D. Solid Waste Management Policy and Trends

Each year, Americans are throwing away more trash. On a per capita basis, Franklin Associates estimates suggest that MSW generation will increase from 4 pounds per person per day in 1988 to 4.86 pounds per person per day in 2010.[56]

A public policy consensus has emerged on how best to handle solid waste; the most desirable approaches to managing MSW, in rank order, are:

1. Waste Reduction at the Source: reducing the amount and impacts of material entering the solid waste stream;

2. Reuse of Materials: reusing a bottle or a diaper again;

3. Recycling: crushing a glass bottle and using the material to make a new glass product, or repulping newspaper to make new paper products;

4. Waste-To-Energy or "resource recovery": incineration accompanied by steam and/or electrical energy production and often accompanied by materials recovery;

5. Landfilling: burying wastes.

From a public policy vantage, reusable diapers are preferred over single-use diapers because they reduce solid waste at the source, rely on reusable materials, and are recycled into rags after the duration of their useful life as diapers.

Landfill disposal

There is now a recognition in the U.S. that landfilling is the least desirable disposal option, even though it is the primary disposal mode for municipal solid waste. Although the percentage of MSW (and therefore single-use diapers) going to landfills is decreasing as old landfills are being closed, a majority of diaper waste will continued to be landfilled during the next decade.

U.S. residents pay an average of nearly $75 per ton, or $298 million annually to dispose of single-use diapers in landfills. When combined with diapers going to resource recovery facilities, total annual collection and disposal cost for single-use diapers is $345 million.[57]

---

[56] Franklin Associates, (1990 "Characterization...").

[57] Carl Lehrburger, " Diapers: A Waste Management Perspective," Nonwovens World, (February 1990). An average cost of $75 per ton for collection and disposal is consistent

One approach being proposed to mitigate the problems of landfilling is the "biodegradable" diaper, whose outer plastic sheeting is said to degrade more rapidly under ideal conditions. Photodegradable plastics that have an accelerated decomposition time as a result of the sun's effect on plastic are now available. Plastic made with cornstarch, which manufacturers claim is fully biodegradable, is now commercially available as a substitute for polyethylene sheeting used in most single-use diapers.

It is now widely held that this particular diaper configuration will have little impact on the problems associated with landfill disposal. Neither the quantity of diaper waste, nor potential public health problems, nor collection and transportation costs associated with single-use diapers will be reduced. Once in a landfill, so-called "biodegradable" diapers may not decompose any more rapidly than conventional single-use diapers. Although diapers with biodegradable elements (such as cornstarch) potentially could be beneficial in a composting or co-composting process, single-use diapers using photodegradable and biodegradable plastic are not a solution to the problems of collecting, transporting, or processing single-use diapers. Use of plastics purported to biodegrade rapidly also eliminates the prospects for reusing and recycling the material.

Waste-To-Energy

Although most MSW is landfilled, a growing trend in the waste management industry is the construction of waste-to-energy plants, commonly called resource recovery. Unlike conventional incinerators, waste-to-energy plants produce steam and electricity and are outfitted with pollution-control equipment. Their main function, however, is to incinerate trash. At least 127 plants handle an estimated 15 percent of total MSW in the U.S. after materials recovery has taken place in 1990. By the end of the century, it is predicted by industry analysts that 40 percent of our total solid waste will be incinerated after recoverable materials have been taken out. A 25-30 percent market share by 2000 is considered more likely by the authors.

---

with estimates made in ADL2.

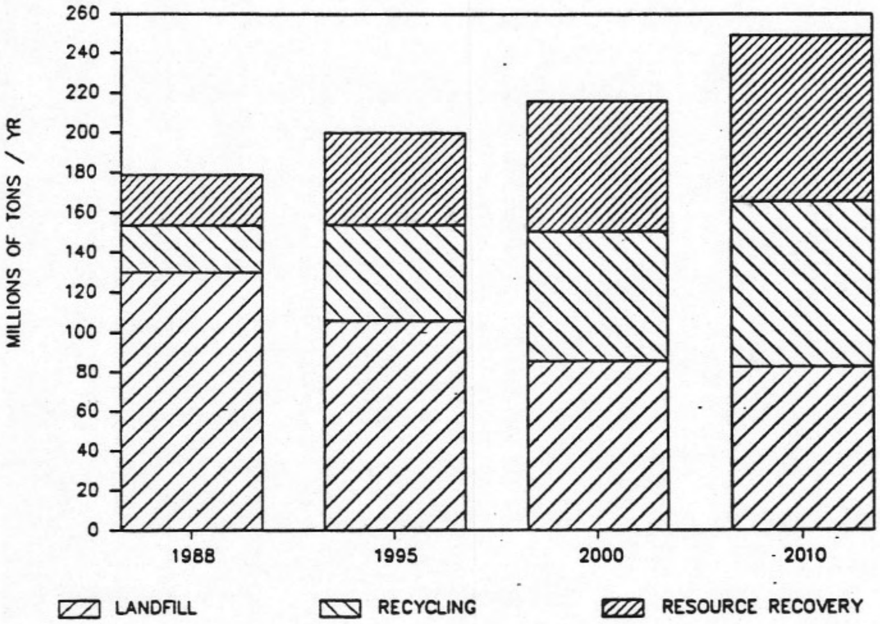

Figure 17. Comparison of solid waste processing[58]

From the perspective of disposal, incinerating single-use diapers is superior to landfilling. As a volume-reduction technique, incineration reduces diaper weight, with about 6 percent of the original diaper weight becoming ash.[59] As a method of eliminating the potential spread of disease, an incinerator's high temperature, which can reach over 1800F, destroys dangerous viruses and bacteria. A clear majority of states name incineration as a recommended treatment for infectious wastes. An additional benefit of incinerating single-use diapers in waste-to-energy plants is the conversion of waste materials to energy. Diapers that are incinerated will produce usable energy. Assuming that approximately 15 percent of MSW is incinerated in 1990, an estimated 612,000 tons of used diapers incinerated could produce 16 megawatts of energy in 1990. Because of the presence of urine/moisture in used single-use diapers, the net energy generated will be substantially lower. However, for the purposes of the energy analyses, the full energy credit was given.

[58] Franklin Associates (1990 "Characterization..."), p. 56.

[59] J. Thomas Schrodt, Air Pollution Potentials on the Incineration Products of Disposable Diapers, (University of Kentucky, July 1973).

In the cases of both air pollution and ash disposal from waste-to-energy plants, technology exists to ensure a relative degree of safety to humans and the environment. Yet, waste-to-energy plants will expel carbon dioxide and create some air and thermal pollution. Adding air pollution controls and building adequate landfills to achieve this degree of safety will increase the cost of waste-to-energy, which rose 18.5 percent in 1988 over 1987. As a greater percentage of single-use diapers are incinerated rather than landfilled, disposal costs will continue to rise. In addition, waste-to-energy does little to protect waste-collection workers from exposure to single-use diaper wastes or to eliminate the volume of the product that must be transported to a resource recovery facility.

The most positive aspect of resource recovery is that it significantly reduces the volume of single-use diaper waste while destroying potentially dangerous viruses and microorganisms and recovering energy. It is a superior method to landfilling, assuming potential water pollution associated with landfill disposal is not transferred to air pollution problems inherent in any incineration system.

Composting

Composting is the decomposition of organic materials by microorganisms in the presence of oxygen. The end result of composting is a rich, soil-like material called humus or compost. This may be sold and used for topsoil or as a soil enhancement if the quality of the compost is good. Co-composting is simultaneous composting with sewage sludge.

Composting of diapers in solid waste (MSW or mixed waste composting) should be distinguished from composting of sewage sludge. Sewage sludge and solid waste which contain used single-use diapers are compatible materials that can be composted separately or together.

Composting of sewage sludge with other organic materials is a desirable processing approach, since the finished compost is rich in nutrients for agricultural use. Concentrated and de-watered sewage sludge is often directly applied to land, or mixed with other organic materials and composted. It is estimated that 25 percent of all sewage sludge is now applied to land.[60]

In addition to sewage sludge, leaf and yard waste, grass clippings, food, and commercial food processing wastes are ideal waste materials for composting. Some of these materials are often banned from landfills and waste-to-energy facilities due to their high moisture content, bulk, and the available of composting alternatives.

Mixed municipal solid waste composting has been recently gaining attention as a viable

[60] Federal Register, "Draft Regulatory Impact Analysis of the Proposed Regulation for Sewage Sludge Use and Disposal," Vol. 54, No. 23, (November 1989).

processing technology. Diapers in solid waste contain moisture, nitrogen and nutrients needed by bacteria to decompose the solid waste. Procter and Gamble is promoting composting as a solution to solid waste problems associated with single-use diapers.

A composting demonstration project funded by P & G was completed in St. Cloud, Minnesota in 1989 using single-use diapers. The percentage of single-use diapers entering the composting system was increased from approximately 2 percent to 7.6 percent of MSW to intensify the effects. The compost did not appear different from normal compost produced at the St. Cloud facility.[61]

Composting of MSW and co-composting of sewage and MSW are only now gaining acceptance in the U.S. with fewer than 10 plants processing 600 tons of MSW daily at the end of 1989. More companies are marketing composting equipment and more municipalities are planning composting alternatives. Even though composting of single-use diapers in MSW represents an improvement over landfilling if the finished compost is acceptable, most single-use diapers will continue to be burned or landfilled in the near future.

Composting does have potential negative impacts. MSW and sewage sludge can contain potentially hazardous materials that will end up in the compost. The presence of toxic contaminants in MSW, such as batteries, heavy metals on printed paper and household hazardous wastes will compromise the final compost product, and may render it unusable on agricultural lands. This can eliminate its potential for diversion from landfill disposal, although the lowest use of compost would be daily landfill cover, which has an economic value instead of a disposal cost.

Composting also has high transportation costs associated with collection, as do both landfilling and waste-to-energy relative to the sewage treatment system. The cost of transporting solid waste exceeds the processing cost on average of landfilling, incineration, or composting.

Finally, MSW composting should not be seen as an alternative to recycling. Composting MSW without source separation of recyclables eliminates the potential to recover materials such as paper. Even though a useful product is produced from composting, maximum recycling of glass, metal, paper and plastic products should precede composting of MSW.

Despite these concerns, composting is a beneficial processing technology, especially for sewage sludge and organic materials if free of toxic and hazardous substances. Composting transforms organics into usable materials and destroys potentially dangerous pathogens if managed properly. Composting raw human wastes would require careful

---

[61] U.S. EPA, "(Draft) Diaper Industry Workshop Report," by Science Application International Corporation (SAIC), (Cincinnati: U.S. EPA Office of Research and Development, August 1990).

monitoring to insure temperatures sufficient to destroy pathogens. Studies of "night soil" or partially processed sewage have shown that agricultural applications can be a pathway for exposure to pathogens.

Recycling

Recycling is becoming a preferred waste management option over landfilling. It is estimated that the 12.9 percent of MSW recycled in 1988 will grow to 20-27 percent by 1995.[62]

Presently, single-use diaper recycling is being practiced only experimentally or in small private operations. Two experiments completed during 1990 were aimed at evaluating the prospects for recycling single-use diapers. Procter & Gamble designed a recycling facility that was built by Rabanco in Seattle, Washington as a pilot facility to separate, sanitize and reclaim 35,000 single-use diapers per week. The equipment is similar to that used in the pulp and paper industry, but has been designed to separate the pulp, plastic and absorbent gel material found in diapers.

P & G reported that the process is successful at separating diaper components, but an economic assessment of the project has not been made available for review. Critical to the economics of the process is the quality and market value of the reclaimed pulp. To improve the economics of the facility, P & G hopes to expand the recycling process to include other high quality soiled papers, such as napkins, towels and milk cartons.

The Weyerhauser company is also undertaking a diaper recycling project in San Diego, California. Weyerhauser has reported that the process was successful in separating out the plastic and the pulp, but requires high water use and significant diaper delivery and pickup costs to consumers.

Critical to the success of single-use diaper recycling will be the added cost of recycling to customers. It is estimated that currently consumers spend on average nearly $0.02 for collection and disposal of each single-use diaper. How much additional cost consumers would be willing to spend for recycling is not known. A private firm in New York City reports that out of 1,000 calls to parents with babies in diapers, 10 percent signed up for diaper recycling at a cost of $18 per month to collect and process single-use diapers.[63]

The success of single-use diaper recycling will depend on a number of factors, including consumers' willingness to pay, the ability of the recycling company to obtain high-value

---

[62] Franklin Associates (1990 "Characterization..."), p. 72.

[63] Telephone interview with Phil Pennestri, Pennco Waste Management, New York City, New York.

pulp and consistent market prices, the added environmental burdens of additional energy and water consumption, and the willingness of diaper manufacturers to provide incentives for diaper recycling to be economically practical. These incentives could be direct or indirect (subsidizing the value of the finished materials, for example).

Interestingly, should single-use diaper recycling become viable, reusable diaper services themselves would be the most likely candidates to facilitate collection, delivery and recycling because of an existing infrastructure for these services.

Reuse and Waste Reduction

There is near universal consensus that waste reduction and material reuse hold the greatest opportunities to reduce the environmental impacts and costs of solid waste disposal. Reusable diapers employ both source reduction and materials reuse, while minimizing any dependence on landfilling.

Approximately 18 percent of all diapers changed are reusable diapers. They minimize diaper contribution to the MSW stream because their discarded contents are flushed down a toilet or expelled from a washing machine. This is an advantage over single-use diapers because it channels the diaper urine and feces into the waste water system. There it is processed at a sewage treatment plant, via mechanical, chemical and biological processes, where the solids are concentrated into a sludge along with the rest of the sewage.

Feces make up a relatively small percentage by weight of discarded diapers, whether reusable or single-use. Even if all sewage sludge were to be landfilled or incinerated, less than 9 percent of the total weight of each reusable diaper change would find its way into the solid waste stream, contrasted with 100 percent of the weight of a single-use diaper.

A growing percentage of treated sewage sludge is being used in agriculture as a soil conditioner and fertilizer. In 1988 it is estimated that about 25 percent of sewage sludge and septic waste is used in agriculture or land applications[64] and that the probability of increased usage exceeds that of all other organic wastes in the U.S.[65]

Reliance on the sewage system for diaper disposal has inherent advantages over reliance on the solid waste stream. It encourages reuse of diaper materials, such as cotton diapers and/or reusable diaper covers. It also transports diaper wastes in an efficient and economical manner and minimizes the exposure of workers to potentially infectious

---

[64] Federal Register, "Draft Regulatory Impact Analysis of the Proposed Regulation for Sewage Sludge Use and Disposal," Vol. 54, No. 23, Feb. 6, 1989, (November 1988).

[65] U.S. Department of Agriculture, Organic Farming Study, (Washington, DC: U.S.D.A., May 1980).

human diaper wastes. In addition, the growth in land applications of sewage sludge creates more opportunities to reuse sludge resulting from diapers. Water used to transport diaper waste is processed at a waste water treatment plant and reused by both humans and nature.

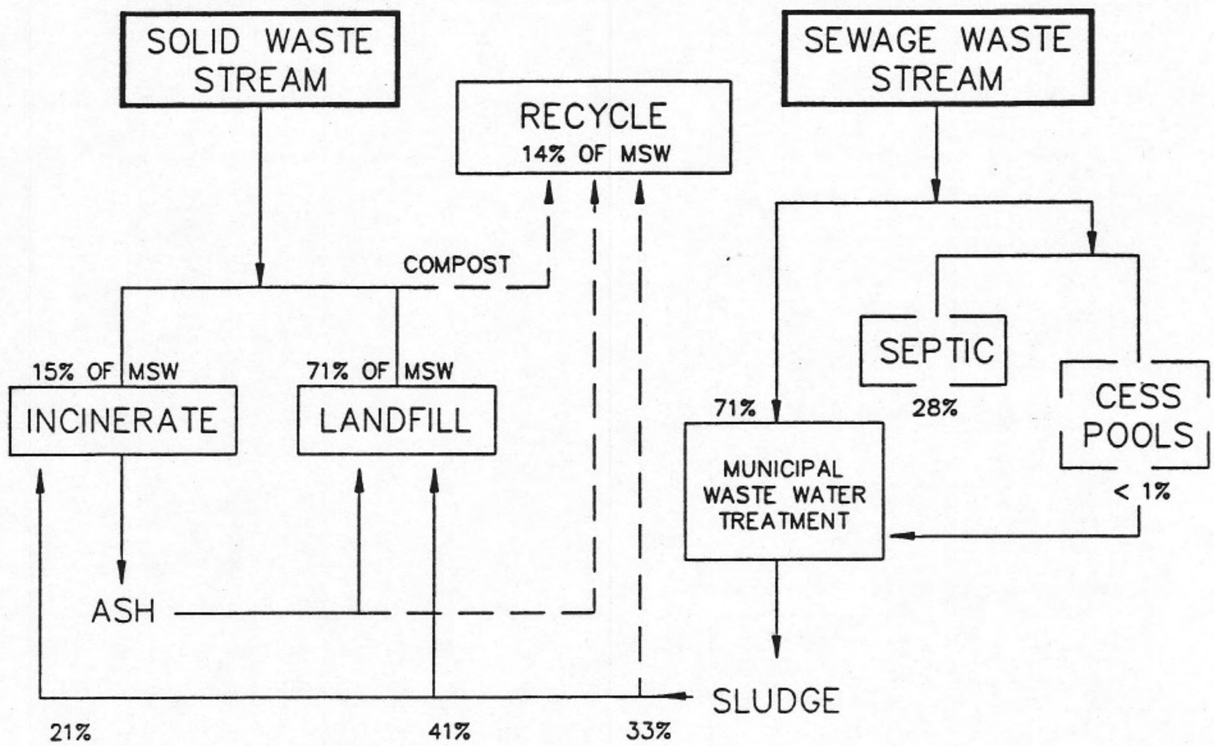

Figure 18. Diaper waste materials flow

Increased use of reusable diapers is the obvious way to minimize single-use diaper waste. It offers economic savings to consumers and eliminates the high cost of disposal associated with single-use diapers. Its reliance on reusable fabric and disposal of feces to the sewage waste stream makes this mode of diapering superior in many respects, given the current disposal methods for single-use diapers and diminishing landfill capacity.

Super absorbent materials in single-use diapers produce a thinner diaper, which has resulted in a reduction in waste volume and a need for less packaging. This may reduce the volume of diaper waste entering the solid waste stream. However, even if all single-use diapers were to be reduced in size by 50 percent, diaper waste overall would be reduced by only an estimated 10 percent to 15 percent by weight. Although use of super absorbent materials in diapers does represent an example of source reduction, this approach should be seen in the context of a 87+ percent solid waste reduction achieved by using reusable diapers.

E. Sewage Treatment as a Perspective on Diapers

In developing an analysis of the relative resource impacts of reusable and single-use diapers, it makes sense to consider waste water utilization by reusable diapers in comparison with total waste water production.

The construction grants program associated with the Clean Water Act of 1972 spent more than $40 billion on new construction and rehabilitation of sewage treatment facilities. This capital construction was judged to have "significant impacts on the Nation's water quality" by the middle 1980s.[66] Virginia, for example, with a one third increase in waste water volume between 1976 and 1983 saw BOD levels fall 22 percent. Degraded stream mileage in North Carolina fell from 3000 to 1000 miles within the same period.

The ability of the solid waste system to handle the nearly 200 million tons of garbage generated every year is now seriously compromised. Total solid wastes in the United States grew from 87.5 million tons in 1960 to 157.7 million tons in 1986. At the same time, the number of landfills is shrinking. In 1978, there were approximately 20,000 operating municipal landfills. By 1986, there were fewer than 6000. By 1993, about 2,000 of the remaining landfills will be at capacity and many more will be closed due to inadequate safety or environmental practices. Furthermore, a significant fraction of the existing facilities fail to meet federal and state environmental standards. In 1984, only 25 percent of the landfills monitored groundwater for possible contamination. More than 50 percent made no effort to control water pollution due to rainwater runoff from the site.[67] The Environmental Protection Agency reports that 22 percent of the sites on the Superfund National Priorities List are municipal landfills.[68]

The National Solid Wastes Management Association estimates that the cost of constructing a landfill -- above and beyond land acquisition -- has risen from $200,000 per acre of capacity in 1975 to $1 million per acre in 1990. Environmental management requirements add another $210,000 an acre.[69]

---

[66] U.S. Environmental Protection Agency, National Water Quality Inventory 1984, (Washington, D.C.: U.S. EPA, 1984).

[67] U.S. Bureau of Census, Census of State, Local, and Territorial Subtitle D Non-Hazardous Waste Programs, (Washington, DC: U.S. Bureau of Census, 1984).

[68] Environmental Quality, (Washington, DC: U.S. EPA, 1988-89).

[69] National Solid Wastes Management Association, Landfill Capacity in the Year 2000, (Washington, DC: National Solid Wastes Management Association).

Tipping fees and collection costs for solid waste in 1989 averaged over $75 per ton,[70] and represent an out-of-pocket expense to the consumer. Assuming a $75 per ton tipping fee and collection cost, the average cost of MSW disposal is approximately 1.8 cents per single-use diaper. This compares with a cost of disposal in the sewage waste system of about 0.6 cents per reusable diaper change.[71]

Costs for municipal water treatment are projected to increase over the next decade because of federal regulations regarding contaminants not covered by previous initiatives. Systems depending on surface water supplies, such as those in New York City, Boston, Seattle, and Tacoma are anticipated to experience substantial capital requirements for filtration systems. Thus, current costs of water to the residential user, approximately $1.40 per 1,000 gallons in 1990 on average nationally, may increase to an average of $2.50 per 1,000 gallons by the end of the decade.[72]

Finally, underlining the importance of such relative comparisons, the National Council for Public Works recently issued a report card for the major infrastructure systems in the United States. Estimates indicate that over 50 percent of all the existing landfills will reach capacity within 7 years.[73] The Environmental Protection Agency has set goals for 1992 in response to this problem. These goals include: (1) decreasing the amount of solid waste created by 25 percent, (2) increasing the overall waste recycling rate to 25 percent, and (3) burning 20 percent of the remaining MSW in waste-to-energy plants.

The relative resource impacts of disposal for reusable diaper wastes are lower than the impacts of single-use diaper disposal. If all diaper consumers relied on reusable diapers, the waste water load from diapers, considered as a proportion of total waste water processed, would be 5 - 10 times less than current solid waste disposal loads of single-use diapers, considered as a proportion of total MSW. The authors recognize, however, that use of reusable diapers results in local water consumption that may place increased burden on regional water supply and treatment systems. In areas of the country where water resources are more valued than solid waste disposal capacity, the volume of single-use diaper waste may have lower relative impacts locally.

---

[70] Lehrburger (1990); ADL2 (1990).

[71] Conservatively assumes two cotton diapers per change, laundering, toilet disposal of fecal contents, and year 2000 residential water rates.

[72] Personal communications with George Craft, American Water Works Association, 1990; and with Dr. Robert Clark, Director, Drinking Water Division, Environmental Protection Agency, Cincinnati, Ohio, 1990.

[73] Patricia W. Hamilton, "Emptying the Trash," Dun & Bradstreet Reports, vol. 37, issue 6 (Nov/Dec 1989), pp. 34-37.

F. Transportation Impacts

Transportation impacts are discussed here from a qualitative perspective, in order to facilitate an overview comparison between single-use and reusable diapers for this category.

A broad characterization of transportation requirements suggests that greater environmental impacts result from single-use diapers. This is primarily because (1) the predominant home laundered diaper use patterns for reusables have relatively little transportation impacts, and (2) the transportation impacts for harvesting and manufacturing reusable diaper raw materials are prorated over many uses.

Tracking the movement of primary raw materials and secondary products used to manufacture both reusable and single-use diapers is complex. Single-use diaper raw materials and key components must be hauled long distances. More than half of the petroleum feedstock for the production of plastic is imported from sites as distant as the Middle East, Venezuela, or the Alaskan arctic. Wood for paper-making comes from relatively remote sites in the United States, and resources employed for harvesting and moving it to pulp production facilities may rival expenditures for harvesting and transporting cotton from the field to ginning operations.

The cultivation of cotton is a transportation intensive process, requiring vehicles for seeding, fertilizer, pesticide and harvesting operations. Most commercially laundered diapers originate in China, requiring overseas transport to the U.S. These pre-diaper use transportation impacts are prorated by the number of uses for each reusable diaper. In contrast, the transportation impacts of single-use diapers are applied to each and every use.

When reusable diapers are purchased in a retail store along with other grocery or shopping items, they are transported to the home, where they remain for the duration of their "product life." The transportation impacts become negligible when divided by an estimated 180 uses for each home laundered reusable diaper. For each diaper laundry cycle, detergents are utilized. Acquisition of supplies for home laundering requires marginal transportation impacts, since (1) the trip to a grocery store occurs with or without diaper laundry supplies, (2) the purchase of diaper laundering supplies are a percentage of all household laundering materials, and (3) the transportation impacts attributable to diaper laundry detergents, which include disposal of detergent containers, are allocated over many diaper laundry cycles (an estimated 7-10 diaper uses).

In the case of commercially laundered diapers, the distances of transporting finished diapers to a diaper service may entail delivering diapers by truck from a domestic manufacturer and wholesaler, or may entail delivery of foreign produced diapers by ship to a wholesaler in the U.S. These initial product transportation impacts are prorated over 78 product uses, and therefore are relatively small, especially when compared to single-use products. Once in use, commercially laundered diapers are transported to and from customer residences by a diaper service delivery trucks, which average 10.6 miles per gallon. Since diaper services deal almost exclusively with diapers, all transportation impacts will be attributable to diapers. These vehicles travel on average 165.7 miles per day to make up 345.7 deliveries/ pickups. This works out to an average nearly 0.5 miles per customer.[74] Supplementary impacts result from the disposal of the used plastic bags from each customer. Thus, it is clear that commercially laundered diapers have significantly greater transportation impacts than home laundered diapers.

Single-use diapers travel from a manufacturing facility, first to a wholesaler and then to a retailer. Unlike reusable diapers, the transportation impacts are not prorated over many diaper uses. However, some of these impacts are prorated, since the trucks may be transporting other products along with the diapers. The diaper purchaser will travel to a retail store and purchase single-use diapers on a regular basis, approximately weekly. Once used, the diaper and its packaging materials are disposed of as solid waste, and transported to a disposal facility, often first travelling to a waste transfer station. As in the case of laundry detergents, the transportation impacts of acquiring and disposing of single-use diapers are prorated by the percentage that diapers comprise of the grocery load (approximately 5-10 percent) and of the waste disposal load (approximately 10-20 percent of the household refuse and a minuscule percentage of the total load on the waste hauling vehicle). The current fleet of waste hauling vehicles in service can expect to get between 3-7 mile per gallon, and make 500 to 700 pickups per shift.

When comparing commercially laundered reusables and single-use diapers, several other factors become apparent. The comparison must rely on prorating purchase and disposal trips for single-use diapers. It also must take into account the efficiency of vehicles of the diaper customer, diaper service and waste hauler. It is likely that the efficiency of the modern customer vehicle will cancel out the inefficiency and many stops of a waste hauling vehicle, when compared to the medium efficiency of a diaper service truck.

It also is likely that the relative efficiency of transporting diapers by a commercial diaper service, which combines pickup and delivery, may be canceled out or lost by prorating single-use diaper purchase and disposal with other elements of grocery shopping and waste disposal. It is therefore reasonable to estimate that commercial diaper services will have transportation impacts in the same order of magnitude as single-use diapers.

---

[74]Authors' diaper service operator survey (1990).

The following conclusions may be drawn from this brief discussion:

- reusable diapers laundered at home have the least transportation impacts associated with their use;

- a comparison of commercially laundered reusables and single-use diapers entails prorating waste disposal loads and establishing average delivery distances. The transportation impacts of using commercially laundered diapers and single-use diapers will probably be in the same range;

- when commercially and home laundered reusables are considered together, taking into account their market share of 13 percent and 87 percent respectively, there is little doubt that reusable diapers impose significantly fewer transportation impacts on the environment than do single-use diapers because of the preponderance of home laundered reusables.

G. Conclusions

Reusable diapers conserve resources. Since the same material is used many times, diaper waste is reduced. From a solid waste management perspective, therefore, they exemplify the best approach to diapering.

The waste water treatment system, contrasted with the solid waste disposal system, is more appropriate for handling diaper waste. Nearly all human sewage is diverted there with the exception of single-use diaper waste which goes to the solid waste system. Also, waste water treatment appears to provide a more efficient, sanitary disposal pathway with greater opportunity for beneficial reuse of concentrated and processed sludge than the solid waste stream.

Estimates of waste disposal impacts of diapers indicate that waste disposal costs for single-use diapers are significantly higher than costs for reusable diaper processing as long as the solid waste stream is relied on for disposal. This holds true for landfilling, waste-to-energy and composting options.

VI. MATERIALS UTILIZATION

Production and use of both reusable and single-use diapers have associated resource and environmental impacts including raw materials consumption/waste, energy consumption, water consumption, air and water degradation, waste generation, and heat and noise generation.

The following sections present the results of the cradle-to-grave analysis.

A. Single-use Diapers

Table E shows the raw materials for 1,000 single-use diapers, and is based on 1988 manufacturing data extrapolated to 1989 market estimates of 17 billion single-use infant diaper equivalents. Petrochemical feedstocks to the manufacturing of polyethylene and polypropylene are included as raw materials. Other significant inputs include salt mineral, an ingredient in chlorine manufacture and sodium hydroxide; limestone, a precursor of lime; and sulfur, an ingredient in sulfuric acid. Small quantities of catalysts, solvents and other additives were not included due to uncertainty about composition and quantity.

B. Reusable Diapers

Table F shows the raw materials for production and use of cotton reusable diapers. The data is presented on the basis of 1,000 equivalent uses of cotton diapers, for direct comparison with 1,000 single-use diapers. The equivalent use calculation assumes that 3.512 billion diaper changes in 1989 were cotton (18 percent of total changes)[75]. A weighted average between home laundered and commercially laundered reusables is assumed, so that 1.72 reusable diapers per diaper change and 167 uses per diaper are employed. Refer to "Assumption" section, IID, for a more detailed derivation.

The major inputs are cotton, fertilizer, pesticides, sodium hydroxide, sulfuric acid, detergents and bleach. Sodium hydroxide requires salt, fertilizer manufacture requires ammonia and therefore natural gas, pesticides requires organic chemicals and petrochemicals, sulfuric acid requires sulfur. Small quantities of catalysts, solvents and other additives were not included due to uncertainty about composition and quantity.

[75] Smith and Sheeran (1990).

Table E. Raw materials use: single-use diapers

Raw Materials (in pounds)	1,000 single-use diapers
Wood	193.36
Chlorine and caustic	10.99
Limestone	5.88
Sulfuric acid	2.13
De-inked waste paper	3.99
Other	0.14
Petroleum feedstocks[1]	27.83
Additives	0.24
Packaging	1.41
Total	**245.97**

Sources: American Paper Institute (1990), Franklin Associates Diaper Profile (1990), MRI (1977).
[1] Consists of raw petrochemicals used in plastics manufacturing process.

Table F. Raw materials use: reusable diapers

Raw Materials (in pounds)	1,000 reusable diaper changes[1]
Ammonia[2]	0.12
Phosphate ore	0.66
Nitric Acid	0.36
Chlorine and Caustic[3]	0.71
Sulfuric acid[4]	0.04
Cotton	1.59
Packaging	1.08
Pesticides	0.02
Subtotal	**4.58**
Detergents	64.55
Total	**69.13**

Totals may not add up due to rounding.
Sources: U.S. Department of Agriculture (1985); ADL2 (1990); MRI (1977); U.S. Department of Agriculture (1989); Sittig (1980); Franklin Associates Diaper Profile (1990).
[1] Assumes 1.72 reusable diapers per change and 167 uses per life of a reusable diaper.
[2] Includes ammonia used in nitric acid mfg.
[3] Includes salt used in caustic and chlorine mfg.
[4] Includes sulfur used in sulfuric acid mfg.

C. Conclusions

From Tables E and F it is apparent that reusable diapers use fewer raw materials per equivalent use than do single use diapers. If detergents are excluded reusables use less than 2 percent of the raw materials of single-use diapers on an equivalent change basis. When detergents are included, reusables use 28 percent of the raw materials of single-use diapers.

Input materials which are not incorporated into the final product, such as fuels, catalysts, cooling water, solvents, etc., are not counted as raw materials. Energy and water are accounted for in other categories such as energy, water use, etc., and small quantity inputs such as catalysts and solvents were not included because of insufficient data. It is important to note, however, that some constituents such as catalysts and solvents consist of high toxicity materials that can have substantial environmental and health implications notwithstanding their small quantity input. Where possible, these materials and their characteristics are discussed on a qualitative basis.

A significant quantity of raw material inputs to single-use diapers are petrochemicals. Since petrochemical feedstocks are derivatives of petroleum and natural gas, their use is in direct competition with other uses of petroleum and natural gas products, namely fuels. Fertilizer and pesticide production also uses petrochemicals, but the contribution of petrochemicals to plastics is much greater. Petrochemical inputs to reusable diapers become further reduced when prorated over multiple use.

Only recently crude oil was $13 per barrel and supply appeared reliable and economical. However, recent occurrences in the Middle East have driven oil prices to as high as $40 a barrel and have threatened the stability of oil supply. Approximately 48 percent of U.S. petroleum is from foreign sources, and use of petrochemicals as feedstock increases dependence on foreign supplies. Decreasing foreign supplies may result in increased exploration and development of domestic reserves, particularly offshore leases in the Pacific and Gulf of Mexico, as well as the Alaskan Wildlife Refuge. Impacts of exploration and development activities are far reaching, but difficult to quantify. Loss of habitat and increased occurrence of spills are two of the most obvious impacts. Over the period of 1978-1989, over eighty spills, each greater than 10,000 gallons, occurred resulting in an estimated loss of 16 million gallons of oil. Every product using petroleum as feedstock or fuel bears a portion of the impacts of these spills.

Raw materials used in the manufacture of single-use diapers enter the solid waste stream immediately after use, adding to the burden of solid waste disposal. From a raw materials allocation and use perspective, reusable diapers are clearly preferable because reusable diapers are used on the average of 78 times by commercial diaper services, and an estimated 180 times by home users before they are recycled yet again as rags.

VII. ENVIRONMENTAL BURDENS AND RESOURCE IMPACTS

A. Energy Generation and Consumption

Energy use data was gathered for each step of each component process in the manufacturing operations of single-use and reusable diapers. Electrical energy was tracked separately from energy provided directly by other fuels. Electrical energy was converted to its equivalent BTU value using a conversion of 10,235 BTUs per kWh, which adjusts for inefficiencies in the electrical generation and transmission systems. Transportation of fuels was not included in this calculation, which is on the conservative side. Other fuel forms were converted to BTU value using the energy value for the specific fuel source.

Energy value of the petrochemical feedstocks to plastics manufacturing is included in the energy figures for single-use diapers. Petrochemicals are used primarily as fuels, and the fuel equivalent is therefore included in the overall energy calculations. Not included in this assessment are: capital equipment in primary and secondary product transformation; energy consumed in space heating and cooling; transportation impacts; air pollution generation impacts of direct combustion of fossil fuel on manufacturing sites; or impacts of detergent manufacturing. Heat and noise emissions are difficult to quantify because of a lack of available data and are not addressed in this study.

Tables G and H summarize the quantity of energy used for single-use and reusable diapers respectively. An analysis of the available data suggests that manufacturing of reusable diapers uses only 17 percent of the energy that is required for manufacturing single-use diapers on an equivalent change basis.

When laundering of reusable diapers is included, the lifecycle energy consumption of the average reusable diaper increases to 59 percent of the overall energy consumption of single-use diapers.

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 drastic difference between commercially and home laundered reusables is a result of 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.

Energy required for manufacturing reusable diapers is distributed over many uses, making the proportion attributable to each use relatively small. Calculations of energy consumption in laundering, or course, are not affected by the number of times the product is reused.

Table G. Energy impacts: single-use diapers

Energy Impacts: single-use diaper production	**BTUs per 1,000 diapers**
Pulp and tissue manufacture[1]	
pulp and tissue	1,303,633
wood	19,556
chlorine/caustic	102,057
limestone	8,522
sulfuric acid	812
deinked wastepaper	12,163
Subtotal: Pulp & Tissue	**1,434,580**
Plastics manufacture	
petroleum feedstock	850,984
plastics and super absorbent gel manufacture[2]	546,895
Subtotal: Plastic	1,397,879
Diaper conversion	
conversion	402,235
packaging	250,000
Subtotal: Conversion	**652,235**
Subtotal: Manufacturing	**3,484,694**
Incineration credit for energy produced[3]	-29,214
Total BTUs per 1,000 single use diapers[4]	**3,455,480**

Totals may not add up due to rounding.
Sources: American Paper Institute (1988); U.S. Bureau of Census (1983); Energy Information Administration (1985); ADL2 (1990); Arthur D. Little (1988); Society of the Plastics Industry (1989); Franklin Associates Diaper Profile (1990); MRI (1977); Kirk and Othmar (1980); OCDE (1985); McKetta (1990); Modern Plastics (1990).

[1] Energy consumed in acquisition of raw materials and manufacturing of intermediate products such as chlorine and caustic are included.

[2] Energy of raw materials feedstock is included in plastics manufacture category.

[3] Assumes that 15 percent of the MSW stream, including single-use diapers, is combusted for energy recovery. This is a generous estimate given that the amount of urine/moisture in a single-use diaper will require significant energy to evaporate during the combustion process.

[4] Electrical energy conversion from kWhs to BTUs = 10,235.

Table H. Energy impacts: reusable diapers

Energy impacts: reusable diaper production and laundry BTUs per 1,000 diaper changes	Weighted Average Home and Commercial[1]	Commercial Diaper Service[2]	Home Laundered[3]
Manufacturing:			
natural gas production	1,690	2,524	1,640
ammonia manufacturing	583	871	566
phosphate mining	48	72	47
nitric acid manufacturing	18	27	16
caustic manufacturing	11,051	16,508	10,728
sulfur mining	40	60	39
sulfuric acid manufacturing[4]	-24	-36	-24
fertilizer manufacturing[5]	794	1,187	771
pesticide manufacturing	2,643	3,948	2,566
detergent manufacturing	488,849	395,531	502,793
packaging manufacturing	11,667	140,782	0
Subtotal: Manufacturing	**517,359**	**561,475**	**519,143**
Cotton conversion			
growth and harvest	5,967	8,914	5,793
cotton ginning	558	834	542
cloth processing/conversion	54,453	81,340	52,859
Subtotal: Conversion	**60,978**	**91,088**	**59,194**
Subtotal: Manufacturing	**578,339**	**652,562**	**578,338**
Home laundry (87%)[6]	1,371,429	0	1,576,355
Commercial laundry(13%)[6]	80,861	456,431	0
Subtotal diaper laundry[7]	**1,452,290**	**456,431**	**1,576,355**
Total BTUs per 1,000 reusable diaper changes[8]	**2,030,628**	**1,108,994**	**2,154,693**

Totals may not add up due to rounding.
Sources: MRI (1977); ADL2 (1990); American Paper Institute (1988); Stout (1987); Fluck (1980); Energy Information Administration (1985); U.S. Bureau of Census (1983); Helsel (1987); National Cotton Council (1989); Pimentel (1980); Texas Agricultural Extension Service (1987, 1990); U.S. Department of Commerce (1990).
[1] Assumptions: 1.72 diapers per diaper change, 167 uses per life.
[2] Assumptions: 1.20 diapers per diaper change, 78 uses per life.
[3] Assumptions: 1.80 diapers per diaper change, 180 uses per life.
[4] Sulfuric acid mfg produces a net energy gain.
[5] Energy of raw materials feedstock is included in the fertilizer manufacture category.
[6] Market data on breakdown of home vs. commercial from Smith and Sheeran (1990).
[7] Laundry energy data from ADL2 (1990).
[8] Electrical energy conversion from kWhs to BTUs = 10,235.

Plastics and petrochemical manufacturing, cotton manufacturing, and single-use and reusable diaper conversion technologies require electrical energy which is, for the most part, purchased from a utility. Paper manufacturing, while demanding electrical energy, also requires steam for heating and drying processes. However, the paper industry has successfully reduced its purchased energy requirements by developing the capability to burn spent liquors from the pulping process as well as slash, bark and other wood wastes. This process has the benefit of less waste generated, but does not reduce gross energy requirements.

The majority of energy consumption in reusables occurs during the laundering process, while manufacturing operations demand more energy in single-use diapers. Results presented in this study differ from other studies due to differing diaper use assumptions, different energy use assumptions for laundering operations and the inclusion or omission of transportation energy use. This study does not address transportation energy use quantitatively, but it is discussed from a relative resource perspective in section VF.

B. Water Use, Consumption and Treatment

Water is a major resource associated with reusable and single-use diapers. It is an essential input to cotton growing, is used in textile mills to clean the cloth product, and in home and commercial laundering of reusable diapers. Single-use diaper water use occurs primarily in production, especially in manufacture of tissue and fluff pulp components where its primary use is as a solvent and a suspension medium.

Table I presents estimates of gross and net water use for single-use diapers. Table J presents estimates of gross and net water use for reusable diapers, distinguishing water use rates for commercially and home laundered reusables. Gross water use is measured from a reference point within the production process, and includes intake water plus recycled water. Net water use is measured by waste water discharge, exclusive of agricultural run-off. Single-use diapers use more water from the gross water perspective than either commercially or home laundered reusables. From a net-water-use perspective, commercially laundered reusable diapers use less water than single-use diapers. Home laundered reusables use more water than either single-use or commercially laundered reusable diapers.

Table I. Water use analysis: single-use diapers

Water use: gallons per 1,000 single-use diapers	Gross water	Net water
Fluff pulp[1]	4,187.51	843.64
Tissue[2]	448.66	108.68
Absorbent gelling material[2]	0.00	79.36
Backsheet (polyethylene)[2]	235.31	66.69
Nonwoven (polypropylene)[2]	176.48	50.02
Minor components[2]	148.24	42.01
Petroleum refining, chemicals, productions, and other back-end steps[3]	40.00	40.00
Subtotal	**5,236.20**	**1,210.40**
Toilet (fecal disposal)[4]	749.99	749.99
Total gallons	**5,986.19**	**1,960.39**

Totals may not add up due to rounding.
[1] Lockwood's Posts Directory of Pulp and Allied Trades (1990).
[2] Van der Leeden, Troise, and Todd (1990), Table 5-45, p. 358.
[3] Franklin Associates Diaper Profile, pp. 3-21, 3-22.
[4] Fifty percent of the 33 percent of infant diapers containing fecal material are shown as being emptied in the toilet, at 4.5 gallons/flush.

Table J. Water use analysis: reusable diapers

Water use: gallons per 1,000 reusable diapers	Commercial laundered[1]		Home laundered[2]	
	Gross water	Net water	Gross water	Net water
Cotton growing[3]	1,202.51	0.0	422.35	0.0
Textile mills[4]	119.92	51.56	42.12	18.11
Plastics	47.32	13.41	1.16	0.34
Fertilizer, pesticide, herbicide	68.5	13.31	24.17	4.70
Back-end steps for plastic production[5]	23.13	23.13	24.74	24.74
Subtotal	**1,461.38**	**101.42**	**514.56**	**47.88**
Toilet (fecal disposal)[6]	75.0	75.0	1,349.99	1,349.99
Laundry	1,200.00	1,200.00	2,070.00	2,070.00
Total gallons	**2,736.38**	**1,376.42**	**3,934.66**	**3,467.87**

Totals may not add up due to rounding.
[1] Authors' diaper service operator survey (1990): 1.2 diapers/change, 78 uses/diaper, 0.22 lbs./diaper.
[2] Franklin Associates Diaper Profile (1990), p. 3-22: water estimate using 1.8 diapers/change, 180 uses/diaper, .12 lbs./diaper.
[3] Franklin Associates Diaper Profile (1990), estimate of average irrigation nationwide, p. 3-21, 3-22.
[4] Van der Leeden (1990), Table 5-45, p. 358.
[5] Franklin Associates Diaper Profile (1990), p. 3-21, 3-22.
[6] Of the 33 percent of infant diapers containing fecal material, 5 percent of commercially laundered diaper changes and 90 percent of home laundered diaper changes are shown as being emptied into the toilet, at the rate of 4.5 gallons/flush.

The computations represent a synthesis of available information; they warrant discussion because of their complexity and because recent studies for Procter and Gamble (ADL2) and the American Paper Institute (Franklin Associates Diaper Profile) reach conclusions that contradict those represented here.

Factors which make consensus on diaper water use difficult 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, like (a) the number of diapers used per diaper change, (b) the number of times a reusable diaper typically is reused (with a further distinction between home and commercial laundering) and (c) the weight of materials in diaper products; (3) uncertainty about the percentage of consumers following advisories on single-use diaper packages to flush fecal matter from soiled single-use diapers down the toilet; and (4) conceptual problems related to selection of net and gross water utilization figures.

The basic assumptions utilized in computing water use for reusable diapers shown in table J are: 180 reuses for home laundered and 78 reuses for commercially laundered reusable diapers and an average of 1.2 reusable diapers per diaper change for commercially laundered and an average of 1.8 diapers per change for home laundered reusable diapers. The weight of materials in Tables I and J has been adjusted upwards from 0.12 pounds per single-use diaper and 0.13 pounds per reusable diaper because paper and plastic accessories, e.g., for packaging or plastic covers for reusable diapers, are relatively water intensive products.[76] With respect to the cloth alone, a home laundered reusable diaper is lighter, weighing approximately 0.12 pounds per diaper, compared with 0.22 pounds per cloth diaper used by commercial diaper services. Franklin Associates Diaper Profile estimates of water use in home laundry operations, 46 gallons per load of 40 diapers, are used in Table J.

One third of all diapers are assumed to contain fecal matter.[77] Higher rates of toilet rinsing of fecal material are assumed for home laundered reusable diapers than for single-use diapers. In the home laundry reusable diaper computation developed in Table J, 90 percent of the soiled diapers are assumed to be rinsed in the toilet at an average of 4.5 gallons per flush.[78] Five percent of the commercially laundered soiled diapers are assumed to be rinsed in the toilet, since diaper services do not require rinsing.

For single-use diapers, if all consumers followed the advisories on single-use packages to flush fecal contents down the toilet, then water use for this particular behavior would be the same as for home laundered reusables. Table I assumes that 50 percent of single-use diaper consumers will follow these instructions, even though this is presently not a common practice (i.e., 50 percent of 33 percent of single-use diaper changes involve toilet flushing at 4.5 gallons per flush). If toilet flushing is excluded from the analysis, single-use diapers would use 1.2 gallons per diaper and commercially laundered diapers would use 1.3 gallons per diaper change. Home laundered diapers use significantly more than either.

These computations show that when the three different diapering modes are evaluated on the basis of net water use, commercially laundered reusable diapers use the least amount of water at 1.37 gallons per diaper change, followed by single-use diapers at 1.98 gallons per diaper change, and home laundered reusables at 3.47 gallons per diaper change. On

---

[76] The weights used conform, in most instances, to estimates in Franklin Associates Diaper Profile (1990), pp. 3-21. See Table 3-11 Water Volume Requirements of Each Diaper System by Individual Component or Material.

[77] Lehrburger (1988), p. 22, based on a composite of 3 studies cited by the author.

[78] An average for low flush toilets (3.5 gallons per flush) mandated in new housing and older toilets (5 gallons per flush).

the basis of gross water use, that is, excluding in-plant water recycling, single-use diapers are more water intensive than both home laundered and commercially laundered diapers.

C. Solid Waste Generation

Two forms of solid waste are important in a product lifecycle analysis. Process solid waste is generated during manufacturing operations associated with production of primary, intermediate, and final products. Post-consumer solid waste is generated after the useful life of the product, and is discussed fully in section V.

All manufacturing and processing operations generate solid waste. However, there has been an industry focus on waste reduction over the past several years which has led to greater recovery and use of waste materials within a manufacturing operation. These recovery programs enable industries to avoid landfill costs and result in more competitive pricing. Two good examples are the use of low quality wood scraps and spent liquors as fuel within the paper industry, and the recovery of unreacted monomer and polymer during plastics manufacturing.

In comparing solid waste generated by two products or processes, quantity is not the only consideration. 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. Cotton fibers have little impact on the environment. Manufacture of pulp and paper, and plastics, on the other hand, produces a low volume of potentially high impact waste materials, in the form of industrial sludge, which include solvents, unreacted polymers, dioxins and furans, as well as other chlorinated hydrocarbons.

The following table summarizes both process and post-consumer waste generated by single-use and reusable diapers.

Solid Waste Impact (in pounds)	1,000 single-use diapers	1,000 reusable diaper changes
Process solid waste (manufacturing)	14.2	3.77
Post-consumer solid waste	428	55.42
Total pounds	**442**	**59.19**

Table K shows the process solid waste generation for single-use diapers. Much of the industry's information on waste generation is proprietary, so the data set is incomplete. While there have been significant reductions in the amount of waste directly attributable to manufacturing operations in the paper and plastics industries, waste in the form of sludge from water treatment systems is still a component.

Table L shows the solid waste impacts for reusable diaper manufacturing, identifying the sources of process solid waste during manufacturing operations. There is little agreement in the literature on the quantity of cotton harvested that becomes waste, so a conservative figure of 18 percent was used.

A comparison of the two tables shows that single-use diaper manufacturing generates almost 4 times more process solid waste than reusable diaper manufacturing. With respect to total waste generation, including process waste and post-consumer waste, single-use diapers generate over 7 times more wastes over the lifecycle of the product.

Table K. Solid waste: single-use diapers

Process and post-consumer solid waste: single-use diapers	**1,000 diaper changes**
Process solid waste	
pulp and tissue manufacturing[1]	11.78
plastics manufacturing[2]	1.67
diaper conversion	0.83
Subtotal manufacturing	**14.29**
Post-consumer waste	
packaging	1.41
disposal[3]	426.44
Subtotal post-consumer solid waste	**427.85**
Total solid waste	**442.14**

Totals may not add up due to rounding.
Sources: ADL2 (1990); Franklin Associates Diaper Profile (1990); MRI (1977); American Paper Institute (1988).
[1] Includes waste generated from combustion of fuels and raw materials refining.
[2] Consists of sludge from water treatment and combustion residues.
[3] Includes weight of feces and urine.

Table L. Solid waste: reusable diapers

Process and post-consumer solid waste: reusable diapers	**1,000 diaper change equivalent[1]**
Process solid waste	
natural gas production	0.0000
ammonia mfg	0.0000
phosphate mining	0.9864
nitric acid mfg	0.0000
caustic mfg	0.2664
sulfur mining	0.0029
sulfuric acid mfg	0.0001
fertilizer mfg	0.0000
pesticides mfg	0.0001
Cotton growth and harvest	0.000
Cotton ginning	0.1732
Cloth mfg and conversion	0.6634
Petrochemical refining[1]	0.0752
Combustion of fuels[2]	1.5990
Subtotal manufacturing	**3.77**
Post-consumer waste	
home laundry (87%) sludge	46.0
commercial laundry (13%) sludge	7.0
packaging	1.08
Subtotal laundry	**54.08**
Diaper disposal	1.34
Total solid waste	**59.19**

Totals may not add up due to rounding.
Sources: ADL2 (1990); Franklin Associates Diaper Profile (1990); MRI (1977); Sittig (1980).
[1] Assumes a weighted average of 1.72 reusable diapers per change, at 167 uses per diaper.
[2] Consists of wastes generated during petrochemical refining for fuels, an input to manufacturing processes, and fuels used to generate electricity for laundering.
[3] Consists of residues generated by combustion of fuels for electricity production for manufacturing and laundering processes. Does not include combustion of raw fuels in industrial boilers.

D. Air Emissions

Data on air emissions from diaper manufacturing operations is not widely available. Secondary and tertiary sources are used as the basis of this discussion.

Major categories of air pollutants and emission quantities are presented in Tables M and N for single-use diapers and reusable diapers respectively. Per equivalent change, single-use diapers create more CO, HC and particulates. Reusable diapers create more NO_x and comparable quantities of SO_x.

Table M. Air emissions: single-use diapers

Air emissions impact per 1,000 single-use diapers (in pounds)[1,2]	**CO**	**HC**	**Parti-culates**	**NO_x**	**SO_x**
Plastics					
petroleum feedstock[3]	0.395	0.126	0.007	0.002	0.145
plastics manufacturing	0.0003	0.051	0.009	0.000	0.000
electrical use[4]	0.018	0.115	0.080	0.251	0.438
conversion	0.036	0.226	0.158	0.492	0.861
fuels refining[5]	0.925	0.295	0.172	0.005	0.033
Subtotal Plastics:	**1.374**	**0.815**	**0.271**	**0.750**	**1.347**
Pulp and tissue:					
lime manufacturing			0.654		
sulfuric acid			0.011		
pulp and tissue manufacturing	1.085		0.109	0.041	0.340
electrical use[6]	0.025	0.158	0.110	0.344	0.602
self-generated energy[7]	0.084	0.036	1.125	0.014	0.003
Subtotal Pulp and tissue:	**1.293**	**0.194**	**1.010**	**0.399**	**0.946**
Subtotal Manufacturing	**2.667**	**1.008**	**1.282**	**1.149**	**2.292**
Incineration[9]	**0.001**			**0.027**	**0.001**
Total lbs. emissions per 1,000 diapers	**2.758**	**1.008**	**1.282**	**1.176**	**2.294**

Totals may not add up due to rounding.
Sources: U.S. EPA, AP-42... (1985); U.S. EPA, Source Assessment... Monsanto (1978); Modetz and Murtiff (1987); MRI (1977); ADL2 (1990); OCDE (1985); Arthur D. Little (1985); Sittig (1980); CRC Handbook of Environmental Control (1972).

1 Data based on 1988 data extrapolated to 17 billion diaper equivalents.
2 Diaper per change equivalent = 1 single-use diaper.
3 Consists of emissions from refining raw material feedstock.
4 Emissions from generation of electricity by utility.
5 Emissions from refining petrochemical for fuel.
6 Emissions from generation of electricity by utility.
7 Assumes half of self generated energy is wood waste.
8 Assumes that 15 percent of MSW, and therefore 15 percent of single-use diapers are incinerated.

Table N. Air emissions: reusable diapers

Air emissions impact per 1,000 diaper changes (in pounds)[1]	CO	HC	Parti-cu-lates	NO_x	SO_x
Raw fuels refining	0.404	0.129	0.007	0.002	0.014
Cotton growth/harvest	0.004	0.012	0.001	0.019	0.001
Fertilizer mfg	0.274	0.001	0.001	0.001	0.001
Cotton fabric	0.003	0.022	0.006	0.048	0.084
Cloth conversion	0.0	0.0	0.015	0.0	0.0
Electricity (mfg)	0.004	0.026	0.018	0.057	0.099
Subtotal manufacturing	**0.725**	**0.190**	**0.050**	**0.013**	**0.199**
Detergent mfg			0.021	0.0	0.0
Laundering air emissions	0.087	0.549	0.383	1.195	2.091
Subtotal laundering emissions	**0.087**	**0.549**	**0.403**	**1.195**	**2.091**
Total lbs emissions per 1,000 diaper changes	**0.812**	**0.739**	**0.454**	**1.323**	**2.291**

Totals may not add up due to rounding.
Sources: U.S. EPA, AP-42... (1985); ADL2 (1990); MRI (1977); Edgar 1983; McKean 1978; H.R. Jones (1973); A.R. Jones (1983).
[1] Diaper change equivalent = 1.72 reusable diapers.

Note that while emissions data is generally reported on a rate basis, in units of mass per volume air or per unit weight of product, the data here has been normalized to represent mass loadings based on the total output of products for each diapering mode. This method makes it difficult to track concentrations of releases for comparison with air quality standards. However, air quality impacts can be assessed on a qualitative basis from the mass loading data.

Laundering of reusable diapers uses substantial quantities of electricity, with resulting air pollution impacts. The manufacturing processes for plastics and for pulp and paper are also energy intensive. Plastics manufacturing is responsible for releases of large quantities of hydrocarbons (HC) and particulates, while paper operations emit significant quantities of sulfur and chlorine compounds. Cotton ginning processes emit substantial quantities of particulates, but few other airborne contaminants. Fertilizer manufacture consumes significant quantities of hydrocarbon feedstocks, thereby generating substantial quantities of CO.

Health impacts of airborne contaminants are based on dose (i.e., concentration) and duration. Neither can be determined from the available data. On a local basis, when the concentration of any pollutant exceeds established standards, compromised health may result. Acute symptoms may include eye, nasal, or dermal irritation, chest tightness and apnea, shortness of breath and wheezing, and decreased exercise tolerance. Patients with pre-existing heart and lung conditions are most sensitive to airborne contamination.

The acute health effects of airborne contamination are well documented, but questions must be raised regarding long term exposures to airborne particulates. Lung autopsies of previously healthy, non-smoking city dwellers, for example, show blacker lungs than those subjects raised in rural environments. Links between cancer and hydrocarbons and particulates, and the oxides of sulfur and nitrogen are being investigated. The influences of long term exposures to airborne contamination on total life span must certainly be explored.

Property damage and more subtle, long-term environmental effects such as acid rain and global warming also result from industrial pollution. Risk assessments are the tools generally used to relate emissions to health and environmental impacts. Site specific information and contaminant concentrations are necessary to perform quantitative impact assessments.

While manufacturing operations for single-use diapers are energy and emission intensive, laundering operations for reusable diapers generate significant quantities of hydrocarbons, nitrogen oxides and sulfur oxides. The two diapering modes generate comparable amounts of priority pollutants and neither mode is environmentally superior with respect to air emissions.

E. Waterborne Emissions

Three well-established indicators of water quality are biological oxygen demand (BOD), chemical oxygen demand (COD), and total suspended solids (TSS). Biological oxygen demand measures the amount of dissolved oxygen used in the biochemical oxidation of organic matter present in a water body. The demand for oxygen by organic material is in direct competition with fish and other flora and fauna, and high BOD levels can indicate an unhealthy ecosystem.

COD is likewise an indicator of the quantity of organic matter present in water, but it is also used to measure the content of compounds potentially toxic to aquatic life. The COD of a waste is generally higher than its BOD because more compounds can be chemically oxidized than biologically oxidized. A broad range of pollutants are encompassed by the COD measure, from harmless organic food materials to potentially toxic organic compounds.

Because the measurement of only a few parameters is required under federal water laws, extensive and reliable data on waterborne emissions from manufacturing operations is not available. Secondary and tertiary sources, therefore, are used as the basis for this discussion.

Note that water emissions data is generally reported on a rate basis, in units of mass per volume of water or per unit weight of product. The data here has been normalized to represent mass loadings based on the total output of products for each diapering mode.

This method makes it difficult to track concentrations of releases for comparison with water quality standards. However, water quality impacts can be assessed on a qualitative basis from the mass loading data.

Table O. Waterborne emissions: single-use diapers

Water Pollution Impacts per 1,000 Single-use Diapers (in pounds)	**Manufacturing**	**Toilet Disposal of Diaper Content[1]**	**Total**
Biological oxygen demand (BOD)	0.816	0.685	1.501
Chemical oxygen demand (COD)	0.448	0.779	1.227
Total dissolved solids (TDS)	1.317	0.622	1.939
Total suspended solids (TSS)	0.255	1.556	1.811
Oil and Grease (O & G)	0.002	0.0	0.002
Other: Acids	0.202	0.0	0.202
Sulfides	0.0003	0.0	0.0003
Metal ions	0.017	0.0	0.017

Totals may not add up due to rounding.
Sources: ADL2 (1990); MRI (1977); Sittig (1979); NCASI (1989); Metcalf and Eddy (1979).
[1] Assumes that 16.5 percent of all single-use diapers will be rinsed in the toilet, resulting in one toilet flush each.

Table P. Waterborne emissions: reusable diapers

Water Pollution Impacts per 1,000 reusable diaper changes[1] (in pounds)	Manufacturing[2]	Laundry and toilet disposal[3,4]	Total
Biological oxygen demand (BOD)	0.007	1.880	1.887
Chemical oxygen demand (COD)	0.057	4.209	4.266
Total suspended solids (TSS)	0.1925	1.6034	1.796
Oil and grease (O & G)	0.001	0.802	0.803
Total dissolved solids (TDS)	**0.180**	**4.008**	**4.188**

Totals may not add up due to rounding.
Sources: MRI (1977); Sittig (1979); ADL2 (1990); Corbitt (1990).
[1] Assumes 1.72 reusable diapers per change at 167 uses per life, except for laundering.
[2] Includes electrical generation from manufacturing.
[3] Assumes that 33 percent of diapers will contain feces, and 90 percent of home washed diapers will be rinsed, while only 5 percent of commercially washed diapers will be rinsed.
[4] Includes electrical generation for laundering.

A comparison of Table O and P shows that reusable diapers generate higher mass loadings of BOD, COD, TDS and O & G, while single-use diapers generate higher mass loadings of TSS. The data reflects several phenomena which require discussion.

It is evident that consumer practices regarding flushing diaper contents could significantly affect water quality. If the contents of all single-use diapers containing feces were flushed, total waterborne emissions would exceed those of reusable diapers in every category except COD.

BOD and TSS levels reported for reusable diapers come primarily from the laundering activities associated with reuse. While cotton finishing steps also generate BOD, COD and TSS, the contribution per 1,000 changes is small compared to laundering. It must also be noted that fertilizer and pesticide application generate water pollution, but due to the non-point source nature of the pollution, those impacts are difficult to quantify and are not addressed here. BOD values for both diapering modes are similar and it is difficult to say if the difference is meaningful.

Not shown in Table P are contributions of nitrogen (N) and phosphorous (P) from laundering. Nutrients like N and P can cause algae blooms in surface water supplies choking other life forms. However, waste water treatment plants are successful in removing a high percentage of N and P.

BOD, COD and TDS from single-use diapers generated during manufacturing can include pollutants for which there are no specific monitoring and treatment requirements. In 1977, many of the effluents produced in the pulp and paper industry were released with minimal treatment. In response to environmental degradation, proposed updates to the Clean Water Act seek to increase the number of regulated substances and lower the maximum allowable release levels.

The extensive system of publicly-owned waste water treatment works (POTWs) in the U.S. has been designed specifically to treat domestic waste water, typically characterized by levels of BOD and TSS similar to that generated by laundering. POTWs represent the ultimate recycling program, returning vast quantities of waste water to the earth's hydrologic system.

High temperature water discharges are another industrial effluent that have significant impacts on the environment. Most stationary power generating facilities require cooling water to condense the steam produced by burning fuels to turn a turbine. Therefore, cooling water use is somewhat proportional to purchased electricity consumption. Other manufacturing operations, particularly plastics, require water for suspending emulsions and cooling extrusions. Unfortunately, little quantitative data exists to document the potential impacts of high temperature cooling water discharge.

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 industry.