SUMMARY

DIAPERS: ENVIRONMENTAL IMPACTS AND LIFECYCLE ANALYSIS

by

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Jocelyn Mullen
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January 1991

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Report to

The National Association of Diaper Services (NADS)
2017 Walnut Street
Philadelphia, Pennsylvania 19103

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I. EXECUTIVE SUMMARY

A. Abstract

A product lifecycle analysis has been undertaken comparing single-use disposable diapers with reusable cotton diapers.[1]

The analysis catalogs resource consumption for energy, water and raw materials, and environmental releases in the form of solid waste, and air and water emissions. Once the relative environmental burdens of each diapering mode are understood, recommendations for minimizing overall environmental burden can be developed, perhaps catalyzing or adding to the formation of public policy in the solid waste arena.

The central conclusion of this study is that single-use diapers have a greater overall environmental impact than reusable diapers when all aspects of diaper production and use are taken into account. Single-use diapers are shown to generate significantly more solid waste, to consume greater quantities of energy and raw materials, and to generate more potentially toxic pollutants on a per-diaper-change basis.

With respect to water use, the results are not as conclusive. Commercially laundered reusable diapers use 30 percent less water than single-use diapers when toilet disposal of soiled single-use diapers is included and 60 percent less water than home laundered reusables. However, when water usage for commercial and home reusables is averaged, reusable diapers are shown to require more water than single-use diapers. Reusables create a greater quantity of water pollution than single-use diapers, primarily from the laundry cycle. From a relative resource impact perspective the waste water burdens of reusable diapers are more readily treated and pose less of a threat to the environment and public health than do waste waters generated by the paper and plastics industries.

Although using single-use diapers generates notably more carbon monoxide and particulate air emissions, both single-use and reusable diapers produce nitrogen oxide, sulphur oxide and hydrocarbon emissions in similar ranges.

Considering the overall environmental burdens, and most notably the higher volumes of solid waste produced and energy and raw materials consumed by single-use diapers, reusable diapers are determined to be superior from an environmental perspective.

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[1] Throughout this report, **single-use** is the term used to refer to disposable diapers, while **reusable** is used to refer to cotton or cloth diapers.

B. Background

The environmental impacts and costs of single-use (disposable) diapers and reusable (cotton) diapers have become a source of heated debate in recent years. This controversy, which has involved environmentalists as well as public policy makers, has recently entered the technical arena of product lifecycle analysis and environmental assessments.

Today, single-use diapers account for about 82 percent of baby diaper changes in the U.S.[2] Since their introduction in 1961, they have become so popular that the word diaper itself has nearly become synonymous with single-use disposables. To many, single-use diapers have come to symbolize the convenience of modern-day products.

However, with growing public awareness of environmental problems such as burgeoning solid waste issues, air and water pollution and the greenhouse effect, consumers are now paying greater attention to the environmental impacts of products they use. In this context, single-use diapers are increasingly viewed as conspicuous waste in a wasteful society.

The following charts contrast reusable and single-use diapers by the number of units sold and by the percentage of diaper changes made in the U.S. among infants.

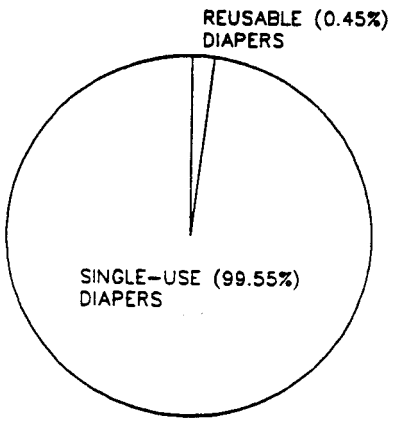

Figure 1.
Diaper market in units sold:
single-use/reusables

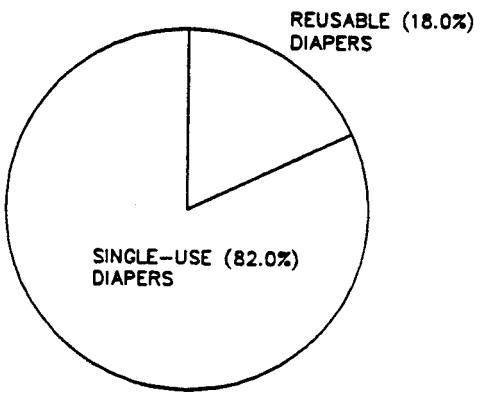

Figure 2.
Number of diaper changes:
single-use/reusables

[2] Dr. Paul M. Smith and Keith D. Sheeran, "Summary: A Profile of Consumer Preference for Baby Diapers," University of Washington, Division of Forest Products and Engineering, (Seattle: University of Washington, July 1990).

C. This Study's Approach

The present product lifecycle analysis comparing single-use to reusable diapers was commissioned by the National Association of Diaper Services. Three fundamental questions arose at the outset:

1. What are the environmental impacts of each diaper system and which diaper is least damaging to the environment?

2. Which waste treatment system is more appropriate for processing diaper waste: waste water or solid waste?

3. Which diapering system is more economical from the perspective of out-of-pocket expenses to consumers?

The primary goal of the investigation was to answer the first question, that is, to determine which diapering mode is less burdensome to the environment based on the impacts of the following categories:

- solid waste generation
- energy production and consumption
- water quantity
- water quality
- air quality
- resource consumption.

This study tracks the resource requirements and environmental burdens of each process involved in the manufacturing, use and disposal/reuse of super absorbent single-use diapers and conventional cotton reusable diapers. A lifecycle or cradle-to-grave analysis identifies the systems or processes to be studied, then catalogs materials and energy flows in and out of the defined system. Processes studied in the diaper lifecycle include raw materials acquisition, fuels refining, intermediate processing, such as fertilizer and propylene, diaper manufacturing, use practices, disposal or reuse systems including laundering, and incidental packaging. The systems under study are shown in figures 3 and 4 on page 15 and 16.

Values for resource requirements and environmental releases in each category in the defined system were then combined and summarized to create the tables in this study.

Recognizing that the two diapering modes have different associated use patterns, basic assumptions regarding use parameters were developed, based on user surveys, marketing and sales data and published literature. These assumptions are fully described in section

IID. Data was collected for each process and converted to a 1,000 equivalent use basis for comparison. The equivalent use measurement incorporates the use of multiple reusable diapers per change.

Since single-use and reusable diapers differ dramatically in their manufacturing and use patterns in each of the six categories evaluated, precise comparisons are difficult. For example, while one single-use diaper is used per diaper change, a parent may use one or more reusable diapers for each diaper change. Once used, a single-use diaper is disposed of, but a reusable diaper will be reused many times, potentially over many years, depending on type of diaper and whether it is laundered at home or by a diaper service.

The analysis shows that when the effects of manufacturing and use on the above resource categories are compared, reusable diapers have notably lower environmental impacts than single-use diapers. These impacts are summarized in sections ID and IIE, and given full treatment in sections VI and VII of the complete study.

In comparing the environmental impacts of diapers, the authors note the fundamental difference between the two diapering modes in disposal of diaper contents: single-use diapers rely on the solid waste system and reusable diapers rely on the waste water or sewage waste system. It has sometimes been overlooked that diaper wastes from single-use diapers are a primary exception to processing human sewage through the waste water treatment system. This study concludes that the waste water treatment system is more economical and performs more efficiently in collecting, transporting and processing diaper waste when compared with the solid waste stream.[3]

In addition to assessing environmental impacts, an economic comparison was completed. Single-use diapers, reusable diapers washed at home, and reusables laundered by diaper services were compared with respect to out-of-pocket expenses to consumers, including disposal and other environmental criteria. This comparison shows that single-use diapers are the most expensive diaper option, even when the cost of labor is included in home laundering of reusables.

This study uses available information and estimates to determine reusable diaper use patterns. Basic assumptions are summarized in section IID and are documented where possible.

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[3] Solid waste processing and waste water treatment co-exist and can be interrelated, however. This is the case with sewage sludge disposal from waste water treatment systems ending up in solid waste processing facilities, such as composting and landfilling. Similarly, waterborne wastes from solid waste processing operations sometimes receive treatment at waste water treatment facilities.

This study does not encompass a public health comparison between reusable and single-use diapers. Although some public health issues are addressed, a complete analysis would include a rigorous investigation of epidemiological, toxicological, sociological, and medical studies, which were beyond the scope of this study.

D. Conclusions

The central conclusions of this study are as follows:[4]

1. Single-use diapers create over 7 times more post-consumer solid waste and over 3 times more manufacturing or process solid waste than do reusable diapers. Unlike single-use diapers, reusable cotton diapers are used many times and incorporate both waste reduction and product reuse practices. Greater reliance on reusable diapers represents the obvious way to reduce solid waste created by disposable diapers.

    - Reusable diapers create less than 13 percent of the solid waste generated by single-use diapers, most of which is sludge generated at waste water treatment facilities.

    - Single-use diapers comprise approximately 2 percent of the U.S. municipal solid waste stream. Not only is the quantity of solid waste from reusable diapers 87 percent less, but the relative loads or resource impacts of reusable diaper wastes are lower than those associated with single-use diapers.

2. More energy is consumed in the lifecycle of single-use diapers than in the lifecycle of reusable diapers.

    - On a per-diaper-change basis, manufacturing of single-use diapers requires nearly 6 times the amount of energy used in manufacturing reusable diapers.

    - Commercially laundered reusables use half the energy of home reusables and one-third the energy of single-use diapers on a per-use basis.

    - On a per-use basis, the laundering cycle for reusable diapers consists of washing and drying the diaper, and treatment of the water involved. Even

[4] Refer to section IID for basic assumptions used to derive these conclusions, and IIE for an elaboration of findings.

when laundering is taken into account along with manufacturing, energy consumption for the weighted average of home and commercially laundered reusable diapers is approximately 80 percent that of single-use diapers.[5]

3. From the standpoint of total water requirements (gross water use), single-use diapers use 37 percent more water than home laundered or diaper service laundered reusables. When in-plant water recycling is taken into account (net water use), reusables laundered by a diaper service use approximately 40 percent less water than single-use diapers when fecal disposal to the toilet is included. Reusable diapers laundered at home use approximately 77 percent more water than single-use diapers.

4. Diaper laundry services have lower resource and environmental impacts than home laundering due to economies of scale. Home laundered reusable diapers use over 2.5 times as much net water per diaper change and nearly 2 times as much energy as commercially laundered reusable diapers.

5. Waste water from growing cotton and manufacturing cloth is relatively high volume and low impact compared to waste water generated from single-use diaper components and product manufacturing. Waste water from the plastic and the pulp and paper industries contains priority pollutants and compounds which are considered hazardous, including dioxins, furans and chlorophenols. Significant environmental degradation has resulted from release of effluents from these industries leading to proposed regulatory actions.

   While water usage and consumption data, and therefore effluent quality data, are difficult to compare for the two diapering modes, the following generalizations can be made:

   - Waste water created by laundering reusable diapers is high in chemical oxygen demand (COD), biological oxygen demand (BOD) and total dissolved solids (TDS), and is similar to other domestic waste waters. Laundry waste water contains little or no hazardous constituents, but can contain high levels of nitrogen and phosphorous.

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[5] These calculations are based on a weighted average between commercially and home laundered reusables. Included in calculating energy consumption in the manufacturing process (for single-use and reusable diapers) is the energy value of the feedstock, e.g., hydrocarbons used as feedstock in plastic for single-use diapers and fertilizer used to grow cotton for reusables.

- Waste water created and recycled in industrial processes included in single-use diaper manufacturing is either discharged with minimal treatment, adding to environmental burdens, or treated on site, creating industrial sludge which requires careful management. Little data was found on the characteristics of industrial sludge.

- Waste water created in reusable diaper manufacturing contains high amounts of suspended solids but relatively low COD. Plastics, pulp and paper waste waters are lower volume, but contain high COD and numerous potentially toxic organic and inorganic residues.

6. Air emissions are comparable for both single-use and reusable diapering modes. Because of lower energy use commercial diaper services produce fewer air emissions on an equivalent change basis than home laundered diapers.

7. Reusable products conserve resources and energy through multiple use, resulting in less resource and energy consumption per use compared to the high energy and resource allocations for single-use products. Because disposable diapers are a single-use product, the material and energy inputs are higher, resulting in immediate and significant solid waste generation. Large quantities of natural resources are consumed in the production of both types of diaper. Obtaining those natural resources results in land degradation, process solid waste generation, air and water pollution, soil erosion, and habitat loss, as well as contributing to the greenhouse effect.

8. Single-use diapers require more out-of-pocket expense per diaper change than reusable diapers. Costs of commercial diaper service laundering lie between home washed reusables and single-use disposables.

   - Out-of-pocket expenses for single-use diapers are approximately 50 percent higher than for reusable diapers laundered commercially, and 66 percent higher than for reusable diapers laundered at home.

   - Allowing for a value for household services of $6.00 per hour for home laundering raises the cost of home laundered reusable diapers above the cost of commercially laundered reusable diapers. However, both are still well below the unit costs of single-use diapers, especially when solid waste collection costs are taken into account.

9. Recent pilot programs aimed at recycling single-use diapers have yet to demonstrate economic viability and are not likely to be feasible without continued subsidies from single-use diaper manufacturers. Recycling single-use diapers may not significantly improve their environmental impact compared to reusable diapers, and would likely increase the cost, energy, and water requirements.

10. The waste water treatment system, contrasted with the solid waste disposal system, is more appropriate for handling diaper waste, since it was specifically designed to handle all human sewage and septage. It also appears to provide a more efficient, sanitary disposal pathway with greater opportunity for beneficial reuse of concentrated and processed sludge.

    - If all diaper consumers relied on reusable diapers, the waste water load from diapers would be less than 0.5 percent of total municipal waste water, compared to 3 percent loading of the solid waste stream if all consumers relied on single-use diapers. From a relative resource impact perspective reusable diapers have a lower environmental impact than single-use disposables.

E. Recommendations

1. Reusable diapers are, and should be promoted as, a more environmentally sound approach to diapering in comparison to single-use diapers. The clear advantages of reusables in reducing solid waste, conserving natural resources, and reducing the generation and release of potentially toxic pollutants should be emphasized.

2. Diapers should be included as part of an integrated solid waste management program that emphasizes waste reduction as the preferred option. Use of reusable diapers instead of single-use diapers is an overlooked source reduction option, that should be encouraged as part of a broader waste reduction strategy to minimize landfilling of solid waste.

3. Although reusable diapers are gaining in popularity, single-use diapers remain the most frequently used diaper. Increased education on the environmental and economic benefits of reusables, particularly in institutional settings and day-care facilities, is necessary.

4. Discussions of which diapering mode is superior from an environmental perspective should include the question of the most appropriate waste path for diaper waste. The waste water treatment system is preferable to the solid waste disposal system because it provides for more efficient and less expensive transportation to processing facilities, and because of reduced risks of exposure to disease-causing organisms.

II. OVERVIEW OF ENVIRONMENTAL AND ECONOMIC ASSESSMENTS OF DIAPERS

A. Introduction: The Controversy Revisited

The environmental impacts of using diapers were virtually ignored by the public until 1989, when Carl Lehrburger published Diapers In The Waste Stream: A Review Of Waste Management and Public Policy Issues[6], a report to the National Association of Diaper Services (NADS). That study, which addressed the solid waste impacts of single-use diapers, concluded that reusable diapers were the clear and obvious solution to the solid waste problem created by single-use diapers, and encouraged closer scrutiny of the overlooked environmental impacts they created.

During 1989 and 1990, the media and policy makers focused intently on the diaper issue as solid waste problems escalated. This new attention to diapers coincided with two emer ging perspectives: 1) "green marketing," whereby manufacturers of products began to emphasize and promote the environmental benefits of their products; and 2) a growing consensus that "cradle-to-grave" evaluations or lifecycle studies are essential to understanding the overall impact of a product.

In response to the growing public debate over diapers, the Procter and Gamble Company (P & G), the largest manufacturer of single-use diapers, sponsored in 1990 an environmental and economic comparison of diapers. This study[7] acknowledged the solid waste differences between reusable and single-use diapers highlighted in **Diapers In The Waste Stream**, but concluded that reusables consume more energy and water and create greater amounts of air and water pollution than single-use diapers. Among the study's conclusions is the declaration that neither reusable nor single-use diapers "are clearly superior in the resource and environmental impact categories considered...," and that disposables have clear health, environmental and economic advantages that "appear to outweigh the more limited advantages of reusable diapering materials..."

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[6] Carl Lehrburger, "Diapers in the Waste Stream: A Review of Waste Management and Public Policy Issues," (December 1988).

[7] Arthur D. Little, Inc., "Disposable Versus Reusable Diapers: Health, Environmental and Economic Comparisons," (Cambridge, MA: Arthur D. Little, Inc., 1990). Hereafter ADL2.

This P & G-sponsored study received attention not only for its content and conclusions, but also as a model for how product lifecycle assessments should or should not be performed. The authors of the present study benefitted from access to this and other diaper studies, and from participating in industry forums seeking to refine the process by which studies of this nature are undertaken.[8]

The authors' present study was initiated in early 1990 to provide an independent diaper lifecycle analysis that encompassed resource impacts not previously considered in Diapers in the Waste Stream. The conclusions are at odds with the P & G-sponsored study, particularly regarding water and energy use comparisons between reusable and single-use diapers. The present study concludes that reusable diapers are superior from an environmental perspective. A more detailed comparison of the assumptions used in this and the P & G-sponsored study are examined in section IIF, "A Review of Other Diaper Assessments".

It is evident that different studies of the same subject may arrive at contradictory conclusions as a result of varying assumptions and depending on the boundaries of the lifecycle assessment, and no one study should be used solely as a basis for evaluations. Public debate must transcend media oversimplification and include review of methodology and assumptions as well as conclusions. However, the authors' believe that this report provides a more comprehensive comparison between reusables and single-use diapers than the P & G-sponsored study as a result of: 1) the expanded boundaries of the present study; 2) a more refined distinction between home and commercially laundered diapers; and 3) the availability of more recent information not accessible to the authors of the P & G-sponsored study.

The diaper debate has moved to the forefront of the emerging field of lifecycle product assessments. As more companies seek to promote the environmental worthiness of their products, additional studies will be completed. More demands will be placed on industry and regulatory agencies to participate in these studies and make environmental data available to the public. Consumers, public-policy makers, and manufacturers of products will benefit from the growing inventory of information useful for making purchasing decisions, improving regulations, and formulating new products.

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[8] Product Lifecycle Assessment Workshop, August 1990, sponsored by the Society for Environmental Toxicology and Chemistry (SETAC).

B. Description of a Product Lifecycle Analysis

Product Lifecycle Analysis (PLA) is generally defined as a cradle-to-grave analysis of a product that includes manufacturing, transportation, processing, consumer use and disposal. It is designed to assess those effects and costs that are not obvious to the consumer when he or she buys or uses a product.

An environmental assessment is only one of several tools used to evaluate the effects of an activity on the environment. A thorough Product Lifecycle Analysis consists of three components: (1) an inventory, (2) an impact assessment, and (3) an impact reduction assessment, or mitigation plan. One of the objectives of such a study is to determine and reduce the environmental burdens associated with an activity or process.

The inventory is an objective quantitative cataloguing of the energy, water, and raw material requirements, air emissions, water effluent and solid wastes generated during all phases of the lifecycle of the product or process defined for study. An impact assessment is a characterization and evaluation of effects associated with energy, water, and materials use, and contaminant releases over the lifecycle of the product. And finally, the impact reduction assessment is a systematic evaluation of needs and opportunities to reduce the environmental burdens associated with energy, water, and materials use, and contaminant releases over the defined lifecycle of the product.

A PLA, consisting of all three components, is a powerful tool for generating information on the potential for reduction of environmental impacts associated with diapers. This study attempts to quantify the materials and energy inputs, and the emissions and release outputs for single-use and reusable diaper manufacturing, use and disposal. Results of the inventory and environmental assessment are documented in the report. Recommendations on how to minimize the environmental impacts associated with the use of diapers are limited to the conclusion that reusable diapers in general, and commercially laundered diapers in particular, create fewer environmental burdens than single-use diapers. This study does not attempt, however, to provide a quantitative risk assessment, and relative impacts are instead discussed qualitatively.

Too often, maintaining the status quo is easier than change, regardless of environmental and resource impact analyses. The most significant potential contribution of a PLA is to make intelligible the impacts of processes or products so that decisions can be made toward reducing the overall environmental loading. There is no such thing as a zero risk or zero impact activity. However, careful analysis and decision making can substantially reduce the impacts.

Environmental assessments and PLAs are useful tools for regulators, public policy makers and consumers in determining the relative importance of different resource categories and impacts.

C. Defining System Boundaries

This diaper lifecycle assessment addresses the manufacturing processes involved in the production of single-use and reusable diapers, including: electrical energy generation; water use, treatment and discharge; raw materials refining; primary and secondary product manufacture; process and post-consumer waste management and disposal; and phases of waste and emissions generation including air, water and solid wastes.

Not included in this assessment are: capital equipment in primary and secondary product transformation; energy consumed in space heating and cooling; air pollution generation impacts of direct combustion of fossil fuels on manufacturing sites; impacts of detergent and pesticide manufacturing; or transportation impacts (transportation issues are discussed in section V F of the complete report). Heat and noise emissions are difficult to quantify because of a lack of available data and are not addressed in this study.

The base year for most of the data is 1988, unless otherwise indicated; 1988 is the most recent year for which the quantity and quality of data necessary to perform this magnitude of assessment are available. Figures 3 and 4 in this section define the systems and their boundaries for single-use and reusable diapers respectively, for the purposes of this study.

Energy from renewable sources has been omitted from energy consumption analyses in earlier lifecycle assessments, leading to a skewed assessment of secondary energy generation and consumption impacts. This study does not differentiate between renewable and nonrenewable energy sources on a quantitative basis, but will discuss the issue on a qualitative level when comparing the impacts and benefits of each type of diaper.

Manufacturing operations produce wastes in the form of heat, noise, waterborne, airborne, and solid wastes. These wastes eventually end up in an environmental sink: air, water, or soil, with uptake into plants, animals and humans as a temporary detour along the Earth's cycle of the elements.

Pollution control technologies commonly used today generally serve only to change the phase of the waste, and rarely are wastes completely destroyed. For example, waste water treatment converts waterborne wastes to a solid sludge through the processes of settling and clarification. Incineration of sludge converts the material into ash, a solid waste, and airborne emissions. Since all processes produce wastes, the characteristics of the wastes and their impacts on the environment must be one of the bases for comparison of alternative products and processes.

Two products with complex manufacturing processes are being compared in this study: disposable or single-use diapers, and cotton or reusable diapers. The criteria for their comparison are energy consumption, raw materials and water consumption, waste and emission generation, and waste toxicity or hazard.

The following components of diaper use and manufacturing processes are considered:

1. reusables
    a. raw materials acquisition,
    b. intermediate impacts,
    c. cotton growth and harvest,
    d. cotton refining,
    e. petrochemical refining,
    f. cloth manufacturing,
    g. conversion to cloth diaper,
    h. laundering processes,
    i. disposal.

2. single-use
    a. petrochemical refining,
    b. raw material acquisition,
    c. petrochemical manufacture,
        (1) low density polyethylene
        (2) polypropylene
        (3) polyacrylic gels
        (4) adhesives
    d. pulp and tissue manufacture,
    e. conversion to diaper,
    f. disposal.

3. processes common to both operations
    a. electrical energy production.

In order to address the question of which diapering system is less burdensome to the environment, this study undertook analysis of the relative resource impacts of each diapering mode on six categories, which are solid waste, energy use, water usage, water quality, air pollution, and resource use. The scope of the study is indicated in the following figures.

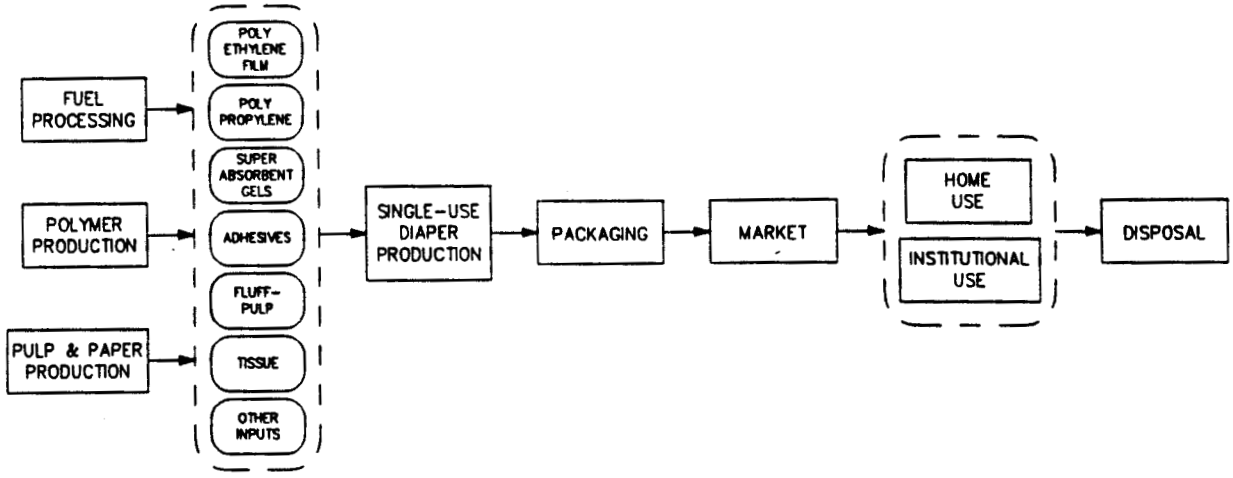

Figure 3. Single-use diaper process overview

Manufacturing Process: Single-use Diapers

The analysis of single-use diapers contained in this report is based on the use of a super absorbent diaper such as the Procter and Gamble Ultra Pampers brand. While this type of diaper was only recently introduced, it represents a significant (21.5 percent) share of the single-use diaper market, and a considerable amount of data is available for analysis. Use trends indicate that super absorbent diapers will continue to capture a significant single-use diaper market share, eventually replacing bulkier, less absorbent single-use diapers.

Single-use diapers are made predominantly of fluff pulp and tissue, with smaller components of plastics such as low density polyethylene and polypropylene. These materials require the ancillary production activities of timber growth and harvest; pulp and fluff pulp manufacturing; chlorine, sulfuric acid and caustic raw material acquisition and intermediate product manufacturing; tissue paper manufacturing; ethylene manufacturing including the refining of crude oil and natural gas; low density polyethylene (LDPE) resin and film manufacturing; propylene resin and polypropylene nonwoven film manufacturing; polyacrylic gel manufacturing including ammonia production; and finally, the conversion to the diaper end product. Natural rubber and hot melt adhesives each represent less than 3 percent of the single-use diaper by weight, and are therefore not addressed in this study.

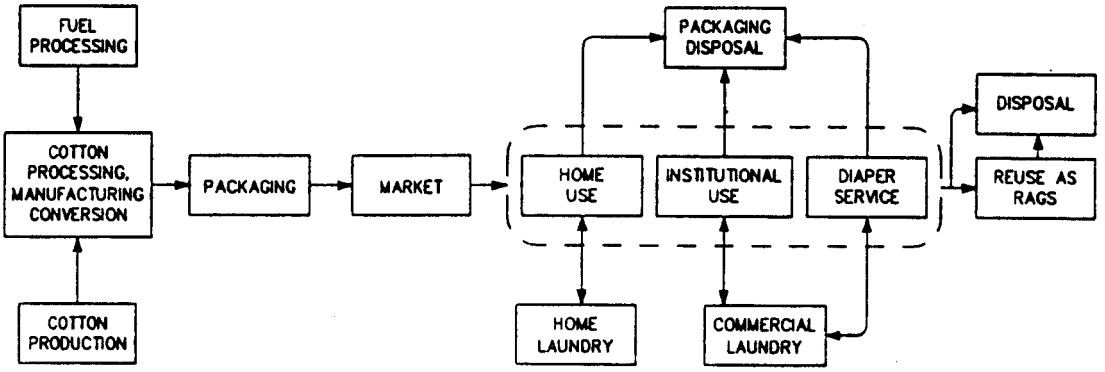

Figure 4. Reusable diaper process overview

Manufacturing Process: Reusable Diapers

Cotton diapers are manufactured from cotton fibers using standard textile processing weaving and manufacturing operations. Analysis of cotton diaper production begins with the initial operations of cotton growth and harvest. Fertilizer manufacture and fertilizer and pesticide application are included in the analysis of cotton growth where data is available, as is the consumption of energy and water. Harvesting, ginning, carding, drawing, spinning, weaving and finishing are secondary operations also included in the analysis, as are the primary operations of conversion of cotton cloth to the finished diaper product. Finally, the laundering operations associated with reuse are analyzed for both the home and commercial wash scenarios. In this analysis, all reusable diapers are assumed to enter the solid waste stream, and are accounted for in the solid waste calculations.

D. Key Assumptions

The key assumptions used in this study are as follows.

1. Number of diapers:

   A. Single-use diapers: 17 billion infant diaper equivalent units for 1989. Single-use diaper sales are reported at 16 billion units for infants and 440 million adult incontinence products. This study estimates a total of 17 billion diapers for 1989 by increasing the number of adult diapers to 1 billion based on: 1) the belief that the adult incontinence market is underestimated, and 2) adult incontinence products are larger than infant diapers and heavier when disposed compared to average infant single-use diapers.

   B. Reusable diapers: estimated at 3.512 billion changes per year. This is derived from an estimate of 16 billion infant single-use diapers used per year with a market share of 82 percent. Therefore, 100 percent of the infant baby diaper market equals 19,512,195,120 infant diaper changes (16,000,000,000 /0.82). Since reusables are estimated to have an 18 percent market share, this equals 3,512,195,122 reusable diaper changes (0.18 X 19,512,195,120). The market share for adult reusable diapers is considered inconsequential and is not included.

2. Market share by diapers changed[9]:

   A. Single-use diapers: 82 percent of infant diaper market.
   B. Reusable diapers: 18 percent of infant diaper market.

3. Market share for reusable diapers[10]:

   A. Home laundered: 87 percent of reusable diapers used.
   B. Commercial diaper services: 13 percent of reusable diapers used.

4. Number of diapers per diaper change:

   A. Single-use diaper: 1 diaper per diaper change.
   B. Commercially laundered reusable diapers: 1.2 diapers per diaper change. A survey of 569 diaper service customers distributed by 21 diaper service operators across the U.S. determined that on average, 1.12 diapers are used

[9] Smith and Sheeran (1990).

[10] Smith and Sheeran (1990).

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	578,337
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 is 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 coumpounds. 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 comparison of single-use diapers is with reusables laundered commercially, with reusables laundered at home, 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 for reusable and single-use diapers in different air emissions categories.

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 diaper service operator survey determined that the average number of diapers delivered by diaper services to customers per week (the average "pack-out") was 64 diapers per customer. The life of a cotton diaper laundered by diaper services 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]

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

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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than one diaper per 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 diapers 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.

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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.

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 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. PUBLIC POLICY ISSUES

Since 1989, over 24 state laws have been proposed concerning diapers, of which at least five were passed.[22,23] This level of activity indicates a willingness on the part of policy makers to effect waste reduction by encouraging changes in consumers lifestyles. A surprising 38 percent of 1,029 people surveyed said they favor a tax on single-use diapers and 43 percent favored a ban in a Gallup Organization poll conducted in June, 1990.[24]

As Product Lifecycle Analysis becomes more common, diapers and other single-use and reusable products are likely to receive increased attention from the public policy arena. The conclusions of this study are that reusable diapers create significantly less solid waste and, overall, are less damaging to the environment than single-use diapers. To encourage the use of reusable diapers, the following public policy recommendations are made:

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.

1. Reusable diapers are a waste reduction opportunity, and should be encouraged over single-use diapers in states developing source reduction programs. Proposals relating to diapers should be integrated into an overall solid waste management program giving highest priority to solid waste management approaches that: 1) encourage waste reduction and 2) emphasize the reuse of materials, such as diapers.

   Some states have already included and evaluated diapers as part of their solid waste management plans. For example, the Senate and House of the General Assembly of Virginia requested that the Virginia Department of Waste Management give appropriate consideration to the environmental, economic and consumer impact of single-use diapers in the development of its statewide comprehensive program for waste management.[25]

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[22] Center For Policy Alternatives, "Update On Diapers (Revised)," (Washington, DC: Center for Policy Alternatives, September 1990).

[23] Kristin Rahenkamp and Frank Kreith, State Legislative Report: A Comparison of Disposable and Reusable Diapers: Economics, Environmental Impacts and Legislative Options, Vol. 15, no. 8, (Denver: National Conference of State Legislatures, April 1990).

[24] Laurie Freeman, "Diaper Image Damaged: Poll," Advertising Age, (June 11, 1990).

[25] Virginia House Joint Resolution no. 145.

2. The waste water treatment system is a more appropriate and more economical disposal pathway for diaper waste than the solid waste stream. Reusable diapers rely on the waste water treatment system, and therefore have significant environmental and economic advantages over single-use throwaway diapers.

   The most significant public policy statements to date concerning diapers are concerned with keeping unprocessed urine and feces out of the solid waste stream. A municipal ordinance for Seattle, Washington prohibits the disposal of untreated human feces in solid waste: "...Human feces must be removed from disposable diapers and placed into an approved sewage system before the diapers are disposed of ..."[26]

   The limitation of untreated sewage in solid waste was recommended in the early 1970s by the World Health Organization (WHO): "...Ideally, solid wastes should contain no fecal matter or urine, and the mixture of these--and of such materials as pathological or slaughterhouse wastes--with household wastes should be prohibited by law." Recommendations for action from WHO included (that) "...National health agencies should be closely involved in forming policy on solid wastes disposal and should promulgate codes of practice for sanitary disposal, emphasizing the control of insects and rodents, faecal matter, and pathological wastes, and the pollution of natural waters."[27]

3. Composting is a waste management process that enhances the beneficial reuse of sewage sludge, and should be encouraged. Preventive measures that will preclude toxic and hazardous materials from entering the waste water treatment system, potentially rendering composted sludge unsafe in agricultural applications, should be adopted. Composting of single-use diapers along with MSW, although a better approach than landfill disposal, does not eliminate the comparatively higher environmental impacts of single-use diapers when contrasted with using reusable diapers many times.

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[26] Seattle Municipal Code 21.36.025

[27] World Health Organization, "Solid Wastes Disposal and Control," WHO Chronicle, vol. 26, no. 4, (Geneva: World Health Organization, April 1972), pp. 147-151; also World Health Organization Technical Report Services, Solid Waste Disposal and Control: Report of a WHO Expert Committee, (Geneva: World Health Organization, 1971), p. 7.

Encouraging Reusable Diapers: Because reusable diapers reduce solid waste and have other environmental advantages over single-use diapers including use of fewer raw materials, and less energy on an equivalent diaper change basis, their use should be encouraged.

1. Economic incentives to cloth diaper services would help to expand the availability of reusable diapers. An example of an economic incentives is Wisconsin's exemption of diapers services from state sales tax (1990 SB 300).

2. Wherever disincentives exist to using cloth diapers, they should be eliminated. California has proposed a bill which would prohibit child day care centers from refusing to care for a child in reusable diapers (SB 2342). The bill was passed by the legislature but vetoed by the Governor. Similar legislation to allow the use of cloth diapers laundered by an accredited diaper service was signed into law in Maine in 1990 (PL 723).

   On the state and national level, assistance programs that allow use of funds for single-use products but not for reusable diapers, such as the federal WIC program and state medicaid programs, should be changed so they do not discriminate against reusable products in general, and diapers in particular.

3. Government funded and operated institutions may derive distinct benefits from changing to reusable products, such as diapers. Evaluations should be required to assess the economic, environmental and health advantages of making reusable available and/or switching from single-use to reusable products in government funded institutions.

So-Called "Biodegradable" Diapers: State proposals and commercial efforts aimed at promoting "biodegradable" single-use diapers as a waste reduction strategy are misguided and should be challenged.

1. Any proposal to promote the use of so-called biodegradable disposable diapers to reduce solid waste is ill-advised because the product is not likely to break down in a landfill environment. Many state proposals regarding diapers have been concerned with so-called biodegradables. At least ten states have introduced proposals to encourage biodegradables, including Nebraska (LB 325) which in May 1989 passed a ban on non-biodegradable diapers effective October 1, 1993, but conditional on a legislative finding. It is now acknowledged that this proposal was promoted by agricultural advocates of biodegradable plastics that use corn starch as an ingredient, rather than by legislative concern with solid waste problems. In December, 1989, national environmental organizations called for a consumer boycott of biodegradable plastics, including trash bags and single-use diapers.

2. Rapidly biodegrading single-use diapers that utilize the sewage stream (flushables) would be a significant improvement over conventional single-use diapers, and their development is desirable. As a single-use product, however, flushables that utilize the sewage waste stream would still require more water and materials on a per diaper change basis than reusable diapers.

Public Education: Public Education is the most direct way to help consumers understand the environmental impacts of diapers.

1. Single-use diaper manufacturers should assume a greater responsibility for promoting proper disposal of their products, including educating parents on the proper disposal of diaper contents. Educating the public about diapers is the purpose of proposals to mandate environmental warnings on packaging of single-use diapers in New York (#A 8004) and in New Jersey (AB 1813,2227).

2. Governments could either promote or sponsor educational campaigns on the environmental impacts of diapering approaches. For example, the State of New York has proposed that hospitals must provide new mothers a copy of a diaper information pamphlet produced by the New York State Consumer Protection Board (A 10587) that addresses the environmental and economic issues related to disposable and reusable diapers. Similar pamphlets have been prepared by the City and County of San Francisco, the State of Vermont and a host of other government agencies.

Discouraging Single-Use Diapers: To help make the transition from a throwaway society to a conservation oriented society, use of single-use diapers should be discouraged and use of reusable diapers should be encouraged as a long term policy.

1. Taxes or other economic disincentives can be used to reduce solid waste and to encourage the use of reusable products. Several states have introduced proposals that seek to tax single-use diapers in order to encourage reusable diapers, although none have passed to date (Colorado HB 1157, Iowa HS 3831, Illinois HB 3634, New Jersey AB 3412, South Dakota HB 1302, 1308, Wisconsin SB 300). Tax revenue from those measures should be directed to public education programs or to fund economic incentives provided to reusable diaper services or products.

2. The possibility of banning the sale of single-use diapers has been raised several times since it was first proposed in Oregon in 1979. Ten states proposed bans in 1990, mostly applying to "non-biodegradable" diapers. Although this approach has merit in locales faced with solid waste crises, a ban is likely to create resentment among consumers deprived of the choice to use throwaway diapers. A comprehensive public policy that seeks to discourage single-use diapers and infectious and

hazardous wastes going to landfills within a set time frame offers a better prospect for increased public awareness of diapering environmental impacts than outright banning the sale of single-use diapers.

Rather than an immediate ban, localities and states should adopt a phased, comprehensive approach, which includes educating the public about benefits of reusable products, providing incentives to diaper services and/or users of reusable diapers, as well as developing a timetable for conversion to reusable diapers.

In conclusion, there are multiple legislative initiatives encouraging consumers to use reusable diapers and to require single-use diapers to bear their associated social and environmental costs. These range from directives to include and evaluate diapers in state solid waste plans (Virginia), exempting cloth diaper services from state sales tax (Wisconsin), and prohibiting unprocessed urine and feces in the solid waste stream (Seattle, Washington). Other legislation is under development or has been proposed, like efforts to mandate environmental warnings on packaging (New York), and required labeling on single-use diapers (Colorado, Iowa, Illinois, New Jersey, South Dakota, and Wisconsin).

IV. INFORMATION ON THE COMPLETE REPORT

The following information pertains to the complete 129 page report, "Diapers: Environmental Impacts and LIfecycle Analysis", from which this "Summary" was compiled.

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