IV. DIAPER MANUFACTURING

A. Introduction

The two primary industries under study are the cotton (reusable) diaper and disposable (single-use diaper) manufacturing industries. Secondary industries for reusable diaper production include cotton growth and harvest, fertilizer and detergent manufacturing, cotton refining, cloth manufacturing, and laundering processes. For production of single-use diapers, the secondary industries consist of hydrocarbon refining; petrochemical manufacture including low-density polyethylene, polypropylene, polyacrylic gels, and adhesives; paper manufacture including timber growth and harvest and pulp and tissue manufacture; and finally, conversion to final diaper product. Processes common to both industry include fuels refining and energy production and generation.

B. Cotton Diaper Manufacturing Processes

Reusable diapers are manufactured from cotton fibers using standard textile processing operations: cotton ginning, carding, drawing, spinning and weaving in the manufacturing operations. Analysis of cotton diaper production begins with the operations of cotton growth and harvest. Nitrogen fertilizer manufacture and application is included in the analysis of cotton growth, as is the consumption of energy and water.

Many different pesticides, insecticides, fungicides and herbicides are used in cotton cultivation, depending on the climate, pests indigenous to the growing region, and the extent of growing infestation. Because of the diversity of chemicals and processes involved in the manufacture of pesticides and the difficulty in acquiring representative data, pesticides were included as a raw material input to the process and impacts are discussed on a qualitative basis.

Harvesting, ginning and weaving also are included in the analysis, as is the conversion of cotton cloth to the finished diaper product. Finally, the laundering operations associated with reuse are analyzed, for both the home and commercial washing scenarios.

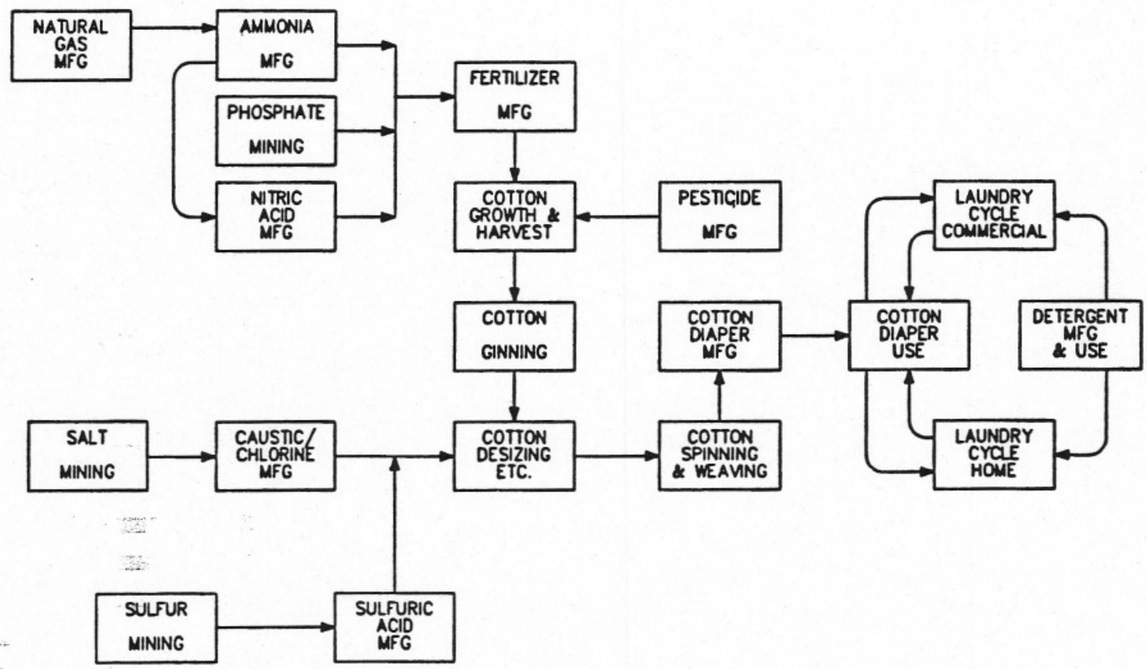

Figure 9. Cotton diaper manufacturing process

Cotton Growth and Harvest

Approximately 12,515,000 acres of cotton were planted in 1988, with 11,759,000 acres ultimately harvested. At an average yield of 706 pounds of cotton per acre, 8,301,854,000 pounds of cotton were produced in the U.S. in 1988. Cotton baled in 1988 equaled 7,392,000,000 pounds resulting in 913,203,940 pounds of waste, or 12 percent of production.[40]

Cotton growth is an energy and chemical intensive agricultural process. Pesticides, herbicides, insecticides and fertilizers may be applied many times during cotton cultivation. The amount and frequency of application is dependent on a variety of factors such as weather and the extent of infestation, and is therefore difficult to track or predict for the purposes of a study such as this. Applications involve significant use of heavy machinery for air or land spraying operations, resulting in fuel consumption and the generation of associated air pollution. Water and air emissions directly resulting from use of fertilizers and pesticides are difficult to measure because frequency of application is not a constant, and because of the non-point source nature of the releases.

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[40] Foreign Agricultural Service, World Cotton Situation: October 1989, (Washington, DC: Foreign Agricultural Service, 1989).

Cotton diapers used in the U.S. used 8,044,800 pounds of cotton in 1988, or 0.109 percent of cotton produced in the U.S. Cotton diapers used in the U.S. accounted for 2,964,800 pounds of fertilizers and 126,900 pounds of pesticides in 1988.[41] All data on cotton manufacturing was adjusted to account for foreign production, which was assumed to be grown and manufactured under the same conditions as prevail in the U.S.

Prior to harvesting, desiccants or defoliants are used to dry the cotton bolls and separate them from the plant to allow mechanical harvesting. Harvesting is also an energy intensive activity, with less than 10 percent of acres planted with cotton hand-picked in 1988. After harvesting, raw cotton is taken to gins, where it is dried in natural gas-fired dryers. It is then processed to separate the cotton fibers from cotton seeds and flowers as well as from dirt and other impurities picked up during the mechanical harvesting process.

After ginning, the cleaned cotton fibers are spun into yarn for weaving. Yarn production involves aligning the fibers through a carding and spinning process similar to the methods used by our foremothers who used wire brushes and spinning wheels to make their own yarn. Relatively small quantities of solid waste are generated in this process, amounting to less than 7 percent of finished product by weight.

After yarn production, a sizing step is often performed to coat and strengthen a portion of the yarn prior to weaving. Starch is the most common sizing agent used in diaper yarn, but other additives are often incorporated into the sizing step. Yarns are then mounted onto weaving looms, forming the basic structural support of the cloth, and yarn is woven through the base strands at perpendicular angles, which form the woven cotton cloth.

Cotton cloth destined for use in diapers goes through a finishing process. De-sizing is a cleaning operation to remove the sizing, or starch. Sulfuric acid or enzymes are used to degrade the starch, which decomposes and solubilizes in a hot water bath. Scouring processes follow to remove any impurities remaining in the cloth. Sodium hydroxide, soap and sodium silicate are used to scour the fabric, which is then rinsed, heated and bleached with chlorine. A second rinsing and chlorine bleaching step, followed by a final rinse yields the final cotton product. The edges are stitched, the cloth can be layered for extra absorbency and the final diaper product is ready for distribution.

Cotton finishing is an energy and water intensive process. The effluent produced contains by-products from the finishing steps, including sodium silicate, sodium hydroxide, sodium phosphate, surfactant, chelating agents, and dissolved solids. Residues from the bleaching and desizing process have environmental impacts, but little data was available because of the proprietary nature of the process. It is important to note that these impacts are distributed over multiple diaper uses during the life of a reusable diaper, and therefore greatly reduced on a per-use basis.

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[41] Foreign Agricultural Service (1989).

C. Single-use Diaper Manufacturing Processes

Fluff pulp and tissue paper comprise almost 65 percent of the single-use diaper by weight, with the other 35 percent comprised of plastics and miscellaneous small quantity materials.

Figure 10 shows the materials breakdown of a typical single-use diaper.

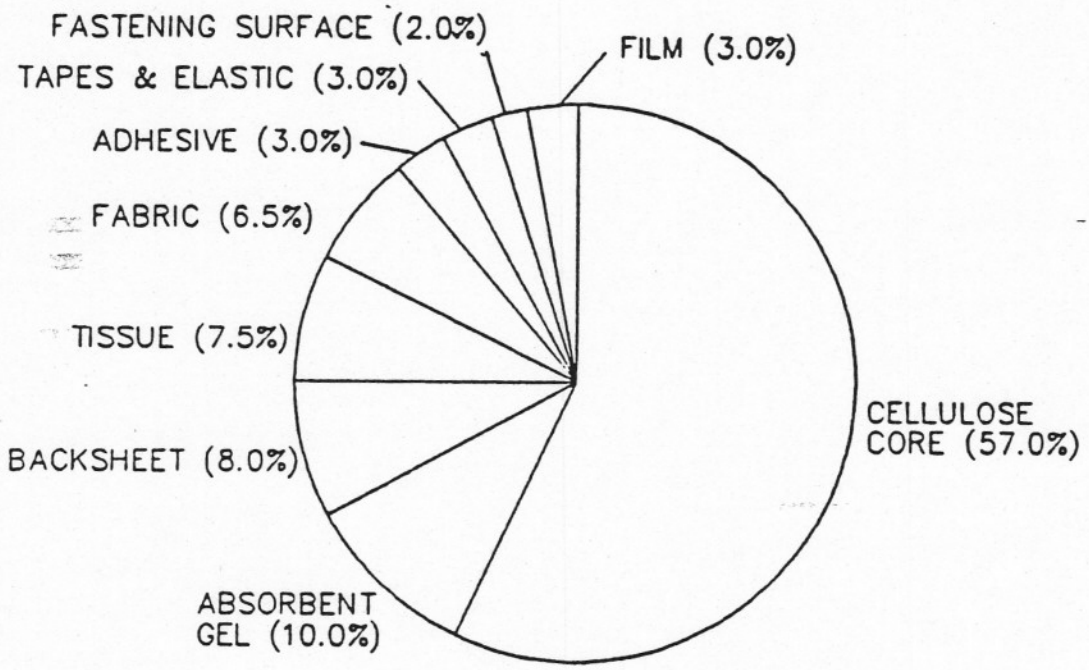

Figure 10. Typical single-use diaper[42]

Pulp and Paper

Single-use diapers are made predominantly of fluff pulp and tissue, with smaller components of plastics such as low density polyethylene (LDPE) and polypropylene, as well as natural rubber and hot melt adhesives. These raw materials require the ancillary production activities of timber growth and harvest; pulp manufacturing; tissue paper manufacturing; ethylene manufacturing including the refining of crude oil and natural gas; LDPE resin and film manufacturing; polypropylene resin and nonwovens manufacturing; polyacrylic gel manufacturing including ammonia production; and finally, the conversion to the diaper end product.

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[42] ADL2 (1990), p. II-16.

Fluff pulp used in diapers is approximately 56 percent virgin market pulp, and 44 percent de-inked recycled wastepaper.[43] Fluff pulp is a high grade pulp product representing approximately 1.3 percent of the pulp market. Approximately 98 percent of fluff pulp produced is used in sanitary products such as feminine hygiene products and diapers.

Virgin market pulp is derived from timber products and by-products. Over the last decade, timber farming in the United States has incorporated the use of chemical defoliants which are applied by aerial spaying to retard the growth of competing undergrowth. For several years, public outcry over areal spraying on publicly-owned lands has reduced the amounts of defoliants used in timber farming and has made it difficult to quantify. Air emissions of carbon dioxide and chemical substrate, as well as contamination of watersheds resulting from defoliant use, are difficult to measure because of the non-point source nature of the release.

Pulp production begins with the harvest of timber. A highly mechanized process involving the use of specialized equipment, timber harvest is an energy intensive industry consuming fuels which create air pollution. Disruption of forest ecosystems, especially during clearcutting activities, results in immeasurable soil erosion and habitat loss, which leads to water pollution and impacts on wildlife. Approximately 10 percent of all harvested timber remains in the forest as waste material.

Harvested timber is delivered directly to pulp mills, where it is processed to remove bark and converted to uniform chips. North American pulp mills use 5 types of pulping processes which provide varying qualities and yields of pulp. Pulp used in fluff pulps and tissue manufacture are generated predominantly through the kraft process, which provides high quality pulp with a relatively low yield of 45 to 55 percent of raw material input. Kraft pulping is a chemical process by which the wood is broken down through a chemical digestion process using a hot water based solution of sodium sulfite liquor. Lignin contained in the wood interferes with the paper making process, so it is separated from the cellulose during the digestion process.

After the pulping process is completed the pulp is separated from the pulping liquor, and is washed and refined by bleaching. After refining, the pulp is either dried for use as market pulp, or prepared for the paper-making portion of the process.

Dried market pulp is used extensively by paper-making operations which do not have integrated pulp mills on site. It is more economical to ship dry pulp. Yet drying pulp requires substantial energy inputs. It is estimated that 40 percent of tissue manufacturing capacity is integrated while 60 percent requires dry market pulp. Most fluff pulp is made from market pulp transported to specialty diaper manufacturing facilities.

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[43] American Paper Institute, Pulp and Paper Fact Book (Washington, D.C.: API, 1988), and authors' estimates.

Market pulp is produced by accumulating the waterborne pulp, referred to as the furnish, on a fine screen and physically and mechanically removing the water, leaving a pulp mat. The pulp is then dried and prepared for shipment by bundling or rolling.

High grade pulps destined for fluff pulp for diapers are usually produced in roll form and shipped to diaper manufacturers who fluff the material to give the end-products the desired absorbency, thickness and softness. Diapers account for over 80 percent of the U.S. consumption of fluff pulps.

By-products of pulp manufacture include the spent liquors from the pulping process and wood of inferior quality not used in pulping. Spent pulping liquors are high in lignin content and allow for turpentine and soap recovery. Water is recovered and reused in the pulping process, and chemicals in the pulping liquors can also be recovered and regenerated.

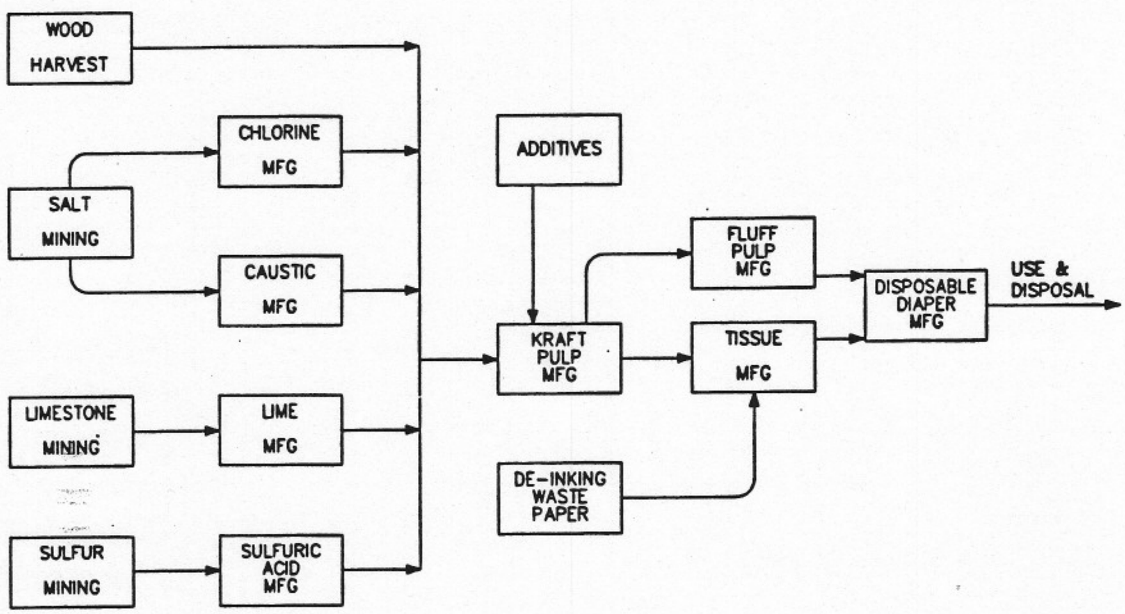

Figure 11. Pulp and paper manufacturing process

The paper industry has accomplished a commendable level of self-sufficiency in energy production in the last 20 years by reconfiguring pulp mill energy production and delivery systems to accept waste wood and spent pulping liquors as a fuel. Approximately 40 percent of the paper industry's energy needs are met by recovering energy from waste products.[44] Non-integrated paper manufacturing operations may not benefit from such self-sufficiency.

Other components of the pulp and paper process require processing prior to the form in which they are used within the paper industry. Chlorine, sodium hydroxide, and sulfuric acid manufacture are described below.

Chlorine Manufacture

Chlorine is used to clean and brighten pulp. A large portion of the chlorine manufactured in the U.S. is produced by electrolytic processes. Sodium chloride is electrolyzed producing chlorine gas at the cathode. The gas is then removed, cooled and dried, and then compressed and cooled until it changes phase to liquid form. A mercury cathode cell is used for about 25 percent of chlorine manufacture, resulting in releases of mercury to the environment. Sodium hydroxide and hydrogen are by-products of chlorine manufacturing.

Lime Manufacture

Lime is a process additive used in pulping and its production and use contribute to the overall environmental impacts of the entire cycle. Lime is produced by the calcination of limestone in a high temperature kiln. Water is driven off and the carbonate is broken up by the generation of carbon dioxide (CO_2). The material remaining is lime, or calcium oxide. The calcining process has significant CO_2 release associated with it, approximately 800 pounds of CO_2 produced for every 1000 pounds of lime.

Sulfuric Acid Manufacture

Sulfuric acid is used in the chemical digestion liquors to break down wood fibers. Sulfuric acid is produced by burning sulfur to form sulfur dioxide. Further oxidation of sulfur dioxide produces sulfur trioxide, which is then absorbed in a weak sulfuric acid bath or water to form sulfuric acid. The majority of sulfuric acid production uses the contact process, which uses metal catalysts such as palladium, platinum, vanadium or iron.

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[44] Arthur D. Little, Inc., Overview of U.S. Pulp and Paper Industry, Vol. 1, (Cambridge, MA: A.D. Little, 1988), pp. 2-14; American Paper Institute, Patterns of Fuel and Energy Consumption in the U. S. Pulp and Paper Industry, 1972-1984, (Washington, D.C.: API, 1985).

Tissue Paper Manufacture

After the pulping process has been completed the pulp is either dried for sale as market pulp, or transferred as wet slush pulp to the papermaking portion of the paper facility. Dry market pulp delivered to a non-integrated paper facility is agitated into slush pulp by mixing with water in a large pulping tank.

Slush pulp is transferred to the first component of a paper machine, an endless wire or plastic screen. Water drains from the screen by gravity or vacuum, and the paper mat is moved along rollers or other transfer equipment which continue to remove water. The final steps involve steam-heated rollers or tunnel drying of the paper before it is removed from the machine onto rolls of finished paper.

Plastic Manufacturing

Raw materials used in manufacturing ethylene and polypropylene include naphtha, oil, and other hydrocarbons. The analysis of environmental impacts associated with the extraction of petroleum feedstocks is not within the scope of this analysis. Petroleum feedstocks are steam cracked and separated into their respective hydrocarbon fractions for further refining. After residual water is removed, the cracked gas fraction is chilled to separate hydrogen, methane, ethane, ethylene, propylene and acetylene.

Ethylene Manufacturing

Ethylene is a member of the petrochemical family known as olefins. The manufacture of ethylene requires the production of several petroleum feedstocks, and represents a major portion of the petrochemical industry output.

Acetylene and ethane are often used as fuels within the olefin production facility reducing dependence on other fuel supplies and increasing process efficiencies. Ethylene is the basis of much of the petrochemical industry and an important precursor to many petrochemicals used widely throughout the U.S. and world.

Because several hydrocarbon co-products are created during ethylene manufacturing, the mass and energy balance has been adjusted to reflect only that percentage of feedstock, fuel, and waste attributable to ethylene and propylene manufacture on a weight percent basis.

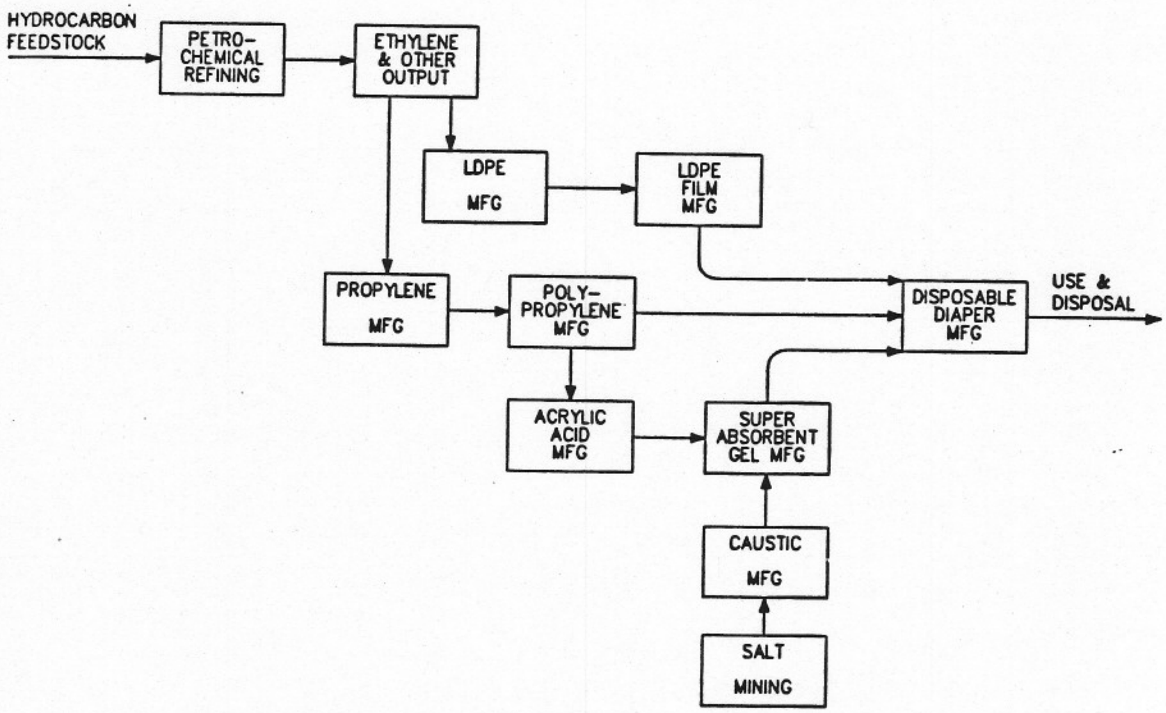


Figure 12. Plastic components manufacturing process

Low-Density Polyethylene Manufacture

Low-density polyethylene (LDPE) is produced from ethylene by a high pressure polymerization process where an initiator catalyzes the formation of polyethylene from the ethylene monomer. Any remaining un-reacted monomer is separated and recycled, while the polymer is extruded, chilled and granulated. LDPE film commonly used in single-use diaper coverstock is produced by heating granulated LDPE, adding the desired additives to produce the desired characteristics, and extruding the material via an air blow or water bath process.

Non-woven Polypropylene Manufacture

Propylene is a co-product of the production of ethylene from hydrocarbon feedstocks. Polypropylene is manufactured by polymerizing propylene in the presence of organo-metallic catalysts under the appropriate heat and pressure conditions. Polypropylene is usually extruded into pellet form for easy shipment to end-use locations. Extrusion processes then convert the pelletized polymer into the non-woven films used in diapers.

Super Absorbent Gels

Acrylic acid is a major constituent of polyacrylate gels. Production of acrylic acid involves the conversion of air, propylene and steam into acrolein in a reactor in the presence of a catalyst. Acrolein is then oxidized to acrylic acid in the presence of a metal oxide, generally vanadium or molybdenum. The reaction is exothermic, resulting in the generation of 2.2 pounds of steam per pound of acrylic acid generated. Hydrocarbon solvent is used to separate the acrylic acid from the condensed steam, and the solvent is recovered from the cooling water by a distillation process. The remaining acrylic acid/solvent mixture is distilled to separate and recover solvent and purify the acrylic acid.

Polyacrylate gels used in single-use diapers are produced by polymerizing acrylic acid with a cross-linking agent. Acrylic acid, which is made from propylene and air, and sodium hydroxide are the main components of super absorbent gels. Polymerization of an acrylic acid-sodium acrylate mixture in water is initiated with a starter compound and water is given off. The polymer is dried into powder form, which can be remelted, pelletized and distributed.

D. Conclusions

Reusable and single-use diaper manufacturing are dependent on a number of secondary industries and activities. For reusable diapers, these include cotton farming (cotton growth and harvest), fertilizer manufacture, cotton refining, and cloth manufacture. For single-use diapers relevant secondary industries and activities include hydrocarbon refining, petrochemical manufacture of low density polyethylene, polypropylene, polyacrylic gels, and adhesives, paper manufacture (timber growth and harvest, pulp and tissue manufacture), and conversion to diapers. Common to production of both types of diaper are fuels refining and energy production and generation.

Detailed knowledge of each step in the production of these inputs is needed to generate a complete profile of the materials, water, and energy requirements; associated emissions of air and water pollution; and generation of solid waste characteristic of reusable and single-use diapers. Specific industry processes are often considered proprietary and complete process data is frequently unavailable or incomplete.

V. DIAPER USE AND DISPOSAL

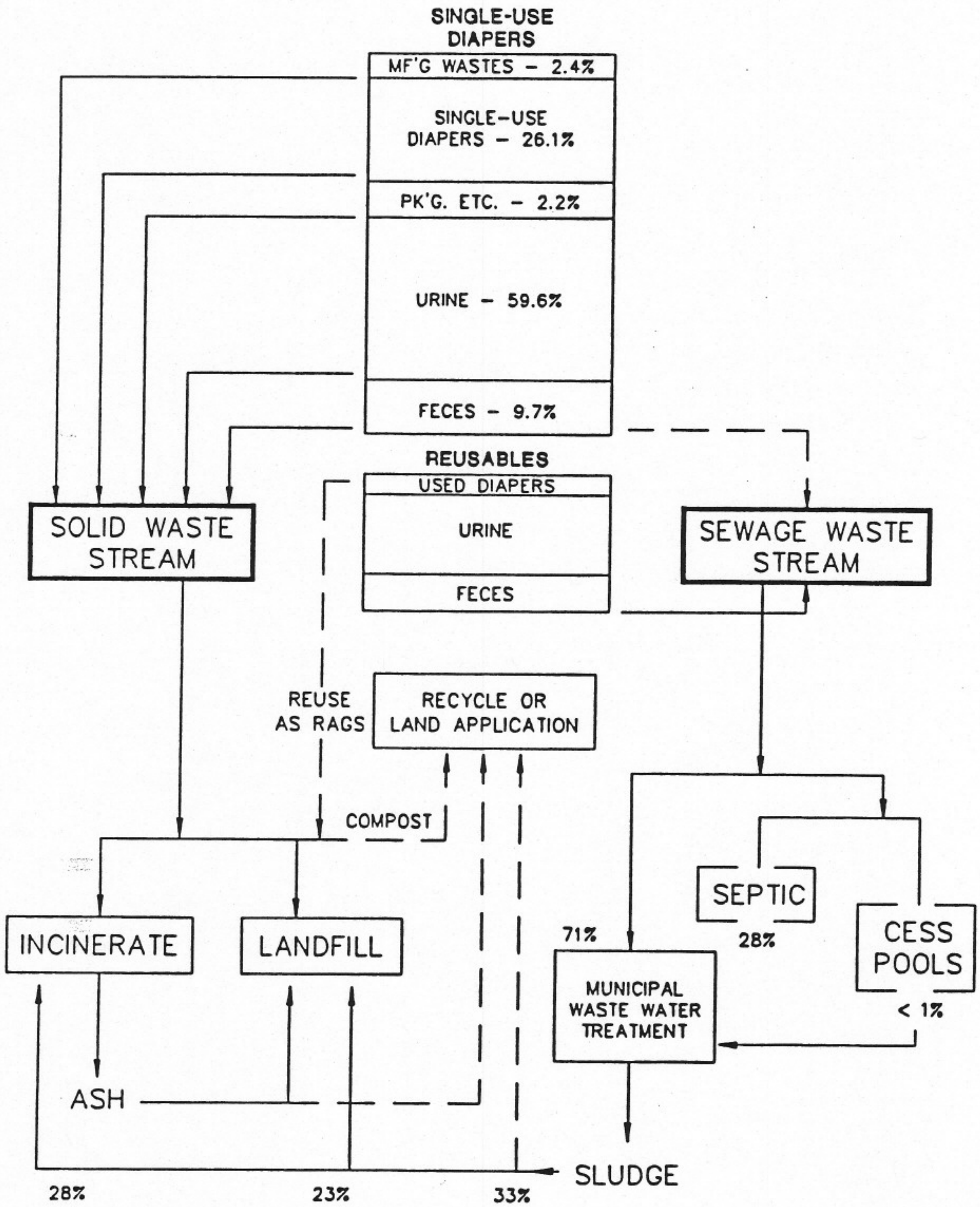
A. Overview to Diaper Processing

Processing of waste includes the collection, transportation, processing, recovery and disposal of discarded materials and products. As Figure 13 shows, diaper waste processing is accomplished by two different, but interconnected waste streams, the solid waste stream and the waste water treatment or sewage treatment system.

Municipal solid waste (MSW) is generally considered to be that portion of the household, commercial, and municipal waste stream delivered to landfills or resource recovery systems. This is primarily comprised of paper products, but also includes discarded metal, glass, food wastes, plastic, and single-use diapers. It often, but not necessarily includes yard wastes, waste water treatment sludge, some wood and construction wastes. Solid waste excludes most industrial, radioactive, and infectious wastes from hospitals (which may include diaper wastes).

The sewage waste stream is that portion of waste diverted to the waste water treatment system via toilets and other water collection and removal systems. This waste stream is almost entirely composed of water, since water is used to transport urine and feces. Sewage contains waste water from toilets, residential and commercial sinks, drinking fountains, laundries, pre-treated and non-treated commercial and industrial waste water. In some old municipal systems, storm water run- off may often pass through the waste water treatment system along with other sewage wastes.

Figure 13. Diaper waste flow

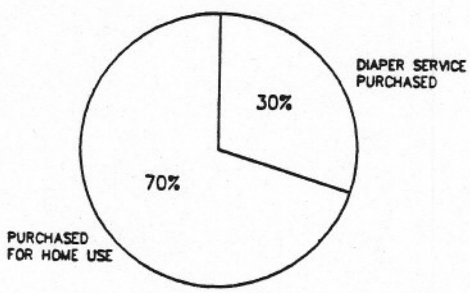


The two diapering modes analyzed here place primary stress on distinct waste disposal systems. Nearly all single-use diaper waste, which includes the diaper itself along with its contents, is processed in the solid waste stream. Presently it is estimated that only a small proportion of consumers follow recommended procedures in emptying the contents of single-use diapers into toilets.[45] Originally Pampers brand single-use diapers had a flushable center section that could be separated from the diaper backing and disposed of via the toilet. However, this feature was dropped after Procter and Gamble determined that consumers were throwing the whole diaper away.

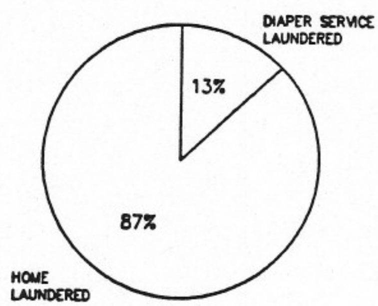
Using reusable diapers, on the other hand, generates demand for waste water treatment, as diapers are laundered and fecal contents are discarded via toilet flushing and laundering. The reusable diaper itself eventually enters the solid waste stream after multiple uses as a diaper and usually additional uses as a rag.

B. Reusable Diaper Wastes

The recent rapid expansion of diaper service business is an important factor in calculating the impact of diapers on the waste water system. A sample of 37 diaper service operators belonging to the National Association of Diaper Services indicated a 28 percent rate of growth in business 1989-90, and 20.5 percent growth rate in business 1988-89.[46]



14a. Market in units purchased



14b. Market by changes

Figure 14. Infant reusable diaper market[47]

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[45] This will change to the extent that consumers follow manufacturers' recommendations of diaper packaging, and laws banning unprocessed sewage in solid waste become more prevalent.

[46] Diaper service operator survey by authors (1990, unpublished). Survey participants comprise an estimated 10 percent of the total commercial diaper service market.

[47] Smith and Sheeran (1990).

The typical diaper laundry service washes about 2500 cotton diapers per load. The cost for this service is about 14 cents per each delivered diaper, or $11.34 per week per infant.

Because of economies of scale, commercial diaper laundries use fewer resources and produce less water and air emissions per diaper washed than home laundering. Reusable diapers washed by a commercial laundry are reused about 78 times before being discarded or used as rags. Table A presents basic resource parameters in commercial laundry operations, as derived from the diaper service operators survey, and compares resource impacts with home laundry operations.

Home laundering of reusable diapers involves household appliances, including washing machines, a gas or electric dryer, and a gas or electric hot water heater. There appears to be little reliable information about behavioral practices regarding the utilization of these appliances, and the actual situation is probably highly variable, both across households and within the same household over time. Where possible, therefore, comparisons are drawn in this report with respect to practices and resource utilization verified for commercial laundry operations. Otherwise, a hypothetical case developed by Arthur D. Little contributes to the analysis.[48]

[48] ADL2 (1990).

Table A. Water and energy comparison of commercial and home diaper laundering

NET LAUNDRY WATER USE (not including flushing)	gallons
Commercial laundering operations[1] Gallons per 1,000 diaper changes laundered (1.2 diapers/change)	858-1,200
Household laundering operations[2] Gallons per 1000 diaper changes laundered (1.8 diapers/change)	2,070
Commercial laundering operations: projected total gallons for 100% reliance	$3 - 5 \times 10^9$
Household laundering operations: projected total gallons for 100% reliance	7.2×10^9
ENERGY USE IN LAUNDRY	**BTUs**
Commercial laundering operations[1] British Thermal Units (BTUs) per 1,000 diaper changes (1.2 diapers/change)	456,430
Household laundering operations[3] British Thermal Units (BTUs) per 1,000 diaper changes (1.8 diapers/change)	1,576,350
Commercial laundering operations: projected total BTUs for 100% reliance	1.6×10^{12}
Household laundering operations: projected total BTUs for 100% reliance	5.5×10^{12}

Conversion from Kilowatt hours to BTUs = 10,235 BTUs/kWh. The 100 percent reliance figure assumes 3,512,195,000 reusable diaper changes per year in the U.S.
[1] Diaper service operator survey by authors (1990 unpublished).
[2] Franklin Associates Diaper Profile water estimates using 1.8 diapers per diaper change.
[3] ADL2 (1990) estimates.

Economies of scale are an important factor in the differences between home and commercial laundering for both water and energy usage. The above table shows that laundering 1,000 reusable diaper changes at home uses nearly 2 times more water than commercial diaper services consume and 3 times more energy. Commercial laundries use less electricity, usually substituting natural gas for electricity as a fuel source, because gas heating for both washing and drying is more efficient than heating with electricity. Because commercial operations use less electrical energy, air pollution impacts associated with energy production are also lower.

Nearly all waste from reusable diapers is diverted to the sewage waste stream via the toilet or washing machines. The solids may eventually enter landfills or other solid waste processing facilities in the form of compressed and dewatered sludge. The sewage waste stream processes nearly all of the human body's wastes with the major exception of that portion diverted to the solid waste stream in single-use diapers and tissues.

Taking into account laundering and toilet disposal of reusable diaper fecal waste, the estimated 1990 contribution of reusable diaper usage to waste water treatment is less than 0.1 percent of total municipal waste water treatment in the United States. If all infants in 1990 used reusable diapers, this figure would rise to less than 0.5 percent of total municipal waste water treatment volume.

These numbers reflect conservative assumptions that seek to avoid underestimation. Estimates on water usage are derived from source materials produced by the engineering firm of Brown and Caldwell in a study of actual water use reduction from various water conserving fixtures, devices, and appliances in several cities during the 1980s,[49] from John R. Mather's study of U.S. water resources,[50] and from a survey conducted by the U.S. Geological Survey.[51]

An average from six studies of end-use water demand for domestic or in-house purposes suggests approximately 20 percent of domestic water use goes to laundering, while, on average, 35 percent goes to toilet flushing. These figures represent a sample of households across the nation, and include families with infants, as well as smaller households of older persons. Data on age structure from the U.S. Bureau of Census suggests children 3 years of age or younger constitute about 3.1 percent of the total United States population in 1990. At maximum, then, households with children under 3 could constitute 9.3 percent of the nation's total households.

To be conservative, it is assumed furthermore that laundering diapers accounts for 30 percent of the wash loads, and 50 percent of the toilet flushes in this 10 percent of the households. Municipal water systems distinguish between residential, commercial, industrial, and public customers, with residential usage constituting roughly 40 percent of total water consumption. In-house or domestic water use is approximately 50 percent of total residential water use as a national average. If all families with children under 3 utilized reusable diapers, the total load on the municipal waste water treatment system would be less than one-half of 1 percent of the total volume of water treated. Furthermore, the best estimate is more on the order of one tenth of 1 percent of total

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[49] U.S. Department of Housing and Urban Development, Survey of Water Fixture Use, Contract H-5230, Brown and Caldwell, Office of Policy Development and Research, Building Technology Division, (Washington, DC: U.S. GPO, March 1984).

[50] John R. Mather, Water Resources: Distribution, Use, and Management, (New York: John Wiley & Sons, 1984).

[51] Wayne B. Solley, Charles F. Merk, and Robert R. Pierce, Estimated Use of Water in the United States in 1985, (U.S. Geological Survey Circular 1004, Washington, 1988).

waste water treatment, accounting for an average family size of 2.3 persons and corresponding reductions in the percent of toilet flushing and laundry use attributable to diapers. Finally, all these numbers are further reduced if non-municipally supplied or treated industrial water is taken into account.

C. Single-Use Diaper Wastes

Prior to "Diapers In the Waste Stream" (1988), single-use diaper manufacturers claimed that diaper waste made up less than 1 percent of solid waste. Most such claims were based on only the used diaper itself, ignoring diaper contents. "Diapers In The Waste Stream" examined five waste characterization studies of municipal solid waste (MSW) and concluded that approximately 2 percent of MSW is composed of diaper waste, as measured by weight. When the household segment of MSW (less commercial and institutional waste) was examined, single-use diapers were estimated to make up between 3.5 percent and 4.5 percent of household solid waste.[52]

Diapers are the largest single product discarded in the solid waste stream after newspaper and beverage containers. However, relative to other non-product components in municipal solid waste like paper or yard wastes, the contribution of diapers is small. The following chart estimates the composition of MSW by materials, based upon "Diapers in the Waste Stream", with diapers broken out separately.

[52] Lehrburger (1988), p. 26.

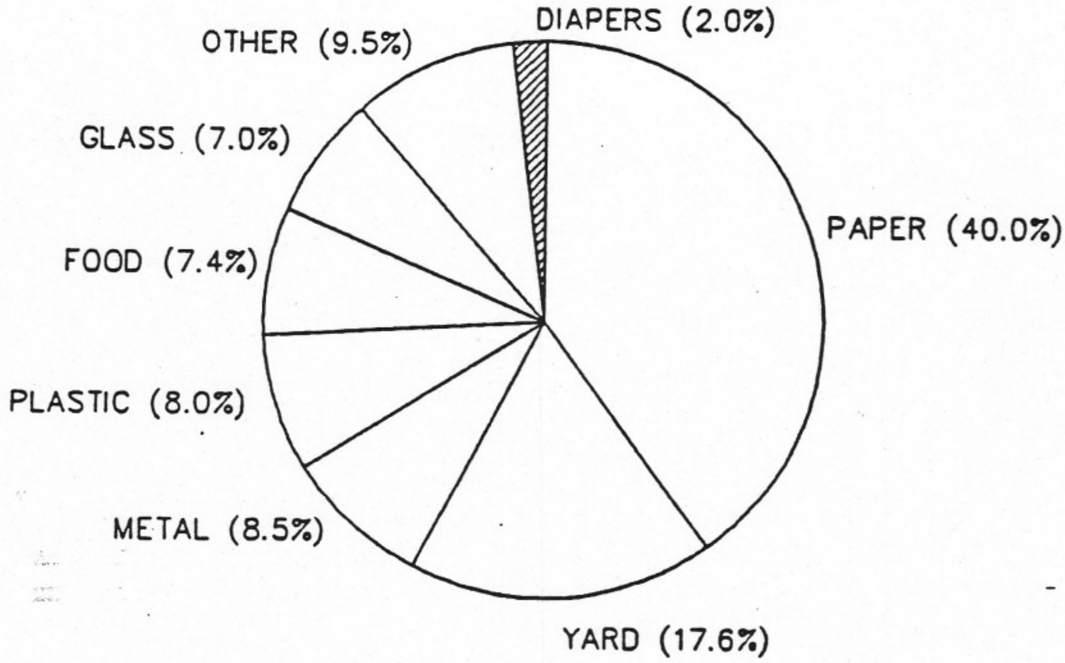

Figure 15. The municipal waste stream

The 1990 update of "Characterization of Municipal Solid Waste in The U.S" completed by the Franklin Associates on behalf of U.S EPA estimated that in 1988, 2.7 million tons of diaper waste resulted in 1.7 percent of MSW by weight and occupied 13.3 million cubic yards, or 3.3 percent by volume. Franklin Associates estimated that the diaper contribution to MSW by weight reached a high of 2 percent by weight in 1985 and declines every year thereafter,[53] as shown below:

[53] Franklin Associates Ltd., "Characterization of Municipal Solid Waste in the U.S., 1990 Update," U.S. EPA 530/SW-90-042, (Washington, D.C.: U.S. EPA, 1990), table 33.

Table B. Franklin Associates estimates of diapers in MSW

Year	1970	1975	1980	1985	1988	1995	2000	2010
Single-use diaper waste:million tons/year	0.3	1.2	2.3	2.9	2.7	2.4	2.3	2.4
Diaper waste as a % of materials generated[1] (%)	0.2%	0.9%	1.5%	1.8%	1.5%	1.2%	1.1%	1.0%
Diaper waste as a % of MSW discarded[2] (%)	0.3%	1.0%	1.7%	2.0%	1.7%	1.5% *	1.4% *	1.3% *

* Estimate by the authors based on Franklin Associates (1990 "Characterization...").
[1]"Materials generated" refers to materials and products as they enter the waste stream before materials recovery, composting or combustion takes place.
[2]"MSW discarded" includes the MSW after material recovery for recycling and composting.

The Franklin Associates base year 1988 numbers for diapers in the waste stream are lower than those projected by Lehrburger, who calculated a similar weight for the diaper, but a significantly higher weight for the diaper contents.

Table C shows estimates of diaper weight by Franklin Associates, Lehrburger and ADL2. Franklin and Lehrburger are shown in million tons, while ADL2 is shown in pounds, based on an average 45 single-use diapers per week disposed per child.

Table C. Diaper waste quantification: a comparison of studies

Study	Used diaper	Feces	Urine	Packaging	Total
Lehrburger					
million tons/year	1.08	0.401	2.475	0.092	4.048
percentage	26.6%	10%	61.1%	2.3%	100%
Franklin Associates					
million tons/year	1.0	combined urine & feces 1.7		---	2.7
percentage	37%	combined urine & feces 63%		---	100%
ADL2					
pounds/week	5.4 pounds	2.02 pounds	14.16 pounds	0.86 pounds	22.44 pounds
percentage	24%	9%	63%	3.8%	100%

Lehrburger, "Diapers in the Waste Stream," (1988).
Franklin Associates, "Characterization of Municipal Solid Waste in the U.S.," (1990).
Arthur D. Little, "Disposable Versus Reusable Diapers," (1990).

The above comparisons suggest that Franklin Associates probably underestimated the weight of the diaper contents, and that total estimates of diaper contribution to municipal solid waste are therefore underestimated. Based on 156 million tons of MSW discarded in 1988, a macro-analysis taking diaper contents into account would conclude that 2.37 percent of MSW by weight is composed of diaper waste based upon the Lehrburger estimate, compared to the 1.7 percent estimate by Franklin. Using actual waste composition data, Lehrburger concluded that approximately 2 percent of MSW by weight is composed of single-use diaper waste.[54]

[54] Lehrburger (1988), p. 26.

The following table projects waste paths and the contribution of single-use diapers to the MSW stream. These projections suggest a declining percentage of single-use diapers in the solid waste stream beginning in 1985, when single-use diapers exceeded 2.5 percent of MSW by weight. This decline is a direct result of the use of super absorbent materials which reduce the weight of single-use diapers. These projections are roughly 30 percent higher than Franklin Associate estimates (refer to tables B and C above) because Franklin Associates estimated a lower weight for the used diaper contents.

Landfill disposal will remain the primary disposal path, but will decline in proportion to increased reliance on resource recovery, and to a lesser extent composting. The potential for commercialization of flushable single-use diapers during the next five years could also have an impact on this equation, and are included in the table.

Table D. Past and projected waste paths for single-use diapers

Year	1975	1985	1988	1995	2000
Total MSW discarded in U.S.					
million tons/yr.[1]	118	145	156	159.8	162
millions diapers used[2]	7,600	15,600	17,000	17,000	17,000
Single-use diaper waste[3]					
million tons/yr.	1.9	3.9	3.7	3.18	2.65
% of total MSW by weight	1.6%	2.7%	2.37%	2%	1.63%
Single-use diaper waste paths: past and projected	1975	1985	1988	1995	2000
Composting					
million tons/yr.	—	—	0.011	0.148	0.176
% of single-use diapers	—	—	0.3%	5-7%	5-10%
Flushables[4]					
million tons/yr.	—	—	—	0.095	0.132
% of single-use diapers	0.1%	0.1%	0.1%	1-5%	3-20%
Incineration					
million tons/yr.	0.02	0.2145	0.503	0.694	0.75
% of single-use diapers	0.6%	5.5%	13.6%	22.0%	28.5%
Landfilling					
million tons/yr.	1.88	3.685	3.186	2.242	1.586
% of single-use diapers	99.4%	94.5%	86.1%	70.5%	60.0%

[1] Assumes Franklin Associates tonnage for 'MSW discarded', (1990, "Characterization...").
[2] Assumes 17 billion baby diaper equivalents as a constant beginning in 1988. Although a net decline in birth is anticipated, a nearly proportional increase in adult incontinents is assumed.
[3] Assumes a decline in the weight of the diaper itself by 5 percent per year from 1985 to 1995, based on a 90 percent market capture in that time period by super absorbent diapers which reduce the weight of the diaper itself by 50 percent (does not include any reduction for diaper contents).
[4] Flushable diaper projections assume introduction and use of diaper products currently not commercialized or in use.

In 1988, Lehrburger also looked at the percentage of diapers contained in the household solid waste stream. The household waste stream refers to material discarded from residences and does not include commercial waste. In considering the household segment of the MSW stream, Lehrburger concluded that single-use diapers make up between 3.5 percent and 4.5 percent by weight, depending on whether yard waste is included. These estimates are consistent with recent household waste composition studies undertaken by the Garbage Project for Phoenix and Tucson, Arizona.[55] That study suggested that single-use diapers comprise 3.31 percent of household solid waste including yard waste, and 4.18 percent of household solid waste without yard waste for the two cities studied.

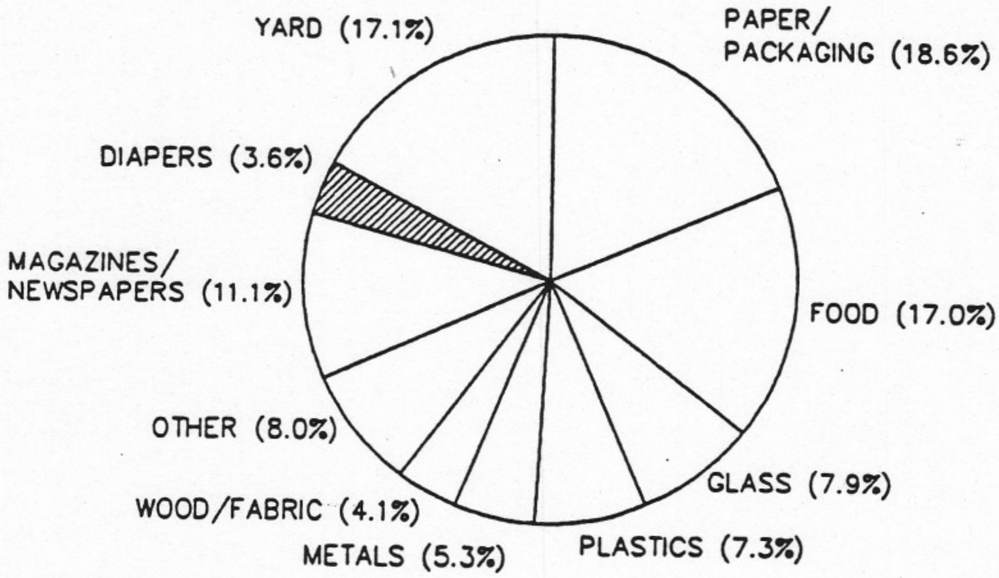

Figure 16. Household waste stream

[55] W.L. Rathje, D.C Wilson, W.W. Hughes, T. Jones, "Characterization of Recyclable Materials in Residential Solid Wastes," The Garbage Project, Bureau of Applied Research in Anthropology, (University of Arizona, May 1989).