I. INTRODUCTION TO THE SECTOR NOTEBOOK PROJECT

I.A. Summary of the Sector Notebook Project

Integrated environmental policies based upon comprehensive analysis of air, water and land pollution are a logical supplement to traditional single-media approaches to environmental protection. Environmental regulatory agencies are beginning to embrace comprehensive, multi-statute solutions to facility permitting, enforcement and compliance assurance, education/ outreach, research, and regulatory development issues. The central concepts driving the new policy direction are that pollutant releases to each environmental medium (air, water and land) affect each other, and that environmental strategies must actively identify and address these inter-relationships by designing policies for the "whole" facility. One way to achieve a whole facility focus is to design environmental policies for similar industrial facilities. By doing so, environmental concerns that are common to the manufacturing of similar products can be addressed in a comprehensive manner. Recognition of the need to develop the industrial "sector-based" approach within the EPA Office of Compliance led to the creation of this document.

The Sector Notebook Project was originally initiated by the Office of Compliance within the Office of Enforcement and Compliance Assurance (OECA) to provide its staff and managers with summary information for eighteen specific industrial sectors. As other EPA offices, states, the regulated community, environmental groups, and the public became interested in this project, the scope of the original project was expanded to its current form. The ability to design comprehensive, common sense environmental protection measures for specific industries is dependent on knowledge of several inter-related topics. For the purposes of this project, the key elements chosen for inclusion are: general industry information (economic and geographic); a description of industrial processes; pollution outputs; pollution prevention opportunities; Federal statutory and regulatory framework; compliance history; and a description of partnerships that have been formed between regulatory agencies, the regulated community and the public.

For any given industry, each topic listed above could alone be the subject of a lengthy volume. However, in order to produce a manageable document, this project focuses on providing summary information for each topic. This format provides the reader with a synopsis of each issue, and references where more in-depth information is available. Text within each profile was researched from a variety of sources, and was usually condensed from more detailed sources pertaining to specific topics. This approach allows for a wide coverage of activities that can be further explored based upon the citations and references listed at the end of this profile. As a check on the information included, each notebook went through an external review process. The Office of Compliance appreciates the efforts of all those that participated in this process and enabled us to develop more complete, accurate and up-to-date summaries. Many of those who reviewed this notebook are listed as contacts in Section IX and may be sources of additional information. The individuals and groups on this list do not necessarily concur with all statements within this notebook.

I.B. Additional Information

Providing Comments

OECA's Office of Compliance plans to periodically review and update the notebooks and will make these updates available both in hard copy and electronically. If you have any comments on the existing notebook, or if you would like to provide additional information, please send a hard copy and computer disk to the EPA Office of Compliance, Sector Notebook Project, 401 M St., SW (2223-A), Washington, DC 20460. Comments can also be uploaded to the Environene World Wide Web for general access to all users of the system. Follow instructions in Appendix A for accessing this system. Once you have logged in, procedures for uploading text are available from the on-line Enviroene Help System.

Adapting Notebooks to Particular Needs

The scope of the industry sector described in this notebook approximates the national occurrence of facility types within the sector. In many instances, industries within specific geographic regions or states may have unique characteristics that are not fully captured in these profiles. The Office of Compliance encourages state and local environmental agencies and other groups to supplement or re-package the information included in this notebook to include more specific industrial and regulatory information that may be available. Additionally, interested states may want to supplement the "Summary of Applicable Federal Statutes and Regulations" section with state and local requirements. Compliance or technical assistance providers may also want to develop the "Pollution Prevention" section in more detail. Please contact the appropriate specialist listed on the opening page of this notebook if your office is interested in assisting us in the further development of the information or policies addressed within this volume. If you are interested in assisting in the development of new notebooks for sectors not already covered, please contact the Office of Compliance at 202-564-2395.

II. INTRODUCTION TO THE TEXTILE INDUSTRY

This section provides background information on the history, size, geographic distribution, employment, production, sales, and economic condition of the textile industry. The facilities described within the document are described in terms of their Standard Industrial Classification (SIC) codes.

II.A. History of the Textile Industry

The textile industry is one of the oldest in the world. The oldest known textiles, which date back to about 5000 B.C., are scraps of linen cloth found in Egyptian caves. The industry was primarily a family and domestic one until the early part of the 1500s when the first factory system was established. It wasn't until the Industrial Revolution in England, in the 18th century, that power machines for spinning and weaving were invented. In 1769 when Richard Arkwright's spinning frame with variable speed rollers was patented, water power replaced manual power (Neefus, 1982).

In the early 17th century of colonial America, textiles were primarily manufactured in New England homes. Flax and wool were the major fibers used, however, cotton, grown primarily on southern plantations, became increasingly important (Wilson, 1979). In 1782 Samuel Slater, who had worked as an apprentice to Arkwright's partner, emigrated to America. In Blackstone River, Rhode Island, he started building Arkwright machines and opened the first English-type cotton mill in America (ATMI, 1997a). In the early nineteenth century, in Lowell, Massachusetts, the first mill in America to use power looms began operations. It was the first time that all textile manufacturing operations had been done under the same roof (Wilson, 1979 and ATMI, 1997a).

The twentieth century has seen the development of the first manmade fibers (rayon was first produced in 1910). Although natural fibers (wool, cotton, silk, and linen) are still used extensively today, they are more expensive and are often mixed with manmade fibers such as polyester, the most widely used synthetic fiber. In addition, segments of the textile industry have become highly automated and computerized (ATMI, 1997a).

The textile industry is characterized by product specialization. Most mills only engage in one process or raw material. For example, a mill may be engaged in either broadloom weaving of cotton or broadloom weaving of wool. Similarly, many mills specialize in either spinning or weaving operations, although larger integrated mills may combine the two operations. These large mills normally do not conduct their own dyeing and finishing operations. Weaving, spinning, and knitting mills usually send out their fabrics to one of the approximately 500 dyeing and finishing plants in the United States (EPA, 1996).

II.B. Introduction, Background, and Scope of the Notebook

Broadly defined, the textile industry consists of establishments engaged in spinning natural and manmade fibers into yarns and threads. These are then converted (by weaving and knitting) into fabrics. Finally, the fabrics and in some cases the yarns and threads used to make them, are dyed and finished.

The manufacturing of textiles is categorized by the Office of Management and Budget (OMB) under Standard Industrial Classification (SIC) code 22. The Standard Industrial Classification system was established by OMB to track the flow of goods and services in the economy, by assigning a numeric code to these good and services. SIC 22 is categorized into nine three-digit SIC codes. Due to the large number of processes used in the textile industry and the limited scope of this notebook, the production of nonwoven synthetic materials and carpets is not discussed in detail. The primary focus of this notebook is on weaving and knitting operations, with a brief mention of processes used to make carpets.

OMB is in the process of changing the SIC code system to a system based on similar production processes called the North American Industrial Classification System (NAICS). In the NAIC system, textile mills (including fiber, yarn and thread mills, fabric mills, and textile and fabric finishing and coating mills) be classified as NAIC 313. Textile product mills (including furnishings, carpets, rugs, curtains, linens, bags, canvas, rope, twine, tire cord and tire fabric) will be classified as NAIC 314.

This notebook covers the textiles industry as defined by SIC 22. Less focus is given to SIC 229, Miscellaneous Textile Goods in the Industrial Process Descriptions Section because the processes used and products manufactured vary substantially within SIC 229. Products categorized under SIC 229 include coated fabrics, not rubberized, tire cord and fabrics, cordage and twine, and textile goods not elsewhere classified. It is important to note, however, that the Miscellaneous Textile Goods category is covered in Section II, Introduction to the Textile Industry; Section IV, Chemical Release and Transfer Profile; Section VIII, Compliance Activities and Initiatives; and other sections of this document. Industry sectors related to the textiles industry, but not categorized under SIC 22 (and thus, not in the scope of this notebook) include the manufacturing of clothing and apparel (SIC 23) and the manufacturing of rubber coated textile goods (SIC 3069).

II.C. Characterization of the Textile Industry

II.C.1. Product Characterization

Within the nine broad categories in the textile industry are 22 four-digit SIC codes which more narrowly define the different types of products made by textile manufacturers. The various SIC codes and their associated products are shown in Table 1.

3-digit SIC code	4-digit SIC Code
SIC 221- Broadwoven Fabric Mills, Cotton	SIC 2211 - Broadwoven Fabric Mills, Cotton
SIC 222- Broadwoven Fabric Mills, Manmade Fiber and Silk	SIC 2221 - Broadwoven Fabric Mills, Manmade Fiber and Silk
SIC 223- Broadwoven Fabric Mills, Wool (Including dyeing and finishing)	SIC 2231 - Broadwoven Fabric Mills, Wool (including dyeing and finishing)
SIC 224- Narrow Fabric Mills: Cotton, Wool, Silk, and Manmade Fiber	SIC 2241 Narrow Fabric Mills: Cotton, Silk Manmade Fiber
SIC 225- Knitting Mills	SIC 2251 - Women's Full-Length and Knee-Length Hosiery, except socks SIC 2252 - Hosiery, not elsewhere classified SIC 2253 - Knit Outwear Mills SIC 2254 - Knit Underwear and Nightwear Mills SIC 2257 - Weft Knit Fabric Mills SIC 2258 - Lace and Warp Knit Fabric Mills SIC 2259 - Knitting Mills, not elsewhere classified
SIC 226- Dyeing and Finishing Textiles, except wool fabrics and knit goods	SIC 2261 - Finishers of Broadwoven Fabrics of Cotton SIC 2262 - Finishers of Broadwoven Fabrics of Manmade Fiber and Silk SIC 2269 - Finishers of Textiles, not elsewhere classified
SIC 227 - Carpets and Rugs	SIC 2273 - Carpets and Rugs
SIC 228- Yarn and Thread Mills	SIC 2281 - Yarn Spinning Mills SIC 2282 - Yarn Texturizing, Throwing, Twisting, and Winding Mills SIC 2284 - Thread Mills
SIC 229- Miscellaneous Textile Goods	SIC 2295 - Coated Fabrics, not rubberized SIC 2296 - Tire Cord and Fabrics SIC 2298 - Cordage and Twine SIC 2299 - Textile Goods, not elsewhere classified
Source: *Standard Industrial Classification Manual*, 1987, Office of Management and Budget, Washington, DC.	

Manufacturing establishments within the textile industry are primarily involved in 1) fiber preparation and manufacture of yarn, thread, braids, twine, and cords; 2) manufacture of knit fabrics, broad and narrow woven fabrics, as well as carpets and rugs from yarn (Broad woven fabrics are generally greater than 12 inches in width, whereas narrow woven fabrics are less than 12 inches in width.); 3) dyeing and finishing fibers, yarns, fabrics, and knitted goods; 4) coating, waterproofing and treating fabrics; 5) integrated manufacture of knit apparel and other products from yarn; and 6) manufacture of felt, lace, nonwoven, and other miscellaneous textile products. More detailed information on the industrial processes used to produce the various textile products is provided in Section III.

II.C.2. Industry Size and Geographic Distribution

According to the *1992 Census of Manufacturers* for SIC 22 (the most recent census data available), there were a total of 5,584 establishments in the textile manufacturing industry. A large proportion of these were knitting mills (SIC 225) and yarn and thread mills (SIC 228), as shown in the shaded rows in Table 2. Together these categories accounted for almost 50 percent of the total number of establishments in the industry. They also accounted for the largest portion of the employment and value of shipments in the textile industry. The knitting and yarn and thread mills categories accounted for 46 percent of the 614,000 people employed in the industry, and 40 percent of the $70.5 million in value of shipments, in 1992. A summary of these statistics is shown in Table 2.

Table 2: Summary Statistics for the Textile Industry (SIC 22)

Industry SIC Code	Establishments (No.)[1]	Companies (No.)[2]	Employment (000's)	Value of Shipments (millions of dollars)[3]
SIC 221	323	281	55.9	5,814
SIC 222	422	321	87.4	8,793
SIC 223	99	87	13.7	1,612
SIC 224	258	224	16.8	1,314
SIC 225	2,096	1,911	193.3	16,968
SIC 226	481	440	50.8	7,077
SIC 227	447	383	49.4	9,831
SIC 228	598	372	92.2	11,277
SIC 229	1,160	1,071	54.5	7,829
Totals	5,584	5,090	614	70,518

Source: adapted from various 1992 *Census of Manufactures, Industry Series*, for SICs 2211 - 2299, U.S. Department of Commerce, Bureau of the Census, 1995.

Note: The shaded rows highlight the SIC codes which contain the largest number of establishments, employment, and value of shipments.
[1]An establishment is a physical location where manufacturing takes place. Manufacturing is defined as the mechanical or chemical transformation of substances or materials into new products.
[2]Defined as a business organization consisting of one establishment or more under common ownership or control.
[3]Value of all products and services sold by establishments in the industry sector.

Most textile mills are small, specialized facilities. A large percentage of establishments in the industry have fewer than 20 employees, as shown in the shaded column. The exceptions include yarn and thread mills (SIC 228) and manmade fiber and silk broadwoven fabric mills (SIC 222), which have 100 employees or more per establishment. Some of the larger 'integrated' mills may employ anywhere from hundreds to thousands of people. A summary of these statistics is shown in Table 3.

Table 3: Summary of Establishment Sizes within the Textile Industry (SIC 22)

Industry SIC Code	Percentage of Establishments[1] with 0-19 Employees	Percentage of Establishments with 20-49 Employees	Percentage of Establishments with 50-99 Employees	Percentage of Establishments with 100 or More Employees
SIC 221	64	4	4	28
SIC 222	40	8	6	46
SIC 223	45	22	9	23
SIC 224	49	14	14	22
SIC 225	44	21	14	21
SIC 226	32	22	15	31
SIC 227	53	12	9	26
SIC 228	24	11	13	52
SIC 229	58	18	11	12

Source: adapted from various 1992 *Census of Manufactures, Industry Series*, for SICs 2211 - 2299, U.S. Department of Commerce, Bureau of the Census, 1995.

Note: The shaded column highlights the large percentage of facilities that have fewer than 20 employees.
[1]An establishment is a physical location where manufacturing takes place. Manufacturing is defined as the mechanical or chemical transformation of substances or materials into new products.

The ten largest textile companies (in terms of sales) in the U.S. are listed in Table 4. The data shown is taken from the *Fairchild's Textile & Apparel Financial Directory*, 1996, which compiles financial data on U.S. textile companies. *Fairchild's* ranks each U.S. company by sales volume. Readers should note that (1) each company was assigned a 3- or 4-digit SIC code that most closely resembles the firm's principal industry using *Ward's Business Directory of U.S. Private and Public Companies*; and (2) sales figures include those of subsidiaries and operations (even those not related to textiles industry). Additional sources of company-specific financial information include Standard and Poor's *Stock Report Services*, Dun and Bradstreet's *Million Dollar Directory*, Moody's Manuals, and the companies' annual reports. In compiling Table 4, the top companies for the 3-digit SIC code categories in the textile industry were identified.

Table 4: Top U.S. Companies in the Textile Industry (SIC 22) and Corresponding Sector

Rank[a]	Company	1995 Sales (millions of dollars)	3-digit SIC code
1	Springs Industries, Fort Mill, SC	$2,233	221
2	Burlington Industries, Greensboro, NC	$2,209	223
3	WestPoint Stevens, West Point, GA	$1,650	221
4	Unifi, Greensboro, NC	$1,555	228
5	Dominion Textile, New York, NY	$1,429	221
6	Collins & Aikman Corp., Farmville, NC	$1,291	221
7	Triarc, New York, NY	$1,128	221
8	Fieldcrest Cannon, New York, NY	$1,095	221
9	Cone Mills, Greensboro, NC	$910	221
10	Guilford Mills, Greensboro, NC	$783	225

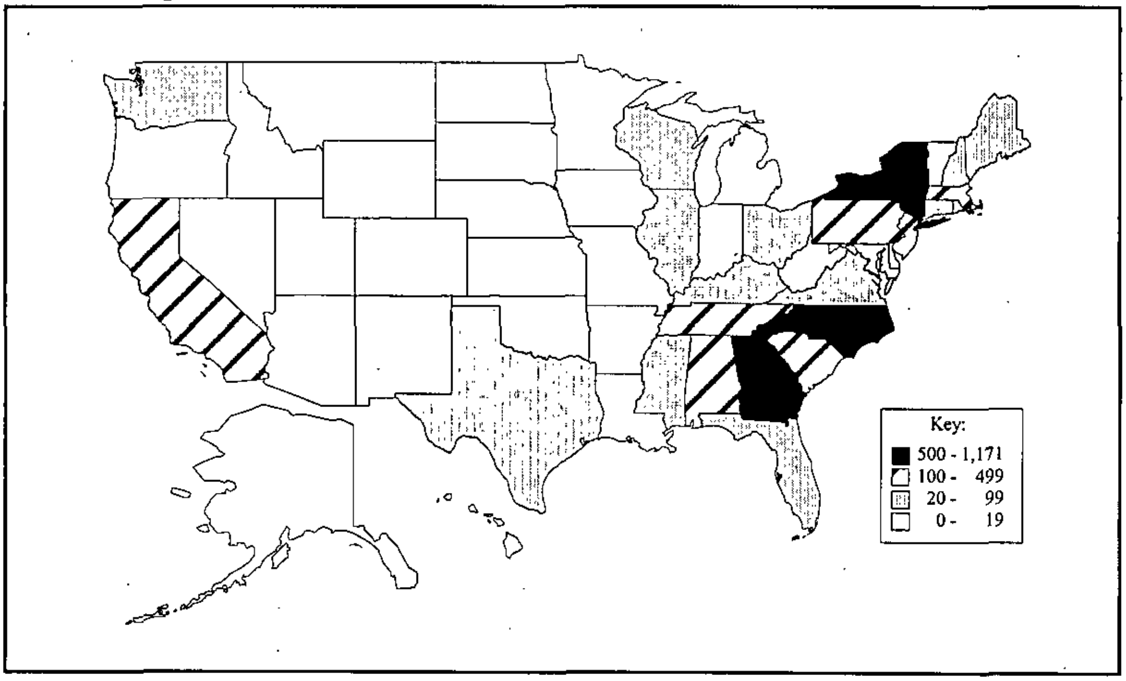
Source: This chart has been adapted from data in *Fairchild's Textile & Apparel Financial Directory*, 1996, with assistance from ATMI.

The geographic distribution of the textile industry in the U.S. is largely governed by its history in this country. The industry began in New England and moved to the South as cotton became the primary source of fibers. The five major states for employment in the textile industry are North Carolina, Georgia, South Carolina, Alabama, and Virginia. Though the majority of mills are located in the South, northern states such as Maine, Massachusetts, New York, New Jersey, Rhode Island, and Pennsylvania are still important to the textile industry. Many finishing and dyeing (SIC 226) operations are located in New Jersey. Narrow fabrics and manmade fiber mills (SIC 224) are more concentrated in Rhode Island and Pennsylvania. Knitting mills (SIC 225) and miscellaneous textile mills (SIC 229) are scattered through several southern and northern states. The leading states in terms of employment for the textile industry are shown by SIC code in Table 5.

A map showing the number of textile establishments (based on census data) in each state follows the table (Figure 1).

Table 5: Geographic Distribution of Textile Mills in the United States		
3-digit SIC code	Major states (based on employment)	approximate % of employment in 3-digit SIC code category, attributable to major states
SIC 221	NC, SC, GA, AL	87
SIC 222	SC, NC, GA, VA	79
SIC 223	VA, GA, ME, NC	69
SIC 224	NC, PA, RI, SC	52
SIC 225	NC, KY, LA, NY, GA, PA, TX, NJ	40
SIC 226	NC, SC, GA, NJ	63
SIC 227	GA	64
SIC 228	NC, GA, SC	70
SIC 229	NC, SC, GA, AL, TN, MA, OH, NY	40
Source: adapted from various 1992 *Census of Manufactures, Industry Series*, for SICs 2211 - 2299, U.S. Department of Commerce, Bureau of the Census, 1995.		

Figure 1: Distribution of Textile Establishments in the U.S.



Source: 1992 *Census of Manufactures, Industry Series*, for SICs 2211 - 2299, U.S. Department of Commerce, Bureau of the Census, 1995.

II.C.3. Economic Trends

Throughout the 1990s, the textile industry indicators have shown improvements. The year 1994 was a peak year for all indicators including exports, capital expenditures, employment, and mill fiber consumption. In 1994, mill fiber consumption set a record with a 6 percent increase to 16.1 billion pounds. In 1995, fiber consumption decreased by 1.7 percent only to increase by 1 percent in 1996 (ATMI, 1997b). Both 1994 and 1996 were record years for fiber consumption and were a substantial improvement over the recession years in the early part of the decade. The industry has also experienced a shift towards increasing international trade with countries such as Canada and Mexico (ATMI, 1996).

Domestic Economy

"The textile industry spends four to six percent of sales on capital expansion and modernization, down from eight to ten percent during the expansionary phase of the 1960s and 1970s. Most recent capital expenditure has paid for mill modernization and factory automation" (EPA, 1996). According to the American Textile Manufacturers Institute (ATMI), the largest trade association for the industry, capital expenditures by domestic textile companies have increased in recent years reaching $2.9 billion in 1995 (ATMI, 1997b). The increase in capital expenditures has led to an increase in productivity. Between 1975 and 1995, loom productivity, measured in square yards of fabric per loom, increased by 267 percent and was up 10.5 percent in 1996 (ATMI, 1997b). In the same period, productivity of broadwoven fabric mills, measured by an index of output per production employee hour, increased by 105 percent, and productivity of yarn spinning mills increased by 88 percent (ATMI, 1996). Industry also reports spending more than $25 million each year on pollution and safety controls.

"Economies of scale in textile manufacturing are significant and limit entry into the market. The cost of a new fiber plant, for example, is approximately $100 million. Costs of raw materials are frequently volatile and typically account for 50 to 60 percent of the cost of the finished product. To hedge against supply shocks and to secure supply, many producers are vertically integrated backward into chemical intermediates (and in the case of companies such as Phillips and Amoco, all the way to crude oil). Forward integration into apparel and product manufacture (e.g. carpeting) also is not uncommon." (US EPA, 1996).

International Trade

Over the past five years, the textile industry has been increasingly influenced by international trade. In particular, with the signing of the North American Free Trade Agreement (NAFTA) in 1994, trade with Canada and Mexico has increased significantly. In 1996, 42 percent of U.S. textile exports were to Canada and Mexico alone. Canada, Mexico, and the Caribbean Basin Initiative (CBI) countries accounted for 50 percent of the total textile exports in 1996.

In 1996, U.S. exports increased by 8.6 percent over the previous year to $7.8 billion. The major export markets for the U.S. textile industry were, in order of decreasing export volumes, Canada, Mexico, United Kingdom, Japan, Hong Kong, Dominican Republic, Germany, Belgium, Saudi Arabia, and South Korea. Between 1995 and 1996, exports to all of these markets grew. Exports to Canada increased by 10 percent to $2.1 billion, to the European Union by 2 percent to $1.1 billion, to the Caribbean Basin Initiative (CBI) countries by 13 percent to $622 million, and to Japan by 8 percent to $299 million. Exports to Mexico increased by 28 percent to $1.2 billion (ATMI, 1997b).

Yarn, fabric, and made-ups (excluding apparel) imports into the United States also have been steadily increasing since 1978. In 1995, the major sources of imports into the U.S. were Canada, China, Pakistan, India, Mexico, Taiwan, South Korea, Thailand, Indonesia, and Japan. Although both exports and imports have risen, the textile trade deficit has widened. In 1996, the U.S. textile trade deficit fell to $2.4 billion (ATMI, 1997b).

Page 12 intentionally left blank.

III. INDUSTRIAL PROCESS DESCRIPTION

This section describes the major industrial processes in the textile industry, including the materials and equipment used and the processes employed. The section is designed for those interested in gaining a general understanding of the industry, and for those interested in the interrelationship between the industrial process and the topics described in subsequent sections of this profile -- pollutant outputs, pollution prevention opportunities, and Federal regulations. This section does not attempt to replicate published engineering information that is available for this industry. Refer to Section IX for a list of reference documents that are available. Note also that Section V, Pollution Prevention Opportunities, provides additional information on trade-offs associated with the industrial processes discussed in this section.

This section describes commonly used production processes, associated raw materials, the byproducts produced or released, and the materials either recycled or transferred off-site. This discussion identifies where in each process wastes may be produced. This section concludes with a description of the potential fate (via air, water, and soil pathways) of process-specific waste products.

III.A. Industrial Processes in the Textile Industry

Much of the following section is based upon *"Best Management Practices for Pollution Prevention in the Textile Industry,"* published by the U.S. EPA Office of Research and Development. Additional references are cited in the text.

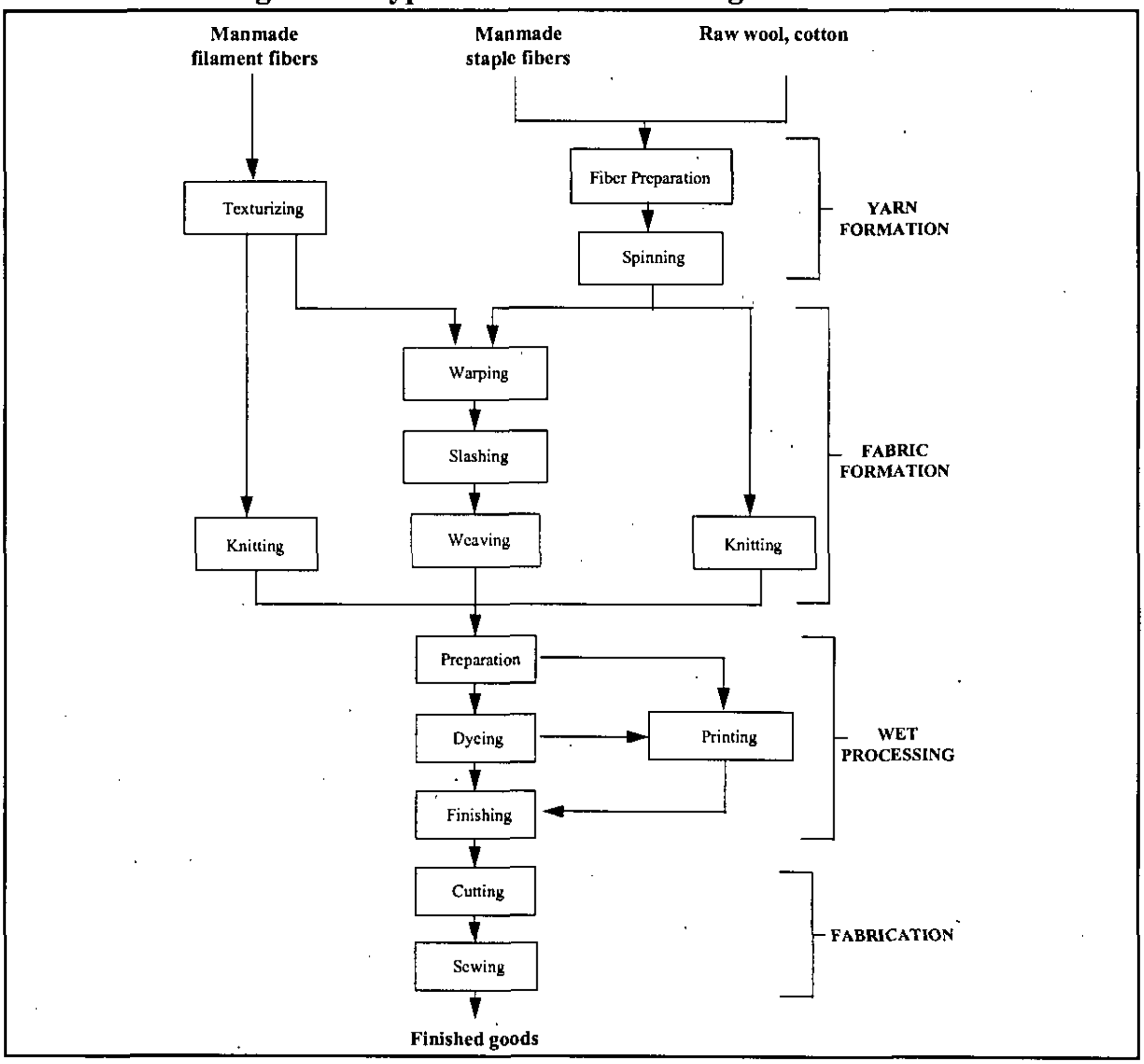
The textile industry is comprised of a diverse, fragmented group of establishments that produce and/or process textile-related products (fiber, yarn, fabric) for further processing into apparel, home furnishings, and industrial goods. Textile establishments receive and prepare fibers; transform fibers into yarn, thread, or webbing; convert the yarn into fabric or related products; and dye and finish these materials at various stages of production. The process of converting raw fibers into finished apparel and nonapparel textile products is complex; thus, most textile mills specialize. Little overlap occurs between knitting and weaving, or among production of manmade, cotton, and wool fabrics. The primary focus of this section is on weaving and knitting operations, with a brief mention of processes used to make carpets.

In its broadest sense, the textile industry includes the production of yarn, fabric, and finished goods. This section focuses on the following four production stages, with a brief discussion of the fabrication of non-apparel goods:

1) yarn formation
2) fabric formation
3) wet processing
4) fabrication

These stages are highlighted in the process flow chart shown in Figure 2 and are discussed in more detail in the following sections.

Figure 2: Typical Textile Processing Flow Chart

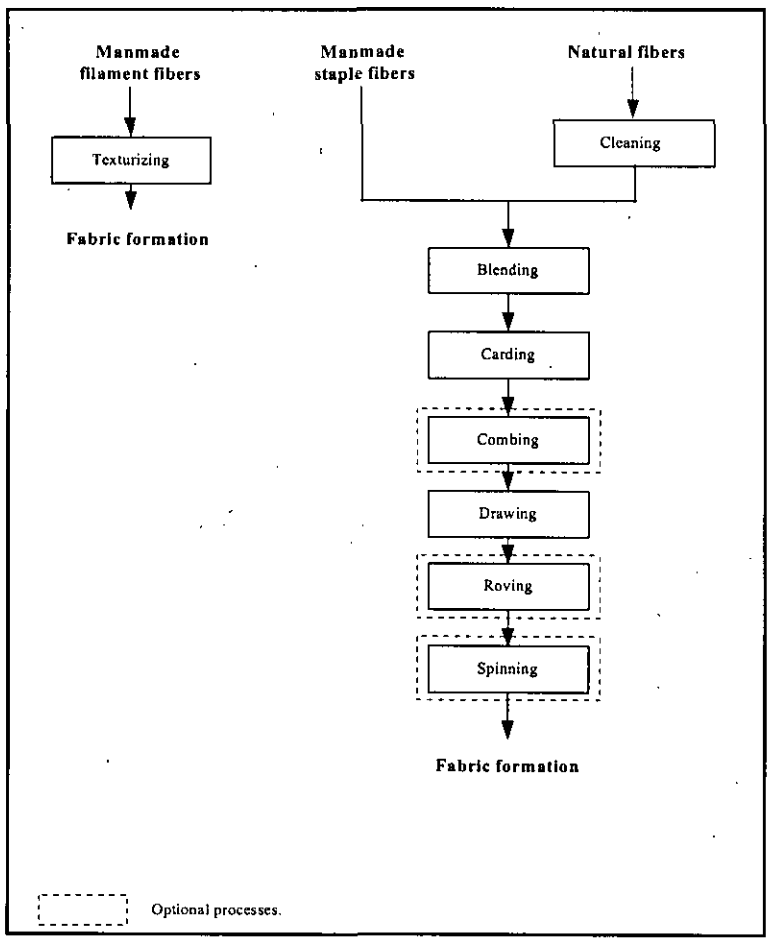


Source: ATMI, Comments on draft of this document, 1997b.

III.A.1. Yarn Formation

Textile fibers are converted into yarn by grouping and twisting operations used to bind them together. Although most textile fibers are processed using spinning operations, the processes leading to spinning vary depending on whether the fibers are natural or manmade. Figure 3 shows the different steps used to form yarn. Note that some of these steps may be optional depending on the type of yarn and spinning equipment used. Natural fibers, known as staple when harvested, include animal and plant fibers, such as cotton and wool. These fibers must go through a series of preparation steps before they can be spun into yarn, including opening, blending, carding, combing, and drafting.

Figure 3: Yarn Formation Processes



Source: ATMI, 1997.

Manmade fibers may be processed into filament yarn or staple-length fibers (similar in length to natural fibers) so that they can be spun. Filament yarn may be used directly or following further shaping and texturizing. The main steps used for processing natural and manmade fibers into yarn are below.

Natural Fibers

Yarn formation can be performed once textile fibers are uniform and have cohesive surfaces. To achieve this, natural fibers are first cleaned to remove impurities and are then subjected to a series of brushing and drawing steps designed to soften and align the fibers. The following describes the main steps used for processing wool and cotton. Although equipment used for cotton is designed somewhat differently from that used for wool, the machinery operates in essentially the same fashion.

- *Opening/Blending.* Opening of bales sometimes occurs in conjunction with the blending of fibers. Suppliers deliver natural fibers to the spinning mill in compressed bales. The fibers must be sorted based on grade, cleaned to remove particles of dirt, twigs, and leaves, and blended with fibers from different bales to improve the consistency of the fiber mix. Sorting and cleaning is performed in machines known as openers. The opener consists of a rotating cylinder equipped with spiked teeth or a set of toothed bars. These teeth pull the unbaled fibers apart, fluffing them while loosening impurities. Because the feed for the opener comes from multiple bales, the opener blends the fibers as it cleans and opens them.

- *Carding.* Tufts of fiber are conveyed by air stream to a carding machine, which transports the fibers over a belt equipped with wire needles. A series of rotating brushes rests on top of the belt. The different rotation speeds of the belt and the brushes cause the fibers to tease out and align into thin, parallel sheets. Many shorter fibers, which would weaken the yarn, are separated out and removed. A further objective of carding is to better align the fibers to prepare them for spinning. The sheet of carded fibers is removed through a funnel into a loose ropelike strand called a sliver. Opening, blending, and carding are sometimes performed in integrated carders that accept raw fiber and output carded sliver.

- *Combing.* Combing is similar to carding except that the brushes and needles are finer and more closely spaced. Several card slivers are fed to the combing machine and removed as a finer, cleaner, and more aligned comb sliver. In the wool system, combed sliver is used to make worsted yarn, whereas carded sliver is used for woolen yarn. In the cotton system, the term combed cotton applies to the yarn made from combed sliver. Worsted wool and combed cotton yarns are finer (smaller) than yarn that has not been combed because of the higher degree of fiber alignment and further removal of short fibers.

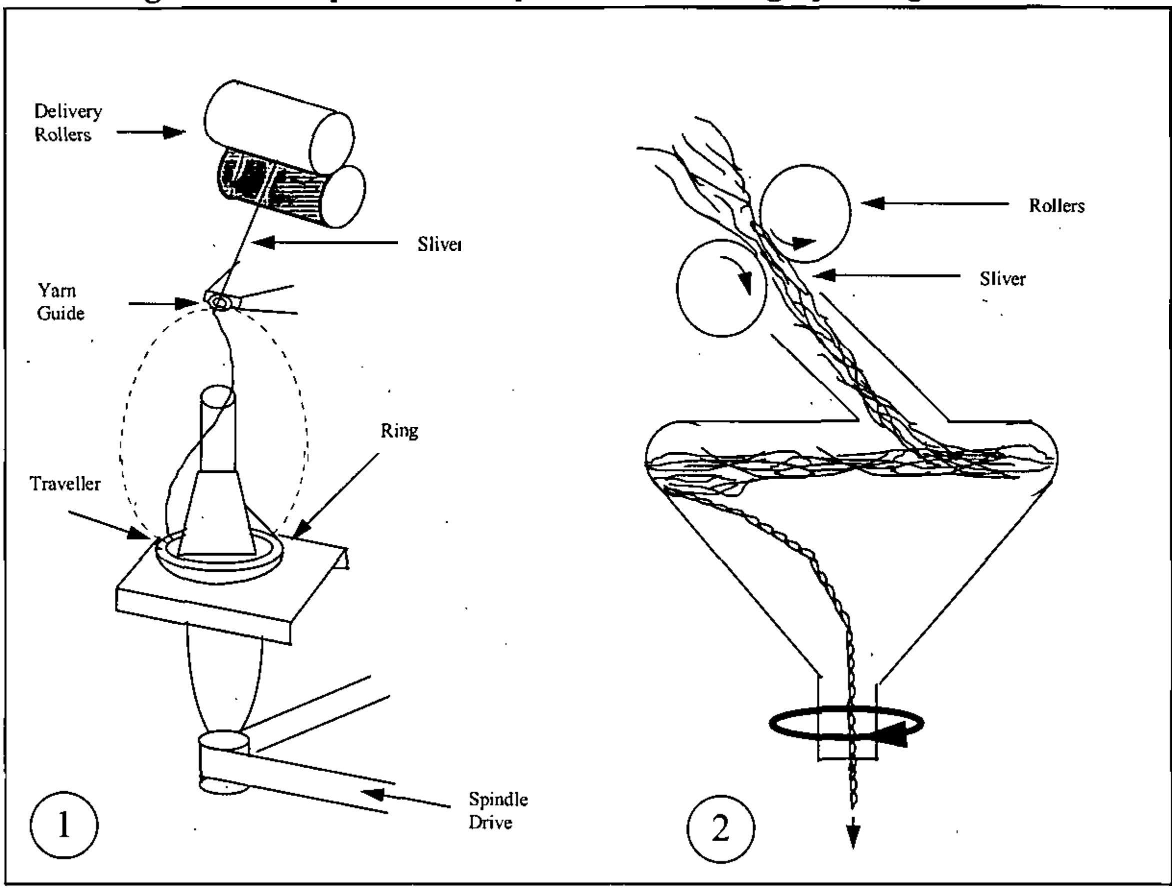
- *Drawing.* Several slivers are combined into a continuous, ropelike strand and fed to a machine known as a drawing frame (Wingate, 1979). The drawing frame contains several sets of rollers that rotate at successively faster speeds. As the slivers pass through, they are further drawn out and lengthened, to the point where they may be five to six times as long as they were originally. During drawing, slivers from different types of fibers (e.g., cotton and polyester) may be combined to form blends. Once a sliver has been drawn, it is termed a roving.

- *Drafting.* Drafting is a process that uses a frame to stretch the yarn further. This process imparts a slight twist as it removes the yarn and winds it onto a rotating spindle. The yarn, now termed a roving in ring spinning operations, is made up of a loose assemblage of fibers drawn into a single strand and is about eight times the length and one-eighth the diameter of the sliver, or approximately as wide as a pencil (Wingate, 1979). Following drafting, the rovings may be blended with other fibers before being processed into woven, knitted, or nonwoven textiles.

- *Spinning.* The fibers are now spun together into either spun yarns or filament yarns. Filament yarns are made from continuous fine strands of manmade fiber (e.g. not staple length fibers). Spun yarns are composed of overlapping staple length fibers that are bound together by twist. Methods used to produce spun yarns, rather than filament yarns, are discussed in this section. The rovings produced in the drafting step are mounted onto the spinning frame, where they are set for spinning. The yarn is first fed through another set of drawing or delivery rollers, which lengthen and stretch it still further. It is then fed onto a high-speed spindle by a yarn guide that travels up and down the spindle. The difference in speed of travel between the guide and the spindle determines the amount of twist imparted to the yarn. The yarn is collected on a bobbin.

  In ring spinning, the sliver is fed from delivery rollers through a traveler, or wire loop, located on a ring. The rotation of the spindle around the ring adds twist to the yarn. This is illustrated in Figure 4(1). Another method, shown in Figure 4(2), is open-end spinning, which accounts for more than 50 percent of spinning equipment used (ATMI, 1997b). In this method, sliver passes through rollers into a rotating funnel-shaped rotor. The sliver hits the inside of the rotor and rebounds to the left side of the rotor, causing the sliver to twist. Open-end spinning does not use rotating spindles since the yarn is twisted during passage through the rotor.

Figure 4: Comparison of Open-End and Ring Spinning Methods



Source: B.P. Corbman, *Textiles: Fiber to Fabric*, McGraw-Hill, Inc., 1975.

Yarn spinning is basically an extension of the preparation steps described above for natural fibers. Additional twisting of the yarn may occur, or multiple yarns may be twisted together to form plied yarns. Plying takes place on a machine similar to a spinning frame. Two or more yarns pass through a pair of rollers and onto a rotating spindle. The yarn guide positions the yarn onto the spindle and assists in applying twist. Plied yarns may be plied again to form thicker cords, ropes, and cables.

Manmade Fibers

Although not classified under SIC 22, manmade fiber production is briefly discussed in the following paragraphs to describe the upstream processing of textiles. Manmade fibers include 1) cellulosic fibers, such as rayon and acetate, which are created by reacting chemicals with wood pulp; and 2) synthetic fibers, such as polyester and nylon, which are synthesized from

organic chemicals. Since manmade fibers are synthesized from organic chemicals, yarn formation of manmade fibers does not involve the extensive cleaning and combing procedures associated with natural fibers. Manmade fibers, both synthetic and cellulosic, are manufactured using spinning processes that simulate or resemble the manufacture of silk. Spinning, in terms of manmade fiber production, is the process of forming fibers by forcing a liquid through a small opening beyond which the extruded liquid solidifies to form a continuous filament. Following spinning, the manmade fibers are drawn, or stretched, to align the polymer molecules and strengthen the filament. Manmade filaments may then be texturized or otherwise treated to simulate physical characteristics of spun natural fibers. Texturizing is often used to curl or crimp straight rod-like filament fibers to simulate the appearance, structure, and feel of natural fibers. (For more information on the synthesis of manmade fibers, refer to the EPA Industrial Sector Notebook on Plastic Resins and Manmade Fibers.)

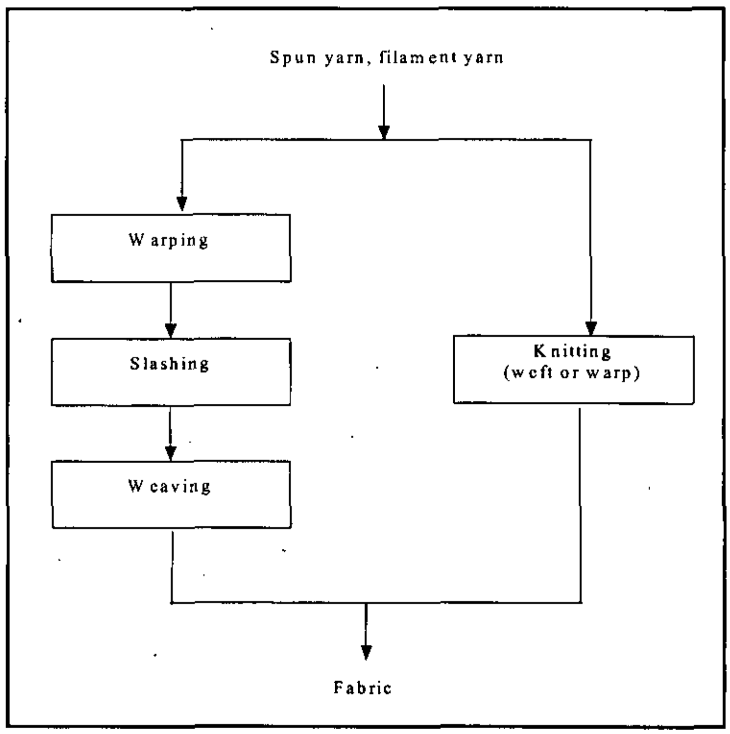
Spun yarns are created using manmade fibers that have been cut into staple-length fibers. Staple-length fibers are then used to process fibers on wool or cotton-system machinery. Methods for making spun yarn from manmade fibers are similar to those used for natural fibers. Some fibers are processed as tow, or bundles of staple fibers.

Fibers can also be produced as filament yarn, which consists of filament strands twisted together slightly. In mills, filament fibers are wound onto bobbins and placed on a twisting machine to make yarn. Filament yarns may be used directly to make fabric or further twisted to the desired consistency. Manmade filaments often require additional drawing and are processed in an integrated drawing/twisting machine. Manmade filaments are typically texturized using mechanical or chemical treatments to impart characteristics similar to those of yarns made from natural fibers.

III.A.2. Fabric Formation

The major methods for fabric manufacture are weaving and knitting. Figure 5 shows fabric formation processes for flat fabrics, such as sheets and apparel. Weaving, or interlacing yarns, is the most common process used to create fabrics. Weaving mills classified as broadwoven mills consume the largest portion of textile fiber and produce the raw textile material from which most textile products are made. Narrow wovens, nonwovens, and rope are also produced primarily for use in industrial applications. Narrow wovens include fabrics less than 12 inches in width, and nonwovens include fabrics bonded by mechanical, chemical, or other means. Knitting is the second most frequently used method of fabric construction. The popularity of knitting has increased in use due to the increased versatility of techniques, the adaptability of manmade fibers, and the growth in consumer demand for wrinkle-resistant, stretchable, snug-fitting fabrics. Manufacturers of knit fabrics also consume a sizable amount of textile fibers. Knit fabrics are generally classified as either weft knit (circular-knit goods) or warp knit (flat-knit goods). Tufting is a process used to make most carpets.

Figure 5: General Fabric Formation Processes Used for Producing Flat Fabrics

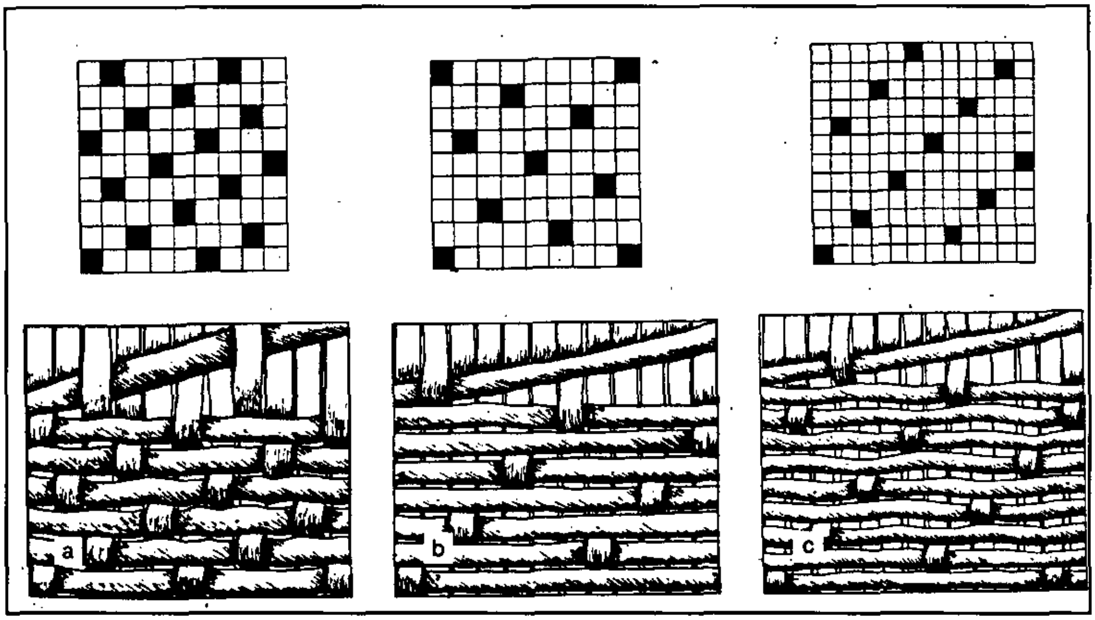


Source: ATMI, 1997.

Weaving

Weaving is performed on modern looms, which contain similar parts and perform similar operations to simple hand-operated looms. Fabrics are formed from weaving by interlacing one set of yarns with another set oriented crosswise. Figure 6 shows an example of satin weave patterns. Satin, plain, and twill weaves are the most commonly used weave patterns. In the weaving operation, the length-wise yarns that form the basic structure of the fabric are called the warp and the crosswise yarns are called the filling, also referred to as the weft. While the filling yarns undergo little strain in the weaving process, warp yarns undergo much strain during weaving and must be processed to prepare them to withstand the strain (Corbman, 1975).

Figure 6: Examples of Satin Weaving Patterns



Source: B.P. Corbman, *Textiles: Fiber to Fabric*, McGraw-Hill, Inc., 1975.

Before weaving, warp yarns are first wound on large spools, or cones, which are placed on a rack called a creel. The warp yarns are then unwound and passed through a size solution (sizing/slashing) before being wound onto a warp beam in a process known as beaming. The size solution forms a coating that protects the yarn against snagging or abrasion during weaving. Slashing, or applying size to the warp yarn, uses pad/dry techniques in a large range called a slasher. The slasher is made up of the following: a yarn creel with very precise tension controls; a yarn guidance system; and a sizing delivery system, which usually involves tank storage and piping to the size vessels. The yarn sheet is dipped one or more times in size solution and dried on hot cans or in an oven. A devise called a "lease" is then used to separate yarns from a solid sheet back into individual ends for weaving (EPA, 1996).

Starch, the most common primary size component, accounts for roughly two-thirds of all size chemicals used in the U.S. (130 million pounds per year). Starch is used primarily on natural fibers and in a blend with synthetic sizes for coating natural and synthetic yarns. Polyvinyl alcohol (PVA), the leading synthetic size, accounts for much of the remaining size consumed in the U.S. (70 million pounds per year). PVA is increasing in use since it can be recycled, unlike starch. PVA is used with polyester/cotton yarns and pure cotton yarns either in a pure form or in blends with natural and other synthetic sizes. Other synthetic sizes contain acrylic and acrylic copolymer components. Semisynthetic sizes, such as carboxymethyl cellulose (CMC) and modified starches, are also used. Oils, waxes, and other additives are often used in conjunction with sizing agents to increase the softness and pliability of the yarns. About 10 to 15 percent of the weight of goods is added as size to cotton warp yarns, compared to about 3 to 5 percent for filament synthetics.

Once size is applied, the wound beam is mounted in a loom. Shuttle looms are rapidly being replaced by shuttleless looms, which have the ability to weave at higher speeds and with less noise. Shuttleless looms are discussed in the next section. The operation of a traditional shuttle loom is discussed in this section to illustrate the weaving process.

The major components of the loom are the warp beam, heddles, harnesses, shuttle, reed, and takeup roll (see Figure 7). In the loom, yarn processing includes shedding, picking, battening, and taking up operations. These steps are discussed below.

- *Shedding.* Shedding is the raising of the warp yarns to form a shed through which the filling yarn, carried by the shuttle, can be inserted. The shed is the vertical space between the raised and unraised warp yarns. On the modern loom, simple and intricate shedding operations are performed automatically by the heddle frame, also known as a harness. This is a rectangular frame to which a series of wires, called heddles, are attached. The yarns are passed through the eye holes of the heddles, which hang vertically from the harnesses.

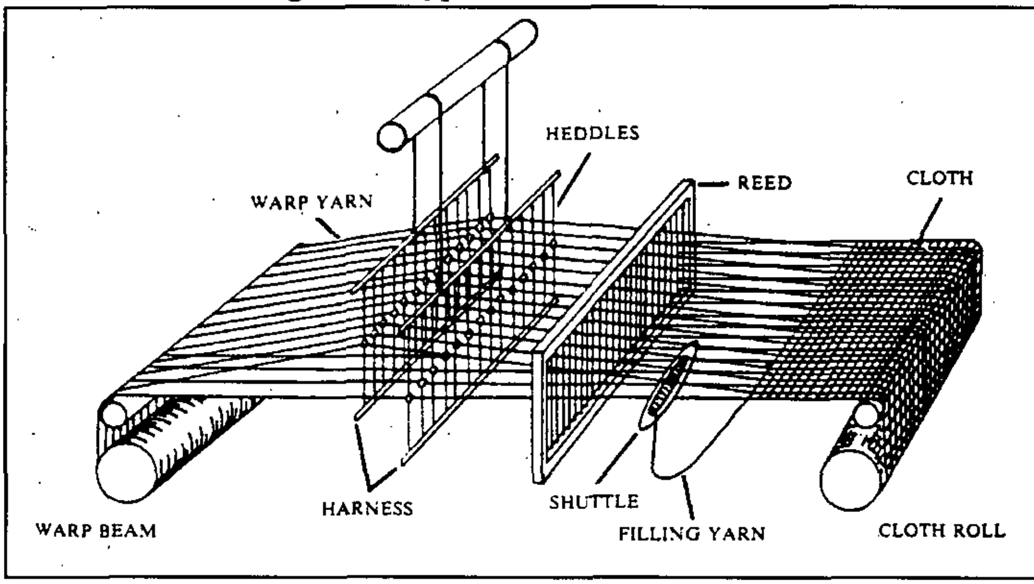
  The weave pattern determines which harness controls which warp yarns, and the number of harnesses used depends on the complexity of the weave (Corbman, 1975).

- *Picking.* As the harnesses raise the heddles, which raise the warp yarns, the shed is created. The filling yarn in inserted through the shed by a small carrier device called a shuttle. The shuttle is normally pointed at each end to allow passage through the shed. In a traditional shuttle loom, the filling yarn is wound onto a quill, which in turn is mounted in the shuttle. The filling yarn emerges through a hole in the shuttle as it moves across the loom. A single crossing of the shuttle from one side of the loom to the other is known as a pick. As the shuttle moves back and forth across the shed, it weaves an edge, or selvage, on each side of the fabric to prevent the fabric from raveling.

- *Battening.* As the shuttle moves across the loom laying down the fill yarn, it also passes through openings in another frame called a reed (which resembles a comb). With each picking operation, the reed presses or battens each filling yarn against the portion of the fabric that has already been formed. Conventional shuttle looms can operate at speeds of about 150 to 160 picks per minute.

- *Taking up and letting off.* With each weaving operation, the newly constructed fabric must be wound on a cloth beam. This process is called taking up. At the same time, the warp yarns must be let off or released from the warp beams (Corbman, 1975).

Figure 7: Typical Shuttle Loom



Source: I.B. Wingate, *Fairchild's Dictionary of Textiles,* Fairchild Publications, Inc., 1979.

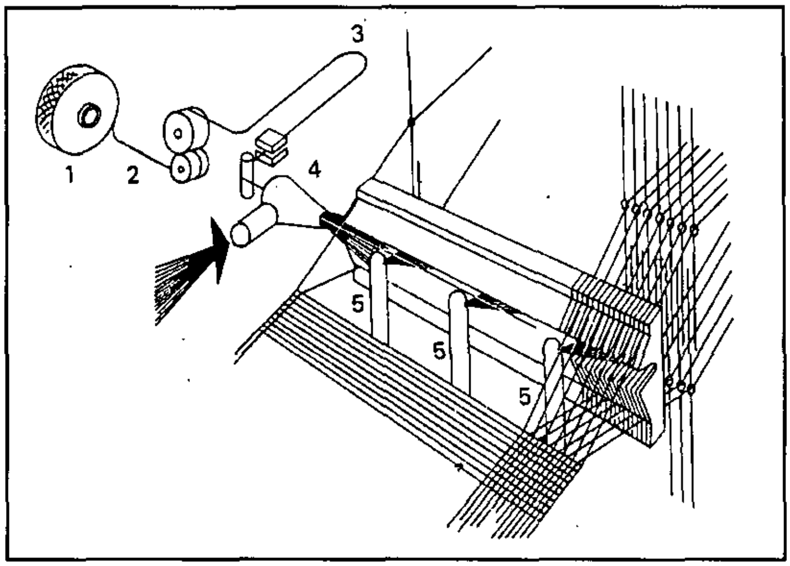
Shuttleless Looms

Because the shuttle can cause yarns to splinter and catch, several types of shuttleless looms have been developed. These operate at higher speeds and reduced noise levels. By the end of 1989, shuttleless looms represented 54 percent of all looms installed, up from 15 percent in 1980. Shuttleless looms use different techniques to transport cut pieces of fill yarn across the shed, as opposed to the continuous yarn used in shuttle looms.

Some of the common shuttleless looms include water-jet looms, air-jet looms, rapier looms, and projectile looms. Water-jet looms transport the fill yarn in a high-speed jet of water and can achieve speeds of 400 to 600 picks per minute. Water jets can handle a wide variety of fiber and yarn types and are widely used for apparel fabrics. Air-jet looms use a blast of air to move the fill yarn and can operate at speeds of 800 to 1000 picks per minute. Rapier looms use two thin wire rods to carry the fill yarn and can operate at a speed of 510 picks per minute. Rapiers are used mostly for spun yarns to make cotton and woolen/worsted fabrics. In a double rapier loom, two rods move from each side and meet in the middle. The fill yarn is carried from the rod on the fill side and handed off to the rod on the finish side of the loom. Projectile looms use a projectile to carry the fill yarn across the weave.

Shuttleless looms have been replacing the traditional fly-shuttle loom in recent years. Air looms, although limited in the types of filling yarns they can handle, are increasing in commercial use. The operation of an air jet loom is shown in Figure 8. As shown in the figure, yarn is drawn from the yarn package (1) by the measuring wheel and drive roller arrangement (2). Between the yarn package and the measuring wheel is a tube through which an air current flows in opposite direction to the yarn. This maintains a straight even feed of yarn. The yarn then forms a loop (3) which shortens as the pick penetrates further into the shed. The main jet (4) is the major projecting force for the yarn, although supplementary jets (5) are activated to prevent the pick from buckling.

Figure 8: Typical Air Jet Loom



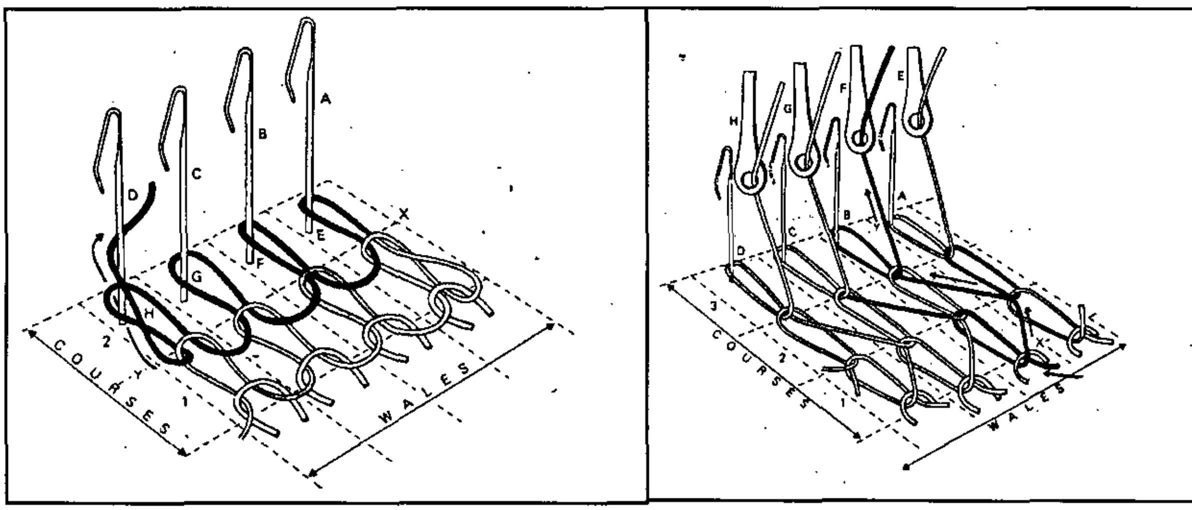
Source: A. Ormerod, *Modern Preparation and Weaving Machinery*, Butterworths, 1983.

Knitting

Knitted fabrics may be constructed by using hooked needles to interlock one or more sets of yarns through a set of loops. The loops may be either loosely or closely constructed, depending on the purpose of the fabric. Knitted fabrics can be used for hosiery, underwear, sweaters, slacks, suits, coats, rugs, and other home furnishings. Knitting is performed using either weft or warp processes, depicted in Figure 9. In weft (or filling) knitting, one yarn is carried back and forth and under needles to form a fabric. Yarns run horizontally in the fabric, and connections between loops are horizontal. In warp knitting, a warp beam is set into the knitting machine. Yarns are interlocked to form the fabric, and the yarns run vertically while the connections are on the diagonal. Several different types of machinery are used in both weft and warp knitting.

Figure 9: Comparison Between Warp and Weft Knitting Methods

(a) Weft **(b) Warp**



Source: D.J. Spencer, *Knitting Technology,* Pergamon Press, 1989.

- *Weft knitting.* Weft knitting uses one continuous yarn to form courses, or rows of loops, across a fabric. There are three fundamental stitches in weft knitting: plain-knit, purl, and rib. On a machine, the individual yarn is fed to one or more needles at a time. Weft knitting machines can produce both flat and circular fabric. Circular machines produce mainly yardage but may also produce sweater bodies, pantyhose, and socks. Flatbed machines knit full garments and operate at much slower speeds. The simplest, most common filling knit fabric is single jersey. Double knits are made on machines with two sets of needles. All hosiery is produced as a filling knit process.

- *Warp Knitting.* Warp knitting represents the fastest method of producing fabric from yarns. Warp knitting differs from weft knitting in that each needle loops its own thread. The needles produce parallel rows of loops simultaneously that are interlocked in a zigzag pattern. Fabric is produced in sheet or flat form using one or more sets of warp yarns. The yarns are fed from warp beams to a row of needles extending across the width of the machine (Figure 9b). Two common types of warp knitting machines are the Tricot and Raschel machines. Raschel machines are useful because they can process all yarn types in all forms (filament, staple, combed, carded, etc.). Warp knitting can also be used to make pile fabrics often used for upholstery.

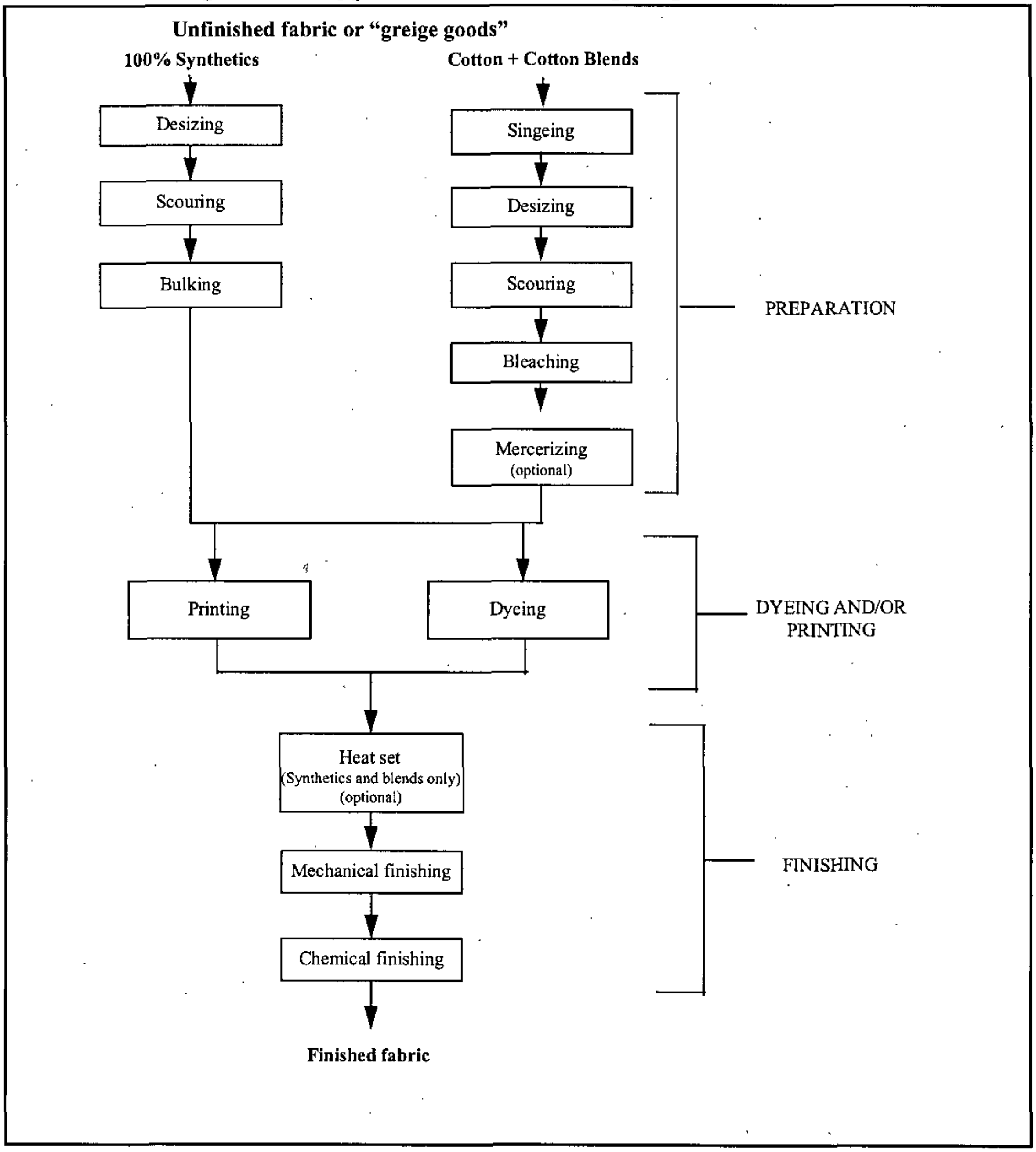
Tufting

Tufting is a process used to create carpets, blankets, and upholstery. Tufting is done by inserting additional yarns into a ground fabric of desired weight and yarn content to create a pile fabric. The substrate fabric can range from a thin backing to heavy burlap-type material and may be woven, knitted, or web. In modern tufting machines, a set of hollow needles carries the yarn from a series of spools held in a creel and inserts the yarn through the substrate cloth. As each needle penetrates the cloth, a hook on the underside forms a loop by catching and holding the yarn. The needle is withdrawn and moves forward, much like a sewing machine needle. Patterns may be formed by varying the height of the tuft loops. To make cut-loop pile, a knife is attached to the hook and the loops are cut as the needles are retracted. Well over 90 percent of broadloom carpeting is made by tufting, and modern machines can stitch at rates of over 800 stitches per minute, producing some 650 square yards of broadloom per hour.

III.A.3. Wet Processing

Woven and knit fabrics cannot be processed into apparel and other finished goods until the fabrics have passed through several water-intensive wet processing stages. Wet processing enhances the appearance, durability, and serviceability of fabrics by converting undyed and unfinished goods, known as gray or greige (*pronounced* grā[zh]) goods, into finished consumers' goods. Also collectively known as finishing, wet processing has been broken down into four stages in this section for simplification: fabric preparation, dyeing, printing, and finishing. These stages, shown in Figure 10, involve treating gray goods with chemical baths and often require additional washing, rinsing, and drying steps. Note that some of these steps may be optional depending on the style of fabric being manufactured.

Figure 10: Typical Wet Processing Steps for Fabrics



Source: ATMI, 1997.

In terms of waste generation and environmental impacts, wet processing is the most significant textile operation. Methods used vary greatly depending on end-products and applications, site-specific manufacturing practices, and fiber type. Natural fibers typically require more processing steps than manmade fibers. For most wool products and some manmade and cotton products, the yarn is dyed before weaving; thus, the pattern is woven into the fabric. Processing methods may also differ based on the final properties desired, such as tensile strength, flexibility, uniformity, and luster (Snowden-Swan, 1995).

Most manufactured textiles are shipped from textile mills to commission dyeing and finishing shops for wet processing, although some firms have integrated wet processing into their operations. A wide range of equipment is used for textile dyeing and finishing (EPA, 1996). Much of the waste generated from the industry is produced during the wet processing stages. Relatively large volumes of wastewater are generated, containing a wide range of contaminants that must be treated prior to disposal. Significant quantities of energy are spent heating and cooling chemical baths and drying fabrics and yarns (Snowden-Swan, 1995).

Fabric Preparation

Most fabric that is dyed, printed, or finished must first be prepared, with the exception of denim and certain knit styles. Preparation, also known as pretreatment, consists of a series of various treatment and rinsing steps critical to obtaining good results in subsequent textile finishing processes. . In preparation, the mill removes natural impurities or processing chemicals that interfere with dyeing, printing, and finishing. Typical preparation treatments include desizing, scouring, and bleaching. Preparation steps can also include processes, such as singeing and mercerizing, designed to chemically or physically alter the fabric. For instance, the mercerizing stage chemically treats the fabric to increase fiber strength and dye affinity, or ability to pick up dyes. This, in turn, increases the longevity of fabric finishes applied during finishing. Many of the pollutants from preparation result from the removal of previously applied processing chemicals and agricultural residues. These chemical residues can be passed on to subsequent stages with improper preparation.

Most mills can use the same preparation equipment for the entire range of products they produce. In most cases, facilities favor continuous rather than batch preparation processes for economic and pollution control reasons. A number of mills, however, prepare goods, particularly knits, batchwise on dyeing machines to simplify scheduling and handling. Sometimes, facilities operate batchwise to reduce high capital costs required for high productivity and the complexity of storing and tracking goods through continuous wet processing operations.

Because preparation is relatively uniform across most of a mill's production, preparation is usually the highest-volume process in a mill and hence an important area for pollution prevention. If fabrics contained no contamination upon arrival for wet processing, preparation processes would be unnecessary, eliminating about half the pollution outputs from wet processing and a significant amount of wastewater. The primary pollutants from preparation is wastewater containing alkalinity, BOD, COD, and relatively small amounts of other contaminants such as metals and surfactants. There are many preparation techniques, some of which are described below.

- *Singeing*. If a fabric is to have a smooth finish, singeing is essential. Singeing is a dry process used on woven goods that removes fibers protruding from yarns or fabrics. These are burned off by passing the fibers over a flame or heated copper plates. Singeing improves the surface appearance of woven goods and reduces pilling. It is especially useful for fabrics that are to be printed or where a smooth finish is desired. Pollutant outputs associated with singeing include relatively small amounts of exhaust gases from the burners.

- *Desizing*. Desizing is an important preparation step used to remove size materials applied prior to weaving. Manmade fibers are generally sized with water-soluble sizes that are easily removed by a hot-water wash or in the scouring process. Natural fibers such as cotton are most often sized with water-insoluble starches or mixtures of starch and other materials.. Enzymes are used to break these starches into water-soluble sugars, which are then removed by washing before the cloth is scoured. Removing starches before scouring is necessary because they can react and cause color changes when exposed to sodium hydroxide in scouring.

- *Scouring*. Scouring is a cleaning process that removes impurities from fibers, yarns, or cloth through washing. Alkaline solutions are typically used for scouring; however, in some cases solvent solutions may also be used. Scouring uses alkali, typically sodium hydroxide, to break down natural oils and surfactants and to emulsify and suspend remaining impurities in the scouring bath. The specific scouring procedures, chemicals, temperature, and time vary with the type of fiber, yarn, and cloth construction. Impurities may include lubricants, dirt and other natural materials, water-soluble sizes, antistatic agents, and residual tints used for yarn identification. Typically, scouring wastes contribute a large portion of biological oxygen demand (BOD) loads from preparation processes (NC DEHNR, 1986). Desizing and scouring operations are often combined (ATMI, 1997).

- *Bleaching*. Bleaching is a chemical process that eliminates unwanted colored matter from fibers, yarns, or cloth. Bleaching decolorizes colored impurities that are not removed by scouring and prepares the cloth for further finishing processes such as dyeing or printing. Several different types of chemicals are used as bleaching agents, and selection depends on the type of fiber present in the yarn, cloth, or finished product and the subsequent finishing that the product will receive. The most common bleaching agents include hydrogen peroxide, sodium hypochlorite, sodium chlorite, and sulfur dioxide gas. Hydrogen peroxide is by far the most commonly used bleaching agent for cotton and cotton blends, accounting for over 90 percent of the bleach used in textile operations, and is typically used with caustic solutions. Bleaching contributes less than 5 percent of the total textile mill BOD load (NC DEHNR, 1986).

The bleaching process involves several steps: 1)The cloth is saturated with the bleaching agent, activator, stabilizer, and other necessary chemicals; 2) the temperature is raised to the recommended level for that particular fiber or blend and held for the amount of time needed to complete the bleaching action; and 3) the cloth is thoroughly washed and dried. Peroxide bleaching can be responsible for wastewater with high pH levels. Because peroxide bleaching typically produces wastewater with few contaminants, water conservation and chemical handling issues are the primary pollution concerns.

- *Mercerizing.* Mercerization is a continuous chemical process used for cotton and cotton/polyester goods to increase dyeability, luster, and appearance. This process, which is carried out at room temperature, causes the flat, twisted ribbon-like cotton fiber to swell into a round shape and to contract in length. This causes the fiber to become more lustrous than the original fiber, increase in strength by as much as 20 percent, and increase its affinity for dyes. Mercerizing typically follows singeing and may either precede or follow bleaching (Corbman, 1975).

  During mercerizing, the fabric is passed through a cold 15 to 20 percent solution of caustic soda and then stretched out on a tenter frame where hot-water sprays remove most of the caustic solution (Corbman, 1975). After treatment, the caustic is removed by several washes under tension. Remaining caustic may be neutralized with a cold acid treatment followed by several more rinses to remove the acid. Wastewater from mercerizing can contain substantial amounts of high pH alkali, accounting for about 20 percent of the weight of goods.

Dyeing

Dyeing operations are used at various stages of production to add color and intricacy to textiles and increase product value. Most dyeing is performed either by the finishing division of vertically integrated textile companies, or by specialty dyehouses. Specialty dyehouses operate either on a commission basis or purchase greige goods and finish them before selling them to apparel and other product manufacturers. Textiles are dyed using a wide range of dyestuffs, techniques, and equipment. Dyes used by the textile industry are largely synthetic, typically derived from coal tar and petroleum-based intermediates. Dyes are sold as powders, granules, pastes, and liquid dispersions, with concentrations of active ingredients ranging typically from 20 to 80 percent.

Methods of Dyeing

Dyeing can be performed using continuous or batch processes. In batch dyeing, a certain amount of textile substrate, usually 100 to 1,000 kilograms, is loaded into a dyeing machine and brought to equilibrium, or near equilibrium, with a solution containing the dye. Because the dyes have an affinity for the fibers, the dye molecules leave the dye solution and enter the fibers over a period of minutes to hours, depending on the type of dye and fabric used. Auxiliary chemicals and controlled dyebath conditions (mainly temperature) accelerate and optimize the action. The dye is fixed in the fiber using heat and/or chemicals, and the tinted textile substrate is washed to remove unfixed dyes and chemicals. Common methods of batch, or exhaust, dyeing include beam, beck, jet, and jig processing. Pad dyeing can be performed by either batch or continuous processes.

In continuous dyeing processes, textiles are fed continuously into a dye range at speeds usually between 50 and 250 meters per minute. Continuous dyeing accounts for about 60 percent of total yardage of product dyed in the industry (Snowden-Swan, 1995). To be economical, this may require the dyer to process 10,000 meters of textiles or more per color, although specialty ranges are now being designed to run as little as 2,000 meters economically. Continuous dyeing processes typically consist of dye application, dye fixation with chemicals or heat, and washing. Dye fixation is a measure of the amount of the percentage of dye in a bath that will fix to the fibers of the textile material. Dye fixation on the fiber occurs much more rapidly in continuous dying than in batch dyeing.

Each dyeing process requires different amounts of dye per unit of fabric to be dyed. This is significant since color and salts in wastewater from spent dyes are often a pollution concern for textile facilities. In addition, less dye used results in energy conservation and chemical savings. The amounts of dye used depends on the dye is exhausted from the dyebaths which determines the required dyebath ratio. The dyebath ratio is the ratio of the units of dye required per unit of fabric and typically ranges from 5 to 50 depending on the type of dye, dyeing system, and affinity of the dyes for the fibers.

Dyeing processes may take place at any of several stages of the manufacturing process (fibers, yarn, piece-dyeing). Stock dyeing is used to dye fibers. Top dyeing is used to dye combed wool sliver. Yarn dyeing and piece dyeing, done after the yarn has been constructed into fabric, are discussed in more detail below.

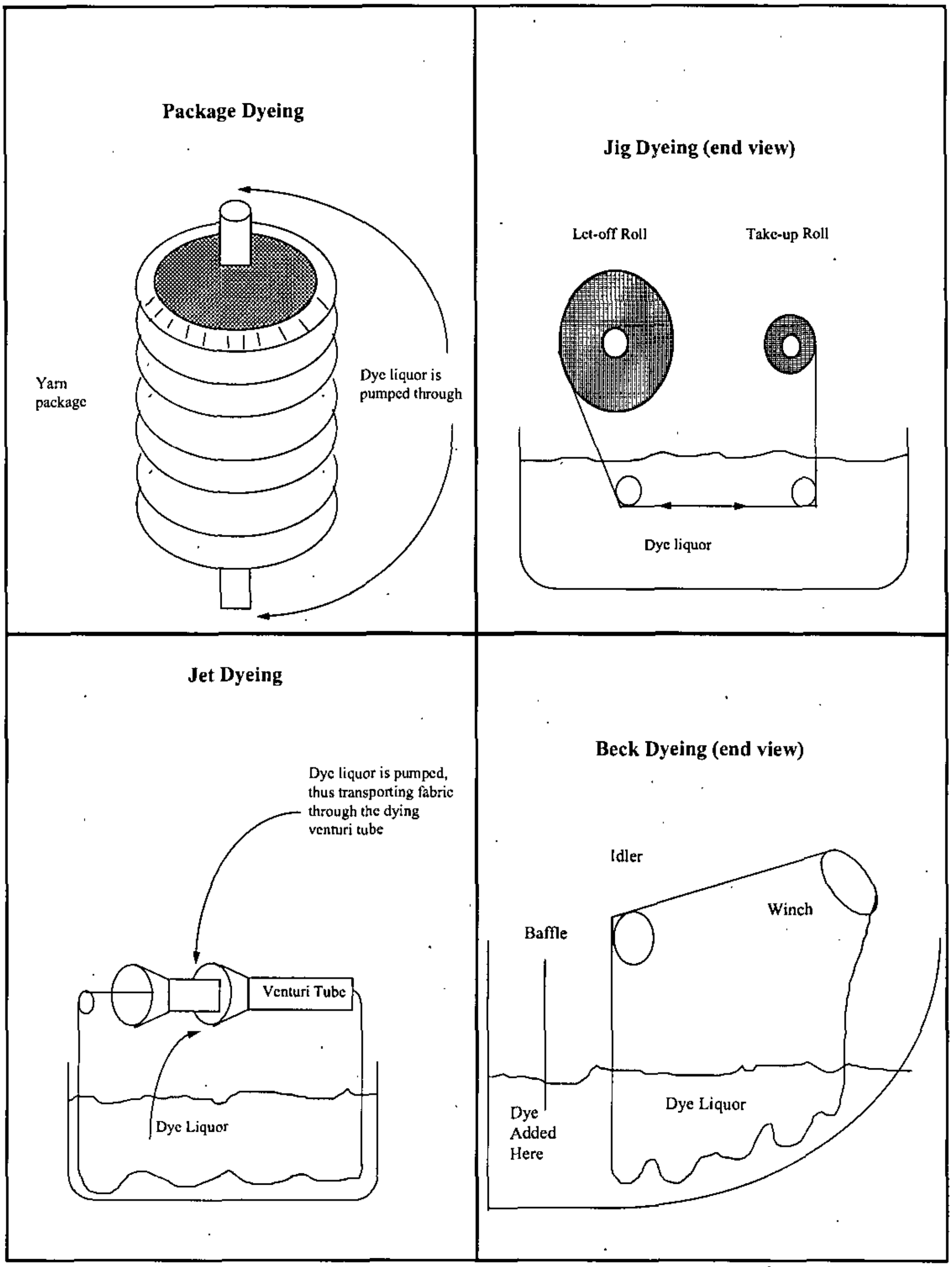
- *Yarn Dyeing.* Yarn dyeing is used to create interesting checks, stripes, and plaids with different-colored yarns in the weaving process. In yarn dyeing, dyestuff penetrates the fibers in the core of the yarn.

  Some methods of yarn dyeing are stock, package, and skein dyeing. Stock dyeing dyes fiber using perforated tubes. In package dyeing (Figure 11), spools of yarn are stacked on perforated rods in a rack and immersed in a tank where dye is then forced outward from the rods under pressure. The dye is then pressured back through the packages toward the center to fully penetrate the entire yarn. Most carded and combed cotton used for knitted outerwear is package-dyed. In skein dyeing, yarn is loosely coiled on a reel and then dyed. The coils, or skeins, are hung over a rung and immersed in a dyebath (Corbman, 1975). Skein-dyed yarn is used for bulky acrylic and wool yarns. Typical capacity for package dyeing equipment is 1,210 pounds (550 kg) and for skein dyeing equipment is 220 pounds (100 kg).

- *Piece Dyeing.* Most dyed fabric is piece-dyed since this method gives the manufacturer maximum inventory flexibility to meet color demands as fashion changes. In terms of overall volume, the largest amount of dyeing is performed using beck and jig equipment (Figure 11). Beck dyeing is a versatile, continuous process used to dye long yards of fabric. About 1,980 pounds (900 kg) of fabric can be dyed on beck equipment at a time. The fabric is passed in rope form through the dyebath. The rope moves over a rail onto a reel which immerses it into the dye and then draws the fabric up and forward to the front of the machine. This process is repeated as long as necessary to dye the material uniformly to the desired color intensity. Jig dyeing uses the same procedure of beck dyeing, however, the fabric is held on rollers at full width rather than in rope form as it is passed through the dyebath (Corbman, 1975). This reduces fabric tendency to crack or crease. Jig dyeing equipment can handle 550 pounds (250 kg) of fabric.

  Other piece dyeing methods include jet dyeing and pad dyeing. Fabric can be jet-dyed (at up to 1,100 pounds (500 kg)) by placing it in a heated tube or column where jets of dye solution are forced through it at high pressures. The dye is continually recirculated as the fabric is moved along the tube. Pad dyeing, like jig dyeing, dyes the fabric at full width. The fabric is passed through a trough containing dye and then between two heavy rollers which force the dye into the cloth and squeeze out the excess (Corbman, 1975). Figure 11 illustrates the beck, jig, and jet methods for dyeing.

Figure 11: Common Dyeing Methods



Source: *Best Management Practices for Pollution Prevention in the Textile Industry,* EPA, Office of Research and Development, 1995.

Types of Dyes

Dyes may be classified in several ways (e.g., according to chemical constitution, application class, end-use). The primary classification of dyes is based on the fibers to which they can be applied and the chemical nature of each dye. Table 6 lists the major dye classes, fixation rates, and the types of fibers for which they have an affinity. Factors that companies consider when selecting a dye include the type of fibers being dyed, desired shade, dyeing uniformity, and fastness (desired stability or resistance of stock or colorants to influences such as light, alkali, etc) (FFTA, 1991).

Most commonly in use today are the reactive and direct types for cotton dyeing, and disperse types for polyester dyeing. Reactive dyes react with fiber molecules to form chemical bonds. Direct dyes can color fabric directly with one operation and without the aid of an affixing agent. Direct dyes are the simplest dyes to apply and the cheapest in their initial and application costs although there are tradeoffs in the dyes' shade range and wetfastness (Corbman, 1975). Direct and reactive dyes have a fixation rate of 90 to 95 percent and 60 to 90 percent, respectively. A variety of auxiliary chemicals may be used during dyeing to assist in dye absorption and fixation into the fibers. Disperse dyes, with fixation rates of 80 to 90 percent, require additional factors, such as dye carriers, pressure, and heat, to penetrate synthetic fibers (Snowden-Swan, 1995; ATMI, 1997). Disperse dyes are dispersed in water where the dyes are dissolved into fibers. Vat dyes, such as indigo, are also commonly used for cotton and other cellulosic fibers.

Table 6: Typical Characteristics of Dyes Used in Textile Dyeing Operations

Dye Class	Description	Method	Fibers Typically Applied to	Typical Fixation (%)	Typical Pollutants Associated with Various Dyes
Acid	water-soluble anionic compounds	Exhaust/ Beck/ Continuous (carpet)	wool nylon	80-93	color; organic acids; unfixed dyes
Basic	water-soluble, applied in weakly acidic dyebaths; very bright dyes	Exhaust/ Beck	acrylic some polyesters	97-98	N/A
Direct	water-soluble, anionic compounds; can be applied directly to cellulosics without mordants (or metals like chromium and copper)	Exhaust/ Beck/ Continuous	cotton rayon other cellulosics	70-95	color; salt; unfixed dye; cationic fixing agents; surfactant; defoamer; leveling and retarding agents; finish; diluents
Disperse	not water-soluble	High temperature exhaust Continuous	polyester acetate other synthetics	80-92	color; organic acids; carriers; leveling agents; phosphates; defoamers; lubricants; dispersants; delustrants; diluents
Reactive	water-soluble, anionic compounds; largest dye class	Exhaust/ Beck Cold pad batch/ Continuous	cotton other cellulosics wool	60-90	color; salt; alkali; unfixed dye; surfactants; defoamer; diluents; finish
Sulfur	organic compounds containing sulfur or sodium sulfide	Continuous	cotton other cellulosics	60-70	color; alkali; oxidizing agent; reducing agent; unfixed dye
Vat	oldest dyes; more chemically complex; water-insoluble	Exhaust/ Package/ Continuous	cotton other cellulosics	80-95	color; alkali; oxidizing agents; reducing agents

Source: *Best Management Practices for Pollution Prevention in the Textile Industry,* EPA, Office of Research and Development, 1995; Snowden-Swan, L.J. "Pollution Prevention in the Textile Industries," in *Industrial Pollution Prevention Handbook,* Freeman, H.M. (Ed.), McGraw-Hill, Inc., New York, 1995.

Printing

Fabrics are often printed with color and patterns using a variety of techniques and machine types. Of the numerous printing techniques, the most common is rotary screen. However, other methods, such as direct, discharge, resist, flat screen (semicontinuous), and roller printing are often used commercially. Pigments are used for about 75 to 85 percent of all printing operations, do not require washing steps, and generate little waste (Snowden-Swan, 1995). Compared to dyes, pigments are typically insoluble and have no affinity for the fibers. Resin binders are typically used to attach pigments to substrates. Solvents are used as vehicles for transporting the pigment and resin mixture to the substrate. The solvents then evaporate leaving a hard opaque coating. The major types of printing are described below.

- *Rotary screen printing.* Rotary screen printing uses seamless cylindrical screens made of metal foil. The machine uses a rotary screen for each color. As the fabric is fed under uniform tension into the printer section of the machine, its back is usually coated with an adhesive which causes it to adhere to a conveyor printing blanket. Some machines use other methods for gripping the fabric. The fabric passes under the rotating screen through which the printing paste is automatically pumped from pressure tanks. A squeegee in each rotary screen forces the paste through the screen onto the fabric as it moves along (Corbman, 1975). The fabric then passes to a drying oven.

- *Direct printing.* In direct printing, a large cylindrical roller picks up the fabric, and smaller rollers containing the color are brought into contact with the cloth. The smaller rollers are etched with the design, and the number of rollers reflects the number of colors. Each smaller roller is supplied with color by a furnisher roller, which rotates in the color trough, picks up color, and deposits it on the applicator roller. Doctor blades scrape excess color off the applicator roller so that only the engraved portions carry the color to the cloth. The cloth is backed with a rubberized blanket during printing, which provides a solid surface to print against, and a layer of gray cloth is used between the cloth and the rubber blanket to absorb excess ink.

- *Discharge printing.* Discharge printing is performed on piece-dyed fabrics. The patterns are created through removal, rather than addition, of color, hence most discharge printing is done on dark backgrounds. The dyed fabric is printed using discharge pastes, which remove background color from the substrate when exposed to steam. Colors may be added to the discharge paste to create different colored discharge areas (EPA, 1996).

- *Resist printing.* Resist printing encompasses several hand and low-volume methods in which the pattern is applied by preventing color from penetrating certain areas during piece-dyeing. Examples of resist printing methods include batik, tie-dyeing, screen printing, and stencil printing.

- *Ink-Jet printing.* Ink-jet printing is a noncontact printing method in which droplets of colorant solution are propelled toward a substrate and directed to a desired spot. Ink jet is an emerging technology in the textile industry and has not yet been adopted for widespread commercial use. The dye types most amenable to ink-jet printing of textiles are fiber reactive, vat, sulfur, and naphthol dyes.

- *Heat-transfer printing.* In heat-transfer printing, the pattern is first printed onto a special paper substrate. The paper is then positioned against the fabric and subjected to heat and pressure. The dyes are transferred to the fabric via sublimation.

Finishing

Finishing encompasses chemical or mechanical treatments performed on fiber, yarn, or fabric to improve appearance, texture, or performance. Mechanical finishes can involve brushing, ironing or other physical treatments used to increase the luster and feel of textiles. Application of chemical finishes to textiles can impart a variety of properties ranging from decreasing static cling to increasing flame resistance. The most common chemical finishes are those that ease fabric care, such as the permanent-press, soil-release, and stain-resistant finishes. Chemical finishes are usually followed by drying, curing, and cooling steps. Application of chemical finishes are often done in conjunction with mechanical finishing steps (Snowden-Swan, 1995). Selected mechanical and chemical finishing techniques are described below.

Mechanical Treatments

- *Heatsetting.* Heatsetting is a dry process used to stabilize and impart textural properties to synthetic fabrics and fabrics containing high concentrations of synthetics. When manmade fibers are heatset, the cloth maintains its shape and size in subsequent finishing operations and is - stabilized in the form in which it is held during heatsetting (e.g., smooth, creased, uneven). Textural properties may include interesting and durable surface effects such as pleating, creasing, puckering, and embossing. Heatsetting can also give cloth resistance to wrinkling during wear and ease-of-care properties attributed to improvements in resiliency and in elasticity. Pollution outputs may include volatile components of spin finishes if heatsetting is performed before scouring and bleaching processes. These components are introduced to the fabrics during the manufacture of synthetic fibers, when proprietary spin finishes are applied to provide lubrication and impart special properties, such as antistatic, to the fiber.

- *Brushing and napping.* Brushing and napping decrease the luster of fabrics by roughening or raising the fiber surface and change the feel or texture of the fabric (ATMI, 1997b). These processes involve the use of wires or brushes that pull individual fibers.

- *Softening.* Calendering, or ironing, can be used to reduce surface friction between individual fibers, thereby softening the fabric structure and increasing its sheen. In calendering, the fabric passes through two or more rolls. Typically, one roll is made of chilled steel, while the other is made of a softer material like cotton fibers. The steel roll may also be heated using gas or steam. Once goods pass through the machine they are wound up at the back of the machine.

- *Optical finishing.* Luster can be added to yarns by flattening or smoothing the surfaces under pressure. This can be achieved by beating the fabric surface or passing the fabric between calendering rolls. The luster can be further increased if the rolls are scribed with closely spaced lines.

- *Shearing.* Shearing is a process that removes surface fibers by passing the fabric over a cutting blade.

- *Compacting.* Compacting, which includes the Sanforizing process, compresses the fabric structure to reduce stresses in the fabric. The Sanforizing process reduces residual shrinkage of fabrics after repeated laundering (Wingate, 1979). The fabric and backing blanket are fed between a roller and a curved braking shoe, with the blanket under tension. The tension on the blanket is released after the fabric and blanket pass the braking shoe. Compacting reduces the potential for excessive shrinkage during laundering.

Chemical Treatments

- *Optical finishes.* Optical finishes added to either brighten or deluster the textile.

- *Absorbent and soil release finishes.* These finishes that alter surface tension and other properties to increase water absorbency or improve soil release.

- *Softeners and abrasion-resistant finishes.* Softeners and abrasion-resistant finishes are added to improve feel or to increase the ability of the textile to resist abrasion and tearing.

- *Physical stabilization and crease-resistant finishes.* These finishes, which may include formaldehyde-based resin finishes, stabilize cellulosic fibers to laundering and shrinkage, imparting permanent press properties to fabrics (ATMI, 1997b).

III.A.4. Fabrication

Finished cloth is fabricated into a variety of apparel and household and industrial products. The simpler of these products, such as bags, sheets, towels, blankets, and draperies, often are produced by the textile mills themselves. Apparel and more complex housewares are usually fabricated by the cutting trades. Before cutting, fabrics must be carefully laid out. Accuracy in cutting the lay fabric is important since any defects created at this point may be carried through other operations and end up in the final product. For simple household and industrial products, sewing is relatively straightforward. The product may then be pressed to flatten the fabric and create crisp edges.

III.B. Raw Material Inputs and Pollution Outputs in the Production Line

Much of the following section is based upon *"Best Management Practices for Pollution Prevention in the Textile Industry,"* by the U.S. EPA Office of Research and Development. Additional references are cited in the text.

Wastewater

Wastewater is, by far, the largest wastestream for the textile industry. Large volume wastes include washwater from preparation and continuous dyeing, alkaline waste from preparation, and batch dye waste containing large amounts of salt, acid, or alkali. Primary sources of biological oxygen demand (BOD) include waste chemicals or batch dumps, starch sizing agents, knitting oils, and degradable surfactants. Wet processing operations, including preparation, dyeing, and finishing, generate the majority of textile wastewater.

Types of wastewater include cleaning water, process water, noncontact cooling water, and stormwater. The amount of water used varies widely in the industry, depending on the specific processes operated at the mill, the equipment used, and the prevailing management philosophy regarding water use. Because of the wide variety of process steps, textile wastewater typically contains a complex mixture of chemicals.

Desizing, or the process of removing size chemicals from textiles, is one of the industry's largest sources of wastewater pollutants. In this process, large quantities of size used in weaving processes are typically discarded. More than 90 percent of the size used by the U.S. textile industry, or 90,000 tons, is disposed of in the effluent stream. The remaining 10 percent is recycled (EPA, 1996). Desizing processes often contribute up to 50 percent of the BOD load in wastewater from wet processing (Snowden-Swan, 1995). Table 7 shows typical BOD loads from preparation processes.

Dyeing operations generate a large portion of the industry's total wastewater. The primary source of wastewater in dyeing operations is spent dyebath and washwater. Such wastewater typically contains by-products, residual dye, and auxiliary chemicals. Additional pollutants include cleaning solvents, such as oxalic acid.

Of the 700,000 tons of dyes produced annually worldwide, about 10 to 15 percent of the dye is disposed of in effluent from dyeing operations (Snowden-Swan, 1995). However, dyes in wastewater may be chemically bound to fabric fibers (ATMI, 1997b). The average wastewater generation from a dyeing facility is estimated at between one and two million gallons per day. Dyeing and rinsing processes for disperse dyeing generate about 12 to 17 gallons of wastewater per pound of product. Similar processes for reactive and direct dyeing generate even more wastewater, about 15 to 20 gallons per pound of product (Snowden-Swan, 1995).

Table 7: Typical BOD Loads from Preparation Processes

Process	Pounds of BOD per 1,000 Pounds of Production
Singeing	0
Desizing	
starch	67
starch, mixed size	20
PVA or CMC	0
Scouring	40-50
Bleaching	
peroxide	3-4
hypochlorite	8
Mercerizing	15
Heatsetting	0

Source: *Best Management Practices for Pollution Prevention in the Textile Industry*, EPA, Office of Research and Development, 1995.
PVA = polyvinyl alcohol; CMC = carboxymethyl cellulose

Finishing processes typically generate wastewater containing natural and synthetic polymers and a range of other potentially toxic substances (Snowden-Swan, 1995). Pollution from peroxide bleaching normally is not a major concern. In most cases, scouring has removed impurities in the goods, so the only by-product of the peroxide reaction is water. The major pollution issues in the bleaching process are chemical handling, water conservation, and high pH.

Hazardous waste generated by textile manufacturers results primarily from the use of solvents in cleaning knit goods (ATMI, 1997b). Solvents may be used in some scouring or equipment cleaning operations, however, more often scouring processes are aqueous-based and cleaning materials involve mineral spirits or other chemicals (ATMI, 1997b). Spent solvents may include tetrachloroethylene and trichloroethylene (NC DEHNR, P2 Pays, 1985). A few of the more common textile industry water pollutants and their sources are discussed below. In addition, Table 8 summarizes the typical pollutant releases associated with various textile manufacturing processes.

Color

Dyes and pigments from printing and dyeing operations are the principal sources of color in textile effluent (EPA, 1996). Dyes and pigments are highly colored materials used in relatively small quantities (a few percent or less of the weight of the substrate) to impart color to textile materials for aesthetic or functional purposes. In typical dyeing and printing processes, 50 to 100 percent of the color is fixed on the fiber, as shown in Table 6. The remainder is discarded in the form of spent dyebaths or in wastewater from subsequent textile-washing operations (EPA, 1996).

Salts

Several authors have identified salts in textile-dyeing wastewater as a potential problem area (US EPA, 1996). Many types of salt are either used as raw materials or produced as by-products of neutralization or other reactions in textile wet processes. Salt is used mostly to assist the exhaustion of ionic dyes, particularly anionic dyes, such as direct and fiber reactive dyes on cotton. Typical cotton batch dyeing operations use quantities of salt that range from 20 percent to 80 percent of the weight of goods dyed, and the usual salt concentration in such wastewater is 2,000 ppm to 3,000 ppm. According to one study, a moderate-sized mill that dyed about 400,000 pounds per week of cotton knit fabrics produced well over 50,000 pounds of salts and a pH of over 10 (US EPA, 1996). The wastewater from this facility contained neutralization salts from six acids and alkalis of 60 ppm. Common salt (sodium chloride) and Glaubers salt (sodium sulfate) constitute the majority of total salt use. Other salts used as raw materials or formed in textile processes include Epsom salt (magnesium chloride), potassium chloride, and others in low concentrations.

Table 8: Summary of Potential Releases Emitted During Textiles Manufacturing

Process	Air Emissions	Wastewater	Residual Wastes
Fiber preparation	little or no air emissions generated	little or no wastewater generated	fiber waste; packaging waste and hard waste
Yarn spinning	little or no air emissions generated	little or no wastewater generated	packaging wastes; sized yarn; fiber waste; cleaning and processing waste
Slashing/sizing	VOCs	BOD; COD; metals; cleaning waste, size	fiber lint; yarn waste; packaging waste; unused starch-based sizes;
Weaving	little or no air emissions generated	little or no wastewater generated	packaging waste; yarn and fabric scraps; off-spec fabric; used oil
Knitting	little or no air emissions generated	little or no wastewater generated	packaging waste; yarn and fabric scraps; off-spec fabric
Tufting	little or no air emissions generated	little or no wastewater generated	packaging waste; yarn and fabric scraps; off-spec fabric
Desizing	VOCs from glycol ethers	BOD from water-soluble sizes; synthetic size; lubricants; biocides; anti-static compounds	packaging waste; fiber lint; yarn waste; cleaning materials, such as wipes, rags, and filters; cleaning and maintenance wastes containing solvents
Scouring	VOCs from glycol ethers and scouring solvents	disinfectants and insecticide residues; NaOH; detergents, fats; oils; pectin; wax; knitting lubricants; spin finishes; spent solvents	little or no residual waste generated
Bleaching	little or no air emissions generated	hydrogen peroxide, sodium silicate or organic stabilizer; high pH	little or no residual waste generated
Singeing	small amounts of exhaust gases from the burners	little or no wastewater generated	little or no residual waste generated
Mercerizing	little or no air emissions generated	high pH; NaOH	little or no residual waste generated

Table 8: Summary of Potential Releases Emitted During Textiles Manufacturing			
Process	**Air Emissions**	**Wastewater**	**Residual Wastes**
Heatsetting	volatilization of spin finish agents applied during synthetic fiber manufacture	little or no wastewater generated	little or no residual waste generated
Dyeing (see Table 6 for pollutants associated with particular dye classes)	VOCs	metals; salt; surfactants; toxics; organic processing assistants; cationic materials; color; BOD; COD; sulfide; acidity/ alkalinity; spent solvents	little or no residual waste generated
Printing	solvents, acetic acid from drying and curing oven emissions; combustion gases; particulate matter	suspended solids; urea; solvents; color; metals; heat; BOD; foam	little or no residual waste generated
Finishing	VOCs; contaminants in purchased chemicals; formaldehyde vapors; combustion gases; particulate matter	BOD; COD; suspended solids; toxics; spent solvents	fabric scraps and trimmings; packaging waste
Product Fabrication	little or no air emissions generated	little or no wastewater generated	fabric scraps
Source: *Best Management Practices for Pollution Prevention in the Textile Industry*, EPA, Office of Research and Development, 1995; ATMI, Comments on draft document, 1997b.			

Regulatory limits imposed on textile facilities and on publicly owned treatment facilities (POTWs) that receive textile wastewater start at 250 ppm. Although the mammalian and aquatic toxicities of these salts are very low, their massive use in certain textile-dyeing processes can produce wastewater with salt levels well above the regulatory limits.

Metals

Many textile mills have few or no metals in their effluent, but whenever metals are present, they may include metals such as copper, cadmium, chromium, nickel, and zinc. Sources of metals found in textile mill effluents may include fiber, incoming water, dyes, plumbing, and chemical impurities. Dyes may contain metals such as zinc, nickel, chromium, and cobalt (ATMI, 1997b). In some dyes, these metals are functional (i.e., they form an integral part of the dye molecule); however, in most dyes, metals are simply impurities generated during dye manufacture. For example, mercury or other metals may be used as catalysts in the manufacture of certain dyes and may be present as by-products. Metals may be difficult to remove from wastewater (EPA, 1996).

Aquatic Toxicity

The aquatic toxicity of textile industry wastewater varies considerably among production facilities. Data are available that show that the wastewater of some facilities has fairly high aquatic toxicity, while others show little or no toxicity. The sources of aquatic toxicity can include salt, surfactants, ionic metals and their complexed metals therein, toxic organic chemicals, biocides, and toxic anions (EPA, 1996; ATMI, 1997b). Most textile dyes have low aquatic toxicity. On the other hand, surfactants and related compounds, such as detergents, emulsifiers, dispersants, are used in almost every textile process and can be an important contributor to effluent aquatic toxicity, BOD, and foaming (EPA, 1996).

Air Emissions

Although the textile industry is a relatively minor source of air pollutants compared with many other industries, the industry emits a wide variety of air pollutants, making sampling, analysis, treatment, and prevention more complex. Textile operations involve numerous sources of air emissions. Operations that represent the greatest concern are coating, finishing, and dyeing operations. Textile mills usually generate nitrogen and sulfur oxides from boilers and are often classified as "major sources" under the Clean Air Act (EPA, 1996).

Other significant sources of air emissions in textile operations include resin finishing and drying operations, printing, dyeing, fabric preparation, and wastewater treatment plants (ATMI, 1997b). Hydrocarbons are emitted from drying ovens and, in particular, from mineral oil from high-temperature (200°C) drying/curing. These processes can emit formaldehyde, acids, softeners, and other volatile compounds. Residues from fiber preparation sometimes emit pollutants during heatsetting processes.

Carriers and solvents may be emitted during dyeing operations depending on the types of dyeing processes used and from wastewater treatment plant operations. Carriers used in batch dyeing of disperse dyes may lead to volatilization of aqueous chemical emulsions during heatsetting, drying, or curing stages. Acetic acid and formaldehyde are two major emissions of concern in textiles. Other potential pollutants can include solvent vapors containing toxic compounds such as acetaldehyde, chlorofluorocarbons, p-dichlorobenzene, ethyl acetate, and others. Some process chemicals, such as methyl naphthalene or chlorotoluene, may exhaust into the fibers and are later emitted from dryers as VOCs (EPA, 1996). Formaldehyde might be emitted from bulk resin storage tanks, finished fabric warehouses, driers, and curing ovens located at facilities that apply formaldehyde-containing resins to cotton and polyester/cotton blends (ATMI, 1997b). ATMI estimates that the majority of resin finishing plants emit less than one ton per year of formaldehyde from storage tanks, fabric, off-gassing.

Textile manufacturing can produce oil and acid fumes, plasticizers, and other volatile chemicals. Acetic acid emissions may arise from storage tanks, especially from vents during filling. Carbonizing processes, used in wool yarn manufacture, may emit sulfuric acid fumes and decating, a finishing process applied to wool fabrics to set the nap and develop luster, produces formic acid fumes. In addition, cleaning and scouring chemicals were estimated at 10,500 metric tons in 1988 (EPA, 1996).

Other Wastes

The primary residual wastes generated from the textile industry are nonhazardous. These include fabric and yarn scrap, off-spec yarn and fabric, and packaging waste. Cutting room waste generates a high volume of fabric scrap that can be reduced by increasing fabric utilization efficiency in cutting and sewing. Typical efficiency for using fabric averages from 72 to 94 percent. As a result, fabrication waste from carpets amounts to about 2 percent of an annual 900 million square yards of production (a value of $100 million). Denim cutting waste accounts for approximately 16 percent of denim production, or 100 million pounds annually.

Although a large portion of cutting waste goes to landfill, some innovative programs being implemented to recycle this material. Some facilities collect cotton lint for resale. Cotton trash, leaves, and stems collected during the yarn formation have been sold to farmers as animal feed.

A materials flow sheet is shown in Figure 12 and summarizes raw materials input and waste output generated during the manufacture of a cotton knit golf shirt.

Figure 12: Materials Flow for a Cotton Knit Golf Shirt

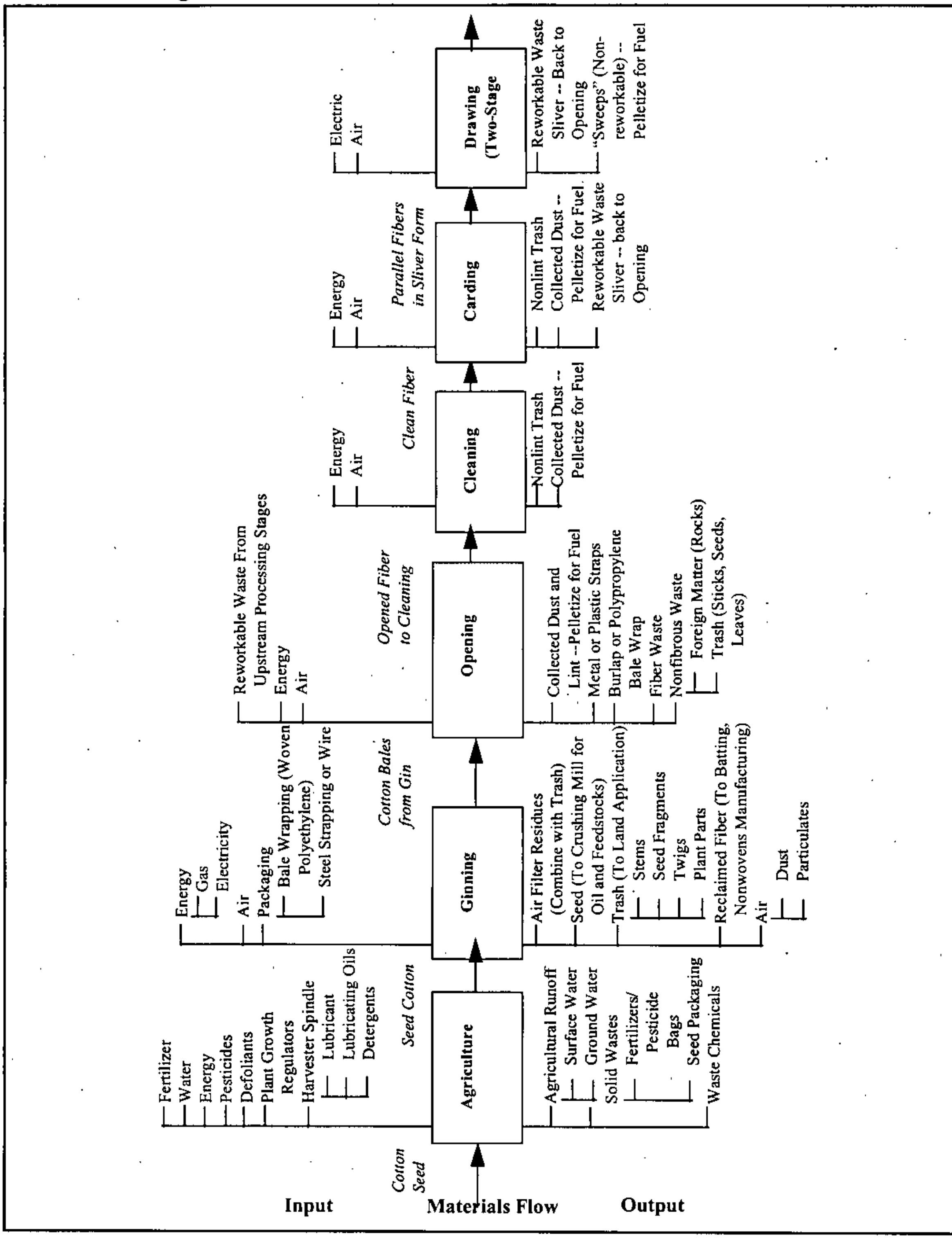


Figure 12 (cont.): Materials Flow for a Cotton Knit Golf Shirt

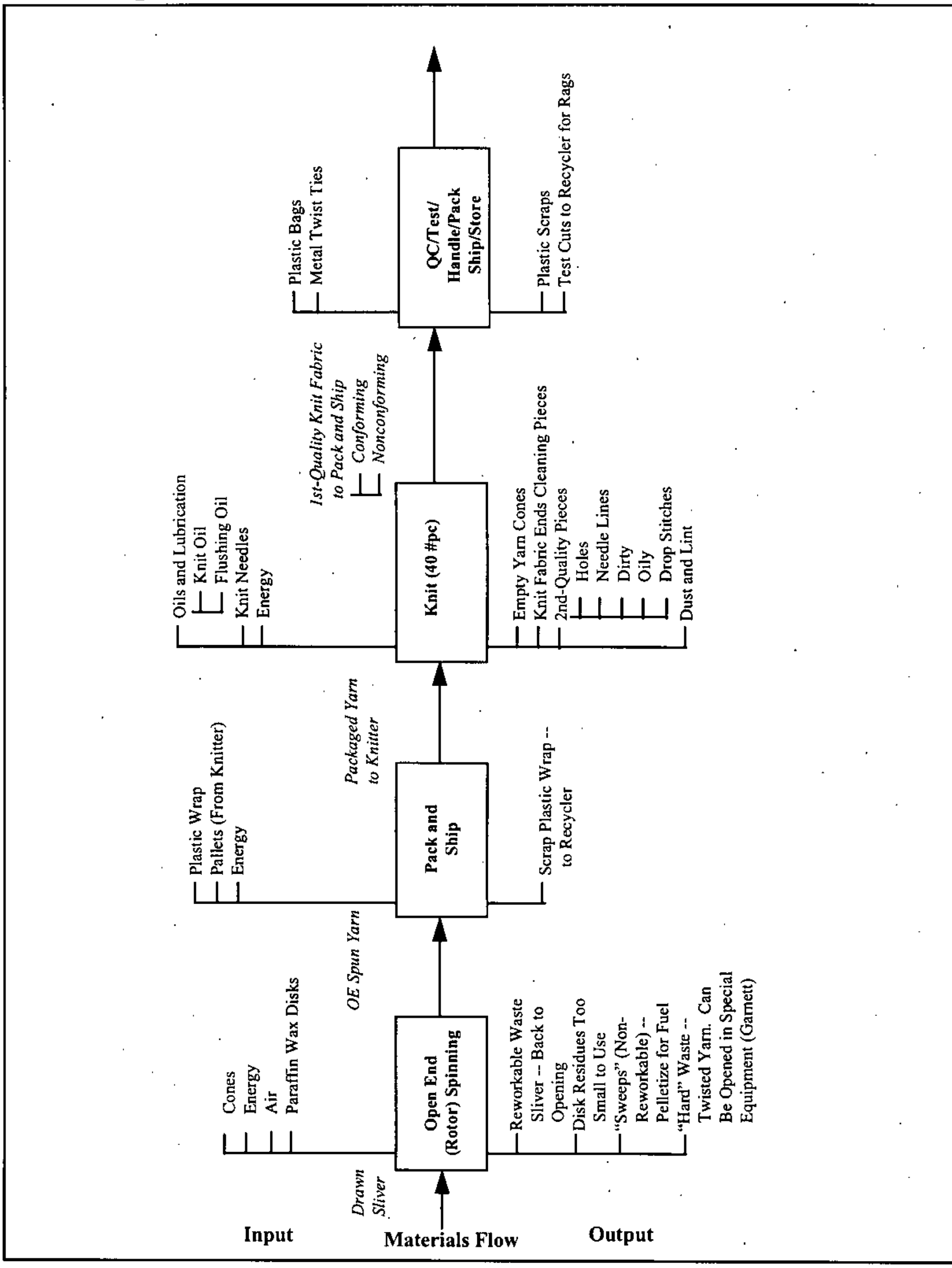


Figure 12 (cont.): Materials Flow for a Cotton Knit Golf Shirt

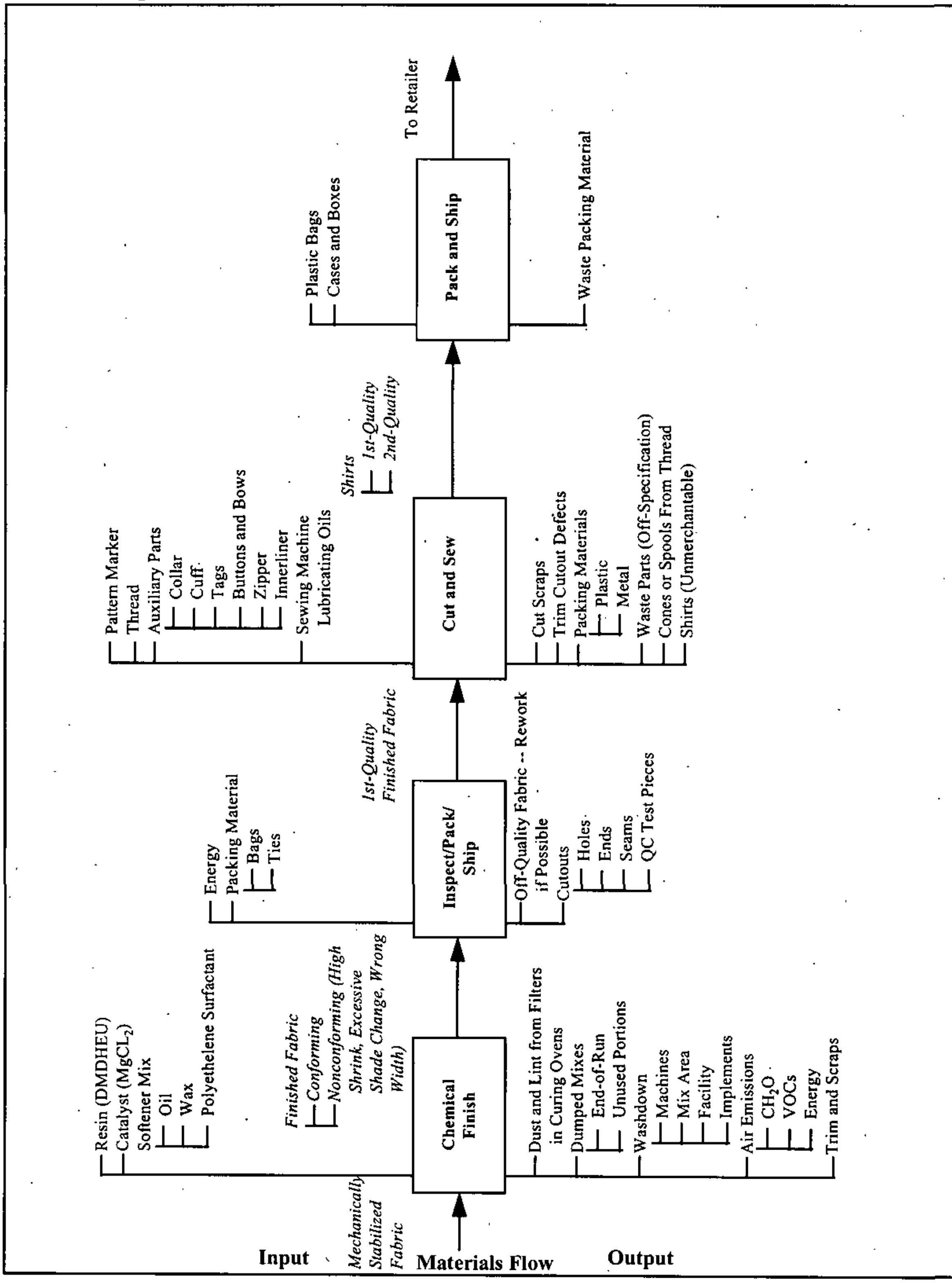
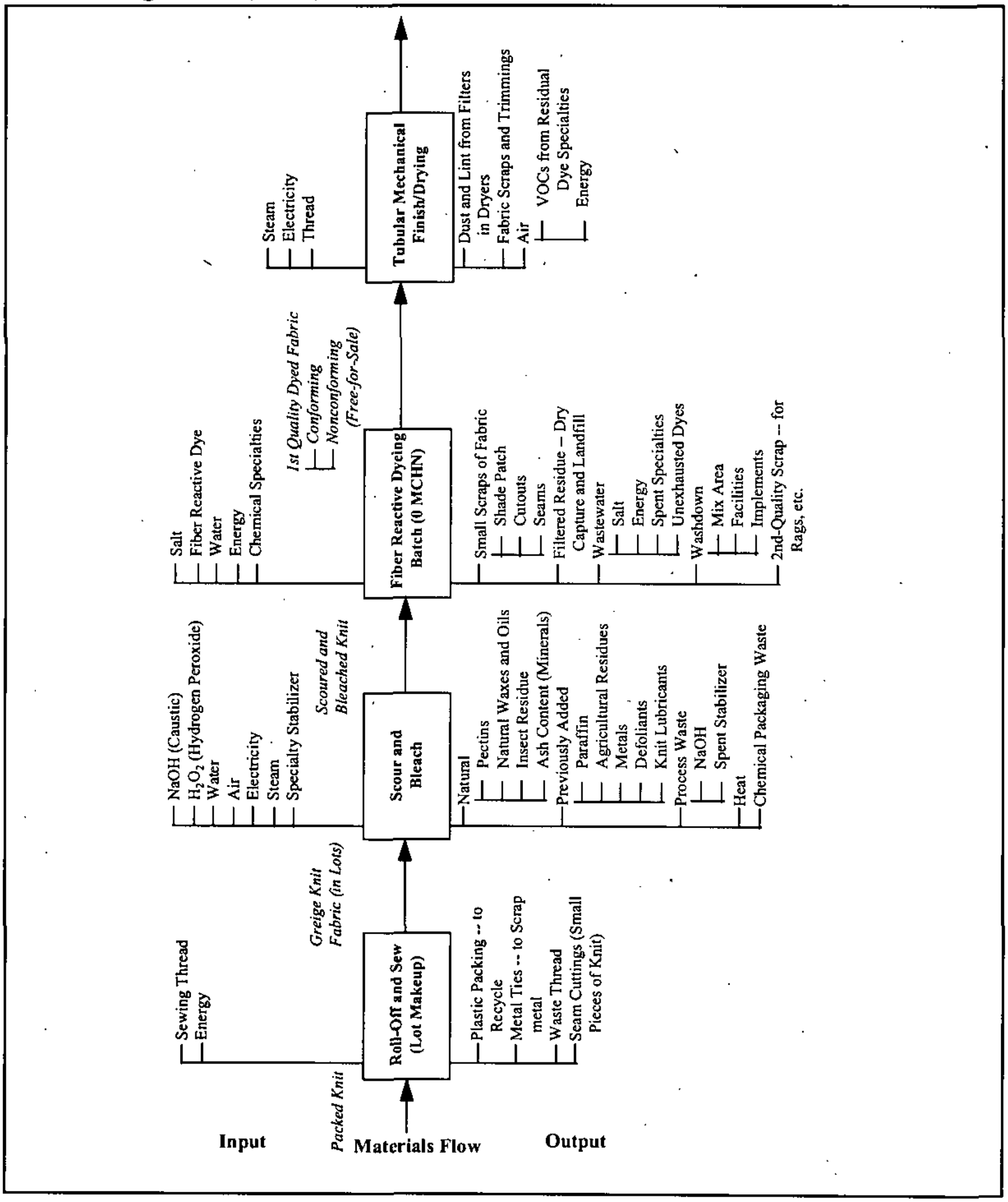


Figure 12 (cont.): Materials Flow for a Cotton Knit Golf Shirt



Source: *Best Management Practices for Pollution Prevention in the Textile Industry,* EPA, Office of Research and Development, 1995

III.C. Management of Chemicals in the Production Process

The Pollution Prevention Act of 1990 (PPA) requires facilities to report information about the management of Toxics Release Inventory (TRI) chemicals in waste and efforts made to eliminate or reduce those quantities. These data have been collected annually in Section 8 of the TRI reporting Form R beginning with the 1991 reporting year. The data summarized below cover the years 1994-1997 and is meant to provide a basic understanding of the quantities of waste handled by the industry, the methods typically used to manage this waste, and recent trends in these methods. TRI waste management data can be used to assess trends in source reduction within individual industries and facilities, and for specific TRI chemicals. This information could then be used as a tool in identifying opportunities for pollution prevention compliance assistance activities. Background information on TRI and its limitations is presented in Section IV.

While the quantities reported for 1994 and 1995 are estimates of quantities already managed, the quantities reported for 1996 and 1997 are projections only. The PPA requires these projections to encourage facilities to consider future waste generation and source reduction of those quantities as well as movement up the waste management hierarchy. Future-year estimates are not commitments that facilities reporting under TRI are required to meet.

Table 9 shows that the TRI reporting textiles facilities managed about 57.6 million pounds of production related wastes (total quantity of TRI chemicals in the waste from routine production operations in column B) in 1995. From the yearly data in column B, it is apparent that the total quantities of production related TRI wastes increased by less than one percent between 1994 and 1995 and are projected to decrease by five percent between 1995 and 1997. Values in column C are intended to reveal the percentage of TRI chemicals that are either transferred off-site or released to the environment. Column C is calculated by dividing the total TRI transfers and releases (reported in Sections 5 and 6 of the TRI Form R) by the total quantity of production-related waste (reported in Section 8). The textile industry is expected to lower the percentage of TRI chemicals transferred off-site or released to the environment by six percent between 1995 and 1997.

The data indicate that about 57 percent of the TRI wastes were managed onsite through recycling, energy recovery, or treatment (columns D, E, and F, respectively) in 1995. About 11 percent of the wastes were managed off-site. The remaining portion of TRI chemical wastes (about 33 percent), shown in column J, were released to the environment through direct discharges to air, land, water, and underground injection, or were disposed off-site. The overall portion of wastes managed onsite (columns G, H, and I) is expected to increase by five percent between 1995 and 1996 and eight percent between 1995 and 1997. The overall portion of wastes managed off-site (columns D, E, and F) change very little from year to year.

Table 9: Source Reduction and Recycling Activity for the Textile Industry (SIC 22) as Reported within TRI

A	B	C	On-Site			Off-Site			J
			D	E	F	G	H	I	
Year	Quantity of Production-Related Waste (10[6] lbs.)[a]	% Released and Transferred[b]	% Recycled	% Energy Recovery	% Treated	% Recycled	% Energy Recovery	% Treated	% Released and Disposed Off-Site[c]
1994	57.1	7.7	23.6%	7.2%	24.0%	1.4%	3.1%	6.0%	34.9%
1995	57.6	43.0	18.6%	8.6%	30.0%	1.4%	3.6%	6.2%	33.0%
1996	55.2	N/A	21.6%	9.0%	31.2%	1.8%	2.6%	5.4%	28.3%
1997	54.5	N/A	22.3%	9.6%	30.8%	2.9%	2.3%	5.4%	26.9%

Source: *Toxics Release Inventory Database, 1995.*

[a] Within this industry sector, non-production related waste was < 1% of production related wastes for 1995.

[b] Total TRI transfers and releases as reported in Section 5 and 6 of Form R as a percentage of production related wastes.

[c] Percentage of production related waste released to the environment and transferred off-site for disposal.