Energy

CONSERVATION

THE U. S. TEXTILE INDUSTRY: AN ENERGY PERSPECTIVE

By
Joseph S. Badin
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January 1988

Work Performed Under Contract No. AC06-76RL01830

For
U. S. Department of Energy
Office of Industrial Programs
Washington, D.C.

By
Energetics, Incorporated
Columbia, Maryland

MASTER

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ABSTRACT

This report investigates the state of the U.S. textile industry in terms of energy consumption and conservation. The specific objectives were:

- o To update and verify energy and materials consumption data at the various process levels in 1984;
- o To determine the potential energy savings attainable with current (1984), state-of-the-art, and future production practices and technologies (2010); and
- o To identify new areas of research and development opportunity that will enable these potential future savings to be achieved.

The results of this study concluded that in the year 2010, there is a potential to save between 34% and 53% of the energy used in current production practices, dependent on the projected technology mix. R&D needs and opportunities were identified for the industry in three categories: process modification, basic research, and improved housekeeping practices that reduce energy consumption. Potential R&D candidates for DOE involvement with the private sector were assessed and selected from the identified list.

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We express our thanks to the American Textile Manufacturers Institute Inc. (ATMI) who provided the expertise related to the economics, structure of and conditions in the textile industry. We thank the American Textile Machinery Association (ATMA) who provided us access to their member companies. We would also like to thank Ms. Nancy Moore of Pacific Northwest Laboratory for her guidance throughout the study. In addition, we would like to acknowledge the contributions of S.A. Azimi of Energetics.

During the course of the study we contacted many individuals within industry and other associations. Where appropriate we have made reference to these contacts within the report. Frequently, however, because of the study's emphasis on future developments with comparative assessments of new technology, information given to us was of a confidential nature or was supplied to us with the understanding that it was not to be credited. Therefore, we extend a general thanks to all those participants for their interest in and contribution to this study.

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SUMMARY

In July of 1985 Pacific Northwest Laboratory awarded Energetics, Inc. (EI) a contract to investigate the state of the U.S. textile industry in terms of energy consumption and conservation. The specific objectives of this effort were:

- o To update and verify energy and materials consumption data at the various process levels;
- o To determine the potential energy savings attainable with current, state-of-the-art, and future production practices and technologies; and
- o To identify new areas of research and development opportunity that will enable these potential future savings to be achieved.

The basic organization of the study of the U.S. textile industry is shown in Figure 1 and the results of the investigation are summarized below.

The U.S. textile industry (SIC 22) accounts for one out of every eight manufacturing jobs, making it the largest industrial employer in the U.S. However, over the past decade, increasing imports and adoption of technical innovations have significantly impacted the industry. Shipments of fabrics from abroad doubled between 1974 and 1984; imports took nearly 23% of the U.S. textile market in 1985. Technical innovations have increased labor productivity by 5% per year between 1976 and 1984, enabling the industry's domestic production to increase by 7% between 1980 and 1984 while at the same time reducing it's employment by 10%. While the value of industry shipments

FIGURE 1: REPORT ORGANIZATION

had a fairly consistent growth rate during the years 1974 through 1984, the total mill fiber consumption did not grow by any appreciable amount during the same time period. Table 1 presents selected industry data.

Table 1: Selected Textile Industry (SIC 22) Data

	<u>Total Shipments</u>	<u>Imports</u> (millions of dollars)	<u>New Capital Expenditures</u> (dollars)	<u>Employment</u> (thousands)	<u>Productivity Index</u> (1977=100)
1974	32,791	1,752	1,060	965	78.3
1975	31,065	1,336	860	868	82.5
1976	36,387	1,791	980	919	87.8
1977	40,558	1,939	1,180	910	100.0
1978	42,324	2,400	1,310	899	102.4
1979	45,141	2,399	1,420	885	105.8
1980	47,280	2,676	1,540	848	106.8
1981	50,275	3,250	1,660	823	110.3
1982	47,159	3,000	1,460	749	121.9
1983	52,203	3,460	1,550	741	125.3
1984	55,054	4,874	1,920	746	128.0
1985	52,617	5,274	1,840	703	n.a.

Source: ATMI Hi-Lites, December 1985

n.a.: not available

The U.S. textile industry is an old and established sector of the economy which has very conservative views regarding expenditures on facilities and equipment not directly related to the product; however, over the past decade the new capital expenditures have climbed fairly steadily. Capital expenditures in 1985 were \$1.84 billion compared to \$860 million in 1975. During this same time period, the ratio of new capital expenditures to the total value of shipments increased from 2.7% to 3.5%, (see Table 1), indicating that the industry is striving to stay competitive through an increased equipment modernization effort.

The textile industry is among the top ten energy consuming industries in the U.S. Its 1984 energy consumption was 0.46 quads, less than 2 percent of the total energy consumed by all U.S. manufacturing industries. However, energy consumption and management is more of a critical parameter for the

textile industry since energy costs average about 3 percent of the value of shipments. Therefore, energy represents a slightly greater expense for the textile industry than it does for many of the other manufacturing industries. Energy costs average approximately 8 percent of the value added by manufacture and can be as high as 25 percent of total production costs for the textile mills.

The figures for energy consumed in production, as stated in this report are based on an energy intensity of 10,500 Btu/kWh-electric as opposed to the direct conversion factor of 3,412 Btu/kWh-thermal. This presents a more realistic picture of the industry's actual energy consumption.

A downward trend in both total and specific energy consumption for the industry has been observed from 1974 through 1984 (see Table 2). The total annual energy consumption was reduced by 12 percent for an annual equivalent of 54 trillion Btu saved during from 1974 through 1984. This reduction in total annual energy consumption is mainly due to the adoption of new conservation measures. Some of the more important conservation measures recently implemented by the textile industry are listed below:

- o Boiler upgrades, improved insulation and maintenance,
- o Computerization,
- o Batch dyeing improvements,
- o Foam finishing and controlling wet pick-up,
- o Oven exhaust heat recovery,
- o High efficiency motors,
- o Combined preparation lines,
- o Efficient HVAC (Heating, Ventilating and Air Conditioning) units,
and
- o Controlling lighting levels.

**TABLE 2: Textile Industry (SIC 22)
Energy Consumption History**

<u>Year</u>	<u>Total Energy Used During Production (trillion Btu)*</u>	<u>Mill Fiber Consumption (10⁶ pounds)</u>	<u>Specific Energy Consumption (Btu/lb of fiber)</u>
1974	515.3	10,778.4	47,809.
1975	495.0	10,260.6	48,243.
1976	527.2	11,189.9	47,114.
1977	534.9	11,515.2	46,452.
1978	517.3	11,650.8	44,400.
1979	502.9	11,891.1	42,292.
1980	477.3	11,223.3	42,528.
1981	473.7	10,715.8	44,206.
1982	432.1	9,378.8	46,072.
1983	472.3	11,122.4	42,464.
1984	461.2	10,816.2	42,643.

*Based on an energy intensity factor of 10,500 Btu/kWh_e to account for electrical losses.

Specific Energy Consumption includes both production and support operations.
"Annual Survey of Manufacturers: Fuels and Electric Energy Consumed", USDOC

This investigation of the U.S. textile industry included a quantitative analysis of the potential energy impacts of both the state-of-the-art and the new, undeveloped (advanced) technologies, in the year 2010. A projected estimate of the production level and mix in the year 2010 was assumed for each of the following scenarios:

- 1) 100 percent production by current (1984) practices.
- 2) 100 percent production by state-of-the-art technology.
- 3) Production technology mix of 90 percent state-of-the-art technology and 10 percent advanced technology (Technology Mix 1).
- 4) Production technology mix of 50 percent state-of-the-art technology and 50 percent advanced technology (Technology Mix 2).
- 5) 100 percent production by advanced technology.

The results of the analysis (See Table 3) indicate that relative to projected energy use, significant reductions in the energy consumption requirements of the industry are possible.

**Table 3: Comparison of Potential Energy Savings
of Several Technology Mixes
In The Year 2010**

Projected Energy Use 0.541 Quads (current practices)

Technology Mix	Potential Energy Savings		Achievability
	(Quads)	(%)	
100% state-of-the-art	0.186	34%	Good
90% state-of-the-art/10% advanced	0.197	36%	Likely
50% state-of-the-art/50% advanced	0.237	44%	Possible
100% advanced	0.288	53%	Less Likely

The R&D needs and opportunities of the U.S. textile industry were assessed based on perceived future textile manufacturing practices. The textile industry can benefit from process modifications, basic research, and improved housekeeping practices that reduce energy consumption. The following R&D needs and opportunities have been determined to be appropriate as potential candidates for DOE involvement with the private sector. The most significant areas that were identified are listed in order of importance:

Process Modifications

- o More research in slashing - reducing heat required in the size application and removal,
- o Tenterframe exhaust heat recovery: cleaning techniques for, or prevention of lint fouling of heat exchanger tubes,

- o Research to improve friction spinning in order to produce commercial quality yarns,
- o Optimize spinning process in order to eliminate the drawing process,
- o Develop xerographic printing,
- o Study to make hot melt sizing more versatile or applicable to more varieties of fabrics,
- o Investigation of radio frequency dye fixation and drying,
- o Research in solvent processing in scouring and bleaching.

Basic Research

- o Quantification study of benefits of ion control systems in dry processing (HVAC reduction),
- o Further research in all types of low wet pick-up dyeing and finishing,
- o Development of automated spinning machinery that can detect, locate and repair fiber defects, breaks and knots on line,
- o Research in room temperature (ambient) dyeing processes,
- o Sensor/bath sampling technology (e.g., pH sensors, near infrared dye analyzer, automatic sampling)
- o Study of solid-on-solid processing,
- o Study of chiller optimization for HVAC reduction,

- o Study of wet-on-wet processing for the dyeing and finishing of fabrics,
- o Research in vapor-phase transfer printing of disperse dyes from paper to cloth which require no pre- or after-treatments,
- o Development of electrostatic techniques to be applied to spinning, chemical application, and waste removal.

Improved Housekeeping

- o More research necessary in dust control in dry processing,
- o Computer modeling of the plant's HVAC system.

SECTION 1. INTRODUCTION

1.1 INDUSTRY PERSPECTIVE

The textile industry, as categorized under SIC 22, performs the industrial processes necessary to transform raw materials such as cotton, wool, and synthetic fibers into yarn and finished fabrics. Products of textile mills are primarily the fabrics which other industries convert into apparel (SIC 23) or into household products, the most notable being floor coverings (carpets and rugs), or into commercial or industrial products.

Figure 1.1 depicts the major segments and linkages of the textile industry, from fiber production through to the final stage, consumer end use. The Textile Mill portion of the textile complex which includes yarn production, fabric production, dyeing and finishing processes is the subject of this study.

Figure 1.1: The Textile Industry

The United States textile industry is mainly centered in the Southeast, primarily in the states of North Carolina, South Carolina, and Georgia, and consists of both large, fully-integrated companies and small (often family owned), plants which perform only a few process operations; many are the primary employers in their communities. Facilities are scattered, and many of the plants were built during the development of the industry in the early 1900s.

The U.S. textile industry is among the old and established sectors of the economy. Firms in the industry tend to be relatively conservative from the standpoint of expenditures on facilities and equipment not directly related to product. In the absence of unusual or disturbing technological influences, they cannot be expected to be especially fast growing; however, they must respond rapidly to changes in fashion.

The U.S. Textile industry's contribution to the gross national product in 1984 was in excess of \$48 billion, compared with \$51 billion for the automotive industry, \$43.1 billion for primary metals and \$31.6 billion for petroleum refining in the same year. The textile industry accounts for one of every eight manufacturing jobs, making it the largest industrial employer in the United States. Thus, the direct and indirect impacts of the U.S. textile industry on the national economy are substantial. As shown in Table 1.1 the value of industry shipments in dollars had a fairly consistent growth rate during the years of 1975 through 1981. The U.S. economic recession impacted the textile industry in 1982, but by the end of 1983, total shipments rose above its pre-recession level. Industry shipments grew by 5.5 percent in 1984, reaching \$55 billion. In 1985, industry shipments returned to approximately the 1983 value, falling to \$52.6 billion, and inventories are considerably leaner than a few years ago when sales began to slide.

TABLE 1.1: TEXTILE SHIPMENTS¹ AND INVENTORIES

	TOTAL SHIPMENTS MILLION \$	MONTHLY AVERAGE INVENTORIES MILLION \$	ANNUAL INVENTORY TURNOVER RATE	AVERAGE MONTHLY INVENTORY/ SHIPMENTS RATIOS
1974	32,791	4,918	6.67	1.80
1975	31,065	4,676	6.64	1.80
1976	36,387	5,104	7.13	1.67
1977	40,558	5,524	7.34	1.63
1978	42,324	5,806	7.29	1.65
1979	45,141	6,005	7.52	1.60
1980	47,280	6,413	7.37	1.63
1981	50,275	6,838	7.35	1.63
1982	47,159	6,389	7.38	1.63
1983	52,203	6,547	7.97	1.50
1984	55,054	7,180	7.67	1.56
1985	52,617	6,772	7.77	1.54

¹ Includes interplant transfers as well as value of shipments.

Source: ATMI Hi-Lites, December 1985.

Fiber consumption for 1985 of 11.1 billion pounds was 3.0 percent higher than the 1984 level (See Table 1.2). Cotton consumption has increased 3.3 percent ahead of 1984 while man-made fiber consumption was also up 3.3 percent over a year ago. Mill wool consumption which experienced strong growth through 1983 and 1984 suffered major setbacks through 1985, falling 16.9 percent below the 1984 level.

Despite the increase in the value of total shipments over the last decade (see Table 1.1) the total mill fiber consumption, a close estimate for production, did not grow by any appreciable amount during the same time period. This is a clear indication of the stagnation of the domestic industry and the competition provided by the imports. The shifts and changes in the share of the three major fiber types are primarily attributed to market demand and consumer preference.

TABLE 1.2: TOTAL FIBER CONSUMPTION BY U.S. TEXTILE MILLS

PERIOD	TOTAL MILL CONSUMPTION	COTTON	MAN-MADE FIBERS	WOOL
(million pounds)				
1974	10,778.4	3,309.0	7,376.4	93.0
1975	10,260.6	3,206.7	7,123.4	110.5
1976	11,189.9	3,419.3	7,648.9	121.7
1977	11,515.2	3,169.9	8,237.2	108.1
1978	11,650.8	3,040.8	8,494.7	115.3
1979	11,891.1	3,077.2	8,696.9	117.0
1980	11,223.3	3,036.4	8,063.5	123.4
1981	10,715.8	2,715.5	7,862.0	138.3
1982	9,378.8	2,487.9	6,775.2	115.7
1983	11,122.4	2,807.9	8,173.9	140.6
1984	10,816.2	2,716.1	7,958.0	142.1
1985	11,141.5	2,805.7	8,217.7	118.1

Compiled by the U.S. Department of Agriculture, Economic Research Service.

The stagnation in the total mill fiber consumption by the U.S. textile industry is very significant in light of world competition and the growing market demand. Internationally, both consumption and production have increased significantly in developing nations, often at the expense of developed countries. This phenomenon has sharply spurred the level and intensity of global competition in the textile industry and this is expected to continue to increase in the future. The development and widespread use of new technology has accelerated competition. A major result has been increasing capital intensity levels in the face of higher risks and costs of new product and process development. This increased international competitiveness has caused calls for government intervention and trade barriers in order to preserve domestic employment.

Historically, the key factors of production have been energy, raw materials, the manufacturing equipment, the skill of the technical staff, the capital necessary to buy the machinery and the funds to employ the skilled operators and maintenance staff.

In the U.S., the textile industry has continuously modernized its equipment in order to ward off international competition. Table 1.3 provides recent information on the new capital expenditures and productivity of the U.S. textile industry. Over the past decade, new capital expenditures have been climbing fairly steadily. For example, actual capital expenditures in 1985 of 1.84 billion dollars more than doubled the non-adjusted 1975 figure of only 860 million dollars. Over this same time period, the ratio of new capital expenditures to the total value of shipments increased from 2.7 percent to 3.5 percent.

The productivity index for the textile industry has also been continuously higher than that of the total manufacturing industries since 1977, which is an indication of the effects of the textile mills' utilization of more modern equipment. Furthermore, the textile mills productivity growth rate has been significantly higher than that of the total manufacturing industries. Given these factors, one might expect the industry to have experienced a large market expansion, however, the market volume remained relatively stable at the 1983-1984 levels of \$2.4 billion (see Table 1.4). Shipments of fabrics from abroad doubled between 1976 and 1984, with most of the increase coming in the past two years. Imports took nearly 23 percent of the U.S. textile market in 1985, double the 1979 level.

To stay competitive and profitable, the following business trends and tactics have evolved in the textile industry:

- o Concentration of companies to achieve growth in areas where foreign competition is weak.
- o Development of more specialized product lines and market segments.
- o Greater use of advanced and more efficient technologies.
- o Consolidation through mergers in order to amass the capital necessary for major technology infusion.
- o Obtaining the leverage to enlist the retail industry in its cause.
- o Development of stronger markets for exports.
- o Using the quick response strategy which take advantage of the American producers' proximity to the markets and advanced

TABLE 1.3: NEW CAPITAL EXPENDITURES AND PRODUCTIVITY

Period	New Capital Expenditures		Productivity Indexes (1977 = 100)		
	Manufacturing Industries (Millions of Dollars)	Textile Mill Products	Total Manufacturing	Textile Mill Products	Apparel Products
1974	52,480	1,060	90.8	78.3	91.3
1975	53,660	860	93.4	82.5	97.6
1976	58,530	980	97.6	87.8	95.8
1977	57,480	1,180	100.0	100.0	100.0
1978	78,580	1,310	100.9	102.4	104.6
1979	95,920	1,420	101.6	105.8	106.8
1980	112,330	1,540	101.7	106.8	111.1
1981	126,540	1,660	104.9	110.3	113.5
1982	120,680	1,460	107.1	121.9	115.9
1983	116,200	1,550	111.6	125.3	119.0
1984	138,820	1,920	115.6	123.0	117.8
1985	152,420	1,840			
1986 ¹	152,300	1,630			
			<u>Growth Rates</u>		
			<u>Per Year (%)</u>		
			1974-1984	2.1	5.0
			1979-1984	1.8	4.8
					2.7
					2.3

¹ Estimates based on planned expenditures reported by business in October and November 1985.

SOURCE: U.S. Department of Commerce, Bureau of Economic Analysis; Index for Manufacturing: BLS; Index for others: ATMI (Real GNP per payroll hour); Growth Rates: ATMI (least squares of natural logarithms of indexes).

TABLE 1.4: U.S. TEXTILE IMPORTS AND EXPORTS

(Millions of Dollars)

(Millions of Pounds)

	Textiles			Textiles and Apparel			Textiles and Apparel	
	Imports	Exports	Trade Balance	Imports	Exports	Trade Balance	Imports	Exports
1974	1,752	1,795	+ 43	4,269	2,195	- 2,074	927.3	706.2
1975	1,336	1,625	+ 289	4,162	2,028	- 2,134	950.2	695.3
1975	1,791	1,970	+ 179	5,729	2,480	- 3,249	1,254.8	779.3
1977	1,939	1,959	+ 20	6,432	2,567	- 3,865	1,286.1	743.4
1978	2,400	2,225	- 175	8,508	2,902	- 5,606	1,572.7	799.1
1979	2,399	3,189	+ 790	8,690	4,120	- 4,570	1,345.2	1,074.6
1980	2,676	3,632	+ 956	9,525	4,834	- 4,691	1,433.9	1,300.0
1981	3,250	3,619	+ 369	11,258	4,851	- 6,407	1,690.3	1,005.8
1982	3,000	2,784	- 216	11,703	3,737	- 7,966	1,692.6	696.1
1983	3,460	2,368	- 1,092	13,752	3,168	-10,585	2,165.7	685.3
1984	4,874	2,382	- 2,492	19,387	3,189	-16,198	2,765.8	703.8
1985	5,274	2,366	- 2,908	21,330	3,121	-18,209	na	681.9

SOURCE: U.S. Department of Commerce, FT-135, FT-140, SITC Classification 65 and 84.

technology. This means shortening the time it takes to bring a product from the raw material stage to consumer purchase. Today, the fiber-to-purchase pipeline takes, on average, 66 weeks. Of this time, only 11 weeks involve actual work-in-process. The remaining 55 weeks are spent in inventory. The quick response strategy seeks to shorten this entire pipeline to 21 weeks.

Over the past decade, the increasing rate of imports and the competitive tactics of the leading domestic producers have directly impacted the smaller producers rather significantly. During this time, the smaller producers have been caught between the lower prices of imported goods and the higher productivity rates of the leading producers. Since 1980, over 250 plants have been closed and more than 100,000 American jobs have been lost. Nearly 50 textile plants have been closed in 1985 and at least 20 others have imposed permanent layoffs. More than 10,000 textile workers have been laid off in 1984 and the industry's unemployment rate stands at 13 percent, compared with a national rate of 7 percent.

As shown in Table 1.5, textile employment closed 1985 with a 6.2 percent or 43,300 worker decrease below 1984, marking the greatest annual decrease in textile jobs since 1981/1982. Apparel employment also decreased 2.9 percent from 1984 to 1985 for its greatest annual decrease since 1981/1982. During the 1984/1985 time frame, employment for all manufacturing industries have remained fairly constant.

TABLE 1.5: EMPLOYMENT

	ALL MANU- FACTURING INDUSTRIES	TEXTILE MILL PRODUCTS INDUSTRY	APPAREL & RELATED PRODUCTS
	(thousands)		
1974	20,077	965	1,363
1975	18,323	868	1,243
1976	18,887	919	1,318
1977	19,682	910	1,316
1978	20,505	899	1,332
1979	21,044	885	1,304
1980	20,285	848	1,264
1981	20,170	823	1,244
1982	18,781	749	1,161
1983	18,434	741	1,163
1984	19,412	746	1,197
1985	19,427	703	1,162

Source: ATMI Hi-Lites, December 1985

The decrease in employment in the textile industry is a result of technical innovation as well as the impact of foreign imports. Labor productivity in the textile industry has increased by 5.0 percent per year between 1974 and 1984 (see Table 1.3). This increased efficiency has enabled the industry's domestic production to increase (in 1972 constant dollars) by 7 percent between 1980 and 1984, while at the same time reducing its employment by 10 percent. This is evident in Figure 1.2, which clearly shows that productivity (due to technological improvements) is increasing even in the face of a diminishing labor force.

In the textile industry, concern exists with labor's productivity despite labor's decreasing importance under conditions of accelerating technological progress and capital intensity. As the equipment and technologies dominate the expanding array of production activities, labor's role has shifted from direct participation in the actual processing functions to servicing machine operations. Labor's responsibilities have become stopping and starting machines, inserting and removing parts, and remaining alert for breakdowns and regular maintenance. In such cases, production rates are determined primarily by equipment designs and engineering standards rather than by fluctuations in worker's efforts. Under these conditions labor can do little to increase feasible output levels. Accordingly, the increase in the productivity index shown in Figure 1.2 is a result of increases in process speed due to technical advances of the equipment relative to the size of the labor force manning it. Technology also permits the manufacture of more technically sophisticated products, which is a competitive advantage for the innovative firms in the textile industry.

Figure 1.2 - Trends in Textile Mill Productivity and Employment

Source: ATMI Hi-Lites, December 1985.
Energetics, Inc.

The machinery and equipment manufacturing industries play an important role in each of the major segments of the textile complex. Many of the manufacturing breakthroughs in the textile industry have occurred from the utilization of new equipment developed by equipment firms. In addition, the revealing fact that most new equipment is developed by equipment firms rather than firms in the textile complex has resulted in new equipment being made available worldwide fairly quickly—i.e., the equipment firms have an incentive to sell their equipment to as many textile firms as possible, no matter in what country they are located.

An increasing percentage of new textile equipment has been developed and manufactured by non-U.S.-based firms. The U.S. textile machinery industry has steadily dwindled over the past 20 years, while those of Europe and Japan grew. For example, U.S. imports of textile machinery grew from less than 9 percent of U.S. consumption in 1963 to nearly 60 percent by 1980, with imports from West Germany and Switzerland alone accounting for over 50 percent of U.S. imports.

To summarize, numerous changes in technology have taken place in the U.S. textile industry over the past several decades. They have influenced many of the changes in employment levels, productivity, and trade patterns. More specifically, new technology-enhanced productivity permitted the manufacture of new and more complicated products, and enhanced the competitiveness of innovative firms that have properly utilized it. The new technology utilized in the textile industry improved product quality as well as reduced the amount of labor required. Thus, these technological improvements often result in declining employment while simultaneously improving the competitive ability of the adopting firms, who remain as the industry leaders.

1.2 OBJECTIVES

The goals of this study are to present an accurate characterization of the textile industry, to assess the potential energy savings in the textile industry and to identify areas of opportunity for research and development in

technologies that will enable these savings to be achieved. To accomplish this, detailed profiles of state-of-the-art and advanced technologies must be developed, as well as profiles of resource consumption in the various process steps that constitute finished woven, non-woven and knitted fabrics and finished floor coverings. In addition, a common base of technical information must be established to ensure consistency within comparative analyses and to form a sound basis from which accurate and realistic judgments of energy conservation research and development opportunities can be made.

The specific objectives of this study are:

- o To update and verify energy and materials consumption data at the various process levels associated with the production of finished fabrics;
- o To determine the potential energy savings attainable with current, state-of-the-art, and future industry technology profiles; and
- o To highlight areas of research and development opportunity that will make it possible for these savings to be achieved.

1.3 TECHNICAL APPROACH

An extensive literature search was performed to obtain the information required for this study. In addition to identifying related DOE and other government agency R&D publications, the Textile Technology Digest data base was searched for relevant articles and technical papers in technical journals and periodicals published both inside and outside the U.S. Information was also obtained from Institute of Textile Technology (ITT), American Textile Manufacturers Institute (ATMI), American Textile Machinery Association (ATMA), the Georgia Institute of Technology School of Textile Engineering and selected textile manufacturing companies.

Several industry experts were also individually interviewed for this study to verify information found in the open literature as well as to obtain other data not generally available. Industry representatives from a number of companies provided recent energy consumption data by process level for

their plants. These experts also described conservation measures used or considered by their companies and estimated the degree of use of specific advanced technologies in the year 2010, assuming no technical or economic constraints. Companies represented by the experts are considered as the leaders by the industry. In addition, Energetics' personnel made several field trips to mills operated by the participating companies.

The information acquired was used to develop updated flow diagrams of the three technology scenarios being considered (current, state-of-the-art, and advanced). These diagrams show the various technology alternatives that exist or most likely will exist in the future for each major process step.

Data gathered on the past and current states of the industry were used to establish trends in the state of technology development from the base year that these data were reported to the target year when improvements in energy use were realized. Using these trends as a base, the energy consumption profiles found in previous reports were updated to 1984. Other types of profiles were developed for current industry practices: import/export, economic, technology mix (by process step), and materials consumption. Recent conservation and modernization efforts within the industry were also identified. For the state-of-the-art and advanced textile industry scenarios, energy consumption profiles were developed based on technology mixes as conceptualized by a consensus of industry experts.

The energy savings potential associated with state-of-the-art and advanced practices as foreseen by the experts for the year 2010 were determined by comparing the energy consumption level for each process step with the corresponding level associated with current practices. In cases where the process technology mix estimated by the experts for the year 2010 was not the most energy efficient one, efforts were made to determine why use of the more efficient alternatives would not be more widespread. Additionally, the specific energy consumption of the process steps up to but not including the raw fiber formation for both state-of-the-art and advanced practices were compared to the calculated energy requirement for this combination of steps. Based on these comparative analyses, areas of R&D opportunity with the highest potential energy savings were identified.

The analysis of specific energy consumption emphasizes the effects of technological change and focuses on the process level since this is one of the lowest levels for the planning of a unified operation. A better understanding of technology at this level should not only improve decision-making but could also provide a building block for improved understanding of technical decisions at higher levels of aggregation.

In Section 2 of this study, current technological practices, production and energy consumption profiles, and recent conservation measures adopted by industry are discussed. Section 3 discusses future trends in textile manufacturing including both state-of-the-art and advanced technologies. Section 4 presents an analysis of the potential energy savings associated with the textile manufacturing trends. In the final section, general areas of energy conservation R&D opportunities are discussed.

The report contains the following appendices:

Appendix A - Data Base of Dry Processing Specific Energy Use in 1984.

Appendix B - Data Base of Wet Processing Specific Energy Use in 1984.

Appendix C - State-of-the-Art Textile Manufacturing Technologies

Appendix D - Advanced Textile Manufacturing Technologies

Appendix E - Energy and Materials Use by Major Processes (for Section 4 Scenarios)

Appendix F - Glossary

SECTION 2. ENERGY CONSUMPTION IN CURRENT TEXTILE MANUFACTURING PRACTICES

This section describes the current technological status of the U.S textile industry, presents energy consumption data for the overall textile-making process and for the individual processes involved in each industry component.

2.1 CURRENT PRODUCTION AND ENERGY CONSUMPTION IN THE INDUSTRY

The textile industry (SIC 22) is among the top ten most energy-consumptive industries in the United States. Its 1984 energy consumption (including electrical losses) was 0.46 quads which accounts for 1.7 percent of the total energy consumed by the U.S. manufacturing industries (27.8 quads) and 0.6 percent of the total energy consumed in the nation.

Energy consumption and management is more of a critical parameter for the textile industry since energy costs average about 3 percent of the value of shipments (total shipments are presented in Table 1.2). Therefore, energy represents a slightly greater expense for the textile industry than it does for many of the other manufacturing industries. Energy costs average approximately 8 percent of the value added by manufacture and can be as high as 25 percent of total production costs for the textile mills.

The table below summarizes the average energy consumption and costs data for the textile industry as compared to the other manufacturing industries. The ratios were calculated based on the information contained in the Annual Survey of Manufacturers, U.S. Bureau of Census.

	<u>Textile Industry (SIC 22)</u>	<u>Top Ten Industrial Energy Users</u>	<u>All Manufacturing Industries</u>
Average Energy Costs Per Value of Shipments (%)	3.	3.	2.
Average Energy Costs Per Dollar of Value Added by Manufacture (%)	8.	8.	6.
Average Energy Consumption (without electrical losses) 1000 Btu's per dollar of value added by manufacture	16.	20.	15.

Ten year overall and specific energy consumption profiles (1974-1984) for the U.S. textile industry are provided in Table 2.1. A downward trend in energy consumption for the industry is shown during this decade. Using data provided for consumption including electric losses, the total annual energy consumption was reduced by 12 percent for an annual equivalent of 54 trillion Btu saved from 1974 through 1984.

The overall energy consumption in the industry is a function of plant production rate, plant capacity utilization and increased equipment modernization. The industry's energy efficiency is directly affected by the mill's capacity use. Figure 2.1 provides a striking testimony of the inverse relationships existing between total production efficiency (specific energy use), and industry capacity utilization. A test case to demonstrate the validity of these relationships is calculated for the three year period of 1981 through 1983. From 1981 to 1982, the total fiber consumption dropped about 12.5 percent due to the economic recession and weak residential construction and automotive markets. This reduced capacity utilization about 16 percent and resulted in an increase of about 4.2 percent in the specific energy consumption. On the other hand, the increase in fiber consumption in the years 1982 to 1983 of about 18.6 percent resulted in a 13 percent increase in capacity utilization which helped in reducing the specific energy consumption by about 7.8 percent.

The breakdown of the total energy consumed by major fuel types for the textile industry and all manufacturing industries in 1984 is exhibited in Figure 2.2. The data provided in this figure shows an unusually large

TABLE 2.1: Textile Industry (SIC 22)
Energy Consumption History

Year	Total Energy Used During Production (trillion Btu)		Mill Fiber Consumption (10 ⁶ pounds)	Specific Energy Consumption** (Btu/lb of fiber)
	Without Electrical Losses*	With Electrical Losses**		
1974	319.7	515.3	10,778.4	47,809.
1975	307.1	495.0	10,260.6	48,243.
1976	328.6	527.2	11,189.9	47,114.
1977	339.2	534.9	11,515.2	46,452.
1978	326.6	517.3	11,650.8	44,400.
1979	314.9	502.9	11,891.1	42,292.
1980	294.9	477.3	11,223.3	42,528.
1981	292.3	473.7	10,715.8	44,206.
1982	262.4	432.1	9,378.8	46,072.
1983	288.6	472.3	11,122.4	42,464.
1984	283.2	461.2	10,816.2	42,643.

*Based on a conversion factor of 3,412 Btu/kWh_{ch}.

**Based on an energy intensity factor of 10,500 Btu/kWh_e to account for electrical losses.

Note: Specific Energy Consumption includes both production and support operations.

"Annual Survey of Manufacturers: Fuels and Electric Energy Consumed", USDOC

Figure 2.1: Comparison of Trends in the Textile Industry

Reference: Annual Survey of Manufacturers: Fuels and Electric Energy Consumed, USDOC.

Figure 2.2: Major Fuel/Energy Types Used in Industry

TRENDS IN FUEL/ENERGY USAGE
IN THE TEXTILE INDUSTRY

(% of Total Textile Mill Consumption)

Reference: Annual Survey of Manufacturers: Fuels and Electric
Energy Consumed, USDOC.

Figure 2.3: Trends in Fuel/Energy Usage in the Textile Industry

dependency by the textile industry on electric energy. The relative electric energy consumption in terms of percent of fuel types used by the textile industry was almost double that of total manufacturing industries. The comparison among the fuel types within the textile industry shows more than three times the demand for electricity than that for its nearest competing fuel (natural gas). By comparison, the chart for all manufacturing industries shows more evenly distributed shares among the major fuel types.

The trend in usage of fuel types is provided in Figure 2.3. The trend shows electricity's share steadily increasing. This reflects the large machine drive requirement with its increasingly faster production speed and the introduction of more electronics, computer control, automation and robotics. Natural gas was the predominant fuel used in process heat applications, primarily drying and steam generation. Natural gas usage has been declining along with liquids (residual and distillate oils). It is the industry's intention to use more coal in lieu of oil and natural gas for process steam generation. On an energy basis (Btu) approximately 20 percent of the total energy consumed was used in boilers to produce steam. The large amounts of thermal energy needed, for the most part, is at relatively low temperatures, for heating textile material, water evaporation, and heating air. Yet, most of the low grade heat is generated in steam boilers fueled by almost the highest grade fuels available. This should be a cause for great concern. In addition, mandatory (and non-productive) pollution control equipment increases the industry's energy requirements. This is one reason that coal use is not growing despite the previously stated industry intention.

2.2 CURRENT ENERGY CONSUMPTION BY INDUSTRY COMPONENT AND BY PROCESS LEVEL

Textile mill products encompass a wide variety of goods which include carpets, fabrics, and yarns. Manufacturing each product requires many intermediate physical transformation processes. The energy requirements for each product are different in quantity and fuel types, making the energy consumption reporting for the industry extremely difficult. As a result, the energy consumption data gathered in the course of this study will be presented using the industry accepted identification of primary production components.

These components divide the production process into two basic categories of dry and wet processes. These two basic categories are consistent with the production process characteristics, depending on whether or not water is involved. The wet and dry categories can be represented by nine primary production process components. Every product is assumed to follow a pre-assigned route which may require one or several of these components in both categories. The nine primary production process components are:

Dry Process Components

- Yarn Formation
- Texturizing (Man-Made Fibers)
- Fabric Formation/Weaving
- Fabric Formation/Knitting
- Fabric Formation/Non-Woven
- Floor Covering: Tufting*

Wet Process Components

- Yarn Dyeing
- Woven Fabric Dyeing and Finishing
- Knit Fabric Dyeing and Finishing
- Floor Covering: Dyeing and Finishing*

*Floor Covering which includes the tufting, dyeing and finishing processes is considered to be one component even though as shown above, it includes both dry and wet processes.

The dry processes are conducted in what is known as the "greige mills." Greige mills are the most common type of operation in which two or more of the preceding dry process components are combined in one building or plant complex. These mills begin with purchased man-made fiber or yarn and/or baled cotton or cotton yarn as feedstocks and carry the manufacturing processes through knitting or weaving yielding greige goods. Virtually all combinations of the intermediate processes are found somewhere in the industry; however, the most common is the yarn formation/weaving combination producing greige (unfinished) woven fabric.

It has been found that pure forms of the preceding components (single-operation mills) are not abundant in the industry, and that energy conservation measures applicable to each of the individual components are generally applicable to greige mills.

Approximately 40 percent of the total energy used by the textile industry is consumed in dry processing.⁽¹⁾ Dry processes use energy mainly as electric power for machine drive. The other 60 percent is consumed in wet processing. The energy required in dry processing is all electrical energy while barely 15 percent of the energy consumed in wet processing is electrical.⁽²⁾ The remaining share of energy consumed in wet processing is thermal energy. Wet processes use various fossil fuels for steam production and natural gas for drying wet yarn or fabric and heat setting. Often, the yarn or fabric is wet and dried several times through various stages or processes. The wet process operations of predrying, drying, and heat setting, together with singeing, are the largest consumers of natural gas used for direct heating in the textile industry.

The feedstock production processes and the energy requirements associated with them are not considered in this study. It is assumed that fiber is the initial raw material in the fabrication processes and the fiber's original internal energy will not be discussed. The energy consumed in producing chemicals such as dyestuffs, solvents, and finishing agents are also not considered. Accordingly, the energy requirements of the previously defined primary components are the focus of the study. All other operations in the industry are classified into miscellaneous textile goods. They are not considered due to their extremely diverse nature and include such products as wool fabrics, hosiery, rope, and tire cords.

Figure 2.4 presents a production sequence diagram of the major current processes which make up the previously identified components. It is important to note that no two textile mills have identical process lines (equipment) nor use exactly the same methods. Therefore, this has made energy consumption analysis extremely difficult. Some mills have kept better pace with the present technology than others. Additionally, due to the diverse nature of the textile mill products, there are constant changes in product mix and production volume. Accordingly, individual mills do not consume similar amounts of energy.

DRY PROCESSES

2.2.1 The Yarn Formation Component

Spun yarns are made by loosely gathering natural fibers, man-made fibers, or blends, into a rope-like form, drawing them out to increase fiber alignment and then applying twist. The yarn formation component most often today consists of the following individual processes:

- o opening, blending, and picking
- o carding,
- o drawing,
- o roving, and
- o spinning.

A few firms still perform lap winding and combing after the drawing operation. Overall, these two processes are considered antiques and are seldom used. Lap winding and combing introduce added expense and extra poundage losses with limited benefits of higher strength and softer yarns.

This investigation is based on the nation's perspective of energy consumption and uses an electrical energy intensity factor of 10,500 Btu/kWh electric, and a conversion factor of 3,412 BTU/kWh thermal. The industry's perspective of energy consumption does not take into account the electrical losses and does not differentiate an electric kWh from a thermal kWh. Both sets of data on a process level are presented in Appendices A and B.

The following sub-sections describe the individual process steps and present ranges of specific energy consumption for each of the individual processes. All processing equipment in this component is run by electricity, and figures in the text are quoted with electrical losses (10,500 Btu/kWh electric). Figure 2.5 illustrates the opening, picking, drawing and roving operations.

Opening, blending, and picking The first operation in a textile mill takes place in the opening room, where bales of cotton or man-made fiber staple are opened. Portions of the fiber staple are placed in opening

Figure 2.4 Current Process Sequence Diagram

Figure 2.4 Current Process Sequence Diagram
(continued)

Figure 2.4 Current Process Sequence Diagram
(continued)

Figure 2.4 Current Process Sequence Diagram
(continued)

Figure 2.4 Current Process Sequence Diagram
(continued)

machines, where the fiber is fluffed and some foreign matter is removed. Two or more fibers can be blended at this point. The fiber emerges from the opening machine as bits of fluff, which are then carried by air to a cleaning machine called a picker. Here the fiber is beaten and further cleaned, and a loose, uniform sheet of fiber (called picker lap) is formed. Picking machines have historically been used for this purpose but chute feeding machines have mainly replaced picking machines since they are less labor intensive.

Opening consumes approximately 954 Btu/lb of yarn. This is about 10 percent of the total energy consumed in the yarn formation component of manufacturing. The cotton portion of the opening process consumes almost twice the energy as the polyester component. Tables A-7 through A-9 in Appendix A show a range for energy consumption in this process.

- Picking on the average consumes approximately 245 Btu/lb.
- Chute-feeding to cards consumes slightly more energy than picker lap-feeding (985 Btu/lb vs 925 Btu/lb) but is less labor intensive.

2.2.1.2 Carding The sheets of fiber so formed are sent on to card machines. A card machine contains many long, rectangular, slowly moving slats covered with fine teeth. The carding process is designed to achieve a more intensive opening of the fibers, parallelism of fibers, almost to complete fiber separation, and to gather the fibers into a rope-like form, called a sliver (sly'ver). Further removal of short fibers and trash is accomplished. For heavy yarns of average or low quality, the card sliver goes directly to the drawing operation. For lighter yarns requiring fineness and strength, the card sliver must be lapped and combed. Carding consumes an average of 754 Btu/lb for coarse carded yarn with yarn counts of 3.0 to 31 (average of 18.5). Specific energy consumption varies from 250 to 1810 Btu/lb. For finer combed yarns of an average yarn count of 35, the average energy consumption is 462 Btu/lb. The specific energy consumption varies from 822 to 1570 Btu/lb for yarn counts between 25 and 49. For blends, the polyester component can consume up to 35% more energy than the cotton portion. Also, lower production rates exact a high energy penalty in carding, as shown in Table A-1. Tables A-5 and A-6 provided more detailed data on the carding energy requirements. A production rate of 20 pounds per hour consumes about twice the specific energy of producing the same sliver at 60 pounds per hour.

Figure 2.5: Various Yarn Formation Processes

In carding the production of a 55 grain per yard sliver takes 55 percent more energy per pound than does a 65 grain per yard sliver.(2)

2.2.1.3 Drawing Drawing follows either carding or combing and serves to further improve uniformity, fiber parallelism and fiber blending by doubling and drafting several individual slivers into a single composite strand. The drawing also reduces the cross-sectional area of the exiting sliver.

Drawing is a small component of the total energy consumed and increases somewhat with the finer yarn count. Drawing consumes an average of 163 Btu/lb for the coarse carded yarn (yarn count 18.5) and an average of 270 Btu/lb for the finer combed yarn (yarn count 35). The range of specific energy consumed is 98 Btu/lb to 323 Btu/lb for yarn counts of 3.0 to 49. The drawing of a 70 grain per yard sliver consumes almost twice the energy per pound than a 60 grain per yard sliver.(2) Drawn slivers can go directly to air-jet or open-end spinning.

2.2.1.4 Lap Winding (Optional) In order to prepare the slivers for combing, they must be lapped. In lapping, several slivers are placed side-by-side and drawn together. The resulting ribbon lappings are laid one on the other and again drawn together or drafted. The doubling and redoubling averages out irregularities in the slivers and enhances blending while the drafting improves fiber parallelism. In some instances, only one lapping process may be utilized before combing.

Lapping consumes on the average 462 Btu/lb for combed yarn (yarn count of 35). The range of specific energy consumption is 114 to 705 Btu/lb for a yarn count range of 25 to 49.

2.2.1.5 Combing (Optional) After lapping, the fibers are combed with fine metal teeth. The combing process removes all fibers below a pre-determined length (fibers which are too short to effectively lend support to the body of the yarn), removes any impurities which have not been removed previously in the opening and carding processes, and arranges the fibers in a more parallel order, so as to obtain the characteristic smoothness and strength of fine yarns.

Combing consumes on the average 1074 Btu/lb for a 35 count yarn. This value can vary from 935 to 1498 Btu/lb for a yarn count of 25 to 49.

Roving On the roving frame, individual slivers (either directly from drawing or after combing) are passed between a series of three rollers, and are compressed and greatly reduced in diameter. During this process the fibers are given a slight twist, which imparts the first man-made strength, and the resulting roving slivers are wound on bobbins.

Roving of carded drawn yarn averages a specific energy consumption of 622 Btu/lb for a yarn count of 18.5. This consumption ranges from 298 to 975 Btu/lb for yarn counts of 3.0 to 31. Roving of card blended yarns have also been reported to have power requirements of 1136 to 1520 Btu/lb for yarn counts of 16 and 24, respectively.

Roving of combed yarn (finer counts) requires an average specific energy consumption of 985 Btu/lb for a yarn count of 35. This consumption ranges from 677 to 1219 Btu/lb for yarn counts of 25 to 49. Roving of draw blended yarns (yarn count of 36) has been reported to have a power requirement of 1335 Btu/lb.

The coarseness of the incoming carded or combed yarn has a great impact on the energy consumption in roving. A 1.0 hank roving takes more than three times the energy per pound than the production of a 0.6 hank roving.

2.2.1.7 Spinning Spinning is the final step in spun yarn formation. In this process draft and twist are applied to the drawn or combed roving or sliver by employing one of the several spinning systems available today. Spinning operations are the most energy consuming steps in yarn manufacturing, comprising between 60 and 80 percent of the total energy used in the spinning component. Spinning takes approximately ten times the energy of the nearest energy intensive process in this component, carding, on a per pound basis. The average specific energy consumption for spinning carded yarn (18.5 yarn count) is 7520 Btu/lb. The range of energy consumption is 1612 to 20,618 Btu/lb for yarn counts of 3.0 to 31. For combed yarn manufacturing the average energy consumption is 15,695 Btu/lb for a 35 yarn count with a range of 12,060 to 28,490 Btu/lb for yarn counts from 25 to 49.

Ring Spinning The most common spinning system today is ring spinning. In this system, the spinning machines drafts the input form (roving) to the necessary dimensions, inserts twist, and forms the yarn which is wound on a spinning bobbin. The rate of front roll feed and the spindle speed determine the amount of twist in the yarn, as shown in Figure 2.6.

Ring spinning power consumption can be broken down into several components with spinning power, package power, secondary power, and ancillary power being the major components, as shown in Figure 2.7.

Package power is the power dissipated in overcoming air drag and is independent of yarn count. Secondary power drives the spindles and tapes and the main shaft and pulleys. Ancillary power is used for the insertion of the twist into the yarn. Table A-10 displays the energy breakdown for spinning yarn with counts of 16 and 30. In both cases, the secondary power is the major consumer of energy accounting for over half of the total energy. Package power accounts for about a quarter of the energy, spinning energy is about 10 to 15 percent of the total and ancillary power accounts for about 6 or 7 percent. Figures 2.8 and 2.9 show the variation of total and component power consumption with varying spindle speed and for different stages of a bobbin build.

Figure 2.10 graphically shows that a direct relationship exists between yarn count and the specific energy consumed in ring spinning.

Open-end, or rotor spinning, a relatively recent innovation, is significantly different from ring spinning systems in that the spinning operations are performed directly on drawn sliver, i.e., roving is eliminated. In this process, the staple fibers in the form of a sliver are fragmented as they are fed into a small spinning centrifugal mechanism. Within this mechanism, the fibers are oriented and discharged in yarn form with twisting added through the rotation of the rotor, as shown in Figure 2.6.

Figure 2.11 depicts the effects of rotor speed and yarn count on the specific energy consumed in open-end spinning. Figure 2.12 shows the

Source: Celanese Corp.

Source: Celanese Corp.

Figure 2.6: Ring, and Open-End Spinning Mechanics Compared

Reference: Balmforth, "Energy Consumption Patterns in the Textile Industry," American Dyestuff Reporter, 8/85.

Figure 2.7: Ring Frame Spinning Power Components

Reference: Catling and DeBarr, "A Study of Power Requirements in Ring Spinning," Journal Textile Inst., 48.11.

Figure 2.8: Ring Spinning Power Variations Due To Spindle Speeds.

Reference: Catlin and DeBarr, "A Study of Power Requirements in Ring Spinning," Journal Textile Inst... 48.11.

Figure 2.9: Ring Spinning Power Variations During the Build of a Bobbin.

(no electrical losses)

Figure 2.10: Effect of Yarn Count on Specific Energy Consumed in Ring Spinning

Reference: IEEE 1983 Annual Textile Industry Technical Conference, Greenville, S.C.

(no electrical losses)

Figure 2.11: Effects of Rotor Speed and Yarn Count on Specific Energy Consumed in Open-End Spinning

Reference: Ibid.

relationship between the power consumed and rotor speed for open-end spinning frames of various rotor diameters.

Open-end spinning is essentially the only process technology applicable to the spinning operations which conserves energy. The open-end spinning equipment is less energy consumptive overall than ring spinning for heavier yarns. Roving is currently eliminated by open-end spinning. The primary disadvantages of open-end spinning are high initial cost and limited applicability. Very fine yarn cannot be spun economically with open-end equipment.

Figure 2.13 compares graphically the cost per pound of ring spun yarn versus rotor spun yarn. This shows that ring spun yarn is more expensive throughout the yarn count range than rotor spun yarn.

Specifically comparing open-end spinning with ring spinning, it is interesting to examine open-end yarn with ring-spun yarn at counts of 16 and 24. The actual spinning process consumes a similar amount of energy:

- 16's/Ring: 5300 Btu/lb; 16's/Open-end: 5250 Btu/lb.
- 24's/Ring: 9180 Btu/lb; 24's/Open-end: 9645 Btu/lb.

However, the elimination of intermediate steps (see Table A-7) can result in energy savings up to 15 percent in the yarn formation component. Also, the elimination of subsequent winding processes with open-end spinning can also eliminate some energy consumption in this component.

Air-Jet Spinning. Air-jet yarns have limited applications. This system is particularly suited for synthetic fibers and blends which have a minimum acceptable length and a very high bending modulus. Air-jet spinning of 100% cotton is very difficult but not impossible. Air-jet spinning does not require lapping, combing and roving.

Figure 2.14 compares the production costs of air-jet spinning with rotor spinning. Air-jet spinning production costs are consistently higher than rotor production costs throughout the yarn count range.

Figure 2.12: Power Consumption per Spinning Position as a Function of Rotor Diameter and Rotor Speed

Reference: "Short-Staple Spinning, Evolution or Revolution,"
Presentation at Georgia Institute of Technology, April 1986.

Figure 2.13: Comparison of Production Costs, Ring vs. Rotor Yarn.
(1986 costs)

Reference: Ibid.

Reference: "Short-Staple Spinning, Evolution or Revolution,"
Presentation at Georgia Institute of Technology, April 1986.

Figure 2.14: Comparison of Production Costs
Air-Jet Spinning vs. Rotor Spinning

In the case of air-jet spinning, more energy is needed for the air compressor and the higher production speed. Figure 2.15 shows that the majority of the compressed air production costs are energy costs. Capital charges and maintenance costs are responsible for only 20% of the compressed air supply costs. Compressed air is a costly but efficient form of energy.

The energy consumption of the HVAC (Heating, Ventilating and Air Conditioning) component is included in the yarn and fabric formation components. The specific energy consumed by the HVAC will be allocated equally between the yarn and fabric formation components.⁽²⁾ The HVAC component will be discussed in its entirety in the auxiliary processes section 2.2.5 of this report.

2.2.2 The Texturizing Component

Texturizing increases the covering power or apparent volume of continuous filament synthetic yarns (purchased from outside the textile industry), so that their appearance more clearly resembles that of conventional (natural) spun yarns. A number of processes can be used for yarn texturing including torsional crimping, edge crimping, compression crimping, and air texturizing. Texturizing consumes between 11,694 to 33,400 Btu/lb, with an average specific energy consumption of 20,500 Btu/lb.

2.2.3 The Fabric Formation/Weaving Component

Weaving is one of the two principal methods of fabric construction. Prior to the actual weaving operation, however, the yarn must be prepared by one or more of the following processes: winding, spooling, warping, and/or slashing (sizing). The purpose of these operations is to transfer the yarn from the type of package which resulted from the spinning or texturizing operation onto a type suitable for fabric manufacturing. For weaving, it is necessary to coat most warp yarns with a plastic sheath (via sizes) to protect the yarn during the weaving operation.

2.2.3.1 Warping. Warping is a winding process in which the warp yarns (the longitudinal yarns in a piece of fabric) for either weaving or warp

Oil free, dry compressed air at 7 bar (100 psi)

Reference: Derived from West German (FRG) Textile Technology Conference.

Figure 2.15: Proportion of Compressed Air Production Costs

knitting are arranged side-by-side on a large spool (warp beam) to the desired width of the fabric to be woven.

The average specific energy consumption in winding spinning bobbins to packages is 850 Btu/lb at a production rate of 5.5 pounds/hour/position. This process is not considered a major user of energy, but as yarn counts becomes finer, energy consumption escalates (Table A-11). The lower counts consume little energy while the higher counts consume 2150 Btu/lb or more.

2.2.3.2 Slashing Following warping, yarn which is used for weaving is commonly fed through the slashing (sizing) process. Slashing consolidates the proper number of warp yarns on the warp beam for the fabric construction, coats the yarn with a size, (usually starch or polyvinylalcohol (PVA) or a blend of the two) and then dries the yarn. Sizing also increases the strength of the yarn in preparation for the weaving operation. The size solution is contained in a steam heated vat through which the warp yarns are passed. The yarns are then dried and the size sheath cured, usually by passing over steam heated cylinders (steam cans), and wound onto warp beams.

Slashing consumes less than 2500 Btu/lb. A typical slasher shown in Table A-14 uses 1523 Btu/lb of steam energy and only 800 Btu/lb of electrical energy. Electrical energy consumption of slashers amount to approximately 53 percent of the steam consumption (17 percent - not including electrical losses).

The slasher steam energy outputs show that about 4 percent of this thermal energy goes into heating the yarn and 18 percent heats the air in the stacks. The moisture evaporated to the stacks accounts for almost 80 percent of the input steam energy, which indicates that slashing is a reasonably energy-efficient operation.

2.2.3.3 Weaving

Weaving In the weaving process, the warp (longitudinal) and filling (transverse) yarns are interlaced in a loom to form the fabric. In the simplest shuttle loom, harnesses raise and depress alternate warp yarns to form an opening called a shed. A shuttle containing the filling yarn is

passed through the opening. The filling yarn is beaten firmly into the apex of the shed and up against the previously woven cloth. As the cloth is woven, it is normally wound on a roll in preparation for transfer to a textile dyeing/finishing process.

The energy consumption data shown in Table A-15 represents the electrical energy used in overall weaving which includes an unspecified mix of weaving technologies, although the figures should be fairly representative of shuttle looms. The Institute of Textile Technology (ITT) is currently involved in an effort to disaggregate this table into its component technologies.(3)

From this table it is interesting to notice that finer yarn counts rapidly escalate the energy consumption per pound. Due to yarn count alone, the energy figures range from 3540 to over 13,850 Btu/lb. The average energy usage in weaving is about 5440 Btu/lb.

Beyond the basic shuttle loom and pattern, there are many complex variations which produce intricate weaving effects. The most complex is the jacquard in which individual warp threads are separately controlled. In addition, shuttleless weaving machines are also used in which the filling is inserted by air, water, or a special metal projectile which replaces the conventional shuttle.

Currently, the most widely used shuttleless weaving systems are:

Projectile weaving. A gripper projectile carries the filling yarn across the shed. Its small size enables the moving parts of the machine to be kept small and the motions short, resulting in high picking rates even with large working widths.

Rapier weaving. Weft insertion is effected by grippers attached to flexible tapes at each side of the machine. The weft thread taken into the shed by the right-hand gripper head is transferred to the left-hand gripper in the middle and drawn to the edge of the fabric.

Air-jet weaving. The weft is inserted by an air-jet. The low mass of this insertion medium allows extremely high machine speeds. The weft, continuously drawn off the supply package and measured to length, is given its initial acceleration by the main nozzle. Relay nozzles continue its onward transport across the whole fabric width.

Water-jet weaving. This is a method of inserting the filling by means of a jet of water instead of with the conventional fly-shuttle. Water-jets are presently limited to hydrophobic filament yarns. Research continues on natural fiber blend applications. These looms require approximately 10 gallons of water per hour. Normally, this water has to be dumped since it is contaminated with sizing chemicals used on the warp yarns. Chemical recovery methods should be in place for these machines. It should be noted that water-jet weaving is not being used much by the industry and could be considered a "dead" technology.

Figure 2.16 illustrates these various methods of weft insertion (weaving).

Figure 2.17 shows the electrical energy consumption bands associated with each type of weaving machine. (Some weaving machines not described in this section appear in Section 3, such as the wave-shed loom which is still in the research stage.) The graph shows that in terms of productivity by commercial looms, air-jets are the fastest while shuttles are the slowest. Also noteworthy is that water-jet looms have the lowest energy consumption while air-jets have the highest with approximately half the required power dedicated to the air compressor.

2.2.4 The Fabric Formation/Knitting Component

Knitting is the second of the two principal methods of fabric construction. It is a process in which rows (courses) of looped stitches are formed into various types of fabric structures such that each knitted course is looped through an adjacent course. A process flow diagram for knitting is shown in Figure 2.4.

Source: Celanese Corp.

Figure 2.16: Various Methods of Weft Insertion (Weaving)

Figure 2.17: Energy Consumption/Requirements Bands As Compared to Productivity For a Variety of Weaving Looms.

Reference: Textile Month, August 1985.

In preparation for knitting, the yarn is oiled or waxed to lubricate the yarn and consequently increase the speed and ease with which knitting can be accomplished. This step may be accomplished in the knitting mill or during yarn formation, either spinning or texturizing.

The knitted fabric may be formed either by circular knitting, in which one or more individual supply yarns are laid across beds of needles so that loops of yarn are drawn through previously made loops, or by warp knitting, in which the fabric is formed by looping together warp threads as they are fed collectively from a warp beam. As a result, the supply yarns for knitting may be on cones for circular knitting or they may be on warp beams for warp knitting.

No known process changes that will reduce energy consumption in knitting are imminent. Knitting consumes between 3540 and 10,860 Btu/lb. Operating procedures and environmental controls similar to those mentioned for weaving are applicable to knitting.

2.2.5 Auxiliary Process

Environmental control in textile dry processing plants is very important in maintaining satisfactory process efficiency, product quality and static control. Both relative humidity and dry bulb temperature must be controlled.

Figure 2.18 shows a complex HVAC system broken down into its major components. The system is designed to remove the heat from the production area, cascade it back through the air washer loop, then through the evaporator and compressor loop and then into the cooling tower loop for dissipation to the outside atmosphere.

Tables A-16 and A-17 show the HVAC component horsepower at three mills which have roughly the same production rates. The breakdown of the average horsepower is: 60% for the chiller, 10% for the cooling tower, and about 30% for the air washers. Not all components, such as the chillers or air washers, operate all year round.

Reference: Balmforth, "Energy Consumption Patterns in the Textile Industry," American Dyestuff Reporter, July 1985.

Figure 2.18: Heating, Ventilating, and Air Conditioning (HVAC) Components.

A wide divergence of energy consumption is noted from mill to mill, but approximately 20% of the total electric energy in the plant is going to the HVAC, and almost 80% is in terms of production-energy consumption. Thus, a typical HVAC system adds a further 5530 Btu/lb to the energy consumption in the greige mill.

Wet Processing of Yarns and Woven/Knitted Fabrics

2.2.6 The Yarn Dyeing Component

Pre-dyed yarn is used in the knitting, weaving, and floor covering components of the industry. Their use eliminates the dyeing of the completed product. All of the processing steps are normally conducted in sequence in a pressurized vat, similar to a large autoclave. The yarn is placed in the vat in the form of spools, from 1.8 to 11 pounds each, or on a wound warp beam. Yarn on warp beams may also be dyed in a batch process essentially identical to that described for woven fabric.

The following processes are necessary in yarn dyeing and are described in the subsequent yarn dyeing process sequence.

2.2.6.1 Scouring and bleaching. These operations are performed on natural and blended yarns to improve whiteness and absorbency and to regulate dyeing characteristics. Hot scouring and bleaching liquors are pumped through the vats, followed by hot rinse water. Synthetic yarns are scoured, but not bleached.

2.2.6.2 Mercerizing. Mercerizing of yarns improves strength, luster and dyeability. It is a comparatively slow process since it must be accomplished under tension. Yarn from a warp beam is unwound, dipped in hot water, entered into a mercerizing solution, allowed a dwell time under tension, rinsed, dried, and rewound. Use of the process is limited and primarily reserved for specialty yarns of high strength.

2.2.6.3 Dyeing. Dyeing is accomplished by forcing a heated dye solution through the spool or beam of yarn under pressure. Pressure and vacuum are alternately applied from inside and outside the center of the spool or warp

to insure complete and uniform dye penetration. Following dyeing, the yarn is dried by forcing heated air (300° to 400°F) under pressure (typically 100 psi) through the dye vat. Table B-32 through B-35 give typical specific energy consumption values for rawstock dyeing and package dyeing of yarns.

2.2.7 The Woven Fabric Dyeing and Finishing Component

Textile finishing is a generic term which refers to the processes used to transform knit or woven greige goods into finished fabric, or into dyed yarn. The basic processes are fabric preparation, dyeing, printing, and finishing, each followed by a drying step. Textile finishing requires large amounts of heat energy and is amenable to relatively dramatic energy conservation.

Typical processes used to produce finished fabric from woven greige goods are shown in Figure 2.4. It should be noted that some processes may be omitted and the order of the processes may vary from that shown depending upon the particular end product desired. Similarly, several technologies are available for some of the steps; e.g., dyeing and washing may be continuous, semi-continuous or batch processes.

Heat setting. Heat setting (is not part of "preparation") is used on fabrics made of man-made materials in order to stabilize shrinkage which may occur as a result of exposure to hot water in subsequent processing operations. There is a tendency to use heat setting in order to preserve the dimensional stability of the fabric. Heat setting is normally accomplished by application of infrared radiation from a gas-fired burner.

Heat setting consumes approximately 530 Btu/lb (range of 500-700 Btu/lb) when the product is being batch processed and consumes approximately 800 Btu/lb on a continuous dye range. In either case, natural gas is the primary fuel supplying 96% of the process energy per pound for batch processing and 80% of the process energy on a continuous range. The energy losses from heat setting are mainly in the stacks (over 60%), fabric losses account for about one-quarter of the thermal inputs and radiation loss for only one-tenth.

Singeing. Singeing is a continuous process in which the fabric is passed near a gas burner in order to remove (burn-off) protruding fibers from the surface of the fabric. The flame burns the infusible fibers and melts the thermoplastic fibers so that the surface of the fabric will be smooth.

Gas consumption in the singeing process averages 155 Btu/lb on a continuous range. Studies have shown this figure to be 300-400 Btu/lb, but present mill operations reflect the lower energy consumption.

Desizing. Before the fabric can be properly dyed, the sizing chemicals applied to the warp yarns in the slashing process prior to weaving must be removed from the fabric. Starch and polyvinylalcohol (PVA) are the most common sizing chemicals used. If starch is present (either pure or as a blend), the desizing solution is padded onto the fabric to achieve a 90 percent uptake and then steamed to increase the starch fragmentation rate. After an exposure time varying from a few minutes to 12 hours (depending on the type of equipment and the type of fabric), the desize solution is rinsed from the fabric. Pure PVA size is removed by washing the fabric with a hot (190°F) water, using a multiple dip operation with countercurrent flow. In some instances, the wastewater from PVA desizing is concentrated by ultrafiltration, and the PVA concentrate and hot water are reused.

On a rope preparation range, the desizing process consumes an average of 435 Btu/lb; however, the desizing process is usually combined with a washing step. Together, energy consumption can vary from 1100 to 1250 Btu/lb. Desizing consumes from 250 to 300 Btu/lb on an open-width preparation range without washing included. Many of the energy conservation measures involve the washing component of this operation.

2.2.7.1 Preparation. Fabric preparation, reserved for natural fiber containing fabric, involves processes such as bleaching, scouring, washing and drying which prepare the fabric properly for the dyeing operation. Preparation cleans the fabric and increases its absorbency and whiteness which ensures better dye uniformity and color fastness.

The two basic preparation ranges are the continuous open-width range and the batch rope range. A typical rope preparation range with no heat recovery consumes 2550 Btu/lb, not including singeing, heat setting, mercerizing or a final drying process. Steam contributes and constitutes the major energy use (97%). An average operating rope preparation range (no mercerization) with 60% heat recovery consumes 3750 Btu/lbs while an average open-width preparation range under similar conditions consumes 5700 Btu/lb. The open-width range energy consumption is higher primarily due to the fact that fabric is dried on this range. Heating wash water is the major consumer of energy on both ranges and the area to be examined for energy conservation.

The following paragraphs discuss the energy consumption of the individual processes accomplished on typical preparation ranges. It should be noted that there is a wide variation in energy consumption due to equipment differences and local conditions which have large impacts such as wash water temperature.

Scouring. Fabric may be scoured in open width or rope form by applying a solution of caustic, some solvent (to remove waxes from man-made and some blended fabrics), a suitable detergent, and allowing adequate retention time for the solution to remove impurities from the fabric. The fabric is then washed in hot water (approximately 140°F) to remove the scouring solution. Use of counter-current water flow in the washer improves washing efficiency by preventing contamination of inflowing fresh water and decreases water and energy requirements (in the form of steam).

Scouring on an open-width preparation range includes scouring, J-Box steaming for up to 30 minutes and washing. The specific energy consumption of this operation varies from 850 to 1090 Btu/lb. Scouring on a rope batch basis consists of caustic saturation, J-box steaming and washing. Average energy consumption values are 95 Btu/lb for the caustic saturation process, 75 Btu/lb are consumed in the J-box and washing can consume as much as 2100 Btu/lb. This yields a total of 2270 Btu/lb for a rope batch range which should be considered a typical upper value. The scouring process on a rope preparation range consumes on the average 1350 Btu/lb.

J-Boxes. J-Boxes, so named because they are constructed in the shape of a "J," (as shown in Figure 2.19) are used to provide the retention time necessary between processing steps to allow various chemical agents to act on the fabric under specific conditions and to provide limited storage on continuous lines to accommodate production surges. A typical J-box steaming on a preparation range with a 45 minute hold time consumes about 250 Btu/lb. A caustic J-box in rope bleaching consumes approximately 75 Btu/lb and a peroxide J-box consumes about 115 Btu/lb. However, not all J-boxes used in the line require steam.

Bleaching. Bleaching is required if the finished natural fiber or blended fabric is to be white or dyed. Bleaching is normally accomplished by treating the fabric with a hydrogen peroxide/weak caustic solution at an elevated temperature for up to 30 minutes. Residual bleach solution is removed through washing. Then the fabric is dried, usually using steamer cans and sometimes using semi-contact driers or a drying range.

Bleaching operations on a continuous open width preparation range includes bleaching, J-Box steaming and washing which consumes between 1335 to 4345 Btu/lb. Bleaching, steaming and washing on a rope preparation range consumes about 850-870 Btu/lb. On a rope range, the bleaching sub-steps consume the following specific energy: Peroxide saturation - 200 Btu/lb; Peroxide steam - 300 Btu/lb; Peroxide J-box - 120 Btu/lb; Peroxide wash - 230 Btu/lb.

Mercerizing. Mercerization of cotton fabrics is accomplished by applying a caustic solution (more concentrated than that used for scouring) in a multiple dip operation to cause swelling of the cotton fiber. Tensioning in a tenter frame for a few minutes improves the chemical take-up and the strength of the fabric, while tensionless treatment improves elasticity and abrasion resistance. Subsequently, the caustic solution is rinsed from the fabric, normally in a manner identical to that used following scouring.

Mercerizing can be accomplished on an open-width preparation range or on a mercerizer. In either case mercerizing consumes an average of 1190

Figure 2.19: Cross-section of a Typical J-Box

Btu/lb and 1575 Btu/lb, respectively. Open-rope fabric on a mercerizer range is processed through a water mangle, mercerizing and drying consumes between 5350 and 6670 Btu/lb. This range is based on mercerizing bleach fabrics with a set of dry cans on the range and ninety foot tenters with on-frame washers.

2.2.7.2 Dyeing. Fabric dyeing may be accomplished by either a continuous or batch process. The majority of woven fabric is continuously dyed with pad/squeeze type equipment (Figure 2.20). In this process, the dye is transferred to the fabric by passing the fabric across rollers which are partially submerged in the dye solution. The moisture content of the fabric is then reduced with squeeze rollers in order to conserve dyestuff and hot water and to reduce drying time. A pre-drier, usually gas-fired infrared, is used to begin the dye fixing process in a way so that the dyes remain evenly distributed through the fabric. The fabric is then heat fired in a thermosol oven if the fabric is a polyester or its blends, then it is dried, and cured. It should be noted that nylon is never thermosoled. Excess dye is sometimes removed by rewetting and drying the fabric. Pre-drying, heat firing, and drying are all large energy consuming processes.

Continuous woven fabric dyeing is basically accomplished on a continuous dye range which applies one of the following three methods: Thermosol oven, Pad/steam, or Thermosol and Pad/steam. Energy consumption for polyester thermosol dyed is about 2400 Btu/lb; for cotton, pad/steam dyed 6760 Btu/lb; for polyester/cotton dyed by thermosol and pad/steaming ranges from 6390 to 8550 Btu/lb, averaging 7345 Btu/lb. Dye range energy consumption can vary from 1000 to 9000 Btu/lb, averaging about 5900 Btu/lb. About two-thirds of this energy is lost through the exhaust stacks and about one-third is lost via the effluent water. Other continuous dyeing methods and their associated average energy consumption are as follows: pad/batch, 3570 Btu/lb; pad/dry, 5270 Btu/lb; pad/dry/bake, 5895 Btu/lb; pad/dry/chem pad/steam, 6050 Btu/lb; and pad/dry/thermofix/chem pad/steam, 6980 Btu/lb.

Batch dyeing of fabric is most often accomplished in atmospheric becks or in pressure jet dyeing machines as shown in Figure 2.21. The particular method selected often depends on characteristics such as level dyeing, batch size, and type of fabric. Methods are somewhat interchangeable. There is a

Source: Celanese Corp.

Source: Celanese Corp.

Figure 2.20: Selected Dyeing Machines

Source: Celanese Corp.

Source: Celanese Corp.

Figure 2.21: Selected Dyeing Machines

trend toward pressure jet dyeing due to increased production efficiencies and energy savings. Following batch dyeing, pieces of batch dyed fabric are sewn together and dried and cured on a continuous range.

The energy required in the batch dyeing of woven fabrics by atmospheric becks varies considerably. Reports as high as 24,100 Btu/lb can be found as well as others reporting 5820 Btu/lb.

In jet dyeing of woven fabrics, a horizontal, tubular-type jet consumes 4500-5100 Btu/lb without heat recovery, or 2100-2700 Btu/lb with cooling-water heat recovery. Autoclave-type jets consume 3300 Btu/lb without heat recovery, or 1500 Btu/lb with heat recovery.

Energy consumption of jigs averages 1765 Btu/lb, varying from a low of 585 to 2950 Btu/lb. Hosiery dyeing machines such as paddle dyeing machines and rotating drum machines consume an average of 23,500 Btu/lb.

2.2.7.3 Printing. Printing is normally accomplished by a semi-continuous flat screen process, continuous rotary screen process, or a roller printing process (Figure 2.22). Either solvent or water-based pigments, or a mixture of the two, can be used, along with water-based dyes. Solvent-based printing is normally more energy consumptive than water-based printing due to the larger volume of air which must be exhausted from solvent systems in order to prevent dangerous build-ups of volatile hydrocarbons in the drier atmosphere. In both flat screen and rotary printing, pigment is applied to fabric in a process similar to silk screening. In roller printing, the pigment/binder system is transferred to the fabric with an engraved roller. Following application to the fabric, the pigment/binder system is fixed in a brief high temperature curing process, and then dried. Synthetic fabrics sometimes require washing with hot water and detergents to remove excess dye materials with subsequent drying, but this is not required for cotton or blended fabrics. A typical rotary screen print range consumes an average of 9570 Btu/lb, varying from 505 to 15,150 Btu/lb.

In recent years, heat transfer printing has begun to approach the status of a common printing process. In this process, the sublimable dye is printed

Source: Celanese Corp.

Source: Celanese Corp.

Figure 2.22: Selected Printing Techniques

on a roll of paper and then transferred to the fabric by passing both paper and fabric through pressure rollers under heated conditions. Printing of small lots of apparel fabric (100% synthetic fibers) is the most common application of this process (Figure 2.22).

2.2.7.4 Finishing. Finishing operations normally involve the padding of a specific chemical onto the fabric, drying, and curing to fix the finish. Finishes such as antistatics, fire retardants, softeners, water repellents, and durable press resins may be applied. The chemicals stay on the fabric while the carrier (usually water) is evaporated when the fabric is dried. Drying is accomplished with pre-driers and drying ovens, and the finish is then cured in order to stabilize it. Mechanical finishing operations are also performed on certain products. These operations may include brushing, napping, shearing, creasing, sanforizing, and/or sanding, and serve to improve the hand of the cloth, dimensional stability, shrinkage characteristics, remove wrinkles, or alter the surface characteristics.

The average energy consumption of a chemical finishing range is 5685 Btu/lb, with a variation from 4050 to 8000 Btu/lb. These finishing ranges include the energy required for resin curing and a final calender. Natural gas is used for the infrared predrier, tenter dryer and curing oven. If fabrics need to be drier before finishing an additional 2470 Btu/lb are necessary.

A typical sanforizing range consumes 1310 Btu/lb, since this process only involves fabric shrinkage with a rubber belt unit and permanent press resin curing to stabilize the shrinkage.

The average energy consumption of the chemical finishing ranges is 2360 Btu/lb, with a variation from 415 to 6760 Btu/lb. Two-thirds of this energy is lost through the exhaust stacks, but interestingly enough radiation losses vary from only 2% to 30%. Properly maintained insulation and housings can easily correct this energy loss.

2.2.8 The Knit Fabric Dyeing and Finishing Component

The operations normally utilized in the knit fabric finishing process are shown in Figure 2.4.

2.2.8.1 Preparation

Knit fabric preparation primarily consists of scouring and bleaching. As shown on Tables B-16, knit preparation ranges have been calculated to consume between 223 and 411 Btu/lb of thermal energy as steam, averaging 355 Btu/lb. When including the range's electrical energy consumption the average specific energy ideally consumed in knit preparation is about 450 Btu/lb, as shown on Table B-46. In practice, however, knit preparation consumes an average of 2660 Btu/lb.

Scouring. Scouring of knit fabrics is employed to remove impurities and may be accomplished by Kier boiling, open-width or rope-form scouring, or solvent scouring. Kier boiling was the original knit fabric cleaning operation. In this process the fabric is treated with caustic, soap, chelating agents, and sodium silicate for 6 to 12 hours, after which the fabric is rinsed with cool water. Use of the process is primarily limited to lightweight fabrics since heavyweight fabrics show dye creases if scoured in this manner.

Open width and rope form scouring use a more concentrated caustic solution with added antioxidants. Steaming of the fabric assures even swelling and rapid destruction of impurities, which are removed during the subsequent rinsing of the fabric. In the case of fabrics knitted from synthetic yarns, scouring consists of washing with a detergent solution to emulsify the knitting oils, followed by rinsing.

Solvent scouring of 100 percent synthetic knits has been used in other countries but has not found widespread application in the United States. The solvent used is perchlorethylene or trichlorotrifluoroethane, and the equipment must be airtight to prevent air pollution and the escape of

valuable solvent. The solvent may be applied by either high velocity jets or by an immersion method. The process has the advantages that the wastewater load from the scouring operation is eliminated and the cost and energy consumption of subsequent fabric drying operations are significantly reduced. However, attrition of the solvent is a high cost factor, and possibly a worker safety and environmental hazard as well.

Bleaching. Bleaching of knit fabrics is normally limited to cotton knit goods such as underwear. Bleaching is normally accomplished by treating the fabric with a hydrogen peroxide/caustic solution and subsequently rinsing to remove residual caustic. Then the fabric is dried in preparation for dyeing.

2.2.8.2 Dyeing. The majority of knitted fabrics are batch dyed using one of a variety of processes, most often pressure or atmospheric becks or jet dyers. However, large lots of knit fabric may be continuously dyed in a manner similar to that described for woven fabrics. Recently, jet dye machines have achieved state-of-the-art for dyeing sensitive knit fabrics. In this process, the fabric is placed in the dye machine in a continuous loop, which is propelled by a continuous jet of dye liquor. The advantage of this process is that the relaxed fabric allows development of a full hand. The venturi jet turbulence assures good dye penetration, and the pressurized process uses less energy and water than other methods of dyeing. Continuous pad batch dyeing is slowly coming into acceptance for tubular knit dyeing. Problems with this method include "edgelines" and an additional drying step is needed after preparation. The advantage is that continuous pad-batch dyeing increases productivity.

Recent figures for atmospheric beck dyeing of knits vary from a low of 1620 to 3850 Btu/lb, and higher. Pressure jet dyeing of knits can vary from 1600 to 6260 Btu/lb. A typical energy consumption value for knit dyeing would be about 5890 Btu/lb as determined from a recent ITT survey.⁽⁴⁾

2.2.8.3 Printing. Printing of knit goods is less common than for woven goods, but may be accomplished with any of the same processes. Heat transfer printing is more common for knit goods than for wovens. The relative

importance of the various printing processes in knit goods production is not yet well defined since the knit industry is so young.

2.2.8.4 Finishing. As described for woven fabric, finishing can merely be washing and subsequent drying of the fabric, or may involve the application of any number of different applied finishes, e.g., permanent press, fire retardant. Mechanical finishing operations are less commonly used than for woven fabric. A typical energy consumption value for knit chemical finishing is about 2360 Btu/lb as determined from a recent ITT survey.⁽⁴⁾

2.2.9 The Floor Covering Component

The principal steps in carpet and rug manufacturing are shown in Figure 2.4. As indicated, carpets and rugs are produced from either dyed or undyed yarns, and may receive a secondary backing of either foam and/or woven material.

2.2.9.1 Heat Setting. After the spinning process, the yarns are twisted. After twisting, the yarns are heat set in an autoclave at high temperatures and pressures. The average energy consumption in twisting is 4500 Btu/lb at a production rate of 0.833 pounds/hour/position. This is over five times the energy consumption for winding. The energy consumed in twisting also escalates with finer yarn counts as is indicated in Table A-13.

2.2.9.2 Tufting. Tufting is the process of attaching carpet yarn to a primary backing material. Using mechanical needles, the yarn is looped into a loosely woven primary backing. The backing is a mesh-like network of (usually) woven polypropylene, which provides shape and body to the carpet. Carpets may also be produced by weaving or through non-woven processes; however, tufting is much faster than these other methods and produces carpet of satisfactory quality for the majority of applications. Tufting can consume a vast range of energy from 185 to 2000 Btu/lb.

2.2.9.3 Dyeing. Tufted carpet produced from undyed yarn is dyed or printed using one of several methods. Large atmospheric dye becks are the most prevalent method of batch carpet dyeing. In this process, the dye

liquor is heated with steam to facilitate penetration of the fibers as the carpet is continuously passed through the dye solution. This process takes approximately an hour, and is followed by several rinse cycles. For carpet dyeing, the current trend is that jet machines are replacing all becks.

Another method of carpet dyeing is the continuous Kuster range. In this process, the carpet is passed over a "swimming roll" that is partially submerged in a dye bath and is coated with a film of dye. As the carpet is passed over the roller, the dye is transferred to the carpet. In addition to the Kuster method, continuous dyeing can be accomplished by simply passing the carpet through a dye bath. After either continuous dyeing technique, the carpet passes into a steam chamber where the dye is set, and the carpet is then washed to remove excess dye and rinsed. An average energy consumption value for Kuster dyed tufted carpet is about 6150 Btu/lb. Similarly, atmospheric beck dyeing consumes about 6000 to 7500 Btu/lb.

2.2.9.4 Drying. Once the color has been established, the carpet is dried. Batch dyed carpet is sewn together to form a continuous run of material through the drying range. Thereafter, the batch or continuous dyed or printed carpet is handled similarly. First, excess moisture is removed by roller squeezing, sometimes accompanied by vacuum extraction. The carpet then passes through a gas-fired drying oven. The rate through the oven is dictated by the weight of the tuft. The dried carpet is then ready to print and/or receive the secondary backing.

2.2.9.5 Printing. The prevalence of carpet printing has increased in recent years; the method that is being phased out is flat bed screen printing. In this process, the carpet is passed along a table divided into a number of sections, the number depending on the number of different colors being applied. On each section, a squeegee forces the pigment through a fine mesh screen to produce a portion of the desired design. The carpet moves to subsequent sections of the table where additional colors are applied. Printing consumes between 18,000 and 60,000 Btu per square yard of carpet, which is approximately 7,200 to 24,000 Btu/lb.

Rotary screening is growing and replacing flat screens. A series of rotary screens, each containing a pigment, is used to transfer the pigment in the desired design to the carpet. A third printing method called ink jet printing uses nozzle jets to direct colors onto the surface of the carpet. Ink jet printing is the fastest growing method and rapidly becoming the "state-of-the-art." After printing, the carpet is cured and then washed in the same manner as was described for continuous dyeing.

2.2.9.6 Finishing

Finishing operations in floorcovering consist of the spraying of chemicals and a number of mechanical processes which improve the appearance of the product. The most common operations are selvage trimming, fluffing, and shearing of the carpet. After finishing, the carpet is rolled for shipment. Chemical finishing consumes between 1200 and 3900 Btu per square yard of carpet. Chemical finishes such as anti-soil and antistatics are sprayed before the carpet is rolled into airing ovens for secondary backing to be cured.

2.2.9.7 Secondary Backing. After tufting (for predyed or printed yarns) or drying, a foam or woven type of secondary backing is applied to the carpet. Both are done in continuous backing ranges.

Woven backing is applied by coating the surface of the primary backing with latex. The woven secondary backing is sandwiched onto the coated primary backing; the composite is compressed via marriage rolls to form a tight bond and cured in a gas fired oven. The nap is then raised by beating with paddles.

Foam backing is normally used for commercial and "kitchen" type carpets and carpet "tiles." It is applied by first spraying a thin layer of latex to the primary backing to assure adhesion. The foam is deposited on the back surface; set with infrared lamps (occasionally gas jets); rolled as required; and cured. Generally, the rate of travel in the curing oven is dictated by the backing thickness. The curing oven is similar to that used for woven backings except that the carpet is passed through the oven.

2.2.10 The Non-Woven Component

The non-woven manufacturing process includes the bonding of fibers with adhesive chemicals which are normally latex compounds. Approximately 40 percent of all non-woven fabrics consist of a sheet or web of fibers which is bonded together with adhesive, the remaining 60 percent of non-woven fabrics are thermally bonded if thermoplastic fibers are used. The bonding step is typically followed by a drying step. Non-woven fabrics are mainly used in the industrial and home furnishing sectors.

2.2.10.1 Web Formation

Non-woven fiber opening and blending are similar to cotton systems. Web formation takes place after these operations. Web formation patterns can be parallel, cross-laid or random. Cards are generally used for parallel web patterns, multiple lappers for cross-laid patterns, and air streams depositing fiber on a rotating screen (air-laid techniques) are used for random patterns.

2.2.10.2 Web Bonding

Web bonding techniques generally fall into one of three categories: mechanical, chemical and self-bonding.

Mechanical web bonding is accomplished by needle punching and uses no chemical additives. The product however has less strength than a chemically bonded non-woven. Stitchbonding is another mechanical technique which yields a product most like knitted fabrics.

Chemical bonding can be split up into wet and dry chemical bonding. Chemical wet bonding uses adhesives. Chemical dry bonding uses thermoplastic bonding and eliminates a drying step.

A typical chemical wet bonding process consumes 4550 Btu/lb., while a typical chemical dry bonding process consumes 2010 Btu/lb.

Self-bonding techniques generally use either a heat/pressure-based system or a solvent bonding system.

2.3 PRODUCTION AND ENERGY CONSUMPTION IN 1984

Detailed information on the U.S. textile industry's total energy consumption in the year 1984 is necessary to establish a reference energy consumption level from which future energy savings can be estimated. The following have been developed using the historical data already discussed:

- o Estimated specific energy consumption for each major process step; and
- o Materials and energy flows for the major process steps.

Table 2.2 attempts to pull together all the collected field data and published survey information. There are of course so many variations in the specific energy consumption figures and so many different ways (using different equipment) in which fabrics can be produced from yarns of various counts, blends, etc., that these figures are gross averages. However, Table 2.2 does serve to show where the major energy consumption takes place in the average textile manufacturing process. The data in Table 2.2 represents the national perspective and includes all electrical losses.

The textile processes listed in Table 2.2 are not applicable to all yarns, or final fabrics or products; therefore, not all processes are used on all poundages and thus the energy figures cannot be directly summed up as presented in this table alone. In order to overcome this limitation, material flows are estimated in Table 2.3 for the major process steps. The energy consumption for each process is summed accordingly, using data provided in Tables 2.2. and 2.3.

Table 2.2:
Summary of Specific Energy Consumption in Current Textile
Manufacturing Processes (Btu/lb)*

<u>Processes</u>		<u>Range of Energy Variation</u>		<u>Typical Average</u>
<u>Yarn Formation</u>		<u>Minimum</u>	<u>Maximum</u>	
<u>Component:</u>				
Opening/Blending		846	969	945
Carding	(a)	252	1809	754
	(b)	822	1569	1419
Drawing	(a)	98	348	163
	(b)	150	323	271
Lapping	(b)	114	705	465
Combing	(b)	936	1499	1077
Roving	(a)	299	976	622
	(b)	677	1219	985
Spinning	(a)	1613	20658	7520
	(b)	10125	23994	15700
(a) carded yarn count 3-31; average: 18.5				
(b) combed yarn count 25-49; average: 35				
<u>Texturizing Component:</u>				
Texturizing		11694	33390	20500
<u>Fabric Formation/Weaving</u>				
<u>Component:</u>				
Warping		46	2788	850
Slashing		1100	2900	2325
Weaving		1650	13990	5440
<u>Fabric Formation/Knitting</u>				
<u>Component:</u>				
Knitting		3540	10865	7200
<u>Non-Woven Component:</u>				
Web Bonding		475	5000	4550

Table 2.2:
Summary of Specific Energy Consumption in Current Textile
Manufacturing Processes (Btu/lb)*
(Continued)

<u>Processes</u>	<u>Range of Energy Variation</u>		<u>Typical Average</u>
	<u>Minimum</u>	<u>Maximum</u>	
Yarn Dyeing Component:			
Rawstock dyeing and drying	6967	11062	9440
Yarn Package dyeing and drying	6364	15036	10700
Woven Fabric Dyeing and Finishing Component:			
Heat setting	230	805	530
Singeing	47	250	154
Desizing	247	1095	465
Scouring	120	2270	1350
Bleaching	383	2256	1200
Mercerizing	593	3874	1920
Dyeing	961	8684	6225
Printing	5050	15150	9570
Finishing	415	6760	2730
Drying (single pass, includes pre-drying)	2710	6364	3455
Knit Fabric Dyeing and Finishing Component:			
Preparation (D/S/B)	225	5100	2660
Dyeing	1600	6260	5890
Finishing	1650	5150	2360
Drying	2000	6000	3000

Table 2.2:
Summary of Specific Energy Consumption in Current Textile
Manufacturing Processes (Btu/lb)*

<u>Processes</u>	<u>Range of Energy Variation</u>		<u>Typical Average</u>
	<u>Minimum</u>	<u>Maximum</u>	
Floor Covering Component:			
Twisting	1865	20150	4500
Heat setting	260	4660	3150
Tufting	185	2000	1050
Dyeing	6000	13600	9800
Printing (Btu/yd ²)	18000	60000	39000
Finishing	1800	5500	3500
Drying	2290	6550	4350
Auxiliary Processes:			
HVAC (greige mill)	1638	2047	5530

*Energy intensity factor 10,500 Btu/kWh-electric
ITT surveys
Energetics, Inc. surveys and field trips to mills

Table 2.3
Breakdown of Current Industry Production

<u>Production</u>	<u>(Million Pounds)</u>	<u>%</u>
Total	10,800	100.
Spun yarn	8,550	79.
Dyed Yarn	1,300	12.
Texturized Yarn	2,250	21.
Woven Fabric	8,330	77.
Dyed Woven Fabric	5,500	51.
Printed Woven Fabric	1,370	13.
Knit Fabric	1,620	15.
Dyed Knit Fabric	1,420	13.
Printed Knit Fabric	135	1.
Non-Woven Fabric	850	8.
Floor Coverings	1,980	18.
Dyed Floor Coverings	1,270	12.
Printed Floor Coverings	190	2.

Source: Energetics, Inc.

Dr. Fred L. Cook, Georgia Institute of Technology.

Detailed calculations of energy and material use by major process in 1984 by the industry are shown in Table 2.4, and as such reflects the nation's perspective of energy consumption and uses an energy intensity factor of 10,500 Btu/kWh-electric.

In an effort to characterize the typical energy use in the textile industry, the data in Table 2.4 represents the energy consumption in the production of an "average product" of each class (woven fabric, non-woven fabric, knit fabric and floor covering) in a fully component integrated mill using a completely continuous operation. In contrast, the data in Table 2.2 represents the full range of energy consumption figures for each process under both batch and continuous operations. Therefore, the typical values

used in each table do not necessarily compare on a one-to-one basis. Additionally, not all processes are found on both tables, since these processes are not necessarily used on all poundages. For example, the drawing process in Table 2.4 includes the drawing and lapping processes in Table 2.2. This is not true for the state-of-the-art and advanced process analyses found in Section 4. It is acknowledged that in the overall analysis, these factors will tend to average out.

The results of Table 2.4 correspond to the 1984 value of total energy consumed with electrical losses in Table 2.1. The 1984 energy figures as categorized by industry components are compared to the 1972 values on the bar chart in Figure 2.23.

The usefulness of comparing present energy consumption to the 1972 value is that industry respondents to Department of Energy surveys still use 1972 as the base year for voluntary energy conservation targets and for measuring their energy efficiency progress, (97 percent of the respondents use 1972, the remaining few use 1978 as the base year).

The 1972 energy consumption figures by industry component are derived from the June 1977 Federal Register as supplied by the then, Federal Energy Administration. Figure 2.23 serves to update these data and shows in which components the most energy conservation and efficiency progress has been made. The results of Figure 2.23 should not be taken at face value alone. The changes in energy consumption over these years reflect changes in technology, procedures and processes, production levels and the production mix.

The major differences in the 1972 and 1984 production mix which explain much of the differences in the energy consumption of the industry components as detailed in Figure 2.23 and are shown in Table 2.5. The more noticeable differences are in the texturizing and knitting components. In 1984 the production of goods from these components are much less while the weaving components experienced an increase of its share of the production. The amount of yarn dyeing and carpet manufacturing are relatively stable.

TABLE 2.4

Energy and Materials Use by Major Process - 1984

<u>Process</u>	<u>Materials Used</u> <u>(10⁶ pounds)</u>	<u>Specific Energy</u> <u>Use (Btu/lb)*</u>	<u>Total Energy</u> <u>Use (10¹² Btu)</u>	<u>Cumulative</u> <u>Energy</u> <u>Use (10¹² Btu)</u>
<u>Yarn Formation Component</u>				
Carding	8550	930	8.0	
Drawing	8550	565	4.8	
Roving ^(a)	5120	710	3.6	
Spinning	8550	9530	81.5	
HVAC ^(b)	8550	2320	<u>19.8</u>	
Subtotal			117.7	117.7
(a) 40% production by open-end spinning: eliminates these processes. 60% production by conventional ring spinning.				
(b) HVAC total from Table 2.2 is allocated among yarn formation, weaving, knitting and floor covering components.				
<u>Texturizing Component</u>				
Texturizing	2250	20500	46.1	163.8
<u>Fabric Formation/Weaving Component</u>				
Winding	8330	850	7.0	
Slashing	8330	2325	19.4	
Weaving	8330	5440	45.3	
HVAC	8330	2270	<u>18.9</u>	
Subtotal			90.6	254.4
<u>Fabric Formation/Knitting Component</u>				
Knitting	1620	7200	11.7	
HVAC	1620	550	<u>1.0</u>	
Subtotal			12.7	267.1
<u>Non-Woven Component</u>				
Fiber Bonding	850	4550	3.9	271.0

TABLE 2.4

Energy and Materials Use by Major Process - 1984
(Continued)

<u>Process</u>	<u>Materials Used</u> <u>(10⁶ pounds)</u>	<u>Specific Energy</u> <u>Use (Btu/lb)*</u>	<u>Total Energy</u> <u>Use (10¹² Btu)</u>	<u>Cumulative</u> <u>Energy</u> <u>Use (10¹² Btu)</u>
<u>Floor Covering (Dry) Component</u>				
Twisting	1980	4500	8.9	
Heat setting	1980	3150	6.2	
Tufting	1980	1050	2.1	
HVAC	1980	560	1.1	
Subtotal			18.3	289.3
<u>Yarn Dyeing Component</u>				
Yarn dyeing & drying	1300	9500	12.4	301.7
<u>Woven Fabric Dyeing and Finishing Component</u>				
Heatsetting	8330	530	4.4	
Singeing	8330	155	1.3	
Preparation	8330	3235	26.9	
Mercerization	8330	1920	16.0	
Dyeing	5500	6225	34.2	
Printing	1370	9570	13.1	
Finishing	8330	2730	22.7	
Drying	8330	3455	28.8	
Subtotal			147.4	449.1
<u>Knit Fabric Dyeing and Finishing Component</u>				
Preparation	1620	2660	4.3	
Dyeing	1420	5890	8.3	
Finishing	1620	2360	3.8	
Drying	1620	3000	4.9	
Subtotal			21.3	470.4

Note: The poundage of printed knit fabric is relatively small and therefore neglected.

TABLE 2.4

Energy and Materials Use by Major Process - 1984
(Continued)

<u>Process</u>	<u>Materials Used (10⁶ pounds)</u>	<u>Specific Energy Use (Btu/lb)*</u>	<u>Total Energy Use (10¹² Btu)</u>	<u>Cumulative Energy Use (10¹² Btu)</u>
<u>Floor Covering (Wet) Component</u>				
Dyeing	1270	9800	12.4	
Finishing	1980	3500	6.9	
Drying	1980	4350	<u>8.6</u>	
Subtotal			27.9	498.3
Note: The poundage of printed floor coverings is relatively small and therefore neglected.				
			GRAND TOTAL**	498.3

*Energy Intensity factor 10,500 Btu/kWhe

**Grand total is within 10% of Table 2.1.

Deviation is due to production mix estimates possibly differing from the actual mix and due to the use of average energy.

Source: Energetics, Inc.

Table 2.5
Comparison of the 1972 and 1984 Industry Production Mix

<u>Component</u>	<u>1972</u> <u>Production 10⁶ pounds</u>	<u>1984</u> <u>Production 10⁶ pounds</u>
Yarn Formation	6321	8550
Texturizing	4130	2250
Fabric Formation/Weaving	5889	8330
Fabric Formation/Knitting	2100	1620
Dyeing & Finishing/Woven	4689	5500
Dyeing & Finishing/Knit	2100	1620
Yarn Dyeing*	1200	1300
Floor Covering	2145	1980
Total	10450	10800

*Includes Package, Skein, Space and Beam Dyed yarns.

Sources: Energetics, Inc.

SCS Engineers, Inc., "Energy Efficiency Improvement

Target in the Textile Mill Products Industry SIC 22," 1977,

FIGURE 2.23: ENERGY CONSUMPTION BY TEXTILE COMPONENT

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SOURCE: ENERGETICS, INC. AND REFERENCE NO. 145

** TARGET WEIGHTED AVERAGE: 22

SECTION 3. STATE-OF-THE-ART AND ADVANCED TEXTILE MANUFACTURING TECHNOLOGIES

Unlike other manufacturing industries, the textile industry has the unique characteristic of modernizing in a very gradual and systematic way. Its ability to make changes on a single piece of process equipment without any drastic risks to the production line or to the financial health of the company has provided the industry with the advantages of flexibility.

The textile industry has made some progress in process modernization and automation over the last 5-10 years. The industry is in the midst of a technological transition that is converting their mills from traditional, low-technology operations to ones utilizing some of the most sophisticated technology available today. Leading companies have increased their energy awareness, and are emphasizing computer monitoring of all process steps in terms of quality, production rate and energy consumption. The textile producing companies regard this step as a competitive edge where new technology must be diligently applied and adopted in order to minimize manufacturing costs, to improve quality and overall productivity and to provide more flexibility in their product offerings.

Often, new technology is developed by the textile machine and equipment manufacturing industries. The trend in the new technology that is being utilized is to reduce the number of process steps and to reduce the labor content of the process. The impetus behind this trend in technology is to move textile manufacturing from an art to a science. This approach will allow exact reproducibility of any process yielding an acceptable quality product the first time through the processes. This will eliminate reprocessing of the same material, thereby allowing energy standards for each individual process, reducing overall manufacturing costs.

This section presents information on the most promising advanced textile-manufacturing technologies that are either under development or have recently completed development. The information is based on recent literature searches and on personal discussions with industry experts.

The results are presented in three parts. The first part (Section 3.1) discusses energy conservative measures which have been adopted by the industry. The second part (Section 3.2) discusses the state-of-the-art in textile processing, including the best available technologies. The third part (Section 3.3) discusses advanced technologies and presents a conceptualized textile mill production sequence that includes some of the more advanced concepts for each process step.

3.1 RECENTLY ADOPTED CONSERVATION MEASURES

There are four major effective approaches to achieve energy conservation in the textile industry. They are:

- o The recovery of energy;
- o The management of energy;
- o Saving energy with old processes (housekeeping); and
- o The development of new processes for energy-savings.

Figure 3.1 indicates how the four approaches are related to the manufacturing processes. The goal is to efficiently make use of machinery and materials without decreasing production or product quality.

The industry has already begun to meet this challenge by implementing many low-cost, high-payback conservation measures, and developing some technology improvements that offer the side benefit of increased energy efficiency. The industry's strategy is to introduce energy-saving techniques through process optimization/modification. Energy conservation has been achieved by:

- o Maximizing output per unit duration of various electrically driven machines,
- o Incorporating effective automatic controls,
- o Reducing and combining processing steps,
- o Using less water intensive processes or those which require low evaporative drying, since water consumption and energy requirements are virtually inseparable. In fact, reduction in water consumption will be beneficial in reducing the volume of effluents and related problems of treatment and disposal,

Reference: Textile Progress, VI3, N3.

Figure 3.1: Energy Conserving Approaches on the Individual Process Level Basis.

- o Installing the proper size and maintaining electric motors and equipment,
- o Improving thermal insulation,
- o Increasing energy awareness and process energy monitoring,
- o Tightening controls on batch dyeing equipment,
- o Conducting energy conservation seminars,
- o Improving lighting level controls,
- o Recovering hot water,
- o Employing microprocessor-based moisture controls on dryers and curing ovens and using differential pressure controls in steam stacks,
- o Reclaiming heat with heat exchangers,
- o Using efficient HVAC units,
- o Using vacuum extractors,
- o Using efficient dye/finish application equipment,
- o Operating with more continuous processing,
- o Controlling wet pick-up (WPU),
- o Shortening of processing sequences,
- o Shutting off non-essential equipment, reducing down-time and change-overs,
- o Recovering boiler condensate,
- o Maintaining steam-traps,
- o Recovering boiler blow-down heat,
- o Attempting to level energy demand curve,
- o Employing counter flow washboxes,
- o Limiting washbox flows,
- o Limiting air flows,
- o Preventing fabric overdrying by using humidity sensors,
- o Running the mill against overall composite plant energy standards,

- o Using low liquor batch dyeing machines,
- o Having effective maintenance and lubrication, and
- o Having a dual drain system: one for hot and one for cold effluent - recovering heat from the hot stream without tempering.

Table 3.1 summarizes some of the more significant conservation measures that have been recently adopted by the industry. Estimated energy savings and percent of industry adoption are shown based on a consensus of industry experts and from survey results.

3.2 STATE-OF-THE-ART TECHNOLOGIES

State-of-the-art textile process technologies are those technologies that have demonstrated their technical feasibility in actual mill environments, such as a commercial or large pilot plant. Application of the best available technology to textile processes is being pursued in all of the major process categories. Figure 3.2 is a simplified process flow diagram of textile manufacturing that incorporates various state-of-the-art process alternatives. These alternative technologies are either current technologies with numerous associated modification measures that increase process efficiency or they are totally new technologies.

Appendix C summarizes some of the more significant state-of-the-art energy conserving technologies that have recently been adopted by the industry. These technologies were chosen independently of their place of origin and current usage. Some were chosen because of their expected impact within the near future. Appendix C shows the potential impact of each measure on the energy consumption of its respective process and its current utilization by the textile industry. These measures are described in more detail in the following paragraphs.

3.2.1 Dry Processes. Although the amount of energy consumed in dry processing is considerable, a relatively small amount of the energy conservation work done in textile industry has been directed toward dry processes. This is due to wet processes being more amenable to reduction in

Table 3.1
TEXTILE INDUSTRY CONSERVATION MEASURES IMPLEMENTED

Description	Estimated Energy Savings (%)	Industry Adoption (%)
Boiler upgrades	15 - 20	H
Water softeners	---	H
Lighting		M
- Reduction	10%	H
- Task point concept of area lighting (e.g., sodium sulfur)	35%	M
Computerisation	10%	M
Environmental conditioning		
- Enthalpy control to monitor environmental air conditioning system	15%	M
Recirculating water to reclaim heat from wet processes through heat exchangers	50%	H
Installation of dye bath recirculator in the beck	10%	L
Highly controlled operations in order to take advantage of the electric rate struoture (i.e., peak vs. non-peak and demand oharges)	5%	M
Combined Preparation lines	30%	L
Dyebath reuse	25%	L
Beck: bump and run	30%	L
Beck indirect steam heating	10%	M
Foam Finishing	40%	M
Oven exhaust heat recovery	30%	L
Differential pressure controls of steamers (minimizes stack losses)	25%	L
High Efficiency Motor	10%	M

H = 50 - 90
M = 20 - 50
L = Less than 20

Figure 3.2 State-of-the-Art Process Flow Diagram

Figure 3.2 State-of-the-Art Process Flow Diagram
(continued)

Figure 3.2 State-of-the-Art Process Flow Diagram
(continued)

Figure 3.2 State-of-the-Art Process Flow Diagram
(continued)

FABRIC FORMATION/
KNITTING COMPONENT

Figure 3.2 State-of-the-Art Process Flow Diagram
(continued)

energy consumption than dry processes, and due to the emphasis on increased productivity from the mechanical-based dry processes. Most of the energy savings in dry processing can be realized by improving the design and sizing of electric motors and reducing the air conditioning requirements. The general technical thrust has been to simplify operations by reducing the number of process steps (See Figure 3.2).

YARN FORMATION

Advances in automation have occurred in all stages of yarn production. The first stages of fiber preparation involve opening, blending, picking, and carding. Conventional operations perform these functions separately, requiring movement between processes. Currently, however, many large plants are using direct-feed carding systems, which combine the opening, blending and carding into one operation and eliminate the picking stage altogether. The direct-feed carding system is more efficient than the conventional methods and eliminates the need to transport the fibers between each stage. At the present time, approximately 10 percent of yarn output is produced by the new method.

Spinning. The final step of yarn manufacturing is spinning. Expenditures for new spinning equipment have focused on open-end or rotor spinning, which produces four to five times the output of ring spinning and integrates roving, spinning, and winding into one operation. This system also can process fibers of different lengths and use waste materials unsuitable for conventional ring spinning. Currently, 40 percent of the yarn used in weaving is produced by the open-end method. Air-jet spinning, which is rapidly becoming the state-of-the-art in certain yarn counts, and friction spinning have also generated great interest among yarn producers because of the high speeds and quality output of these systems. New open-end spinning frames can produce yarn routinely at 250-300 ft/min, and new air-jet spinning equipment promises to deliver output as high as 600 ft/min. Modern equipment also has dramatically reduced the number of steps to convert baled fiber into yarn.

TEXTURIZING.

Air-jet technology is being introduced in the texturizing process. Texturizing with air-jet crimpers is a replacement for mechanical false-twist texturizing. The state-of-the-art machines can texture yarn at over 3000 ft/min, and there is more improvement to come.

WEAVING.

Economic factors are responsible for the fly-shuttle loom's certain demise. Fly-shuttle looms are rapidly being phased out and replaced with modern shuttleless looms. These shuttleless looms operate at three times the rate of conventional shuttle looms. Many kinds of shuttleless looms are available, including rapier, projectile, water-jet, and air-jet looms. The new looms currently produce about one-half of all woven fabric output. In addition to improving productivity, these looms are quieter and take up less floor space per unit of production than conventional looms.

Worldwide, there are 3.5 million operating weaving machines. Approximately 3 million are fly-shuttle looms. The 500,000 shuttleless looms are divided as follows: 230,000 rapier weaving machines, 150,000 projectile looms, 70,000 air-jet looms, and 50,000 water-jet weaving machines. In the United States, 34% of the 225,000 units in operation (i.e., approximately 75,000 looms) are shuttleless weaving machines, (refer to Table 3.2).

The current trends in weaving technology are:

Rapier technology: This technology offers advantages of versatility, high productivity, short set-up times, easy turning, and low strain on warp and filling yarns.

Air-Jet technology: This technology provides high efficiency for standard fabrics, high production with low space requirements, and a favorable price/productivity relationship. With this technology,

TABLE: 3.2 Global Weaving Installations (1985)

Types of Weaving Machine	USA		WORLDWIDE	
	Units	%	Units	%
Shuttles	150,000	66.66	3,000,000	85.71
Rapier	31,000	13.77	230,000	6.58
Projectile	24,000	10.66	150,000	4.28
Air-jet	13,000	5.77	70,000	2.00
Water-jet	7,000	3.11	50,000	1.43
TOTAL	225,000	100	3,500,000	100

Reference: Textile Month, August 1985.

it is especially important that the quality of yarns and the preparation meet the requirements of air-jet weaving machinery. (Optimizing yarn preparation is required).

The trade-off of the priorities of versatility and the highest possible output is usually combined with the constraint of the minimum of financial commitment. This combination of demands cannot be met with a single machine. A mix of different types of machines (technologies) is still necessary to achieve high output. The following details the state-of-the-art features of the currently available weaving machines:

Air-Jets:

- Speeds continued to climb up to 800 picks per minute (ppm)
(normal operating range 400-600)
- Automatic defective filling removed
- Computer controlled weft-insertion nozzles
- Microprocessor-based technology-performance data for bidirectional communication (feedback) system
- Insertion rate 420-1900 yards per minute (ypm).

Flexible Rapiers:

- Speeds up to 560 ppm (normal operating range 170-350)
- Up to 8 color selection
- Electronic monitoring
- Automatic pick finding
- Excellent terry weaving machines
- Insertion rate 279-1190 ypm.

Rigid Rapiers:

- Weft insertion systems and projectiles provide the most weaving versatility
- Speeds up to 560 ppm (normal operating range 275-400)
- Insertion rate 598-1344 ypm.

Multisheds: (Discussed in detail in Section 3.3)

(Research Stage)

Industry interest, yet no major U.S. production unit is in operation

Speeds up to 600 ppm (range 565-600)

Insertion rate 2040-2367 ypm

Application for producing sheeting.

Projectiles:

Wide versatility

4-color selection

Speeds up to 400 ppm (normal operating range 250-350)

Insertion rate 784-1094 ypm.

Water Jets:

Not as much interest as air jets

2-color and filling mixture selection

Speeds up to 1000 ppm (normal operating range 450-600)

Insertion rate 838-1944 ypm.

The specific energy consumption index numbers and the productivity index numbers of the state-of-the-art weaving technologies presented in Table 3.3 are based on the graph in Figure 2.14. These index numbers are based on the productivity and energy consumption data for shuttlelooms as the normalized standard of 100. These index numbers can be used to rank the competing weaving technologies.

Table 3.3

State-of-the-Art Weaving Technology Summary

	Average Specific Energy Consumption Index (Shuttleloom=100)	Average Productivity Index	Production Rate (ppm)	Insertion Rate (ypm)
Air Jets	125	300	400-600	420-1900
Flexible Rapiers	100	175	170-350	279-1190
Rigid Rapiers	100	175	275-400	598-1344
Multi-Sheds*	75	525	565-600	2040-2367
Projectiles	88	250	250-350	784-1094
Water Jets	75	250	450-600	838-1944

*Advanced technology included for comparative purposes only.

KNITTING

Knitting is not an energy intensive process. One development that will become firmly entrenched is a knitting systems without needles, or at least without latch needles. Needle costs can be very high. A 28-cut machine uses about 6,000 needles with an average life of six months. Needle costs can run as high as \$15,000 per year for each machine. In order to cut production costs, knitting mills will adopt this system.

Warp knitting machines will continue to dominate in the drapery and apparel material markets which demand sophisticated patterns.

Recent Advances: Recent developments in knitting have placed some knitting techniques in a very competitive position in markets dominated by weaving. One example is the flat crochet knitting machine's versatility. The products of this machine have dimensional stability at least equal to woven goods, but at two to three times the present weaving production rates.

Another development is the introduction of knitting machine memory by photosensors. Patterns of about 51,000 to 114,000 stitches can be stored.

Synthetic Lubricants A relatively small amount of energy conservation work done in the textile industry has been directed toward dry processes. Besides replacing old motors with high efficiency motors and utilizing variable speed controllers, some mills have experimented with the use of synthetic rather than petroleum lubricants. These experiments or trial runs have achieved mixed results due to their non-scientifically controlled approach. One mill reported only a 1 to 2 percent increase of efficiency due to the use of synthetic lubricants. Recently however, a well documented study conducted by a textile manufacturer has indicated increases up to 27 percent over the existing efficiency of equipment using traditional petroleum based lubricants. The study has proven the importance of cleaning before repacking lubricating seals. In this study, a proprietary cleaning technique was used. The following data in Table 3.4 provides the results of the study.

Table 3.4
Energy Savings Potential Due To Synthetic Lubricants
Over Petroleum Lubricants

<u>Process</u>	<u>Changes in efficiency</u>
Carding	7.6%
Drawing	18.0%
Ring spinning	11.5% to 27.0%
Winding	18.7%
Fly shuttle loom	17.0%
Air-jet loom	18.2%

Reference: Energetics, Inc. Survey.

Non-Woven Web Formation: State-of-the-art techniques in this area have been borrowed from paper-making. Wet laying and dry laying are two such techniques. Wet laying involves suspending fibers in water onto a rotating perforated cylinder. Excess moisture is removed by vacuum extraction. Wood fiber is sometimes mixed with the textile fiber. Random patterns can be formed by dry laying which can be produced using electrostatic deposition.

Non-Woven Web Bonding: One method of thermoplastic bonding is ultrasonic bonding. The heat needed to bond thermoplastic fibers is generated by ultrasounds produced by a horn. This process has been commercialized for quilt manufacturing.

3.2.2 Wet Processes

The wet processing of textiles is the most energy-consumptive part of textile processing. Most of the energy for the wet processes is in the form of thermal energy. The drying of wet fabric is the major user of energy in textile processing (2000 - 5000 Btu/pound of evaporated water). Water's primary role in the textile wet process is as a medium for uniformly applying chemicals to the fabric. Energy conservation efforts entail reducing water consumption per pound of fabric, reducing the number of washings and dryings between processes as well as shortening their duration, lowering process temperatures, and using other low cost mediums which have a lower heat of vaporization than water, such as solvents. Air is ideal since it is already gaseous and there is no heat required for vaporization. This characteristic is properly exploited in foam processing technology.

Efforts have been made to reduce the number of discrete processes in wet processing (preparation, dyeing and finishing) drastically by combining as many steps as possible.

A summarization of the state-of-the-art wet processes follow.

WARPING/SLASHING⁽⁵⁾

One system that saves energy and serves as a cost-reducer is the combined warping and slashing single operation. This is accomplished by eliminating the section beam by using huge creels containing large yarn cones. In this system, sophisticated stop motion systems will provide the ultimate in quality control measures. Yarns feed directly in a sheet to the slasher for sizing.

However, the drawback in accepting this technology has been that most mills will still rely on section beams, feeling they give top quality assurance for slashing. They also make it easier for the attendant to repair breaks without creating a problem in weaving.

Efforts to reduce energy consumption in slashing involve lowering the cooking and drying temperatures. There are several new slashing methods which focus on the reduction of moisture applied to the yarn. The most utilized method is detailed below:

High Pressure Squeezing⁽⁶⁾

Several systems are presently available for new slashers or as a retrofit which include high-pressure squeeze rolls and modified size boxes. The new system is able to remove more moisture from the warp yarns before they pass over the dryer cans, thus reducing the drying energy requirements. However, the electrical energy requirements are higher for the high-pressure system because a larger motor is required to produce the higher roll pressures. The increased electrical energy is small in comparison to the savings gained in drying. Other advantages of the high-pressure system are faster slashing speeds and better size penetration. The primary disadvantage is that size migration to the surface is decreased causing a "flattening effect" to the yarn.

Foam Sizing

Refer to the foam technology section.

Solvent Slashing

Refer to the solvent processing section.

Sizing Recovery with Wash-Water Reuse⁽⁷⁾

Most woven goods require the use of warp size (traditionally starch and/or PVA) during manufacture to prevent damage to the warp from excessive abrasion during weaving. The size is generally removed as the first operation in fabric finishing. Pure polyvinyl alcohol (PVA) is becoming the material of choice for warp sizing of synthetics, such as polyester, and polyester/cotton blends. Its use in the textile industry accounts for about 60% of all sizes used. PVA is generally removed from fabric by washing in water at temperatures of 190-200°F, with much energy lost in the waste water. It has been demonstrated that PVA can be recovered by the ultrafiltration (reverse osmosis) process. This process has now been commercialized and there have been no serious operating problems with the filtration system by several manufacturers. The systems have been saving money (recovered chemicals), but not energy due to the additional pump energy and the low quality of the recovered hot water.

Combining the Desize, Scour, and Bleach (DSB) Processes^(8,9)

The process of fabric preparation accounts for about 17% of the total energy consumed by the textile industry. In proper perspective, fabric preparation consumes approximately 85 trillion Btu's per year of the nation's energy supply.

Conventional continuous preparation of cotton-containing woven fabrics generally involves three stages: desizing, scouring and bleaching. The process is exceptionally intensive in energy, material and space requirements. Surprisingly, the preparation process has received the least research and development to reduce energy consumption of any of the textile wet processes.

A logical approach to energy/material conservation in preparation is to shorten the sequence events by combining the operations of desizing-scouring-bleaching (DSB) into one stage. Such a combined DSB process would establish conservation-through-elimination while drastically reducing operating costs.

Four combined DSB preparation processes have recently been investigated:

1. KPP (tetrapotassium peroxydiphosphate) process
2. C/P (Caustic soda/hydrogen peroxide) foam process; and
3. SPS (sodium disper sulfate) process
4. AA (actiron ash and Protegal DM).

All the processes involve a single pad-steam-wash sequence.

Of these processes, the SPS and AA yielded poorly prepared fabrics. The KPP and C/P yielded commercial-quality goods. Of these two, the KPP process requires no additional capital investment in order to implement, and the KPP process is projected to have a 50% market penetration.

Overall energy consumption for the conventional fabric preparation is 2400 Btu/lb for the range as compared to a total of 525 Btu/lb for the KPP process. Therefore, the projected textile-industry conservation potential for this technology is approximately 10 trillion Btu per year.

Solvent Processing⁽¹⁰⁾

Solvent processing offers the prospect of substantial energy savings over conventional aqueous processing, principally because about eight and one-half times more energy is required per pound to heat and vaporize water than to heat and vaporize typical organic solvents. Further, because nonaqueous solvents have higher vapor pressures, drying rates are appreciably faster. Solvent processing is potentially applicable to most major wet processing operations such as sizing and desizing, scouring, bleaching, dyeing, and various finishing processes. However, solvent processing is not without major economic and environmental disadvantages. Direct solvent

losses from the process can be in the range of 5-8%, and more than 98 percent of the solvent must be recovered to make the economics of the processes acceptable and to meet air quality requirements. However, there are installations in the textile industry with carbon adsorption systems for solvent recovery, and the users claim acceptable economics and compliance with air pollution and worker exposure regulations.

To date, there has been no appreciable commercial use of solvent finishing for woven goods. However, solvent processing has established a firm, if specialized, position in the finishing of synthetic knit fabrics. Solvent processing has also found commercial use where superior fabric properties are desired, for example, in the application of stain-repellent finish to upholstery and drapery materials. In this case, aqueous treatment is not always possible, because the fabric is sensitive to water. Similarly, solvent scouring and finishing of synthetic knit fabrics is widely practiced, because improved quality is obtained by avoiding contact with water. Some finishes, furthermore, are not available in water-soluble or water-dispersible forms. If these could be introduced, considerable investment in new equipment would be required, together with development of an expanded range of solvent-compatible reagents, dyes, and finishing chemicals.

Batch Dyeing Processes at Low Ratios of Dye Liquor to Cloth⁽¹¹⁾

A variety of dyeing machines are currently used in the textile industry. Some of these, including atmospheric dye becks and pressurized dye machines, have been in service for a long time. Considerable energy can be saved by enclosing the open becks and controlling stack losses to prevent steam escape. Pressurized machines use considerably less water. It is estimated that improving the average level of operations to that of the best existing in the industry might save 15% to 20% of the current energy use in dyeing operations, or about 2% to 3% of the total energy used in a typical mill.

Additional energy could be saved by reducing the amount of water used in dyeing. However, as the ratio of dye solution to cloth decreases, the difficulty of obtaining uniform color increases. This problem varies with the dye

and fiber mix in the fabric. However, processes and equipment have been developed for dyeing at very low ratios of dye liquor to cloth with uniform dyeing. Liquor-to-fabric ratios of 5:1 have been demonstrated for pressure batch dyeing of knit fabric. The ratio for foam dyeing is even lower (1:1). This is a considerable reduction from the commonly used 25:1 to 10:1 ratios, with consequent savings in energy and water.

Bump-and-Run(12)

In the beck dyeing process, a substantial amount of energy is required to heat the water to the dyeing temperature and to hold it during the dye cycle. An exhaust hood and fan are required to remove the large volume of water vapor and steam produced at the surface of the bath.

Experiments conducted by Georgia Institute of Technology researchers revealed that 45% to 60% of the total energy used in the dye beck is lost through the exhaust stack. The need to reduce this loss is clearly indicated. The technology of bump-and-run, in which the dyebath temperature is allowed to drift for the last 85% of the hold time instead of being maintained by active steam sparging has been shown to cut stack losses by 75% with no detectable reduction in product quality.

Bump-and-run is an excellent example of the somewhat rare variety of process energy conservation opportunity that offers substantial energy savings (up to 38%) at an insignificant initial cost or equipment modification.

Indirect Steam Heating(13,14)

The indirect steam heating of dye becks through heat transfer surfaces and coils is becoming economically feasible as energy costs rise.

The major advantages of indirect steam heating over sparging are the ability to return condensate to the boiler and the elimination of steam that passes through the dyebath without condensing. Since the condensate can be returned to the boiler, the temperature of the feedwater is increased thus

improving the boiler efficiency. Chemical treatment of feedwater can be reduced since the returned condensate does not have to be retreated. Boiler capacity is freed for other uses due to the reduced steam demand from the dye becks. The condensed steam is not present to dilute the dyebath and increase the water volume.

An inherent characteristic of indirect heating is that the temperature control must be very precise in order to prevent overheating. This technique has reached the in-plant demonstration stage.

Dye Bath Reuse(15,16)

A typical batch dyeing operation, once finished, will have appreciable quantities of auxiliary chemicals, a small quantity of dyestuff, and a large amount of hot water in the dye bath, which is flushed down the drain. In some cases, a small part of the energy is routed through various types of heat exchangers, but in general, approximately half of the energy that is lost in batch dyeing processes is dumped down the drain.

Research at the Georgia Institute of Technology has shown that carpet has been successfully dyed to the same shade five times using the same dye bath after chemical replenishment, and hosiery has been successfully dyed reusing the dye bath up to 41 times. This technique has reached the in-plant demonstration stage.

Procion™ High-Temperature Reactive Dyes(1)

The textile industry has long desired a combined system whereby both the disperse dye and the reactive dye could be applied simultaneously. With the introduction of high temperature stable Procion T and Procion H-E reactive dyes by Imperial Chemical Industries (ICI), such an application is now possible.

The new dyes, arising from flame retardant research initiated at the Stanford Research Institute, contain phosphorous acid or phosphoric functional groups which form a covalent bond with the cellulose on reaction. The major characteristic of the dyes are:

- o Unaffected by water in any form;
- o Function best under mildly acid conditions; and
- o Relatively high temperatures required for fixation.

The Procion T/Dispersol T system is designed for simultaneous dye application to polyester/cotton blends in continuous ranges. The variety of Procion T reactive dye shades offered by ICI have many benefits over conventional low-temperature reactive dyes. The application procedure is much shorter than a conventional cycle. A considerable energy reduction (~150 Btu/lb of fabric) is realized because of the elimination of the steamer which is inherently necessary in the conventional process, after the low-temperature reactive/caustic pads. In addition, the caustic/hydrosulfite reduction clearing bath traditionally located after disperse dyeing is eliminated.

Vacuum Impregnation and Extraction⁽¹⁷⁾

In vacuum impregnation, the fabric contacts a perforated cylinder, and air is extracted by the vacuum. Dye solution contacts the fabric before the fabric is returned to atmospheric pressure, thus promoting penetration of dye into the fabric. This technique is particularly useful for dyeing heavy fabrics, which are difficult to dye uniformly by conventional means. Vacuum impregnation is also potentially applicable to various finishing processes, such as durable-press and flame-retardant finishing.

Evaporation of water is the most energy-consuming part of textile processing. Typically, wet fabric that has been squeezed between mechanical rollers still contains 50-100% of its weight as water, depending on the particular fabric being treated. Vacuum extraction by slots or porous rollers will reduce the water content more effectively, thus reducing the amount of energy required for drying.

The vacuum extraction method is a very beneficial technique. In processing, the fabric can be soaked yet vacuum extraction yields the same benefit of other low wet pick-up techniques reducing energy consumed in the

drying process. The key in exploiting vacuum extraction is to be able to economically separate (via a cyclone separator) air and water, and recycle the dye solution.

Advanced Yarn/Beam Dyeing System(18)

An example of an advanced dyeing system is the MAD (Morton Accelerated Dyeing) Program which claims to be able to cut some yarn/beam dyeing cycles by as much as 75% over conventional procedures. The program makes use of Morton's total automation capabilities, in conjunction with modifications of the dyeing procedures such as vacuum fill, preformulated dye bath, increased flow, rapid reversal of flow, high rate of rinse, hot drain and vacuum extraction.

Dielectric Heating Fixation of Dyes(19,20)

With dielectric technology (includes radio frequency and microwave techniques), heating fabrics and fibers is quicker than conventional heating and there are less heat losses. Radio frequency energy can have a conversion efficiency up to 80%, whereas conventional heating systems are no better than 37%. Despite the relatively high cost of electricity, cost per unit of processed fiber is approximately 40% of that of conventional dyeing. As shown in Figure 3.3, microwave dyeing consumes less electric and thermal energy than the conventional dyeing methods.

Washing(21)

Washing or rinsing after wet processing such as dyeing uses one to three times as much hot water as the process itself and in some operations (e.g., continuous dyeing) much more. Hence, improved washing methods offer significant energy savings. Techniques being developed include more effective continuous counter-current rinsing. In one proposed method, fabric is rinsed at slightly elevated pressures in continuous equipment to remove chemicals more efficiently. Experimental units using vibrating-reed jet washers and cam-driven beater rollers are on field trial in the textile industry. Mechanical devices to increase turbulence and sonic devices for increased removal of dirt and excess dye are being developed.

Reference: "Microwave Dyeing," Textile Industries, July 1983.

Figure 3.3: Comparison of Electric and Thermal Energy Consumption of Various Dyeing Methods.

Foam Technology(22,23,24)

Foam technology can be used to save energy in all wet processes used to convert loom-state (greige) goods to finished textile products. This includes desizing, scouring, bleaching, dyeing, printing and finishing of fabrics. The energy intensive step in most of these processes is drying the fabric. By having less water on the fabric as it enters a drying oven, proportionately less energy is consumed in drying the fabric. The result of this technology will be smaller, more efficient dryers which will consume less energy while maintaining or increasing production.

Foam Finishing(25,26,27,28,29)

In commercial practice, energy consumption is reduced 40 to 80% by converting from conventional wet finishing to foam finishing. The process could be retrofitted to all existing pad/dry/cure finishing ranges.

The foam finishing process applies the finish to the fabric in an air-blown foam, rather than a pure liquid state. Foam finished fabrics picked up 48 to 53% less water than the wet finished fabrics. The foam process consists of preparing a concentrated solution (or dispersion) of the chemical or chemicals in water, and then incorporating suitable foaming aids. The concentrate is then mechanically foamed and is applied to the fabric by means of equipment such as a doctor blade over a roll coater. The foam is then forced to collapse and flow over the fibers. This can be done by passing the foam-coated fabric over a vacuum slot and then through a pad mangle, or by using a foam which collapses when heated. The coated fabric is then passed through a conventional oven to remove the small amount of water used in the concentrate and to cure the finish.

This results in the following advantages over conventional aqueous systems:

- o Reduction in energy consumption for drying and curing per pound of fabric;

- o More efficient use of chemicals;
- o Application to wet fabric without first drying; and
- o Reduction in water content of the finish resulting in higher production rates, decreased dryer temperatures and decreased fuel consumption.

In new mills, foam processing is even more attractive since all the increased productivity of foam finishing can be designed into the plant.

To date, foam finishing has gained wider acceptance than foam dyeing, mainly because of the wider uniformity and latitude allowed for colorless finishes than for solid-shade colored fabrics.

Foam Dyeing(26,28,30)

The state of the art of foam dyeing has not progressed as rapidly as that of foam finishing. The foam process is only applicable to continuous dyeing. Unlike conventional continuous dyeing where fabric is immersed in a liquid and excess dye liquor squeezed out before fixation and/or drying, the precise amount of foamed dye composition is applied to the fabric. Dye penetration and uniformity are problems to be solved. However, foam dyeing has been in limited commercial practice with certain textiles, such as nylon carpet, polyester and acrylic non-wovens, and polyester/cotton narrow width industrial toweling. Flocked and velour type plush fabrics have been successfully foam dyed in limited production trials, however, this technology has recently given way to spray and liquid slot dyeing techniques in carpet production.

Foam Printing(26,29,31,32)

The use of foams in printing has been intensively studied over the last couple of years. Foam printing research has progressed much faster than originally anticipated. While not as dramatic as for foam finishing, foam printing energy savings of 35% have been demonstrated in commercial trials, and 30 to 35% increases in line speed have been achieved.

In conventional commercial printing, the rheology of the print paste is primarily controlled by the nature and the amount of thickener used in the print pastes. In foam printing on the other hand, virtually no thickener is used in the system. Instead, the rheology of the print paste is controlled by the volume of air that is whipped into the print formulation and the size of the air bubbles in the foamed mix. A problem is that for printing, the useable life of the foam must be 8 to 10 hours as opposed to dyeing and finishing foams whose useable life need only be a few minutes. Advanced methods have reduced the print foam's needed useful life down to only ten minutes.

On a pilot-plant scale, foam printing inks and compositions can be printed on roller printers (primarily), rotary screen; and flat bed screens. In all cases, good product quality, even with fairly intricate patterns, were realized.

Foam printing will increase as more rotary printing machines are designed specifically for foamed print colors. Since the textile industry is moving more toward rotary screen print machines and away from flat screen print machines, the mechanical problems of feeding foamed colors to rotary machines will have to be overcome for foam printing to increase substantially.

Competitive Foam Systems

"FFT (Foam Finishing Technology) system"⁽¹⁸⁾ is based on a new process developed by Gaston County/Union Carbide. This system consists of a chemical foamer/feeder air application nozzle assembly and a process controller. Wet pick-up levels can be as low as 10%, with savings of energy (compared to pad dyeing) of up to 80%, water savings of up to 80%, higher range speeds (drying capacity is no longer a factor) and elimination of chemical injection problems.

"Triangular print head" foam application for use in carpet dyeing.⁽¹⁸⁾ The applicator uses a rotating wire mesh screen to apply the foam on top of the substrate, and vacuum below the substrate to draw the foam through it.

It is claimed that the pick-up is only 80% of the yard weight, with the corresponding reduction in energy requirements as compared to the pad dyeing process.

"Tanns" foam applicator for retrofits to machines with rollers.(18)
One model of the applicator can be used for foam dyeing for pile fabrics such as acrylic pile with cotton backing, and it can simultaneously apply two different colors, one to each side of the fabric, or the same color to both sides, or one color to one side of the fabric. Pick-up is said to be 30 to 35% of the pick-up in the pad dyeing process with corresponding energy savings.

"RSF finishing system" which puts to good use existing screen printing technology.(18) Basically, the screen is used in conjunction with a squeegee and a foam mixer. Automatic controls are used and exact reproducibility is claimed. Another claim is that unstable foam types as well as very sensitive and unstable substrates can be processed by their machinery. To this, significant energy savings (when compared with conventional processes) must be added. Of course, these claims will only be practically proven when some of this machinery will have been in use for an extended period.

Drying(1,33,34)

After textile materials have been dyed and finished the water which has been added in these processes must be removed. A large portion of the water present can be removed by mechanical means, which consumes considerably less energy than thermal water removal. The moisture in the material to be dried can be reduced to 30 to 40% of the weight of the goods by mechanical predrying, which consumes approximately 60% less energy than removing the same amount of water by thermal means. Therefore, mechanical predrying should be utilized whenever possible.

Since some of the water chemically binds itself to the polymers comprising the fibers, it must be evaporated in order to be removed. After mechanical predrying, the textile material enters the tenter frame or oven.

The two largest areas of energy consumption in dryers is heating makeup air and evaporating water. The amount of water to be evaporated can be reduced by mechanical predrying with energy consumption being reduced. If the amount of air exhausted from the dryer was reduced, then less makeup air would have to be added to take its place. Insurance regulations prohibit too low of an exhaust due to the danger of explosions.

Once the dryer has been made as efficient as possible, heat recovery from exhaust flue gases should be considered. It is estimated that recovering heat from dryer exhaust can save from 20 to 50 percent of the total energy input. Many problems have been encountered while attempting heat recovery on textile ovens which limit savings of only 10 to 20 percent of the total energy input. Lint buildup and resin and finish condensation can cause clogging quickly and the amount of time required to maintain the heat exchangers can be prohibitive. However, there are several new heat recovery systems for dryers such as those which use glass tubes instead of metal, which combat the clogging problem. Glass tubes, however, suffer from breakage during startup due to thermal shock. No matter what type of heat exchanger is utilized, sufficient time must be taken to maintain it properly or the purpose is defeated.

Low Wet Pickup Technologies(10,18,35)

Several methods are presently available which reduce the wet pickup of textile materials. Squeeze rolls and vacuum slots are the most common types of mechanical predrying methods for fabric and carpets. Centrifuging is an excellent method for predrying stock. Several available methods for reducing wet pickup initially are foam and spray applications, kiss roll techniques, and transfer operations. These methods will be discussed in the following paragraphs.

Squeeze Rolls: Harder roll covers reduce the nip area which results in a higher nip pressure per square inch of nip, thus serving to increase the amount of water removed. Several new roll types are replacing the conventional rubber covered rolls. These porous rolls achieve a lower wet pickup due to the absorptive nature of the material from which they are made.

Most of the new rolls are fiber filled. There is an optimum speed for squeezing which can result in the maximum water removal for any pad system. Due to the complex nature of the padding system, the best means of determining this speed is by experimentation. A problem with this technique is non-uniform water removal causing streaks in dyeing.

The following squeeze roll techniques can be used to reduce wet pickup:

- o Kiss Roll Coaters - A roll is partially immersed in a liquid and the liquid is carried to the fabric by the roll. The roll may turn in the same direction as the fabric travel or in the reverse direction to the fabric travel. Finish pickup is controlled by the speed of the revolving roll in relation to the fabric speed, and the pressure between the fabric and the roll. Uniform absorbency of the prepared fabric is critical to even finish application. Fabrics also must be perfectly flat to insure even finish pickup.
- o High-Compression Pad Rolls - These rolls can be used to replace the regular rubber covered rolls on existing pads. Pick-up uniformity is excellent; however, moisture pick-up levels are generally much higher than with foam applications.
- o Engraved Roll - This process uses an engraved print roll and doctor blade similar to that used on roller print machines. This process is most suitable if there are no variations in fabric width.

Vacuum Extractors: are also an effective means of reducing the moisture content of a textile material before it enters the dryer. Vacuum extractors are most effective on fairly porous, synthetic materials. As the temperature of the water being removed increases, the viscosity decreases and allows more water to be stripped away from the material. Therefore, whenever the material can be extracted while it is still hot, it should be done then so as to remove the most water possible. It is not economical to heat cold water for the purpose of extraction, however.

Another mechanical method for removing moisture prior to thermal drying is the machnozzle.(36,37) The machnozzle allows the feeding of supersonic steam flows through the material, thus blowing out the moisture which is attached to the surface. The machnozzle is commercially available and plant trials have been completed on its efficiency.

The low wet pickup technology in the finishing component includes:

- o Spraying - This is usually a one-side application of finish, but can be applied to both sides. Very precise control of the sprays are necessary to insure uniformity of application. Moisture levels of around 10% are possible but wet pickup is usually in the range of 14-32% on fabric; however, most of the finish remains on the fabric surface.
- o Low add-on finishing - In a typical pad-bath finishing range, the wet pickup can be 200-300% leaving the immersion bath. Using a curved blade applicator (CBA) and chemical pump, the moisture pickup can be controlled.(38) The CBA system can keep wet pickup at a 35% level which is an improvement over the pad-bath and mechanical squeeze system (50-90% WPU). Energy savings of 45% are claimed, (Westpoint Foundry & Machine Co.), and a chemical saving of 22%. Higher finishing speeds and productivity can be achieved with the same drying frames.
- o Triatex MA(18) - MA stands for "Minimum Application". This technique does not require a pad roll. Finishes are applied with a kiss roll film transfer. Liquid is pumped to the roll by the positive pressure of the compression nip and moisture is monitored by a nuclear beta gauge.
- o Vacuum Technique - This technique is used with pad rolls. After the fabric is impregnated and squeezed it then passes over a vacuum slot which removes excess chemical solution and eliminates the need for the pre-drier. The chemical solution droplets are separated by a cyclone unit, the droplets recondense, and the liquid is pumped back to the feed unit.

- o Transfer⁽³⁹⁾ - Pad liquor is carried to the nip of a padder with an endless loop of felt or other highly absorbent material where it is brought into contact with the fabric that is to be finished. Maintaining uniform absorbency of the loop while running and preventing chemical buildup in the loop while running are two possible problems with this system.

3.3 ADVANCED TECHNOLOGIES

The ultimate in energy savings would be a system of sequential simultaneous processes where fabric is dried once, rather than the three to four times during the source of processing greige fabric to finished goods. Simultaneous processes are those which accomplish two separate and distinct operations or the application of separate chemical solutions without intermediate drying. High extraction techniques, such as a vacuum slot or machnozzle, in conjunction with foam chemical and/or dye application can accomplish this coupled to a non-conventional energy efficient curing system. Foam finishing also eliminates the washing and drying steps after curing.

3.3.1 Dry Processes

Appendix D summarizes some of the more significant advanced energy conserving technologies that have been identified and conceptualized by the industry. Figure 3.4 shows the advanced process sequence diagram. The advanced technologies are described in more detail in the following paragraphs.

Yarn Formation

There is potential for the automation analysis of incoming bales of fiber, particularly if a robot or other automatic device could be involved in the analysis and then direct the bale to the appropriate storage area.

Figure 3.4 Advanced Process Flow Diagram

Figure 3.4 Advanced Process Flow Diagram
(continued)

FABRIC FORMATION/
WEAVING COMPONENT

Figure 3.4 Advanced Process Flow Diagram
(continued)

Figure 3.4 Advanced Process Flow Diagram (continued)

Automated bale storage is a labor-saving technology that leads to less handling, as well as presenting the opportunity of coding each bale for future identification.⁽⁴⁰⁾ This is important because of the desirability of tracking the identity of the material in each textile process, from the initial bale through all of the process steps. This in turn allows one to know the accurate history of all materials and processes and allows the solution of quality control problems on a more rational basis.

Cards can be loaded and unloaded automatically, and their output can be conveyed automatically to draw frames. However, the need to mix the inputs to draw frames in such a way as to ensure good blending is important; these patterns also need to be capable of being changed from time to time.

The issues in yarn formation generally point toward reducing the number of process steps. One view is that devising processes that can successfully eliminate other steps is more important than devising automated materials handling systems to move materials between process steps. In general, the ideal yarn manufacturing process would take fiber from a bale, convert it to a card sliver, and move it to a spinning process, with automatic transfer of the spun yarn output either to a warper or to a loom.

Emphasis must also be placed on computer monitoring, both of quality and production rate, with the quality monitoring being tied to appropriate feedback and control mechanisms throughout the processes. The monitoring technology is already available for drawing, and the technology for monitoring either open-end yarn or other kinds of yarn is on the horizon.⁽⁴¹⁾

Another area of considerable importance is to determine the need for machine maintenance by continuous monitoring of yarn from, for instance, open-end spinning rotors. This requires that all ends be monitored continuously, and that faulty positions be identified immediately. The repair, when it is needed, could be made automatically, or that end could be stopped and machine maintenance ordered. A useful system would also monitor and record for long-term gradual deterioration, as opposed to short-term problems. In this whole system, the philosophy is to prevent defective material at its source.

In general it is important to measure and to control quality on the spot at every step of the yarn formation process. The computer technology is already available and it is used in more advanced and selective plants by the industry leaders.

There are a number of opportunities in present yarn processes for automated materials handling, including the use of robots, particularly for systems that have reduced the number of process steps. It could also be used within the automation of roving frames.

Connecting winders to large spinning frames is a good idea, but winders need to be designed to accommodate some flexibility of yarn count; this could perhaps be accomplished by designing winders with space for extra positions. This linking technique allows less handling of yarn packages, which is a distinct advantage, and it also allows better package identification and control.

Although techniques for the continuous monitoring of various stages of yarn processes are available and used, knowing where most efficiently to direct that information or what corrective actions to take still is unknown to a large extent. Since it is necessary to be able to identify abnormal parts of the process, the real issue is to determine where in a process faults occur, what their relations with other process steps will be, and the feedback loops in which to exercise control.

Vortex Spinning.⁽⁴²⁾ This system involves a process whereby staple fibers are fed into some sort of vortex and transformed into spun yarns. Yarn splicing by pneumatic rather than mechanical techniques has come to replace traditional knotting, so that these machines produce only knotless yarn packages.

Electrostatic Spinning.⁽¹⁸⁾ The Southern Regional Research Center (SRRC) electrostatic spinner is a low energy method for the production of yarn. It can be adopted to the present feed systems for yarn production and can save about 30% of the energy consumed by present spinning equipment.

Friction Spinning.⁽⁴²⁾ The friction spinning system which is best known as the DREF system was named for Dr. Ernest Fehrer. This system is just beginning to penetrate the textile industry. The higher production rates (up to 300 ypm) will depend on further progress in the fiber feeding arrangement. The difficulties in friction spinning are:

- o Orderly and parallel deposit of fiber in the twist zone or nip point;
- o Fast delivery speed;
- o Inferior performance with natural fiber yarns;
- o Unsatisfactory yarn strength;
- o Reproducibility of twist from position to position - negative impact on aesthetics; and
- o No present economic or energy consumptive advantages over rotor spinning, as shown in Figure 3.5, over most yarn counts.

In order to decrease energy consumption in spinning, the yarn quality and interaction with the spinning method must be studied. There is a strong interdependence between the fiber properties and the spinning method and costs. This is shown in Figure 3.6. Research must be done to search for ways to maximize fiber properties. As presented in Figure 3.7 the limiting factor in rotor speed hence production is primarily fiber properties.

KNITTING

Combining Weave/Knit Functions⁽¹⁸⁾ Knitting is inherently less energy consumptive than weaving. Up to 10% energy savings could result by combining weave/knit functions in one machine.

For example, the Metap weave/knit machine of Czechoslovakia uses a new system of weft insertion whereby the weft threads are interlaced with the warp ends as in conventional weaving and are interconnected by means of a chain stitch knit construction. One limitation is the striping effect.

Figure 3.5: Comparison of Production Costs
Friction Spinning vs. Rotor Spinning
(fully automated)

Reference: "Short-Staple Spinning, Evolution or Revolution,"
Presentation at Georgia Institute of Technology,
April 1986.

Fiber Properties

Sequence of Importance to Various Spinning Systems
(present state of the art)

Ring Spinning	Rotor Spinning	Air-Jet Spinning	Friction Spinning
Length/Uniformity	Strength	Fineness	Fineness
Strength	Fineness	Length/Uniformity	Strength
Fineness	Length/Uniformity	Strength	Length/Uniformity
	Cleanliness	Friction	Friction
		Cleanliness	Cleanliness

Figure 3.6: Interdependence Among Fiber Properties And Spinning Methods.

Reference: "Short-Staple Spinning, Evolution or Revolution,"
Presentation at Georgia Institute of Technology,
April 1986.

Rotorspeed

x 1000

Figure 3.7: Dependence on New Fiber Technology and Research for Increased Rotor Speed and Productivity, (1980 - 2000).

Pneumatic Knitting without Needles⁽⁴³⁾ Pneumatic knitting without needles is accomplished by having yarn-feeding air nozzles and ejector nozzles of a circumferentially perforated cylinder open and close intermittently. Synchronized with these action is a yarn feed system which intermittently feeds yarn to the yarn-supply jets in lengths corresponding to the loop size. Productivity is improved and yarn breakage is rare.

WEAVING

As in spinning automation, monitoring and control can be applied to materials handling. This again is mainly a labor-savings. It is desirable to have a system with automatic doffing of cloth with automatic cutting in conjunction with automatic inspection and grading.

Multished machines^(18,44) are ultra-high production workhorses principally applicable in sheeting and print cloth mills. Multiphase weaving machines are a new concept based on rapier weaving. The British Orbit machine uses 18 rigid rapiers which operate in a large cylinder which carries the warp yarns and between the rapiers is mounted a unique disc roller system which automatically forms sheds throughout the weaving cycle. Size is not required, thereby eliminating the energy intensive slashing process.

ANCILLARY PROCESSES⁽¹⁸⁾

Electrostatic Waste Removal. Electrostatic methods for cleaning the dust and trash from under the carding machines could replace the present energy consuming methods such as cleaning by suction and air jets.

Machnozzle Waste Removal. Machnozzles can be used not only for accelerating the removal of water from fabrics, but the application of sonic and supersonic vapor flows can also be used to efficiently remove large-scale impurities, sizing materials and residual chemicals left after washing from fabrics. The energy consumption is negligible because the thermal energy of the vapor can be completely recovered and only mechanical energy is used.

3.3.2 Wet Processes⁽³⁵⁾. Advanced wet processes enhancements will continue to stress low wet pickup and lower processing temperatures.

The goal is to make dyeing and finishing a truly continuous process rather than a series of batch processes, each with its own control and material handling problems.

This implies the use of sophisticated monitoring and control systems, with the ability to control the color of wet fabric, as well as to monitor and control the moisture content. The aim is to be able to predict accurately the color of the final dry fabric by measuring its characteristics at the moment of dyeing.

Such a monitoring and control system would allow rapid color changeover from lot to lot on a continuous basis, affording flexibility and minimum fabric length between the changes. It is extremely important to have absolutely uniform fabric preparation for this purpose.

There are general needs for reducing the energy costs in wet processing, This is being done by reducing the dye fixation requirements in coloration and lowering the drying requirements. And for some products, it would be very useful to have dyeing as the last of all finishing steps to improve order and warehouse versatility.

Direct Application of Process Chemicals to Fibers and Fabrics^(45,46). An alternate route to applying chemical solutions to fabrics at low liquor ratios is spraying. An electrostatic system helps improve uniformity and distribution which is notoriously bad with sprays. Very little work appears to have been done in this area. Electrostatic deposition of finishes and dyes would reduce or eliminate intermediate washing and drying steps (permit wet-on-wet processing) and would minimize energy requirements in final drying.

Other promising techniques involve the use of gaseous reactants in bleaching (ozone, singlet oxygen) or vapor phase reactants. The estimated energy conserved can be as much as 10% of the total energy consumed in dyeing and finishing.

Hot Melt Sizing⁽⁴⁷⁾. A new slashing system utilizes sizes which are melted and applied to the yarn and set up without heat. The hot melt size does not need to be cooked, but the melting point range of the hot melt sizes presently available is 260°F to 310°F. It is not clear at the present time how much energy is required to keep the size in the liquid form. This energy consumption could reduce the savings available due to the elimination of the drying step. All of the sizes can be removed (desized) with hot water. Slashing speeds may be able to be increased by this method, the speed being dependent upon the solidification time of the size used. Similar or improved yarn quality has been found to be produced thus far by hot melt sizing. This process requires new equipment as no retrofit systems are available. The production machinery is not yet available on the market but should be available soon. A disadvantage to this technique is that the polymers properties change during the melt, but this method does allow single-end slashing.

New Bleaching Technology⁽⁴⁸⁾. A new bleaching technology has been developed which will use a non-peroxide approach. This bleaching process uses sodium chlorite activated by hypochlorite. This enables fabrics to be bleached without the requirement of hot water or steam. An important criterion to the successful adoption of non-peroxide bleaching would be the ability to maintain operation speeds used in peroxide bleaching.

Foam in Fabric Preparation^(24,49). The feasibility of utilizing foams in fabric preparation has been demonstrated. The foam technology can be potentially applied to all textile process areas that presently use

pad/nip application followed by drying of the fabric. The desired properties of a well prepared fabric are good absorbency, whiteness and uniform dyeability.

An advantage of foam preparation is that during wet-on-wet dyeing, it eliminates a color bleeding problem because of the low moisture content of the foam.

The use of foam in slashing or bleaching can save energy if the warp sizes (starch, PVA, wax, etc.) did not have to be washed out before drying. If this additional wash step is not done, fabric quality is downgraded.

Wet-on-Wet Processing(50,51). The wet-on-wet dyeing technique is a continuous dyeing process similar to the conventional pad method of dyeing dry fabric. By using wet fabric, energy savings could be obtained as a result of omitting a drying stage. The wet-on-wet method has also been tested on roller printing machines. Machines which intensify the contact between cloth and dye liquor, should make the dye penetration of wet cloth easier. Wet-on-wet application of durable press finishes on cotton and cotton-containing fabrics has been shown to be more efficient than the pad-dry-cure process.

Non-Woven Web Bonding: Energy savings in thermoplastic bonding can be achieved by lowering the melting point of the thermoplastic fiber. Significant research activity is being done in this area. Also, very precise temperature settings and controls are required on the calender rolls used in thermal bonding.

Self-bonding by fibrillation is a promising concept for non-wovens borrowed from the paper industry. Webs of fibrillated fibers are interlaced on a paper machine. More research is needed for this technology to produce fabrics of acceptable quality.

Low Temperature Curing Resins/Adhesives(52,53,54). Thermal energy required to cure polymeric resins and adhesives has been one of the most energy intensive segments of the textile industry. Developments have been directed toward synthesis of low-temperature curing polymers and systems to reduce thermal input into the process.

Feasibility studies should investigate hot catalyst curing, microwave curing, radiation curing, and curing via chemical reactants. Ambient temperature curing using chemical reactants is the most promising, yet a major disadvantage remains: the time required for "full cure" can vary up to seven days at room temperature.

Solid-on-Solid (SOS) Technologies:* In solid-on-solid processing, chemicals (size, dyestuffs, prints, finishes) are applied to fabrics without the use of liquids. This technology uses electrostatic fluidized powder beds for the chemical application to textile yarns and fabrics. The slashing process is most amenable to solid-on-solid technology.

In SOS slashing, a textile staple yarn is passed through a bed of electrically-charged powder, where the particles attach to the fiber surface. A melt stage is then used to form a film, or sheath, of the chemical finish around the fiber. The SOS slashed yarns are comparable in quality to conventionally slashed yarns, and the process has the potential to save approximately 85 percent of the energy currently consumed in the slashing process.

Xerographic printing of fabrics using modified paper xerography techniques is a research area of great industrial interest due to the high-speed nature of modern xerographic copying. This process is based on the electrostatic attraction between charged plates and toner powder (consists of pigment and resin). Transfer of the image occurs only on the

*Reference: Conversations with Dr. Fred Cook, Georgia Institute of Technology School of Textile Engineering.

charged areas, creating a positive image, then the print is "fixed" by thermally melting the toner. Present paper toners do not meet textile requirements for printed fabrics, such as proper fastness/aesthetic properties. Material research for textile toners must be done to develop this technology. Xerography also holds promise for printing patterns on non-wovens. The biggest advantage in xerographic printing is that the print information can be stored optically by computer, rather than on rotary screens.

SECTION 4. ENERGY SAVINGS POTENTIAL IN THE TEXTILE INDUSTRY

This section provides assessments of the potential savings in energy associated with future textile manufacturing processes. Section 4.1 discusses the energy savings potential associated with the current production level and mix, given the scenario that all current practices are replaced with the state-of-the-art (best technology currently available) technology. Section 4.2 presents the energy savings potential associated with advanced technology. This is on a per pound of product basis for each process step. Section 4.3 discusses the energy savings potential associated with several technology mix scenarios, ranging from current practices to advanced technology, given an estimated production level and mix for the year 2010.

The state-of-the-art and advanced technologies considered in these analyses are those that were identified in Section 3. Detailed calculations for these analyses are presented in Appendix E.

The results presented in this section include:

- o Energy savings potential per pound of product for each process step;
- o Energy savings potential for each industry component;
- o Overall industry energy savings potential per year.

4.1. ENERGY SAVINGS POTENTIAL ASSOCIATED WITH STATE-OF-THE-ART TECHNOLOGIES

The assessment of the energy savings associated with state-of-the-art technology has been divided into two parts. In the first part; energy savings per pound of product are estimated for each process step. In the second part these data are used to calculate the energy savings potential for the industry to process the current production level and mix.

4.1.1 Energy Savings Potential by Primary Processes

The impact of state-of-the-art technologies on energy consumption in the textile industry is summarized in Table 4.1. This table presents the following types of energy consumption data for each process step technology:

- o The estimated current U.S. textile industry average (from Table 2.2); and
- o The value associated with the best technology available today which is defined as the state-of-the-art technologies and current practices. These data reflect a national perspective and accordingly are based on an energy intensity factor of 10,500 Btu/kWh-electric.

4.1.2 Energy Savings Potential by Industry Component

The results of this section are based on the production level and mix presented in Section 2.3 and are compared by the energy consumption levels which are calculated in that same section. The calculations for this section (4.1.2) can be found in Table E-1.

Using alternate state-of-the-art technology such as that depicted in the process sequence diagram (Figure 2.4) would conserve overall one-third of the current energy consumed by the textile industry. This potential savings would be about 160 trillion Btu per year, as shown in Figure 4.1. Approximately 32 percent of the current dry process energy and about 36 percent of the current wet process energy is conserved. This data shows that both dry and wet processes are about equally amenable to energy conservation.

In the spinning component, it is assumed that 90 percent of yarn production is open-end spun as compared to the 40 percent presently produced using this technology. The other components have adopted the technologies discussed in Section 3.2. The impacts of the state-of-the-art technology is shown by component in Figure 4.2.

FIGURE 4.1 : ENERGY USE FOR CURRENT PRODUCTION MIX (1984) FOR CURRENT AND STATE-OF-THE-ART SCENARIOS

Source: Energetics, Inc.

Table 4.1: Summary of Potential Savings of Specific Energy Consumption in State-of-the-Art Textile Manufacturing Processes (Btu/lb)

<u>Processes</u>		<u>Current Practice Energy Consumption</u>	<u>State-of-the-Art Energy Consumption</u>	<u>Potential Savings</u>
Yarn Formation Component				
Opening/Blending		945	846	99
Carding	(a)	754	252	502
	(b)	1419	822	597
Drawing	(a)	163	98	65
	(b)	271	151	120
Lapping	(b)	465	114	351
Combing	(b)	1077	936	141
Roving	(a)	622	299	323
	(b)	985	677	308
Spinning	(a)	7520	4924	2596
	(b)	15700	10125	5575
(a) carded yarn count 3-31; average: 18.5				
(b) combed yarn count 25-49; average: 35				
Texturizing Component:				
Texturizing		20500	11695	8805
Fabric Formation/Weaving Component:				
Warping		850	460	390
Slashing		2325	1200	1125
Weaving		5440	3230	2210
Fabric Formation/Knitting Component:				
Knitting		7200	3540	3660
Non-Woven Component:				
Web Bonding		4550	2010	2540

Table 4.1: Summary of Potential Savings of Specific Energy Consumption in State-of-the-Art Textile Manufacturing Processes (Btu/lb)
(Continued)

<u>Processes</u>	<u>Current Practice Energy Consumption</u>	<u>State-of-the-Art Energy Consumption</u>	<u>Potential Savings</u>
Yarn Dyeing Component:			
Rawstock dyeing and drying	9440	6967	2473
Yarn Package dyeing and drying	10700	6364	4336
Woven Fabric Finishing Component:			
Heat setting	530	250	280
Singeing	154	100	54
Desizing	465	247	218
Scouring	1350	735	615
Bleaching	1200	790	410
Mercerizing	1920	1100	820
Dyeing	6225	3400	2825
Printing	9570	5050	4520
Finishing	2730	1385	1345
Drying (single pass, includes predrying)	3455	2710	745
Knit Fabric Dyeing and Finishing Component:			
Preparation (D/S/B)	2660	1500	1160
Dyeing	5890	3840	2050
Finishing	2360	1875	485
Drying	3000	2000	1000

Table 4.1: Summary of Potential Savings of Specific Energy Consumption in State-of-the-Art Textile Manufacturing Processes (Btu/lb)
(Continued)

<u>Processes</u>	<u>Current Practice Energy Consumption</u>	<u>State-of-the-Art Energy Consumption</u>	<u>Potential Savings</u>
Floor Covering Component:			
Twisting	4500	1880	2620
Heating setting	3150	1650	1500
Tufting	1050	615	435
Dyeing	9800	7500	2300
Printing (Btu/yd ²)	39000	18000	21000
Finishing	3500	1800	1700
Drying	4350	2290	2060
Auxiliary Processes:			
HVAC (greige mill)	5530	5000	530

*Energy intensity factor 10,500 Btu/kWh-electric
ITT surveys
Energetics, Inc. surveys and field trips to mills

FIGURE 4.2: ENERGY CONSUMPTION BY TEXTILE COMPONENT

SOURCE: ENERGETICS, INC.

The total and specific component energy consumption figures are also presented in Figure 4.2. Table 4.2 summarizes these results and presents the potential savings.

The weaving and wet processing components are the largest overall energy consumers in the textile industry. Additionally, these components show the largest potential for energy savings.

Table 4.2: Summary of Energy Consumption by Industry Components

(1984 Production Mix)

(refer to Section 2.3 and Table E-1)

<u>Primary Industry Components</u>	<u>Energy Consumed (10^{12} Btu)</u>		
	<u>Current Practices</u>	<u>State-of-the-Art Technology</u>	<u>Potential Savings</u>
Yarn Formation	117.7	92.4	25.3
Texturizing	46.1	26.3	19.8
Fabric Formation/Weaving (includes slashing)	90.6	57.8	32.8
Fabric Formation/Knitting	12.7	6.3	6.4
Non-Woven	3.9	1.7	2.2
Floor Covering (Dry Processes)	<u>18.3</u>	<u>9.2</u>	<u>9.1</u>
Dry Components Subtotal	289.3	193.7	95.6
Yarn Dyeing	12.4	8.5	3.9
Woven Fabric Dyeing & Finishing	147.4	91.7	55.7
Knit Fabric Dyeing & Finishing	21.3	14.1	7.2
Floor Covering (Wet Processes)	<u>27.9</u>	<u>17.6</u>	<u>10.3</u>
Wet Components Subtotal	209.0	131.9	77.1
Grand Total	498.3	325.6	172.7

*Energy Intensity factor 10,500 Btu/KWh-electric.

Source: Energetics, Inc.

4.2 ENERGY SAVINGS POTENTIAL ASSOCIATED WITH ADVANCED TECHNOLOGIES

This section presents the results of an assessment of the potential energy savings associated with the advanced technologies described in Section 3.2. The results are presented in Table 4.3 at the process level, on a per pound of product basis.

In Table 4.3, a comparison of the specific energy consumption associated with the current, state-of-the-art and advanced technologies are made. The most noticeable aspect of this table is that in the advanced technology column, many of the processes are eliminated due to more advanced spinning, weaving and finishing processes. Also some processes have been combined into a single process such as desizing, scouring and bleaching.

The next section 4.3 uses these specific energy consumption figures with a projected production level and mix in order to calculate potential energy savings for several technology mix scenarios.

4.3 TOTAL ENERGY SAVINGS POTENTIAL IN THE YEAR 2010

4.3.1 Potential Energy Savings by Industry Components

The total potential energy savings for the U.S. textile industry in the year 2010 can be made on the basis of various combinations of textile manufacturing routes. The five hypothetical production scenarios investigated are:

- 1) 100 percent production by current (1984) practices alone.
- 2) 100 percent production by state-of-the-art technology alone.
- 3) Production technology mix of 90 percent state-of-the-art technology and 10 percent advanced technology (Technology Mix 1).

Table 4.3: Comparison of Specific Energy Consumption for Each State of Technology on the Process Level (Btu/lb)*

<u>Processes</u>	<u>Current Practice Energy Consumption</u>	<u>State-of-the-Art Energy Consumption</u>	<u>Advanced Energy Consumption</u>
Yarn Formation Component:			
Opening/Blending	945	846	815
Carding (a)	754	252	
(b)	1419	822	
Drawing (a)	163	98	-
(b)	271	151	-
Lapping (b)	465	114	-
Combing (b)	1077	936	-
Roving (a)	622	299	-
(b)	985	677	-
Spinning (a)	7520	4924	3445
(b)	15700	10125	7088
(a) carded yarn count 3-31; average: 18.5			
(b) combed yarn count 25-49; average: 35			
Texturizing Component:			
Texturizing	20500	11695	10500
Fabric Formation/Weaving Component:			
Warping	850	460	200
Slashing	2325	1200	-
Weaving	5440	3230	2380
Fabric Formation/Knitting Component:			
Knitting	7200	3540	2800
Non-Woven Component:			
Web Bonding	4550	2010	1950

Table 4.3: Comparison of Specific Energy Consumption for Each State of Technology on the Process Level (Btu/lb)*
(Continued)

<u>Processes</u>	<u>Current Practice Energy Consumption</u>	<u>State-of-the-Art Energy Consumption</u>	<u>Advanced Energy Consumption</u>
Yarn Dyeing Component:			
Rawstock dyeing & drying	9440	6967	5965
Yarn Package dyeing & drying	10700	6364	5350
Woven Fabric Dyeing & Finishing Component:			
Heat setting	530	250	200
Singeing	154	100	100
Desizing	465	247	800
Scouring	1350	735	
Bleaching	1200	790	
Mercerizing	1920	1100	-
Dyeing	6225	3400	3000
Drying (single pass, includes predrying)	3455	2710	2000
Printing	9570	5050	4500
Finishing	2730	1385	1300
Knit Fabric Dyeing & Finishing Component:			
Preparation (D/S/B)	2660	1500	225
Dyeing	5890	3840	2720
Finishing	2360	1875	1650
Drying	3000	2000	1700

Table 4.3: Comparison of Specific Energy Consumption for Each State of Technology on the Process Level (Btu/lb)*
(Continued)

<u>Processes</u>	<u>Current Practice Energy Consumption</u>	<u>State-of-the-Art Energy Consumption</u>	<u>Advanced Energy Consumption</u>
Floor Covering Component:			
Twisting	4500	1880	1800
Heat setting	3150	1650	1580
Tufting	1050	615	600
Dyeing	9800	7500	6000
Printing (Btu/yd ²)	39000	18000	17000
Finishing	3500	1800	1600
Drying	4350	2290	1800
Auxiliary Processes:			
HVAC (greige mill)	5530	5000	4000

*Energy intensity factor 10500 Btu/kWh-electric
ITT surveys
Energetics, Inc. surveys and field trips to mills

- 4) Production technology mix of 50 percent state-of-the-art technology and 50 percent advanced technology (Technology Mix 2).
- 5) 100 percent production by advanced technology. This scenario is not realistic in terms of an actual mill operation in the year 2010, but is presented as a case showing the maximum technical potential energy savings.

Tables E-2 through E-6 present the detailed calculations for these scenarios.

The following estimated forecast of the production breakdown in the year 2010 is used in all the scenarios in this section:

<u>Production</u>	<u>(million pounds)</u>	<u>%</u>
Total	12,000	100.
Spun yarn	9,600	80.
Dyed yarn	1,680	14.
Texturized yarn	2,400	20.
Woven fabric	8,400	70.
Dyed woven fabric	5,600	47.
Printed woven fabric	1,400	12.
Knit fabric	1,920	16.
Dyed knit fabric	1,680	14.
Printed knit fabric	165	1.
Non-woven fabric	1,680	14.
Floor coverings	2,400	20.
Dyed floor coverings	1,550	13.
Printed floor coverings	240	2.

Source: Energetics, Inc.

Dr. Fred L. Cook, Georgia Institute of Technology,
School of Textile Engineering.

It is assumed that the U.S. textile industry will hold its approximate present production output against the pressures of increasing imports in a more slowly increasing market..

Figure 4.3 shows the impact of the technology mixes on the amount and share of energy consumed in the dry and wet processes. Figures 4.4 and 4.5 break down the energy consumed by industry components. The results are summarized in Table 4.4 and the potential energy savings are noted.

4.3.2 Overall Energy Savings Potential

If current industry practices were used to process the forecasted production mix, 0.541 quads would be consumed by the textile industry. As shown in Figure 4.3 and Table 4.4, if current practices were all completely replaced by advanced technology the textile industry would conserve 0.288 quads. A mix of 50% state-of-the-art technology and 50% advanced technology would save 0.237 quad. The industry is already moving towards implementing the state-of-the-art technology. The following table summarizes the results.

Projected Energy Use 0.541 Quads			
Potential Energy Savings			
Technology Mix	(Quads)	(%)	Achievability
100% state-of-the-art	0.186	34%	Good
90% state-of-the-art/10% advanced	0.197	36%	Likely
50% state-of-the-art/50% advanced	0.237	44%	Possible
100% advanced	0.288	53%	Less Likely

FIGURE 4.3 : ENERGY USE FOR OPERATING SCENARIOS FOR
THE PRODUCTION MIX OF THE YEAR 2010

Source: Energetics, Inc.

Table 4.4: Summary of Energy Consumption and Potential Savings by Industry Components
(2010 Production Mix)
(refer to Tables E-2 through E-6)

Primary Industry Components	(10 ¹² Btu)*								
	Current Practices		State-of-the-Art Technology		Technology Mix 1		Technology Mix 2		Advanced Technology
	Energy Consumption	Consump. Savings	Consump. Savings	Consump. Savings	Consump. Savings	Consump. Savings	Consump. Savings	Consump. Savings	Consump. Savings
Yarn Formation	132.9	104.7	28.2	101.7	31.2	90.0	42.9	75.3	57.6
Texturizing	49.2	28.1	21.1	27.8	21.4	26.6	22.6	25.2	24.0
Fabric Formation/Weaving (includes slashing)	89.9	57.9	32.0	55.6	34.3	46.0	43.9	34.3	55.6
Fabric Formation/Knitting	14.8	7.7	7.1	7.5	7.3	6.8	8.0	6.1	8.7
Non-Woven	7.6	3.4	4.2	3.3	4.3	3.3	4.3	3.3	4.3
Floor Covering (Dry Processes)	<u>22.3</u>	<u>11.3</u>	<u>11.0</u>	<u>11.2</u>	<u>11.1</u>	<u>11.0</u>	<u>11.3</u>	<u>10.6</u>	<u>11.7</u>
Dry Components Subtotal	316.7	213.1	103.6	207.1	109.6	183.7	133.0	154.8	161.9
Yarn Dyeing and Drying	16.0	10.9	5.1	10.7	5.3	10.1	5.9	9.2	6.8
Woven Fabric Dyeing & Finishing	149.3	92.7	56.6	89.8	59.5	76.5	72.8	60.0	89.3
Knit Fabric Dyeing & Finishing	25.2	16.8	8.4	16.1	9.1	14.0	11.2	11.7	13.5
Floor Covering (Wet Processes)	<u>34.0</u>	<u>21.4</u>	<u>12.6</u>	<u>21.0</u>	<u>13.0</u>	<u>19.5</u>	<u>14.5</u>	<u>17.2</u>	<u>16.8</u>
Wet Components Subtotal	224.5	141.8	82.7	137.6	86.9	120.1	104.4	98.1	126.4
Grand Total	541.2	354.9	186.3	344.7	196.5	303.8	237.4	252.9	288.3

*Energy Intensity Factor 10,500 Btu/KWh-electric

**Potential Savings are based on current practices

FIGURE 4.4: ENERGY USE BY DRY PROCESS COMPONENTS
FOR OPERATING SCENARIOS

FIGURE 4.5: ENERGY USE BY WET PROCESS COMPONENTS
FOR OPERATING SCENARIOS

SECTION 5. U.S. TEXTILE INDUSTRY R&D NEEDS AND OPPORTUNITIES

Over the past decade, the textile industry has achieved noticeable progress in energy conservation implementation, process improvements and equipment modernization. The textile industry has increased its energy awareness. In 1976, a voluntary industry-wide energy conservation target of 22 percent (of the 1972 energy consumption figure) was set which represented a reasonable goal based on the 29 percent level determined to be the maximum feasible improvements in energy efficiency that the industry could possibly achieve by 1980.* Surveys show the energy efficiency improvement actually realized from 1972 to 1980 was slightly less than 19 percent. Industry practices and technology improved but fell short of the target.

The specific energy consumption efficiency for the entire U.S. textile industry improved 12 percent from 1974 to 1984 (from a national perspective, see Table 2.1). The pace of energy-efficiency progress may be leveling off. Many low-cost, high payback conservation measures have already been implemented as detailed in Table 3.1. The textile industry can benefit from process modifications, basic research, and improved housekeeping practices that reduce energy consumption. Of these areas, energy conservation via improved housekeeping practices has been nearly saturated. Additional benefits from more housekeeping improvements will be marginal. A list of R&D needs in these three categories as suggested by the industry survey participants is presented in Table 5.1. In this table, the identification of R&D needs and opportunities that is made are assessed based on the future textile manufacturing practices projected in Section 4, keeping in mind the design and equipment of existing U.S. plants and how these factors relate to future decisions.

Textile manufacturing of the future is envisioned by the experts as entailing more continuous and higher speed operations with higher and more consistent quality, and will promote quick response to demand. Figure 3.4 presented a flow chart of such a system, in which textile manufacturing is expected to be carried out as a continuous process on a stream that passes

*The study was performed by SCS Engineers, Inc. for the Federal Energy Administration.

through closely coupled operations. Future operations will therefore require fewer process steps than current practices.

The potential impact of advanced textile manufacturing technologies on energy consumption and production efficiency is large (up to a 53% decrease in specific energy use), and processing speeds will continue to increase. The closely coupled operations of the future textile manufacturing process will require much closer control and more stringent limits than current processes. To achieve this, continuous real-time monitoring is needed. Therefore, the development of reliable/low-maintenance sensors, measuring devices, computer controls, robotization and automation are essential to the successful implementation of advanced textile manufacturing technologies. These monitoring and automated control systems will demand electricity, causing the electric energy use by the industry to increase as the thermal energy use will be decreasing. Compressed air consumption will also increase in the short-term as the result of more air-driven machines used in the spinning, weaving and texturizing components. However, in the long-term, friction spinning systems will dominate air-jet spinning systems since friction spinning offers higher speeds of production.

The key to energy savings through automation, computer monitoring and controls is to establish process energy standards so that wasteful deviations as well as improvements can be identified and quantified.

The results of the industry survey show that the major R&D emphasis in the dry process components is introducing new spinning systems and optimizing present systems. Spinning is the largest energy user in the yarn formation sequence. One major area of research, in yarn formation, is to be able to directly spin carded slivers thereby eliminating drawing as well as roving. More R&D is needed in order to allow higher processing speeds which will require the use of automation, robotic material handling and controls which can detect fiber defects, breaks and knots. Another important area of R&D is heating, ventilating and air conditioning (HVAC). Studies are needed in reducing the refrigeration load, optimizing chiller operations as well as economically controlling dust and static.

The major R&D emphasis in the wet process components is limiting the amount of aqueous processing and the number of repetitive drying steps. More research is needed in foam technology, solid-on-solid technology, solvent technology, low-wet pick up technologies and low temperature (ambient) processing.

In this section, 36 survey-suggested R&D areas are identified which warrant development (see Table 5.1). These areas are presented in the order of priority to the industry, within the three previously defined categories. Twenty of these R&D areas have been determined to be appropriate as potential candidates for DOE involvement with the private sector.

The qualitative assessment of the identified R&D areas of opportunity and their consequences has been made based on two factors: 1) their perceived impact on production (e.g., increased productivity, reduced energy intensiveness, and industry acceptance); and 2) the views of the industry experts.

Industry experts interviewed for this study commented that in addition to the R&D efforts in the suggested areas, the textile industry needs to be more accommodating to change. The industry tends to be very risk averse and in this regard tends to hold on the old technologies too long (e.g., shuttle looms, atmospheric becks) and abandon new technologies too quickly (e.g., foam dyeing) before their own merits can be proven. The textile industry has a low profit margin and therefore cannot afford to make too many mistakes involving large capital expenditures on plant and new equipment. A favorite saying in the industry is, "We love to be the first to be second." This quote typifies the industry's approach to follow only well proven and successful techniques without bearing the innovation risk. Additionally, there is usually a long lead time between obtaining new knowledge from R&D efforts and applying it effectively in the mill. This knowledge often comes from outside sources such as equipment manufacturers, universities, research institutes and fiber companies. A reliable and acceptable technology transfer mechanism with appropriate monitoring and control structures should be set up by the industry.

The implementation of new technology usually reduces the amount of traditional labor which is required. The textile industry can slow the projected labor displacement by providing retraining and skill-upgrading in order to develop more productive workers and sophisticated managers. The future manpower needs of the industry can be addressed by an industry-backed redirection of emphasis in educational programs and research at colleges and universities.

TABLE 5.1: INDUSTRY SUGGESTED R&D NEEDS

Potential DOE Candidate	Description	Conservation Classification	Priority
	Development of better process control technology	PM	H
X	More research in slashing - reducing heat required in the size application and removal	PM	H
X	Tenterframe exhaust heat recovery: cleaning techniques for, or prevention of lint fouling of heat exchanger tubes	PM	H
	Optimization of washing process for minimizing washbox temperatures	PM	H
	Development of vacuum extraction for solid shade, low add-on dyeing	PM	H

Classification
PM = Process Modification
BR = Basic Research
HK = Housekeeping

Priority
H = greater than 75% of the interviewed representatives
M = 35 - 75%
L = Less than 35%

TABLE 5.1: INDUSTRY SUGGESTED R&D NEEDS
(Continued)

Potential DOE Candidate	Description	Conservation Classification	Priority
X	Quantification study of benefits of ion control systems in dry processing (HVAC reduction).	BR	H
X	Further research in all types of low wet pick-up dyeing and finishing	BR	H
X	Development of automated spinning machinery that can detect, locate and repair fiber defects, breaks and knots on line	BR	H
X	Research in room temperature (ambient) dyeing processes	BR	H
X	Sensor/bath sampling technology (e.g., pH sensors, near infrared dye analyzer, automatic sampling)	BR	H
	Training workforce in standardized operations on process controls	BR	M
X	Optimization of spinning process in order to eliminate the drawing process	PM	M

**TABLE 5.1: INDUSTRY SUGGESTED R&D NEEDS
(Continued)**

Potential DOE Candidate	Description	Conservation Classification	Priority
X	Research to improve friction spinning in order to produce commercial quality yarns	PM	M
X	Research in solvent processing in scouring and bleaching	PM	M
X	Develop xerographic printing	PM	M
	Development of combining of de-sizing, scouring and bleaching on the preparation range	PM	M
X	Investigation of radio frequency dye fixation and drying	PM	M
X	Study of chiller optimization for HVAC reduction	BR	M
X	Study of wet-on-wet processing for the dyeing and finishing of fabrics	BR	M

TABLE 5.1: INDUSTRY SUGGESTED R&D NEEDS
(Continued)

Potential DOE Candidate	Description	Conservation Classification	Priority
	Develop energy standard for processing based on historical experience	HK	M
	Development of methanol- water mixture in finishing formation	PM	L
X	Study to make hot melt sizing more versatile or applicable to more varieties of fabrics	PM	L
	Study of efficient movement of liquid through fabric	BR	L
	Research in special print-paste formulation for discharging dyes by curing	BR	L
	Research in highly active catalyst system for pigment printing and resin finishing by flash curing	BR	L
	Methods other than membranes which can extract chemicals and color from effluent waste water	BR	L
	Development of automated real-time monitoring of the processes	BR	L
X	Computer modeling of the plant's HVAC system	HK	L

TABLE 5.1: INDUSTRY SUGGESTED R&D NEEDS
(Continued)

Potential DOE Candidate	Description	Conservation Classification	Priority
X	Study of Solid-on-Solid processing	BR	M
	Research to improve fiber properties which allow higher processing speeds	BR	M
X	Research in vapor-phase transfer printing of disperse dyes from paper to cloth which require no pre- or after-treatments	BR	M
X	Development of electrostatic techniques to be applied to spinning, chemical application, and waste removal	BR	M
	Develop lower energy dyeable polyester	BR	M
X	More research necessary in dust control in dry processing (presently - mechanical filtering used)	HK	H
	Study towards reducing refrigeration season by providing more data and awareness of process operating parameter	HK	M
	Inventory control system to manage and reduce aging stocks in inventory	HK	M

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**APPENDIX A - Data Base of Dry Processing
Specific Energy Use in 1984**

This specific contains data gathered from field trips to various mills and several current ITT (Institute of Textile Technology) Research Reports as well as data from the open literature. This section contain process data from mainly the spinning and weaving components. The wide variations in the quantities of process energy required are due to the variation and upkeep of the equipment at different mills and the cycles which are used.

TABLE A-1 SUMMARY OF ELECTRICAL ENERGY USED IN CARDING
(Average Figures)

<u>Process Fiber</u>	<u>Watt-hours/lb</u>	<u>Btu/lb*</u>	<u>Btu/lb**</u>
55 gr./yd. sliver	115	392.4	1,207.6
60 gr./yd. sliver	94	320.7	986.9
65 gr./yd. sliver	74	252.5	777.0
20 lb./hr.	116	395.8	1,218.0
40 lb./hr.	72	245.7	756.1
60 lb./hr.	63	215.0	661.6
Carded Yarn No. 18.5	72	244.8	753.3
Combed Yarn No. 35	135	461.4	1,419.9

* Conversion factor of 3412 Btu/kWh

** Energy intensity factor of 10,500 Btu/kWh_e (with electrical losses)
ITT Research Report No. 50
ITT Research Report No. 265 Supplement

TABLE A-2 SUMMARY OF ELECTRICAL ENERGY USED IN DRAWING
(Average Figures)

<u>Process Fiber</u>	<u>Watt-hours/lb</u>	<u>Btu/lb*</u>	<u>Btu/lb**</u>
60 gr./yd. sliver	13	44.4	136.6
70 gr./yd. sliver	24	81.9	252.0
Carded Yarn No. 18.5	15	52.8	162.5
Combed Yarn No. 35	26	88.0	270.0

* Conversion factor of 3,412 Btu/kWh

** Energy intensity factor of 10,500 Btu/kWh_e (with electrical losses)
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TABLE A-3 SUMMARY OF ELECTRICAL ENERGY USED IN ROVING
(Average Figures)

<u>Process Fiber</u>	<u>Watt-hours/lb</u>	<u>Btu/lb*</u>	<u>Btu/lb**</u>
0.6 hank	26	88.7	273.0
0.8 hank	57	194.5	598.5
1.0 hank	85	290.0	892.4
2 lb/hr.	55	187.7	577.6
4 lb/hr.	20	68.2	209.9
6 lb/hr.	12	40.9	125.9
Carded Yarn No. 18.5	59	201.9	621.3
Combed Yarn No. 35	94	319.7	983.8

* Conversion factor of 3412 Btu/kWh

** Energy intensity factor of 10,500 Btu/kWh_e (with electrical losses)
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TABLE A-4 SUMMARY OF ELECTRICAL ENERGY USED IN SPINNING

<u>Process Fiber</u>	<u>Watt-hours/lb</u>	<u>Btu/lb*</u>	<u>Btu/lb**</u>
10's	320	1,091.9	3,360.2
20's	720	2,456.8	7,560.5
30's	1,130	3,855.8	11,865.7
0.05 lb/hr	660	2,252.0	6,930.2
0.10 lb/hr	400	1,364.9	4,200.3
0.15 lb/hr	340	1,160.1	3,521.4
Carded Yarn No. 18.5	716	2,444.1	7,521.4
Combed Yarn No. 35	1,495	5,102.0	15,700.8

* Conversion factor 3412 Btu/kWh

** Energy intensity factor 10,500 Btu/kWh_e (with electrical losses)

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TABLE A-5 ELECTRICAL ENERGY USE IN CARDED YARN MANUFACTURE
(Various machines, yarn numbers, fibers, blends)

<u>Yarn No.*</u>		<u>Carding</u>	<u>Drawing</u>	<u>Roving</u>	<u>Spinning</u>	<u>Total</u>
3.0	(a)	155.9	32.3	120.5	524.1	832.8
	(b)	479.8	99.4	370.8	1612.9	2562.9
9C	(a)	346.7	49.3	162.4	1126.0	1684.4
	(b)	1066.9	151.7	499.8	3465.1	5183.5
12	(a)	378.8	49.5	215.7	1432.4	2076.4
	(b)	1165.7	152.3	663.8	4408.0	6389.8
15	(a)	587.6	112.8	159.0	1968.8	2828.3
	(b)	1808.3	347.1	489.3	6058.7	8703.4
18	(a)	192.4	59.0	106.1	1258.8	1616.3
	(b)	592.1	181.6	326.5	3873.8	4974.0
18.5**	(a)	244.8	52.8	201.9	2444.1	2943.6
	(b)	753.3	162.5	621.3	7521.4	9058.5
20	(a)	233.2	49.8	203.7	3052.6	3539.3
	(b)	717.6	153.3	626.9	9394.0	10891.8
21.3	(a)	176.4	62.1	96.6	2424.4	2759.5
	(b)	542.8	191.1	297.3	7460.8	8492.0
24	(a)	204.7	40.9	317.3	4016.0	4578.9
	(b)	629.9	125.9	976.5	12358.7	14091.0
30	(a)	226.6	90.4	216.7	6712.8	7246.5
	(b)	697.3	278.2	666.9	20657.8	22300.2
31	(a)	81.9	68.2	273.0	4698.6	5121.7
	(b)	252.0	209.9	840.1	14459.3	15761.3

(a) Conversion factor 3,412 Btu/kWh

(b) Energy intensity factor 10,500 Btu/kWh_e (with electrical losses)

** Median value

* Different mills

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TABLE A-6 ELECTRICAL ENERGY USED IN COMBED YARN MANUFACTURE
(Various machines, yarn numbers, fibers, blends)

<u>Yarn No.*</u>		<u>Carding</u>	<u>Drawing</u>	<u>Lapping</u>	<u>Combing</u>	<u>Roving</u>	<u>Spinning</u>	<u>Total</u>
25	(a)	267.2	68.0	51.5	486.9	377.7	3920.6	5171.9
	(b)	822.3	209.3	518.4	1498.4	1162.3	12065.2	15915.9
30	(a)	437.1	49.4	37.0	317.5	291.4	4463.8	5596.2
	(b)	1345.1	152.0	113.9	977.1	896.7	13736.8	17221.6
30	(a)	494.8	91.5	228.6	304.2	220.4	4285.7	5625.2
	(b)	1522.7	281.6	703.5	936.1	678.2	13188.7	17310.8
30	(a)	267.2	68.0	51.5	486.9	377.7	5251.4	6502.7
	(b)	822.3	209.3	518.5	1498.4	1162.3	16160.5	20011.2
30	(a)	509.8	105.0	46.2	385.7	395.5	4599.6	6041.8
	(b)	1568.8	323.1	142.2	1186.9	1217.1	14154.7	18592.9
30	(a)	509.8	105.0	46.2	385.7	395.5	3842.1	5284.3
	(b)	1568.8	323.1	142.2	1186.9	1217.1	11823.6	16261.8
30	(a)	509.8	105.0	46.2	385.7	395.5	4009.3	5451.5
	(b)	1568.8	323.1	142.2	1186.9	1217.1	12338.1	16776.3
35**	(a)	461.4	88.0	150.5	348.7	319.7	5102.0	6470.3
	(b)	1419.9	270.8	463.1	1073.1	983.8	15700.8	19911.5
36	(a)	494.8	91.5	228.6	304.2	258.3	5241.1	6618.5
	(b)	1522.7	281.6	703.5	936.1	794.9	16128.8	20367.6
38	(a)	494.8	91.5	228.6	304.2	258.3	5288.9	6666.3
	(b)	1522.7	281.6	703.5	936.1	794.9	16275.9	20514.7
40	(a)	494.8	91.5	228.6	304.2	220.4	5674.5	7014.0
	(b)	1522.7	281.6	703.5	936.1	678.2	17462.6	21584.7
40	(a)	494.8	91.5	228.6	304.2	242.2	5674.5	7135.8
	(b)	1522.7	281.6	703.5	936.1	745.3	17462.6	21959.5
40	(a)	494.8	91.5	228.6	304.2	258.3	5674.5	7051.9
	(b)	1522.7	281.6	703.5	936.1	794.9	17462.6	21701.3
42	(a)	494.8	91.5	228.6	304.2	342.2	5705.2	7166.4
	(b)	1522.7	281.6	703.5	936.1	1053.1	17557.0	22053.7
49	(a)	494.8	91.5	228.6	304.2	342.2	7796.9	9258.1
	(b)	1522.7	281.6	703.5	936.1	1053.1	23994.0	28490.6

(a) Conversion factor 3412 Btu/kWh

(b) Energy intensity factor 10,500 Btu/kWh_e (with electrical losses)

* Different mills

** Median Value

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TABLE A-7 ENERGY REQUIREMENTS FOR YARN MANUFACTURE

		Ring Spinning								Open End Spinning					
		Card Blend				Draw Blend									
		16's		24's		36's				10's		16's		24's	
		Btu/lb	\$	Btu/lb	\$	Btu/lb	\$	C	PE	Btu/lb	\$	Btu/lb	\$	Btu/lb	\$
Opening	(a)	307.1		307.6		275.5	135.5			307.1		307.1		312.3	
	(b)	945.1	11.1	946.6	7.4	792.4	417.0	4.3	2.3	945.1	19.7	945.1	13.0	961.1	8.2
Carding	(a)	273.3		275.0		169.4	237.2			245.7		259.3		258.9	
	(b)	840.1	9.9	846.3	6.6	521.3	730.0	2.9	4.0	756.1	15.7	798.0	11.0	796.7	6.8
Pre-Blend	(a)	---	---	---	---	169.4	33.9			---	---	---	---	---	---
	(b)	---	---	---	---	521.3	104.3	2.9	0.6	---	---	---	---	---	---
Drawing	(a)	88.7		88.6		135.5				88.7		88.7		102.8	
	(b)	273.0	3.2	272.7	2.1	147.0		2.3		273.0	5.7	273.0	3.8	316.4	2.7
Roving	(a)	368.5		494.1		433.7				---	---	---	---	---	---
	(b)	1134.0	13.3	1520.5	11.9	1334.7		7.3		---	---	---	---	---	---
Spinning	(a)	1723.2		2983.0		4350.6				921.3		1706.1		3134.0	
	(b)	<u>5302.9</u>	<u>62.4</u>	<u>9179.8</u>	<u>71.9</u>	<u>13388.4</u>		<u>73.5</u>		<u>2835.2</u>	<u>58.9</u>	<u>5250.3</u>	<u>72.3</u>	<u>9644.5</u>	<u>82.3</u>
Totals	(a)	2760.5		4148.3		5922.7				1562.8		2361.1		3808.0	
	(b)	8495.1	100	12756.9	100	18226.4		100		4809.4	100	7266.4	100	11718.7	100

* C = Cotton

PE = Polyester

(a) Conversion factor 3412 Btu/kWh

(b) Energy intensity factor of 10,500 Btu/kWh_g (with electrical losses)

Shirley Institute, 12th International Seminar, 1980

TABLE A-8 AVERAGE ENERGY CONSUMPTION IN YARN MANUFACTURING (ELECTRICAL)

Process	Watt-Hour/lb	Btu/lb*	Btu/lb**
<u>Picking</u>	23.9	81.6	251.1
<u>Carding</u>			
Lap Fed	88	300.3	924.1
Chute Fed	94	320.7	289.3
<u>Drawing</u>	14	47.8	147.1
<u>Roving</u>			
0.45 - 0.59 Hank	28	95.5	293.9
0.60 - 0.69 Hank	23	78.5	241.6
0.70 - Finer	68	232.0	714.0
<u>Spinning</u>			
Carded warp spun			
11.9/1 - Coarser	326	1,112.4	3,423.3
12/1 - 18.9/1	540	1,842.6	5,670.4
19/1 - 31/1	1,039	3,545.3	10,910.2
Carded direct spun filling			
11/1 - 19/1	369	1,259.1	3,874.7
Combed			
40/1	1,734	5,916.7	18,207.9

* Conversion factor 3412 Btu/kWh

** Energy intensity factor 10,500 Btu/kWh_e (with electrical losses)
ITT Research Report No. 50TABLE A-9 ENERGY REQUIREMENTS FOR SPINNING 50/50 POLYESTER
COTTON YARN (24 COUNT) - BLENDING AT DRAWING

Process	Btu/lb*	Btu/lb**	Percent
Opening (cotton)	190.7	586.9	5.2
Opening (polyester)	86.3	265.6	2.4
Carding (cotton)	168.0	517.0	4.6
Carding (polyester)	168.0	517.0	4.6
Predrawing, Lapping, Combing (cotton)	181.6	558.9	5.0
Drawing & Blending	272.4	838.3	7.5
Roving	154.4	475.1	4.2
Spinning	<u>2,428.9</u>	<u>7,474.6</u>	<u>66.5</u>
Total	3,650.3	11,233.4	100.0

* Conversion factor 3412 Btu/kWh

** Energy intensity factor 10,500 Btu/kWh_e (with electrical losses)
Shirley Institute, Energy Requirements in Textile Processing II, 1982

TABLE A-10 COMPONENTS OF TOTAL RING SPINNING ENERGY

Yarn Count	16s			30s		
Ring Diameter (in.)	2½			2		
Traverse (in.)	10			10		
Spindle Speed (RPM)	10,000			11,000		
	Btu/lb*	Btu/lb**	%	Btu/lb*	Btu/lb**	%
Spinning Energy	250.8	771.8	16.9	300.1	923.5	11.9
Package Energy	302.7	931.5	20.4	640.6	1971.4	25.3
Secondary Power	830.3	255.1	56.0	1411.1	4342.5	55.7
Ancillary Power	98.5	303.1	6.6	180.4	555.2	7.1
Total Power	1482.3	4561.5	100.0	2532.2	7792.6	100.0

* Conversion factor 3412 Btu/kWh

** Energy intensity factor 10,500 Btu/kWh_e (with electrical losses)
A study of power requirements in Ring Spinning, Journal of Textile
Institute, V48

TABLE A-11 ELECTRICAL ENERGY USE IN WINDING
(Spinning bobbins to packages)

Yarn No.	Production Rate (lb/hr/position)	Btu/lb*	Btu/lb**
2.50	3.5	296.0	910.9
2.75	35.0	53.6	164.9
3.25 (carpet yarn)	21.0	130.8	402.5
3/2 (worsted)	30.0	15.7	48.3
6.0	4.24	54.3	167.1
6 - 14.5 (average)	2.02	105.0	323.1
6.74	3.20	37.5	115.4
7.85 - 15 (average)	5.01	299.0	920.1
7.85 - 15 (average)	5.01	256.0	787.8
7.85 - 15 (average)	5.01	278.3	856.4
10	1.90	160.4	493.6
1/15 (worsted)	2.75	309.2	951.5
1/42 (worsted)	1.75	491.0	1511.0
15	3.30	493.9	1519.9
16 - 24 (average)	1.91	652.4	2007.7
16/1	3.88	183.1	563.5
9, 18 (average)	1.67	109.7	337.5
18	1.85	124.4	382.8
20	2.66	363.2	1117.7
20	2.59	399.7	1230.0
20	2.66	402.6	1239.0
18	3.96	253.3	724.1
1/32 (acrylic)	2.97	196.9	605.9
25	2.32	682.4	2100.0
30	1.80	905.9	2787.8
30	0.40	296.9	913.7
35	0.6072	108.8	334.8
3.1	0.7806	87.9	270.5
AVERAGE	5.5	276.1	849.7

* Conversion factor 3412 Btu/kWh

** Energy intensity 10,500 Btu/kWh_e
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TABLE A-12 ELECTRICAL ENERGY USE IN WINDING
(Spinning Bobbins to Package)

Reported in Various Literature

<u>Yarn Count</u>	<u>Btu/lb*</u>	<u>Btu/lb**</u>
16	324.2	997.7
24	512.7	1577.8
36	853.9	2627.8

* Conversion factor 3412 Btu/kWh

** Energy intensity factor, 10,500 Btu/kWh_e (with electrical losses)
Dr. Dennis Balmforth, ITT

TABLE A-13 ELECTRICAL ENERGY USED IN TWISTING

<u>Yarn Count</u>	<u>Production Rate</u>	<u>Btu/lb*</u>	<u>Btu/lb**</u>
2.75	1.5	607.4	1869.2
2.75	1.5	539.1	1659.0
2.75	1.5	764.3	2352.0
3.00/2	1.5	662.0	2037.2
3.25	0.96	914.0	2814.3
6.50/4	1.11	917.9	2824.7
6.50/12	4.5	208.1	640.4
6.50/12	1.18	308.3	948.8
9/2	0.24	662.0	2037.2
10/2	0.2730	436.8	1344.2
16/2	0.1262	1320.5	4063.7
18/2	0.1143	1361.5	4189.8
2/24	0.7331	917.9	2824.7
18/2	0.3118	2112.1	6499.7
2/28	0.0888	1446.0	4452.3
31/2	0.07	2221.3	6835.8
50/2	0.033	6548.0	20150.6
45/2	0.03	4548.4	13997.1
70/4	0.06	1313.7	4042.7
AVERAGE	0.833	1463.7	4504.4

* Conversion factor 3412 Btu/kWh

** Energy intensity factor 10,500 Btu/kWh_e
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TABLE A-14 SLASHER STEAM ENERGY CONSUMPTION

<u>Slasher Number</u>	<u>Btu/lb*</u>
1	1448
2	1071
3	2201
4	1315
5	1581
Average	1523

* Conversion of 3412 Btu/kWh
ITT Survey, Dr. Dennis Balmforth

TABLE A-15 ELECTRICAL ENERGY USED IN WEAVING

<u>Yarn Number</u> <u>(Warp/Fill)</u>	<u>Production Rate</u> <u>(lb/hr)</u>	<u>Btu/lb*</u>	<u>Btu/lb**</u>
5.5/5/5	5.49	1,153.3	3549.1
7.5/9:85	5.06	1,381.9	4252.6
7.5/9.85	11.70	825.7	2541.0
9/8	5.94	546.0	1680.2
14.5/14.5	2.94	1,105.5	3402.0
7.5/36	7.4	1,286.4	3958.7
18/2/18/2	3.08	2,368.1	7287.5
18/13	3.87	839.4	2583.1
15/40	1.274	4,258.4	13104.7
15/40	1.526	4,545.0	13986.7
31/41	1.467	2,869.7	8831.1
31/41	1.539	2,187.2	6730.8
31/41	1.680	2,552.3	7854.4
7.1/3/8/3	8.38	1,115.8	3433.7
9.45/9.45	10.7	713.1	2194.5
11.07/3/11.07/3	20.66	535.7	1648.5
AVERAGE	5.794	1,767.7	5439.9

* Conversion factor 3412 Btu/kWh

** Energy intensity factor 10,500 Btu/kWh_e (with electrical losses)
ITT Survey, Dr. Dennis Balmforth

TABLE A-16 HVAC COMPONENT HORSEPOWERS

	<u>Plant</u>			<u>averages</u>
	<u>A</u>	<u>B</u>	<u>C</u>	
Production (lb/yr x 10 ⁶)	12.5	11.7	16.8	13.7
Chiller HP	2,660	1,390	3,083	2,378
(Chiller (%))	70.1	59.0	52.6	59.4
Cooling Tower HP	298	335	420	351
Cooling Tower (%)	7.9	14.2	7.2	8.8
Air washer, fan and pump HP	838	630	2,355	1,274
Air washer, fan and pump (%)	22.1	26.8	40.2	31.8
TOTAL HP	3,796	2,355	5,858	4,003

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TABLE A-17 HVAC ENERGY CONSUMPTION

<u>Plant</u>	<u>HVAC</u>			<u>Production</u>			<u>Total</u>	
	<u>Btu/lb*</u>	<u>Btu/lb**</u>	<u>%</u>	<u>Btu/lb**</u>	<u>Btu/lb**</u>	<u>%</u>	<u>Btu/lb*</u>	<u>Btu/lb*</u>
A	1,637.9	5040.4	15.0	9,247.0	28456.5	85.0	10,884.9	33496.9
B	1,706.1	5250.3	23.5	5,561.9	17116.0	76.5	7,268.0	22366.3
C	2,047.3	6300.3	33.1	4,128.8	12705.9	66.9	6,176.1	19006.2

* Conversion factor 3412 Btu/kWh

** Energy intensity factor 10,500 Btu/kWh_e (with electrical losses)
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**APPENDIX B - Data Base of Wet Processing
Specific Energy Use in 1984**

This appendix contains data gathered from field trips to various mills and several current ITT (Institute of Textile Technology) Research Reports as well as data from the open literature. This section contains process data for preparation, dyeing, drying and finishing of woven and knit fabrics as well as floor coverings. The wide variations in the quantities of process energy required are due to the variation and upkeep of the equipment at different mills and the cycles which are used.

TABLE B-1 ENERGY CONSUMPTION OF ROPE PREPARATION RANGES
(Desize, Scour, Bleach, Excludes Heat Set and Singers)

Btu/lb					
Range Number	Electrical*	Electrical Losses	Steam	Total*	Total
1	65.46	136	4842.1	4907.5	5043.5
2	97.81	203	2588.2	2685.9	2885.9
3	10.33	21	1994.2	2004.5	2025.5
4	85.74	178	3094.5	3180.2	3358.2
5	11.17	23	3101.8	3112.9	3135.9
6	152.04	316	1336.9	1488.9	1804.9
7	117.89	245	2402.1	2519.9	2764.9
8	92.1	191	1310.7	1402.9	1593.9
AVERAGE	79.1	164	2583.8	2662.9	2826.9

* Conversion factor 3412 Btu/kWh
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TABLE B-2 ENERGY OUTPUTS FOR ROPE-BLEACH RANGES
(Singers Excluded)

Btu/lb					
Range Number	Radiation	Exhausts	Water	Loss on Fabric (Gain)	Total
1	40.9	863.4	3,912.5	25.3	4,842.1
2	30.3	612.9	1,928.5	16.5	2,588.2
3	12.0	574.2	1,419.0	(11.0)	1,994.2
4	37.1	700.0	2,267.2	(9.9)	2,994.4
5	35.3	702.6	2,363.9	--	3,101.8
6	124.3	13.9	1,219.2	(20.4)	1,337.1
7	95.8	21.2	2,302.6	(17.6)	2,402.1
8	57.5	68.1	1,185.1	--	1,310.7
AVERAGE	54.2	444.3	2,074.8	(2.1)	2,571.3

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TABLE B-3 CALCULATED VS ACTUAL ENERGY CONSUMPTION ROPE
PREPARATION RANGE (PE/C)
(Heat Set, Singe, Desize, Scour/Bleach, Pile in Bins)

Btu/lb						
Process	Electrical	Electrical Losses	Steam	Nat. Gas	Total No losses	Total With losses
Heat Set	31.52	65.48	---	521.61	653.13	718.61
Singe	8.45	17.55	---	386.92	395.37	412.92
Desize	32.73	67.99	475.77	---	508.50	576.49
Scour/ Bleach	70.32	146.08	951.54	---	1021.86	1167.94
Heat water	---	---	1176.94	---	1176.94	1176.94
Misc.	3.03	6.29	---	---	3.03	9.32
Efficiency Adjust.	---	---	511.20	---	511.20	511.20
TOTALS	146.05	303.39	3115.37	1008.53	4269.95	4573.34

ACTUAL

Plant	Electrical	Electrical Losses	Thermal*	Total No losses	Total with losses	Gal water/lb
1	138	287	4290	4428	4715	3.24
2	113	235	3739	3852	4067	1.60
3	111	231	2860*	2971	3202	4.48
AVERAGE	121	251	3630	3751	4002	3.11

* Includes 60% heat recovery, includes efficiency adjustment

TABLE B-4 PREPARATION FOR CONTINUOUS DYEING (Including Merc.)
CALCULATED FIGURES (8 oz/sq yd, 50/50, 110 ypm, 5867 lb/hr)

Process	Btu/lb					Total without Losses	Total with Losses
	Electrical	Electrical Losses	Steam	Nat. Gas			
Let-off Scray	2.2	4.6	--	--		2.2	6.8
Brush	5.4	11.2	--	--		5.4	16.8
Singe	2.2	4.6	--	395.5		381.7	386.3
Steam Snuff	--	--	29.6	--		29.6	29.6
Heat Set	26.1	54.2	--	702.3		728.9	783.1
Desize Sat.	3.3	6.8	34.0	--		37.3	44.1
Desize Steamer	4.3	8.9	251.5	--		255.8	264.7
Desize Washers	7.6	15.8	187.4	--		195.0	210.3
Caustic Sat.	4.3	8.9	28.1	--		32.4	41.3
Caustic Steamer	17.8	37.0	304.2	--		358.0	395.0
Scour Washers	7.6	15.8	126.0	--		133.6	149.4
Vac. Extract	4.3	8.9	--	--		4.3	13.2
Peroxide Sat.	3.3	6.8	--	--		3.3	10.1
Peroxide Steam	5.5	13.5	281.1	--		287.6	301.1
Peroxide Wash	7.6	15.8	119.2	--		126.8	142.6
Vac. Extract	4.3	8.9	--	--		4.3	13.2
Caustic (merc)	6.5	13.5	--	--		6.5	20.0
Time Cans	2.2	4.6	--	--		2.2	6.8
90 ft. Tenter	44.3	92.0	68.2	--		112.5	204.5
Merc. Wash	9.8	20.4	92.0	--		101.8	122.2
Vac. Extract	4.3	8.9	--	--		4.3	13.2
Dry Cans	4.3	8.9	417.2	--		412.5	430.4
Scray	1.3	2.7	--	--		1.3	4.0
Batch	3.3	6.8	--	--		3.3	10.1
TOTALS	182.9	379.5	1,974.6	1,082.3		3,239.8	3,619.1

Hot Water 0.60 gal/lb
Cold Water 0.26 gal/lb
Total 0.86 gal/lb

From ATMI Finisher's Energy Committee Report

TABLE B-5 PREPARATION FOR JET OR BECK DYEING CALCULATED FIGURES
(8 oz/sq yd, 150 ypm, 8000 lb/hr)

Process	Btu/lb					Total without Losses	Total with Losses
	Electrical	Electrical Losses	Steam	Nat. Gas			
Let-off Scray	1.6	3.3	--	--		1.6	4.9
Brush	4.0	8.3	--	--		4.0	12.3
Singe	1.6	3.3	--	280.0		279.6	282.9
Steam Snuff	--	--	21.7	--		21.7	21.7
Heat Set	19.1	39.7	--	514.7		533.8	573.5
Desize Sat.	2.4	5.0	24.9	--		27.3	32.3
Desize Steamer	4.8	10.0	--	--		4.8	14.8
Washers	4.8	10.0	66.1	--		70.9	80.9
Vacuum	3.2	6.6	--	--		3.2	9.8
Cold Bleach Sat.	3.2	6.6	--	--		3.2	9.8
Vac. Extract	3.2	6.6	--	--		3.2	9.8
Batch	3.2	6.6	--	--		3.2	9.8
Scray	0.9	1.9	--	--		0.9	2.8
Washers	4.8	10.0	98.1	--		102.9	112.9
Vacuum	3.2	6.6	--	--		3.2	9.8
Scray	3.2	6.6	--	--		3.2	9.8
TOTALS	63.0	131.1	201.9	792.6		1066.5	1197.8

Water Consumption

Cold 0.13 gal/lb
Hot 1.16 gal/lb
TOTAL 1.29 gal/lb

From ATMI Finisher's Energy Committee Report

TABLE B-6 GAS CONSUMPTION IN SINGEING

<u>Range Number</u>	<u>Btu/lb</u>
1	153.5
2	103.2
3	227.1
4	47.2
5	81.9
6	142.6
7	163.0
8	162.6
9	225.7
10	147.6
11	200.4
12	151.1
13	132.3
14	248.5
15	128.0
16	100.0
17	206.1
AVERAGE:	154.2

ITT Research Survey, Dr. Dennis Balmforth

TABLE B-7 ENERGY CONSUMPTION OF HEATSET RANGES
(Btu/lb)

<u>Range No.</u>	<u>Electrical</u>	<u>Electrical Losses</u>	<u>Nat. Gas</u>	<u>Total w/out losses</u>	<u>Total w/losses</u>
1	88.1	183.0	222.6	310.7	493.7
2	24.8	51.5	205.5	230.3	281.8
3	38.6	80.2	333.9	372.9	452.7
4	111.2	231.0	466.5	577.7	808.7
5	128.9	267.8	389.3	518.2	786.0
6	41.7	86.6	240.8	282.5	369.1
AVERAGE	72.2	150.0	309.8	382.0	532.0

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TABLE B-8 ENERGY CONSUMPTION OF MERCERIZERS
(Btu/lb)

<u>Range No.</u>	<u>Electrical</u>	<u>Electrical Losses</u>	<u>Steam</u>	<u>Total w/o losses</u>	<u>Total w/losses</u>
1	218.6	454.1	3655.1	3873.7	4327.8
2	97.9	203.4	1256.0	1354.0	1557.4
3	387.0	803.9	1954.6	2341.6	3145.5
4	106.6	221.4	751.4	822.0	1043.4
5	89.8	186.5	942.2	1032.0	1218.5
6	121.6	252.6	1626.3	1747.9	2000.5
7	62.3	129.4	530.2	592.5	721.9
8	211.1	438.5	1857.3	2068.4	2506.9
9	209.8	435.8	982.4	1192.2	1628.0
10	149.8	311.2	778.6	928.4	1239.6
11	183.6	381.4	1172.2	1355.8	1737.2
AVERAGE	167.1	347.1	1406.4	1573.6	1920.7

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TABLE B-9 BREAKDOWN OF THERMAL ENERGY OUTPUTS
HEAT SET RANGE
(Btu/lb)

<u>Range No.</u>	<u>Radiation</u>	<u>Stack Loss</u>	<u>Heat Loss on Fabric</u>	<u>Total</u>
1	37.7	87.0	97.9	222.6
2	--	195.6	9.9	205.5
3	--	222.2	111.7	333.5
4	121.2	321.1	24.2	466.5
5	48.1	262.2	79.0	389.3
6	--	85.1	155.7	240.8
AVERAGE	34.5	195.5	79.7	309.8

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TABLE B-10 BREAKDOWN OF THERMAL ENERGY OUTPUTS MERCERIZER
(Btu/lb)

<u>Range No.</u>	<u>Radiation</u>	<u>Exhausts</u>	<u>Effluent</u>	<u>Loss on Fabric</u>	<u>Total</u>
1	114.5	--	3510.3	30.3	3655.1
2	28.5	--	1195.1	32.5	1256.1
3	97.0	--	1794.8	57.8	1954.6
4	91.6	--	588.2	35.6	715.4
5	26.0	--	868.4	47.7	942.1
6	12.4	29.0	1584.9	--	1626.3
7	40.9	40.9	448.3	--	530.1
8	25.9	--	1817.9	13.6	1857.4
9	20.9	--	943.5	18.1	982.5
10	89.0	147.3	514.3	28.0	773.6
11	40.8	395.9	728.9	6.6	1172.3
AVERAGE	53.4	55.7	1272.6	24.5	1406.2

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TABLE D-11 ENERGY CONSUMPTION OF MERCERIZER RANGES
(Open-Pop PE/C fabric, Water Range, Mercerize, Dry)

<u>Range Number</u>	<u>Electrical*</u>	<u>Electrical Losses</u>	<u>Thermal*</u>	<u>Total No losses</u>	<u>Total with losses</u>	<u>Gal water/lb</u>
1	245	509	4125	4370	4879	1.59
2	294	611	7206	7500	8111	2.47
3	204	424	7927	8131	8555	5.29
AVERAGE	248	515	6419	6667	7182	3.12

Auburn University Energy Study
* Conversion factor 3412 Btu/kWh

TABLE B-12 ENERGY CONSUMPTION - DYE PAD AND JIGS
(Pad dye on fabric, dye and after treat)

<u>No.</u>	<u>Electrical*</u>	<u>Electrical Losses</u>	<u>Thermal</u>	<u>Total (no losses)</u>	<u>Total (with losses)</u>	<u>Gallon water/lb</u>
1	106	220	2840	2946	3166	3.46
2	123	256	461	584	840	5.52
AVERAGE	114	238	1651	1765	2003	4.49

Auburn University Energy Study
* Conversion factor 3412 Btu/kWh

TABLE B-13 ENERGY CONSUMPTION OF OPEN-WIDTH BLEACH RANGES
(Btu/lb)

<u>Range No.</u>	<u>Electrical</u>	<u>Electrical Losses</u>	<u>Steam</u>	<u>Total (no losses)</u>	<u>Total (with losses)</u>
1	58.7	121.9	1273.9	1332.6	1454.5
2	131.2	272.6	3380.7	3511.9	3784.5
3	105.0	218.1	4238.8	4343.9	4562.0
4	92.8	192.8	1873.1	1965.9	2158.7
5	123.7	256.9	6311.9	6435.5	6692.4
6	139.3	289.4	5741.1	5880.3	6169.7
7	130.0	270.1	2901.9	3031.8	3301.9
8	57.4	119.2	1417.8	1475.1	1594.3
9	125.5	260.7	1957.1	2082.5	2343.2
10	165.5	343.8	2550.2	2715.8	3059.6
11	88.3	183.4	2278.6	2366.9	2550.3
12	93.6	194.4	2240.5	2334.1	2528.5
13	195.6	406.3	2671.5	2867.1	3273.4
14	149.8	311.2	3769.6	3919.5	4230.7
15	235.6	489.4	3371.2	3606.9	4096.3
AVERAGE	126.1	262.0	3065.1	3190.8	3452.3

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TABLE B-14 BREAKDOWN OF THERMAL ENERGY OUTPUTS
OPEN-WIDTH RANGE
Btu/lb

<u>Range Number</u>	<u>Radiation</u>	<u>Exhausts</u>	<u>Water</u>	<u>Loss on Fabric</u>	<u>Total</u>
1	50.7	321.5	863.8	31.8	1273.8
2	103.1	1541.3	1630.6	105.6	3380.5
3	153.0	316.7	3732.4	36.8	4238.8
4	48.1	110.7	1682.1	32.5	1873.1
5	62.5	2621.0	3531.7	96.8	6311.9
6	87.8	1768.8	3861.0	23.7	5741.3
7	84.5	1163.9	1547.7	105.6	2901.7
8	130.1	594.0	670.0	23.7	1417.8
9	28.5	---	1894.4	34.1	1957.1
10	203.8	816.0	1488.1	42.4	2550.4
11	77.7	328.1	1834.3	38.4	2278.6
12	68.6	806.1	1333.3	32.5	2240.5
13	233.8	290.4	2036.6	110.0	2670.9
14	187.8	1727.9	1804.9	48.9	3769.5
15	133.2	1476.6	1700.9	60.5	3371.2
AVERAGE	110.2	925.9	1974.1	54.9	3065.1

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TABLE B-15 ENERGY CONSUMPTION OF OPEN-WIDTH PREPARATION
CALCULATED (BTU/lb)

Process	Electrical	Electrical Losses	Steam	Gas	Total (no Losses)	Total (with Losses)
Heat Set	37.36	77.61	--	666.95	704.31	781.92
Singe	9.18	19.07	--	343.40	352.58	371.65
Desize	36.73	76.30	1060.10	--	1096.83	1173.13
Caustic Scour	32.13	66.75	1060.10	--	1092.23	1158.98
Peroxide Bleach	32.13	66.75	1060.10	--	1092.23	1158.98
Mercerize	100.34	208.44	816.97	--	917.31	1125.75
Dry & Batch	26.23	54.49	1467.32	--	1493.55	1548.04
Efficiency Adjust	---	---	1092.92	--	1092.92	1092.92
TOTAL	274.10	569.41	6557.51	1010.35	7841.96	8411.37

ACTUAL
(No Mercerization)

Plant	Electrical*	Electrical Losses	Thermal	Total (no losses)	Total (with losses)	Gallon Water/lb
1	165	343	6670	6835	7178	4.96
2	143	297	5554	5697	5994	2.70
3	128	266	4481	4609	4875	6.90
AVERAGE	145	302	5568	5713	6015	4.85

* 60% heat recovery, includes efficiency adjustment
Auburn University Energy Study

TABLE B-16 POLYESTER KNIT PREPARATION
THERMAL ENERGY OUTPUTS
(Btu/lb)

Machine No.	Fabric	Water	Radiation	Total
1	10	150	63	223
2	13	335	63	411
3	25	315	64	404
4	33	290	60	383
AVERAGE	20	273	63	355

ITT Energy Survey, Dr. Dennis Balmforth

TABLE B-17 CONVENTIONAL PROCESS OPEN WIDTH BLEACHING

Process	Energy Consumed (Btu/lb)
Singe	323
Desize sat.	304
Caustic pad/roll	418
Wash	6631
Can dry	2090
Peroxide pad/roll	380
Wash	6213
Can dry	2090
TOTAL	18449

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TABLE B-18 AMENDED PROCESS. OPEN-WIDTH BLEACHING

<u>Process</u>	<u>Energy Consumed (Btu/lb)</u>
Singe	380
Pad (caustic + chem.)	304
Steam	7410
Wash	95
Pad (perox. + chem.)	--
Steaming	1767
Washing	779
Can dry	2090
TOTAL	12825

Shirley Institute, 12th International Seminar

TABLE B-19 PAD/BATCH PROCESS OPEN WIDTH BLEACHING

<u>Process</u>	<u>Energy Consumed (Btu/lb)</u>
Singe	323
Cold Pad	---
Storage	---
Cold Pad	---
Storage	---
Wash	980
Can dry	2090
TOTAL	3401

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TABLE B-20 ENERGY REQUIREMENTS FOR FABRIC PREPARATION, BEFORE AND AFTER
ENERGY CONSERVATION MEASURES (STEAM AND GAS ENERGY ONLY) ROPE BLEACHING

<u>Process</u>	<u>Energy Consumption (Btu/lb)</u>	
	<u>Before</u>	<u>After</u>
Singeing	456	456
Desizing	247	171
Washing	1007	76
Caustic sat.	95	95
Caustic J-box	76	76
Washing	2109	380
Peroxide sat.	190	190
Peroxide J-box	114	114
Washing	2033	342
Can drying	2660	1710
Losses	1026	1026
TOTALS	10013	4636

TABLE B-21 BREAKDOWN OF ENERGY OUTPUTS DYE RANGE
(Btu/lb)

<u>Range Number</u>	<u>Radiation</u>	<u>Exhausts</u>	<u>Water</u>	<u>Loss on Fabric</u>	<u>Total</u>
1	99.9	6116.3	994.4	92.8	7308.4
2	197.9	4784.6	845.2	31.5	5859.1
3	344.1	6654.5	2154.5	72.9	9225.9
4	102.1	1306.4	928.1	81.2	2417.8
5	142.2	1109.7	778.9	86.2	2113.7
6	28.7	5321.2	2121.3	66.3	7537.5
7	32.3	849.5	1010.9	8.3	1901.1
8	11.1	157.4	828.6	24.9	1022.0
9	1.3	1056.7	---	46.4	1104.4
10	66.5	3399.1	2536.6	102.8	6103.7
11	28.3	2329.1	861.8	67.9	3289.2
12	202.9	2065.3	712.6	34.8	3015.6
13	40.8	699.4	861.8	19.9	1621.8
14	112.4	3016.1	1375.5	111.0	4615.7
15	316.7	2681.1	845.2	102.7	3950.3
16	417.3	291.2	---	46.4	754.9
17	41.8	326.3	696.1	21.5	1035.7
18	110.5	1792.6	1624.1	89.5	3616.7
AVERAGE	127.6	2441.5	1065.6	60.8	3696.6

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TABLE B-22: ENERGY CONSUMPTION OF CONTINUOUS DYE RANGES
Calculated (Btu/lb.)
(64" wide, 115ypm, 8oz/sq. yd. = 6133 lb/hr)

<u>Process</u>	<u>Electrical</u>	<u>Electrical Losses</u>	<u>Steam</u>	<u>Gas</u>	<u>Total (no losses)</u>	<u>Total (with losses)</u>
Let off	2.10	4.36	-	-	2.1	6.46
Dye pad	6.20	12.88	-	-	6.2	19.08
Pre-dry	5.00	10.39	-	437.1	442.1	452.49
Dry cans	7.05	14.64	424.6	-	431.65	446.29
Thermosol	2.50	5.19	-	369.9	372.4	377.59
Cooling cans	1.25	2.60	-	-	1.25	3.05
Chem. pad	4.15	8.62	-	-	4.15	12.77
Steamer	4.15	8.62	155.6	-	159.75	168.37
Wash boxes	34.6	71.88	275.3	-	309.9	381.78
Vacuum	4.15	8.62	-	-	4.15	12.77
Dry cans	6.20	12.88	467.0	-	473.2	486.08
Cool cans	1.25	2.60	-	-	1.25	3.85
A-frame	3.0	6.44	-	-	3.1	9.54
TOTALS	81.7	169.72	1322.5	807.0	2211.2	2380.92

Run-time energy consumption 2211.2 Btu/lb
Down-time energy consumption 279.1 Btu/lb

Grand Total 2409.3 Btu/lb

Gallons water/lb 0.90 Cold
0.68 Hot
1.58 Total

ATMI Finishers' Energy Subcommittee Reports

TABLE B-23: CONTINUOUS DYE RANGE ENERGY CONSUMPTION
Calculated (Polyester/Cotton)
(Btu/lb)

<u>Process</u>	<u>Electrical</u>	<u>Electrical Losses</u>	<u>Steam</u>	<u>Gas</u>	<u>Total (no losses)</u>	<u>Total (with losses)</u>
Radiant Pre-dry	1.22	2.53	-	1433.08	1434.30	1436.83
Pre-dry cans	4.86	10.1	743.33	-	748.19	758.29
Thermosol	37.95	78.84	-	1177.79	1215.74	1294.58
Steamer	18.00	37.39	588.00	-	606.00	643.39
Wash boxes	45.00	93.48	619.70	-	664.70	758.18
Dry cans	55.24	114.75	1176.00	-	1231.24	1345.99
Exhaust air	14.60	30.33	1212.86	-	1227.46	1257.79
Efficiency adjustment	-	-	1103.54	-	1103.54	1103.54
TOTALS	176.87	367.42	5443.43	2610.87	8231.17	9598.59

Actual (Btu/lb)

<u>Plant</u>	<u>Electrical</u>	<u>Electrical Losses</u>	<u>Thermal*</u>	<u>Total (no losses)</u>	<u>Total (with losses)</u>
1	158	328.22	6226	6384	6712.22
2	128	265.90	8421	8549	8814.90
3	149	309.53	6934	7083	7392.53
Average	145	301.22	7194	7339	7640.22

*60% heat recovery from wash waters includes efficiency adjustment

Auburn University Energy Study

TABLE B-24: ENERGY CONSUMPTION OF DYE RANGES
(Btu/lb)

<u>Range No</u>	<u>Electrical</u>	<u>Electrical Losses</u>	<u>Steam</u>	<u>Gas</u>	<u>Total (no-losses)</u>	<u>Total (with losses)</u>
1	381.2	791.09	6596.0	563.5	7540.6	8332.49
2	99.4	206.49	9551.9	1243.0	6894.3	7100.79
3	248.6	516.43	6761.7	1673.8	8684.1	9200.53
4	430.9	895.14	5137.6	679.5	6247.9	7143.04
5	198.9	413.20	4673.5	2485.9	7358.3	7771.50
6	116.0	240.97	4209.5	2055.0	6380.5	6621.47
7	248.6	516.43	4640.4	1740.1	6629.1	7145.53
8	16.6	34.48	828.6	165.7	1010.9	1045.38
9	16.6	34.48	994.4	265.2	1276.1	1310.58
10	99.4	206.49	3762.0	1980.7	5830.2	6056.69
11	49.7	103.24	4789.5	530.3	5369.6	5472.84
12	265.2	550.92	5071.3	2088.2	7424.6	7975.52
13	49.7	103.24	4773.0	1789.9	6612.5	6715.74
14	132.6	275.46	4706.7	2485.9	7325.2	7600.66
15	215.4	447.47	5684.5	2154.4	8054.4	8501.87
16	99.4	206.49	447.5	414.3	961.2	1167.69
17	99.4	206.49	5038.1	2717.9	7855.5	8061.99
18	99.4	206.49	2784.2	1707.0	4590.7	4797.19
AVERAGE	159.3	330.93	4247.2	1486.0	5892.5	6223.43

TABLE B-25: BATCH DYE MACHINERY COMPARISON (AVERAGE FIGURES)

<u>Machine</u>	<u>Btu/lb.</u>	
	<u>Without cooling-water heat recovery</u>	<u>With cooling-water heat recovery</u>
Circular type jet (PEK)*	1,600	700
Autoclave type jet (PEK)	2,400	1,140
Horizontal tubular type jet	5,100	2,700
Horizontal tubular type jet (PEW)	4,500	2,100
Autoclave type jet (PEW)	3,300	1,500

*PEK = polyester knit PEW = polyester woven

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TABLE B-26: ENERGY CONSUMPTION OF BATCH DYEING (CALCULATED)
(Pre-scour, dry, dye bath, rinse, post scour, dry, heatset, scour)

		<u>(Btu/lb.)</u>
Cotton:	Atmospheric Beck, Knit	3850
	Pad/Batch, Knit	4375
Polyester:	Atmospheric Beck, Knit	2338
	Pressure Jet, Knit	2768
Polyester/Cotton:	Atmospheric Beck, Knit	3599
	Pressure Jet, RID, Knit	3650
	Pressure Jet, Knit	4029
Nylon:	Enclosed Jig, Roll	1217
	Atmospheric Beam, Tricot	1618
	Pressure Beam, Tricot	1677
	Atmospheric Beck, Upholstery	2499
	Carpet Beck, Carpet	3489
Acrylic:	Pressure Stock, Staple	2871
	Atmospheric Beck, Knit	3068
	Atmospheric Paddle, Knit	3068
	Atmospheric Package, Yarn	3089
	Skein Dyeing, Yarn	4312

Energy Demand in Dyeing & Finishing, Dr. Wallenberger
Textile Chemist & Colorist V13, No. 8

TABLE B-27: ENERGY CONSUMPTION OF TOW DYEING (CALCULATED)

		<u>Btu/lb</u>
Polyester:	Serracant, Pressure Dye, Tow	3670
Acrylic:	Serracant, Pressure Dye, Tow	4460

Energy Demand in Dyeing & Finishing, Dr. Wallenberger
Textile Chemist & Colorist V13, No. 8

TABLE B-28: ENERGY CONSUMPTION OF CONTINUOUS DYEING (CALCULATED)

		<u>Btu/lb</u>
Cotton:	Pad/Steam, Woven	6760
Polyester:	Thermosol, Woven	2409
Polyester/Cotton:	Thermosol and Pad/Steam, Woven	6388
Nylon:	Kuester, Carpet	6147

Energy Demand in Dyeing & Finishing, Dr. Wallenberger
Textile Chemist & Colorist V13, No. 8.

TABLE B-29: DRYING VERSUS WET PROCESSING ENERGY FOR DYEING
(High and Low Energy Processes of Tables B-26-28)

<u>Dry Processing</u>			<u>Wet Processing</u>		
<u>Process</u>	<u>Fiber</u>	<u>Energy (Btu/lb)</u>	<u>Process</u>	<u>Fiber</u>	<u>Energy (Btu/lb)</u>
Pad Steam	Cotton	4100	Continuous Carpet	Nylon	4262
Range Dye	PE/C	3720	Pressure Jet	PE/C	3301
Pad Batch	Cotton	2750	Skein (Atm/Press)	Acrylic	2796
Continuous Carpet	Nylon	2280	Pad Steam	Cotton	2662
Average		1618	Average		1956
Open Beck	PE	856	Pressure Stock	Acrylic	1161
Open Beam	PE	799	Pressure Beam	Nylon	878
Pressure Beam	Nylon	799	Open Beam	Nylon	819
Open Beck	Nylon	713	Encl. Jig	Nylon	564
Encl. Jig	Nylon	713	Thermosol	PE	408

Energy Demand in Dyeing & Finishing, Dr. Wallenberger,
Textile Chemist & Colorist V13, No. 8.

TABLE B-30: DETAILED BATCH DYEING MACHINERY ANALYSIS
(Average Figures)
(Btu/lb.)

	<u>Circular type jet</u>	<u>Autoclave type jet</u>	<u>Horizontal type jet</u>
Liquor ratio:	6/1	12/1	22/1
To heat water:	1,200	2,050	4,300
To heat fabric:	80	76	709
To heat machine	185	240	700
TOTALS	1,465	2,366	5,070

ATMI Finishers' Energy Subcommittee Reports

TABLE B-31: BATCH DYEING COMPARISON

<u>Equipment</u>	<u>Process</u>	<u>Btu/lb.</u>	<u>Gal/lb</u>
Calculated:			
Jet	250°F disp/react dyes	4,510	7.14
Jet	RID 250°F	4,600	5.95
Pad/jet	RID PB	3,750	2.38
Jet	250°F 2 Bath/1 Step D/F	2,622	5.54
Jet	250°F 1 Bath/1 Step D/F	1,734	3.70
Beck	205°F 1 Bath/1 Step D/F	2,570	9.46
Actual:			
Jet	Prebleach, dye, rinse	2,430	14
Beck	Prebleach, dye, rinse	5,820	32

*Rapid inverse dyeing. PB = pad/batch

ATMI Finishers' Energy Subcommittee Reports

TABLE B-32: YARN DYE STEAM ENERGY CONSUMPTION
(Btu/lb)

Cycle no.	1	2	3
Fiber	Cotton	Poly/cotton	Synthetic
Dye	(Sulfur)		
Heat yarn	320	425	56
Heat machine	1,200	1,600	140
Heat water	5,800	7,750	2,550
Radiation	120	500	140
Washes	3,750	13,300	-
TOTALS	11,190	23,575	2,886

ATMI Finishing's Energy Subcommittee Reports

TABLE B-33: ENERGY CONSUMPTION: RAWSTOCK DYEING
(Btu/lb of fiber)
(cellulosic and man-made fibers)

Dye Type	Electrical*	Electrical losses	Thermal	Total no losses	Total with losses
Directs	946	1965	6021	6967	8932
Vats	1032	2144	8410	9442	11586
Naphthols	1158	2406	9904	11062	13468
Premetallized	788	1637	6768	7556	9193
Basics	<u>1060</u>	<u>2202</u>	<u>9785</u>	<u>10845</u>	<u>13047</u>
Average	997	2071	8178	9174	11245

Note: Includes 360 Btu/lb for electrical drying
2750 Btu/lb for thermal drying

No Heat Recovery

*3412 Btu/kWh conversion factor

Auburn University Energy Study

TABLE B-34: ENERGY CONSUMPTION FOR THE BLEACH PROCESS
PRIOR TO YARN PACKAGE DYEING
(Btu/lb of Yarn)
(Cellulosic and Blend Yarns)

	Electrical*	Electrical Losses	Thermal	Total (no losses)	Total (includes losses)
Plant A:					
Wet Process	1500	3116	9800	11300	14416
Drying	<u>676</u>	<u>1404</u>	<u>3060</u>	<u>3736</u>	<u>5140</u>
	2176	4520	12860	15036	19556
Plant B:					
Wet Process	1115	2316	6000	7115	9431
Drying	<u>1100</u>	<u>2285</u>	<u>2450</u>	<u>3550</u>	<u>5635</u>
	2215	4601	8450	10665	15266

Note: No Heat Recovery

Auburn University Energy Study

*Conversion factor 3412 Btu/kWh

TABLE B-35: ENERGY CONSUMPTION - YARN PACKAGE DYEING
(Btu/lb of Yarns)
(Cellulosic and Blend Yarns)

	<u>Electrical*</u>	<u>Electrical Losses</u>	<u>Thermal</u>	<u>Total (no losses)</u>	<u>Total (includes losses)</u>
Plant A: Dye Types					
Direct	1266	2630	6490	7756	10386
Vat	1826	3793	9225	11051	14844
Naphthol	2226	4624	10533	12759	17383
Sulphur	1851	3845	11390	13241	17086
Reactive	<u>1636</u>	<u>3399</u>	<u>13010</u>	<u>14646</u>	<u>18045</u>
Average	1751	3658	10130	11891	15549
Note: Includes: 676 Btu/lb of Electrical Drying 3060 Btu/lb of Thermal Drying					
Plant B: Dye Types					
Direct	1832	3806	4532	6364	10170
Vat	2468	5127	6248	8716	13843
Naphthol	3010	6253	6860	9870	16123
Sulphur	2563	5324	12373	14936	20260
Reactive	<u>2630</u>	<u>5463</u>	<u>7962</u>	<u>10592</u>	<u>16055</u>
Average	2501	5195	7595	10096	15290
Note: Includes: 1100 Btu/lb of Electrical Drying 2450 Btu/lb of Thermal Drying					
Overall Average	2131	4427	8863	10994	15420
Average: Drying: 8800 Btu/lb of Electrical Energy 2755 Btu/lb of Thermal Energy					

*Conversion factor 3412 Btu/kWh,
Suburn University Energy Study

TABLE B-36: ENERGY CONSUMPTION OF FINISHING RANGES
(Btu/lb)

Range No.	Electrical	Electrical Losses	Steam	Gas	Total (no losses)	Total (with losses)
1	82.9	172.2	-	646.3	729.2	901.4
2	33.1	68.7	-	3132.3	3165.4	3234.1
3	33.1	68.7	232.0	3264.8	3530.0	3598.1
4	198.9	413.2	-	1093.8	1292.7	1735.9
5	149.2	309.9	-	778.9	928.1	1238.0
6	132.6	275.5	-	1491.5	1624.1	1899.6
7	215.4	447.5	729.2	679.5	1624.1	2071.6
8	248.6	516.4	5005.0	-	5253.6	5770.0
9	397.7	826.2	1723.6	1259.5	3380.8	4207.0
10	845.2	1755.8	-	4209.5	5054.7	6810.5
11	99.4	206.5	-	911.5	1010.9	1217.4
12	33.1	68.7	-	994.4	1027.5	1096.2
13	99.4	206.5	1143.5	281.7	1524.7	1731.2
14	132.6	275.5	-	994.4	1126.9	1402.4
15	82.9	172.2	546.9	1740.1	2369.9	2542.1
16	82.9	172.2	348.0	1723.6	2154.5	2326.7
17	165.7	344.2	-	1823.0	1988.7	2332.9
18	165.7	344.2	729.2	994.4	1889.3	2233.5
19	49.7	103.2	2950.0	3397.4	6397.1	6500.3
20	580.0	1204.9	1789.9	875.4	3248.3	4453.2
21	82.9	172.2	-	928.1	1010.9	1133.1
22	198.9	413.2	-	2088.2	2287.0	2700.2
23	66.3	137.7	-	1773.3	1839.6	1977.3
24	116.0	241.0	82.9	928.1	1126.9	1357.9
25	248.6	516.4	-	165.7	414.3	930.7
26	248.6	516.4	298.3	414.3	961.2	1477.6
27	33.1	68.7	2701.4	4027.2	6761.7	6830.4
Average	178.6	371.0	677.0	1504.4	2360.1	2731.1

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TABLE B-37: BREAKDOWN OF ENERGY OUTPUTS
FINISHING-RANGE
(Btu/lb.)

Range No.	Radiation	Exhausts	Loss on Fabric	Total
1	99.4	679.5	82.9	861.8
2	82.9	331.5	132.6	546.9
3	132.6	198.9	132.6	464.0
4	116.0	232.0	16.6	346.6
5	82.9	165.7	33.1	281.7
6	116.0	165.7	33.1	314.9
7	99.4	2,237.3	66.1	2,343.4
8	265.2	729.2	33.1	1,027.5
9	49.7	2,171.0	33.1	2,253.9
10	165.7	2,038.4	33.1	2,237.3
11	99.4	464.0	13.3	576.7
12	132.6	845.2	16.6	994.4
13	66.3	696.1	82.9	845.2
14	116.0	2,403.0	16.6	2,535.6
15	198.9	1,425.3	33.1	1,657.3
16	82.9	795.5	33.1	911.5
17	99.4	165.7	16.6	281.7
18	82.9	1,673.5	8.3	1,765.0
19	116.0	3,298.0	33.1	3,447.1
20	132.6	1,955.6	6.6	2,094.8
21	33.1	464.0	6.6	503.8
22	99.4	1,226.4	16.6	1,342.4
23	99.4	1,955.6	82.9	2,137.9
24	49.7	397.7	49.7	497.2
25	182.3	679.9	16.6	878.4
26	265.2	1,939.0	49.7	2,253.9
27	99.4	3,844.9	92.9	4,027.2
AVERAGE	117.2	1,228.8	40.8	1,386.2

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TABLE B-38: ENERGY CONSUMPTION OF CAN DRYING INSTALLATIONS
(Btu/lb.)

Range No.	Electrical*	Electrical Losses	Steam	Total (no losses)	Total (with losses)
1	38.3	79.6	1153.8	1192.1	1271.7
2	38.3	79.6	1430.8	1469.1	1548.7
3	69.6	144.6	667.7	737.3	881.9
4	33.2	69.0	739.2	772.4	841.4
5	16.2	33.7	411.5	427.7	461.4
6	17.2	35.7	624.5	641.7	677.4
7	16.3	33.9	571.3	587.6	621.5
8	31.5	65.4	1036.2	1067.7	1133.1
9	24.8	51.5	1702.0	1726.8	1778.3
10	90.6	188.2	1656.5	1747.1	1935.3
11	32.3	67.1	1866.9	1899.2	1966.3
12	68.9	143.1	661.7	730.6	873.7
13	16.7	34.7	847.0	863.7	898.4
14	20.4	50.2	1795.0	1815.4	1865.6
15	12.8	26.6	709.5	722.3	748.9
16	18.0	37.4	2631.7	2649.7	2687.1
17	12.5	26.0	626.2	638.7	664.7
18	13.8	28.7	719.5	733.3	762.0
19	27.2	56.5	175.0	202.2	258.7
AVERAGE	31.5	65.4	1054.0	1085.5	1150.9

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*Conversion Factor 3412 Btu/kWh

TABLE B-39: DRYING COMPARISON
(50/50 Polyester/Cotton 8 oz./sq. yd. 64", 1.25 lin. yd./lb.)

Dryer type	Speed (ypm)	Btu/lb.			
		Water content In (%)	Water content out (%)	Fabric	Water
I/R Predry	115	55	35	678	3,388
Dry Cans	115	55	3	927	1,783
Tenter (drying)	140	35	3	857	2,679
	140	35	3	1,500	4,688
	140	35	3	1,000	3,125
Tenter (heat set)	125	35	0	967	2,759
	125	35	0	1,650	4,714
	125	35	0	1,150	3,286
Screen print	50(1)	0	0	1,570	2,243
Oven	50(2)	70	0	1,793	2,561

(1) Dry only

(2) Dry and Cure

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TABLE B-40: ANALYSIS OF TENTER ENERGY OUTPUTS
(Average Figures)
(Btu/Lb.)

Dryer No.	DHSPEK 1	DHSPEW 4	DPC 6
Fabric Loss	106	72	-
Housing Loss	45	213	-
Stack loss (water)	176	1,585	917.2
Stack loss (air)	458	780	864.3
TOTAL	785	2,650	1,801

DHSPEK = Drying and heat setting polyester knit one range.
DHSPEW = Drying and heat setting polyester woven four range.
DPC = Drying polyester/cotton 6 ranges.

ATMI Finishers' Energy Subcommittee Reports

TABLE B-41: DRY CAN ANALYSIS

Function	Btu/lb. fab.	(%)
Evaporate water	550.0	68.2
Heat fabric	66.0	8.2
Heat air	70.6	8.7
Radiation		
Losses	120.4	14.9
TOTALS	807.0	100.0

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TABLE B-42: ENERGY CONSUMPTION - ROTARY SCREEN PRINT RANGE
(Apply Print Paste, Dry Fabrics, Cure)
(Btu/lb.)

Range No.	Electrical	Electrical Losses	Thermal	Total (no losses)	Total (with losses)	Gal Water/ Lb
1	236	490	4812	5048	5538	1.15
2	144	299	15000	15144	15443	1.50
3	295	613	8225	8520	9133	1.20
AVERAGE	225	467	9346	9571	10038	1.28

Auburn University Energy Report
Conversion factor 3412 Btu/kWh

TABLE B-43: CONTINUOUS PROCESSING ENERGY CONSUMPTION (ROPE PREPARATION)
(Btu/lb.)

Energy	Prep*	Dyeing	Finish	Total
Steam	2,584	4,247	677	7,508
Electricity (no losses)	79	159	179	417
Gas	-	1,486	1,504	2,990
TOTALS	2,663	5,892	2,360	10,915

*No heat setting, singeing, or mercerizing.

ITT Energy Surveys, Dr. Dennis Balmforth

TABLE B-44: CONTINUOUS PROCESSING ENERGY CONSUMPTION
(Open-Width Preparation)
(Btu/lb.)

<u>Energy</u>	<u>Prep.</u>	<u>Dyeing</u>	<u>Finish</u>	<u>Total</u>
Steam	3,065	4,247	577	7,989
Electricity	126	159	179	464
Gas	-	1,486	1,504	2,990
TOTALS	3,191	5,892	2,360	11,443

ITT Energy Surveys, Dr. Dennis Balmforth

TABLE B-45: SUMMARY FIGURES

<u>Process</u>	<u>Energy (Btu/lb)</u>	<u>Water (Gal/lb.)</u>
Preparation (for continuous dyeing)	3,240	0.86
Continuous dye	2,211	1.58
Continuous finish	1,040	-
Continuous Totals	6,491	2.44
Prep. for batch dyeing	1,067	0.29

ATMI Finishers' Energy Subcommittee Reports

TABLE B-46: BATCH ENERGY CONSUMPTION
(Polyester Knit)
(Btu/lb.)

<u>Energy</u>	<u>Prep.</u>	<u>Dyeing</u>	<u>Finish</u>	<u>TOTAL</u>
Steam	370	3,000	100	3,470
Electricity	82	840	413	1,335
Gas	-	-	1,360	1,360
TOTALS	452	3,840	1,873	6,165

ITT Energy Survey, Dr. Dennis Balmforth

APPENDIX C:
STATE-OF-THE-ART TEXTILE MANUFACTURING TECHNOLOGIES

<u>PROCESS AREA</u>	<u>ALTERNATE/ADVANCED TECHNOLOGY</u>	<u>POTENTIAL IMPACT ON ENERGY CONSUMPTION</u>	<u>REFERENCES</u>
Dry Processes: (includes opening, carding, drawing, lapping, combing, roving and spinning)	New installation of high efficiency motors	Low	Survey Participants, Energy Conservation for the Textile Industry Conference, Georgia Institute of Technology, 1981
	Improving power factor	Low	Survey Participants, Energy Conservation for the Textile Industry Conference, Georgia Institute of Technology, 1981
	Utilizing variable speed controllers	Low	Survey Participants, Energy Conservation for the Textile Industry Conference, Georgia Institute of Technology, 1981
	Synthetic Lubricants	Low	Survey Participants
	Automated material handling for opening, blending, and carding processes	Low	Survey Participants, Textile Industries, March & April 1984
	Computer monitoring of process	Low	Survey Participants, Textile Industries, March & April 1984

APPENDIX C:
STATE-OF-THE-ART TEXTILE MANUFACTURING TECHNOLOGIES
(continued)

<u>PROCESS AREA</u>	<u>ALTERNATE/ADVANCED TECHNOLOGY</u>	<u>POTENTIAL IMPACT ON ENERGY CONSUMPTION</u>	<u>REFERENCES</u>
Spinning	Open-end spinning	Moderate, eliminates roving and drawing process steps	Textile Month, March 1985
	Air-jet spinning	Low	Textile Month, March 1985
Texturizing	Air-texturizing	Low	International Textile Machinery 1984
Slashing	High Pressure squeeze	Moderate	Textile World, April 1984
	Size recovery	Low; more of a method for chemical savings	Textile World, September 1983
	Foam Slashing	Significant	American Dyestuff Reporter, April 1985
	Solvent Slashing	Significant	Textile World, September 1983
Warping	Combine warping and slashing into a single operation	Low	Textile Industries, April 1984

APPENDIX C:
STATE-OF-THE-ART TEXTILE MANUFACTURING TECHNOLOGIES
(continued)

<u>PROCESS AREA</u>	<u>ALTERNATE/ADVANCED TECHNOLOGY</u>	<u>POTENTIAL IMPACT ON ENERGY CONSUMPTION</u>	<u>REFERENCES</u>
Weaving	Rapier	Moderate, as compared to shuttle looms	Textile Month, August 1985
	Air-jet	Low	Textile Month, August 1985
	Water-jet	Significant	Textile Month, August 1985
	Projectile	Moderate	Textile Month, August 1985
Knitting	Pneumatic knitting without needles	Low	Textile Asia, August 1984
Tufting	Computerized Yarn Placement (CYP) Loom using a hollow needle concept	Low	International Textile Machinery, 1984

APPENDIX C:
STATE-OF-THE-ART TEXTILE MANUFACTURING TECHNOLOGIES
(continued)

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<u>PROCESS AREA</u>	<u>ALTERNATE/ADVANCED TECHNOLOGY</u>	<u>POTENTIAL IMPACT ON ENERGY CONSUMPTION</u>	<u>REFERENCES</u>
Wet Processes (includes preparation, dyeing and finishing)	Modular Wet Processing (WP) Line	Moderate	Textile Month, April 1985
	Wet-on-wet dyeing and finishing	Substantial, eliminates drying step	American Dyestuff Reporter, January 1983
	Wet-on-dry vacuum finishing	Substantial, eliminates drying step	Textile Industries, October 1983
Preparation	Combine desize, scour, and bleach (DSB) processes	Significant	Dr. Fred Cook, Georgia Institute of Technology
Washing	Wash water use	Significant	American Dyestuff Reporter October 1980
	Continuous counter-current rinsing	Significant	Textile Dyer & Printer, October 1983
	Rinsing at slightly elevated pressures	Moderate	Textile Dyer & Printer October 1983
	Vibrating-reed jet washers and cam-driven beater rollers	Moderate	Textile Dyer & Printer October 1983
Dyeing	Jet dyeing at low ratios of dye liquor to cloth	Moderate	Textile Month, January 1985
	Bump and run beck dyeing	Moderate	Textile World, October 1982
	Indirect steam heating of dye becks	Significant	American Dyestuff Reporter, June 1980
	Dye bath reuse	Significant	Textile World, September 1983

APPENDIX C:
STATE-OF-THE-ART TEXTILE MANUFACTURING TECHNOLOGIES
(continued)

<u>PROCESS AREA</u>	<u>ALTERNATE/ADVANCED TECHNOLOGY</u>	<u>POTENTIAL IMPACT ON ENERGY CONSUMPTION</u>	<u>REFERENCES</u>
Dyeing	Procion High-temperature Reactive Dyes	Moderate	Energy Conservation in the Textile Industry, Phase I & II, Georgia Institute of Technology, 1977/1978
	Vacuum impregnation of dyes	Low	Textile Month, January 1985
	Dielectric fixation of dyes	Moderate	Textile Industries, July 1983
	Foam dyeing	Significant	American Dyestuff Reporter, February 1981
Printing	Engraved print roll	Moderate	Textile Industries, May 1984
	Transfer printing from paper to cloth	Substantial	Textile Industries, May 1984
	Foam printing	Substantial	Textile Industries, May 1984, Textile Month, March 1985

APPENDIX C:
STATE-OF-THE-ART TEXTILE MANUFACTURING TECHNOLOGIES
(continued)

<u>PROCESS AREA</u>	<u>ALTERNATE/ADVANCED TECHNOLOGY</u>	<u>POTENTIAL IMPACT ON ENERGY CONSUMPTION</u>	<u>REFERENCES</u>
Finishing - Low wet pick-up technology	Foam finishing	Significant	American Dyestuff Reporter, February 1981
	Spraying	Significant	American Dyestuff Reporter, April 1983
	Low-add-on finishing, curved blade applicator	Significant	American Dyestuff Reporter, May, 1985, Textile Chemist and Colorist, January, 1985
	Eiss roll coater	Moderate	Textile Industries, December 1983
	High compression pad rolls	Moderate	Textile Industries, December 1983
	Pad rolls with vacuum extraction	Significant	Textile Industries, December 1983

APPENDIX C:
STATE-OF-THE-ART TEXTILE MANUFACTURING TECHNOLOGIES
(continued)

<u>PROCESS AREA</u>	<u>ALTERNATE/ADVANCED TECHNOLOGY</u>	<u>POTENTIAL IMPACT ON ENERGY CONSUMPTION</u>	<u>REFERENCES</u>
Drying	Machnozzles (mechanical pre-dry)	Moderate	American Dyestuff Reporter, February, 1981, Textile Chemist & Colorist, August, 1983
	Heat recovery from exhausts of tenters and thermosol ovens	Moderate	Energy Recovery from Textile Dryer Operations, ERI, DOE, June 1980/1981
	Drying under low pressure conditions in a rotating drum	Substantial	Textile Dyer & Printer, October 1983
	Radio-frequency drying	Substantial	JSDC, September 1983, IEEE Conference 1984
	Direct gas-fired tenters	Moderate	Textile Dyer & Printer, October 1983
	Pressurized closed system for efficient moisture removal	Moderate	Textile Dyer & Printer, October 1983

APPENDIX C:
STATE-OF-THE-ART TEXTILE MANUFACTURING TECHNOLOGIES
(continued)

<u>PROCESS AREA</u>	<u>ALTERNATE/ADVANCED TECHNOLOGY</u>	<u>POTENTIAL IMPACT ON ENERGY CONSUMPTION</u>	<u>REFERENCES</u>
Auxiliary	Enthalpy control for reducing air conditioning load	Moderate	Survey participants, Energy Conservation for the Textile Industry Conference, Georgia Institute of Technology, 1981
	Static reduction by controlling moisture content of the fiber	Low	Survey participants
	Chemical static control (heavy molecular weight of positive and negative ions)	Low	Survey participants
	Catalyst enhanced heat exchanger (e.g., Torvex)	Low	Survey participants

APPENDIX C:
STATE-OF-THE-ART TEXTILE MANUFACTURING TECHNOLOGIES
(continued)

<u>PROCESS AREA</u>	<u>ALTERNATE/ADVANCED TECHNOLOGY</u>	<u>POTENTIAL IMPACT ON ENERGY CONSUMPTION</u>	<u>REFERENCES</u>
Ancillary Plant	Cogeneration	Substantial	Survey participants, Textile Industries, October 1984
	Economizers	Moderate	Survey participants
	Fluidized bed	Moderate	Survey participants
	Wood, carpet, and other production wastes used to produce process steam	Moderate	Survey participants

Low: 0 - 25% savings

Moderate: 25 - 50% savings

Significant: 50 - 100% savings

APPENDIX D:
ADVANCED TEXTILE MANUFACTURING TECHNOLOGIES

<u>PROCESS AREA</u>	<u>ADVANCED TECHNOLOGY</u>	<u>POTENTIAL IMPACT ON ENERGY CONSUMPTION</u>	<u>REFERENCES</u>
Dry Processes: (includes opening, carding, drawing, lapping, combing, roving and spinning)	Computerized automation and robotics for material handling and quality control	Low	Textile Industries, March & April 1984
	Continuous monitoring	Moderate	Survey participants, Textile Industries, March 1984
	Hierarchical computer control from order entry to final shipped product	Moderate	Survey participants, Textile World, June 1984
Spinning	Electrostatic spinning	Low	ATMA High Technology Report, October 1984
	Friction spinning	Low	Short-staple spinning, evolution or revolution, Georgia Institute of Technology, April 1986
Weaving	Multished looms	Significant	Textile Month, August 1985
Knitting	Combine knit/weave functions	Low	ATMA High Technology Report, October 1984
Slashing	Hot melt sizing	Low	Textile World, April 1984
	Dry sizing	Moderate	Dr. Fred Cook, Georgia Institute of Technology

APPENDIX D:
ADVANCED TEXTILE MANUFACTURING TECHNOLOGIES
(continued)

<u>PROCESS AREA</u>	<u>ADVANCED TECHNOLOGY</u>	<u>POTENTIAL IMPACT ON ENERGY CONSUMPTION</u>	<u>REFERENCES</u>
Wet Processes: (includes preparation, dyeing and finishing)	Combining separate and distinct non-conventional, efficient systems, thereby eliminating conventional processes	Substantial	Survey participants
	Direct application of process chemicals to cloth with the minimal use of liquids	Substantial	Survey participants
Preparation:	Non-peroxide bleaching	Moderate	ATMA High Technology Report, October 1984
	Foam bleaching	Moderate	American Dyestuff Reporter, April 1985
Dyeing:	Low temperature (ambient) dyeing, using efficient reducing agent (e.g. sulphonylic acid)	Substantial	Textile Dyer & Printer, October 1983
Printing:	Discharge printing by curing special print-paste formula	Moderate	Textile Dyer & Printer, October 1983

APPENDIX D:
ADVANCED TEXTILE MANUFACTURING TECHNOLOGIES
(continued)

<u>PROCESS AREA</u>	<u>ADVANCED TECHNOLOGY</u>	<u>POTENTIAL IMPACT ON ENERGY CONSUMPTION</u>	<u>REFERENCES</u>
Finishing:	Electrostatic deposition of finishes	Substantial	ATMA High Technology Report, October 1984
	Flame/flash rapid curing	Substantial	Textile Dyer & Printer, October 1983
	Low-energy cure polymers	Substantial	American Dyestuff Reporter, October 1980
	Solid-on-solid technology	Substantial	Dr. Fred Cook, Georgia Institute of Technology
Ancilliary Plant	Machnozzle waste removal	Low	ATMA High Technology Report, October 1984
	Electrostatic waste removal	Low	ATMA High Technology Report, October 1984
Human Resources	More craft-trained operators	Substantial	Survey participants

Low: 0 - 25% savings

Moderate: 25 - 50% savings

Significant: 50 - 100% savings

Table E-1

**Energy and Materials Use By Major Process - State-of-the-Art Technology,
(1984 Production Mix)**

<u>Process</u>	<u>Materials Used (10⁶ Pounds)</u>	<u>Specific Energy Use (Btu/lb)*</u>	<u>Total Energy Use (10¹² Btu)</u>	<u>Cummulative Energy Use (10¹² Btu)</u>
<u>Yarn Formation</u>				
Carding	8550	850	7.3	
Drawing	8550	250	2.1	
Roving(a)	855	500	0.4	
Spinning	8550	7550	64.6	
HVAC(b)	8550	2100	<u>18.0</u>	
Subtotal			92.4	92.4
(a) 90% production by open-end spinning; eliminates roving.				
(b) HVAC total from Table 4.1 is allocated among yarn formation, weaving, knitting and floor covering components.				
<u>Texturizing Component</u>				
Texturizing	2250	11695	26.3	118.7
<u>Fabric Formation/Weaving Component</u>				
Winding	8330	460	3.8	
Slashing	8330	1200	10.0	
Weaving	8330	3230	26.9	
HVAC	8330	2050	<u>17.1</u>	
Subtotal			57.8	176.5
<u>Knitting Component</u>				
Knitting	1620	3540	5.7	
HVAC	1620	400	<u>0.6</u>	
Subtotal			6.3	182.8
<u>Non-Woven Component</u>				
Fiber Bonding	850	2010	1.7	184.5

Table E-1 Continued

<u>Process</u>	<u>Materials Used</u> <u>(10⁶ Pounds)</u>	<u>Specific Energy</u> <u>Use (Btu/lb)*</u>	<u>Total Energy</u> <u>Use (10¹² Btu)</u>	<u>Cummulative</u> <u>Energy</u> <u>Use</u> <u>(10¹² Btu)</u>
<u>Floor Covering (Dry)</u>				
<u>Component</u>				
Twisting	1980	1880	3.7	
Heat setting	1980	1650	3.3	
Tufting	1980	615	1.2	
HVAC	1980	500	1.0	
Subtotal			9.2	193.7
<u>Yarn Dyeing Component</u>				
Yarn Dyeing & Drying	1300	6500	8.5	202.2
<u>Woven Fabric Dyeing Finishing</u>				
<u>Component</u>				
Heatsetting	8330	250	2.1	
Singeing	8330	100	0.8	
Preparation	8330	2000	16.7	
Mercerization	8330	1200	10.0	
Dyeing	5500	3500	19.3	
Printing	1370	5050	6.9	
Finishing	8330	1560	13.0	
Drying	8330	2750	22.9	
Subtotal			91.7	293.9
<u>Knit Fabric Dyeing & Finishing</u>				
<u>Component</u>				
Preparation	1620	1500	2.4	
Dyeing	1420	3840	5.5	
Finishing	1620	1875	3.0	
Drying	1620	2000	3.2	
Subtotal			14.1	308.0

Note: The poundage of printed knit fabric is relatively small and therefore neglected.

Table E-1 Continued

<u>Process</u>	<u>Materials Used</u> <u>(10⁶ Pounds)</u>	<u>Specific Energy</u> <u>Use (Btu/lb)*</u>	<u>Total Energy</u> <u>Use (10¹² Btu)</u>	<u>Cummulative</u> <u>Energy</u> <u>Use</u> <u>(10¹² Btu)</u>
<u>Floor Covering (Wet)</u>				
<u>Component</u>				
Dyeing	1270	7500	9.5	
Finishing	1980	1800	3.6	
Drying	1980	2290	<u>4.5</u>	
Subtotal			17.6	325.6
			Grand Total:	325.6

*Energy Intensity factor 10,500 Btu/KWh_e
Source: Energetics, Inc.

Table E-2

Energy and Materials Use by Major Process - Current Practices

(year 2010 Production Mix)

<u>Process</u>	<u>Materials Used (10⁶ Pounds)</u>	<u>Specific Energy Use (Btu/lb)*</u>	<u>Total Energy Use (10¹² Btu)</u>	<u>Cummulative Energy Use (10¹² Btu)</u>
<u>Yarn Formation</u>				
Carding	9600	930	8.9	
Drawing	9600	565	5.4	
Roving ^(a)	5760	710	4.1	
Spinning	9600	9530	91.5	
HVAC	9600	2400	<u>23.0</u>	
Subtotal			132.9	132.9
(a) 40% production by open-end spinning: eliminates roving.				
(b) HVAC total from Table 2.2 is allocated among yarn formation, weaving, knitting and floor covering components.				
<u>Texturizing Component</u>				
Texturizing	2400	20500	49.2	182.1
<u>Fabric Formation/Weaving Component</u>				
Winding	8400	850	7.1	
Slashing	8400	2325	19.5	
Weaving	8400	5440	45.7	
HVAC	8400	2100	<u>17.6</u>	
Subtotal			89.9	272.0
<u>Fabric Formation/Knitting Component</u>				
Knitting	1920	7200	13.8	
HVAC	1920	500	<u>1.0</u>	
Subtotal			14.8	286.8
<u>Non-Woven Component</u>				
Fiber Bonding	1680	4550	7.6	294.4

Table E-2 Continued

<u>Process</u>	<u>Materials Used</u> <u>(10⁶ Pounds)</u>	<u>Specific Energy</u> <u>Use (Btu/lb)*</u>	<u>Total Energy</u> <u>Use (10¹² Btu)</u>	<u>Cummulative</u> <u>Energy</u> <u>Use</u> <u>(10¹² Btu)</u>
<u>Floor Covering (Dry)</u>				
<u>Component</u>				
Twisting	2400	4500	10.8	
Heating setting	2400	3150	7.6	
Tufting	2400	1050	2.5	
HVAC	2400	600	<u>1.4</u>	
Subtotal			22.3	316.7
<u>Yarn Dyeing Component</u>				
Yarn Dyeing & Drying	1680	9500	16.0	332.7
<u>Woven Fabric Dyeing Finishing</u>				
<u>Component</u>				
Heatsetting	8400	530	4.5	
Singeing	8400	155	1.3	
Preparation	8400	3235	27.2	
Mercerization	8400	1920	16.1	
Dyeing	5600	6225	34.9	
Printing	1400	9570	13.4	
Finishing	8400	2730	22.9	
Drying	8400	3455	<u>29.0</u>	
Subtotal			149.3	482.0
<u>Knit Fabric Dyeing & Finishing</u>				
<u>Component</u>				
Preparation	1920	2660	5.1	
Dyeing	1680	5890	9.9	
Finishing	1920	2360	4.5	
Drying	1920	3000	<u>5.7</u>	
Subtotal			25.2	507.2

Note: The poundage of printed knit fabric is relatively small and therefore neglected.

Table E-2 Continued

<u>Process</u>	<u>Materials Used</u> <u>(10⁶ Pounds)</u>	<u>Specific Energy</u> <u>Use (Btu/lb)*</u>	<u>Total Energy</u> <u>Use (10¹² Btu)</u>	<u>Cummulative</u> <u>Energy</u> <u>Use</u> <u>(10¹² Btu)</u>
<u>Floor Covering (Wet)</u>				
<u>Component</u>				
Dyeing	1550	9800	15.2	
Finishing	2400	3500	8.4	
Drying	2400	4350	<u>10.4</u>	
Subtotal			34.0	541.2
			Grand Total:	541.2

Note: The poundage of printed floor covering is relatively small and therefore neglected.

*Energy Intensity factor 10,500 Btu/KWh_e
Source: Energetics, Inc.

Table E-3

Energy and Materials Use By Major Process - State-of-the-Art Technology

(Year 2010 Production Mix)

<u>Process</u>	<u>Materials Used (10⁶ Pounds)</u>	<u>Specific Energy Use (Btu/lb)^a</u>	<u>Total Energy Use (10¹² Btu)</u>	<u>Cummulative Energy Use (10¹² Btu)</u>
<u>Spinning Component</u>				
Carding	9600	850	8.2	
Drawing	9600	250	2.4	
roving ^(a)	960	500	0.5	
Spinning	9600	7550	72.5	
HVAC ^(b)	9600	2200	<u>21.1</u>	
Subtotal			104.7	104.7
(a) 90% production by open-end spinning: eliminates roving.				
(b) HVAC total from Table 4.1 is allocated among yarn formation, weaving knitting and floor covering components.				
<u>Texturizing Component</u>				
Texturizing	2400	11695	28.1	132.8
<u>Fabric Formation/Weaving Component</u>				
Winding	8400	460	3.9	
Slashing	8400	1200	10.1	
Weaving	8400	3230	27.1	
HVAC	8400	2000	<u>16.8</u>	
Subtotal			57.9	190.7
<u>Fabric Formation/Knitting Component</u>				
Knitting	1920	3540	6.8	
HVAC	1920	450	<u>0.9</u>	
Subtotal			7.7	198.4
<u>Non-Woven Component</u>				
Fiber Bonding	1680	2010	3.4	201.8

Table E-3 Continued

<u>Process</u>	<u>Materials Used (10⁶ Pounds)</u>	<u>Specific Energy Use (Btu/lb)^a</u>	<u>Total Energy Use (10¹² Btu)</u>	<u>Cummulative Energy Use (10¹² Btu)</u>
<u>Floor Covering (Dry)</u>				
<u>Component</u>				
Twisting	2400	1880	4.5	
Heating setting	2400	1650	4.0	
Tufting	2400	615	1.5	
HVAC	2400	550	<u>1.3</u>	
Subtotal			11.3	213.1
<u>Yarn Dyeing Component</u>				
Yarn Dyeing & Drying	1680	6500	10.9	224.0
<u>Woven Fabric Dyeing & Finishing</u>				
<u>Component</u>				
Heatsetting	8400	250	2.1	
Singeing	8400	100	0.8	
Preparation	8400	2000	16.8	
Mercerization	8400	1200	10.1	
Dyeing	5600	3500	19.6	
Printing	1400	5050	7.1	
Finishing	8400	1560	13.1	
Drying	8400	2750	<u>23.1</u>	
Subtotal			92.7	316.7
<u>Knit Fabric Dyeing & Finishing</u>				
<u>Component</u>				
Preparation	1920	1500	2.9	
Dyeing	1680	3840	6.5	
Finishing	1920	1875	3.6	
Drying	1920	2000	<u>3.8</u>	
Subtotal			16.8	333.5

Note: The poundage of printed knit fabric is relatively small and therefore neglected.

Table E-3 Continued

<u>Process</u>	<u>Materials Used</u> <u>(10⁶ Pounds)</u>	<u>Specific Energy</u> <u>Use (Btu/lb)*</u>	<u>Total Energy</u> <u>Use (10¹² Btu)</u>	<u>Cummulative</u> <u>Energy</u> <u>Use</u> <u>(10¹² Btu)</u>
<u>Floor Covering (Wet)</u>				
<u>Component</u>				
Dyeing	1550	7500	11.6	
Finishing	2400	1800	4.3	
Drying	2400	2290	<u>5.5</u>	
Subtotal			21.4	354.9

Note: The poundage of printed floor covering is relatively small and therefore neglected.

Grand Total: 354.9

* Energy Intensity factor 10,500 Btu/KWh_e
Source: Energetics, Inc.

Table E-4

Energy and Materials Use By Major Process - Technology Mix 1

90% State-Of-The-Art/10% Advanced

(Year 2010 Production Mix)

<u>Process</u>	<u>Materials Used (10⁶ Pounds)</u>	<u>Specific Energy Use (Btu/lb)</u>	<u>Total Energy Use (10¹² Btu)</u>	<u>Cummulative Energy Use (10¹² Btu)</u>
<u>Yarn Formation Component</u>				
Carding	8640	850	7.3	
	960	815	0.8	
Drawing	8640	250	2.2	
Roving ^(a)	864	500	0.4	
Spinning	8640	7550	65.2	
	960	5285	5.1	
HVAC ^(b)	8640	2200	19.0	
	960	1750	1.7	
Subtotal			101.7	101.7
(a) 90% production by open-end spinning; eliminates roving.				
(b) HVAC total from Table 4.3 is allocated among yarn formation, weaving, knitting and floor covering components.				
<u>Texturizing Component</u>				
Texturizing	2160	11695	25.3	
	240	10500	2.5	
Subtotal			27.8	129.5
<u>Fabric Formation/Weaving Component</u>				
Winding	7560	460	3.5	
	840	200	0.2	
Slashing	7560	1200	9.1	
	840	-	-	
Weaving	7560	3230	24.4	
	840	2380	2.0	
HVAC	7560	2000	15.1	
	840	1500	1.3	
Subtotal			55.6	185.1

Table E-4 Continued

<u>Process</u>	<u>Materials Used (10⁶ Pounds)</u>	<u>Specific Energy Use (Btu/lb)^a</u>	<u>Total Energy Use (10¹² Btu)</u>	<u>Cummulative Energy Use (10¹² Btu)</u>
<u>Fabric Formation/Knitting Component</u>				
Knitting	1728	3540	6.1	
	192	2800	0.5	
HVAC	1728	450	0.8	
	192	360	0.1	
Subtotal			7.5	192.6
<u>Non-Woven Component</u>				
Fiber Bonding	1512	2010	3.0	
	168	1950	0.3	
			3.3	195.9
<u>Floor Covering (Dry) Component</u>				
Twisting	2160	1880	4.1	
	240	1800	0.4	
Heat setting	2160	1650	3.6	
	240	1580	0.4	
Tufting	2160	615	1.3	
	240	600	0.1	
HVAC	2160	550	1.2	
	240	440	0.1	
Subtotal			11.2	207.1
<u>Yarn Dyeing Component</u>				
Yarn Dyeing & Drying	1512	6500	9.8	
	168	5500	0.9	
			10.7	217.8
<u>Woven Fabric Finishing Component</u>				
Heatsetting	7560	250	1.9	
	840	200	0.2	
Singeing	7560	100	0.8	
	840	100	-	
Preparation	7560	2000	15.1	
	840	800	0.7	

Table E-4 Continued

<u>Process</u>	<u>Materials Used (10⁶ Pounds)</u>	<u>Specific Energy Use (Btu/lb)*</u>	<u>Total Energy Use (10¹² Btu)</u>	<u>Cummulative Energy Use (10¹² Btu)</u>
<u>Knit Fabric Dyeing & Finishing</u>				
<u>Component</u>				
Mercerization	7560	1200	9.1	
	840	-	-	
Dyeing	5040	3500	17.6	
	560	3000	1.7	
Printing	1260	5050	6.4	
	140	4500	0.6	
Finishing	7560	1560	11.8	
	840	1300	1.1	
Drying	7560	2750	20.8	
	840	2000	1.7	
Subtotal			89.8	307.6
Preparation	1728	1500	2.6	
	192	225	-	
Dyeing	1512	3840	5.8	
	168	2720	0.5	
Finishing	1728	1875	3.2	
	192	1650	0.3	
Drying	1728	2000	3.4	
	192	1700	0.3	
Subtotal			16.1	323.7
Note: The poundage of printed knit fabric is small and therefore is neglected.				
<u>Floor Covering (Wet)</u>				
<u>Component</u>				
Dyeing	1395	7500	10.5	
	155	6000	0.9	
Finishing	2160	1800	3.9	
	240	1600	0.4	
Drying	2160	2290	4.9	
	240	1800	0.4	
Subtotal			21.0	344.7
Grand Total:				344.7

Note: The poundage of printed floor covering is small and therefore is neglected.

*Energy Intensity factor 10,500 Btu/KWh_e

Source: Energetics, Inc.

Table E-5

Energy and Materials Use By Major Process - Technology Mix 2

(50% State-Of-The-Art, 50% Advanced) Year 2010 Production Mix

<u>Process</u>	<u>Materials Used (10⁶ Pounds)</u>	<u>Specific Energy Use (Btu/lb)^a</u>	<u>Total Energy Use (10¹² Btu)</u>	<u>Cumulative Energy Use (10¹² Btu)</u>
<u>Yarn Formation</u>				
Carding	4800	850	4.1	
	4800	815	3.9	
Drawing	4800	250	1.2	
Roving ^(a)	480	500	0.2	
Spinning	4800	7550	36.2	
	4800	5285	25.4	
HVAC ^(b)	4800	2200	10.6	
	4800	1750	8.4	
Subtotal			90.0	90.0
(a) 90% production by open-end spinning; eliminates these processes.				
(b) HVAC total from Table 4.3 is allocated among yarn formation, weaving, knitting, and floor covering components.				
<u>Texturizing Component</u>				
Texturizing	1200	11695	14.0	
	1100	10500	12.6	
Subtotal			26.6	116.6
<u>Fabric Formation/Weaving Component</u>				
Winding	4200	460	1.9	
	4200	200	0.8	
Slashing	4200	1200	5.0	
	4200	-	-	
Weaving	4200	3230	13.6	
	4200	2380	10.6	
HVAC	4200	2000	8.4	
	4200	1500	6.3	
Subtotal			46.0	162.6
<u>Fabric Formation/Knitting Component</u>				
Knitting	960	3540	3.4	
	960	2800	2.7	
HVAC	960	450	0.4	
	960	360	0.3	
Subtotal			6.8	169.4

Table E-5 Continued

<u>Process</u>	<u>Materials Used (10⁶ Pounds)</u>	<u>Specific Energy Use (Btu/lb)*</u>	<u>Total Energy Use (10¹² Btu)</u>	<u>Cummulative Energy Use (10¹² Btu)</u>
<u>Non-Woven Component</u>				
Fiber Bonding	840	2010	1.7	
	840	1950	<u>1.6</u>	
Subtotal			3.3	172.7
<u>Floor Covering (Dry) Component</u>				
Twisting	1200	1880	2.3	
	1200	1800	2.2	
Heating setting	1200	1650	2.0	
	1200	1580	1.9	
Tufting	1200	615	0.7	
	1200	600	0.7	
HVAC	1200	550	0.7	
	1200	440	<u>0.5</u>	
Subtotal			11.0	183.7
<u>Yarn Dyeing Component</u>				
Yarn Dyeing & Drying	840	6500	5.5	
	840	5500	<u>4.6</u>	
Subtotal			10.1	193.8
<u>Woven Fabric Dyeing & Finishing Component</u>				
Heatsetting	4200	250	1.1	
	4200	200	0.8	
Singeing	4200	100	0.4	
	4200	100	0.4	
Preparation	4200	2000	8.4	
	4200	800	3.4	
Mercerization	4200	1200	5.0	
	4200	-	-	
Dyeing	2800	3500	9.8	
	2800	3000	8.4	
Printing	700	5050	3.5	
	700	4500	3.2	
Finishing	4200	1560	6.6	
	4200	1300	5.5	
Drying	4200	2750	11.6	
	4200	2000	<u>8.4</u>	
Subtotal			76.5	270.3

Table E-5 Continued

<u>Process</u>	<u>Materials Used</u> <u>(10⁶ Pounds)</u>	<u>Specific Energy</u> <u>Use (Btu/lb)*</u>	<u>Total Energy</u> <u>Use (10¹² Btu)</u>	<u>Cummulative</u> <u>Energy</u> <u>Use</u> <u>(10¹² Btu)</u>
<u>Knit Fabric Dyeing & Finishing</u>				
<u>Component</u>				
Preparation	960	1500	1.4	
	960	225	0.2	
Dyeing	840	3840	3.2	
	840	2720	2.3	
Finishing	960	1875	1.8	
	960	1650	1.6	
Drying	960	2000	1.9	
	960	1700	<u>1.6</u>	
Subtotal			14.0	284.3

Note: The poundage of printed knit fabric is relatively small and therefore is neglected.

Floor Covering (Wet)

Component

Dyeing	775	7500	5.8	
	775	6000	4.7	
Finishing	1200	1800	2.2	
	1200	1600	1.9	
Drying	1200	2290	2.7	
	1200	1800	<u>2.2</u>	
Subtotal			19.5	303.8
			Grand Total:	303.8

Note: The poundage of printed Floor Covering is relatively small and therefore is neglected.

*Energy Intensity factor 10,500 Btu/kWh_e
Source: Energetics, Inc.

Table E-6

Energy and Materials Use By Major Process - 100% Advanced Technology

(Year 2010 Production Mix)

<u>Process</u>	<u>Materials Used (10⁶ Pounds)</u>	<u>Specific Energy Use (Btu/lb)*</u>	<u>Total Energy Use (10¹² Btu)</u>	<u>Cummulative Energy Use (10¹² Btu)</u>
<u>Yarn Formation</u>				
Carding	9600	815	7.8	
Spinning	9600	5285	50.7	
HVAC(a)	9600	1750	<u>16.8</u>	
Subtotal			75.3	75.3
(a)HVAC total from Table 4.3 is allocated among yarn formation, weaving, knitting and floor covering components.				
<u>Texturizing Component</u>				
Texturizing	2400	10500	25.2	100.5
<u>Fabric Formation/Weaving Component</u>				
Winding	8400	200	1.7	
Weaving	8400	2380	20.0	
HVAC	8400	1500	<u>12.6</u>	
Subtotal			34.3	134.8
<u>Fabric Formation/Knitting Component</u>				
Knitting	1920	2800	5.4	
HVAC	1920	360	<u>0.7</u>	
Subtotal			6.1	140.9
<u>Non-Woven Component</u>				
Fiber Bonding	1680	1950	3.3	144.2
<u>Floor Covering (Dry) Component</u>				
Twisting	2400	1800	4.3	
Heat setting	2400	1580	3.8	
Tufting	2400	600	1.4	
HVAC	2400	440	<u>1.1</u>	
Subtotal			10.6	154.8

Table E-6 Continued

<u>Process</u>	<u>Materials Used (10⁶ Pounds)</u>	<u>Specific Energy Use (Btu/lb)*</u>	<u>Total Energy Use (10¹² Btu)</u>	<u>Cummulative Energy Use (10¹² Btu)</u>
<u>Yarn Dyeing Component</u>				
Yarn Dyeing & Drying	1680	5500	9.2	164.0
<u>Woven Fabric Dyeing & Finishing Component</u>				
Heatsetting	8400	200	1.7	
Singeing	8400	100	0.8	
Preparation	8400	800	6.7	
Dyeing	5600	3000	16.8	
Printing	1400	4500	6.3	
Finishing	8400	1300	10.9	
Drying	8400	2000	16.8	
Subtotal			60.0	224.0
<u>Knit Fabric Dyeing & Finishing Component</u>				
Preparation	1920	225	0.4	
Dyeing	1680	2720	4.6	
Finishing	1920	1650	3.2	
Drying	1920	1800	3.5	
Subtotal			11.7	235.7
Note: The poundage of printed knit fabric is relatively small and therefore neglected.				
<u>Floor Covering (Wet) Component</u>				
Dyeing	1500	6000	9.3	
Finishing	2400	1600	3.8	
Drying	2400	1700	4.1	
Subtotal			17.2	252.9
Note: The poundage of printed floor covering is relatively small and therefore neglected.				
Grand Total:				252.9

*Energy Intensity factor 10,500 Btu/KWh_e

Source: Energetics, Inc.

APPENDIX F: GLOSSARY

Acetate - A manufactured fiber made from cellulose acetate.

Acid Dyes - A type of dye commonly used to color wool and nylon but may be used on other fibers.

Acrylic - A manufactured fiber in which the fiber-forming substance is any long-chain synthetic polymer composed at least 85% by weight of acrylonitrile units. Made in both filament and staple form.

Advanced Processing - An assembly of unit operations in a knit or woven fabric mill which are designed to minimize water and energy use.

Aesthetics - In textiles, properties perceived by touch and sight, such as the hand, color, luster, drape, and texture of fabrics and garments.

Aftertreatment - A term which is normally used in relation to processes carried out after dyeing or printing to improve fastness properties and/or to produce normal shades.

Backcoating - The application of latex to the back of a carpet to anchor the tufts, usually followed immediately by the addition of a secondary backing material such as woven jute or nonwoven polypropylene.

Backing - (1) A general term for any system of yarn which interlaces on the back of a textile material; (2) A knit or woven fabric or plastic foam bonded to a face fabric; (3) A knit or woven fabric bonded to a vinyl or other plastic sheet material; and (4) See "Carpet Backing".

Backwinding - (1) Rewinding yarn from one type of package to another; and (2) Winding yarn as it is deknit.

BCF Yarns - Bulkied continuous filament yarns for carpet trade, mostly nylon but occasionally polypropylene.

Beam - A cylinder of wood or metal, usually with a circular flange on each end, on which warp yarns are wound for slashing, weaving, and warp knitting.

- Beam Dyeing Machine** - A high-temperature dyeing machine for dyeing warp yarns or fabrics which have been wound onto a special beam, the barrel of which is evenly perforated with holes. The dye liquor is forced through the yarn or fabric from inside to outside.
- Beaming** - The operation of winding warp yarns onto a beam in preparation for slashing, weaving, or warp knitting.
- Beck** - A vessel for dyeing fabric in rope form, consisting primarily of a tank and a reel to advance the fabric.
- Bleaching** - Any of several processes to remove the natural and artificial impurities in fabrics to obtain clear whites for finished fabric or in preparation for dyeing and finishing.
- Bleeding** - Loss of color by a fabric or yarn when immersed in water, a solvent, or a similar liquid medium, as a result of improper dyeing or use of dyes of poor quality. Fabrics that bleed cause staining of white or light-shade fabrics in contact with them while wet.
- Blending** - The combining of staple fibers of different physical characteristics to assure a uniform distribution of these fibers throughout the yarn.
- Brushing** - A finishing process in which rotating brushes raise a nap on knit or woven fabrics. Brushing is used on sweaters, scarves, knit underwear, wool broadcloths, etc.
- Calendering** - A mechanical finishing process for fabrics to produce special effects, such as high luster, glazing, moire', and embossed effects. In this operation, the fabric is passed between heated rolls under pressure.
- Carding** - A process in the manufacture of spun yarns whereby the staple is opened, cleaned, aligned, and formed into a continuous, untwisted strand called a sliver.
- Carpet Backing** - A primary backing through which the carpet tufts are inserted is always required for tufted carpets. The backing is usually made of woven jute or formed (nonwoven) man-made fibers. A secondary backing, again made of jute or man-made fibers, is normally added at the latex backcoating stage. Carpet backings are an important end use for formed fabrics.

Carpets - Heavy functional and ornamental floor coverings consisting of pile yarns or fibers and a backing system. They may be tufted or woven. Also see "Tufted Carpet."

Caustic Soda - A strong alkali used, for example, in mercerizing.

Cellulose Material - Material composed of or derived from cellulose (e.g., cotton, rayon, acetate, and triacetate).

Circular-Knit Fabric - A tubular weft-knit fabric made on a circular-knitting machine.

Coated Fabric - A fabric to which a substance such as lacquer, plastic, resin, rubber, or varnish has been applied in firmly adhering layers to provide certain properties, such as water impermeability.

Combing - A step subsequent to carding in cotton and worsted system processing which straightened the fibers and extracts neps, foreign matter, and short fibers. Combing produces a stronger, more even, more compact, finer, smoother yarn.

Coning - The transfer of yarn from skeins or bobbins or other types of packages to cones.

Converted Fabric - A finished fabric as distinguished from greige fabric.

Crimp - The difference in distance between two points on an unstretched fiber and the same two points when the fiber is straightened under specified tension.

Cut Pile - A pile surface obtained by cutting the loops of yarn in a tufted or woven carpet.

Denier - A weight-per-unit length measure of any linear material. Officially, it is the number of unit weights of 0.05 gram per 450-meter length. This is numerically equal to the weight in grams of 9,000 meters of the material.

Dyes - Substances which add color to textiles by absorption into the fiber. Dyes differ in their resistance to sunlight, perspiration, washing, gas, alkalis, and other agents; their affinity for different fibers; their reaction to cleaning agents and methods; and their solubility and method of application. Dyes are commercial preparations containing only

approximately 50% pure dyestuff, with the rest being some inert filler such as sugar and surfactants.

Desize - Removal of size. Several methods may be used.

Doctor Blade - A metal knife which cleans or scrapes the excess dye from engraved printing rollers, leaving dye paste only in the valleys of engraved areas. Also used to describe other blades which are used to apply materials evenly to rollers or fabrics.

Double-Knit Fabric - A circular-knit fabric with a double thickness produced by using a double stitch on machines employing two sets of needles (dial and cylinder).

Drawing - (1) The process of attenuating or increasing the length per unit weight of laps, slivers, slubbings, or rovings; and (2) The hot or cold stretching of continuous filament yarn or tow to align and arrange the crystalline structure of the molecules in order to achieve improved tensile properties.

Drying Cylinders - Any of a number of heated revolving cylinders for drying fabric or yarn. They are arranged either vertically or horizontally in sets, with the number varying according to the material to be dried. They are often internally heated with steam and Teflon-coated to prevent sticking.

Dyeing - A process of coloring fibers, yarn, or fabrics with either natural or synthetic dyes.

Dyestuff - The chemical component of dyes that imparts the color to a fabric; usually a complex, organic compound.

Fastness - Resistance to fading.

Filament - A fiber of indefinite or extreme length such as found naturally in silk. Man-made fibers are extruded into filaments which are converted into filament yarn, staple, or tow.

Filling - In a woven fabric, the yarn running from selvage to selvage at right angles to the warp. Each crosswise length is called a pick. In the weaving process, the filling yarn is carried by the shuttle or other type of yarn carrier.

Finish - A substance or mixture of substances which are added to textile materials to impart desired properties; a process, physical or chemical, applied to textile materials to produce a desired effect; a property, such as smoothness, drape, luster, water repellency, flame retardancy or crease resistance which is produced by (1) and/or (2) above; and The state of a textile material as it leaves a process.

Finishing - All the processes through which the fabric is passed after bleaching, dyeing, or printing in preparation for the market or use. Finishing includes such operations as heat-setting, napping, embossing, pressing, calendering, and the application of chemicals which change the character of the fabric. The term finishing is also sometimes used to refer collectively to all processing operations above, including bleaching, dyeing, printing, etc.

Fixation - The process of setting a dye after the dyeing or printing operation, usually by steaming or other heat treatment.

Fly - The short, waste fibers that are released into the air in textile processing operations such as picking, carding, spinning, and weaving.

Formed Fabric - An assembly of textile fibers which are held together by the mechanical interlocking in a random web or mat, by fusing the fibers or by bonding with a cementing medium such as starch, glue, casein, rubber latex, or one of the cellulose derivatives or synthetic resins. Formed fabrics are used for expandable items, such as hospital sheets, napkins, diapers and wiping cloths, as the base material for the coated fabrics, and in a variety of other applications.

Greige Fabric - A fabric just off the loom or knitting machine, i.e., in an unfinished state.

Hand - The qualities of a fabric, e.g., softness, firmness, elasticity, fitness, resilience, and other qualities perceived by touch.

Hank - continuous strand of yarn, or cord in the form of a collapsed coil. An intermediate state between sliver and yarn.

Heat-Setting - The process of imparting dimensional stability and often other desirable properties such as wrinkle resistance to man-made fibers, and fabrics by means of either moist or dry heat.

Hydrophobic - Lacking affinity for, or the ability to, absorb water.

J-Box - A J-shaped holding device used in continuous operations to provide varying amounts of intermediate material storage such as in wet processing of fabrics and in tow production. The material is fed at the top and is plaited down to fill the long arm before being withdrawn from the short arm.

Jet Dyeing Machine - A high-temperature piece-dyeing machine which circulates the dye liquor through a Venturi jet, thus imparting a driving force to move the fabric. The fabric, in rope form, is sewn together to form a loop.

Jig - A dyeing machine in which the fabric in open-width form is transferred repeatedly from one roller to the another, passing each time through a batch of relatively small volume. Jigs are used for scouring, dyeing, bleaching, and finishing.

Jute - A bast fiber used for sacking, burlap, and twine, and as a backing material for tufted carpets.

Kier - A large metal tank, capable of being heated uniformly and used for wet processing.

Kier Boiling - The process of boiling cellulosic materials in alkaline liquors in a kier at or above atmospheric pressure.

Knitting - A method of constructing fabric by interlocking a series of loops of one or more yarns. The two major classes of knitting are warp knitting and weft knitting.

Kusters Dyeing Range - Continuous dry range for carpets. The unit wets the carpet, applies dye and auxiliary chemicals by means of a doctor blade, fixes the dye in a festoon steamer, and washes and dries the carpet in one pass through the range. An optical auxiliary unit may be installed to randomly drip selected dyes onto the background shade for special styling effects. This process is called TAK dyeing.

Lap - A continuous, considerably compressed sheet of fiber tufts which is rolled under pressure into a cylindrical package, usually weighing 40 to 50 pounds.

Latex - A milky rubber raw material used as a backing for carpets.

Long Staple - A long fiber. In reference to cotton, long staple indicates a fiber length of not less than 1 1/8 inches. In reference to wool, the term indicates fiber 3 to 4 inches long suitable for combing.

Loom - A machine for weaving fabric by interlocking a series of vertical, parallel threads (the warp) with a series of horizontal, parallel threads (the filling). The warp yarns from a beam pass through the heddles and reed, and the filling is shot through the "shed" of warp threads by means of a shuttle or other device and is settled in place by the reed and lay. The woven fabric is then wound on a cloth beam. The principal elements of the loom are the shedding, picking, and beating-up devices. In shedding, a path is formed for the filling by raising some warp threads while others are left down. Picking consists essentially of projecting the filling yarn from one side of the loom to the other. Beating-up forces the pick, which has just been left in the shed, up to the fell of the fabric. This is accomplished by the reed which is brought forward with some force by the lay.

Loop Pile - Carpet construction in which the tufts are formed into loops from the supply yarn.

Lubricant - An oil or emulsion finish applied to the fibers to prevent damage during textile processing or to the knitting yarns to make them more pliable.

Man-Made Fiber - A class name for various genera of fibers (including filaments) produced from fiber-forming substances which may be: (1) polymers synthesized from chemical compounds, e.g., acrylic, nylon, polyurethane, and polyvinyl fibers; (2) modified or transformed natural polymers, e.g., alginic and cellulose-based fibers such as acetates and rayons; or (3) mineral, e.g., glass.

The term man-made usually refers to all chemically produced fibers to distinguish them from the truly natural fibers such as cotton, wool, silk, flax, etc.

Mercerization - A treatment for cotton yarn or fabric to increase its luster and affinity for dyes. The material is immersed under tension in a cold sodium hydroxide (caustic soda) solution in warp, skein form, or in the piece, and is later neutralized in acid. The process causes a permanent swelling of the fiber and thus increases its luster.

Napping - A finishing process that raises the surface fibers of a fabric by means of passage over rapidly revolving cylinders covered with metal points or teasel burrs. Outing, flannel, and wool broadcloth derive their down appearance from this finishing process. Napping is also used for certain knit goods, blankets, and other fabrics with a raised surface.

Narrow Fabric - Any nonelastic woven fabric, 12 inches or less in width, having a selvage on either side, except for ribbon or seam binding.

Natural Fiber - A class name for the various genera of fibers (including filaments) of (1) animal, (2) mineral, or (3) vegetable origin. For example: (1) silk and wool, (2) asbestos, and (3) cotton, flax, jute, and ramie.

Nonwoven - A material made of fibers in a web or mat generally held together by a bonding agent.

Nylon - Generic name for "a manufactured fiber in which the fiber-forming substance is any long-chain synthetic polyamide having recurring amide groups as an integral part of the polymer chain."

Opening - (1) A preliminary operation in the processing of staple fiber. and removes the heavier impurities. (2) An operation in the processing of tow that substantially increases the bulk of the tow by separating the filaments and deregistering the crimp.

Padding - The application of a liquor or paste to textiles either by passing the material through a bath and subsequently through squeeze rollers, or by passing it between squeeze rollers, the bottom one of which carries the liquor or paste.

Paddle Dyeing Machine - A machine used for dyeing garments, hosiery, and other small pieces which are packaged loosely in mesh bags. The unit consists of an open tank and revolving paddles that circulate the bags in the dyebath.

Permanent Finish - Fabric treatments of various kinds to improve glaze, hand, or performance of fabrics. These finishes are durable to laundering.

Picking - (1) A process which continues the opening and cleaning of staple and forms a continuous fiber sheet (or lap), which is delivered to the card. (2) The operation of passing the filling through the warp shed during weaving.

Pile - (1) A fabric effect formed by introducing tufts, loops, or other erect yarns on all or part of the fabric surface. Types of pile are warp, filling, and knotted pile, or loops produced by weaving an extra

set of yarns over wires which are then drawn out of the fabric. Plain wires leave uncut loops; wires with a razor-like blade produce a cut pile surface. Pile fabric may also be made by producing a double-cloth structure woven face to face, with an extra set of yarn interlacing with each cloth alternately. The two fabrics are cut apart by a traversing knife, producing two fabrics with a cut pile surface. Pile should not be confused with nap. Corduroys are another type of pile fabric, where long filling floats on the surface are slit, causing the pile to stand erect.

(2) In carpets, pile refers to the face yarn, as opposed to backing or support yarn. Pile carpets are produced by either tufting or weaving.

Plying - Twisting together two or more single yarns or ply yarns to form, respectively, ply yarn or cord.

Polyester - A manufactured fiber in which the fiber-forming substance is any long-chain synthetic polymer composed of at least 85% by weight of an ester of dihydric alcohol and terephthalic acid.

Printing - A process for producing a pattern on yarns, warp, fabric, or carpet by any of a large number of printing methods. The color or other treating material usually in the form of a paste, is deposited onto the fabric which is then usually treated with steam, heat, or chemicals for fixation.

Print Paste - The mixture of gum or thickener, dye and appropriate chemicals used in printing fabrics. Viscosity varies according to the types of printing equipment, the type of cloth, the degree of penetration desired, etc.

Raw Fiber - A textile fiber in its natural state, such as silk "in the gum" and cotton as it comes from the bale.

Rayon - A generic name for man-made fibers, monofilaments, and continuous filaments, made from regenerated cellulose. Fibers produced by both viscose and cupram-monium process are classified as rayon.

Reactive Dyes - Dyes that react chemically with the fiber.

Roving - (1) In spun yarn production, an intermediate state between the sliver and the yarn. Roving is a condensed sliver which has been drafted, twisted, doubled, and redoubled. The product of the first roving operation is sometimes called slubbing. (2) The operation which produced roving (see 1).

Sanforizing - A mechanical process to preshrink the fabric.

Scouring - Removal of foreign components from textiles. Normal scouring materials are alkalies (e.g., soda ash) or trisodium phosphate, frequently used in the presence of a surfactant. Textile materials are sometimes scoured by use of a solvent.

Selvage - The narrow edge of the woven fabric that runs parallel to the warp. It is made with stronger yarns in a tighter construction than the body of the fabric to prevent raveling. A fast selvage encloses all or part of the picks, and a selvage is not fast when the filling threads are cut at the fabric edge after every pick.

Shuttle - A boat-shaped device, usually made of wood with a metal tip, that carries the filling yarns through the shed in the weaving process. It is the most common weft-insertion device. The shuttle holds a quill, or pirn, on which the filling yarn is wound. It is equipped with an eyelet at one end to control the rate. The filling yarn is furnished during the weaving operation.

Singeing - The process of burning off protruding fibers from yarn or fabric by passing it over a flame of a heated copper plate. Singeing gives the fabric a smooth surface and is necessary for fabrics which are to be printed and for those fabrics where smooth finished are desired.

Single Knit Fabrics - A fabric constructed with one needle bed and one set of needles, also called plain knit.

Sizing - (1) A generic term for compounds which are applied to the warp yarn to bind the fiber together and stiffen the yarn to provide abrasion resistance during weaving. Starch, gelatin, oil, wax, and man-made polymers such as polyvinyl alcohol, polystyrene, polyacrylic acid, and polyacetates are employed. (2) The process of applying size compounds. (Also see "Slashing.") (3) The process of weighing sample lengths of yarn to determine the count.

Skein - A continuous strand of yarn or cord in the form of a collapsed coil. It may be of any specified length and is usually obtained by winding a definite number of turns on a reel under prescribed conditions.

Slashing - A process of sizing warp yarns on a slasher. Also see "Sizing (1)."

Sliver - A continuous strand of loosely assembled fibers without twist.

The sliver is delivered by the card, the comber, or the drawing frame.

The production of sliver is the first step in the textile operation that brings staple fiber into a form that can be drawn (or reduced in bulk) and eventually twisted into a spun yarn.

Solvent Processing - An assembly of unit operations in which a solvent such as perchloroethylene is used instead of water to transfer chemical to and from the fabric.

Specific Energy - Energy Use during production per pound of product.

Staple - Natural fibers or cut lengths from filaments. The staple length of natural fibers varies from less than 1 inch as with some cotton fibers to several feet for some hard fibers like linen. Man-made staple fibers are cut to a definite length, from 8 inches down to about 1 1/2 inches (occasionally down to 1 inch), so that they can be processed on cotton, woolen, or worsted yarn spinning systems. The term staple (fiber) is used in the textiles industry to distinguish natural or cut-length man-made fibers from filament.

Tenter Frame - A machine that dries the fabric to a specified width under tension. The machine consists essentially of a pair of endless chains on horizontal tracks. The fabric is held firmly at the edges by pins or clips on the two chains, which diverge as they advance through the heated chamber, adjusting the fabric to the desired width.

Textured - Bulkied yarns that have greater volume and surface interest than conventional yarn of same fiber.

Thread - (1) A slender, strong strand or cord, especially one designed for sewing or other needle work. Most threads are made by plying and twisting yarns. A wide variety of thread types are in use today, e.g., spun cotton and spun polyester, core-spun cotton with a polyester filament core, polyester or nylon filaments (often bonded), and monofilament threads. (2) A general term for yarns used in weaving and knitting, as in "thread count" and "wrap threads."

Tow - A large strand of continuous man-made fiber filaments without definite twist collected in loose, rope-like form, usually held together by crimp.

Tricot - Warp-knitted fabric. Tricots are flat knitted with fine ribs on the face (lengthwise) and ribs on the back (widthwise).

Tubular fabric - A fabric woven or knit in a tubular form with no seams, such as seamless pillowcases, most knit underwear fabrics, and seamless hosiery.

Tufted Carpet - Carpet produced by a tufted machine instead of a loom. It is an outgrowth of hand-tufted bedspreads. Today, broadloom tufting machines produce over 90% of all domestic carpeting. Tufting machines are essentially multineedle sewing machines which push the pile yarns through a primary backing fabric and hold them in place to form loops as the needles are withdrawn. The loops are then either released for loop-pile carpets or cut for cut-pile carpets. The pile yarns may be either predyed or uncolored in which case the greige carpet is then piece-dyed or printed. In either case, a latex or other binding agent is applied to the backstitch to lock the tufts in place and to secure the secondary backing fabric. Formerly, all carpets were woven, either by hand or machine. The vastly greater productivity of tufting has revolutionized the carpet industry and has made soft floor coverings available to the mass market for the first time.

Warping - The operation of winding the warp yarn onto a beam in preparation for weaving or warp knitting. Also called beaming.

Warp-Knit Fabric - A fabric that is knit with the yarns running lengthwise, e.g., tricot, milanese, and raschel.

Warp-Sizing - See "Slashing."

Weaving - The method or process of interlacing two yarns of similar materials so that they cross each other at right angles to produce a woven fabric. The warp yarns, or ends, run lengthwise in the fabric, and the filling threads (weft), or picks, run from side to side. Weaving may be done on a power or hand loom or by several hand methods.

Winding - The transfer of a yarn or thread from one type of package to another (e.g., from cakes to cones).

Woven Fabric - A fabric composed of two sets of yarns, warp and filling, formed by weaving, which is the interlacing of these sets of yarns to form a fabric. There may be two or more warps and fillings in fabric, depending on the complexity of the pattern. The manner in which the two sets of yarns are interlaced determines the weave. By using various combinations of the three basic weaves (i.e., plain, twill, and satin), it is possible to produce an almost limited variety of fabrics. Other effects may be obtained by varying the type of yarns, filament or spun, fiber types, twist levels, etc.

Yarn - A generic term for a continuous strand of textile fibers, filaments, or material in a form suitable for knitting, weaving, or otherwise intertwining to form a textile fabric. Yarn occurs in the following forms: (1) A number of fibers twisted together (spun yarn), (2) A number of filaments laid together without twist (a zero-twist yarn), (3) A number of filaments laid together with a degree of twist, (4) A single filament with or without twist (a monofilament), or (5) A narrow strip of material, such as paper, plastic film, or metal foil, with or without twist, intended for use in a fabric.

Yarn Count - A relative measure of the fineness of yarns. The yarn number is inversely proportional to the linear density.