Associates does not document the basis for the laundry energy consumption data used, so it is difficult to state the source of differences.

ADL2 presents estimates of energy requirements associated with single-use diapers that differ from those of the present study. By-products in some industrial processes can be reclaimed as material for co-generation energy, e.g., wood chips in paper manufacture. The reason for the difference in energy requirement estimates may be that ADL2 subtracts the amount of such self-generated energy from the direct energy utilization, to arrive at the total energy estimate. While industries should be commended for developing energy self-sufficiency, this approach is misleading because it masks gross energy consumption. Other environmental impacts such as air pollution associated with energy production are calculated based on gross energy consumption.

Concerning water use in diaper manufacturing and laundering, ADL2 and the Franklin Associates Diaper Profile both arrive at the conclusion that single-use diapers use less water per diaper change than reusables. In contrast, the present study maintains that commercial diaper services use less water than single-use diapers per diaper change.

Factors that hinder consensus on diaper water use include: (1) relative lack of information about home laundering practices, an area of water-use which is likely to be highly variable, (2) lack of agreement on basic reusable diaper parameters, e.g., the number of diapers used per diaper change, (3) uncertainty about the percentage of consumers following advisories on single-use diaper packages to flush fecal material from soiled diapers into the toilet, and (4) conceptual problems and reporting consistency related to selection of net or gross water utilization figures.

The present study assumes a higher rate of toilet rinsing for home laundered reusables than for commercially laundered diapers. In the water computations developed in this study, one third of all diapers are assumed to contain fecal matter. Ninety percent of home laundered reusable diaper changed with fecal material (30 percent) are assumed to be rinsed and flushed down the toilet, at an average of 4.5 gallons per flush. Because diaper services do not require rinsing, only 5 percent toilet rinsing is included for commercially laundered reusable diapers containing fecal material (1.7 percent of all commercially laundered diapers).

In contrast, probably a minority of single-use diaper customers flush fecal material prior to disposal of the diaper. If all consumers followed the advisories on single-use diaper packages to empty fecal contents before disposal, water use for this particular behavior would be similar to that of home washed reusables. The present study assumes that 50 percent of consumers using single-use diapers follow these advisories.

Franklin Associates Diaper Profile assumes extremely low rates of toilet rinsing of diaper fecal material for single-use diapers, roughly 5-6 flushes over 66 days, but assumes about 50 percent of commercially and 100 percent of home laundered reusables involve toilet flushing. ADL2 does not appear to deal with toilet flushing of fecal contents in either diaper mode.

Comparison of the estimates of water use in the three studies reveals inconsistencies and selection of divergent information. For example, the Franklin Associates Diaper Profile appears to rely on net water figures for plastics manufacturing but relies on gross water use estimates for laundry operations and for textile manufacturing. On the other hand, ADL2 does not discuss the constituents of non-laundry water use, but allocates all depreciation of washing machines to diaper washing, implying no other household garments are washed. This results in an unjustified bias in favor of single-use diapers.

ADL2 also apparently relies on maximum feasible water recycling capabilities in plastics production, assuming the best available technology (BAT). ADL2 uses a figure of 0.7 gallons of waste water per pound for plastics manufacturing, which is the BAT for water recycling in plastic materials production suggested in recent sources. The present study and Franklin Associates Diaper Profile use 6.67 gallons of intake water per pound of product.[21]

Another difference among studies is that ADL2 overstates estimates of commercial water use in diaper laundering, as judged by the diaper service operator survey carried out in conjunction with this study. Survey results suggest between 0.7 and 1 gallon per diaper washed by commercial diaper services. The higher of these figures, 1 gallon per reusable diaper, is used in the present study. Franklin Associates Diaper Profile uses 0.907 gallons per diaper and ADL2 appears to use 1.69 gallons per diaper.

The problem of what water to include in the process and what to exclude becomes acute when agricultural growth processes are considered in diaper lifecycle comparisons. What agricultural water use should be counted: consumptive water use, total irrigation water, total water allotments inclusive of evaporation? If water in cotton production is counted, why is it not included in the growth processes of trees, which over decades will consume vast quantities of water? In the case of ADL2, Franklin Associates Diaper Profile and the present study, agricultural water for cotton was included and water for cultivating trees was excluded from the analysis, probably unfairly.

In addition to these issues is the challenging conceptual problem of defining the boundaries of net versus gross water use. Net water use -- water not including recycled water -- has an appeal from the standpoint of resource conservation. However, gross

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[21] F. Van der Leeden, F. Troise, and D. Todd, The Water Encyclopedia, 2nd edition, (Lewis Publishers, 1990), p. 57, table 5-44.

water use -- total water used including recycled water -- also has meaning in this context, since recycled water in plastic, paper and textile production processes is employed primarily as a solvent or cleaning agent. Gross water use provides collateral evidence useful for assessing water pollution involved with these processes, as well as providing information on potential capacity demand, a useful measure for planners.

In defining gross and net water use for evaluating diaper impacts, it is not clear exactly how to distinguish the boundaries of recycled water. In-plant recycling, characteristic of plastic, paper and textile production processes, presents few problems. Municipal water systems recycle water during the treatment process. Drawing the definitional boundary for recycled water at the manufacturing plant overlooks the water recycling that is accomplished in secondary and tertiary municipal water treatment processes. Acknowledging these ambiguities and difficulties, the present study offers both gross and net water use estimates.

III. BACKGROUND TO THE PRESENT ASSESSMENT

The following sections of this report present information about single-use and reusable diapers and describe their resource utilization and environmental effects. After a review of the diaper markets, trends in diaper use and technology developments are discussed. Efforts to recycle single-use diapers and recent developments are noted. Basic manufacturing processes relevant to reusable and single-use diapers are considered next. These sections provide a context for the quantitative estimates of resource and environmental impacts that follow in sections VI and VII.

A. Overview of the Diaper Industry

An emerging awareness of the environmental impacts of contemporary manufacturing practices and consumer lifestyles has led to a reevaluation of many consumption habits previously taken for granted. Single-use diapers are one of many products to come under scrutiny, mainly because of their association with excessive waste in an era of dwindling landfill space and increasing costs of waste disposal.

It was just forty years ago that nearly all diapers were cotton reusable diapers, primarily washed in the home. The forerunner of today's single-use diaper was popularized in Sweden, where a two-piece diaper system made of sheets of cellulose wadding was utilized. The Procter and Gamble Company (P & G) developed and patented the first U.S. single-use diaper in 1961. The Pampers brand product set into motion a technological and marketing revolution that has blossomed into a billion dollar industry in the U.S. Measured by diaper changes, single-use diapers account for approximately 82 percent of all diapers changed, while reusables account for about 18 percent.[22]

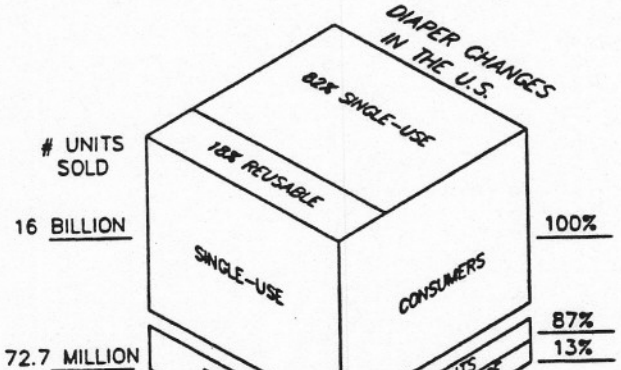

Figure 5. U.S. infant diaper market

[22] Smith and Sheeran (1990).

Although total dollar value of U.S. diaper sales is relatively easy to confirm, the number of units sold are not. Kimberly-Clark, the second largest manufacturer of single-use diapers, estimates that 16 billion infant diapers were sold in 1989,[23] and Arthur D. Little, Inc. cites 18 billion for 1987.[24] In 1988, Lehrburger estimated that 17-18 billion units were sold, of which 90 percent were baby diapers.[25] The U.S. Industrial Outlook - 1990 Paper and Allied Products estimated 16 billion baby diapers and about $180 million in adult diapers were sold in the U.S.[26]

Based on these estimates, this study assumes that 16 billion infant single-use diapers were sold in 1989, and an additional 1 billion infant diaper equivalent adult incontinent products were sold,[27] for a total of 17 billion single-use diapers. This doubling of the estimated number of adult incontinent diapers sold takes into account larger sizes and increased weight when the diaper is disposed of, compared with the average infant single-use diaper.

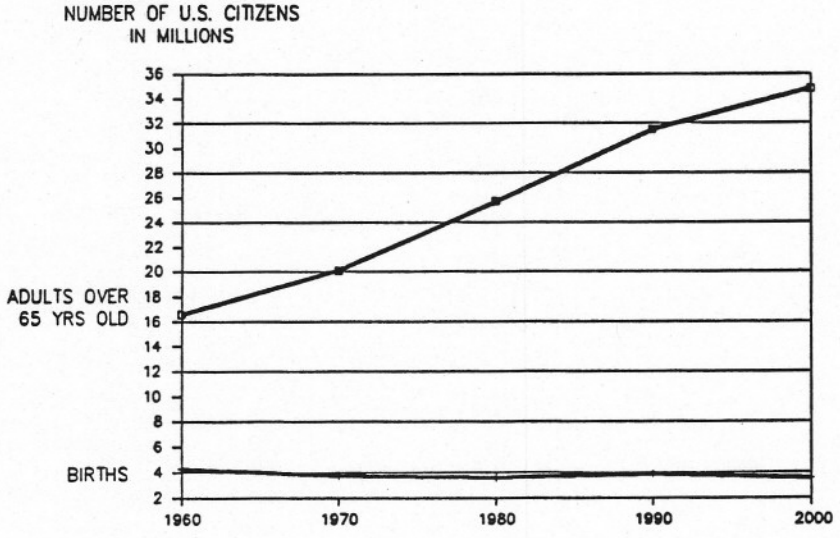

Figure 6. U.S. Population: births/adults over 65 years

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[23] Kimberly-Clark 1989 Annual Report, (Kimberly-Clark Corporation, 1989), p. 14.

[24] ADL2 (1990), p. II-20.

[25] Lehrburger (1988), p. 9.

[26] U.S. Department of Commerce, U.S. Industrial Outlook, (Bureau of Industrial Economics, 1990).

[27] The number of adult incontinent products sold in 1989 was 440 million, according to the Kimberly-Clark 1989 Annual Report, and Nonwovens Industry, "The Adult Incontinence Products Market," (March 1989).

While the infant diaper market is expected to stay fairly flat due to a projected decrease in live births during the next decade, the growth in the number of adults over 65 years old, as shown above, will result in increasing sales of adult incontinence products, and relatively consistent manufacturing volumes.

In 1989, $3.7 billion dollars was spent on single-use diapers, with Procter and Gamble (Pampers and Luvs Brands) accounting for about 49 percent of the market, Kimberly-Clark (Huggies Brand) for 32 percent, and private labels 19 percent (Weyerhauser being the largest).[28]

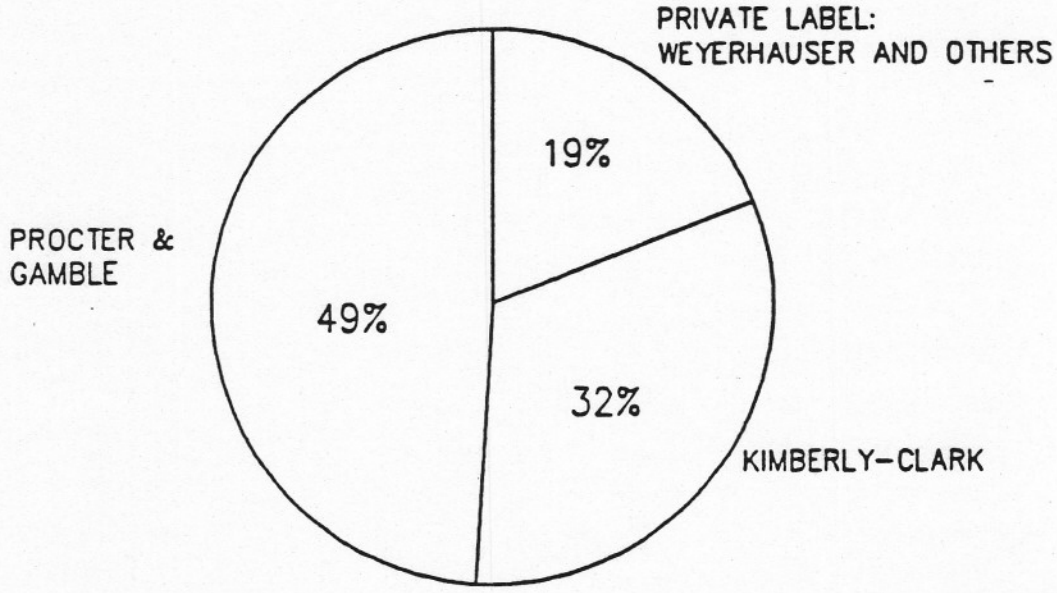

Figure 7. Single-use diaper manufacturers

The U.S consumption of single-use diapers accounts for about 40 percent of the estimated 40 billion units sold worldwide in 1989. Increases in foreign diaper sales continue to out pace increases in domestic sales.

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[28] First Boston Equity Research, "Shift in Diaper Usage Immaterial for Kimberly-Clark, Procter and Gamble," (The First Boston Corp., July 30, 1990).

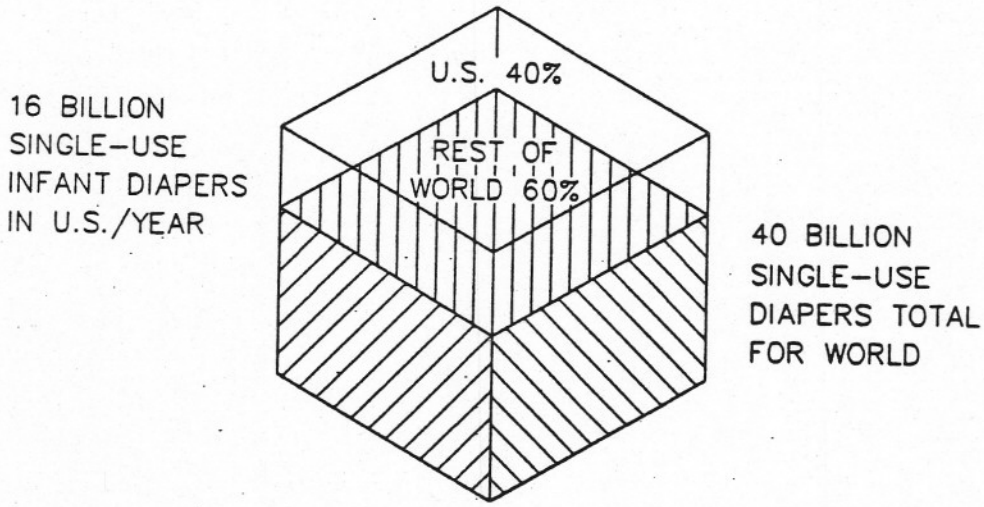

Figure 8. Single-use infant diaper market:U.S./World

The reusable diaper industry is small by comparison, with 72.7 million units sold in the U.S. in 1989, for a value of $60 million dollars.[29] Of these, about 9.5 percent were imported, mostly from China, and nearly all of these were sold to diaper services. Of the domestic producers, Gerber has an estimated 78 percent market share, while Dundee Industries has an estimated 22 percent market share.[30]

It is estimated that 87 percent of all reusable diapers sold were purchased by parents, and about 13 percent by diaper services. Generally, diaper services use a heavy weave, while most diapers sold to parents are the Birdseye weave. Data from a survey of diaper services, conducted in 1990 by the authors, indicates that diaper services will use a diaper 78 times before it is sold as a rag. This is contrasted with home washed diapers, which the authors estimate will be used about 180 times.[31]

There are a variety of sizes and different weaves available for reusable diapers today, which in general remain similar to those used before the advent of single-use diapers. Three significant changes are the decreasing use of pins, the increasing use of diaper

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[29] First Boston Equity Research, p. 5.

[30] Diaper service operator survey by authors (1990, unpublished).

[31] Refer to section IID(5c) for an explanation of how 180 uses per home laundered diapers was determined.

Three significant changes are the decreasing use of pins, the increasing use of diaper covers, and the development of multi-ply diapers with extra absorbent layers in the areas most likely to get wet. Diaper covers come in a variety of types, including plastic pants and nylon and wool covers with velcro fastening systems. Some cotton diapers themselves now come with velcro fasteners. Assuming that a small number of diaper covers will last the entire diapering life of a child, the impacts associated with each use are negligible and are not addressed in this study.

B. Trends in Diaper Use and Technology

Over the past several years, there have been indications that parents are relying more on reusable diapers. These indications include a reported surge in diaper service business by 28 percent in 1990 over 1989 and by 20.5 percent in 1989 over 1988.[32] There has also been an increase in shipment of all cloth diapers of 24 percent in 1989 over 1988 and of 20 percent in 1988 over 1987.[33]

Much of the increase in use of reusable diapers can be attributed to environmental concerns. A Gallup poll conducted for Advertising Age in June 1990 found that a large number of consumers favor taxing or banning disposable diapers to protect the environment. Of the 1,029 respondents, 38 percent favored a tax on disposables and 43 percent favored a ban.[34]

Although the changes in consumer perceptions are significant, the increased sales and utilization of reusable diapers have apparently not resulted in a reduction in business for single-use diaper manufacturers. There has not been a substantive change in the single-use diaper industry's growth rate, which has been steady during the past five years, although P & G's domestic diaper business has enjoyed a 4 percent unit growth during the first half of 1990.[35]

The most dramatic change in single-use diapers themselves has been the addition of absorbent gel materials, which provide increased absorbency with reduced bulk and weight. Introduced in the U.S. by Procter and Gamble in 1986, the use of super absorbent materials in single-use diapers is responsible for reducing the volume of an unused diaper

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[32] Diaper service operator survey by authors (1990, unpublished).

[33] Personal communication with National Cotton Council/Cotton Inc.

[34] Laurie Freeman, "Poll: P & G Seeks to Defend Its Diapers," Advertising Age, vol.61, issue 24 (11 June 1990), p. 1, 57.

[35] First Boston Equity Research.

by about 50 percent.[36] However, this only translates into an estimated 10-15 percent reduction in the weight of the used diaper when disposed.[37]

Some single-use manufacturers have recently introduced diapers that are purported to biodegrade once in landfills. These "biodegradable" single-use diapers employ plastic cover stock made with cornstarch. In an oxygen rich environment these diapers degrade more rapidly than conventional plastic diapers. Hence, the alleged benefits of "biodegradable" diapers, such as Napies and Tendercare brands, include saving landfill space. Degradation times have not been substantiated in actual landfill environments where oxygen and sunlight are scarce, and most solid waste professionals see little benefit from biodegradable diapers in landfills. However, this particular materials configuration may have benefits if single-use diapers are composted instead of landfilled, since the plastic would be composted and would not require disposal after final screening of the compost.

One potentially significant development in diaper processing is the attempt being made to recycle single-use diapers. Both Procter and Gamble and the Weyerhauser Company have initiated pilot recycling programs using wet washing processes aimed at recovering the valuable fiber.

Although both companies have reported success at separating the fiber from the used single-use diapers, at this time neither has reported the economics or the environmental burdens of the process, or projected how diaper recycling would be accomplished on a large scale. Based upon current municipal recycling economics, the cost of collecting and processing single-use diapers for recycling could approach the cost of the diaper itself. Although the recovered fiber could have value, the use of super absorbent gels may make recovery and reuse of used diaper pulp difficult or impossible. There is no assurance that the quality of the fiber is sufficient to realize a market value comparable with virgin fiber used in diapers, nor that this benefit would offset the cost of the recycling program itself.

While single-use diaper recycling offers the possibility of conserving materials and saving landfill space, none of the pre-use environmental impacts of single-use diaper manufacturing will be reduced as long as virgin raw materials are relied upon. In addition, there will be increased consumption of water and energy for recycling. Gross water consumption and energy use already exceeds that of reusables in the lifecycle of single-use diapers. Other potential problems include contamination of the recovered fiber with absorbent gel material, and oversupplying materials markets should the process prove successful. One of the most interesting aspects of the proposed single-use diaper recycling projects is the potential shift from reliance on solid waste disposal to waste water treatment, the method used by reusable diapers.

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[36] ADL2 (1990), p. II-8.

[37] Lehrburger (1988), p. 38.

A logical extension of a shift away from disposal in the solid waste stream is the anticipated development of single-use flushable diapers, which would utilize the sewage system. Product development is underway at several companies,[38,39] and flushable single-use diapers may begin to make an impact on the market during the early 1990s. Their benefits would be use of fewer raw materials than conventional single-use diapers and a reliance on the waste water treatment system, like reusables. However, a flushable single-use diaper, which would necessitate one toilet flush for each diaper, would require about 4 times the water as diapers processed by diaper services, and significantly more water than used in home laundering of reusables.

Changes in reusable diaper processing and use have been less dramatic than changes in single-use diapers. Most noteworthy is the appearance of a variety of different types and styles of reusable diaper covers. Reusable diaper covers can be made of polyethylene plastic, wool, cotton, nylon or synthetic materials and are fastened with strips of Velcro fastener.

In the past, cotton diapers were a constant thickness. Manufacturers have now developed diapers with more plys in the part of the diaper prone to greater wetness. These new reusable diapers, in combination with the newer diaper covers, fit better and reduce leakage, removing a barrier to public day care and institutional use.

C. Conclusion

Single-use diapers presently account for about 82 percent of diaper changes for infants. Recent increases in commercial diaper service business are reported, fueled in part, according to several opinion polls, by environmental concerns. Signs of change in the single-use diaper industry are the appearance of diapers using super absorbent materials (which require less fluff pulp and therefore weigh less and are smaller in bulk); attempts to recycle single-use diapers; and development of diapers which (misleadingly) purport to be "biodegradable" in landfills. Changes in reusable diapers include the development of thicker diapers with more plys of cloth near areas of the body prone to greater wetness, and better diaper covers.

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[38] R-MED International, Inc., Sedona, Arizona, as reported in "Nonwovens Markets and Fiber Structures Report," Nonwovens World newsletter (San Francisco: Miller Freeman Publications, Inc, March 16, 1990).

[39] Bio-Sept, Inc., of Greenville, South Carolina, as reported in Nonwovens World, "Degrading the Disposable Diaper," vol. 5, no. 2 (San Francisco: Miller Freeman Publications, Inc., February 1990), p. 23.