A GUIDE TO POLLUTION PREVENTION IN WOOLEN MILLS

Prepared for:
NORTHERN TEXTILE ASSOCIATION

CAPSTONE PROJECT
Submitted in partial fulfillment of the requirements for a Master of Science degree in the Department of Civil and Environmental Engineering at Tufts University

Prepared by:

Lyle Calfa
Jean Holbrook
Cheryl Keenan
Tim Reilly

Advisor:
Robert B. Pojasek, Ph.D.

July, 1993

This document is printed on recycled paper

A GUIDE TO POLLUTION PREVENTION IN WOOLEN MILLS

Prepared for:
NORTHERN TEXTILE ASSOCIATION

CAPSTONE PROJECT
Submitted in partial fulfillment of the requirements for a Master of Science degree in the Department of Civil and Environmental Engineering at Tufts University

Prepared by:

Lyle Calfa
Jean Holbrook
Cheryl Keenan
Tim Reilly

Advisor:
Robert B. Pojasek, Ph.D.

July, 1993

This document is printed on recycled paper

A GUIDE TO POLLUTION PREVENTION IN WOOLEN MILLS

Prepared for:
NORTHERN TEXTILE ASSOCIATION

CAPSTONE PROJECT
Submitted in partial fulfillment of the requirements for a Master of Science degree in the Department of Civil and Environmental Engineering at Tufts University

Prepared by:

Lyle Calfa
Jean Holbrook
Cheryl Keenan
Tim Reilly

Advisor:
Robert B. Pojasek, Ph.D.

July, 1993

This document is printed on recycled paper

TABLE OF CONTENTS

THE CAPSTONE TEAM

The Tufts University Capstone Team was composed of four members of varied backgrounds as follows:

Lyle Calfa received her B.A. in Chemistry from Wayne State University in Detroit, Michigan and a M.S. in Chemical Engineering from Michigan State University in East Lansing, Michigan. She is an Senior Quality Assurance Engineer with the Boston Edison Company, Pilgrim Nuclear Power Station, Massachusetts.

Jean Holbrook received her B.A. in Mathematics from Middlebury College in Vermont and her M.B.A. from Boston University. She is currently Compliance Manager and Assistant General Manager of Total Waste Management Corporation in Newington, New Hampshire.

Cheryl Keenan received her B.S. in Mechanical Engineering from Lehigh University in Bethlehem, Pennsylvania. Prior to commencement of studies at Tufts, Cheryl was a manufacturing engineer with Precision Robots, Inc. in Billerica Massachusetts. She is currently completing an internship in the Research group at the Toxics Use Reduction Institute in Lowell, Massachusetts.

Tim Reilly received his A.B. in Chemistry from Brown University. For the past ten years, he has worked for The Specialty Chemicals Group of Hoechst Celanese Corporation at its Coventry, Rhode Island Plant.

ACKNOWLEDGEMENTS

We wish to thank our advisor Robert B. Pojasek, Ph.D. of the Tufts University HMM Program and Corporate Vice President of Environmental Programs at GEI Consultants, Incorporated. His advice and assistance during this project was appreciated. Our team also wishes to thank our client Tim Harrall, Director of Regulatory Affairs for The Northern Textile Association. Several NTA member companies generously allowed us to tour and study their facilities.

Our contacts at the Case Study Facility played an important role in our understanding of the manufacturing processes within the woolen mill. Their assistance, ideas, and enthusiasm for Pollution Prevention was appreciated. Additionally, The Capstone Team wishes to thank the many people who assisted us by granting interviews, providing access to manufacturing facilities, and by supporting our efforts.

1.0 Executive Summary

Woolen mills in the United States face many challenges due to their varied processes, global competition, and equipment and technology ranging from as old as 100 years to as new as state-of-the-art. Environmental regulations are becoming increasingly more stringent. As a result, the industry is seeking better ways to minimize wastes and releases to the environment, while maintaining manufacturing costs that are competitive within the global marketplace.

The Northern Textile Association requested this study to examine the complete manufacturing process in the woolen mill for the purposes of identifying loss reduction and Pollution Prevention opportunities. The Capstone Team developed this Guidance Manual to provide woolen mills with a Pollution Prevention "roadmap" to conserve resources and minimize losses. Environmental problem have been one impetus for some companies to develop Pollution Prevention Programs. Others are motivated by reasons such as a desire to be perceived as environmental leaders, or by the economic need to provide their product to the marketplace at the most competitive cost, and therefore the least cost of waste. Pollution Prevention is an increasingly popular tool for reducing wastes and improving process efficiency. A Case Study Facility was selected to assess the effectiveness of this Pollution Prevention Guide.

The Capstone Team visited the Case Study Facility from April through mid-July 1993. The Team used the Descriptive Approach to Pollution Prevention, which integrated process flow analysis, activity based costing, total quality management tools and employee participation to identify and select opportunities for improvement. The Pollution Prevention opportunities were prioritized using screening criteria designed to identify the opportunities with maximum potential for achieving improvements in Pollution Prevention, employee health and safety, manufacturing costs and environmental protection. Opportunities were identified that are relatively easy to implement, cost efficient, and have potential for improved efficiency, improved working conditions and reduction in regulatory impact as well as a positive impact on Pollution Prevention in the woolen mill.

During the course of its investigation at the Case Study Facility, the Capstone Team identified opportunities for improvement for many of the varied processes within the mill. Corresponding Pollution Prevention alternatives were generated for many of these identified opportunities. Although many opportunities were identified, the Team selected a single unit process, "carbonizing", for further study. This process was chosen based on environmental and health and safety concerns, management and worker concerns, and technical reasons.

The carbonizing process removes vegetable matter such as grass, twigs, burrs and other extraneous debris from the wool. The process utilizes sulfuric acid and heat to convert the vegetable matter into carbon. The resulting carbon is brittle enough to fall out of the fabric when it is crushed between heavy rollers in a subsequent process.

Utilizing the process flow diagram, three critical carbonizing losses were identified. These were:

1. Vapors from the carbonizing bath
2. Chemical smoke or haze from the carbonizing oven
3. Sulfuric acid loss in effluent

These losses cause atmospheric problems which are a safety and health concern for workers and contribute to material losses from the process.

Total Quality Management tools were used to analyze these problems. The Team worked jointly with the Case Study Facility personnel to generate Pollution Prevention alternatives for the carbonizing process by brainstorming and additional discussion. The generated alternatives were put into the categories of "Low Hanging Fruit" or "Longer Term Alternatives". The category "Low Hanging Fruit" represents ideas that could be quickly and easily implemented in the short term, require minimal capital expenditure, and could potentially be very effective in reducing or even eliminating the loss. The "Longer Term Alternatives", which require additional planning and analysis, greater capital expenditures, evaluation of potential product quality impacts and/or longer implementation time, may not be necessary depending on the success of the short term alternatives.

Both short term and long term alternatives were identified for the three critical carbonizing losses. These Pollution Prevention recommendations included operational, maintenance, and process changes.

Low Hanging Fruit included:

- Monitor of Bath Parameters
- Identify and Repair Leaking Seals in the Carbonizer
- Develop a Preventive Maintenance Program for the Carbonizer

Longer Term Alternatives included:

- Pre-Wet the Fabric and Lower the Rollers Over the Bath
- Decrease the Initial Dryer Temperature
- Investigate a Substitute Fiber Lubricating Oil
- Improve the Accuracy of the Automatic Monitoring System for the Bath

If implemented, these alternatives have the potential to improve or possibly eliminate atmospheric problems in the carbonizer area as well as minimizing losses of sulfuric acid in wastewater.

2.0 Introduction

The first textile operations in America were those of the Indians and early American settlers. U. S. industrial production of textiles began in the northeastern United States, principally in the area of Lowell, Massachusetts. Large textile manufacturing operations were located where there was an abundant supply of water which was used for the process and plant power. "In those days, each plant had its river and to a great degree, each river had its plant."[1] At that time, there seemed to be unlimited amounts of water and natural dyes. The early abundance of water and dyes contributed to lax operating practices leading to the critical environmental problem which the industry now faces. The environmental problem has been one impetus for some companies to develop Pollution Prevention programs. Others are motivated by reasons such as a desire to be perceived as environmental leaders, or by the economic need to provide their product to the marketplace at the most competitive cost, and therefore the least cost of waste. Pollution Prevention is an increasingly popular tool for reducing wastes and improving process efficiency.

This document was prepared to assist woolen mills in setting up and implementing a Pollution Prevention program. The first chapters of the manual is a guideline that describes how to select the Pollution Prevention team, develop Process Flow Diagrams (PFDs) and establish the criteria necessary for prioritizing Pollution Prevention projects. This part of the manual includes a generic look at the woolen industry, illustrating how Pollution Prevention principles are applied, how the PFD is used to identify all process steps, inputs and losses, and how to generate materials accounting data. Armed with this information, it is next explained how group decision-making principles can be applied to identify opportunities for loss reduction, prioritize them utilizing a ranking system, and select a priority opportunity for further analysis. Next, the guide discusses how to generate options to accomplish the selected loss reduction target(s) and to select from among these options based on technical, financial and cultural feasibility.

The last chapter of the manual demonstrates the principles developed in the first sections. A case study woolen mill is used to illustrate how the guide can be used to develop a Pollution Prevention program. Long term process improvements as well as many shorter term ones are recommended in this study. Methods for implementation are also provided. This guide points out the importance of success with short term initiatives in validating the process and providing added impetus for continuation of the program. Without the short-term successes, few programs gain the momentum necessary to realize many of the longer term savings that can result from the Pollution Prevention program.

Pollution Prevention is a management system that requires an integrated approach. This guide attempts to demonstrate that Pollution Prevention successes are achieved in much the same manner as product quality improvements under the Total Quality Management concept. In both cases, winning ideas and their successful implementation emanate not from one group but from the entire organization. This is the philosophy of the Pollution Prevention program. Pollution Prevention should be woven into the fabric of the facility culture.

2.1 A Perspective on the Wool Manufacturing Industry

The wool manufacturing industry in the United States has grown over the last few years due to an increase in demand for natural fibers. Currently, approximately 5 billion pounds of wool (raw unprocessed wool called "grease wool") per year are produced, with about 4 billion pounds used for apparel and 1 billion used as carpet wool. Australia is the world's largest producer of wool, although sheep are raised in virtually every country in the world, producing hundreds of different varieties of wool. Other major raw wool producers include New Zealand, South America, England and the United States.

The textile industry as a whole includes producers of natural and manmade fiber products, textile equipment manufacturers, as well as producers of fabrics and apparel. This report concentrates specifically on the woolen mills, where raw wool is made into woolen fabric (Figure 1).

The annual production of woven fabrics in the wool textile industry is approximately 3 million cubic meters, worldwide. About 8% of this fabric is produced in mills in the United States.[2]

Woolen mills are currently facing some unique environmental challenges. In coming years the Environmental Protection Agency (EPA) plans to institute programs and guidelines for the industry relating to the Clean Water Act. Specifically, in 1995 the EPA is expected to begin developing effluent guidelines for the textile industry. In addition, control technologies and permit requirements mandated by the Clean Air Act Amendments, may apply to several operations in the woolen mills. Requirements for Stormwater Discharge Permitting, Toxics Release Inventory Reporting, and the phase out of Ozone Depleting Chemicals add to the complexity. Environmental issues are complicated by the diversity of the types of production processes and equipment used which range from 100 years old to state-of-the-art technology, all within the same production line.

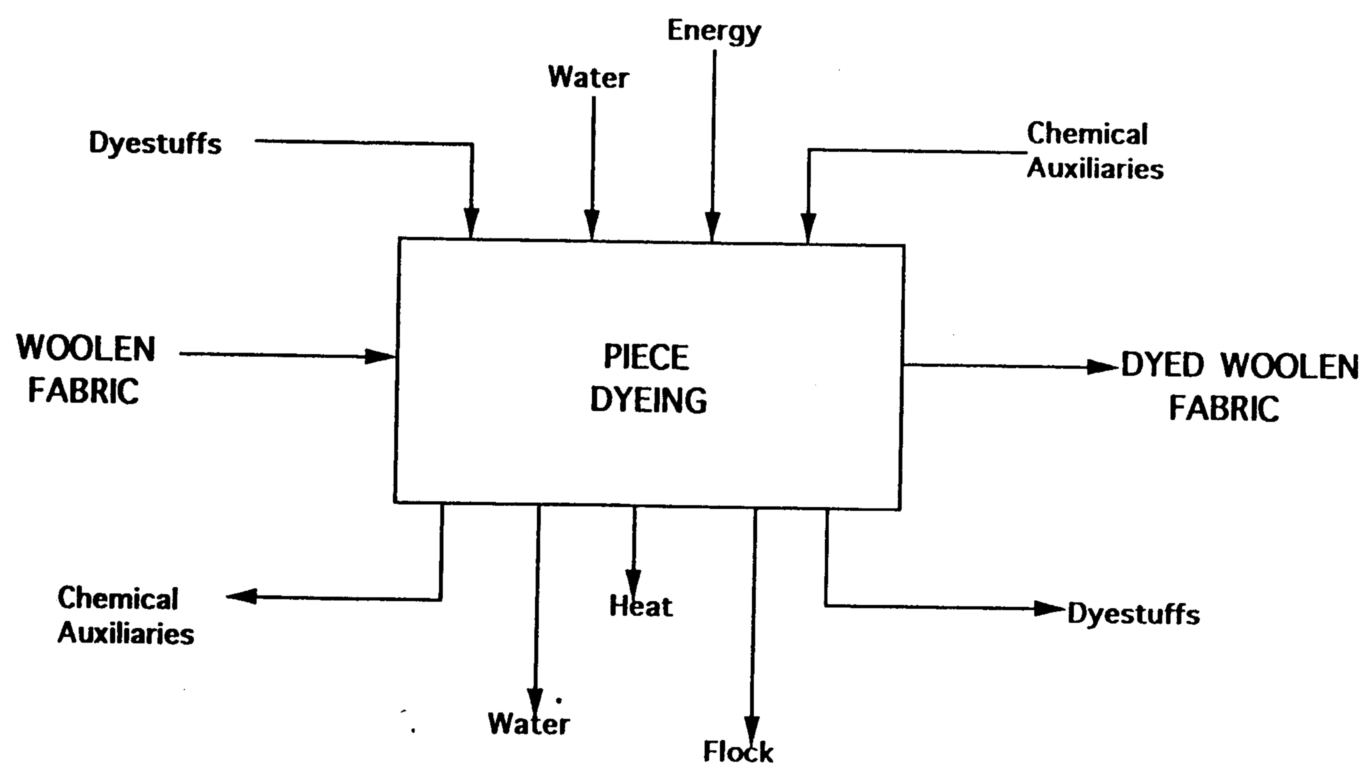
before starting the audit. Once constructed, the diagram gives a global view of the process and the functionality of interconnecting processes.

The flow diagram is then *verified* by walking through the facility. As the team tours the facility, notes are taken on the diagram. The diagram becomes a working document. Material flows into and out of each unit operation, as well as wastes, are designated by arrows on the flow chart. Each arrow is labeled to identify the material input and output or loss (Figure 4). It should be recognized that the arrows can indicate material flows in time as well as through equipment.[6] Complex processes are usually divided into two or more sub-processes. For example, in the case of the process step of yarn formation, several sub-steps can be depicted. These would include blocks for mixing, oiling, blending, carding, drawing, spinning, and coning.

Unlike "checklist" approaches, the process flow diagram is a common sense tool which tends to stimulate rather than stifle investigatory thought.

As the walkthrough proceeds, the condition of the area should be assessed for spills/leaks, excess waste, and potential for accidents. Ancillary activities that affect the process should also be noted on the working flow diagram. Discussions should be held with personnel who work with the processes on a daily basis in order to gather as much information as possible. The completed process flow diagram contains a snapshot of virtually every process occurring at the manufacturing facility. There are two distinct benefits to the diagram: one is its documentary and communications power, and the other is in the thorough understanding of the process required for its construction. Unlike "checklist" approaches, the process flow diagram is a common sense tool which tends to stimulate rather than stifle investigatory thought. *Verification* of the Process Flow diagram and materials flow is a key feature of the Descriptive process, because this is where the actual process is "tested" against the expected process and where realizations of the unique aspects of the facility will be noted.

Figure 4: Process Flow Diagram Block



A materials accounting for the process is done to quantify and balance process inflows and outflows. This is analogous to an engineering mass balance, but at a lesser level of precision and detail. In addition to the process flow diagram, other data such as purchasing and accounting records, inventories, standard operating procedures, production records and waste disposal manifests are used to identify and quantify process inputs and outputs. Activity Based Costing (explained in more detail in Section 6) is used to assure that all costs associated with each process step are accounted for, including those more traditionally considered as overhead costs. The advantage to this approach is that it is focussed. The materials accounting information is easily viewed on the process flow diagram and costs can be directly related to specific process operations. This tool assists in targeting and prioritizing Pollution Prevention opportunities and additionally enables establishing of a baseline against which to measure future progress.[7]

After this information is reviewed, an overall assessment can be made about losses associated with the manufacturing process. These losses can be viewed as opportunities for Pollution Prevention. They can then be prioritized and the best one(s) selected. The process flow diagram and the materials accounting are used as tools to select the best Pollution Prevention opportunity(s) for in-depth study. The selection will be based on defined screening criteria. Such criteria may include: environmental impact, employee health and safety, cost savings and return on investment, ease of implementation, potential for management and employee support, elimination of regulatory compliance problems, and potential for customer or quality impact. Techniques for prioritizing and selecting opportunities will be more fully discussed in Section 6.

Once a loss is selected, it is analyzed and then a list of alternatives for reducing or eliminating that loss is constructed. Pollution *control* strategies have traditionally focussed on waste treatment and reduction of disposal costs through energy recovery (i.e. burning of waste for fuel) and waste segregation and concentration. Pollution Prevention seeks a higher level of resource conservation and cost reduction through the application of strategies for recycling and source reduction. Recycling refers to the use or reuse of potential emissions or waste as an effective substitute for a commercial product, or as an ingredient in an industrial process. Source reduction refers to practices that reduce or eliminate the generation of waste at the source. These include:

Procedural Changes:

Spill and Leak Prevention

Inventory Control

Scheduling Improvements

Material Handling and Storage Improvements

Improved Operation and Maintenance of Equipment

Technology Modifications:

Water and Energy Conservation

Process Modifications

Equipment Modifications

Raw Material Substitution

Product Alteration or Reformulation

Ultimately, following an analysis of the technical and financial feasibility of the identified alternatives for achieving a loss reduction, one or more alternative will be selected for implementation using a process similar to that used for selection of losses.

Once the process flow and materials accounting have been initially established for the facility, they form the basis for continued review and re-evaluation. Such re-evaluation should be conducted periodically, however, with the basis established, the re-evaluation process is significantly simplified and the focus in future years becomes the process of identification of other losses and the options for reducing those losses.

3.2 Total Quality Management and the Descriptive Approach to Pollution Prevention

Total Quality Management (TQM) is a process of continuous improvement which has its roots in manufacturing. TQM encompasses management systems, the work environment, employee behavior, manufacturing processes, and the goods produced or services rendered.[8] The tools used in TQM can be readily applied to environmental management. When these principles are applied to environmental issues, the concept is often referred to as Quality Environmental Management or Total Quality Environmental Management. Successful companies utilize TQM via the participation of their employees to meet or exceed their customer's expectations. The Descriptive Approach and TQM tools can be simultaneously applied to pollution opportunities (losses) resulting in attainment of breakthroughs or lasting solutions. An added benefit of this method is it makes good business sense. This dual approach results in Pollution Prevention and economic savings.

Pollution Prevention Quality and ISO 9000

Customer focus and quality are becoming increasingly important in our global marketplace. Companies are attempting to gain competitive advantage by registering their quality systems through ISO 9000 certification. ISO 9000 is an international standard that describes the elements of an effective quality system. Fifty-three nations have adopted ISO 9000 as their national quality standard.[9] This certification system can be applied to all businesses and specifies the elements of a system that need to be in place in order to effectively manage quality. This certification is becoming a market requirement in some industries. Presently, there are only eight ISO 9000 certified textile mills in the United States.[10] In industries such as electronics, machinery, and chemicals, companies using ISO 9000 have realized benefits. For example, one Dupont plant increased its first-pass yield from 72% to 92%, and another of its chemical plants reduced its product cycle from 15 days to 1.5 days.[11] Improved efficiency equals Pollution Prevention!

Woolen mills and other textile manufacturers should investigate ISO 9000 certification for their facilities. In addition to helping produce a quality product, it will enhance the organization's Pollution Prevention efforts. In the not too distant future, environmental management systems will be linked with quality management systems.

Companies will obtain certification of their environmental systems by ISO criteria. European customers are already requiring Environmental Management System (EMS) certification of its suppliers. Although it is now voluntary, it is not unreasonable to assume that this type of certification may someday be mandated. With our emphasis on the environment, our government, consumers, and the public may insist on EMS certification.

Pollution Prevention: Using a Participative Approach

Companies that have adopted a participative approach to running their business realize that "none of us is as smart as all of us" and that teamwork is critical to the company's success. By bringing all employees into the Pollution Prevention process, an often untapped resource can reduce inefficiencies within the plant. The Descriptive Approach attempts to gain broad participation from different sectors of the organization (e.g., manufacturing, engineering, quality, human resources). A synergy develops which enables the Pollution Prevention team to be creative and imaginative. Another benefit of this cross-functional team is "objectivity". All employees have built-in biases to the efficiency of their own department. A factual approach by the Pollution Prevention team is necessary to insure proper diagnosis of chronic problems.

By using a structured approach (TQM tools) to Pollution Prevention, losses can be minimized. Many Pollution Prevention success stories exist within the textile industry. M. Lowenstein Corporation maintains a plant in South Carolina which produces unfinished sheeting fabric. A quality team investigated losses associated with oil streaks on cloth at the weaving machines. The team applied TQM tools to achieve a 93% reduction in losses.[12] The annual savings was $36,000 as a result of this effort. Some state governments have actively formed partnerships with quality organizations to encourage teamwork in solving pollution problems. The State of Rhode Island's Office of Environmental Coordination and the Rhode Island Chapter of the

Companies that have adopted a participative approach realize that "none of us is as smart as all of us".

Association for Quality and Participation have sponsored training programs to aggressively move toward increased company and employee involvement in Pollution Prevention projects. Similarly, the Massachusetts Office of Technical Assistance sponsors TQM/Pollution Prevention seminars for industry. Hyde Tools,Inc., of Southbridge Massachusetts is an example of focused TQM efforts in the Pollution Prevention area. This company has been able to decrease its effluent discharge by 75%.[13] Company officials credit their success to employee participation, teamwork, and the application of the principles: COMMITMENT, ACTION, FEEDBACK, and CORRECTION.

Many of the tools utilized in the Descriptive Approach to Pollution Prevention, are derived from the TQM process. These tools are described in section 5.2.

4.0 Wool Manufacturing Overview

To analyze the losses associated with each of the steps in wool fabric manufacturing, a detailed process flow diagram was prepared. Initially, this diagram was constructed by researching current wool industry periodicals, books on wool preparation and other wool industry publications. Once the initial flow diagram was complete, the team visited several fabric production mills to verify the flow diagram. It was necessary to break the production operations into smaller steps in order to analyze the inputs and outputs at each step. By adding these inputs and outputs to the flow diagram, the team was able to identify areas where losses may occur. This section describes the general process. Sections 4.1 - 4.6 describe the manufacturing processes and their associated losses in more detail.

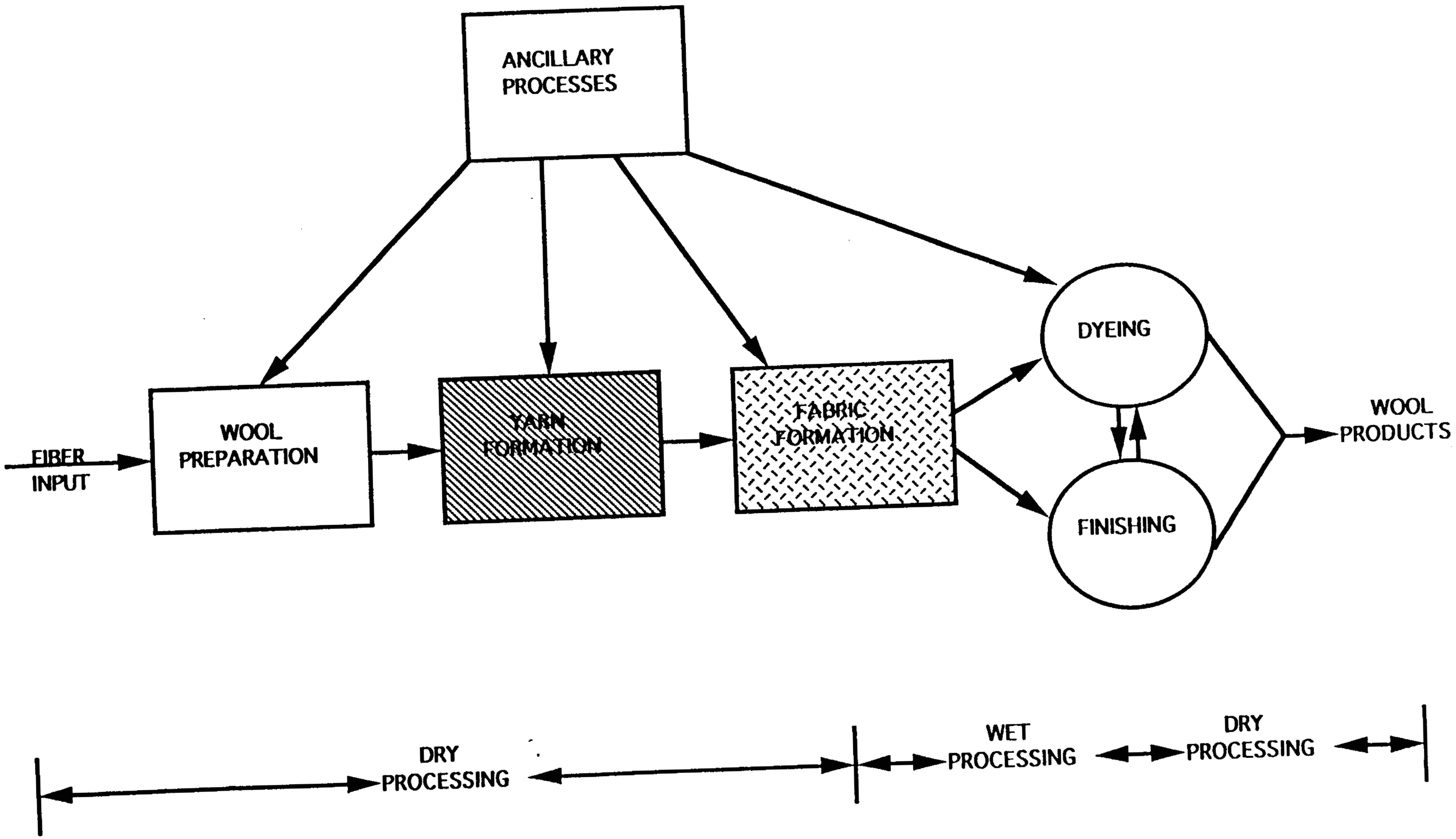
Wool manufacturing consists of five basic processes as illustrated by Figure 5. The manufacturing process starts with the raw wool and processes it into wool fabric.

Wool Preparation can include scouring, stock dyeing and blending operations. In most New England mills, the scoured, raw wool is delivered to the mill and the first processing step is blending. Blending is necessary to achieve uniformity of the product due to the wide variation in raw wool from lot to lot. During blending, the wool is also oiled. Oiling of the wool is necessary in order to insure proper lubrication for carding and spinning.

Yarn Formation processes convert the bulk, raw wool to spools of yarn. The first step in yarn formation is carding. Carding is a process which aligns the randomly placed fibers parallel to each other so they can be properly twisted into yarn in the spinning process. Spinning is performed after initial fiber preparation and consists of drawing out the fibers, twisting them into yarn and then winding the newly made yarn onto a bobbin. Yarn from several bobbins is wound to a cone holding a length of yarn suitable for the warping and weaving processes. At this point the yarn is ready for conversion to fabric.

In **Fabric Formation**, the yarn is woven into fabric. A warping machine winds

Figure 5: PROCESS FLOW DIAGRAM OVERVIEW



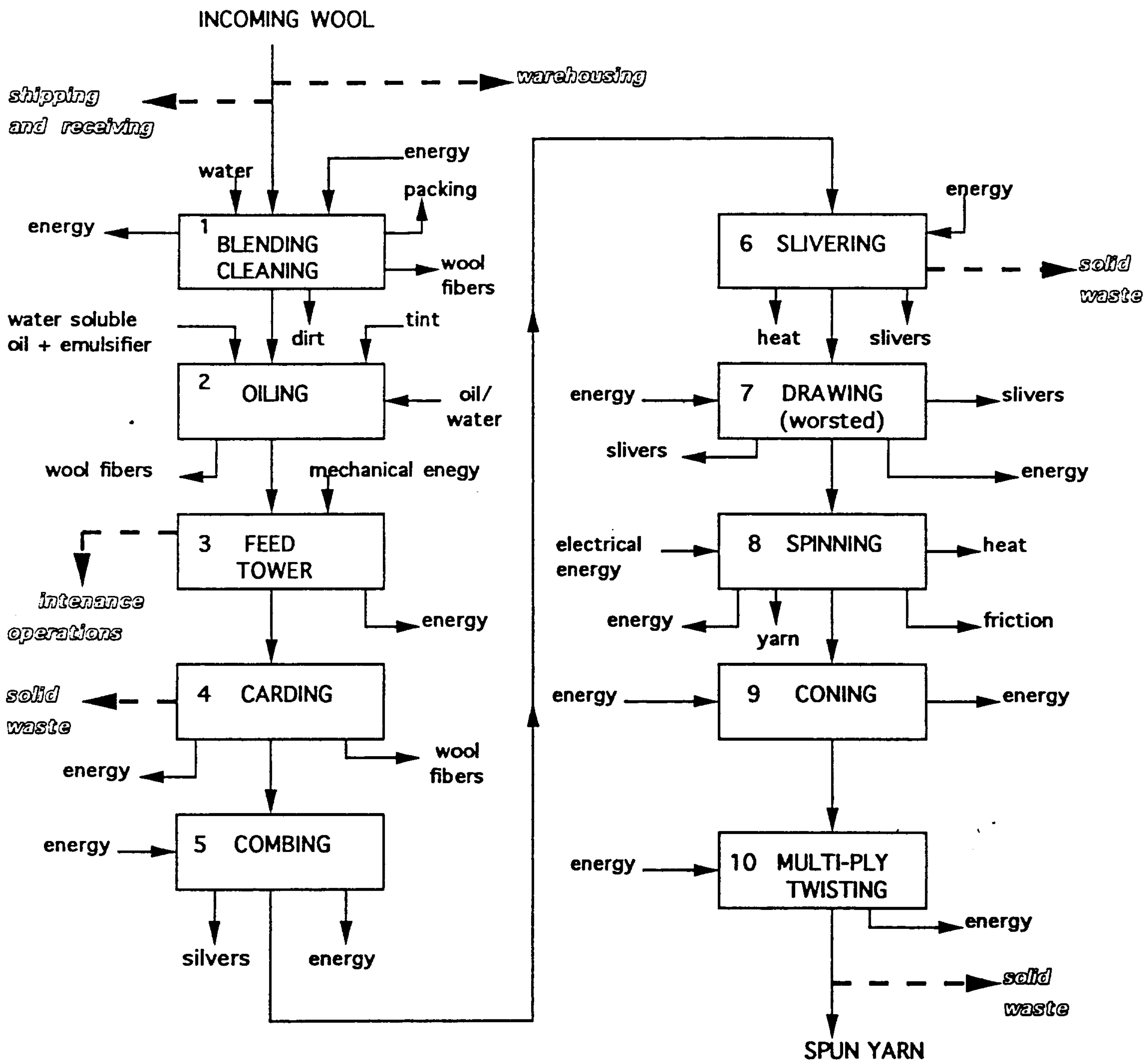
numerous separate strands of yarn onto a beam. These fibers will run in the lengthwise direction of the woven cloth. The yarn is then woven into griege, or unfinished fabric. The fabric then goes through a process called carbonizing. It is impregnated with sulfuric acid, dried and baked to oxidize vegetable matter impurities from the raw wool. From carbonizing, the wool may be washed and neutralized or it may go into the fulling process, which tightens the flat weave into a dense three-dimensional fabric.

Dyeing can be done at various stages in the process. If the raw wool or yarn was not dyed (stock dying or yarn dying), the fabric is dyed before entering the finishing process (piece dying). The final process, **Finishing**, varies with the fabric and use. Finishing can include napping, polishing, steam sizing and dyeing. These processes are designed to impart qualities such as color fastness, feel and protection from shrinkage.

All steps in the process can be placed into two broad categories, dry and wet, depending on whether or not a liquid is involved. Usually the process is considered dry up until final dyeing and finishing.

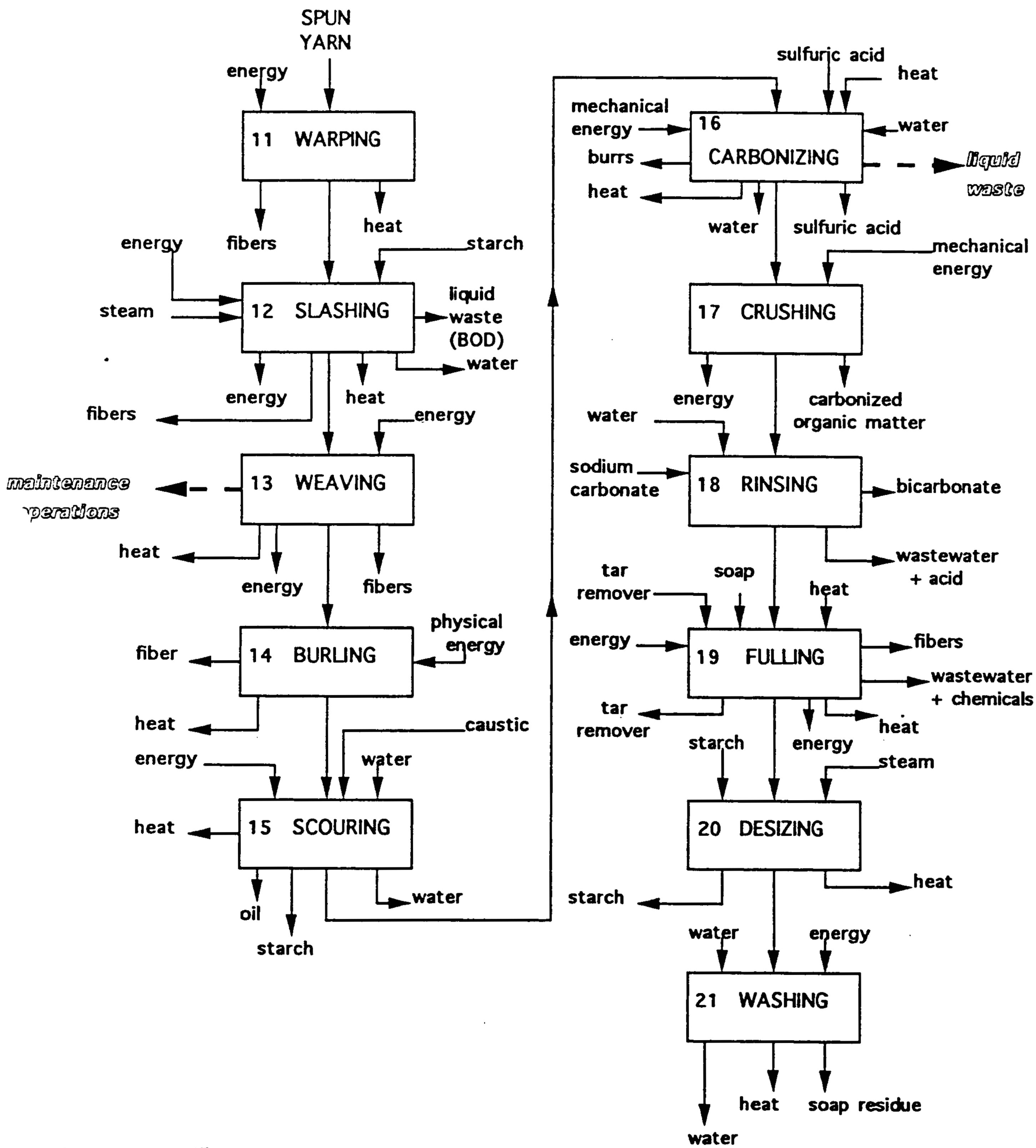
The process is further broken down into more detailed steps as shown in Figures 6, 7, and 8. Each process step is described in more detail in the remainder of this chapter. The losses associated with each process step are also described. These losses are summarized in table format in Figure 9.

Figure 6: YARN FORMATION



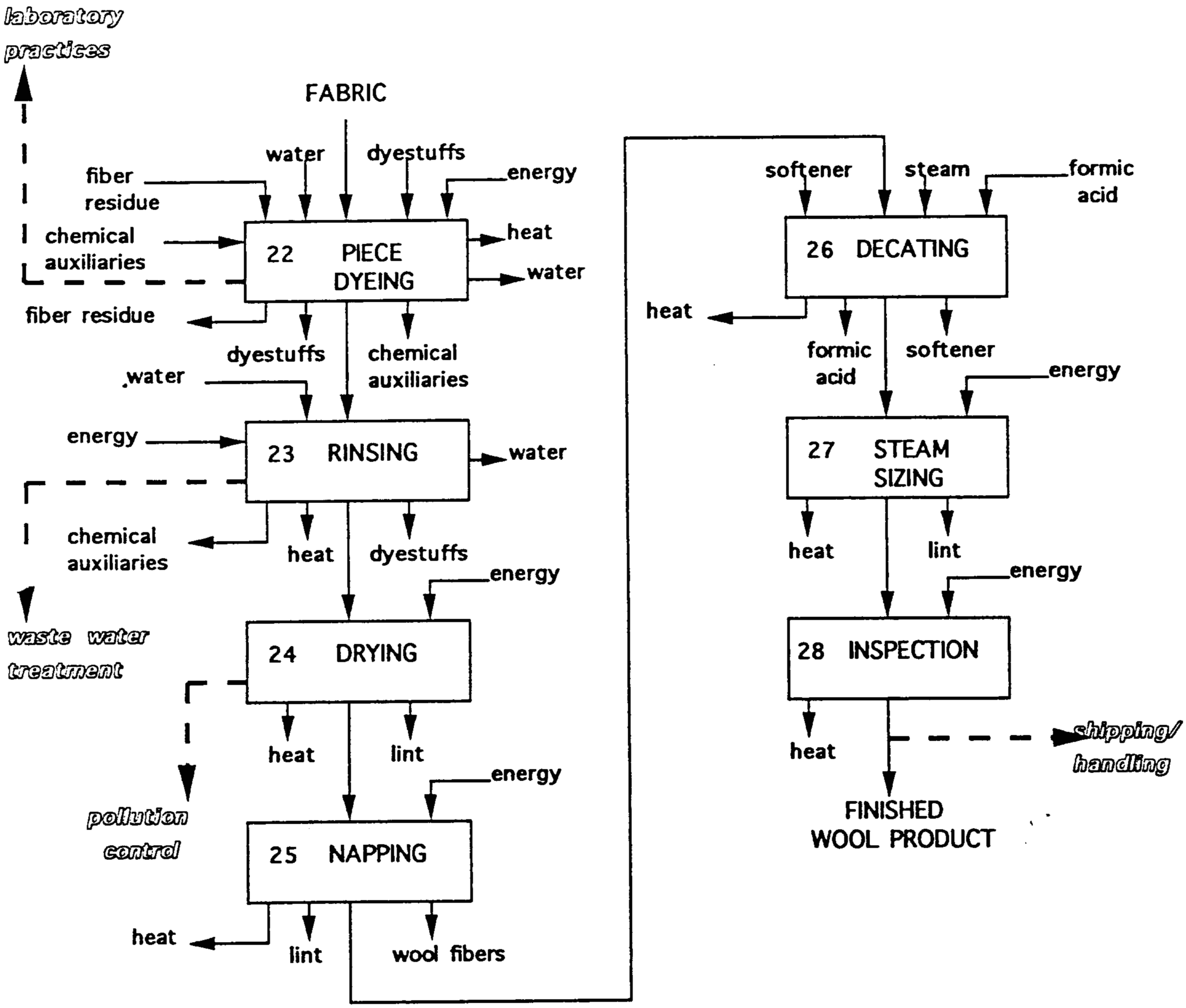
Key: Print in italic is *ancillary*

Figure 7: FABRIC FORMATION



Key: Italic print is *ancillary*

Figure 8: FINISHING



Key: Italic print is *ancillary*

Figure 9: WOOLEN L PROCESS LOSSES

NAME/NUMBER OF UNIT	MATERIALS USED	MATERIALS LOST	LOSS TO AIR	LOSS TO WATER	SOLID WASTE	ACTIVITY-BASED COST
Blending/1	energy, water,raw wool	energy, vegetable matter, packing, wool fibers	energy	none	vegetable matter, packing, wool fibers	
Oiling/2	water soluble oil+ emulsifier, tint	wool fibers, oil/water	none	oil/water	wool fibers	
Feed Tower/3	mechanical energy	energy	energy, maintenance operations	none	maintenance operations	
Carding/4	energy	energy, wool fibers	energy	none	wool fibers	
Combing/5	energy	energy, slivers	energy	none	slivers	
Slivering/6	energy	heat, slivers	heat	none	slivers	
Drawing/7	slivers	energy, slivers	energy	none	slivers	
Spinning/8	electrical energy	energy, heat, yarn, friction	energy, heat, friction	none	yarn	
Coning/9	energy	energy	energy	none	none	
Multi-Ply Twisting/10	energy	energy	energy	none	none	
Warping/11	spun yarn, energy	fibers, heat	heat	none	fibers	
Slashing/12	energy, starch, steam	liquid waste (BOD), water, heat, energy	heat, energy	BOD	none	

Figure 9: WOOLEN MILL PROCESS LOSSES

NAME/NUMBER OF UNIT	MATERIALS USED	MATERIALS LOST	LOSS TO AIR	LOSS TO WATER	SOLID WASTE	ACTIVITY-BASED COST
Weaving/13	energy	energy, fibers, heat	heat, energy, maintenance operations	none	fibers, maintenance operations	
Burling/14	physical energy	heat, fibers	heat	none	fibers	
Scouring/15	energy, caustic, water	heat, oil, starch, water	heat	water/starch / oil	none	
Carbonizing/16	mechanical energy, sulfuric acid,heat, water	heat, water, sulfuric acid, burrs	heat, sulfuric acid fumes	sulfuric acid, liquid waste	burrs	
Crushing/17	mechanical energy	carbonized organic material,	energy	none	carbonized organic material	
Rinsing/18	water, sodium bicarbonate	bicarbonate, waste water+acid	acid fumes	acid, bicarbonate	none	
Fulling/19	energy, heat, soap, tar remover/ mineral spirits	fibers, waste water+chemicals energy, heat, tar remover	energy, heat, mineral spirits	soap residue, tar remover	none	
Desizing/20	steam, starch	starch, heat	heat	starch	none	
Washing/21	water, energy	water, heat, soap residue	heat	soap residue, water	none	
Piece Dyeing/22	water, dyestuffs, energy, fiber residue,	water, dyestuffs, heat, chemical auxiliaries,	chemical fumes, laboratory practices	water, dyestuffs, chemical auxiliaries	fiber residue, laboratory practices	

Figure 9: WOOLEI ILL PROCESS LOSSES

NAME/NUMBER OF UNIT	MATERIALS USED	MATERIALS LOST	LOSS TO AIR	LOSS TO WATER	SOLID WASTE	ACTIVITY-BASED COST
Rinsing/23	water, energy	heat, dyestuffs, water, chemical auxiliaries	heat, dyestuff fumes	water, chemical auxiliaries, wastewater treatment	wastewater treatment	
Drying/24	energy	heat, lint	heat, pollution control	none	lint	
Napping/25	energy	wool fibers, lint, heat	heat	none	wool fibers, lint	
Decating/26	softener, steam formic acid	heat, formic acid, softener	formic acid fumes, heat	softener	none	
Steam Sizing/27	energy	heat, lint	heat	none	lint	
Inspection/28	energy	heat, finished wool product	heat	none	shipping, handling	

4.1 Wool Preparation

After wool is sheared from the sheep, it is graded and sorted with regard to wool type, length, fineness, and shade of fibers. This unprocessed raw wool is called "grease wool" and requires further processing prior to yarn formation. Grease wool contains the sheep's natural oils, dirt, vegetable matter, dried perspiration (suint), and other extraneous debris. The fleece of the sheep may contain as much as 60% by weight of this matter.[14] The raw grease is typically removed from the wool by a scouring process prior to receipt at the mill, however, wool fiber in the mill still contains a small amount of grease and foreign matter, as well are oil added for lubrication prior to spinning. All of these materials must ultimately be removed from the final product to prevent degradation of the fiber by bacterial action, however, the positioning in the process of this step varies and it may not appear as a separate operation. The scour process consists of washing the fabric with detergents, wetting agents, emulsifiers and alkalis.[15]

Blending and Oiling

The purpose of blending is to mix various grades or shades of fibers as uniformly as possible in order that an acceptable yarn is made. Blending can be accomplished by many methods. One such method starts by inserting premeasured fiber bales (wool, synthetics) into blending feed boxes. These machines have spiked aprons which open the compacted fibers and feed them onto a conveyor belt at a specified rate. Several feed boxes simultaneously feed fibers thereby enabling a layering or blending effect. The clumps of fibers are then passed through an in-line toothed machine (delumper/picker) which opens the fibers still further.

The fibers are then pneumatically transported to a mixing bin. The fibers enter the rectangular bin via an overhead rotary spreader which distributes the material evenly onto the floor of the bin. Additional blending can be accomplished by moving fiber material bin to bin via a mechanical emptying machine and pneumatic transfer lines. Once the fiber is adequately blended, it can then be further processed.

During the blending process, a water soluble oil or emulsion is uniformly added to the fiber. The wool fiber enters an oiling chamber which adds an atomized oil spray at a uniform rate. Oiling may occur before the wool is conveyed to the mixing bin, or after the fibers exit the mixing bin. After blending and oiling, the lubricated fiber is then ready for yarn formation.

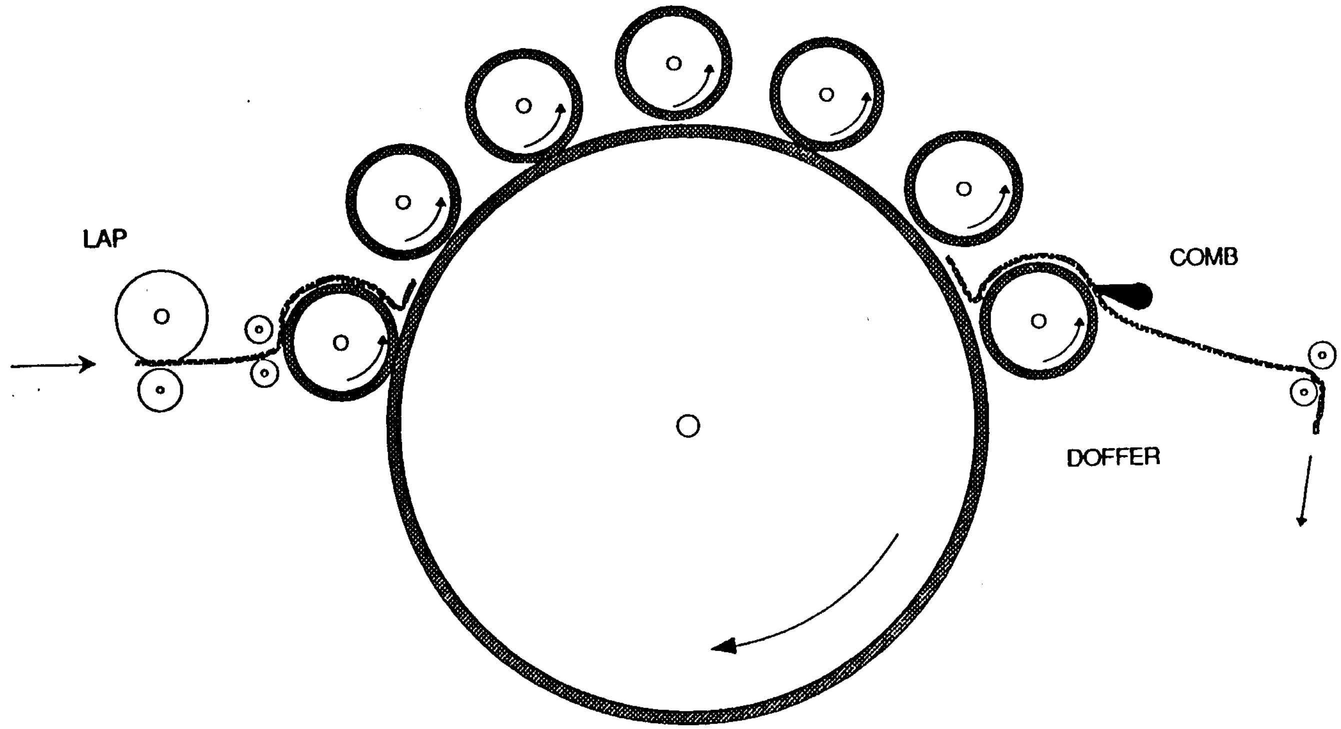
Losses: Small amounts of wool loss occur during the blending process. Normally, this material can be recycled back into the system. Some extraneous debris gets separated from the wool and it is discarded. It is important that wool is oiled properly. Too much or too little oil can cause processing problems and can result in additional use of energy and resources to rework the material.

4.2 Yarn Formation

After initial preparation by blending, oiling and mixing, wool is made into yarn in preparation for weaving. Formation into yarn involves carding, combing, slivering, drawing, spinning, winding and coning. The process is dry and mechanical and uses no heat. Inputs to the process include cleaned, oiled raw wool, and electrical energy. The product is spun yarn ready for weaving (or in some cases, yarn dyeing).

Carding and Preparation into Slivers

After blending, the wool is transported to the carding machine **feed tower** either manually or via overhead ducts. Recycled wool may also be added at the feed tower. Carding prepares the wool for spinning by straightening the fibers and laying them parallel. The carding machine consists of a cylinder about 50 inches in diameter covered with wire teeth (Figure 10). The wool is fed into the carding wheel by a smaller lap wheel and revolves with the cylinder against a series of wire covered rollers or combs above the main cylinder. Another small wire covered roller at the front of the machine, called a doffer, strips the fiber from the main cylinder. The fine web produced is removed from the doffer by a comb. This web may be collected by passing through a tapered hole into a round sliver, or it may be folded over onto itself into a thick loose bundle and carded one or more additional times to improve the consistency of the fiber.



CARDING. MACHINE CONCEPTUAL DIAGRAM

FIGURE 10

At the end of this process, the resultant fibre is divided into thick slivers for formation into yarn. This may be done, as mentioned by collecting the fine web through a tapered hole, or by condensing the web to a thicker mat and slicing it with leather belts into thin sections. The slivers are then rolled into a thick loose roving which has little tensile strength. This may be wound onto spools directly for spinning, or combed and drawn to further improve parallelism and uniformity.

Losses: Most of the fibers lost from the process are collected for recycling back into the blending or carding process, although some fibers become mixed with dirt and debris on the floor and are unsuitable for reuse in the process. Fiber losses from carding are short fibers are often recycled in felting operations.

Combing

Worsted wools are combed to further improve the parallel positioning of the fibers and remove shorter fibers. The wool is combed through pins on two combing circles revolving in the same direction. The wool passes through the combing circles and smaller shorter hairs, called noils, are left on the pins of the smaller circles.

Losses: Noils are removed by knives, and recycled for use as felt or flock, or to produce woolen goods by blending with longer fibers.

Drawing

Drawing can involve two steps. Slivers are first passed between rotating rollers to draw the combined product out. If the second pair of rollers is set to run four times as fast as the first, the resulting sliver becomes four times as long as the input sliver. This improves the parallelism of the fibers. Additionally, by combining several slivers together in parallel and passing them through a similar set of roller pairs results in more uniform weight and thickness.

Losses: Losses from drawing are minimal. Waste product which does not become mixed with debris can be recycled into the blending or carding processes.

Spinning

In spinning, the roving is drawn again by rollers and twisted to create a yarn. Twisting of the loose fibers creates strength and results in a fine yarn. Spinning of a number of spools of roving simultaneously is accomplished on high speed, automated equipment. Several techniques are used such as mule spinning, ring spinning, flyer spinning and bobbin spinning. In each case a twist is imparted to the roving as it is fed onto the rotating bobbin or package. [16]

Losses: Losses from spinning include small pieces of yarn which are not recyclable into the process because they have become condensed into a firm strand. These wastes can be recycled outside the mill in stuffing and padding products. They can also be processed into wool fiber suitable for blending back into the carding operation by specialty houses through a process called "picking".

Coning

Bobbins from the spinning machine hold relatively short lengths of yarn. The spun yarn is wound from the bobbins onto cones weighing about 12 pounds to provide longer length packages for the weaving and warping operations. This is also a high speed, highly automated operation which may involve automated sensors to detect yarn breakage and automated tying machines to repair breakage.

Losses: Losses from Coning are minimal and are treated similarly to spinning losses.[17]

Multi-Ply Twisting

In some mills, the two or more cones of yarn are twisted together to form two-ply or multi-ply yarn, which is also spun onto a cone.

Losses: Losses from Twisting are minimal and are treated similarly to spinning losses.

4.3 Fabric Formation

Warping

After coning, the yarn is prepared for weaving at the loom. The yarn wound in the previous operation, coning, is not long enough for use on the loom, therefore several additional processes are required to "warp" the yarn in preparation for weaving. Warping involves the transfer of the yarn from hundreds of cones onto a large spool. This is done for two reasons: 1) to obtain longer lengths of yarn to permit the continuous production of long lengths of fabric and 2) to produce a spool of evenly spaced, parallel yarns. The finished warp can have thousands of yarn ends.

The process by which the yarn is drawn off the cones onto the warp is called beaming. The cones are placed on the creel, which consists of a metal frame with a matrix of 300 - 800 pegs. Each peg holds one cone in position while allowing it to rotate as the yarn is drawn off. The creel is equipped with a yarn breakage detector which will immediately stop the winding onto the beam when a break is detected. It is critical that the broken end does not reach the beam, because it would be extremely time consuming to locate the broken end among the hundreds of ends on the beam. The yarns pass from the creel through a comb, which separates the individual yarns. After passing through a tensioning device and an expanding reed, which uniformly space the yarn, the threads are wound onto the beam.[18]

Losses: Wool fiber is lost where the yarn rubs against the creel as it winds off the cone at high speeds. Loss of mechanical energy in the form of heat is minimal.

Slashing and Sizing

The loom-ready beam may consist of several thousand ends, which is greater than the capacity of the creel. In some cases, this capacity problem is addressed by winding the cones into several beams, all with the yarns of the required length. These beams are then wound onto the weaver's beam in a process known as slashing.

One alternative to slashing is to wind one group of warp threads onto the beam and then wind another group next to the first winding on the beam. All the windings are placed side by side across the width of the beam and make up the number of ends required for the loom. This process is known as section warping. Some systems combine warping and slashing in one machine, such as the Benninger. In such a system, one machine is used to take the yarn from the cones to the beam to the warp.[19]

After slashing, a process, called sizing is occasionally done. The purpose of sizing is to improve weavability. To accomplish this, a protective coating is applied to the yarn to mitigate the abrasive action of the loom and to give the yarn sufficient strength and extensibility to withstand the stresses of the weaving process. Since most wool weaving yarns have sufficient strength, sizing is seldom necessary.[20] Traditionally, starch has been the basis of most sizes, but now a much wider range of materials is available, including cellulose, gelatine and a variety of synthetic products such as acrylics and polyesters. In addition to the sizing material itself, wetting agents, anti-foams and lubricants are usually added to the sizing mix.[21] After slashing and, if required, sizing, the warp is ready for the loom.

Losses: Losses associated with slashing include fiber losses as the yarn rubs against the guidance fixtures, and the energy losses in the form of heat from the machinery. Sizing materials can be lost during sizing through disposal of containers that still contain material, through accidents and spills and through application of excess sizing material. If a water based sizing solution is used, water and liquid waste, typically high in BOD can also be lost.

Weaving

Weaving is a process of creating fabric by interlacing two sets of threads at right angles on a loom. The lengthwise set of threads is known as the warp threads. The set of threads that are placed on the loom in the crosswise direction are know as the weft threads. Before weaving can begin, the operator must select the warp thread in consecutive order and tie them to an existing warp or thread them through the appropriate healds (needles), reed (spacer) and droppers (thread separators). Tying a new warp onto an existing warp is a preferred procedure as several steps are eliminated. However, this is possible only if the new warp is to be woven with the same pattern as the previous warp.[22]

When a warp is to be used on the loom that is identical to the previous one, a knotting machine is used to connect the new warp to the ends of the one on the loom. When a new warp is used, several additional steps are required. Each yarn end must be drawn through the eye of the heald (the needle) in the correct order as defined by the weaving pattern. Some facilities have "drawing-in" and "reaching" machines to automate this process, however, many operations still carry out these steps manually. Manually, two operators are needed. The "reacher-in" selects the warp thread individually and in the correct order. The "drawer-in" passes a hook through the eye of the heald to grab the warp thread and pulls the thread through the eye of the heald. The yarns are then woven into fabric sheets. Individual warp threads are alternately raised and lowered by the loom shuttles according to the pattern of the weave while allowing the weft thread to cross between them to form the weave.

Losses: The rubbing action of the yarn on the loom frame can cause some fiber loss. If a thread breaks at the loom and is not properly repaired, the losses the losses incurred from the damaged piece of fabric can be great. These losses may be reflected in increased rework, increased need for inspectors and increased time spent on that piece of cloth by the burlers.

Burling

After weaving, the fabric is stretched across a vertical light table. In an inspection process known as burling, an inspector will look for broken threads and knots. If a broken thread is found, the inspector will repair it by sewing it back into the cloth manually or by pushing it through to the backside of the fabric. Occasionally, the fabric is beyond repair and it is rejected at this step.

Losses: The intensive repetitive manual motions associated with burling can cause carpal tunnel syndrome. The losses in associated medical costs can be great.

Piece Scouring

The oils and sizing materials added to the wool to facilitate spinning and weaving operations are generally removed from piece goods by scouring. Scouring is done to remove the natural and acquired impurities from the fabric. In general, the scouring process is somewhat similar to that used for raw wool in that the action depends on detergents and alkalies. Most goods are scoured using the "Dolly Washer". The fabric is passed continuously through a scouring liquor and then squeeze rolled, which forces the scouring liquid into the material.

Losses: As the fabric passes through the washer and squeeze rollers, starch, oils and trace amounts of suspended dirt are removed from the fabric. Scouring waste also contributes to the BOD content in waste water.

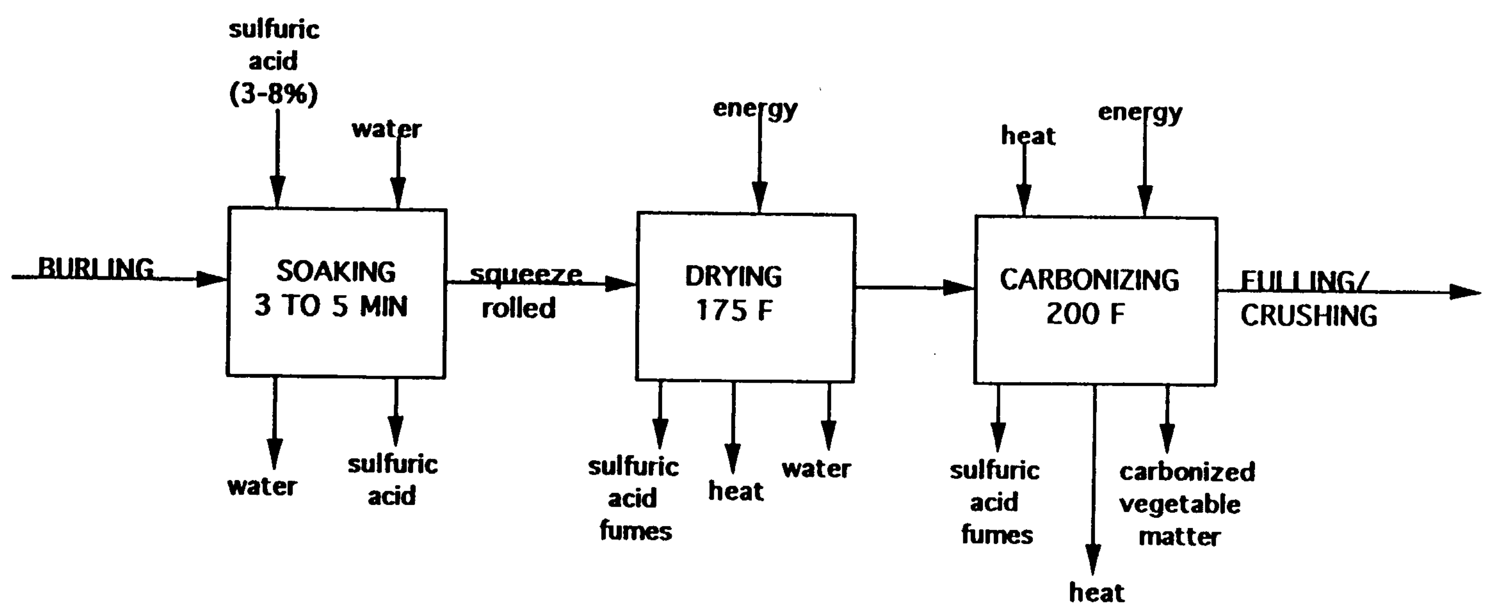
Carbonizing

All wool contains some amount of vegetable matter, such as burrs, seeds, twigs or grass, picked up by the sheep while grazing. Scouring alone often does not remove all vegetable matter from the wool. A chemical treatment, known as carbonizing, is used to remove these impurities from the fabric. Sulfuric acid is typically the chemical used. The acid chars the vegetable matter, turning it into carbon, which is subsequently removed by mechanically crushing and beating the fabric. Wool may be carbonized at virtually any stage of the process, including raw wool, slivers, yarn and fabric.[23] It is rarely done on yarn and is most often done on fabric after weaving.

The carbonizing process consists of the steps shown in Figure 11 which are described below:

1. Soaking: The fabric (either wet or dry) is soaked in a weak acid bath at room temperature. Sulfuric acid concentrations of 4% - 8% are typical in wool production.[24] The immersion time is dependent on the quantity of vegetable matter, the character of the wool, the acid concentration and the type of equipment used. Typically, the fabric is immersed for approximately 3 to 5 minutes. After the acid bath, the wool is squeezed through heavy rollers. The squeezing step removes excess acid and impregnates the acid in the vegetable matter.[25] The acid concentration and immersion time are optimized to maximize the vegetable matter uptake of acid, while minimizing the acid damage to the wool.

Figure 11: CARBONIZING PROCESS



2. Drying: Before entering the carbonizer, the fabric is pre-dried to a 10% moisture content at temperatures between 150°F (65°C) and 200°F (93°C). Sulfuric acid which contacts the wool fiber is chemically absorbed (bound). Acid contacting the vegetable remains as free acid. The drying process evaporates water from the free acid, thus concentrating the acid on the vegetable matter, while causing no damage to the wool fiber.

3. Carbonizing: Next the fabric enters the carbonizing section of the dryer where temperatures are typically between 220°F (106°C) and 280°F (140°C). The vegetable matter is transformed to carbon under the influence of the concentrated acid at the high temperatures.

4. Crushing: The fabric is passes through a series of heavy rollers that pulverize the charred material. Then, the pulverized, charred material is mechanically shaken or beaten out of the fabric.

5. Neutralizing: In some mills, excess acid is removed using a pre-rinse and a neutralization bath. The cold water pre-rinse reduces acid content by up to 50%. The neutralization bath contains an alkali (usually sodium carbonate or soda ash) and water. In the neutralizing bath, the sodium carbonate chemically reacts to form bicarbonate, which, in turn is converted into sodium sulfate and free carbonic acid.[26] Neutralizing is usually followed by a drying step where the wool is dried at 140°F (60°C) for approximately 15 minutes.

In other production scenarios, the excess acid is needed for the next process step, fulling. In this case, there is no separate neutralization step.

For production scenarios where an acid dye is to be used on the fabric after carbonizing, the fabric can go directly to the dye bath after crushing, skipping the neutralization step. By using the acid retained from carbonizing, less acid is needed for the dye bath, plus the neutralization step can be eliminated.

Losses: The conditions of carbonization (including temperature, acid content and soaking time) are interdependent and must be optimized to obtain the maximum absorption of the acid by the vegetable matter and least damage of the wool (resulting in loss of wool). If these parameters are properly controlled, fiber losses during carbonizing can be significantly reduced.

Wastewater from carbonizing is acidic, low in organic content and high in total solids. Due to the rinsing required to remove potentially harmful acid residues from the fabric, carbonizing has the potential to significantly increase hydraulic load, however, when acid dying follows carbonizing, intermediate rinse and neutralization may not be required.

Other losses include heat and sulfuric acid. These losses are discussed in further detail in the Case Study.

Wash After Carbonizing

The fabric may be washed after carbonizing or it may go directly to fulling. This will produce a clean fabric, free from processing oils and dirt with impurity levels less than 2 percent. Detergents, soaps or solvents are used to remove substances imparted during the carbonizing process. The carbonizing process produces about 0.2 pounds BOD per thousand pounds of cloth (ptpc) and accounts for only 1 percent of the total BOD, most of it being contributed by the breakdown of the burrs and other vegetable matter trapped in the wool. The equalized waste will typically have a pH of 3-4 with 100 mg/l BOD, 4000 mg/l total solids and 3000 mg/l sulfate.[27]

Losses: Scum may be formed from the soaps, oils, and solvents. This could cause unsightly stains, odorous conditions, may reduce oxygen transfer and could be difficult to incinerate. Foam may be produced by both non-biodegradable and biodegradable detergents. The foam should be reduced by either water sprays or special defaming agents since it could also cause stains and odorous conditions.

Fulling

The fulling process crushes the fibers and causes them to creep into a natural self-tightening mat. The original weave becomes obscured and the result is a dense, three dimensional durable fabric. There are two common methods, alkali and acid. In the alkali fulling, the cloth is saturated with water and soap and rubbed between slow-revolving rollers to produce the amount of shrinkage desired. In some processes hot water is used. In other processes, the friction of the rollers generates sufficient heat. The soap provides the needed lubrication and moisture for proper felting action. The heat and mechanical action produces the shrinkage. In acid fulling an aqueous solution of sulfuric acid, hydrogen peroxide and a small amount of a metallic catalyst is used. The general practice for both methods is to saturate the fabric first in the fulling machine with heated fulling solution to achieve uniform distribution. Often penetrating agents, tar removers, such as Naphtha, mineral spirits or stoddard solvent, and other materials are added with the soap solution to remove marking materials used in the field to identify animals. When acid fulling, synthetic detergents and penetrating agents stable to acids are used.[28] Typically fulling and scouring operations represent a single process, but sometimes the wool must be washed after fulling.

Losses: When alkali fulling is used, the waste stream will contain soap or detergent. The soap losses contribute to the BOD in the waste waters. When acid fulling is used, sulfuric acid, hydrogen peroxide and metal catalysts may be present. Additionally, penetrating agents such as mineral spirits and naphtha are lost to the atmosphere.

Desizing

Prior to scouring, starch, gum or gelatin type substances applied during the sizing process are removed in a process called desizing. Desizing breaks down the size compounds so that they are soluble in water without damaging the fiber. The size is broken down using either mineral acid or enzymes. Acid desizing uses a solution of dilute sulfuric acid to hydrolyze the starch and render it water soluble. Enzyme desizing, on the other hand, uses vegetable or animal enzymes to decompose starches to a water soluble form. In both cases the desizing agent is applied to the fabric by a rolled pad and then steeped in storage bins or steamers. After the size has been solubilized, the solution is discarded and the fabric is washed and rinsed.

Losses: The starch used in the sizing process contributes heavily to the BOD of textile waste water. The desizing process produces 50 pounds of BOD ptpc and contributes more than 50% of the total BOD when starch is used for sizing. Minimal operation in dyeing vessels. In addition to the dye, other dyebath components include water, energy (heat), chemical auxiliaries, and agitation. Chemical auxiliaries are dyebath assistants which might include salts, mordants, leveling agents, acids, bases, wool protective agents, and UV absorbers. These materials play a role in the final color quality of the wool fiber. Depending on the dye used, wool dyeing can occur under acid, neutral, or slightly basic conditions. Figure 12 shows a graphical representation of a dyeing process for wool fabric by use of acid dyes. Acid dyes are widely used in wool coloration. The dyeing process within the dyebath occurs as follows:[29]

1) The dye migrates from the solution to the fiber interface, accompanied by adsorption on the surface of the fiber.

2) The dye diffuses from the fiber surface toward the center of the wool fiber.

3) Anchoring of the dye molecule occurs by ionic bonding, covalent bonding, or other physical forces.

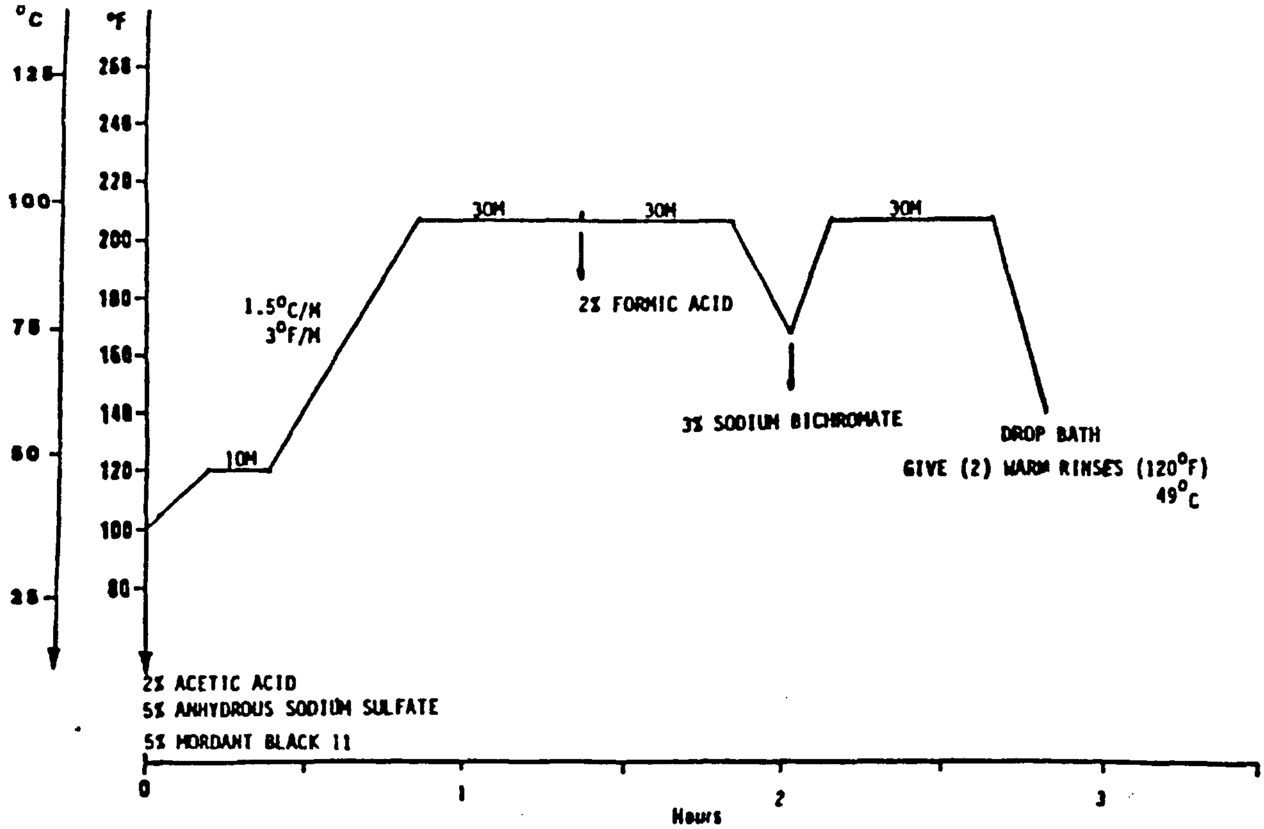
As a batch process, coloration is accomplished in the dyeing vessel by the circulation of the dye through the fiber (eg. pump or propeller) or circulation of the fiber material through the dye (eg. Beck vessel) to insure even uptake of the dye and level dyeing of the wool.

Dyeing Processes

The wool dyeing process occurs either at the stock, top, yarn, or piece stage. Occasionally coloration occurs at the final garment stage. Figure 13 represents the wool processing stages where dyeing occurs within the industry, while Figure 14 graphically depicts some common wool dyeing processes which are described below:

<u>Stock Dyeing:</u> Stock (wool fiber) is dyed in a pressure kettle or atmospheric vessel such as a vat.

<u>Top Dyeing:</u> The top (combed wool slivers) are dyed prior to yarn formation in a dual purpose (i.e., atmospheric or pressure) dyeing vessel. Fibers for worsted fabric are usually dyed in this manner.



Procedure:

- Set bath at 38C (100F) and add:
  - 2.0% Acetic Acid (56%)
  - 5.0 anhydrous Sodium Sulfate
  - 5.0% C.I. Mordant Black 11
- Circulate for 10 minutes at 49C (120F)
- Raise temperature in 30 minutes to 100C (212F)
- Run at 100C (212F) for 30 minutes, then add 2.0% Formic Acid (pH 3.5-4)
- Run for 30 minutes at 100C (212F)
- Cool to 77C (170F); add 3.0% Sodium Bicarbonate
- Raise temperature rapidly to 100C (212F)
- Run at 100C (212F) for 30 minutes
- Cool to 60C (140F)
- Drop bath
- Give two warm rinses 49C (120F) (original volume)
- Drop bath

Figure 12: An example of Exhaust Dyeing Wool Fabric with Acid Dyes at 30:1 Liquor Ratio utilizing a Beck Machine (Source: Kulkarni, S.U. et al, Textile Dyeing Operations, Noyes Publications, 1986, P. 326-7.)

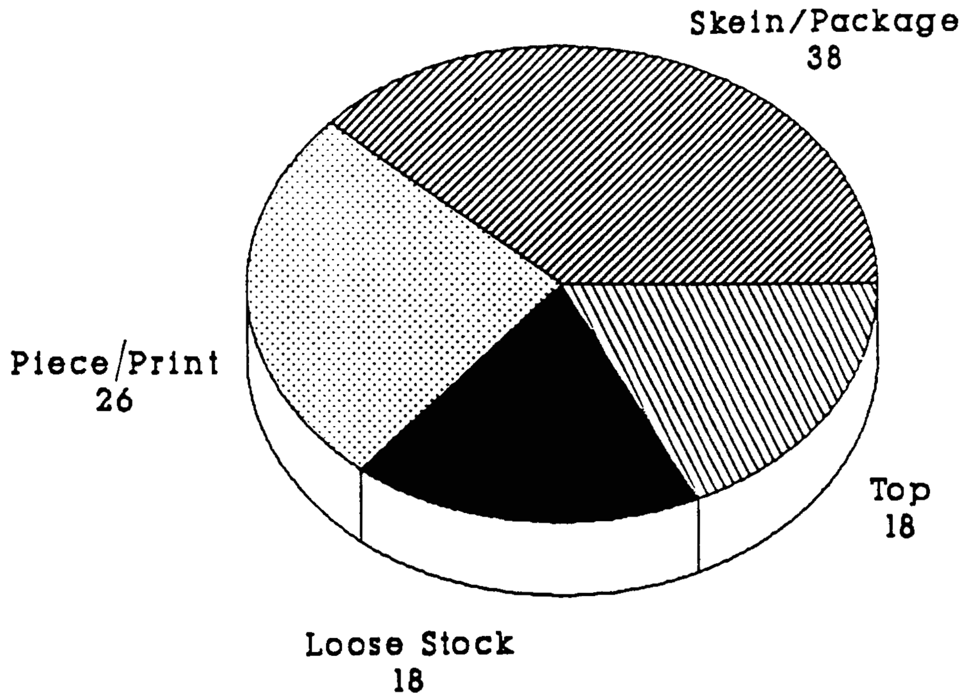


Figure 13: Stages of Wool Dyeing
(Source: IWS, 1986.)

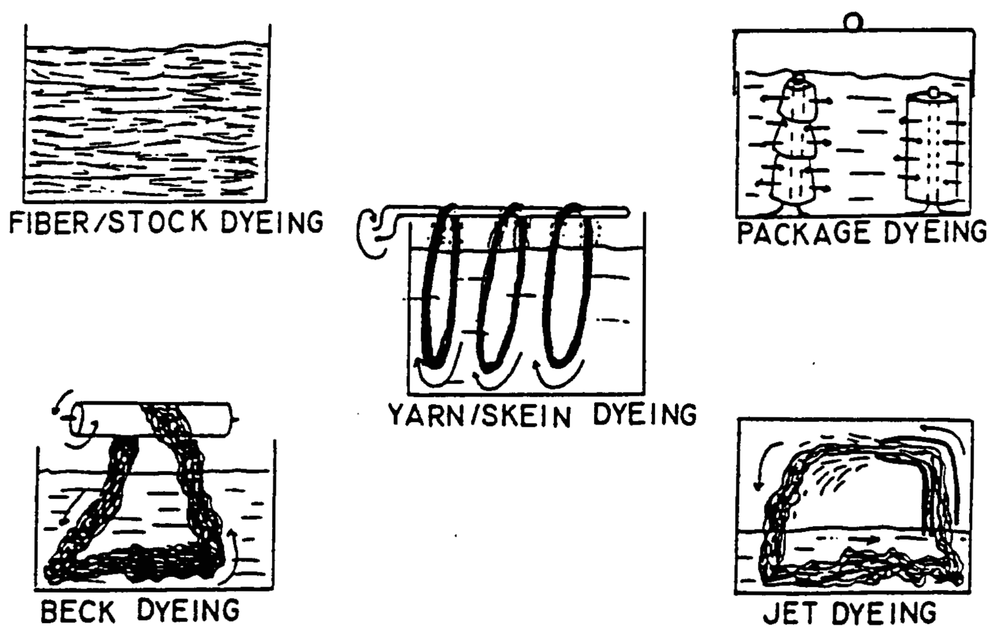


Figure 14: Graphical Representations of
Some Wool Dyeing Processes.
(Source: Needles, Howard L. Textile Fibers,
Dyes, Finishes, and Processes, Noyes Publications, 1986,P.18)

Package/Skein: Package dyeing is the dyeing of yarn within a pressure vessel. This method is the most common way of dyeing yarns. The yarn is tightly wound onto cones or spools. Dye liquor is pumped through the yarn. Skein dyeing is accomplished by placing loose turns of yarn on frames and immersing them in an atmospheric vessel containing a dyebath. Yarn is dyed at this stage to enable fashionable stripes, plaids, and blends with different colored yarns during the weaving process.

Piece Dyeing: Piece dyeing occurs at the fabric stage (a fabric is constructed from yarn material). This method gives the manufacturer maximum flexibility for his inventory to meet large or small demands for a given color as fashion requires.[30] Piece dyeing may involve rolling the wool onto a perforated cylinder which is lowered into a dye vat. The dye bath is pumped into the central cylinder and forced out through the rolled wool fabric until the desired shade is achieved. Piece dyeing may also be done by continuously rotating the wool fabric through the dye vat.

Losses: The dyeing process utilizes chemicals which contribute to the woolen mill effluent. In many instances, chemical inputs are used in larger amounts than are necessary and end up as a "loss". These losses contribute to BOD, COD, color, metals, dissolved salts, and hydraulic load. Currently, there are four critical problem areas causing concern.[31] These areas are as follows:

1) Color in effluent: It is estimated that 15% of the total world production of colorants is lost (128 tons/day) in the synthesis and processing of colorants. The main source of this loss is to be found in residual liquors, because of the incomplete exhaustion of dyes. Since wool is a protein fiber with many reactive groups, it tends to enable good exhaustion of the dyebath when compared to other natural and synthetic fibers.

2) Heavy metals: Metal ions originating from mordants, metal complex and chrome dyes can pose a toxicity problem to biological systems. In wool dyeing, chrome in mill effluent is of much concern. About 70% of wool dyeing currently involves the use of heavy metals, mainly chromium.[32]

3) High concentration of dissolved salts: Salts are necessary in the dyebath for

proper reaction rates and level dyeing. They are often used in large quantities and can have toxic effects on biological systems. Salts such as ammonium sulfate and sodium sulfate are widely used in wool dyeing.

4) Biological Oxygen Demand (BOD)/Chemical Oxygen Demand (COD): Since many of the chemical auxiliaries don't bind to the woolen fiber, they become part of the waste stream in addition to excess dye. Dye, leveling agents, acids, lubricants, surfactants, and other auxiliaries contribute to BOD/COD. In textile mill effluent, the dyeing process contributes 10 - 30% of total plant BOD.[33] For example, acetic acid is widely used in wool dyeing and has a high BOD impact. Its use may cause 50 - 90% of the dye house waste BOD.[34]

- **Dye Rinsing and Extraction**

The rinsing of the wool occurs within the dyeing vessel. Warm or cold water rinses are added at the end of the dyeing cycle to bring the wool to room temperature, and remove excess dye and chemical auxiliaries.

The rinsed dyed wool contains excess water which must be removed before drying. Squeeze rollers or centrifugal extractors are used to physically extract water from the wool.

Losses: Heat, dyestuffs, and chemical auxiliaries are released to the process drain during the dye rinse. Depending upon the method of dyeing used, considerable flock can be generated. This flock can be retrieved from dyeing vessel after the vessel has been emptied of the rinses. Water, trace quantities of dye, and small quantities of flock result from the extraction process.

4.5 Finishing

The aim in finishing is to produce a fabric that the customer will find attractive in handle, appearance and weight. In the finishing processes, the amount of water used and the layout of flow within any one process varies widely from plant to plant.

Drying

After rinsing and extraction, the fabric is dried. The fabric is first squeeze rolled to remove moisture and open up the fabric width. Then it proceeds through a cloth dryer where it makes multiple passes through steam heated coils with heated air blown through or around the material to be dried. The warm, moist air is then exhausted to the atmosphere. The fabric is then flat or roll folded. The energy in the dryer exhaust stream is in two forms: 1) the sensible heat of the entire hot stream, and 2) the latent heat of the water vapor in the stream. Recently, industrial drying has become even more energy-intensive, since water has replaced organic solvents.

Losses: The energy in the dryer exhaust is usually not recovered and as a result, energy costs make up a large percentage of the total cost of drying. The efficient recovery of this energy is the most significant energy conservation problem facing the drying industry today. Lint losses from the dryer screens are minimal.

Napping

In the napping process the short fibers of the fabric (called the "nap") is raised on the fabric by means of thousands of little steel hooks on a roller that scratch the surface. The raised nap is then trimmed or sheared. Napping can either occur before or after the dryer, thus lending the names, wet and dry napping respectively.

Losses: The waste fiber from the napping process is sold to plants that use flock for automobile fabrics. Other losses from this process include heat and lint.

Decating

The decating or semi-decating process is a shrinking process that gives the fabric stability. The wool is tightly wound onto a perforated cylinder and layered between a cotton leader with steam being passed through it. By the use of heat and pressure, a permanent luster is applied to the fabric. Decating also softens the hand, reduces shine and helps even the set and grain of the cloth.

Losses: Losses from this process are minimal. They include trace amounts of dilute formic acid, softener and heat.

Steam Sizing

In the steam sizing process the fabric is pressed between hot plates and then dry-steamed. This process shrinks the cloth to the proper dimensions in order to meet the specifications.

Losses: In the steam sizing process waste heat is lost and minimal amounts of lint are lost. The lint is typically disposed of and not recycled.

Inspection

Fabrics are given a final inspection prior to shipping. They are typically visually inspected on a perching stand for foreign matter and other defects in the fabric. They are classified as first quality or second quality depending on customers' specifications and/or industry standards.

Losses: Heat is released during the inspection process. This process requires minimal physical energy but due to the nature of the job, could cause back problems.

4.6 Ancillary Operations

Ancillary Operations to the wool manufacturing process include the power plant, waste water management, solid waste management, air emissions management, receiving, shipping and storage of raw materials and finished goods, and maintenance and cleaning operations.

Steam Management

Boilers in the range of 10MM Btu/hour to 100MM Btu/hour supply heat in the form of steam to a variety of processes in the mill. In New England, where the case study in this guide was conducted and where over 35% of U.S. wool manufacturing facilities are located,[35] such boilers are typically fueled by #2, #4 or #6 oil. In other regions of the country, natural gas may be more typical. For oil fired boilers, oil consumption is in the range of 10,000 to 100,000 gallons of fuel per week, or 500,000 to 15,000,000 gallons annually. At current delivered prices of #4 and #6 oil in New England of $19/Bbl (1 Bbl = 42 gallons) and $25/Bbl, annual fuel costs of $200,000 - $300,000 might be expected.

Steam is used in the mill for heating the water in the dye baths, the washers and in rinsing operations, for heating the air in the carbonizer and the air for the dryer. Steam is also typically used to heat the manufacturing facility. The major consumers of steam are the pressurized dye baths which operate under pressure at temperatures of 265°F.

Losses: Fuel losses may occur as a result of a tank leak, spill or overflow. Additionally, poorly insulated steam pipes or malfunctioning "steam traps" will cause heat losses. Heat is also lost when hot air from drying and carbonizing operations is vented to the atmosphere and when hot water from dying and fulling is discharged. Losses to the air of SO_2, NO_x, VOC's, CO and particulate matter from industrial boilers are regulated under the Clean Air Act. Equipment for control of these emissions may be specified by the mill's air permit.

Waste Water Management

In the wool fabric manufacturing process, beginning with raw scoured wool and ending with dyed woven fabric, a large amount of water is consumed. Two to seven times the volume of water per pound of product is discharged which is more than any other class of textile manufacturing. This high discharge rate is principally due to the many low temperature rinses required to remove natural contaminants, carbonizing process chemicals and the soaps from the fulling operation.[36]

Waste water is typically directed by piping or open pits from the various process operations to a centralized collection area. Sometimes substations collect the water ahead of the central pretreatment plant to adjust the pH prior to entering the main pretreatment area. Whereas in the main pretreatment area, the water is defoamed, the pH is further controlled and the flock is removed from the water. Flock and foam can clog and foul biological treatment systems and they are also aesthetic problems. High or low pH can damage treatment plants or inhibit the bacteria used in the biological process.

Typically, the deflocking operation is present ahead of the main pretreatment area to remove wool fibers. This consists of a slanted perforated metal sheet over which the water stream is passed. The water falls through and the fibers remain on the surface. The surface is slanted and is sufficiently slippery that the fiber load slides off into a collection area as it builds up. Fibers may be dried and recycled or disposed of depending on cost. After removal of fiber, water may pass into a tank where a defaming agent is added.

In the treatment tank, pH can be continuously monitored electronically. In such systems, sodium hydroxide, soda ash or hydrochloric acid is dispensed in accordance with the monitoring data. An alternative approach involves dispensing a flow rate dependent quantity of magnesium hydroxide to the treatment tank. This process does not require electronic feedback since the magnesium hydroxide provides sufficient buffering to bring typical wool acid wastes to the required pH without monitoring. The automatic control process using magnesium hydroxide requires less manpower to operate and it maintains the pH in a tighter, more consistent range. However, this automatic control requires a 45 minute residence time and thus must be accomplished in a baffled flow through tank with capacity to hold 45 minutes of maximum flow rate discharge.[37]

Following these operations, organic wastes are removed by biological treatment which may be accomplished at the local Publicly Owned Treatment Works (POTW) or at the mill. In both cases, traditional biological treatment processes are employed.

Losses: Wool Scouring operations which remove the lanolin and grease from the sheep prior to processing are a specialty operation. They use little water but contain exceptionally high BOD loads. Because scouring is typically done off-site, these waste waters were not considered in the present study. Wool finishing waste waters from the processes of yarn formation through weaving, dyeing, and finishing are typically low in concentration of BOD_5, COD, TSS, oil and grease. However, due to the volume of water discharged, total loadings are high compared to other textile processing industries. Other heat losses are also incurred in this process.

Wash After Fulling

Fabrics may be washed with detergents, soaps, or solvents to remove natural or artificial waxes, oils, tints, or other substances in preparation for dyeing. This is either accomplished by a continuous or cascade washing cycle or a single cycle which typically uses a Dolly Washer. In cascade washing, approximately 36 to 40 cuts or pieces of fabric sewn together are added to a solution of soap and soda ash and then are rinsed in series of water baths. After about 8 or 12 cuts, defoamer is added to the solution. After the final rinse the fabric is squeeze rolled to remove the water prior to drying. In the Dolly washer the washing process is accomplished in one step. The wash after fulling process produces 75 percent of the total BOD (150 pounds ptpc), most of it being contributed by the soap and the carding oil. Soda ash is used to provide alkalinity, in the case of acid fulling only, and the equalized waste will have a pH near 11 with 9,000 mg/l BOD, and 18,000 mg/l total solids.6

Losses: The BOD waste may be treated with alum or sulfuric acid or calcium chloride and steam to provide 80 percent BOD reductions. The soap, grease or metallic soap possibly may be used in other products or they may be burned if desired. The effluent would still contain appreciable BOD. The waste may also be pumped into the municipal anaerobic digester to produce methane gas. The final rinse waters may be reused as the first rinse in the next cycle. Such wastes also may be evaporated and incinerated but the sodium hydroxide and carbonate in the ash may be a slight problem. Sulfuric acid can be used for fulling in place of soap and has been demonstrated to produce an appreciable reduction in BOD loads. The acid may be more easily recovered and re-used than the soap.

4.4 Dyeing

Wool dyeing is a complex chemical process which normally takes place as a batch traditionally monitored pollutants, phenols, chromium, sulfide and color tend to be high in both concentration and total mass. Wool processing waste waters present difficulties in treatment and pretreatment processes. This is due to fluctuation in batch operations and frequent changes in product.[38]

Materials Acquisition and Storage

Wool manufacturing involves a wide variety of process chemicals used in various operations in addition to the raw wool. Raw wool is delivered and handled in bales, by forklift until it is broken down for the blending process. Raw wool may be re-baled after blending and oiling to be sent out to be made into yarn or for temporary storage.

A limited number of process raw materials are purchased and stored in bulk storage tanks. Typical bulk storage chemicals include sulfuric acid used in carbonizing, formic acid used in dying and magnesium hydroxide used in waste water neutralization. Sodium hydroxide, soda ash, soaps, tar removers, dyes and other process chemicals are purchased and stored in drums or by pallet load, and a variety of maintenance materials may be handled in yet smaller quantities. Finished goods are stored on rolls of approximately 100 yds. length until shipment for sale.

Losses: Losses in material handling and storage can occur due to poor housekeeping and improper handling of containers, causing breakage and spills. Improper storage conditions can result in product spoilage. Insufficient control over ordering and inventorying can lead to redundancy and obsolescence.

Solid Waste Management

The principal solid waste generated by the mill is wool fiber. Fiber waste is produced in various stages of processing and in varying degrees of contamination and it may contain vegetable matter, extraneous non-wool fibers from packaging materials and maintenance operations, and miscellaneous wastes. Wool fiber is virtually 100% recyclable. The highest value for reuse is realized when wool wastes are carefully segregated according to potential for reuse.

Losses: Since wool wastes are recyclable, losses are principally due to lack of sufficient waste stream segregation, or contamination of wool wastes with vegetable matter, miscellaneous trash of foreign fibers (cotton , polyester). Although improperly segregated wastes are typically still recyclable, the cost of recycling may diminish their value.

5.0 Losses in the Wool Fabric Manufacturing Industry

5.1 Identification of Losses

After the process functions are identified using process flow diagrams (PFD), energy and materials inputs and losses are identified for each process step and added to the diagram. Inputs include raw materials, energy in the form of electricity or heat, water, cleaning agents, lubricants, and other process aids. Losses include wastes for disposal, spills, accidents, losses to volatilization, off-specification or reject products and energy losses. It is important that all inputs are accounted for as some form of output, either by incorporation into the product or as a loss. For some complex processes, further detail may be required to give a better understanding of its functionality.

The Process Flow Diagram is a tool used to obtain a better understanding of process functionality

Once all this information is incorporated onto the PFD, the diagram is verified against the actual operation. This is accomplished by walking through the facility to observe both the functionality and the actual materials and energy inputs and losses. Several walkthroughs at various times may be useful to assure that infrequent operations such as maintenance are included.

Inputs and outputs to each unit process operation, shown with arrows to and from the process operations on the process flow diagram, may then compiled in a table format. The tabulation may be structured to assure that all inputs have been accounted for either as product or losses and to identify the path (air, water, solid waste) by which each loss occurs. Space may be provided on the tabulations for noting additional information useful to the prioritization process, for example, comments indicating employee health and safety concerns, or Activity Based Costing information. This can assist in prioritization and selection of one or more unit processes for further detailed study.

5.2 Prioritization and Selection of Losses

The next step in the Pollution Prevention process is the prioritization of the losses. The goal of prioritization is to separate the "critical few" from the "trivial many".[39] Consider, for example, the common "80/20 Rule" which is used in management, manufacturing and marketing. If applied to pollution prevention efforts it would read "80% of the losses are caused by 20% of the processes". Although this is a generality and not true in all cases, it provides the Pollution Prevention team a focus that "certain process losses exist within our plant which when solved or minimized will make a significant difference to overall plant performance". In general, the team must be creative and diligent in determining the real issues and criteria which should be considered in the prioritization process. There are numerous criteria that can be used to assist in this process. The following list provides some examples, but is by no means comprehensive:

- Cost
- Recovery of energy and other valuable by-products
- Safety Issues
- Increased production efficiency
- Quantity and hazardous properties of losses
- Potential environmental liability
- Treatment and disposal costs
- Regulatory compliance issues

Once the criteria for ranking the losses is established, group decision making tools are next used to prioritize the losses. These are summarized in Figure 15. The most commonly used are the **Relative Ranking Method**, and the **Nominal Group Technique.** They are described below. It is important to remember that any one or a combination of these tools can be used in making the decisions.

In the **Relative Ranking Method**, losses can be rated against criteria such as technology, economics, environmental impact, and health and safety. Their potential significance is ranked in accordance with the individual facility. A simplified rating system such as a [+,0,-] is helpful to assess "relative" impacts. For example, the "+" could correspond to a highly significant loss for which a solution is highly desirable, a "-" for a loss of extremely minor consequence, and a "0" could be assigned to signify neutral or undetermined. Any type of description can be applied to each of the ranking terms, depending on what best suits the situation.

The **Nominal Group Technique** (NGT) is a weighted ranking method that allows a team to prioritize a large number of issues without creating "winners" and "losers"[40]. This type of tool is useful when there is no clear consensus by other criteria of tools as to which items should receive more "weight" than others. NGT tries to give each individual in the group an equal voice in the selection process (see Appendix E for specific example).

FIGURE 15

TOOLS USED IN THE DESCRIPTIVE APPROACH TO POLLUTION PREVENTION

PROCESS	USEFUL TOOLS	SECTION
I. IDENTIFY LOSSES	Process Flow Diagram	3.1
	Materials Accounting	3.1
II. PRIORITIZE/SELECT LOSSES	Activity-Based Costing	6.2
	Selection Criteria	5.2
	Relative Ranking Method	5.2
	Nominal Group Technique	5.2
	Multi-voting	5.2
	Pareto Chart	App. C
III. ANALYZE LOSSES	Cause/Effect Diagrams	5.2
	Data Collection	5.2
IV. GENERATE ALTERNATIVES TO PREVENT LOSSES	Brainstorming	5.2
	Force Field Analysis	App. G
V. SELECT BEST ALTERNATIVE(S)	Screening Criteria	6.1
VI. FEASIBILITY ANALYSIS	Cost/Benefit Analysis	6.2
	Pareto Chart	App. C
VIII. REPEAT PROCESS FOR ADDITIONAL POLLUTION PREVENTION OPPORTUNITIES	Repeat Tools Above	

5.3 Analysis of the Selected Loss

Once the team has selected an important loss or losses for further study, an analysis must be done to better understand the problem and determine root causes. The problem must be adequately understood before "alternatives" for resolving the "loss" are proposed.

Root causes of loss may be widely varied, and analysis techniques must be suitable to the nature of the problem. Usually, the first step in loss analysis will be a simple common-sense observation of the process in operation, coupled with discussions with equipment operators, maintenance personnel, and other plant personnel to identify problems related to good operating practices and to generally develop an understanding of the nature of the problem. Some initial operating practices which should be considered are:

- Inventory Control
- Scheduling
- Spill and Leak Prevention
- Maintenance Operations
- Process Documentation
- Training

Technological and operational factors should also be considered. These may include problems with equipment design or operating parameters, materials related problems, and operational procedures. A **Cause and Effect Diagram** is a method for identifying causes of a problem. This technique is used to identify the cause of "losses". The detailed cause and effect diagram is frequently called a "fishbone" diagram since it resembles the skeleton of a fish. It is also referred to as an Ishikawa Diagram, after its originator, Kaoru Ishikawa. When using this diagram, the "effect", or problem, is a desirable or undesirable situation, condition or event, produced by a system of "causes". This can include categories such as materials, methods, manpower, and machinery. Specific causes within each group are listed along the main ribs designating the basic categories. For example, under Materials, there may be categories for "Off-specification", "inadequate supply" or "packaging problems". Different groups may be selected suitable to the particular problem under analysis (Figure 16).

To use this method, a facilitator or moderator is selected to lead the team in the cause and effect exercise. Next, the problem statement or "effect" is determined. Brainstorming is used to identify the possible causes which are recorded on the diagram. Then the most likely cause or causes are selected. This can be done in a variety of ways. Multi-voting can be used, for example, or the facilitator can request that the team members individually select the three most likely causes. The causes with the most votes is selected for further examination. As a cross-check on the voting process, which can at times produce arbitrary results, the team should then verify the selected cause(s). Existing data, experiments, general knowledge of the participants, or other methods may be used.

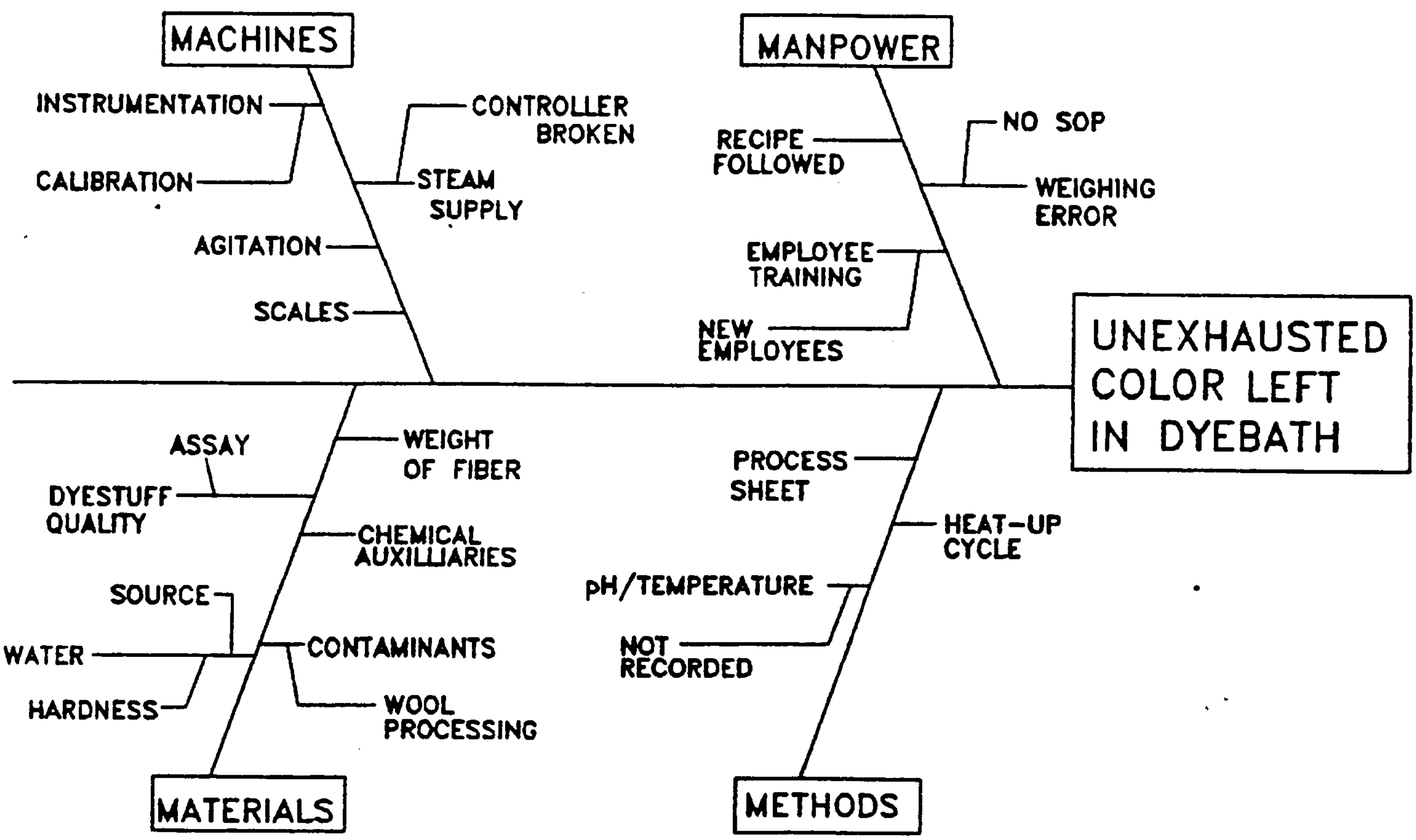
When losses are related to or affected by highly technical process parameters, complex engineering or chemical analyses may further be required to fully understand the nature of physical and chemical interactions resulting in a loss.

The analysis process must be sufficiently thorough to provide an in-depth understanding of the process operation and all potential causes of the loss. In the process of this analysis, it may be tempting to jump to proposed alternative solutions, by-passing the complete analysis process. This temptation should be avoided. Potential solutions should, at this stage, be phrased not as solutions, but as causes, otherwise the complete analysis process may be short-circuited in favor of a less-than-optimal quick fix. For example, in the situation where a problem may exist with operating temperature, the solution of "Install Computerized Bath Temperature Control" or "Train Operators to Measure Bath Temperature" or "Implement Statistical Process Control on Bath Temperature" should not be applied at this stage. Rather the causes of the problem should be considered. For example,the problem statement should be phrased as "Process Bath Too Cool". Potential solutions discovered at this stage should be carefully noted and set aside for use in the process of Generation of Alternatives.

FIGURE 16

CAUSE/EFFECT DIAGRAM

CAUSE & EFFECT DIAGRAM EXAMPLE:
PROBLEM: UNEXHAUSTED COLOR LEFT IN WOOLEN MILL DYEBATH



SUGGESTED READING: Ishikawa, Dr. Kaoru. GUIDE TO QUALITY CONTROL, Quality Resources, White Plans, New York.

6.0 Alternatives to Reduce the Losses

6.1 Generation and Selection of Alternatives

After the loss(es) have been prioritized, selected, and analyzed, alternative proposals are then generated to resolve the problem or loss. Establishment of a cross-functional team is a great strength in generating alternatives. Each team member must be given the opportunity to contribute. The team must be open to all ideas (which may have been generated during a "Brainstorming" session) from its members or outside sources, regardless of how practical or impractical these ideas are initially perceived. One common pitfall to avoid in the process of alternative generation is the "Killer Phrase"[41]. "Killer Phrases" are frequently key factors in stifling creativity and all the benefits that could lead to improved quality, cost savings, higher profits, better morale and a better quality of life.[42] Examples of some commonly used "Killer Phrases" are:

Continuous improvement happens in steps: major breakthroughs do not always occur.

- **"We've always done it another way."**
- **"We tried that before."**
- **"Great idea, but not for us."**
- **"Let's stick with what works."**
- **"If it ain't broke, don't fix it."**
- **"No !"**

These phrases have the ability to inhibit the consideration of good and innovative ideas so their potential merits will never come to light. Organizations which are not on guard against this type of behavior are at a distinct disadvantage in our competitive global market. Creativity is often lost, and there is a good chance that a competitor will generate and implement the same idea at a future date.

The generation of ideas can be fun, creative, and a satisfying part of the problem solving process. Brainstorming is a useful creativity technique that can be used by the Pollution Prevention team to create as many alternatives as possible within a short period of time. This process enables the collective thinking power of the group to create ideas. A benefit of the group approach is that as ideas are offered by individuals, additional related or non-related ideas from other members result. Brainstorming is a catalyst for the team members' creativity. (See Appendix D for more information and suggested readings on this technique).

Once all the alternatives have been generated by the brainstorming process, the team can then systematically select the most promising ones using the same selection tools discussed in Section 5.2 for prioritizing losses. These can include, as discussed, such techniques as Relative Ranking Methods.

The process of identification, selection, and analysis of the losses to generate alternatives focuses the team effort and narrows down choices by the use of an iterative process. By these proven, structured methods, the Pollution Prevention team will achieve positive results. It is important to note when reviewing the results of these efforts that continuous improvement happens in steps: major breakthroughs do not always occur. The team must not be discouraged, but must realize the value of incremental improvements. When the alternatives have been prioritized, the team is **ready to investigate the feasibility of the alternatives.**

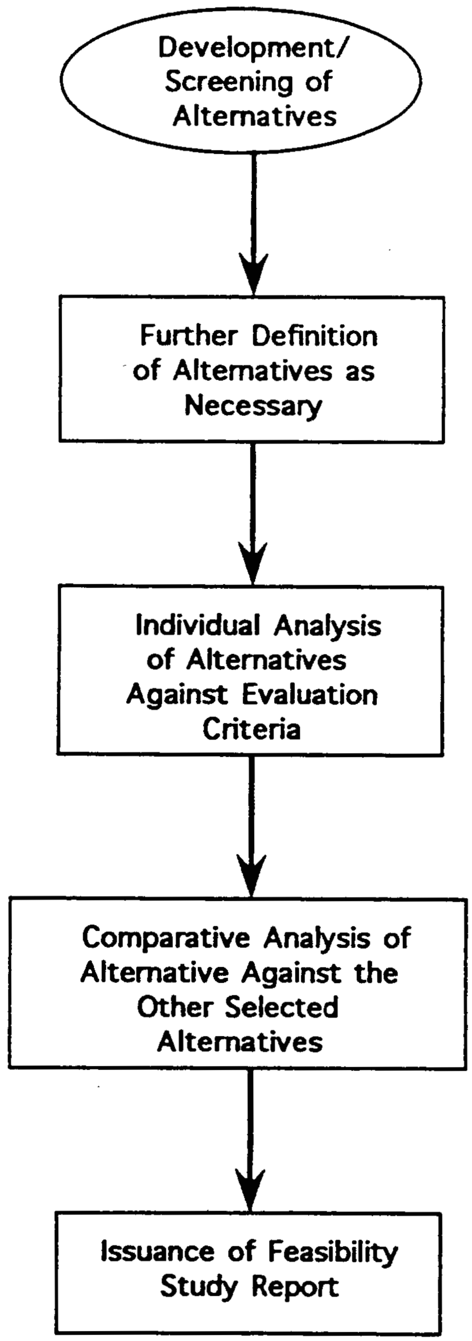
6.2 Feasibility Study

Once the alternatives for the primary losses are selected, a feasibility study is conducted. The alternatives are screened using a procedure that is flexible enough to allow common group decision-making techniques (Figure 17). No matter what group method is used, criteria such as potential effectiveness, ease or ability to implement, and cost are included. This process reduces the number of alternatives to those which appear to be the most favorable for implementation. Typically, the primary focus is on effectiveness factors at this stage. After the initial screening has identified the most likely alternatives, the selected alternatives are further examined in more detail using the following evaluation criteria:

- cost
- potential regulatory compliance
- liability
- workplace safety
- technical and cultural feasibility
- implementability

The remaining alternatives are then compared, and a selection is made that provides the best balance of loss prevention and engineering reliability with cost.

Figure 17: FEASIBILITY STUDY



Activity Based Costing

When considering the costs associated with a pollution prevention project, it is essential that all costs associated with implementing the project be compared with all costs of **not** implementing the project. Traditional costing methods, which rely solely on the consideration of direct costs associated with a project, do not provide adequate estimates of the costs and savings of pollution prevention projects. Many of the costs typically associated with a Pollution Prevention project are indirect costs. Traditionally only direct costs are analyzed in project cost assessments.[43] Direct costs include labor, raw materials, capital equipment and waste disposal. Indirect costs, such as waste treatment, permit costs, pollution control equipment operating costs and liability are often ignored. Costing projects without consideration of the indirect costs can lead to distortions in actual cost and, consequently a project may look more or less financially attractive than it actually is.

Overhead costs can account for up to 45% - 55% of a company's costs. In traditional costing methods, overhead is distributed evenly among processes. An alternate method of costing, called Activity Based Costing (ABC) is designed to assign overhead and indirect costs appropriately among activities. In ABC, each overhead and indirect cost is analyzed to determine which activities are driving it and these costs are then distributed to the processes in appropriate proportions.

ABC allows a company to more rationally assess the costs of the losses associated with each process step. Using ABC, the costs and benefits of each alternative loss reduction can be more adequately evaluated and prioritized.

Many companies have switched from traditional accounting systems to ABC to determine the cost of their products. In this context, ABC is used as a management tool to trim waste, improve service and provide a guide to the achievement of continuous cost improvement by identifying the sources of the greatest proportion of product costs.[44] The same costing principles are applied to pollution prevention projects to obtain accurate actual costs of manufacturing losses.

In order to assess the costs as accurately as possible, a multidisciplinary team approach is required. The team should include members with access to a wide variety of different kinds of information and knowledge about the processes. Assessing costs can further involve interviews with many different people in the facility, for example, the purchasing, materials control, quality assurance, production, maintenance, environmental, and health and safety functions may all contribute different kinds of cost information to a process cost evaluation.

Frequently precise cost data is not immediately available when ABC is initially implemented. However, when inputs are obtained directly from the functional areas contributing to the cost, a "best effort" estimate will often provide adequate information. Use of such "best effort" estimates carefully reviewed for "sensibility", frequently provides a quicker and more cost effective means of targeting appropriate cost reductions than lengthy detailed cost data gathering.

Two pro-forma examples of assigning activity based costs in a woolen mill are shown in Figures 18 and 19. In evaluating loss reduction alternatives, activity based costs should be evaluated based on the operation as it currently exists and based on the operation as potentially revised. This cost difference is used to make comparisons between competing opportunities and alternatives, and to evaluate potential return on investment for the project.

Dry Process Example: Blending and Oiling
Figure 18

1. List Cost Factors

a. Energy
Electricity to fun feeder chute, material transport system, blender, pumps

b. Materials
Water
Oil
Emulsifier

c. Labor
Equipment Operator

d. Scrap and Rework Cost
Lost fiber (cost of reclaiming or disposal)
Manpower cost to segregate improperly oiled product
Manpower cost to recycle improperly oiled product

2. Evaluate Itemized Costs

a. Energy

E = Total Energy/Year (KW) x Blending Energy Use % of Total Use x $\frac{1}{\text{lbs. wool blended/year}}$ x $/KW = **Energy $ / lb.Wool Blended**

b. Materials

Water = Gallons / lb. Wool Blended x $/Gallon = **Water $ / lb.Wool Blended**
Oil = Gallons / lb. Wool Blended x $/Gallon = **Oil $ / lb.Wool Blended**
Emulsifier = Gallons / lb. Wool Blended x $/Gallon = **Emulsifier $ / lb.Wool Blended**

c. Labor

Labor = Operator Fully Loaded Cost x # Operators/Shift x $\frac{1}{\text{lb. Wool Blended/Shift}}$ = **Labor $ / lb.Wool Blended**

d. Scrap and Rework

Fiber = lbs. Fiber Lost / lb. Wool Blended x $ / lb for Disposal = **Lost Fiber $/lb.Wool Blended**

Segregation = lbs. Improperly Oiled Wool / year x $\frac{1}{\text{lbs. Wool Blended / year}}$ x Manhours / lb. x $ / Manhour = **Segregation $ / lb.Wool Blended**

Rework = lbs. Improperly Oiled Wool / year x $\frac{1}{\text{lbs. Wool Blended/year}}$ x Manhours/lb. x $/Manhour = **Rework $/lb.Wool Blended**

3. Activity Based Cost =

Energy $ / lb. Wool + Water $ / lb. Wool + Oil $ / lb. Wool +

Emulsifier $ / lb. Wool + Labor $ / lb. Wool +

Lost Fiber $ / lb. Wool + Segregation $ / lb. Wool + Rework $ / lb. Wool

Wet Process Example: Carbonizing

Figure 19

1. List Costs

a. Energy

Electricity to run roller drives, pumps, squeeze rollers

#6 Oil to Heat Steam for Oven Heat

b. Materials

Sulfuric Acid

Water

Soda Ash (used in water treatment)

c. Water Treatment Cost

% Wastewater Treatment O&M Costs

% POTW fees

d. Labor

Equipment Operator

% Environmental Staff for TRI Reporting

% Health and Safety Staff for Repiratory Protection Program, Air Quality Monitoring

Manpower to monitor Waste Water During Tank Dump

Carbonizer Oven Maintenance

Cost of Environmental Consultants for Stack Testing, Permitting

e. Scrap and Rework Cost

·Value of Lost Fabric Due to Excess Treatment

Cleaning Cost for Oil Spots on Fabric

2. Evaluate Itemized Costs

a. Energy

E1 = Total KW / Year x Carbonizer KW Use % of Total KW Use x

$$\frac{1}{\text{lbs. Wool Carbonized/Year}} \times \$/\text{KW} = \textbf{Electrical \$ / lb. Wool Carbonized}$$

E2 = Total Bbl #6 Oil Used / Year x Carbonizer Steam Use % of Total Steam Use x

$$\frac{1}{\text{lbs. Wool Carbonized/Year}} \times \$/\text{Bbl} = \textbf{Oil \$ / lb. Wool Carbonized}$$

b. Materials

Sulfuric Acid = Gallons / lb. Wool Carbonized x $ / Gallon = **Acid $ / lb.Wool Carbonized**

Water = Gallons / lb. Wool Carbonized x $ / Gallon = **Water $ / lb.Wool Carbonized**

Soda Ash = Gallons / lb. Wool Carbonized x $ / Gallon = **Soda Ash $ / lb.Wool Carbonized**

c. Water Treatment Cost

WWT = Carbonizer Waste % Total Waste Water x O&M Annual Cost Water Treatment x

$$\frac{1}{\text{lbs. Wool Carbonized/Year}} = \textbf{WWT \$ / lb. Wool Carbonized}$$

POTW = Carbonizer Waste % Total Waste Water x POTW Annual Cost x

$$\frac{1}{\text{lbs. Wool Carbonized/Year}} = \textbf{POTW \$ / lb. Wool Carbonized}$$

d. Labor

Labor = Operator Fully Loaded Cost / Year x # Operators x

$$\frac{1}{\text{lbs. Wool Carbonized/Year}} = \textbf{Labor \$ / lb. Wool Carbonized}$$

Envir = Annual Cost Environmental Dept. x % Effort For Carbonizing x

$$\frac{1}{\text{lbs. Wool Carbonized/Year}} = \textbf{Envir. \$ / lb. Wool Carbonized}$$

(Continued)

Wet Process Example: Carbonizing
Figure 19 (continued)

H&S = Annual Cost H&S Dept. x % Effort For Carbonizing x

$\frac{1}{\text{lbs. Wool Carbonized/Year}}$ = **H&S $ / lb. Wool Carbonized**

TD Labor = Operator Fully Loaded Cost / Year x Hours/Tank Dump x Tank Dumps/Year x

$\frac{1}{\text{lbs. Wool Carbonized/Year}}$ = **T D Labor $ / lb. Wool Carbonized**

Maintenance = Mechanic Fully Loaded Cost / Year x # Mechanics for Carbonizing x

$\frac{1}{\text{lbs. Wool Carbonized/Year}}$ = **Maintenance $ / lb. Wool Carbonized**

e. Scrap & Rework

Fabric = lbs. Fabric Lost / lb. Wool Carbonized x Standard Cost / lb. After Carbonizing

= **Lost Fabric $ / lb. Wool Carbonized**

Cleaning = Operator Fully Loaded Cost / Year x # Operators x

$\frac{1}{\text{lbs. Wool Carbonized/Year}}$ = **Cleaning $ / lb. Wool Carbonized**

3. Activity Based Cost =

Electrical $ / lb. Wool + Oil $ / lb. Wool + Acid $ / lb. Wool +

Water $ / lb. Wool + Soda Ash $ / lb. Wool +

WWT O&M $ / lb. Wool + POTW $ / lb. Wool + Labor $ / lb. Wool +

Envir. $ / lb. Wool + H&S $ / lb. Wool + TD Labor / lb. Wool +

Maintenance $ / lb. Wool + Consultant $ / lb. Wool +

Lost Fabric $ / lb. Wool + Cleaning $ / lb. Wool

6.3 Implementation

Often good ideas obtained during the feasibility study fail during implementation. A number of barriers can stand in the way or discourage the implementation of pollution prevention ideas, such as regulations, management, culture, and economic obstacles. In order to ensure the chosen alternative is implemented, a program must be set up to address each of the following items:

- Obtaining a clear commitment from senior management
- Establishing priorities and goals
- Preparing detailed plans and specifications
- Planning operation and maintenance training
- Documenting the results

To implement pollution prevention ideas, an organization must be established, which is an individual who acts as a single source of authority and makes the recommendations to the upper management. This should be a person who is respected and has established credibility in the company. It would be difficult for an outside consultant to fill this role. This person should be given the authority and support needed to successfully implement the alternative(s). For each Pollution Prevention project, this person would either serve as project manager or appoint a project manager.

To implement the alternative(s), the assigned project manager would select a work team. The line manager for the area should be part of this team if he/she is not the project manager. The work team should also include operators and maintenance personnel who are responsible for the daily area operations. Ideally, the focus of the work team extends beyond the implementation of individual management initiatives in pollution prevention. In the best case, the work teams meet periodically to work out problems in their areas. All are encouraged to submit ideas that may help prevent waste, cut costs or optimize the operation. When problems cross departments, teams can be pulled together from the different operations. It is important that progress is sustained once implementation of a particular alternative has been accomplished. When the novelty of the implemented idea is gone, the gains in that accomplishment should remain. Thus, continued evaluation and refinement of the alternative must take place. Pollution prevention is a fluid process. A scheme or program should be developed to measure the progress. As the competitive environment, technology, or management changes, the company must continue to update and look forward.

Implementation Strategy

The task of obtaining a company-wide commitment to implementing the ideas is critical. Often management supports the concept of pursuing improvement, however, support often quickly vanishes in the face of realization of the amount of money, time, and effort that is needed to implement the Pollution Prevention alternative(s). It is important to delineate the magnitude of change required to move forward with the plan and to balance costs against expected benefits. Therefore, to rank the alternatives with the easiest and lowest cost first, is often helpful. Planning and implementing the shorter term alternatives first is often beneficial since successes provide the continued incentive to move forward. In other words, start with the "Low Hanging Fruit" first, such as housekeeping, and chemical storage. Benefits in these areas can be realized relatively quickly while maintaining the spirit, and a track record of success is established. Both management and the workforce then find it more palatable when moving into the longer-term projects that require greater resources and capital.

7.0 Case Study

The capstone group selected one woolen mill in order to perform a case study in Pollution Prevention. This case study was done following the generic guidance presented in the preceding chapters. The facility selected was visited throughout May, June and July in order to observe the wool manufacturing process. The following sections will illustrate how to employ the Pollution Prevention techniques to identify, analyze, and prioritize each of the unit operation losses. Next the selection process will be illustrated to determine the priority loss(es) and how to use group decision making tools to identify the best alternative solution. Additionally, this study will show how to establish the criteria to perform a feasibility study and implementation of the selected alternative.

7.1 Facility Background

The woolen mill in this case study is one of the largest producers of woven fabrics in New England. It started in the textile business in the early 1900's and continues to grow and be successful in today's economy. Since the early 1970's it has been one of the leading suppliers of fabric to the contract market. The plant currently employs approximately 250 union and nonunion employees. They produce a variety of fabrics for different applications ranging from garments to blankets to office fabric coverings.

The facility considers the one-to-one relationships with older contract customers is their most important obligation, however they also pursue continuous development and penetration into new markets. The facility has recently formed quality problem solving teams. A recent accomplishment was their attack on a continuing plant problem, fluctuation in pH in the waste water treatment plant. This was solved using a team approach with assistance from plant employees. The problem solving method they used is similar to that used in Pollution Prevention. Focussing in on the losses, coming up with alternatives to the problems by working with the employees and upper management, and then implementing the alternative and charting its performance. Continuous improvement in today's economy is the key to a successful business.

7.2 Identification of Losses

Following the generic guideline, a Process Flow Diagram was constructed based on literature and plant records, as described in section 3.0. The Process Flow Diagram was subsequently verified during facility walkthrough tours and through conversations with various plant personnel including representatives from the Health and Safety, Maintenance, Operations and Engineering departments. This process required several tours of the plant, brainstorming sessions, and records reviews. The plant records used included water use records, wastewater discharge volume records, wastewater analysis, purchasing records, fuel use data, energy use data, consultants' air emissions reports, permits and the plant layout.

A simplified block diagram of the complete process flow for the case study facility is shown in Figure 20. Using the block diagram as a guide, the process was broken down into three areas: Wool Preparation/Yarn Formation, Fabric Formation and Dyeing/Finishing. Detailed Process Flow Diagrams for these three areas are shown in Figures 21, 22 and 23. Based on the final Process Flow Diagram, the inputs and losses from each step of the process were identified. These losses were summarized in a table as shown in Figure 24. Since detailed activity based costing data were not available within the time frame allocated for the case study, activity based costs were assigned qualitative rankings of "low", "medium" or "high". This rating was based on information that was available from plant records and plant personnel. These qualitative rankings served as a rough guide in identification of areas of primary interest for further study.

Figure 20: CASE WOOL PROCESS FLOW DIAGRAM

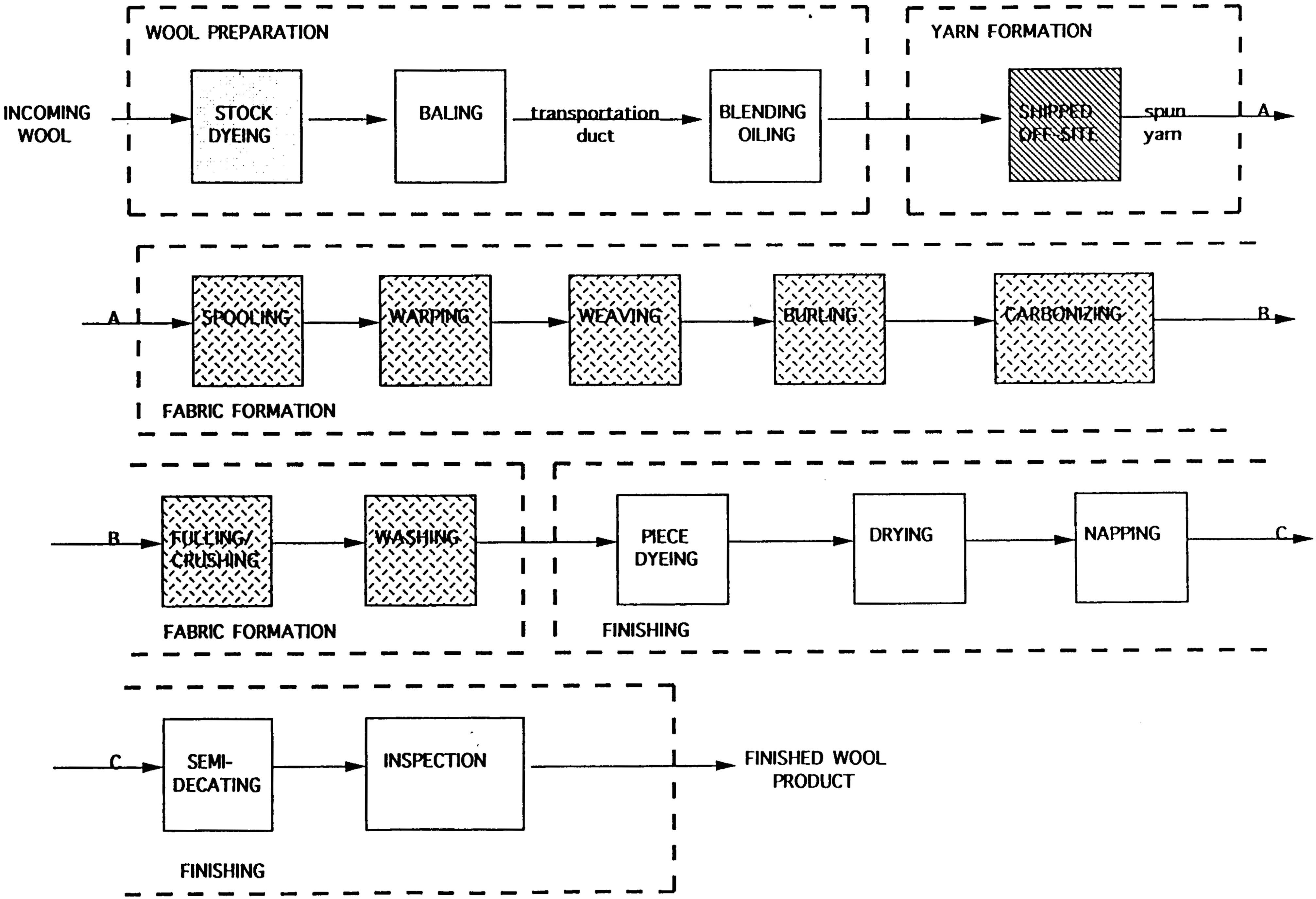
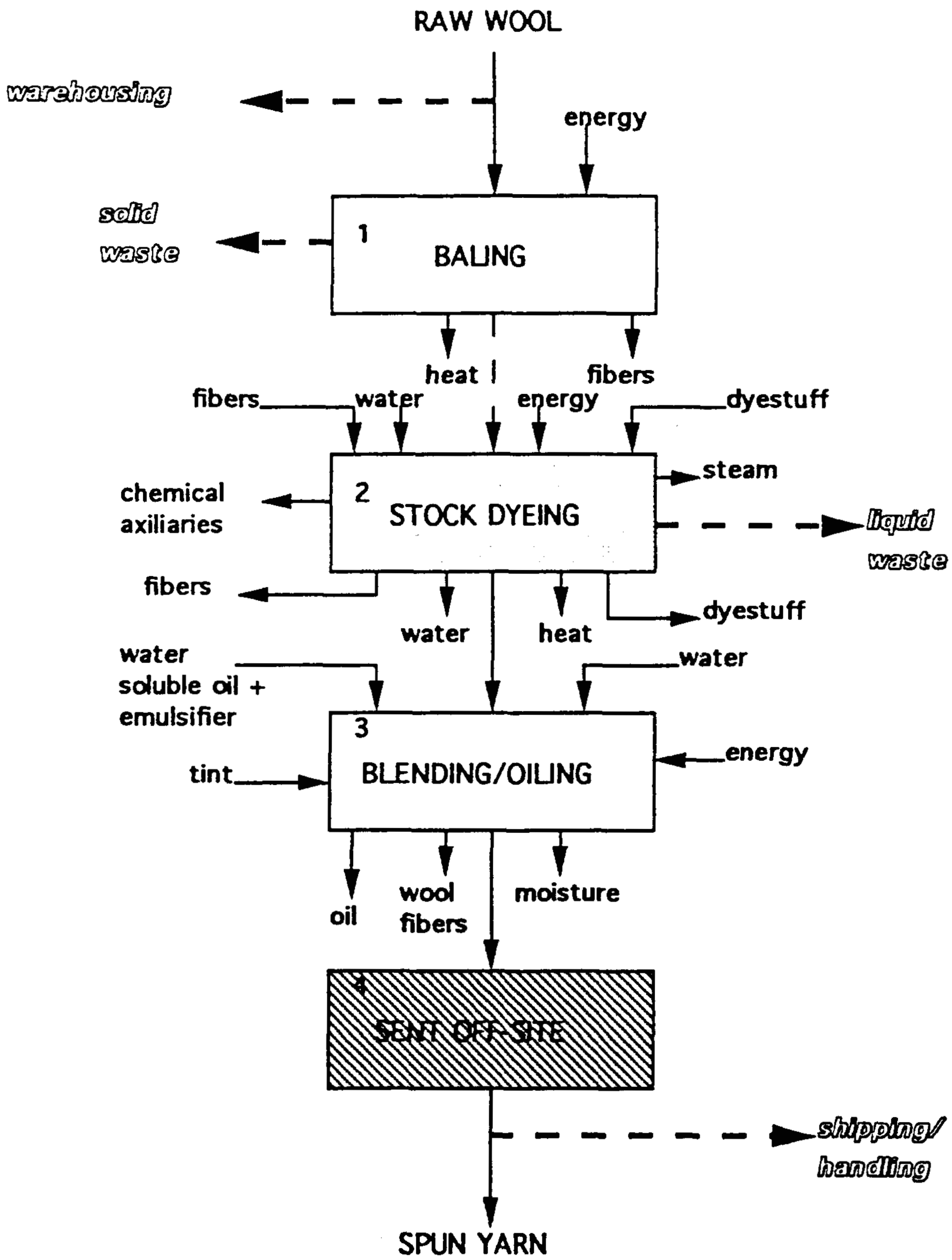


Figure 21: CASE WOOL PREPARATION

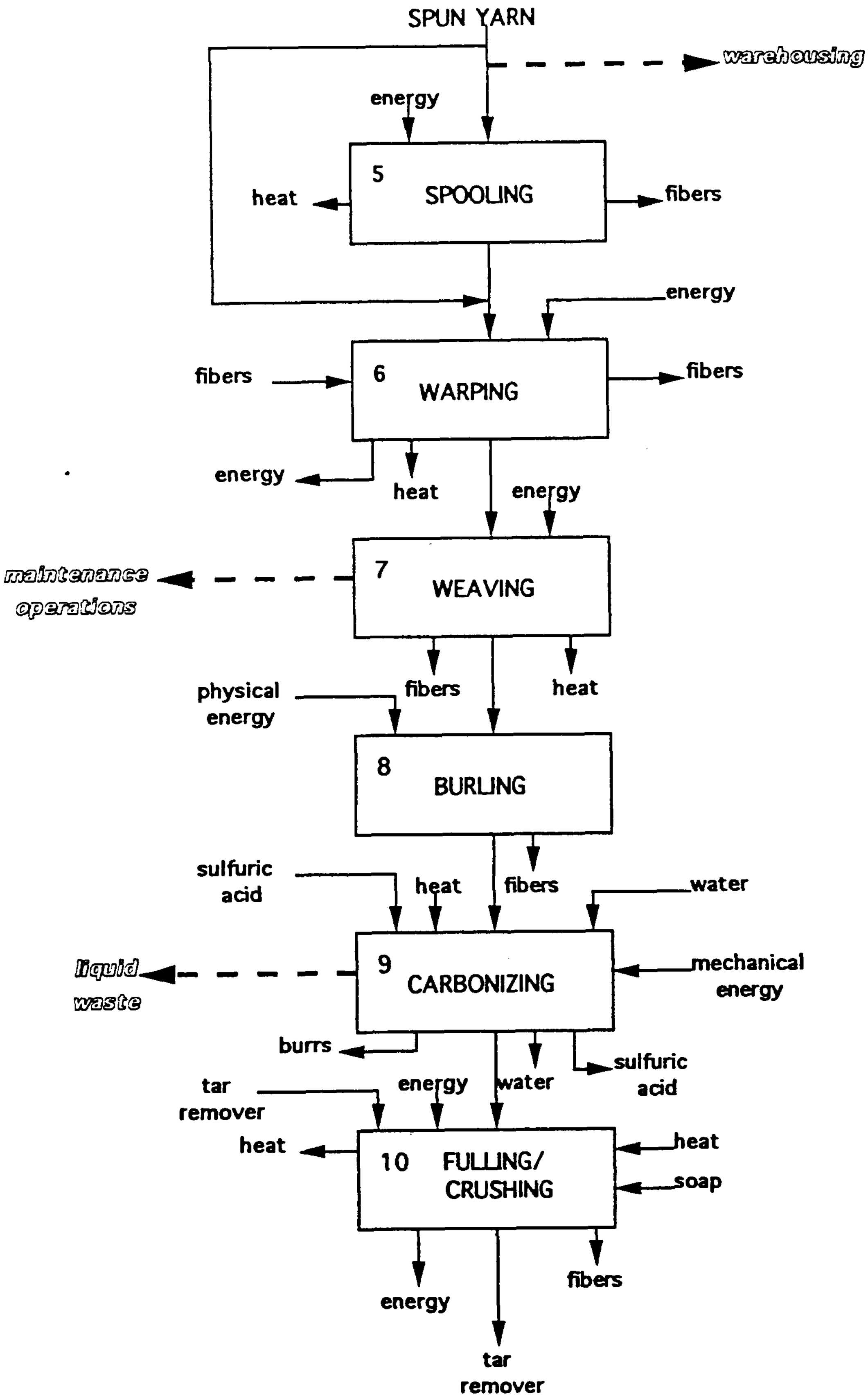


KEY:

☐ Fibers requiring variegated color are stock dyed at the raw fiber stage

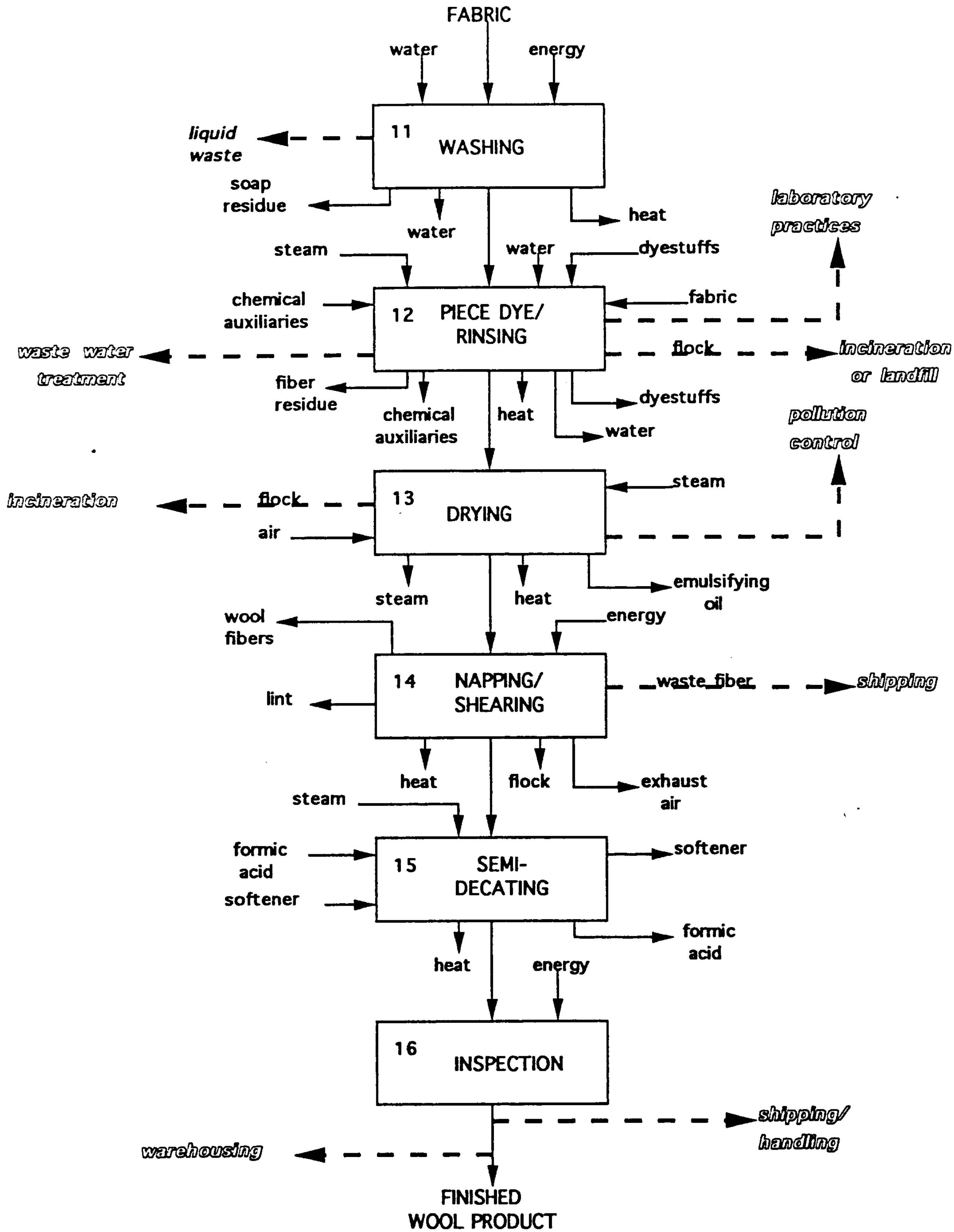
Italic print is *ancillary*

Figure 22: CASE FABRIC FORMATION



Key: Italic print is *ancillary*

Figure 23: CASE FINISHING



Key: Italic print is *ancillary*

Figure 24: CA! .OSSES CHART

NAME/NUMBER OF UNIT	MATERIALS USED	MATERIALS LOST	LOSS TO AIR	LOSS TO WATER	SOLID WASTE	ACTIVITY-BASED COST (losses)
Baling/1	energy	heat, fibers	heat	none	fibers, warehousing	low
Stock Dyeing/2	water, fibers, energy, dyestuff	steam, chemical auxiliaries, fibers, water, heat, dyestuff	steam, heat	water, chemical auxiliaries, dyestuff, liquid waste	fibers	medium/high
Blending/Oiling/3	water soluble oil + emulsifier, tint, water, energy	oil, moisture, wool fibers	oil/water	none	wool fibers	low
Sent Off-Site/4	energy	energy	energy	none	shipping, handling	N/A
Spooling/5	spun yarn, energy	heat, fibers	heat	none	fibers, warehousing	low
Warping/6	energy, fibers	fibers, energy, heat	heat, energy	none	fibers	low
Weaving/7	energy	fibers, heat	heat, maintenance operations	none	fibers, maintenance operations	medium
Burling/8	physical energy	fibers	none	none	fibers	low
Carbonizing/9	sulfuric acid, heat, water, mechanical energy	burrs, water, sulfuric acid	sulfuric acid fumes	water, sulfuric acid, liquid waste	burrs	high
Fulling/Crushing/10	energy, tar remover, heat, soap	heat, energy, fibers, tar remover	heat, energy	tar remover	fibers	high

Figure 24: C.‚.JE LOSSES CHART

NAME/NUMBER OF UNIT	MATERIALS USED	MATERIALS LOST	LOSS TO AIR	LOSS TO WATER	SOLID WASTE	ACTIVITY-BASED COST
Washing/11	water, energy	soap residue, water, heat	heat	soap residue, water	none	medium
Piece Dye/Rinsing/12	water, steam, dyestuffs, chemical auxiliaries, fabric	flock, dyestuffs, water, heat, chemical auxiliaries, fiber residue	steam, chemical auxiliaries, heat, incineration	dyestuffs, water, chemical auxiliaries, heat, wastewater treatment	flock, fiber residue, landfill, laboratory practices	high
Drying/13	air, steam	flock, emulsifying oil, heat, steam	heat, steam, incineration, pollution control	emulsifying oil	flock	medium/high
Napping/Shearing/ 14	energy	wool fibers, lint, heat, flock, exhaust air	heat, exhaust air	none	wool fiber, lint, flock, shipping	low
Semi-Decating/15	steam, formic acid, softener	softener, formic acid, heat	formic acid fumes, heat	softener, formic acid	none	low
Inspection/16	energy	finished wool product	none	none	shipping, handling	low

7.3 Prioritization and Selection of the Losses

Prioritization of the Losses

As described in the guide, criteria must be established in order to prioritize the identified losses. Loss types for each unit process were generally classified as Energy Loss, Fiber Loss, Chemical Loss and Water Loss. The Relative Ranking System and Brainstorming Techniques were used as the tools to rank the losses. Both methods were used to verify that the same results would be obtained. For the Relative Ranking, five selection criteria were established to evaluate the losses, Environmental Impacts, Regulatory Issues, Health and Safety Impacts, Cost of Waste Treatment and Disposal, and Cost of Material Lost to the Process. Each process was evaluated against these criteria and ranked with either a "+", "0" or a "-" (Figure 25). Generally, the "+" denoted that if the loss were eliminated there would be a significant impact, a "0" meant minor impact and a"-" indicated no expected impact. More specifically, the criteria rankings were defined as follows:

1. *Environmental* (E): If this loss was eliminated, how much would the impact on the environment be reduced?

"+" = The reduction in the impact on the environment would be great if this loss was eliminated.

"0" = There would be some reduction in the impact on the environment would be great if this loss was eliminated.

"-" = There would be no reduction in the impact on the environment would be great if this loss was eliminated.

2. *Regulatory* (R): If this loss was eliminated, would there be a reduction in the time spent by mill personnel on regulatory compliance issues or in the fees paid for permits, filing or other regulatory activities?

"+" = There would be a significant impact on the time and/or money spent on regulatory compliance if this loss was eliminated.

"0" = There would be a minor impact on the time and/or money spent on regulatory compliance if this loss was eliminated.

"-" = There would be no impact on the time and/or money spent on regulatory compliance if this loss was eliminated.

3. *Health and Safety* (HS): If this loss was eliminated, would there be a reduction in situations or conditions that are potentially dangerous to worker health and safety?

"+" = There would be a significant improvement in worker health and safety conditions if this loss was eliminated.

"0" = There would be some improvement in worker health and safety conditions if this loss was eliminated.

"-" = There would be no change in worker health and safety conditions if this loss was eliminated.

4. *Cost of Waste Treatment/Disposal* (WT$): If this loss was eliminated, would there be a savings in waste treatment and/or disposal costs? These costs include the chemicals, energy, equipment and personnel required to administer the treatment or disposal process.

"+" = There would be a significant reduction in waste treatment and/or disposal costs if this loss was eliminated.

"0" = There would be some reduction in waste treatment and/or disposal costs if this loss was eliminated.

"-" = There would be no reduction in waste treatment and/or disposal costs if this loss was eliminated.

5. *Cost of the Lost Material* (M$): If this loss was eliminated, would there be a savings in materials costs? This includes the cost of lost wool, chemicals or energy.

"+" = There would be a significant savings in materials costs if this loss was eliminated.

"0" = There would be some savings in materials if this loss was eliminated.

"-" = There would be no savings in materials if this loss was eliminated.

Figure 25

Relative Ranking of Process Losses
Case Study Mill

Process/Associated Loss	Source of Loss	E	R	HS	W$	M$	SUM
STOCK DYEING							
Chemical Loss	Dyestuff additions are inconsistent.	+	+	0	+	0	+3
Energy loss	Heat from spent bath is not recovered.	0	-	-	-	+	-2
Water Loss	Kettles are flushed until water runs clear. No measurement or control.	0	-	-	+	-	-2
Fiber Loss (flock)	Flock left in kettle after dyeing.	-	-	-	+	0	-2
WOOL PREP							
Oil loss	If wool is over-oiled, it is processed again to remove excess oil.	-	-	-	0	-	-4
Energy loss	Re-processing requires added energy.	0	-	-	-	0	-3
Fiber loss (flock)	Fibers lost on open conveyor or clogged in transport system.	-	-	0	-	0	-3
YARN FORMATION	This process is performed off-site at the case study facility.						
Energy loss							NA
Fiber loss							NA

Process/Associated Loss	Source of Loss	E	R	HS	W$	M$	SUM
FABRIC FORMATION							
Fabric loss (reject/rework)	Yarn breaks in weaving cause reject work. This leads to more work in burling which could result in more cases of carpal tunnel syndrome in the workers.	-	-	+	0	+	0
CARBONIZING							
Chemical loss	Vapors from the acid bath and smoke from the carbonizer are released to the environment and inhaled by workers.	+	+	+	+	0	+4
Energy loss	Heat escaping from carbonizing unit.	0	-	-	-	+	-2
Fabric Loss (reject/rework)	Oil builds up inside carbonizer and drips on fabric.	-	-	-	0	+	-2
FULLING							
Chemical loss	Mineral spirits vaporize; under CAAA, controls may be required in the future.	+	+	0	-	+	+2
Energy loss	Mechanical energy.	0	-	-	-	+	-2
WASHING							
Energy loss	Mechanical energy of washers and pumping water.	0	-	-	-	+	-2
Water loss	Clean water from last wash is not reused in initial wash.	0	-	-	+	0	-1
Fiber loss (flock)	Fibers clog waste water treatment system.	-	-	-	0	0	-3

Process/Associated Loss	Source of Loss	E	R	HS	W$	M$	SUM
PIECE DYEING							
Chemical loss	Recipe not strictly followed. Potential for acid spills, accidents are high.	+	+	0	+	0	+3
Energy loss	Temperature control is manual; Heat from bath is not recovered.	0	-	-	-	+	-2
Water loss	When light colors are scheduled after dark colors, excessive kettle scouring is required.	0	-	-	+	-	-2
Fiber loss (flock)	Greatest contributor to flock build up in water treatment.	-	-	-	+	0	-2
Fabric loss (reject/rework)	Reject fabric must be recycled as black fabric or used for a lower quality purpose (e.g., remanants).	-	-	-	0	+	-2
FINISHING							
Energy loss	Heat from dryer exhaust is not recovered.	0	-	-	-	+	-2
Fiber loss	Flock from napping process is lost.	-	-	-	+	0	-2
Fabric loss		-	-	-	-	+	-3
OTHER							
Storage - Chemical loss	Broken bags, expired chemicals, off-spec chemicals or spoiled chemicals.	+	+	+	0	+	+4
PCB Transformers	Potential environmental and health hazard if there is a sill or leak.	+	+	+	-	-	+1
Power Plant - Energy loss	Heat loss from boiler inefficiencies.	+	+	-	-	+	+1

Selection of the Losses

After each process was ranked, the categories were summed. Four areas scored high. The highest categories were "Chemical Loss in Stock Dying", "Chemical Loss in Piece Dying", "Chemical Loss in Carbonizing", and "Chemical Loss From Storage". Although these areas ranked closely, "Chemical Loss in Carbonizing" presented the most promising opportunity and was selected as the focus of this first round of Pollution Prevention activity.

This process/loss was selected over the other three areas because it has losses to air, water and solid waste and also because the carbonizing process has been a source of continuing concern at the mill. Atmospheric problems in the area, which are a serious worker health and safety concern and losses of sulfuric acid in the effluent were identified as the primary focus of this first round of Pollution Prevention activity.

7.4 Analysis of the Selected Losses

Once chemical loss from the carbonizing process was selected as the primary loss for further analysis, the team took a closer look at how the carbonizing process works.

Some insight was gained from industry publications regarding the chemical processes taking place and the appropriate operating parameters. It was learned that in the wool is soaked in a weak acid which is concentrated in the drying stage. When process parameters are properly controlled, acid contacting the wool fabric is chemically bound and thus is not concentrated, whereas acid contacting the vegetable matter is free acid and becomes concentrated when water is evaporated from it in the dryer. Acid concentration, exposure time and temperature must be carefully controlled to assure that acid contacting the wool is chemically absorbed or bound to the wool. Improper control of parameters can result in free acid damage to the wool fabric, or incomplete carbonization of the vegetable matter. Bath strength, immersion time, drying temperature, baking temperature, and the moisture content of the cloth prior to baking are also critical process parameters.[45]

After developing a better understanding of the theoretical process operation, the team returned to the plant floor to observe the process again. Three potential loss factors were identified: vapors from the acid bath, smoke or haze escaping from the carbonizing oven, and sulfuric acid loss to the effluent.

Atmospheric problems and odor in the carbonizing area are readily apparent even on a brief tour of the operation. Operators report respiratory and eye discomfort. Additionally, sulfuric acid emissions from the system are reportable under the Toxic Release Inventory (TRI) and smoke emissions from the stack resulting in high emissions opacity values are a source of concern to the NH DES.

Sulfuric acid losses is the area are mainly due to the large quantity of acid dumped to the waste water pretreatment system. When the sulfuric acid bath is considered spent, it is dumped to the waste water pretreatment area so the bath can be cleaned out and refilled with fresh acid and water. When the acid is dumped to the pretreatment system, many additional operations are needed in order to maintain the required pH.

A brainstorming session was conducted with plant personnel involved with the carbonizing process and a maintenance engineer experienced with the carbonizer's past problems. Subsequent interviews with equipment operators validated ideas generated in this session.

Ideas and information gathered was used by the team to construct a "fishbone" diagram for each problem. Causal groups were identified as Manpower, Machinery, Methods and Materials. Figures 26, 27 and 28 show the three diagrams constructed. A multi-voting technique was used to select the most likely causes for each of the problems.

Figure 26: CAUSE AND EFFECT DIAGRAM: VAPORS FROM BATH

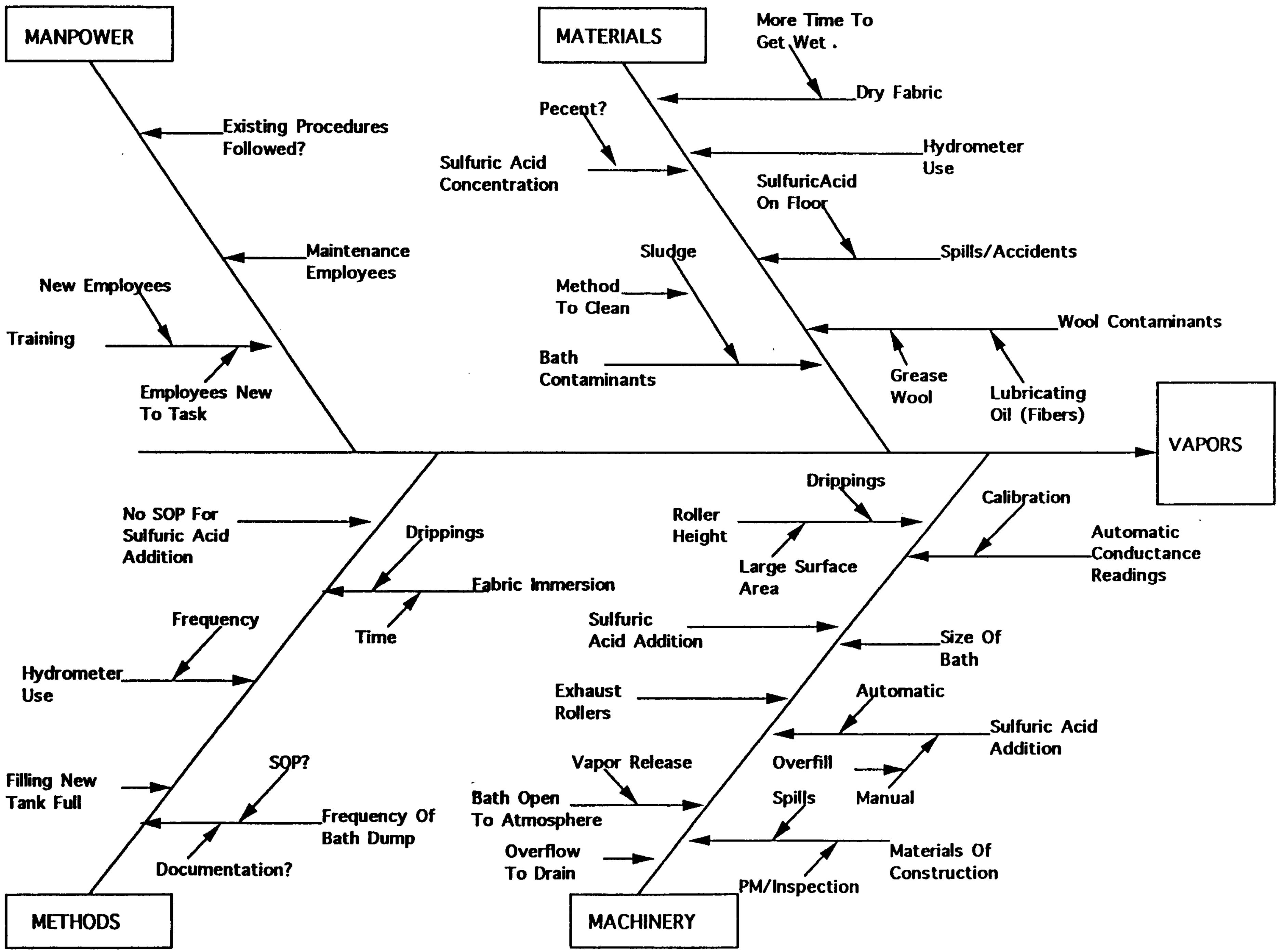


Figure 27: CAUSE AND EFFECT DIAGRAM: HAZE FROM CARBONIZER

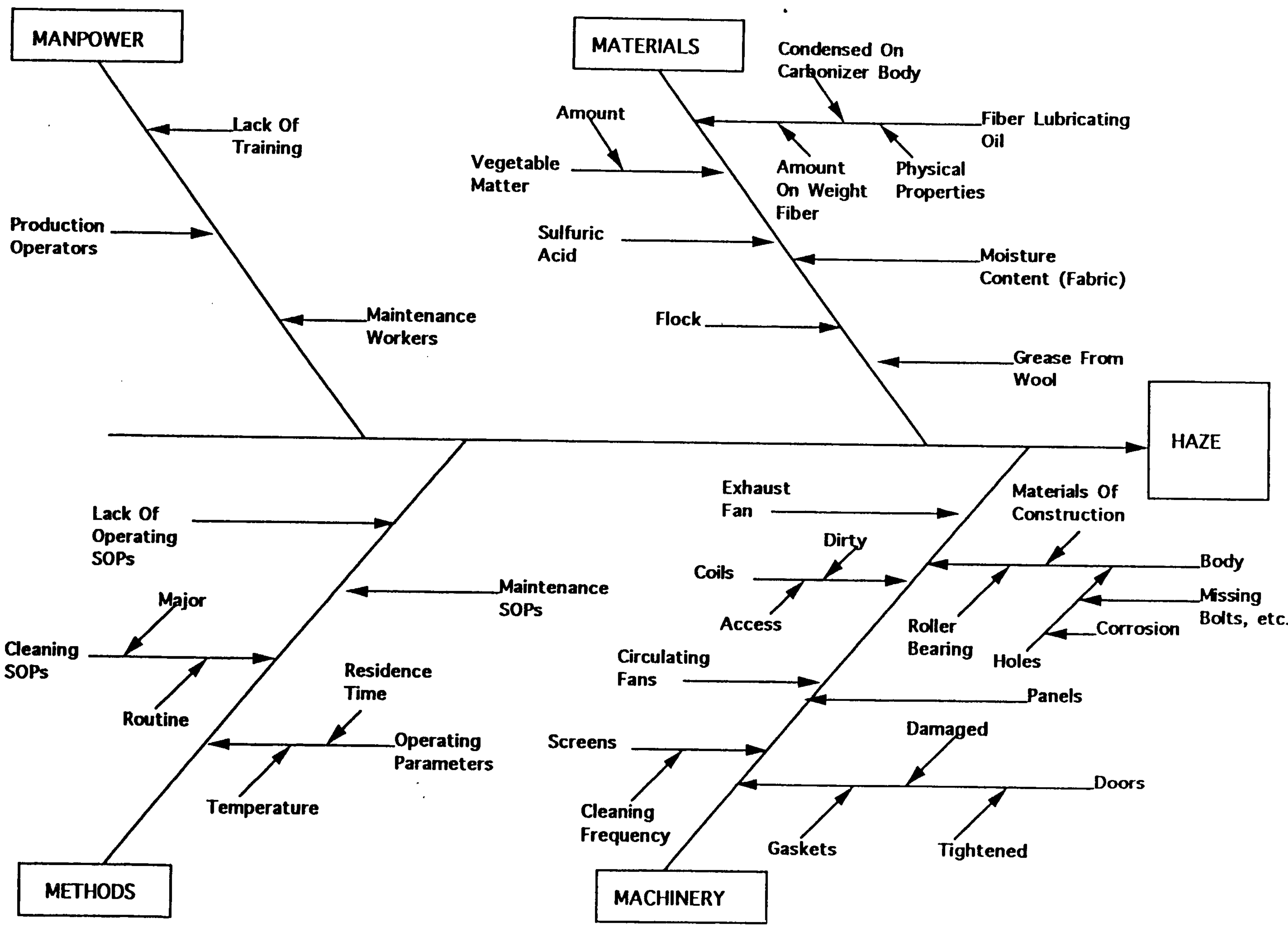
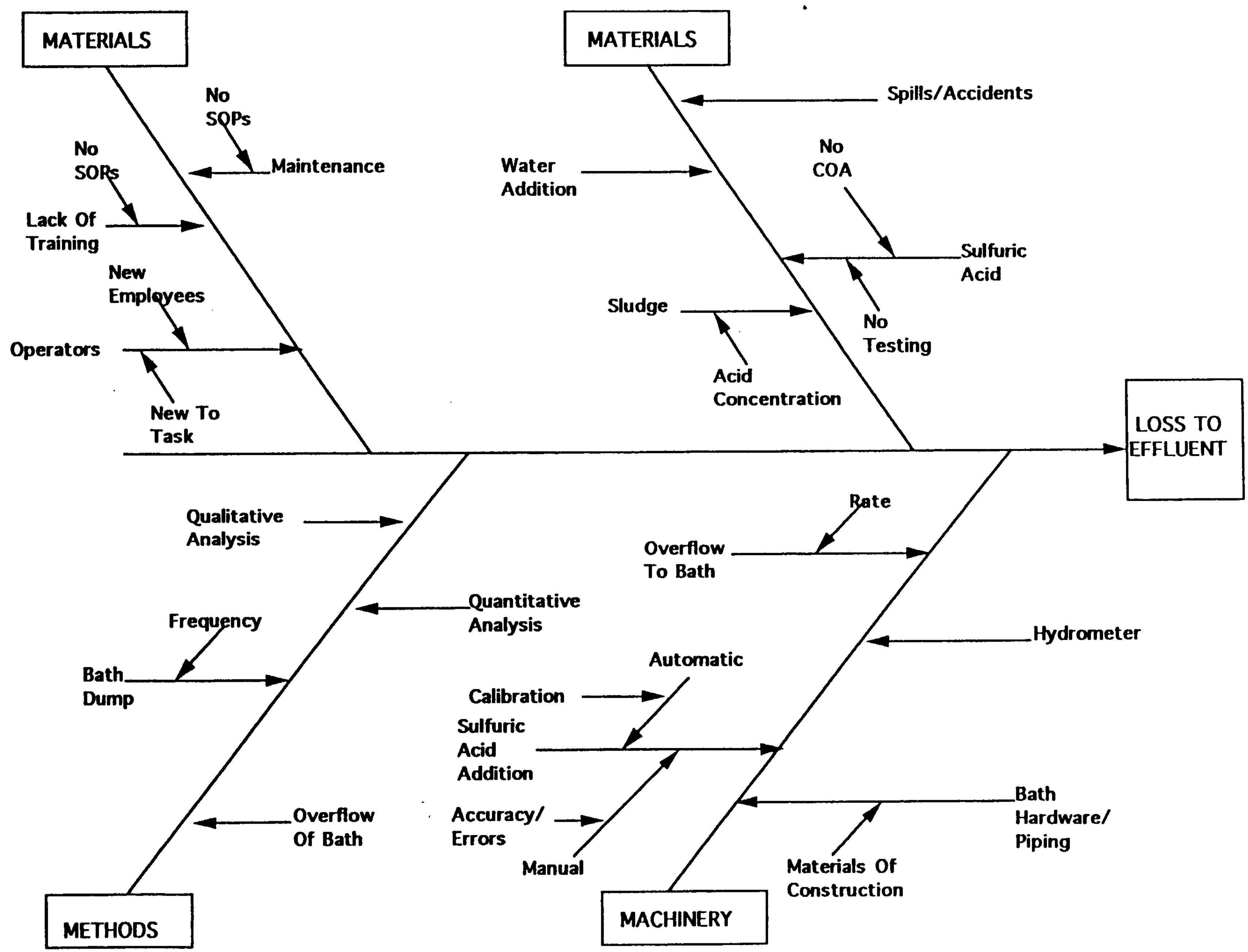


Figure 28: CAUSE AND EFFECT DIAGRAM: ACID IN EFFLUENT



7.5 Generation and Selection of Alternatives

Generate the Alternatives

Based on the identified causes, brainstorming was used to generate alternative solutions for each problem. The team generated a list of alternatives that have the potential to reduce the identified losses in the carbonizing area and additionally may increase operating efficiency of the process, reduce labor in rework of soiled fabric, and eliminate or reduce stack emissions problems. Alternatives were included in this list if at least half the project team agreed they had potential merit.

In order to prioritize the alternatives identified, a further analysis of each alternative was required. This section explains each alternative in greater detail. Based on this information, these alternatives were subsequently prioritized based on the selected criteria as described in the following section.

Problem 1: Sulfuric Acid Vapors Entering the Atmosphere from the Tank

1-1. Monitor Bath Parameters

Bath temperature, room temperature and humidity, acid concentration, or sludge buildup and impurities in the bath may be contributing to the atmospheric problem. Charting these parameters against a subjective evaluation of discomfort and a record of employee complaints may yield potential control strategies. Initially is it suggested to monitor parameters and atmospheric condition at the beginning, middle and end of each shift, and to review data weekly.

1-2. Determine Optimal Frequency of Tank Dump

Currently the sulfuric acid tank is dumped when it is qualitatively determined that the bath is spent. Analysis of the carbonizing system to determine the optimum time to dump the sulfuric tank can result in a cost savings by increasing the life of the bath. A longer bath life would not only reduce acid use, but would also reduce the volume of waste water generated and treated.

1-3. Clean Sludge from Tank Every Time it is Dumped

Sludge buildup in the bath may contribute to excess acid use and possibly to excess acid release to the atmosphere. Impurities in the bath may also be contributing to the vapor problem.

1-4. Pre-wet the Fabric

Fabric passes in and out of the bath in a snake-like fashion on a roller system. The fabric is exposed to the acid both in the bath and while the soaked fabric is exposed to the air above the bath passing over the rollers. This method of soaking the fabric may contribute significantly to the atmospheric problems in the area as the liquid is dragged out of the bath on the fabric, exposing the acid-soaked fabric to the air, several times. Pre-wetting the fabric allows the acid to penetrate more quickly, reducing the soaking time required. Pre-wet fabric may require fewer passes through the bath, and thus reduce contact time between the acid soaked fabric and the air.

1-5. Pre-scour the Fabric

Prescouring removes oils but also leaves the fabric wet. It thus has the same advantages as pre-wetting. At one time, fabric was prescoured.

1-6. Lower the Upper Roller Height In the Acid Bath

Contact between the acid soaked fabric and the air may be a source of acid transfer to the air. Lowering the rollers so the fabric spends little or no time in contact with air may improve the problem. Since this alone decreases acid/fabric contact time, it can be coupled with either pre-wetting or bath size increase to allow for sufficient acid/fabric contact time.

1-7. Make the Acid Bath Deeper and/or Longer

Reduced contact time between the acid soaked fabric and the air could be accommodated if the acid bath were made longer or deeper to allow the acid/fabric contact to take place in the bath rather than in the air space above the bath.

1-8. Enclose the Carbonizing Tank

Transfer of acid to the room atmosphere may also be controlled by means of an air tight enclosure around the entire acid tank/roller system. Entry and exit doors for fabric would require appropriate seals.

Problem 2: Chemical Smoke/Haze from Carbonizer Oven

2-1. Implement a Preventive Maintenance Schedule for Cleaning of Blower Filter Screens

The carbonizer oven is supposed to maintain a negative pressure to contain emissions. Clogging of filter screens may be causing back pressure defeating the negative pressure system. A maintenance schedule exists for the screens, but it is reported that it is not routinely practiced.

2-2. Assure Carbonizer Oven Door Seals are Designed for High Temperature Environment

Door seals may deteriorate and fail if not designed for the high temperature and acid environment of the carbonizer oven, thus causing leakages.

2-3. Implement a Routine Inspection and Cleaning Schedule for Door Seals, Roller Bearing Seals and Clean out Panels

Door seals are replaced on an "as needed" basis, however a routine inspection program is not in place for either the door seals or clean out panels. Routine inspection, coupled with cleaning of gaskets and seats after opening may improve emissions. Bearing seals for the series of rollers transporting the fabric through the oven are also a potential source of air leaks. Bearing seals should be inspected and repaired according to a planned schedule.

2-4. Use a Heat Sensor To Detect Carbonizer Oven Air Leaks

Current maintenance procedures can only detect visually apparent leaks. Use of a heat sensing probe could detect hot contaminated air leaking from the oven so air leaks could be fixed, eliminated or reduced.

2-5. Implement a Preventive Maintenance Schedule for Cleaning of Steam Coils, Sprinkler Heads, Oven Walls and Ducts

Oil condenses on internals of the dryer equipment and creates a thick coating for the flock to adhere. This provides additional surface area for oil buildup. The excess oil and flock buildup may contribute to the smoke problem. Current PM procedures do not appear to result in thorough regular cleanings. Preventive maintenance procedures should be written and a routine cleaning schedule documented. Training of workers on correct PM procedures and the reasons for them should be implemented to assure that the program is successful.

2-6. Investigate Changing the Type of Oil Used

The type of oil may contribute to the smoke problem. Alternative oils may exist.

2-7. Substitute Persulfuric Acid for Sulfuric Acid

Persulfuric acid is derived from the action of hydrogen peroxide on concentrated sulfuric acid. Persulfuric is a strong irritant to eyes, skin and mucous membranes. Literature states that using persulfuric acid instead of sulfuric allows for a reduced baking time and that at a temperature of 140°C, the baking time was reduced from 5 minutes to 3 minutes.

2-8. Reduce the Amount of Oil Used in the Blending Process

If the amount of oil used in the blending process is minimized, it could contribute to a reduction in the oil buildup in the drying and baking.

2-9. Prescour Fabric

Prescouring may reduce the amount of oil and vegetable matter impurities of the fabric. These impurities may contribute to smoke generation from the dryer.

2-10. Decrease Drying Temperature

Decreased drying temperature may reduce volatilization of oil and improve carbonizer performance. The drying temperature in carbonizing has been found to be of critical importance. Up to 25 percent of the total carbonizing damage to the wool can occur in the drying step, even at a low drying temperature of 70°C. A study showed that with a drying temperature below 70°C the rate of wool hydrolysis was low, however, when the temperature was increased to 80°C, the hydrolysis rate increased dramatically. This data agreed with weight loss results for wool exposed to aqueous sulfuric acid at different temperatures. Additionally, studies have demonstrated that with the combination of the reduction in the rate of drying and a time delay between acidification and drying, of about 15 minutes, the local fiber damage is reduced. The initial rate of wool hydrolysis in drying is also greater during the first 10 to 15 minutes. For lower drying temperatures, such as 70°C or below, virtually all the hydrolytic damage occurs in the first 10 minutes of drying. A direct correlation was shown between loss of fiber strength and drying temperature. This work has led to the recommendation that acidized wool should be dried at temperatures below 70°C. Currently the mill being studied uses a drying temperature of 87°C. It is recommended that an evaluation be done and consideration be given to lower the drying temperature.

2-11. Modify Dryer Design to Improve Access to Coils for Cleaning

Buildup of oil and flock on coils may contribute to both smoke generation and reduced efficiency. Improved access to the coils should make it more probable that the regular cleaning schedule will be observed.

Problem 3: Sulfuric Acid in Waste Water

3-1. Monitor Bath Parameters to Determine the Optimum Time to Dump the Sulfuric Tank

Currently the sulfuric acid tank is dumped without regard to whether it has been spent or not. Analysis of the carbonizing system to determine the optimum time to dump the sulfuric tank can result in a cost savings. The present method of dumping the tank after each run could be using excess acid. The optimum time could not only cut down on the sulfuric acid use but also the volume of waste water generated and treated.

3-2. Implement Statistical Process Control for Bath Parameters

Training operators in Statistical Process Control will enhance the ability to use bath parameter measurements to determine the optimal time for tank dumps.

3-3. Develop and Implement Standard Operating Procedures for Bath Cleaning and Maintenance

Standard Operating Procedures (SOP's) can be used to document the appropriate maintenance and cleaning requirements. These can provide assurance that the bath is dumped as often as necessary for optimal process performance. Procedures can also specify how and when sludge is cleaned from the tank to avoid bath contamination.

3-4. Train Operators in Bath Maintenance Procedures

Operator training in the maintenance procedures and the reasons for them will assist in assuring that procedures are implemented. Thoroughly trained operators may additionally provide better feedback regarding maintenance problems.

3-5. Automatic Control/Monitoring of the Acid Level

The mill has been experiencing pH difficulties in the waste water treatment plant.

Usually the pH is run low outside the acceptable band that the POTW can receive. Installation of an automatic control device to monitor the amount of acid input into the system can provide more consistent discharge levels.

3-6. Foam Application of Sulfuric Acid

Studies have shown that a foam application of sulfuric acid can successfully replace the liquid soak in acid. With a foam application it is possible to apply the exact volume required for complete uptake by the vegetable matter. The result is a reduction in the amount of acid used. Additionally, the need to dispose of an exhausted liquid sulfuric acid bath is eliminated. By eliminating the need for bath disposal, the quantity of soda ash used in waste water treatment would be greatly reduced. Other advantages of foam application include improved breakdown of the vegetable matter and a lower free acid content in the wool. The disadvantage to foam application is that higher concentrations of acid, 11 - 12% are needed.

3-7. Reuse Acid Bath After Cleaning Sludge from Tank

If the bath contaminants precipitate, one option is to remove the acid bath from the tank, clean out the sludge buildup and replace the bath thus reducing acid usage.

3-8. Require Certification of Acid Quality from the Manufacturer on Delivery

Impurities and sludge may be in the acid product as received from the vendor. Purchase order documents should specify that a product quality certification is required upon delivery, or, alternatively, an incoming material Quality Control program should be implemented. These measures may result in improved product quality.

3-9. Discontinue Unloading of Tank Trucks Delivering Product by Air Pressure

This method of delivery tends to insure that any sludge residual in the truck is transferred to the receiving tank. Additionally, it is generally considered more prone to leaks and accidents than pumping off. Considerations of personal safety and spills also favor this modification.

Prioritize the Alternatives

The alternatives were prioritized by dividing them into two categories, namely Short Term Alternatives (or "Low Hanging Fruit") and Longer Term Alternatives.

Short Term Alternatives (Low Hanging Fruit)

The "Low Hanging Fruit" are alternatives that can be quickly and easily implemented, that require minimal capital expenditures and that potentially could be effective in reducing or even eliminating the loss. Most often, these solutions are maintenance and training related. The Short Term Alternatives were prioritized qualitatively. The team selected the alternatives that would be most effective in reducing the losses.

Longer Term Alternatives

The Longer Term Alternatives typically require process changes, materials substitutions or equipment modifications. These alternatives often require more planning, capital, time, and testing before they can be implemented successfully. Since the Short Term Alternatives have the potential to solve the identified problems, the longer term alternatives are not addressed in detail in this case study analysis. The methodology, however, is described in the guideline. The Descriptive Approach to Pollution Prevention is a continuous process and therefore, is always being refined. It is quite possible that implementation of the Short Term solutions alone will be required. If the longer term alternatives become necessary for implementation, further analysis is required. Issues for further quantification include:

- The activity based cost of the process (including the loss),
- The anticipated cost reduction based on expected improvement if the alternative is implemented
- The implementation cost.

A complete feasibility study for each of the identified alternatives, and an implementation plan should be prepared. This process requires considerable effort and support from all levels of management, but is an essential step in the process prior to implementing potentially costly changes. Each alternative should be analyzed considering criteria such as:

- Cost Effectiveness
- Technical Feasibility
- Cultural Feasibility
- Implementability

Based on the results of the ranking and feasibility analysis, the Longer Term Alternatives will be prioritized.

Select the Best Alternatives

Short Term Alternatives

- Monitor Bath Parameters
- Identify and Repair Leaking Seals in the Carbonizer Oven
- Develop a Preventive Maintenance Procedure for the Carbonizer

Longer Term Alternatives

- Pre-wet the Fabric and Lower the Rollers Over the Acid Bath
- Decrease the Initial Dryer Temperature
- Investigate Substitution of an Alternative Fiber Lubricating Oil
- Improve the Accuracy of the Automatic Monitoring System for Bath

7.6 Recommendations for Implementation of Selected Alternatives

Time and capital are very limited at the case study facility. However, it is important to implement Pollution Prevention alternatives quickly in order to build enthusiasm and support for the program. Therefore, it is recommended that the facility implement the Short Term Alternatives first. These alternatives may result in significant loss reductions so that the Longer Term Alternatives may not be necessary. Additionally, the short term successes provide momentum while the facility organizes for implementation of the longer term alternatives.

It is crucial that the facility assign one person who is given full responsibility to implement the Pollution Prevention alternatives for the carbonizer. This person then selects a cross-functional team of plant personnel. A representative of the maintenance department and a representative from the Operations Department must be included on the team. Management must agree that this Pollution Prevention project is a priority and therefore allow the team members to spend a certain percentage of their time working on the project.

When implementing any alternative, documentation must be thorough in order to be able to measure the extent to which pollution is curtailed. This is important when first starting a Pollution Prevention program since documentation provides evidence of a trend of progress. Successes realized by both the employees and the managers build enthusiasm for the program. If management can see the improvements early in the process, they will be more likely to support future Pollution Prevention projects which may require a greater capital investment.

In order to accurately measure progress, it is important to gather some baseline data for the alternatives recommended for the carbonizer. For example, the levels of particulate matter and sulfuric acid in the air should be monitored for a period of several days at several locations. This includes areas such as including above the tank, in the workers' breathing zone, at the exhaust on the roof, and in the area over the carbonizing unit.

After obtaining the baseline data, the team should agree to which Short Term Alternative to implement first. Team members should then generate a detailed list of the tasks required to implement the alternative. A team member should be assigned responsibility for completing that task by a predetermined deadline. Once the alternative is implemented, the monitoring should be repeated. Reduction in losses should be quantified and publicized to build enthusiasm for further Pollution Prevention projects. A time table should be defined for each alternative implemented and progress should be carefully monitored. The degree of success realized by each effort should be documented.

Once all short term alternatives have been implemented, an evaluation should be made to determine the need for implementation of the Long Term Alternatives. If sufficient progress has been made, no further action may be required. If additional improvement is still needed the most promising Long Term Alternative should be selected, using prioritization techniques previously demonstrated, for further evaluation.

7.7 Areas for Further Pollution Prevention Activity

After the team reviews the new data, they must decide which alternative should be implemented next. The implementation process is a cyclic one, where continuous improvements are based on reviewing progress at each step.

Although this case study concentrated on the losses associated with the carbonizing process, the group did identify several other opportunities for Pollution Prevention in the case study facility. If implemented, these could result in a significant reduction in losses. These options are presented in Figure 29 and are explained in greater detail in Appendix A. The options highlighted in bold type are considered "Low Hanging Fruit" because they require minimal time and money, yet they will reduce losses significantly if implemented.

FIGURE 29

CASE STUDY WOOLEN MILL
ALTERNATIVES - All Operations

Process/Associated Loss	Options to Reduce or Eliminate the Loss
STOCK DYEING	#3 steam user; #3 water user
Dyestuff Loss	Replace dyestuffs containing heavy metals with non-metal dyestuffs.
	Reconstitution/reuse of dyebath if technologically and economically feasible.
Water Loss	Install automatic shutoff valves with timers on water rinse lines to eliminate water loss.
	Reuse of final rinse from dyeing for dyebath make-up.
Chemical Loss	Seek environmentally "friendlier" chemical substitutes whenever possible.
Energy Loss	Optimize load sizes. Determine actual cost of small batch sizes versus inventory carrying costs.
	Install steam controllers with recorders and pneumatically operated valves to optimize dyebath heatups and hold times.
Health & Safety	Utilize existing exhaust system in drug room when weighing dyestuffs.
	Improve labeling and container storage of weighed dyestuffs.
Other	Chart reworks and adds. Determine root causes. Continue efforts to implement improvements.
	Investigate cost/benefit for the purchase of newer technology dyeing vessels which would result in better quality and less process losses.
WOOL PREP	
Oil loss	Lost to air when over-oiled - Better controls on oil feed
Fiber loss	Enclose blending conveyor

	Most lost at baler: vacuum it up and recycle it
Energy loss	Minimal energy losses
	Preventive Maintenance
YARN FORMATION	
Energy loss	Carding: Increase speed to decrease energy use
	Spinning: Install Open End or Air Jet spinning equipment
	Preventive Maintenance - machinery heat loss
Fiber loss	Carding: Recycle into process
	Spinning, warping: Recycle into process
FABRIC FORMATION	
Fabric loss	More inspection/QC at weaving to decrease time in burling and decrease rework at the end of process
Health and safety	Burlers experiencing carpal tunnel syndrome
CARBONIZING	
Chemical loss	Replace faulty gauge on outdoor H_2SO_4 storage tank. Potential for accident next to river, cafeteria.
	Discontinue the unloading of tank trucks by air pressure due to proximity of river. For added safety, use a pump to unload. Investigate installation of an unloading trench for sulfuric acid deliveries in order that a catastrophic spill will be collected.
	Quantitative analysis to determine when to dump tank. Measurement to optimize H_2SO_4 use.
	Develop SOP for tank fill and dump to optimize H_2SO_4 use.

	Study how vapor is getting into the air: Put together a multi-disciplinary team to study
	Determine "critical concentration" of acid to maximize vegetable matter destruction and minimize wool loss.
	Change to foam application of H_2SO_4 solution. (Also greatly reduces effluent)
	Automatic control/monitoring of acid level.
	Press the fabric between hard rollers before acidizing to improve acid uptake by the veg. matter.
	Use statistical process control (SPC) to chart acid concentration over time.
	Neutralize the bath before dumping it.
Energy loss	Get heat exchanger up and running.
	Preventive Maintenance inside dryer.
	Add a booster fan in the stack (if necessary).
	Develop a PM schedule for carbonizer, fans, rollers, etc.
	Roller application technique instead of bath. Less drying E and faster production rates possible.
	Measure CFMs to obtain baseline reading. This information will help trouble shoot equipment upsets.
	Measure pressure drop across 1st section of carbonizer by use of permanently installed manometer.
	If necessary, have carbonizer manufacturer do a complete audit of unit. Request written report. Develop action plan to implement improvements.
	Use persulfuric acid to allow for a reduced baking time.
Fabric Loss	Oil from rollers dripping onto fabric. Select different oil. Check during PM.
	Decrease drying temperature to 70C (now at 87C) to minimize wool hydrolysis.

FULLING	
Energy loss	Preheated solution speeds up process and increases uniform distribution.
	Capture piece dyeing heat to heat up solution.
Chemical loss	Capture mineral spirits used in fulling. Currently evaporate in room.
	Use of H_2SO_4 instead of alkali soap.
WASHING	Largest water use in plant (~40%)
Water loss	Recycle water from cleanest tank to dirtiest tank.
	Install tower washer.
Fiber loss	Recycle flock from after-wash squeeze rollers with the flock from piece dye baths.
PIECE DYEING	#1 steam user; #2 water user
Dyestuff loss	Replace dyestuffs containing heavy metals with non-metal dyestuffs whenever feasible.
	Build partnerships with major suppliers. Use them as a technical resource whenever possible.
	Improve pH monitoring. Investigate automatic addition of acids/bases for pH adjustments.
	Install drip-board to eliminate loss of dyestuff solution to floor during addition from pails to sieve located in beck vessel.
Water loss	Investigate reuse of final rinse from dyeing for dyebath make-up.
Chemical loss	Be a "minimalist". Implement formal program to track progress and savings in chemical auxiliary use reduction.
	Insure exact recipe amounts of chemical auxiliaries get added to dyebath.

Fiber loss	Continue efforts of Case Study Waste Water Improvement Team to retrieve flock from vessels. Recycle/sell material if possible.
Energy loss	Capture heat via heat exchangers if economically possible.
	Install steam controllers with recorders on beck machines and install pneumatically operated valves to optimize dyebath heatups and hold times.
Health & Safety	Investigate hard piping of sulfuric acid directly to vessel. Automatic shutoffs should be installed.
	Employees should be in "full" acid gear when handling sulfuric acid and caustic soda.
Other	A formal production/marketing meeting concerning scheduling should be held on a regular basis in order to optimize campaign length, color changes, and vessel cleanouts.
	Investigate use of formic acid as a chemical substitute for acetic acid to attain BOD reduction.
FINISHING	Dryer is #4 steam user.
Material loss	Find alternative leader.
Energy loss	Reuse heat (heat exchanger).
	Vapor recompression to recover energy from water vapor.
	Mechanical pre-dry.
	Microwave drying.
	Radio frequency drying.
	Infrared and gas systems for pre-dry.
Fiber loss	Reuse flock from napper.
WASTE WATER TREATMENT	
Chemical loss	Substitute $MgOH_2$ for sodium hydroxide, soda ash.
	Improve materials storage and/or incoming inspection to avoid crystallization of sodium hydroxide.

	Change pit in water treatment building to a flow through process to get more control with a known holding time.
Fiber loss	Recover/ recycle flock. Let it fall into an extractor or at least let it fall into the dumpster to minimize back injury.
OTHER	
Storage	Centralize all chemical storage, except one day's use, to minimize broken bags, expired chemicals.
	Develop a chemical control program to eliminate incompatible storage practices.
	Review all MSDSs before accepting chemicals.
	Consolidate chemicals and eliminate duplicate products.
	Improve conditions in remnants storage area to eliminate mildewy fabrics.
	Move all materials under the roof to minimize the potential for spills to the river.
	Replace USTs. Move them inside or to vaults.
PCB Transformers	Build a diked area around transformers.
	Replace PCB transformers.
Health and Safety	Implement an eye protection policy.
	Measure noise and implement an ear protection policy.
	Prohibit food and drink in the production area.
	Prohibit shorts.
Procedures/Maintenance	Develop SOPs for all areas.
	Develop preventive maintenance procedures and schedules for each area. Give production personnel responsibility for routine PM.
	Measurement of parameters of operation.

ENDNOTES

1. Day, William J. "Textile Plant Waster Reuse, Recycle and Conservation and Wastewater Treatment", AATCC Symposium. The Textile Industry and the Environment, Washington, D.C. May 22-24, 1973, p 72.

2. International Wool Textile Organization. "Wool Statistics, 1988-89", London: Commonwealth Secretariat Publications. 1989, p.35.

3. Hammer, Michael, Champy, James. Reengineering The Corporation: A Manifesto For Business Revolution. Harper Collins Publisher Inc., 1993.

4. Pojasek, Robert B. and Cali, Lawrence J. "Contrasting Approaches to Pollution Prevention Auditing", Pollution Prevention Review. Summer 1991, p. 230.

5. Pojasek, Robert B., Vice President. GEI Consultants, Inc., Winchester, MA.

6. Pojasek, Robert B. and Cali, Lawrence J. op.cit., p. 231.

7. Pojasek, Robert B. and Cali, Lawrence J. op.cit., p.231.

8. Quality Environmental Management Subcommittee, President's Commission on Environmental Quality. Total Quality Management: A Framework for Pollution Prevention. Washington, DC 1993, p. v.

9. Jackson, Susan L. "Certification of Environmental Management Systems - For ISO 9000 and Competitive Advantage", Total Quality Environmental Management. Spring 1993, p. 252.

10. Jackson, Susan L. op.cit., p .252.

11. Jackson, Susan L. op.cit., p. 251.

12. Riche, Bob. "Trouble Shooters Gun Down Oil Streaks", Quality Circle Journal. June 1985, p. 20.

13. Paluzzi, Joseph E., Greiner, Timothy J.. "Finding Green In Clean: Progressive Pollution Prevention at Hyde Tools", Total Quality Environmental Management. Spring 1993. p. 283.

14. Chapman, C.B.. Fibres, Butterworth & Company, 1974, p. 55.

15. U.S. EPA, Development Document of Effluent Limitations Guidelines and Standards for the Textile Mills, EPA 440/1-82/022, September, 1982, pp 83-85.

16. Collier, Ann M. A Handbook of Textiles. Oxford: Pergamon Press. 1970, pp. 64-73.

17.Collier, Ann M. op.cit., pp. 64-73.

18. Collier, Ann M. op.cit., 1970, pp. 97.

19. Collier, Ann M., op.cit., 1970, pp. 97.

20. Brown, T. D. "The Wool Apparel Weaving Industry", Wool Science Review. vol. 66, p.72.

21. Brown, T. D. op.cit., p. 72.

22. Brown, T. D. op.cit., p. 72.

23. Pailthrope, Michael T. "Developments in Wool Carbonizing", Review of Progress in Coloration, vol. 21. The Society of Dyers and Colorists. 1991, p.11.

24. Bearpark, Ian, Marriott, William F., Park, James. A Practical Introduction to the Dyeing and Finishing of Wool Fabrics. Society of Dyers and Colorists, London. 1986. p.7.

25. Von Berger, Werner. Wool Handbook, Volume 2. Interscience Publishers, NY. 1969, p. 92.

26. Von Berger, Weerner. op.cit., p. 97.

27. Masselli, Joseph W., Masselli, Nicholas W. and Burford, M. G. "Textile Waste Treatment Past, Present and Future", AATCC Symposium. The Textile Industry and the Environment, Washington, D.C., May 22-24, 1973, p. 3.

28. Speel, Henry C., and Schwarz, E.W.K. Textile Chemicals and Auxiliaries. Reinhold Publishing Corporation, New York. 1957, p. 45.

29. US EPA, Development Document For Effluent Limitations Guidelines and Standards For The Textile Mill. Washington, D.C. September 1982, p. 42.

30. Corbman, Bernard, B.. Textiles: Fiber to Fabric, McGraw Hill Book Company. 1975, p. 236.

31. Tincher, Wayne C. "Mills Will Face New Effluent Challenges", Textile World. May 1993, p. 60.

32. Shaw, Dr. Trevor. "Environmental Issues in Wool Processing", Wool In The Nineties Technical Seminar. The Wool Bureau Inc., Plymouth, MA. April 25 & 26, 1990, p. 89.

33. Kulkarni, S.V. et al, Textile Dyeing Operations, Noyes Publications. 1986, p. 284.

34. Kulkarni, S.V. et al,. op.cit. p. 285.

35. U.S. EPA, Development Document of Effluent Limitations Guidelines and Standards for the Textile Mills, EPA 440/1-82/022. September, 1982, p.19.

36. U.S. EPA, Development Document of Effluent Limitations Guidelines and Standards for the Textile Mills, EPA 440/1-82/022. September, 1982, p. 68 and 96.

37. Brown, Calvin. personal communication to J.E. Holbrook, 6/2/93.

38. U.S. EPA, Development Document of Effluent Limitations Guidelines and Standards for the Textile Mills, EPA 440/1-82/022. September, 1982, p 119.

39. Juran, Joseph. Juran on Quality Improvement. Juran Enterprises Inc., 1981, P. 11-8.

40. Goal/QPC. The Memory Jogger: A Pocket Guide of Tools for Continual Improvement. Goal/QPC, 1988.

41. Thompson, Charles. What A Great Idea!. Harper Perennial, 1992. P. 23.

42. Thompson, Charles, op.cit., p. 26.

43. Northeast Waste Management Officials Association and Massachusetts Office of Technical Assistance, "Costing and Financial Analysis of Pollution Prevention Projects". 1992.

44. Pare, Terence P., "A New Tool form Managing Costs", Fortune. June 14, 1993, p.124.

45. Pailthorpe, Michael T., op.cit., p. 11.

Appendix A
Alternatives for the Reduction of Losses

Although this case study concentrated on the losses associated with the carbonizing process, other opportunities for Pollution Prevention in woolen mills were identified. These options may be useful to mills embarking on Pollution Prevention programs.

Stock Dyeing

Membrane technology provides varied solutions to wastewater cleanup including recovery of chemicals. Cost savings are generated from reuse of salt, reuse of water, recovery of heat, and if reused, the value of the dyes.[1] Although it is difficult to reuse exhausted dyebaths in a batch operation with numerous product changes, the mill should work with vendors to obtain information on available technology for chemical separation and dyebath reuse (eg. membrane technology). This may or may not prove to be economically feasible at this time; however, regulatory issues may make this a necessary alternative at some point in the future.

Approximately 75% of the time no chemical adds have to be made to the dyebath, and 95% of time the final quality of the stock dyed material is acceptable.[2] This performance and progress should be charted. Root cause analysis should be done to determine opportunities for improvement. Improvements will result in pollution prevention.

Carding

In dry processes, such as carding, new technologies are directed toward product quality improvement and the reduction of production time. Energy conservation efforts are limited and have usually concentrated on improving the design and sizing of electric motors, utilizing variable speed controllers and adjustable speed drives, and reducing heating and air conditioning loads. The trend for the carding unit process has been toward consolidation of production steps.[3] Direct-feed carding has shown that potential energy savings could be achieved. Additionally, studies have shown that tripling the carding rate will cut the per unit electricity requirement by one-half.

Spinning

Spinning is considered one of the most energy-intensive steps in the dry processing. Some of the major processing trends in the energy conservation area are the increase in the use of open end spinning and air-jet spinning. Open-end spinning has been demonstrated to be good for spinning basic yarns but not very fine yarns. The approximate electricity savings using this method is equivalent to 20 percent of the electricity used in the spinning yarn production. It holds about 40 percent of the current market for spinning yarn for weaving and is nearly 5 times the output of ring spinning.[4] Air-jet processing has been found to be best suited for weaving standard fabric less than 9 feet wide or for spinning synthetics or blends. However, in this method, about a 50 percent greater electrical usage is realized for weaving output due to the power requirements of the air compressor.[5] Case studies have shown that the weaving productivity in air jet processing is nearly 3 times that used in shuttle weaving.

Fulling

Sulfuric acid has been used for fulling in place of soap and has been demonstrated to reduce appreciable BOD loads. This can also be a cost and time benefit since neutralization after the carbonizing step in theory could be eliminated. Additionally, use of the acid is more easily recovered and re-used than the soap. This could be an economic saving as well.

Piece Dyeing

The dyebath vessel must be viewed as a "chemical reactor" with optimum operating conditions and process parameters such as pH, temperature, and concentration.[6] Improved pH monitoring will aid dyebath exhaustion and result in savings of chemical auxiliaries. Acid dyeings should actually be run by pH control rather than by percentages of acid on the weight of materials.[7] This enables the dyer to know before the lot is started that the acid amount is correct. A second pH reading may be taken when the temperature of the dyebath reaches the boil. Such controls reduce redyes and speed up dyeing cycles, saving time and money.[8] Improved pH monitoring should be implemented. Investigate automatic addition of acids and bases for pH adjustment to save chemical inputs.[9]

The rinse water from the final rinse in a batch operation is fairly clean and can be used directly for further rinsing or for make-up of subsequent dyebaths.[10] Additionally this water can be used for the piece dye operation or adjacent finishing operations in the Case Study Facility.

Often, many chemical auxiliaries can be used at less than 50% of what the manufacturer specifies.[11] A formal program should be implemented to track progress in reducing chemical inputs to dyebath.

Installation of automatic steam controllers with recorders on Beck Machines to optimize dyebath heatups and hold times will reduce energy losses.

Approximately 3 - 5% of the finished pieces do not pass quality specifications.[12] Many of these are redyed. Chemical adds to the dyebath and reworks should be tracked. Root causes should be determined whenever possible, and improvements will result in Pollution Prevention savings.

Carbonizing

Critical Operating Conditions

Many researchers have investigated the carbonizing process in order to determine the optimal operating conditions to maximize the acid uptake by the vegetable matter while minimizing the acid damage to the wool.

The three most critical factors that determine the acid absorption and wool loss are:[13]

1. acid content of the wool as it enters the dryer
2. moisture content of the fabric as it enters the dryer
3. air temperature used to dry the fabric prior to baking in the carbonizer.

By optimizing these three factors, the vegetable matter in the wool can be completely carbonized without causing any measurable reduction in wool strength. When these conditions are not properly set, significant fiber losses (up to 5%) can occur.[14] Since these three factors are interrelated, there is not one optimum set of conditions, but instead, there is a range of conditions that will give the best results.

Exhaust Heat Recovery

At this facility, heat for the carbonizer oven is the second highest user of steam at the facility. Steam is generated by the plant's 33MMBtu/hour boiler which is permitted to burn 500,000 gallons of 2% sulfur #6 oil annually. Heat from this operation could be recovered through use of a heat exchanger to preheat fresh air intake to the dryer. Heat recovery will require installation of duct work. This is necessary to pass oven exhaust air back through the air intake with sufficient surface area to maximize heat transfer. Gauging should be placed at the intake and exit points of the heat exchanger unit for both the oven exhaust and fresh air. Additionally the entire system should be insulated to minimize heat transfer to the atmosphere. A condensate collection system can also be installed on the exhaust line to recover condensed vapors which could possibly contain small amounts of sulfuric acid. This technology is currently available and has been used at the cloth dryer at this facility. Performance data can be estimated from the cloth dryer. Prior to final system design and costing, a determination of the acid content of exhaust air should be made in order to properly specify material for the exhaust duct. This option is not anticipated to impact employee health and safety. In addition, cooling and condensation in the heat exchange unit may eliminate air emissions concerns if any acid is present in the exhaust stream.

Bath Neutralization Before Dumping

The 3% sulfuric acid carbonizing tank, is dumped once every 1-2 weeks at most mills due to a buildup of sludge. Wastewater from all process operations at the case study mill is collected in a holding pit estimated at 7,000 gallons capacity. In this pit, a preliminary neutralization is conducted using automated dispensing of NaOH, soda ash or hydrochloric acid in response to pH measurements. Variation in pH in effluent can cause difficulty in achieving adequate pH control in the final waste water treatment and thus POTW violations. Due to the high acid load when the carbonizing bath is dumped, manual control of pH adjustment using 2 1000 gallon tanks of water/soda ash solution is practiced.

The alternative of neutralizing the carbonizing bath before dumping it to the wastewater collection pit it advanced for consideration. This could be accomplished either by direct dispensing of the neutralizing solution into the carbonizing tank or by transfer of the carbonizing solution to an intermediate tank for neutralization.

In both cases, all equipment is available off the shelf and performance and testing requirements are similar to those currently in place. Utility requirements will be those necessary to connect required pumps and mixers and any automated pH adjustment equipment. Delivery and installation times can be coordinated without disruption to operations, although a minimal amount of downtime may be experiences during actual connection of piping if a separate new tank is used. Personnel training requirements will depend on whether the same operators currently overseeing the manual adjustment of pH of carbonizing waste can be utilized. If so, training requirements will be minimal. Safety and health impacts will be similar to current, however, compliance with POTW discharge limits may be expected to improve. Production rate may be impacted if neutralization is conducted in the carbonizing tank due to usage of the tank during the neutralization and anticipated need for tank cleaning subsequent to neutralization. Product quality may be impacted if the carbonizing tank is used for neutralization and not adequately cleaned.

Alternative Technologies for Drying and Heating

Radiofrequency Drying and Heating

Radiofrequency (RF) drying is used in the textile industry to dry yarn and fabrics. Specific textile industry applications of RF drying of thin webs of fabric has not yet been done in a commercial setting. RF drying of warped yarns during slashing and sizing operations is currently at the laboratory stage. Since RF is a non-contact drying method, there are indications that the common problem of size material sticking to drying cylinders can be eliminated. An added benefit may be a reduction of requirements for sizing wax. One major disadvantage of RF is its high initial capital costs. The cost of an RF heater or dryer may range from $1,000 to $3,500 per kW depending on the size of the system. In spite of RF's high capital cost, a number of textile applications have proven economical.[15] However, operating costs can vary, and an examination of current operating costs is required to evaluate the potential benefits. Currently this form of drying is typically not applicable to the drying of woolen fabrics.

Microwave Processing

The textile industry applications of microwaves falls into two categories: the removal of moisture from fibers and the heating of solids and liquids used to coat and dye or otherwise process fibers, fabrics, and floor coverings. Microwaves have been used for finished drying carpets and to dry different samples of textile fibers (polyester and cotton fibers) and lubricants. Conventional heating provides efficient drying of products with high moisture content whereas microwave drying is more efficient for drying products with lower moisture contents. However, when a product has a moisture content of 50 percent or more, microwave heating might cause undesirable boiling.

One of the major problems with microwaves in textile applications is the lack of a detailed assessment of the economics and high capital costs. Most microwave systems cost between $2,000 and $4,000 per kW.[16] Much of this variance is due to the type of operation (e.g. batch or continuous). Increased competition, however, is now forcing the textile industry to look for ways to increase productivity and decrease costs. This has helped to build a new interest in a variety of industrial heating applications. In general, benefits of microwave processing include increased production, decreased energy consumption, reduced material loss, as well as space and labor savings provided the application is suitable for microwaves.

Materials Recovery

Textile processes require and produce considerable quantities of hot and cold streams for various operations. Membrane separation has great potential for energy savings. In general, membrane processes do not involve phase change and they are less energy intensive than other separation processes. Reverse osmosis and ultrafiltration have been proven to be of value and are cost effective in the textile industry. Reverse osmosis (RO) is a process that uses a semipermeable membrane which allows solution permeation, but acts as a barrier to dissolved and suspended substances. The solution transport in RO is accomplished by using high pressure to overcome the natural osmotic pressure in the solution.

Membrane processes fall into two broad categories: water purification and waste water treatment and recovery. Purified water in many of the textile wet processes is required. For example, purified water is used to rinse fabrics and fibers after dyeing, for boiler feed waters, and for waters used in climate control systems. Membrane separation can be used to purify the water for these processes. Textile wet finishing processes also generate considerable streams containing chemical dyes, other chemicals and heat. Many of these have high BOD which requires treatment prior to discharge. Their reuse can result in cost savings. Membranes have been used to remove color from waste water, separate brine from dyes to be reused in dye setting and recover concentrates, textile lubricants and sizes for reuse.

Economic benefits of membrane systems are, less floor space due to compact size of membrane equipment, lower design/maintenance costs due to modular design of membrane units, and increased productivity due to improved system reliability. The capital costs of membrane systems depends on the type and size of the membrane modules, feed stream properties, process requirements, and system capacity. As a result, there is a wide variation in capital costs.

Materials Acquisition and Storage

Materials acquisition and storage activities are frequently benefitted by the applications of relatively simple "good operating practices". It should be noted that although these good operating practices are conceptually simple, they can involve cultural and procedural changes which are difficult to implement in practice, but can also result in significant reductions in losses due to overall greater control and awareness.

Chemical Control Program

At the case study mill for this guide, MSDS sheets are available for chemicals used onsite, but no chemical prequalification program is in place. Recommended storage requirements (Figure 30)[17] for the chemicals used in the facility are not consistently followed. Materials storage is decentralized, and broken containers, spoiled material and incorrect quantity usage were observed on a number of occasions.

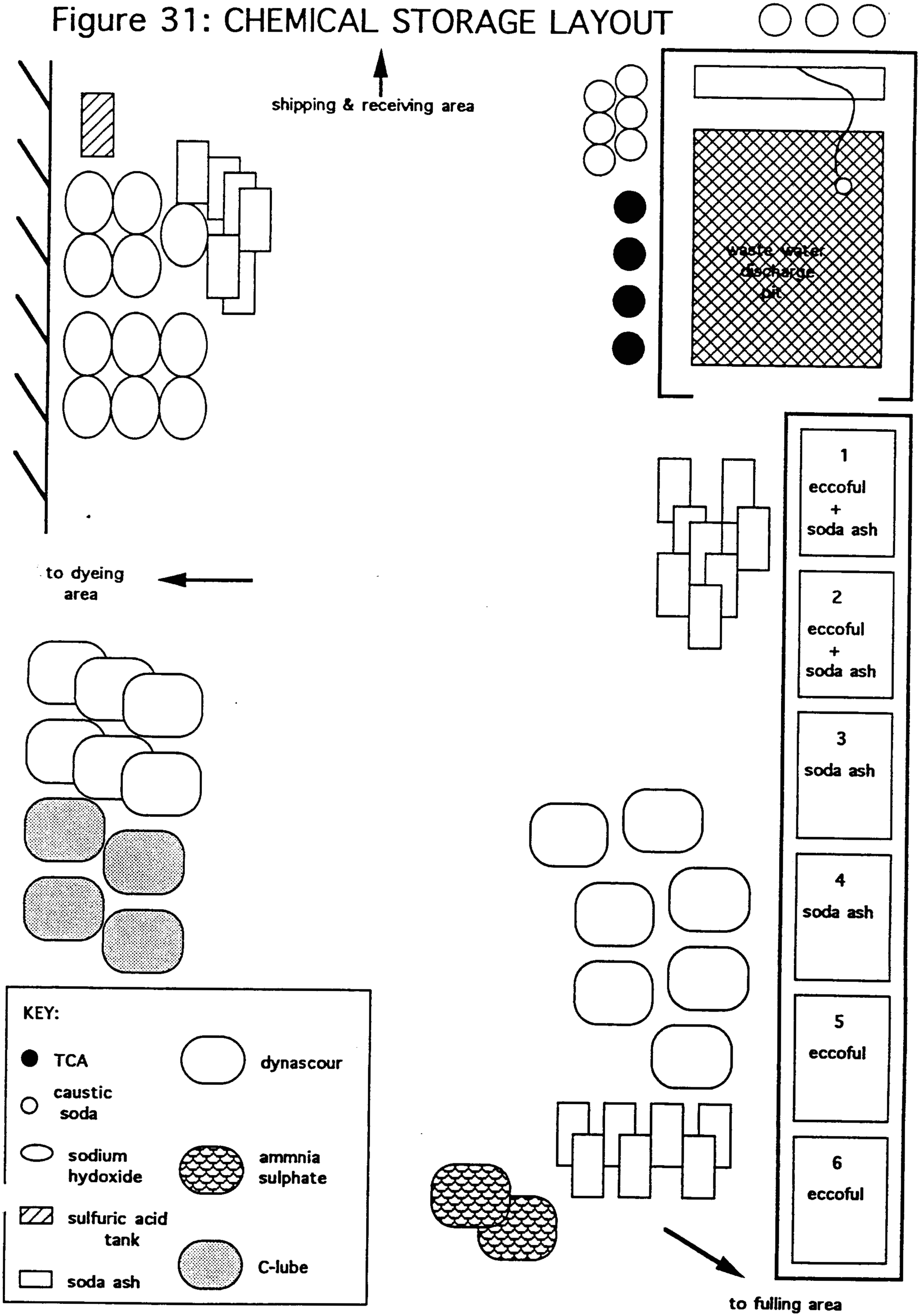
Figure 31 is an example of one of the storage areas in the case study facility. Quantification of loss would be difficult due to lack of central control.

Implementation of a chemical control program (CCP) is a way to reduce the usage of hazardous chemicals and to minimize waste through centralized storage and warehousing.

Figure 30: CHEMICAL CONTROL CHART

CHEMICAL	HEALTH HAZARDS	PHYSICAL HAZARDS	PHYSICAL-STORAGE	TEMPERTURE-STORAGE
Acids	Tissue burning, highly corrosive and toxic	Violent reaction with alkalais or water	Need special storage for drums	35F TO 120F
Alkalais	Tissue burning, corrosive, toxic	Toxic fumes when burned	Keep dry, avoid damage	35F TO 120F
Chlorinated Solvents	Dermatitis, Toxicity	Toxic fumes when burned	Keep away from acids, heat, fire	35F TO 120F
Compressed Gases	Variable	Explosive pressures	Keep away from high heat, damage to	Less than 120F
Coolants	Frostbite, Toxicity	Groundwater contamination	Keep away from acids, alkalais, protect from damage	Less than 120F
Flammable Solvents	Dermatities	Highly flammable	Keep away from heat, fire, sparks. Need special storage cabinet.	Less than 120F
Fuels	Dermatitis, poisonous	Highly flammable, explosive	Safety cans and cabinets. Keep away from sparks, flames.	Less than 120F
Paints & Thinners	Toxic fumes	Flammable, contaminate groundwater	Safety cabinets	40F TO 120F
Phenolics	Corrosive to tissue, toxic	Incompatible with acids, calcium hypochlorite	Keep dry, away from heat, sparks, provide good ventilation	35F TO 120F
Oils & Lubricants	Skin irritation	Sustain Combustion	Protect from spills	35F TO 120F

Figure 31: CHEMICAL STORAGE LAYOUT



Several steps are necessary to implement such a program. First, a procedure should be written to provide the appropriate guidance and instruction for the administration of the CCP. The program should be headed by a single authority, for example a Chemical Control Coordinator (CCC). This person will have control over the entire program and not only approve purchasing of all chemicals prior to coming on site but determine which area(s) the materials can be stored. If a central storage area cannot be accommodated, areas where chemical/chemical materials are stored should be approved by the CCC. In this case, a work group or individual is designated as responsible to maintain control over the chemical/chemical materials stored in that area.

This program establishes controls over chemical materials potentially harmful to plant personnel and it should ensure that chemical materials are properly stored and are compatible with plant processes. The CCP can also minimize hazardous waste by identifying and evaluating alternatives to hazardous materials.

An evaluated chemical list should be generated which is a complete listing of those chemicals and chemical-based materials that have been approved by the CCC. Since the Occupational Safety and Health Administration (OSHA) requires Material Safety Data Sheets (MSDS), the chemical contents of commercial products is readily available. The chemicals on the list will be evaluated using some type of criteria which can include:

* potential for intrusion into, or contact with main plant processes
* known or expected detrimental effects to process materials
* corrosivity and reactivity
* hazards to personnel
* impact on waste treatment systems
* environmental control requirements
* ability to dispose of waste solutions safely and economically
* availability of a less hazardous substitute

Based on the above criteria and available chemical references, the CCC will assign a classification code and designate it on the material by a color coded dot.[18] For example, a red color dot (painted or a decal) placed on a chemical container identifies the material as an acid and hazardous to personnel. This process can be easily visualized and implemented. The color scheme can be selected based on the number of chemical classifications and detail wanted in the program. It should be kept as simple as possible in order to be successful and easily followed by Figure 31 the employees. A training section can be conducted prior to implementation with the employees on what the color coding system signifies and how the program works. Signs should be posted as reminders of the color coding.

Bulk Materials Storage Tanks

Bulk storage at the mill is typically in underground or above ground tanks for process chemicals (acids, and various hydroxides) and fuel oil (typically #4 or #6 oil). Underground oil storage tanks and piping have the potential for unseen leakage and must be upgraded in the next 5 years to include cathodic protection and spill and overfill protection. This is an expensive proposition. Above ground tanks in New England currently have no regulatory status, with the exception of the Federal requirements for and SPCC plan and containment for aboveground oil storage tanks over 1320 gallons. Relocating these tanks indoors or to vaults can provide a significant measure of protection from costly cleanups.

PCB Transformers

Mills with PCB transformers on site, should be aware of the associated regulatory requirements and risks. If PCB transformers do not leak, the regulatory requirements are relatively minimal. The facility is required to notify the local fire department that PCBs are on the premises. There are also some record keeping requirements. Containment areas are not required. In the event of a spill or leak, however, significant fines and cleanup and disposal costs can be incurred. Such costs could include construction areas around the transformers, retrofill, and replacement. Containment areas do not eliminate possible fines in case of a spill, but substantially limit cleanup and disposal costs. At the case study facility, retrofill is a viable option for 6 of the 13 transformers, containing a total of 359 gallons of PCB oil. Four more 167 - 200 KVA transformers containing a total of 402 gallons of PCB oil from 610 ppm to 2300 ppm could be replaced for an estimated cost in the range of approximately $3500 for disposal and $3500 for replacement units, plus labor costs. Three 15 KVA transformers containing a total of 30 gallons of PCB oil from 610 to 1500 ppm of PCB's could be replaced for an estimated cost in the range of approximately $750 for disposal and $1200 for replacement units, plus labor costs.[19]

Any mill with PCB transformers should consider an electrical analysis to determine the necessity of the transformers. NH DES has discovered that in older facilities, the actual electrical current usage is a fraction of what is available and older transformers should be eliminated or replaced.[20] Potential disposition of transformers depends on the PCB content, size (weight), and whether the voltage required is common. Transformers with PCB content less than 500 ppm can usually be "retrofilled". This is a process which involves draining and disposing of the PCB oil, refilling it with non-PCB oil, and then stabilizing it for 90 days. After 90 days, it is reevaluated and this cycle may have to be repeated two or three times. Retrofilling typically costs $25-$30 per gallon. Transformers with higher PCB concentrations can be replaced with new or rebuilt transformers.

Fuel Use

Fuel tanks should be properly maintained with leak detection and spill and overfill protection. Single wall underground tanks and piping should be eliminated. All steam pipes should be insulated. In place insulation should be maintained. Steam "traps" should be installed and properly maintained to regulate the loss of steam to the atmosphere. Condensate return should be used to preheat boiler makeup water. Re-use of waste heat from hot water and hot air operations through the use of heat exchangers to preheat process air and water should also be evaluated. Boilers fired with #4 or #6 oil experience regulatory constraints such as opacity of emissions, rate of SO_2 emissions and NO_x emissions. Consideration may be given to the potential for increased energy efficiency or reduced emissions potential by gas conversion, however, capital and fuel costs must also be considered.

Waste Water Management

Waste water at the case study mill is treated for pH, deflocking and defoaming before discharge. Mill personnel report that the only difficulty experienced with waste water discharge is relative to pH control. Control of pH at the mill is in two stages; preliminary and final. The mill has recently installed a computerized system at the preliminary stage to dispense sodium hydroxide, soda ash or hydrochloric acid in response to measured pH. Some startup problems resulting in unsatisfactory pH at the discharge were experienced, however, significant progress has been made in resolving these. Installation of an equalization tank or a baffled flow-through tank for equalization may be considered for better control of pH and possible reduction in chemical usage.

Air Quality

Industrial boilers are regulated under the Clean Air Act for emissions of SO2, NOx, VOC's, Carbon Monoxide and particulate matter. For oil fired boilers in the northeast, SO2 emissions are typically controlled by regulation of the sulfur content of the fuel. Another technologies for control of SO2 emissions is a wet scrubbers. Carbon Monoxide, NOx and VOC emissions are typically controlled by boiler design and operational parameters. Particulate matter may be controlled by baghouses. Some or all of the above controls may be specified in the individual facility permit. The 1990 Amendments to the Clean Air Act mandated a new federally enforceable operating permit program which extends the provisions of the Act to a significantly larger number of facilities than previously. In addition State air quality programs may apply. In New Hampshire, where the case study for this guide was conducted, compliance plans for NOx and VOC emissions were due by March 15, 1993 under regulations effective in November, 1992. A discussion of the requirements of the 1990 Amendments and the regulations of the State of New Hampshire can be found in Appendix B.

Solid Waste Management

- **Wool Fiber**

Depending on the products produced, raw wool may be worth from $.80-$2.50 per pound[21], to $3.25-$3.05 per pound for higher grade product[22] and higher for products such as cashmere or camel hair. Fiber collection should segregate wool depending on its highest value recycling option. Almost all wool fiber lost from the process can be collected and recycled either into the original process or into another process. Wool may be processed at a commercial recycling processor who either charges a processing fee and returns the wool to the mill or buys the waste fiber bales and resells the reclaimed fiber to another mill. Wool recycled into the process has a value equal to the value of the raw material, less the cost of collection. Wool which is recycled outside the mill is baled at a cost of approximately $.02 per pound or $40 per ton for shipping. How and where the wool is recycled depends on a number of factors.

Fiber length: Fibers of ordinary length which have not yet been spun can be recycled into the blending and carding processes. Very short fibers, such as fibers rejected by the carding machine can be recycled for non-woven felts[23] with a value of $.10-$.12 per pound[24].
Spun fibers: Fibers which have not been spun may be recycled into blending and carding (depending on other factors discussed), however fibers which have been spun into yard must be torn apart by a process called "picking" by a cylinder with hook wire before it is suitable for reuse. This service is provided by a commercial recycler and costs about $.15 per pound. "Picked" fiber may be returned to the mill that shipped it, or it may be sold to another mill.

Dyeing: Wool which has been dyed may be unsuitable for recycling back into stock dye processes and for certain colors of piece dye.

Vegetable Matter and Miscellaneous Trash: Wool recycling houses can process virtually any level of contamination, however, the per pound price will vary depending on amount of extraneous matter.

Type of Product being Manufactured: Short fibers can be used in felting operations. Some shorter fibers can be used as "filler" mixed with longer fibers for certain yarns. "Filler" may not be suitable to all yarns, including yarns which require more strength, such as knitting yarns.[25] Blankets and felt products can contain a wide variety of fibers,[26] as can wool intended for use in commercial manufacture of braided rugs.[27] Waste yarn can also be recycled outside the mill as low grade stuffing and filler material.

Other options besides recycling for use as wool fabric are in investigatory stages. Since wool is an organic material with approximately the same Btu value as wood, it thus has a potential for use as an alternative fuel in boilers or in other applications where wood chips, tire chips and various pelletized wastes are used.[28] Wood chips as fuel are currently worth around $14/ton. There is currently no viable method of handling the material, and the relatively small volume waste stream does not merit individual materials handling system development. Research and development into other higher volume alternative fuels may ultimately produce systems and burners capable of handling wool wastes.[29]

Composted wool also has a potential value as an agricultural product. NH DES is currently considering an application from one New Hampshire woolen mill for a Certificate of Direct Reuse composted waste wool.

Finally, a prototype of a sorbent material made with waste wool has been developed for cleanup of oil spills. This capitalizes on the ability of wool to hold large volumes of moisture.[30]

Wool Fabric

Most wool fabric which is not suitable for sale can be reclaimed. Damaged or off color finished fabric can be sold as blankets or remnants or used in the mill as rags.

[1] Woerner, Douglas L. and Wheeler, Nancy E. "How Mills Can Save Money While Treating Wastewater", Textile World, May 1993, P. 65.

[2] Stock Dye Supervisor of Case Study Facility. personal communication to T. Reilly. June 3, 1993.

[3] Electric Power Research Institute. Textile Industry: Profile and DSM Options. CU06789. Research Project 2885-1, Resource Dynamics Corp., Vienna, Va, and Battelle-Columbus Division, Columbus, OH. July, 1990,p.1-8.

[4] Electric Power Research Institute. op.cit., p.1-8.

[5] Electric Power Research Institute. op.cit., p.1-9.

[6] Cusmano, Dr. John, Dye Research Chemist and Pilot Plant Section Leader, Hoechst Celanese Corporation. personal communication to T. Reilly. May 27, 1993.

[7] Collier, Ann M., A Handbook of Textiles, Oxford: Pergamon Press, 1970, p. 646.

[8] Collier, Ann M., op.cit., p. 646.

[9] Bide, Dr. Martin, Textile Chemistry Associate Professor, University of Rhode Island. personal communication to T. Reilly. May 26, 1993.

[10] "Water Conservation For Textile Mills", Pollution Prevention Pays Program, State of North Carolina. March 1991, P.2.

[11] Olken, Ken, Dyecraftsmen Inc.. personal communication to T. Reilly. May 25, 1993.

[12] Piece Dye Supervisor of Case Study Facility. personal communication to T. Reilly., June 3, 1993.

[13] Pailthorpe, Michael T. "Developments in Wool Carbonizing", Review of Progress in Coloration, Vol. 21. 1991, p. 100.

[14] Pailthorpe, Michael T. op.cit., p. 100.

[15] Electric Power Research Institute. op.cit., p.D-1.

[16] Electric Power Research Institute. op.cit., p.D-42.

[17] Hopcraft, Francis J., Vitate, David L. and Anglehart, Donald L. Hazardous Material and Hazardous Waste. Kingston, MA, Construction Consultants and Publishers, 1989.

[18] Boston Edison Company. "Chemical Control Program". Pilgrim Nuclear Power Station. May 10, 1993, p.15.

[19] Technical Services Representative (anonymous), PCB Disposal Facility, personal communication to J.E. Holbrook, 6/18/93

[20] White, Robert, NH Department of Environmental Services. personal communication to J.E. Holbrook, 6/22/93

[21] Wool Buyer (anonymous). personal communication to J.E. Holbrook 6/16/93

[22] Brown, Jim, Fiber Processing Corp. personal communication to J.E. Holbrook, 6/17/93

23 Brickles, Sam, Northern Woolen Mills. personal communication to J.E. Holbrook, 6/15/93.

24 Wool Buyer (anonymous). personal communication to J.E. Holbrook 6/16/93

25 Brown, Jim, Fiber Processing Corp. personal communication to J.E. Holbrook, 6/17/93.

26 Brickles, Sam, Northern Woolen Mills. personal communication to J.E. Holbrook, 6/15/93

27 Wool Buyer (anonymous). personal communication to J.E. Holbrook 6/16/93

28 Plant Engineer (anonymous). personal communication to J.E. Holbrook, 6/17/93

29 Murdoch, William, Yankee Environmental Systems. personal communication to J.E. Holbrook, 6/15/93

30 Brickles, Sam, Northern Woolen Mills. personal communication to J.E. Holbrook, 6/15/93

Appendix B
Regulatory Issues

The costs associated with compliance with for the existing, new and pending regulations governing the use and management of hazardous chemicals, including air emissions, effluent quality, solid waste management and disposal, employee exposure to hazardous chemicals in the workplace, and Toxic Release Inventory (TRI) Reporting should also be considered in the prioritization process. Moreover, the Pollution Prevention process can be viewed as a unique opportunity to reduce compliance costs either through elimination of the hazardous chemicals from the process, or through more effective conservation of those materials within the process.

Current regulatory issues of primary concern to the woolen mill may include: POTW pretreatment program compliance costs, disposal costs of solid wastes, costs of compliance with existing state air emissions rules and pending federal regulations under the Clean Air Act of 1990, the costs of compliance with OSHA regulations relative to employee exposure to hazardous chemicals, and the cost of TRI reporting compliance. Each of these affects, or will affect, the woolen mill to varying degrees. They may impact on costs of treatment and disposal, permitting, in plant controls and operating procedures.

Waste Water Discharge Regulations

Over 160 billion gallons of process waste water is discharged annually by the textile industry.[1] The wastes come from two sources, the natural impurities present in the fibers and the process chemicals used. In raw wool processing, the natural impurities are the largest source of pollution and are contained in a highly concentrated effluent. In wool finishing, the principal impurities are BOD. The disposal of the water from the different processes is of particular importance to the wool processing industry. Many of the waste water streams from a textile plant are at moderately high temperatures, and contain contaminants such as starch, formaldehyde, soap, sodium hydroxide, and dyestuffs. Most waste water requires treatment to remove, or significantly reduce, the concentrations of these contaminants before discharge. The recovery of the process water and many of the chemicals in the process waste waters may be an important consideration for the industry. The water required for many textile processes can be supplied by recycled water, thus cutting the cost of using fresh water. If the water can be recycled at process temperature, energy can also be conserved. Energy savings may be significant, due to the large quantities of heated water that are required. Recovered chemicals, such as dyes, can be recycled, thus cutting the costs of acquisition of new chemicals. Recovery of chemicals is also important when new supplies are not readily available.

Wool finishing wastes produce approximately 200 pounds of BOD per thousand pounds of cloth (ptpc) and usually will be discharged in three processes: wash after fulling, wash after carbonizing and stock or piece dyeing.[2]

Waste water may be discharged to a POTW pursuant to a POTW permit, with or without pretreatment, or direct to a receiving stream pursuant to a National Pollutant Discharge Elimination System (NPDES) permit. In a 1982 EPA study, approximately 67% of wool mills surveyed discharged to POTWs[3], although 57% of discharge volume was direct.[4] Regulations governing discharge differ for direct (NPDES) and indirect (POTW) discharges. In addition, concerns are currently expressed that existing regulations insufficiently address issues of color, heavy metals, dissolved salts, and low BOD/COD ratios and further regulation may be on the horizon.[5]

Under current regulations, for NPDES permitting, EPA has determined that only chromium poses a hazard which is of national concern, is not sufficiently controlled by treatment methods intended to address pollutants which are otherwise controlled, and is toxic and present in amounts sufficient to justify treatment or pretreatment standards.[6] POTW permits are governed by the standards of the local POTW industrial pretreatment program which are designed to ensure that the POTW will be capable of meeting the requirements of its NPDES permit.

Waste Water Effluent Issues

Typical untreated wastewater concentrations of EPA regulated pollutants for the woolen industry are:

BOD5	150 mg/l	(63.6 kg/kkg)
COD	650 mg/l	(204.8 kg/kkg)
TSS	50 mg/l	(16.3 kg/kkg)
O&G	280 mg/l	(177.8 kg/kkg)
Sulfide	1100 ug/l	(451.7 g/kkg)
Phenols	120 ug/l	(11.4 g/kkg)[7]

Contributions of pollutants from major processing steps are described below:

Carbonizing: Wastewater from carbonizing is acidic, low in organic content and high in total solids. Due to the rinsing required to remove potentially harmful acid residues from the fabric, carbonizing has the potential to significantly increase hydraulic load, however, when acid dyeing follows carbonizing, intermediate rinse and neutralization may not be required.

Fulling: Fulling may be either alkali or acid based. When alkali fulling is used, the waste stream will contain soap or detergent. When acid fulling is used, sulfuric acid, hydrogen peroxide and metal catalysts may be present. Fulling also contributes significantly to hydraulic load and to the BOD load in the case of alkali fulling.

Bleaching: Bleaching is minimal in wool processing. Hydrogen peroxide is generally used and the BOD and other conventionally measured parameters are minimally affected.

Dyeing: Acid and metal dyes are most common. The use of mordant dyes have diminished due to the hazards of chromium in the sodium dichromate mordant. The acid dyeing process contributes Glauber's salt (sodium sulfate), sulfuric and formic acid. Metalized dyes are almost completely exhausted in wool dyeing so that only a small quantity of metal ions is discharged.

Scouring: The scour process consists of washing the fabric with detergents, wetting agents, emulsifiers and alkalis. Heavy fabrics and those containing recycled fiber require heavy detergents, long washes and extensive rinsing. For lighter fabrics with less recycled content, washing and rinsing operations associated with fulling and dyeing may suffice to remove undesirable materials.[8] Although the raw grease is typically removed from the wool by a scouring process prior to receipt at the mill, the wool fiber still contains a small amount of grease and foreign matter, as well are oil added for lubrication prior to spinning. All of these materials must ultimately be removed from the final product to prevent degradation of the fiber by bacterial action.

Observed Pollutants in Effluent

Woolen mills studied by EPA in the process of generating NPDES effluent guidelines showed 17 organic compounds and 10 metals[9]:

Average Concentrations in ug/l	
Benzene	8
Chlorobenzene	9
1,2,4 trichlorobenezene	4195
1,1,1 trichloroethane	26
Chloroform	10
1,2 dichlorobenzene	160
1,3 dichlorobenzene	705
1,4 dichlorobenzene	299
1,1 dichloroethylene	10
1,2 trans dichloroethylene	10
ethylbenzene	267
methylene chloride	8
naphthalene	17

N-nitrosodiphenylamine	120
pentachlorophenol	50
phenol	18
bis (2-ethylhexyl)phthalate	10
diethyl phthalate	7
dimethyl phthalate	3
anthracene	12
phenanthrene	12
tetrachloroethylene	193
toluene	15
trichloroethylene	39
heptachlor	5
alpha-BRC	4
gamma-BRC (lindane)	5
antimony	28
arsenic	37
asbestos	3
cadmium	13
chromium	310
copper	28
cyanide	5
lead	109
mercury	2
nickel	50
selenium	9
silver	24
zinc	1307

Air Emissions Issues

Most of the regulations depend on implementation through federally approved state programs. Since many of the state programs are currently in place that are more strict than the old Clean Air Act, some period of duplication, inconsistency and confusion is expected. The issues raised will be of varying importance to the woolen mill depending on the specifics of state program implementation, toxic chemicals used, and size of industrial boilers used. The Clean Air Act Amendments of 1990 became effective on November 15, 1990. The law significantly tightened the requirements for air pollution controls. A new operating permit program was established to cover existing facilities, which extended the coverage to an array of smaller industrial and commercial concerns not previously covered for air emissions and permitting requirements for both existing and new facilities. It also established new federal programs for control of air toxics and accidental release reporting and control, mandated the elimination of certain ozone depleting chemicals and increased the potential civil and criminal liability for non-compliance.

Operating Permit Program

For the first time, under the new Clean Air Act rules, a federally enforceable operating permit program will be implemented. The program requires states to submit permit programs to EPA by November, 1993 for approval by November, 1994. Individual facility permit applications under state programs are due by November 1995. Annual permit fees of a minimum of $25/ton of emissions, adjusted for inflation are mandated by statute.[10]

The amendments change the definition of "major source", in areas of serious, severe and extreme non-attainment. Facilities to be covered under the program include any "major source" for ozone, carbon monoxide, particulate matter, any major source of hazardous air pollutants, and any source for which EPA issues a Control Technology Guideline by 1993. Sources subject to these rules will be required to implement Reasonably Available Control Technology (RACT) by May 31, 1995[11] It is estimated that more than 50,000 facilities may be subject to these requirements.[12] Major sources subject to the Operating Permit program are those with potential annual emissions in excess of tabulated values:[13]

Pollutant / Area Classification	Potential Annual Emissions
Attainment Areas	100 Tons
Non-Attainment Areas	
Carbon Monoxide	
Moderate	100 Tons
Serious	50 Tons
PM10	
Moderate	100 Tons
Serious	70 Tons
Ozone (VOC's & NOx	
Marginal & Moderate	100 Tons
Serious	50 Tons
Transport Regions (Northern Virginia to Maine)	50 Tons
Severe 25 Tons	
Extreme	10 Tons
189 Hazardous Air Pollutants	
Any individual	10 Tons
Any combination of 2 or more	25 Tons

In New Hampshire, where the case study was conducted, the state major source levels are 50 Tons per year for VOC's and NO2. The deadline for submission of programs for compliance is mandated by March 15, 1993.[14] New Hampshire no longer has any PM10 or CO non-attainment areas.[15]

New Sources and Modifications of Existing Sources

The status of new sources depends on whether they are located in an attainment area or a non-attainment area. In attainment areas, the 1990 Amendments have not changed the requirements for a PSD (Prevention of Significant Deterioration) permit, which includes the requirement for implementation of Best Available Control Technology (BACT), a process which takes into account both technological feasibility and economic impact. PSD permits are required for any new source in one of 28 specified categories with potential emissions over 100 tons per year (textile mills are not included on the list, however fossil fuel boilers over 250 mmBtu / hour are included), any new source with potential emissions over 250 tons per year, and any modification to an existing major source with potential emissions increases above the tabulated values[16]. State permitting programs for new sources in attainment areas may additionally apply.

Emissions Increases Triggering PSD Requirements	Potential Annual Emissions
Carbon Monoxide	100 Tons
NOx	40 Tons
SO2	40 Tons
Particulate Matter (PM/PM10)	25/25 Tons
VOC's	40 Tons
Hydrogen Sulfide	10 Tons
Total Reduced Sulfur	10 Tons
Reduced Sulfur Compounds	10 Tons
Sulfuric Acid Mist	7 Tons
Florides (as HF)	3 Tons
Vinyl Chloride	1 Ton
Lead	0.6 Tons
Mercury	0.1 Tons
Asbestos	0.007 Tons
Beryllium	0.0004 Tons

In non-attainment areas, the federal requirement for a New Source Review (NSR) permit is retained by the 1990 amendments. This includes the requirements for implementation of Lowest Achievable Emissions Rate (LAER) technology, a strict requirement which does not take into account the cost of implementation, and the provision offsetting reductions equaling or exceeding each emissions increase. The criteria triggering the review for particulate matter, SO2, CO, and NOx, and the 1:1 offsetting reduction requirement have not changed. The limits are the same as those listed above for PSD permits in attainment areas.

For Ozone non-attainment areas, The 1990 Amendments reduce the size of the major source category triggering the NSR permitting process and increase the offset requirements:[17]

NSR Criteria for Ozone Non-Attainment Areas

Non-Attainment Classification	Major Source Size (Tons/Year)	Modification Size (Tons/Year)	Offset Required
Marginal	100	40	1.1:1
Moderate	100	40	1.15:1
Serious*	50	25	1.2:1
Severe*	25	25	1.3:1
Extreme*	10	Any	1.5:1
Transport	50	Same as region classification	

*In general new sources and modifications must meet LAER technology with the exception of modifications to existing sources with existing potential to emit less that 100 tons per year.

In New Hampshire, where the case study was conducted, the VOC trigger limits are 50 tons per year (TPY) VOC's and 100 TPY for NO2 for new sources. For modifications, they are 40 TPY for VOC's and NO2 except in the four southern counties of Rockingham, Strafford, Hillsborough and Merrimack, where they are 25 TPY. Offset requirements are 1.15:1 except in the four southern counties where they are 1.2:1.[18]

Air Toxics

The 1990 Amendments identify 189 hazardous air pollutants (HAP) to be regulated. The 189 substances will be regulated by control standards issued by industry category. EPA published a draft timetable for HAP standard on September 24, 1992 (57 FR 44147). Standards for these industries are not expected to be issued for several years according to the draft, however, industries emitting more than 10 TPY of any individual HAP or more than 25 TPY of any two or more HAPs become major sources and are subject to the operating permit requirements of the Act. Categories which may be of concern to the woolen industry are industrial boilers, fabric dyeing, fabric printing and fabric surface coating. The implications for the wool industry will be somewhat facility specific, however it is notable that one chemical in heavy use in the wool manufacturing process, sulfuric acid, is not included among the 189 federal HAPs. Since the EPA has 10 years to implement these standard, with the exception of the possible designation of major source status, state regulations will most probably be of greater concern in the near term.[19]

In New Hampshire, the Department of Environmental Services has issued Ambient Air Quality Limits (AAQL) for 150 substances, 66 of which are on the Federal HAP list. Substances are classified as High, Moderate and Low toxicity. Permits are required for new emissions of any regulated substances and for existing devices emitting any substance classified as high toxicity.[20] Woolen mills in New Hampshire may be subject to permit requirements for emissions of sulfuric acid used in carbonizing or emissions of mineral spirits or Stoddard Solvent used as a tar remover in fulling if State AAQLs are exceeded.

Stratospheric Ozone Protection

Title IV of the Amendments requires the phase out of the use and production of these substances over a 10 year period. For the wool manufacturing industry the ban will principally affect the use of 1,1,1 Trichloroethane which is used in removing spots, especially residuals occurring in the raw wool from branding of sheep. Relatively small quantities are in use, but no effective substitute has been identified. Congress attempted to bring about greater reductions earlier by imposing labeling requirements on products produced with or containing CFCs and HCFCs. However, the textile industry, among others, has obtained an exemption from this rule (February 11, 1993 Federal Register), which allows some temporary relief. The ultimate problem of finding an effective substitute has not been resolved.

Other Chemical Usage Related Regulatory Issues

OSHA regulations (29 CFR 1910.1000) govern employee exposure to hazardous chemicals. The regulations specify permissible exposure levels and require the implementation of engineering controls to prevent employee exposure above permissible levels. Under certain circumstances, if it can be demonstrated that engineering controls are infeasible, the use of personal protective equipment, such as respirators, is permitted. Rigorous training, supervision and maintenance programs are required, however.

Regulations promulgated under SARA Title III require reporting of hazardous chemicals produced or used in the workplace in quantities greater than their tabulated threshold planning quantities. Further release reporting is required for facilities with manufacture or use any chemicals on a list of Extremely Hazardous Chemicals. A "Form R" is required to be submitted which is time consuming and focuses public scrutiny on reporting facilities. In the woolen industry, the chemical sulfuric acid, typically triggers the Form R reporting requirement.

EPA's stormwater discharge permit rules require industrial facilities with point source discharge to obtain an individual, group, or general permit. Permitting requirements include monitoring of discharge and engineering analysis. Individual permits can be cost-prohibitive for small to medium sized industries. However, many industry associations sponsor group permit applications. Facilities in certain SIC codes, including SIC code 22, are exempt from the permitting requirements (under 40 CFR 122.26(b)(14)(xi)) if the facility can document that no stormwater contacts any process operation, including materials storage and dumpsters.

[1] Electric Power Research Institute. Textile Industry: Profile and DSM Options. CU-6789, Research Project 2885-1 , Resource Dynamics Corporation, Vienna, Virginia, and Battelle-Columbus Division, Columbus, Ohio. July, 1990, p.1-1 .

[2] Masselli, Joseph W., Masselli, Nicholas W.and Burford, M. G. "Textile Waste Treatment, Past, Present and Future", AATCC Symposium. The Textile Industry and the Environment. Washington, D.C., May 22-24, 1973, p.2.

[3] U.S. EPA, Development Document of Effluent Limitations Guidelines and Standards for the Textile Mills, EPA 440/1-82/022, September, 1982, p 28.

[4] U.S. EPA, op.cit., p. 100.

[5] Tinchere, Wayne C., "Mills will face new effluent challenges", Textile World, May 1993, pp. 60-62.

[6] U.S. EPA, op.cit. pp 197-199.

[7] U.S. EPA, op.cit., pp. 195-196.

[8] U.S. EPA, op.cit., pp 83-85.

[9] U.S. EPA, op.cit., pp 129-130.

[10] TRC Environmental Consultants, Inc. "The Clean Air Act Amendments: Strategies for the 1990's", Hale and Dorr and TRC Environmental Consultants, Inc., 1991, p. 28.

[11] TRC Environmental Consultants, Inc. op. cit., p. 5.

[12] TRC Environmental Consultants, Inc. op. cit., p. 17.

[13] TRC Environmental Consultants, Inc. op. cit., p. 24.

[14] Cheney, Robert P., Jr., "Federal and State Regulatory Initiatives under the Clean Air Act - 1993 Update", Sheehan Phinney Bass + Green, PA, 1993, p 42-43.

[15] Strickland, Sonny, State of New Hampshire Department of Environmental Services, Air Resources Division, personal communication to J.E.Holbrook.

[16] TRC Environmental Consultants, Inc. op. cit., pp. 32-35.

[17] TRC Environmental Consultants, Inc. op. cit., pp. 38-41.

[18] Cheney, Robert P., Jr.. op.cit., pp. 44-45.

[19] Cheney, Robert P., Jr. op.cit., pp. 51-54.

[20] Cheney, Robert P., Jr. op.cit., p. 53.

APPENDIX C

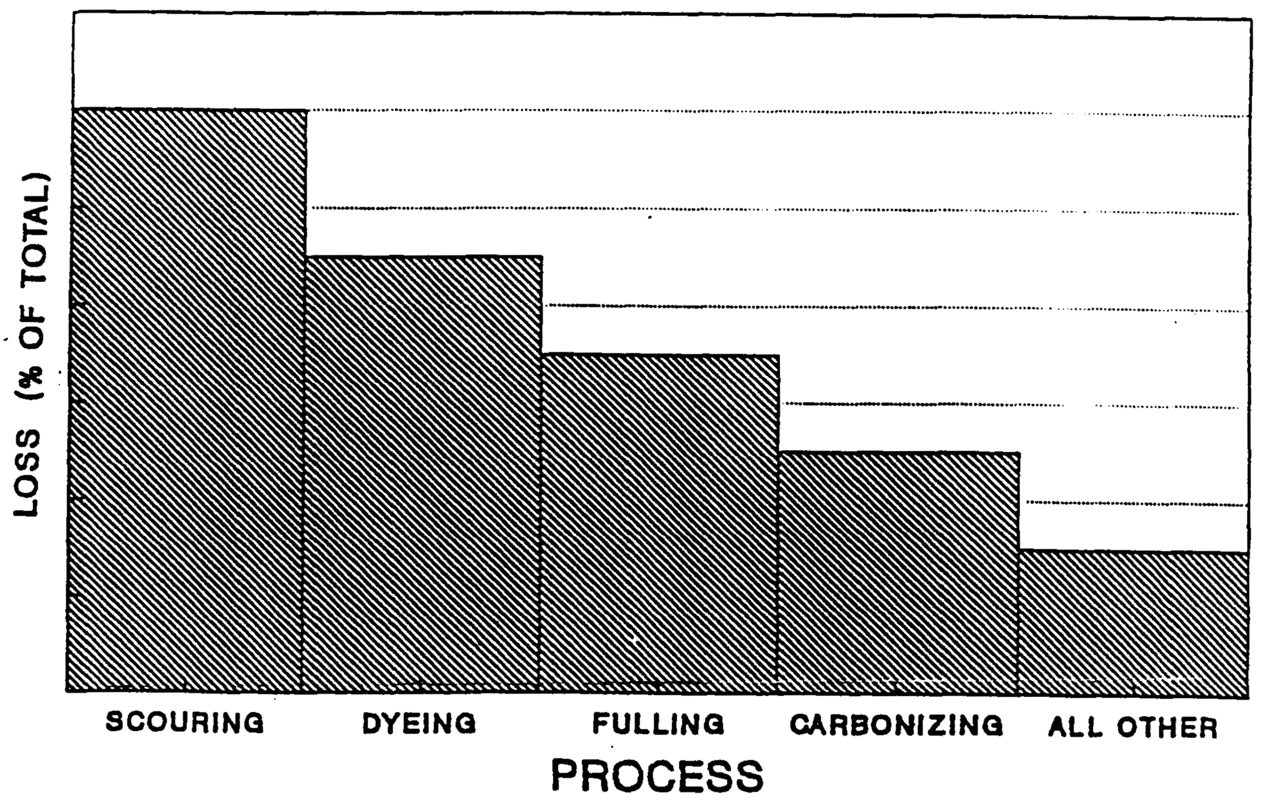
PARETO CHART

Pareto Analysis is a decision making tool to separate the "vital few" from the "trivial many". By applying this concept, the P2 team focuses on those few problems which will yield big results. A Pareto Chart is a vertical bar graph which helps determine which problems to solve in what order. Tally sheets, check sheets, and other data collection techniques can be the source of information for the Pareto Chart. By use of the Pareto Chart, the P2 team can prioritize losses.

METHOD:

- IDENTIFY PROBLEM TO BE ANALYZED
- SELECT CLASSIFICATIONS
- DETERMINE NUMBER OF OCCURRENCES OR FREQUENCY
- CREATE PARETO CHART

EXAMPLE: TOTAL LOSSES TO WATER AT XYZ WOOLEN MILL



APPENDIX D
BRAINSTORMING

Brainstorming is a creativity tool to enable a team to generate as many ideas as possible and effectively address problems and opportunities for improvement. The greater the quantity of ideas, the greater the probability of success that a good solution will be established. After these ideas are generated, they are then evaluated and judged. The most promising ideas may eventually be chosen for implementation. **The goal of brainstorming is "IDEA GENERATION". The reasonableness of the generated ideas will be evaluated at a later time.** The P2 team should proceed as follows:

SOME PRELIMINARIES
- A Facilitator should be chosen by the team to lead the brainstorming session. He/she should be familiar with the brainstorming process and ground rules.
- All members have an equal voice.
- All ideas are recorded on a flipchart.
- Team members are encouraged to be creative, freewheeling, offbeat, and humorous. Listening skills are important, and exaggeration and risk taking is encouraged.

METHOD
1. TEAM AGREES ON THE PROBLEM DEFINITION OR STATEMENT.
2. TEAM MEMBERS SILENTLY GENERATE IDEAS.
3. FACILITATOR LEADS THE SERIAL COLLECTION OF BRAINSTORMED IDEAS BY ROTATION METHOD (ie. EMPLOYEES TAKE TURNS OFFERING IDEAS).
4. EACH TEAM MEMBER GIVES ONE IDEA AT A TIME.
5. IT IS "OK" TO PASS AND "OK" TO RE-ENTER THE BRAINSTORMING SESSION.
6. NO CRITIQUE IS ALLOWED!
7. HAVE FUN!
8. TEAM MEMBERS SHOULD ATTEMPT TO BUILD ON PREVIOUS IDEAS.
9. DEPENDING ON THE TOPIC, BRAINSTORMING MAY BE LIMITED TO 15 MINUTES, ALTHOUGH IT IS SUGGESTED THAT BRAINSTORMING CONTINUES UNTIL EVERYONE ON THE TEAM "PASSES" (ie. NO FURTHER IDEAS TO OFFER).
10. AFTER BRAINSTORMING IS COMPLETE, THE TEAM DECIDES HOW TO CLARIFY, COMBINE, AND PRIORITIZE GENERATED IDEAS.

SOURCES/ADDITIONAL READING:

Wycoff, Joyce. MIDNDMAPPING: YOUR PERSONAL GUIDE TO EXPLORING CREATIVITY AND PROBLEM SOLVING. Berkley Books, 1991.

Thompson, Charles "Chic". WHAT A GREAT IDEA!. Harper Perennial Publishers, 1992.

APPENDIX E

NOMINAL GROUP TECHNIQUE (NGT)

The Nominal Group Technique gives all team members an equal voice in problem, idea or alternative prioritization.

METHOD

1. The team generates ideas that it feels are most important in contributing to a specific problem. These should be documented and recorded on a flipchart in column form.

2. Letters are assigned to each idea. For example:
PROBLEM: NEIGHBOR COMPLAINT OF ODOR FROM MILL

ASSIGNED LETTER	IDEAS (SOURCES) GENERATED BY TEAM
A	CARBONIZER
B	DYEING PROCESS
C	CHEMICAL STORAGE AREA
D	BOILER
E	TREATMENT PLANT

3. After discussion of all the available information and data, team members individually rank the ideas on a piece of paper. Assignment of a high number indicates more importance than a lower number (less importance). Since there were five generated ideas, the #5 represents most important while #1 is least important.

ASSIGNED LETTER	IDEA (SOURCE)	RANKING (BY INDIVIDUALS)	
A	CARBONIZER	2, 3, 2, 2, 2	T = 11
B	DYEING PROCESS	3, 2, 3, 3, 3	T = 14
C	CHEMICAL STORAGE AREA	1, 1, 1, 1, 1	T = 4
D	BOILER	5, 5, 4, 5, 5	T = 24
E	TREATMENT PLANT	4, 4, 5, 4, 4	T = 21

4. After reviewing available information and then totaling the individual rankings of the ideas, the **TEAM** feels the boiler is the most important contributor to the odor problem while the chemical storage area contributes the least. The team might then focus available resources to work on both the boiler and treatment plant or perhaps just one of these to begin with.

MULTI-VOTING TECHNIQUE

This is a simple technique to rank or prioritize multiple ideas that have been recorded on a flipchart.

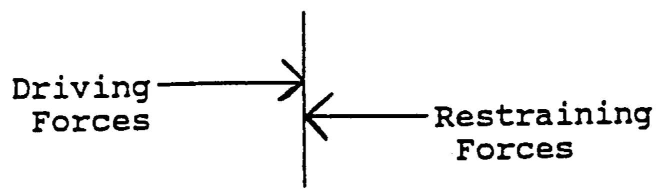
METHOD

1. The Team Leader/Facilitator informs the group that they may vote for as many previously brainstormed ideas as they wish.
2. Each idea is voted on with each team member voting for the items they feel are of importance to the given situation.
3. After all items have been voted on, a total vote tally is recorded next to each item.
4. The ideas with the highest number of votes are the items that the **TEAM** feels are most important.
5. The team then decides what action will be taken on these prioritized items.

APPENDIX G

FORCE FIELD ANALYSIS

Force Field Analysis is a technique which displays the "driving" or positive forces, and the opposing "restraining" or negative forces. This balance sheet lists driving forces on the left side. Driving forces are factors which contribute toward the attainment of a goal. Likewise, restraining forces are listed on the right side, and are those factors which keep improvement from occurring. WHEN BOTH FORCES ARE EQUAL, NO CHANGE OCCURS.

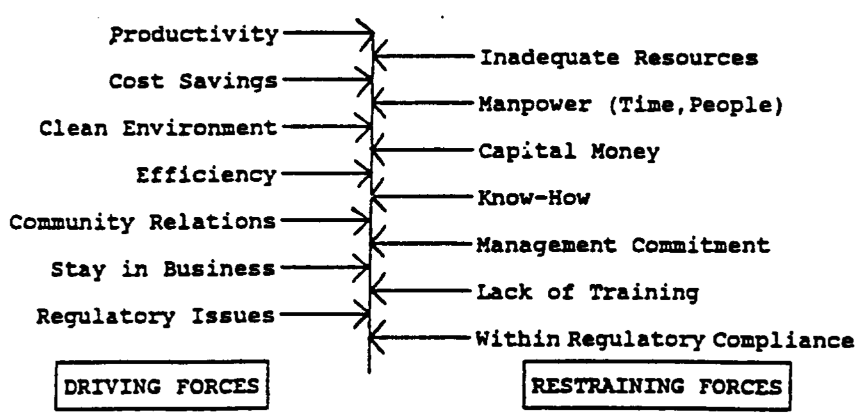


METHOD

1. The P2 team states the desired goal or change.
2. The team brainstorms the opposing forces.
3. The team then selects some forces to improve, minimize, or eliminate to bring about the necessary change.
4. The selected forces are studied to generate alternatives to bring about change.

EXAMPLE

IMPLEMENTING A FORMAL POLLUTION PREVENTION PROGRAM



In this example, the P2 team might find that the most important driving force to bring about change is cost savings. Likewise, it may have identified the need for more management commitment to bring about the necessary change. If the team initially focuses on these two areas, perhaps significant improvement can be made in the pollution prevention area.

SOURCES/ADDITIONAL READING: Goal/QPC. The Memory Jogger: A Pocket Guide Of Tools For Continual Improvement, Goal/QPC, 1988.